IAH 2026

World Groundwater Congress

53rd Congress of the
International Association
of Hydrogeologists

14-18 September 2026
Budapest Congress Center



Program and Book of Abstracts

ISBN 978-615-5270-88-8





IAH 2026
World Groundwater Congress

53rd Congress of the International Association of Hydrogeologists

14-18 September 2026
Budapest Congress Center

ISBN 978-615-5270-88-8

WELCOME

We are delighted to invite you to the 53rd World Groundwater Congress of the International Association of Hydrogeologists, taking place from 14 to 18 September 2026. This prestigious event returns to Hungary after half a century, and we are proud to have you here with us in the beautiful city of Budapest.

This city is connected to water in many ways. The Danube River flows majestically through the heart of Budapest, providing drinking water for 1.8 million people through the efficient riverbank filtration technology. Budapest is also known as the city of spas, because there is no other place in the world with so many natural hot springs and spas offering relaxing and therapeutic experiences. The naturally discharging thermal waters have shaped the city's karst landscape, creating unique hypogenic caves and mineral formations. Due to the favorable natural conditions, geothermal energy exploration gains importance in the area in response to the growing global demand for sustainable energy solutions.

The topics of the conference highlight the diverse and critical roles that groundwater plays in environmental sustainability, resource management, and societal well-being. Thus, we aim to provide a platform for leading experts, researchers, and professionals from around the globe to engage in discussions and explore the multifaceted role of groundwater in our world.

We hope you enjoy your time in Budapest and make the most of the days ahead – exchanging ideas, sharing knowledge, meeting colleagues from around the world, and contributing to inspiring discussions on the future of groundwater. We wish you a memorable and rewarding Congress!



Anita Erőss
Congress Chair

ABOUT THE LOGO

The logo represents the deep connection between groundwater and Hungary's cultural heritage. The gémeskút (sweep pole well), a traditional Hungarian well structure depicted in the design, has been a vital water-lifting device for centuries. Originating from the ancient shadoof used in Mesopotamia and Egypt, it likely spread to Hungary during the Ottoman era. For generations, it was the most common method of accessing groundwater across the Great Hungarian Plain, owing to the shallow water table related to discharge areas. Such wells are still in use today on small farms and in some villages. Beyond its practical use, the gémeskút also played a role in rural communication, signalling daily activities to shepherds and field workers. Today, it remains an iconic symbol of Hungary's water heritage.

The bottom represents the aquifer, highlighting the crucial role of subsurface water storage and the richness of this resource. The orange gradient symbolizes geothermal potential, emphasising the connection between groundwater and geothermal energy, a prominent feature of the Pannonian Basin.





This visual identity reflects the core themes of the conference: groundwater, sustainability, multi-resource management, and the balance between tradition and innovation.

Sources:

Almási, István, & Szanyi, János (2024). Hydrogeology of the Pannonian Basin. The Groundwater Project, Guelph, Ontario, Canada. https://doi.org/10.21083/978-1-77470-044-0

Hungarian Ethnographic Encyclopedia

THE ORGANIZERS



Petra Baják
University of Milan, Italy



Tamás Buday
University of Debrecen, Hungary



Brigitta Czauner
Eötvös Loránd University, Hungary



Katalin Hegedűs-Csondor
Budapest Spas cPlc., Hungary



András Jakab
Jakab és Társai Ltd., Hungary



Rita Miklós
University of Miskolc, Hungary



Ádám Tóth
Utrecht University,
the Netherlands



Zsóka Szabó
SARA Geological Survey, Hungary



János Szanyi
HUN-REN EPSS Rybach
Research Centre, Hungary



Márk Szijártó
Eötvös Loránd University, Hungary



Teodóra Szőcs
Ludovika University of
Public Service, Hungary



Ágnes Tahy
General Directorate of
Water Management, Hungary

Local Scientific Committee



Judit Mádl-Szőnyi
Scientific Committee Chair
Eötvös Loránd University



Péter Szűcs
University of Miskolc



Attila Kovács
Geokovacs Hydrogeological
Services (GHS)
Budapest University of
Technology and Economics



Ildikó Erhardt
Scientific Committee Secretary
Eötvös Loránd University

- **Abou Amani**, UNESCO
- **Bartolomé Andreo Navarro**, University of Malaga, Spain
- **Okke Batelaan**, Flinders University, Australia
- **Serge Brouyère**, Université de Liège, Belgium
- **Catalin Stefan**, Technical University Dresden, Germany
- **Pierre-Yves Jeannin**, Swiss Institute of Speleology and Karstology, Switzerland
- **Joanna Doummar**, American University of Beirut, Lebanon
- **John Cherry**, The Groundwater Project, Canada
- **Marco Petitta**, Sapienza University of Rome, Italy
- **John W. Molson**, Université Laval, Canada
- **Nina Rman**, Geological Survey of Slovenia, Slovenia
- **Beth L. Parker**, University of Guelph, Canada
- **Nataša Ravbar**, Karst Research Institute, Slovenia
- **Seifu Kebede Gurmessa**, University of KwaZulu-Natal, South Africa
- **Zoran Stevanovic**, University of Belgrade, Serbia
- **Wendy Timms**, Deakin University, Australia
- **Zheng Chunmiao**, Southern University of Science and Technology, China
- **Martin Sauter**, University of Göttingen, Germany
- **John Doherty**, Watermark Numerical Computing, Australia
- **Adam Porowski**, Polish Academy of Sciences, Poland
- **Thomas Boving**, University of Rhode Island, USA
- **Grant Ferguson**, University of Saskatchewan, Canada
- **Andrew H. Manning**, U.S. Geological Survey, USA
- **Tibor Stigter**, IHE Delft, The Netherlands
- **Karen Grothe Villholth**, Water Cycle Innovation Ltd., South Africa
- **Daniela Benedicto van Dalen**, Acacia Water, The Netherlands
- **Sandra Garcia Gabas**, Federal University of Mato Grosso do Sul, Brazil
- **Peter Malik**, State Geological Institute of Dionyz Stur, Slovakia
- **Masaki Hayashi**, University of Calgary, Canada
- **Jodie Miller**, Isotope Hydrology Section, IAEA
- **Aqeela Parker**, GEOSS, South Africa
- **Shammy Puri**, Centre for Sustainable Solutions with Practical Hydrogeology, UK

EXTENDED SCIENTIFIC COMMITTEE

GROUNDWATER – A KEY MULTI-RESOURCE

The conference focuses on the crucial role of groundwater as a multi-resource essential for environmental sustainability, societal well-being, and resource management. It explores the complex interactions within groundwater systems, including deep and shallow aquifers, karst and fractured rock formations, and processes in the unsaturated zone. The event emphasizes the importance of groundwater in supporting green energy transition, particularly through geothermal and mineral resources.

Topics also include governance and management strategies such as transboundary aquifers, international regulations, and sustainable practices within a circular economy framework. Innovative solutions like numerical simulations, artificial intelligence, and experimental research are highlighted, along with approaches to address pollution, emerging contaminants, and remediation.

Adaptation to climate change is a key focus, considering drought resilience, extreme event impacts, and human interventions affecting the water cycle. The conference underscores the societal significance of groundwater, promoting awareness, citizen science, sanitation, health, and education to foster more resilient and equitable water management systems worldwide.

Congress topics

1. Interacting groundwater systems in the Water Cycle
2. Groundwater in green transition
3. Conjunctive water management
4. Next generation solutions
5. Climate change adaptation
6. Groundwater and Social awareness/Society

AGENDA

Opening hours of the registration desk

Monday	14:00–18:00	14 September 2026
Tuesday–Thursday	08:00–19:00	15–17 September 2026
Friday	09:00–18:00	18 September 2026

Monday – 14 September 2026

07:00–18:00 Field trips

19:30–22:30 Welcome Reception on the Danube

Celebrate the opening of the 53rd World Groundwater Congress aboard the Europa Boat, the largest event ship on the Danube, for an unforgettable evening.

During this two-hour standing reception, guests will enjoy a selection of delicious finger foods and drinks while cruising through the heart of the Hungarian capital. The route offers spectacular views of Budapest's UNESCO World Heritage riverfront, including iconic landmarks such as Buda Castle, the Chain Bridge, Gellért Hill and the magnificent Hungarian Parliament illuminated against the evening sky.

The Welcome Reception provides the perfect opportunity to reconnect with colleagues, make new acquaintances and begin the Congress in a relaxed and welcoming atmosphere.

Departure from the Buda side of the Chain Bridge. Please note that no organised transportation to or from the departure point will be provided.

Boarding: 19:30
Departure of the boat: 20:00



FIELD TRIPS

FT1
Szeged

FT2
Danube–Tisza Interfluve

FT4
Tata

FT5
Lake Velence

FT6
Bükkábrány

FT8
Tihany

FT9
Szentendre Island

FT11
Budapest Rose Hill

FT12
Budapest Gellért Hill

FT13
Budapest geothermal

Tuesday – 15 September 2026

08:00–09:00 Opening Ceremony Room: Pátria

09:00–09:30 Keynote: Xiao-Wei Jiang Room: Pátria



The international development of theoretical groundwater flow system studies

Dr. Xiao-Wei Jiang is Professor of Hydrogeology and Vice Dean of the School of Water Resources and Environment at China University of Geosciences (Beijing), and co-chair of the IAH Regional Groundwater Flow Commission. His research focuses on the physics and chemistry of groundwater flow systems, with applications to large sedimentary basins such as the Ordos Basin and the North China Plain. He has advanced the understanding of regional groundwater dynamics in major aquifer systems. He has received several national awards, including recognition for outstanding doctoral research and major national science funding awards. He is the author of History and Hydraulics of Flowing Wells, widely used internationally in groundwater education and research.

09:30–10:00 Keynote: John Molson Room: Pátria



Groundwater flow system modelling: A historical and practical perspective

Dr. John Molson is Professor in the Department of Geology and Geological Engineering at Université Laval, Canada. His research focuses on hydrogeological modelling, including numerical simulation of groundwater flow and coupled processes such as reactive contaminant transport, heat transport, density-dependent flow, and cryo-hydrogeology in porous and fractured media. He applies modelling approaches to groundwater protection, remediation, and basin-scale hydrogeological characterization. He has contributed to environmental risk assessments and large-scale groundwater studies, including projects under Quebec's PACES program. He promotes numerical modelling as a core tool in hydrogeology education and research and contributes to the development of modelling tools for the Groundwater Project. He serves as Vice-President of the Canadian Chapter of the International Association of Hydrogeologists (IAH-CNC).

10:00–10:30 Coffee break & Group photo 1

10:30–12:30 Parallel oral sessions:

Room: Pátria **Session 5.3 pt. I** Progressive advances in urban hydrogeological processes	**Room: Brahms** **Session 6.2 pt I** Advancing socio-hydrogeology: bridging groundwater science, social systems, and decision-making	**Room: Lehár** **Session 2.1 pt I** Groundwater-dependent geothermal systems	**Room: Bartók** **Session 1.3 pt I** Processes, tools and advancements in coastal hydrogeology
Room: Mozart **Session 6.1 pt I** Groundwater for water security and resilience in low- and middle-income countries (LMICs)	**Room: Liszt I** **Session 1.4 pt I** Evolving from Tóth's gravitational systems of groundwater flow to integrated basin-scale fluid systems for addressing 21st-century challenges	**Room: Liszt II** **Session 6.5** Role of hydrogeologists in geological surveys — their work, impact, and benefits to society	**Room: Kodály**

12:30–13:30 Lunch

Tuesday – 15 September 2026

13:30–14:00 Keynote: Miklós Antics Room: Pátria



Innovative well architectures to maximise heat extraction in areas with low transmissivity hot sedimentary aquifers. A review of Paris Basin well design achievements

Dr. Miklos Antics is Managing Director and Associate Partner at GPC Instrumentation Process (GPC IP) and GEOFLUID France. His work focuses on geothermal energy development across low- to high-enthalpy systems in Europe, Africa, Central America, the Caucasus, and Southeast Asia. He specializes in integrated geothermal reservoir development, combining geoscience, reservoir engineering, drilling, and completion design, with an emphasis on sustainable heat extraction and innovative well architectures. He has developed sustainable reservoir concepts for multiple geothermal fields and has lectured internationally on geothermal reservoir simulation and sustainable resource development. He has authored and co-authored more than 75 technical papers and four textbooks. He serves as President of the European Geothermal Energy Council (EGEC) and is a member of EGEC, EAGE, GRC, and SPE.

14:00–14:30 Keynote: Tom Gleeson Room: Pátria



Creative, caring socio-hydrogeology: community-based science and art to enrich how we engage with partners, place, and other disciplines

Dr. Tom Gleeson is Professor of Civil Engineering and President's Chair at the University of Victoria, where he leads the Groundwater Science and Sustainability research group. His research focuses on groundwater science, sustainability, and interdisciplinary approaches that integrate community engagement and co-production of knowledge. He collaborates with governments, communities, and organizations to support equitable and sustainable water futures. He is a Clarivate Highly Cited Researcher and a member of the Royal Society of Canada's College of New Scholars, Artists and Scientists. His work bridges scientific understanding and societal decision-making in groundwater systems.

14:30–14:45 Technical break / room change

14:45–15:45 Parallel oral sessions:

Room: Pátria **Session 5.3 pt II** Progressive advances in urban hydrogeological processes	**Room: Brahms** **Session 6.2 pt II** Advancing socio-hydrogeology: bridging groundwater science, social systems, and decision-making	**Room: Lehár** **Roundtable discussion 1:** The groundwater debate: open issues in hydrogeology	**Room: Bartók**
Room: Mozart **Session 6.1 pt II** Groundwater for water security and resilience in low- and middle-income countries (LMICs)	**Room: Liszt I** **Session 1.4 pt II** Evolving from Tóth's gravitational systems of groundwater flow to integrated basin-scale fluid systems for addressing 21st-century challenges	**Room: Liszt II** **Session 3.6 pt I** Approaches for climate-resilient and sustainable water planning	**Room: Kodály**

15:45–16:45 Posters and coffee break & Opening of the Art Exhibitions

Tuesday – 15 September 2026

16:45–18:45 Parallel oral sessions:

Room: Pátria **Session 5.3 pt III** Progressive advances in urban hydrogeological processes	**Room: Brahms** **Session 2.2** Mining Impacts on groundwater systems: hydrogeology, geochemistry and sustainable management	**Room: Lehár** **Session 2.1 pt II** Groundwater-dependent geothermal systems	**Room: Bartók** **Session 1.3 pt II** Processes, tools and advancements in coastal hydrogeology
Room: Mozart **Session 3.8** Aligning Practice and Policy: Building Groundwater Secure Systems through Conjunctive Management and Law	**Room: Liszt I** **Special Session for József Tóth**	**Room: Liszt II** **Session 3.6 pt II** Approaches for climate-resilient and sustainable water planning	**Room: Kodály**

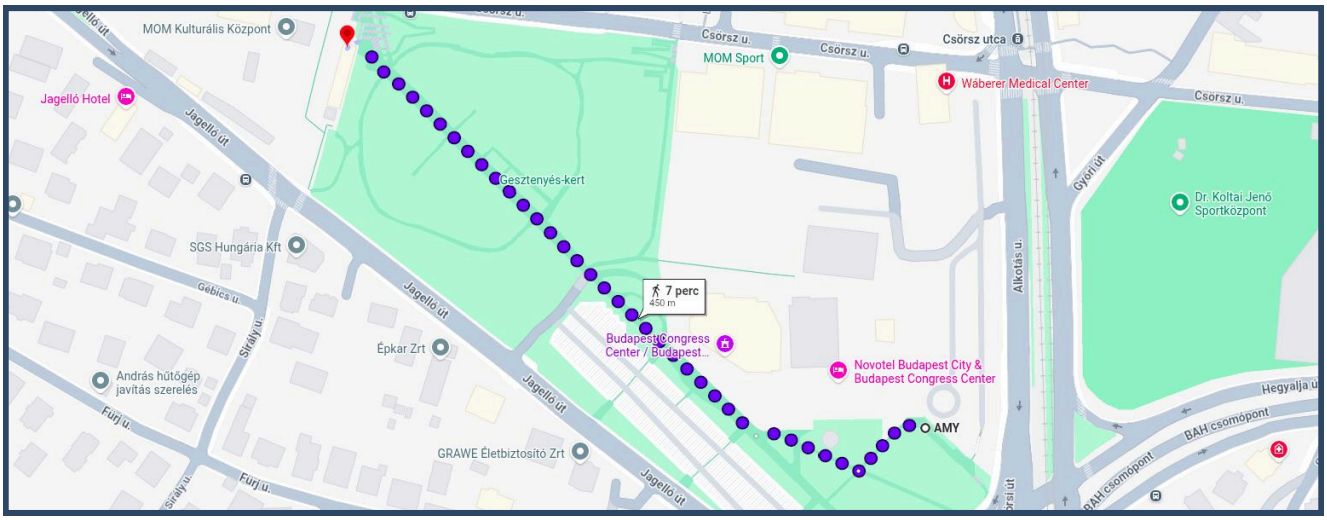
19:00–20:00

Room: Lehár Early Career Hydrogeologists' Network (ECHN) Annual General Meeting	**Room: Mozart** Coastal Groundwater Network	**Room: Liszt I** IAH Regional Groundwater Flow Commission

20:00–22:00 Social event hosted by ECHN Larus Event Center

The Early Career Hydrogeologists' Network (ECHN) invites students and early career professionals to an informal networking evening designed to help young hydrogeologists connect with peers from around the world.
Whether you are looking to expand your professional network, exchange ideas or simply meet fellow participants in a relaxed setting, this event offers an excellent opportunity to build new international connections. Please note that participation in this event required advance registration. Those who signed up have received their invitation card and drink vouchers at the Congress registration desk. Unfortunately, no additional participants can be accepted at this stage.

1124 Budapest, Csörsz utca 18/b (just a 5-minute walk from the Congress venue)



Special Session for József Tóth



Celebrating József (Joe) Tóth (1933–2026)
A commemorative session honouring his life, character, teaching, and lasting contributions to hydrogeology

This commemorative session celebrates the life and legacy of József (Joe) Tóth, one of the most influential hydrogeologists of our time. His pioneering concept of regional groundwater flow systems fundamentally changed our understanding of groundwater flow and its role in geological and environmental processes, and continues to shape hydrogeological research worldwide.

Beyond his outstanding scientific achievements, Joe inspired generations of researchers, students, and professionals through his teaching, mentorship, generosity, and enthusiasm for science.

The session welcomes contributions from former students, colleagues, collaborators, and friends, as well as from researchers whose work and scientific thinking have been influenced by his ideas. Contributions may include personal memories and reflections, shared scientific or field experiences, and perspectives on the impact and continuing development of his concepts.

The aim of the session is to create a collective tribute reflecting both Joe Tóth's extraordinary scientific legacy and the profound personal influence he had on the international hydrogeological community.

Session Chair:
Judit Mádl-Szőnyi

Co-chair:
Brigitta Czauner

Wednesday – 16 September 2026

08:30–09:00 Keynote: Chunmiao Zheng Room: Pátria



The future of groundwater modeling: Large-scale, integrated, and AI-Enabled

Dr. Chunmiao Zheng is Chair Professor and Vice President at the Eastern Institute of Technology (EIT), Ningbo, China. His research focuses on contaminant transport modelling, groundwater–surface water interactions, and sustainable water resources management. He has held academic positions at several leading universities in China and the United States. He developed the widely used MT3D/MT3DMS contaminant transport models, applied in over 100 countries. He is the author of *Applied Contaminant Transport Modeling* and a *Clarivate Highly Cited Researcher*. He has received major international awards recognizing his contributions to groundwater science and modelling.

09:00–09:30 Keynote: Bridget R. Scanlon Room: Pátria



Running Out of Water or Managing Climate Extremes?

Dr. Bridget R. Scanlon is a Research Professor at the Bureau of Economic Geology, Jackson School of Geosciences, University of Texas at Austin. Her research focuses on water resources, including satellite-based assessments, hydrological modelling, and water management under climate extremes. She works on adaptation strategies such as managed aquifer recharge to store floodwaters for use during droughts. She has authored or co-authored approximately 200 publications. She is a Fellow of the American Association for the Advancement of Science, the American Geophysical Union, and the Geological Society of America, and a member of the National Academy of Engineering.

09:30–10:00 Coffee break

10:00–12:30 Parallel oral sessions:

Room: Pátria **Session 4.1 pt I** Big data and machine learning applications in hydrogeology	**Room: Brahms** **Session 4.3 pt I** Advances in modeling groundwater dynamics from regional to global scales	**Room: Lehár** **Session 5.4 pt I** Managed aquifer recharge for climate change adaptation	**Room: Bartók** **Session 1.7 pt I** Hydrogeochemical and isotopic fingerprinting of groundwater systems: from water–rock interaction to human impacts
Room: Mozart **Session 1.2 pt I** Hydrogeology of karst and fractured systems: from field studies to quantitative characterization	**Room: Liszt I** **Session 1.8 pt I** Environmental tracers to investigate the anthropogenic impacts on groundwater	**Room: Liszt II** **Session 4.8 pt I** Groundwater model optimization and uncertainty	**Room: Kodály**

12:30–13:30 Lunch

13:30–14:30 Plenary Session 1 Room: Pátria

Groundwater at the Heart of the 2026 UN Water Conference: IAH Positions and UN Perspectives

further details on the page 12

14:30–14:45 Technical break / room change

Plenary Session 1

Groundwater at the Heart of the 2026 UN Water Conference: IAH Positions and UN Perspectives

The 2026 United Nations Water Conference, to be held in Abu Dhabi in December 2026, represents a rare high-level opportunity to shape the global water agenda. Ensuring that groundwater is fully recognized across all dimensions of this agenda is therefore critical. The International Association of Hydrogeologists (IAH) is committed to strengthening the visibility of groundwater in global water policy and decision-making processes.

In support of this objective, the IAH has been actively contributing to the preparatory process for the 2026 UN Water Conference (UNWC) through the development of IAH's Position Paper, a dedicated webinar series about groundwater contribution to the achievement of the 6 Interactive UNWC Dialogues, inputs to the High-Level Preparatory Meeting in Dakar, and participation in the UN Informal Preparatory Working Groups (IPWG) across all six Interactive Dialogues: Water for People, Water for Prosperity, Water for the Planet, Water for Cooperation, Water in Multilateral Processes, and Investing in Water.

Building on this engagement, we propose a 60-minute interactive plenary session to present the IAH Position Paper and foster dialogue among IAH congress participants, UN agencies, and policymakers before presenting it at the 2026 UN Water Conference in December.

The proposed plenary session will be structured in two parts. The first 10 minutes will feature one keynote presentation introducing the IAH position paper in the frame of the UNWC, drafted by the IAH's LUNA network and highlighting the urgent need for stronger representation of groundwater in multilateral processes. The remaining 50 minutes will consist of a moderated panel discussion in line with the six Interactive Dialogues to promote the exchange of ideas and perspectives to advance the SDGs. High-level panellists from UN agencies (IGRAC, UNESCO) and Indigenous Science scholar along with conference attendees (through Wooclap and questions from the audience) will explore how groundwater- specific indicators, scientific evidence, education, and local expertise can be integrated into each of these global dialogues. To strengthen the link between the congress venue and the session's theme, a water expert from Hungary will participate, recognizing Hungary's expertise in groundwater governance and helping to connect national perspectives with global priorities.

In conclusion, the session will highlight the IAH's broader engagement in the UN Water Conference process, as well as in other multilateral processes, and its unique role in advancing groundwater on the global agenda.

Expected outcomes of the plenary session include a revised IAH position paper for the 2026 UN Water Conference (including the main findings of the IAH Webinar series) and a congress-wide statement to UN-WATER, that could be named the "Budapest Statement on Groundwater". Ultimately, this session aims to advance a unified voice for the IAH, ensuring that groundwater is visible and is fully considered in all pillars of the upcoming UN deliberations.

Participants are encouraged to read the current IAH position paper in advance of the session!

Keywords: *Groundwater governance, 2026 UN Water Conference, IAH Position Paper, Transboundary Aquifers, SDG 6 Integration, Abu Dhabi 2026; LUNA network*

Plenary keynotes:



Marie-Amélie Pétré



Patrick Lachassagne

Moderators: Elena Egidio, Cynthia McClain
Rapporteur: Patrick Lachassagne

Wednesday – 16 September 2026

14:45–17:15 Parallel oral sessions:

Room: Pátria **Session 4.1 pt II** Big data and machine learning applications in hydrogeology	**Room: Brahms** **Session 4.3 pt II** Advances in modeling groundwater dynamics from regional to global scales	**Room: Lehár** **Session 5.4 pt II** Managed aquifer recharge for climate change adaptation	**Room: Bartók** **Session 1.7 pt II** Hydrogeochemical and isotopic fingerprinting of groundwater systems: from water–rock interaction to human impacts
Room: Mozart **Session 1.2 pt II** Hydrogeology of karst and fractured systems: from field studies to quantitative characterization	**Room: Liszt I** **Session 1.8 pt II** Environmental tracers to investigate the anthropogenic impacts on groundwater	**Room: Liszt II** **Session 4.8 pt II** Groundwater model optimization and uncertainty	**Room: Kodály**

17:15–18:15 Posters and coffee break

17:15–18:15

Room: Lehár Commission on Mineral and Thermal Waters	**Room: Bartók** Commission on Groundwater and Climate Change	**Room: Mozart** IAH-Liaison with UN Activities (LUNA) Network	**Posters and coffee break**

18:15–19:45 Room: Pátria

IAH Annual General Meeting

Thursday – 17 September 2026

08:30–09:30 Plenary Session 2 Room: Pátria

Towards a Transdisciplinary Global Groundwater Sustainability Network (GGSN)

This session will describe the establishment of a Global Groundwater Sustainability Network (GGSN), a virtual network of transdisciplinary partners – across universities, research institutions, government agencies, non-profits, the private sector, financiers, and communicators – to pave ways towards groundwater sustainability through transformative and unprecedented integration and collaboration across groundwater measurement, monitoring, science, and management. The GGSN is envisioned as a network of regionally-focused aquifer initiatives, linked through a central coordinating hub, for advancing sustainable management of the world's major groundwater systems. The GGSN will enable both locally grounded action and global integration. GGSN will conduct research that underpins compelling narratives for ministerial-level engagement on destabilizing socioeconomic and ecological consequences of continued groundwater depletion, facilitating critically-needed policy transformations; contribute to co-developed, region-specific, science-informed sustainability pathways for aquifers on the network; and work to substantially elevate groundwater within UN agendas towards dramatically reducing non-renewable groundwater use globally. An important feature of the GGSN will be to will integrate novel satellite observations of groundwater storage changes with in situ measurements and advanced AI-driven analytics, to build decision-support systems usable across scales. By prioritizing accessibility, transparency, and equitable access to data and tools, GGSN will promote inclusive, effective, and durable water governance worldwide. The GGSN concept, its potential structure, and pilot activities will be discussed by the expert panelists, with a view towards broad feedback and engagement, and preparation for the 2026 UN Water Conference. The session will feature a keynote followed by a panel and an audience question and answer period.

Keywords: *Groundwater sustainability; transdisciplinarity; groundwater management; groundwater resilience; groundwater depletion*

Session chair:



Jay Famiglietti

Co-conveners: Elisabeth Lictevout, Richard Taylor, Xander Huggins

09:30–10:00 Coffee break

10:00–12:00 Parallel oral sessions:

Room: Pátria **Session 5.1 pt I** Groundwater and climate change: predictive studies and forecasting methods	**Room: Brahms** **Session 5.2** Managed aquifer recharge: essential for groundwater security?	**Room: Lehár** **Session 5.4 pt III** Managed aquifer recharge for climate change adaptation	**Room: Bartók** **Session 1.7 pt III** Hydrogeochemical and isotopic fingerprinting of groundwater systems: from water–rock interaction to human impacts
Room: Mozart **Session 1.2 pt III** Hydrogeology of karst and fractured systems: from field studies to quantitative characterization	**Room: Liszt I** **Session 4.2 pt I** From data to action: the contribution of groundwater monitoring as a driver of change	**Room: Liszt II** **Session 3.3 pt I** Monitoring and modeling groundwater-dependent ecosystems: recent advances and traditional knowledge	**Room: Kodály** **Session 1.1 pt I** Isotopic studies from precipitation to groundwater

12:00–13:00 Lunch

Thursday – 17 September 2026

13:00–15:00 Parallel oral sessions:

Room: Pátria	**Room: Brahms** **Session 4.3 pt III** Advances in modeling groundwater dynamics from regional to global scales	**Room: Lehár** **Session 4.4 pt I** 21st-century groundwater quality challenges	**Room: Bartók** **Session 1.7 pt IV** Hydrogeochemical and isotopic fingerprinting of groundwater systems: from water–rock interaction to human impacts
Room: Mozart **Session 6.4** Hydrogeology education – good practices and new openings	**Room: Liszt I** **Session 4.2 pt II** From data to action: the contribution of groundwater monitoring as a driver of change	**Room: Liszt II** **Session 3.3 pt II** Monitoring and modeling groundwater-dependent ecosystems: recent advances and traditional knowledge	**Room: Kodály** **Session 1.1 pt II** Isotopic studies from precipitation to groundwater

15:00–16:00 Posters and coffee break

16:00–17:00

Room: Pátria	**Room: Brahms** Commission on Managing Aquifer Recharge	**Room: Lehár** National Chapters Committee Members Meeting	**Room: Bartók**
Room: Mozart Roundtable discussion 2: Model Uncertainty in Hydrogeology	**Room: Liszt I** Urban Groundwater Network	**Room: Liszt II** Burdon Groundwater Network for International Development	**Room: Kodály** IAH-SHG

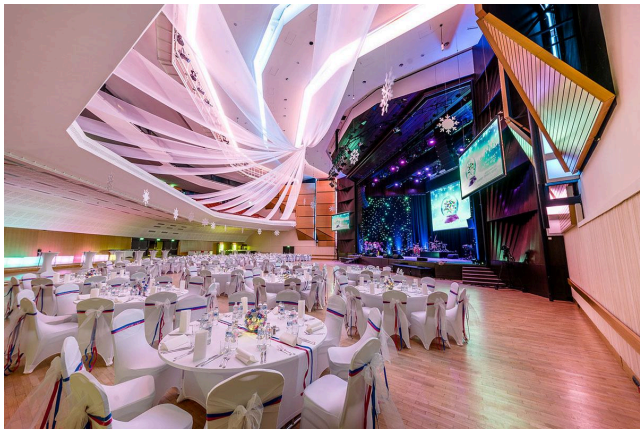
17:00–19:00 Room: Bartók

3D Cave Projection (3 × 30-minute presentations + technical breaks)

19:00–22:00 Room: Pátria

Gala Dinner

Join colleagues and friends for a memorable evening featuring an excellent buffet dinner showcasing a selection of Hungarian and international cuisine. The relaxed atmosphere, carefully selected wines and music will provide the perfect setting to celebrate another successful World Groundwater Congress.
After dinner, we invite everyone to stay, enjoy the music and, we hope, fill the dance floor for an unforgettable evening together.
Entry to the Gala Dinner is only possible with your congress badge, so please make sure to bring it with you.



Friday – 18 September 2026

08:30–09:00 Keynote: Marc F.P. Bierkens Room: Pátria



Groundwater sustainability and the limits of groundwater use

Dr. Marc Bierkens is Professor of Earth Surface Hydrology at Utrecht University. His research focuses on the global water cycle, groundwater systems, and the impacts of climate change and human water use. He develops high-resolution global hydrological and water resources models, including global groundwater flow modelling, widely used in scientific research and water risk assessment tools. His work supports applications such as the National Geographic World Water Map and the World Resources Institute Aqueduct Water Risk Atlas. He has contributed significantly to advancing global-scale understanding of water availability and water-related risk under environmental change.

09:00–09:30 Keynote: Joanna Doummar Room: Pátria



From data scarcity to decision support: A scaleable framework for groundwater management

Dr. Joanna Doummar is Associate Professor of Groundwater Hydrology and Chairperson of the Department of Earth Sciences at the American University of Beirut, Lebanon. Her research focuses on groundwater quantity and quality assessment in Mediterranean, semi-arid, and snow-governed karst and fractured aquifers. She specializes in high-resolution monitoring and collection of time series data, subsurface characterization, and numerical groundwater flow modelling. She has authored and co-authored numerous scientific publications and serves as Vice President (MENA Region) of the International Association of Hydrogeologists (IAH). She is also an elected member of the IAH Karst Commission and a member of the World Economic Forum Young Scientists Community (Class of 2020).

09:30–10:30 Posters and coffee break

10:30–12:30 Parallel oral sessions:

Room: Pátria **Session 5.1 pt II** Groundwater and climate change: predictive studies and forecasting methods	**Room: Brahms** **Session 3.5** Nature-based solutions for sustainable groundwater management	**Room: Lehár** **Session 4.4 pt II** 21st-century groundwater quality challenges	**Room: Bartók** **Session 4.5** Groundwater temperatures in a warming climate: risks, opportunities, and pathways for sustainable thermal management
Room: Mozart **Session 1.6** Developments in mineral and thermal waters: from exploration to sustainable use	**Room: Liszt I** **Session 4.2 pt III** From data to action: the contribution of groundwater monitoring as a driver of change	**Room: Liszt II** **Session 4.6** Data-driven and hybrid methods for groundwater vulnerability assessment	**Room: Kodály**

12:30–13:30 Lunch

Friday – 18 September 2026

13:30–14:00 IAH Distinguished Lecture: Jay Famiglietti Room: Pátria



The emergence of groundwater as the most valuable natural resource of the 21st century

Professor Famiglietti's research has helped transform the understanding of global freshwater systems through the use of satellite observations, particularly in tracking groundwater depletion and changes in terrestrial water storage at continental to global scales. His work has been central in identifying widespread groundwater decline and in advancing methods that allow freshwater changes to be observed from space.

The inaugural lecture will explore the accelerating depletion of groundwater resources across the world's major aquifers and thousands of smaller systems. It will highlight how groundwater, despite being the largest reservoir of the planet's unfrozen freshwater, remains among the least protected components of the Earth system. The lecture will present the latest satellite-based evidence of global freshwater change and examine the development of large-scale "mega-drying" regions where groundwater will increasingly shape future water availability. It will also address the broader implications of these trends, from climate-driven hydrological change to biodiversity loss and water insecurity, and argue for a stronger global effort to elevate groundwater within scientific, policy, and public climate dialogues.

The International Association of Hydrogeologists (IAH) launched its new Distinguished Lecturer Series this year, an initiative designed to strengthen international engagement and highlight the critical role of groundwater in addressing global environmental and societal challenges.

The inaugural Distinguished Lecturer title has been awarded to **Professor Jay Famiglietti**, marking the first lecture in this new series.

sponsored by General Directorate of Water Management

14:00–15:00 Closing Ceremony Room: Pátria

15:00–17:45

Room: Lehár	**Room: Bartók**
Short course: General introduction to COMSOL – Subsurface and groundwater flow simulation	WREG meeting

Meet our supporters

Platinum sponsors

Nemzeti Vízművek

SARA Supervisory Authority for Regulatory Affairs

DROTAQUA

Gold sponsor

VEOLIA

GEOHIDROTERV

Silver sponsors

DHI

sciengineer

Szentkirályi

TRAQUA We track water

AGT ADVANCED GROUNDWATER TECHNIQUES

MOLGROUP

Supporters

National Research, Development and Innovation Office Hungary
PROGRAM FINANCED FROM THE NRDI FUND

Project no. MEC_SZ 157097 has been implemented with the support provided by the Ministry of Culture and Innovation of Hungary from the National Research, Development and Innovation Fund, financed under the MEC_SZ_26 funding scheme.

unesco

BUDAPEST GEOTHERMAL ENERGY SUMMIT

OVF

ELTE EÖTVÖS LORÁND UNIVERSITY

Supported by the University Excellence Fund of Eötvös Loránd University, Budapest, Hungary (ELTE)

József & Erzsébet Tóth Endowed Hydrogeology Chair Foundation

iah aih

BGYH BUDAPEST GYÓGYFÜRDŐI ÉS HÉVIZEI ZRT. BUDAPEST

35 Geo-Log

MTA HUNGARIAN WATER SCIENCE PROGRAMME

Exhibitors

AGILA Renewable Energy Services Kft.

Albillia FLUOROMETERS

AQUAVEO®

iah aih

Packers Made differently Perform better

In-Situ | water simplified.

SGS

BETA

OVF

TRAQUA We track water

ROYAL Eijkelkamp Meet the difference

Meet our supporters

National Waterworks Private Company ltd. (Nemzeti Vízművek Zrt.)

PLATINUM SPONSOR

National Waterworks is a state-owned enterprise acting on behalf of the Hungarian State to exercise ownership rights and obligations over publicly owned water utility service providers and water utility infrastructures. The 16 water utility providers under the umbrella of the company operate 45,000 km of drinking water pipelines and 35,000 km of sewer networks, 680 water treatment plants and 575 wastewater treatment facilities. The service areas cover approximately 2,000 municipalities, with a total population equivalent of 7.4 million.

Nemzeti Vízművek

ROTAQUA Ltd.

PLATINUM SPONSOR

ROTAQUA Ltd. is a Hungarian company with decades of professional experience in geological exploration, well drilling, and the construction of water and geothermal wells. Our expertise covers the entire project cycle, from planning and exploration to complex drilling operations. With modern technology and an experienced professional team, we deliver projects across Central and Eastern Europe.

ROTAQUA

Hungarian Geothermal Cluster

PLATINUM SPONSOR

The fundamental objective of the Hungarian Geothermal Cluster is to promote, by every possible means, the exploitation of the exceptional geothermal potential of the Carpathian Basin and, through the intensification of geothermal energy utilization, to strengthen Hungary's energy sovereignty and its role as a regional geothermal hub. The broader mission of the Cluster is to serve as an umbrella organization for the entire Hungarian geothermal sector, creating a cooperation platform and comprehensive knowledge-sharing network connecting governmental, scientific, and market actors, while also providing professional representation for stakeholders across the Hungarian geothermal value chain.

Contact us on www.geocluster.hu..

SARA Supervisory Authority for Regulatory Affairs

GEOHIDROTERV Kft.

GOLD SPONSOR

Established in 1990, GEOHIDROTERV Kft. is a leading professional firm equipped with state-of-the-art technologies and extensive experience in environmental protection, remediation, and waste management.
Over the past decades, our highly qualified engineers and specialists have specialized in delivering complex solutions across key sectors. Today, we provide comprehensive services in environmental engineering, engineering geology, water management, and hydraulic structures—both nationwide and internationally.

GEOHIDROTERV

Meet our supporters

Veolia

GOLD SPONSOR

Veolia is one of the market leaders in Hungary in the energy, water and wastewater management industries.
The energy line produces and supplies electricity and heat in 18 towns and provides energy services to various institutions and industrial businesses.
The water utility line of the company supplies drinking water and provides wastewater treatment services for hundreds of thousands families.
The water technology line is engaged in the development and production of membranes used for drinking water and wastewater treatment. It also provides engineering services for the construction and renovation of municipal and industrial water and wastewater treatment plants, as well as wastewater treatment services for industries and municipalities using specialised technologies.

DHI Group

SILVER SPONSOR

DHI is a global consultancy and technology company advancing knowledge and solving challenges in water environments since 1964. With 1,100+ engineers and other specialists, DHI delivers solutions across sectors including cities, marine and coast, energy, water resources, groundwater and mining, and ports and maritime. From the head office in Denmark to offices across the globe, the company combines expertise, advanced technologies and modelling solutions to help decision-makers manage and protect water globally.

TRAQUA

SILVER SPONSOR

At TRAQUA, we combine expertise in field hydrogeology with the development of our own innovative, compact sensors. We use these to answer questions related to water flows (groundwater, surface water, distribution water, wastewater, etc.), hydraulic connectivity, groundwater behaviour, the vulnerability of water resources and water quality monitoring. We operate in the fields of drinking water production, quarrying and mining, urban water management, geothermal systems, infrastructure and tunnelling, and karst risks.

TRAQUA has developed and produced its own in-situ measurement equipment. The STREAM® fluorometer/ turbidimeter enables direct, high-resolution measurement of fluorescence, turbidity and water temperature. Its small size and light weight allow for quick and easy installation in the field, even in remote locations such as natural sites, wells, pipelines and cave systems. STREAM® fluorometers are autonomous and do not require an external datalogger or power source, allowing them to be installed in almost any location.

In addition to providing our hydrological and hydrogeological expertise, we also offer our STREAM fluorometers for rent.

Meet our supporters

MOL Group

SILVER SPONSOR

MOL Group is an international, integrated oil, gas, petrochemicals and consumer retail company, headquartered in Budapest, Hungary. It is active in over 30 countries with a dynamic international workforce of 25,000 people and a track record of more than 100 years. MOL Group operates three refineries and two petrochemical plants under integrated supply chain-management in Hungary, Slovakia and Croatia, and owns a network of almost 2400 service stations across 10 countries in Central & South-Eastern Europe. With more than 85 years of experience in hydrocarbon exploration and production, MOL currently operates production activities in 8 countries and has exploration assets in 10 countries. MOL is committed to transform its traditional fossil-fuel-based operations into a low-carbon, sustainable business model and aspires to become net carbon neutral by 2050 while shaping the low-carbon circular economy in Central and Eastern Europe.

MOLGROUP

Advanced Groundwater Technologies

SILVER SPONSOR

Specialising in technically demanding groundwater challenges, AGT delivers evidence-based consultancy in dewatering, numerical modelling, aquifer storage and geothermal energy. Research and innovation are central to our approach, enabling us to integrate scientific knowledge with state-of-the-art field technologies. Around 30 engineers and geoscientists operate across Belgium, with a growing portfolio in Europe, Africa and the Middle East.

AGT
ADVANCED GROUNDWATER TECHNIQUES

SciEngineer

SILVER SPONSOR

SciEngineer is the official COMSOL Multiphysics partner across Central and Eastern Europe. For 20+ years, we have supported engineering and research teams in solving complex multiphysics challenges, from groundwater and geothermal systems to structural, chemical, and other coupled processes.

With deep COMSOL expertise and hands-on engineering experience, we help our customers turn complex simulation challenges into validated, real-world results.

sciengineer

Meet our supporters

The Hungarian Academy of Sciences - Hungarian Water Science Programme

Following a year of preparatory work the Hungarian Academy of Sciences decided to launch the Hungarian Water Science Programme in 2016. As part of the programme, the National Water Science Research Program was initiated to provide the scientific foundation for the National Water Strategy (the Jenő Kvassay Plan) and to elevate Hungarian water science research to the international forefront. As a key milestone of the program, the research concept—which has also been incorporated into the government's water strategy—identified six priority areas: safe drinking water, water quality, sustainable water use, water management, the protection of aquatic ecosystems, and water-related social conflicts.

Over the past decade, the Programme has become one of the most significant multidisciplinary platforms in the Hungarian water science sector. Throughout its operation, it has supported decision-making as an advisory body and has also served as the cradle of key research initiatives. Among its outstanding achievements are the National Excellence Program Clean Drinking Water, which takes a multidisciplinary approach to the protection of surface-filtered drinking water sources and the safety of the drinking water distribution network; the establishment of the National Laboratory for Water Science and Water Security, as well as the provision of support for the Hungarian Academy of Sciences' National Program for Sustainable Development and Technologies, and the provision of academic expert support for the Constitutional Court's review of the Climate Act.

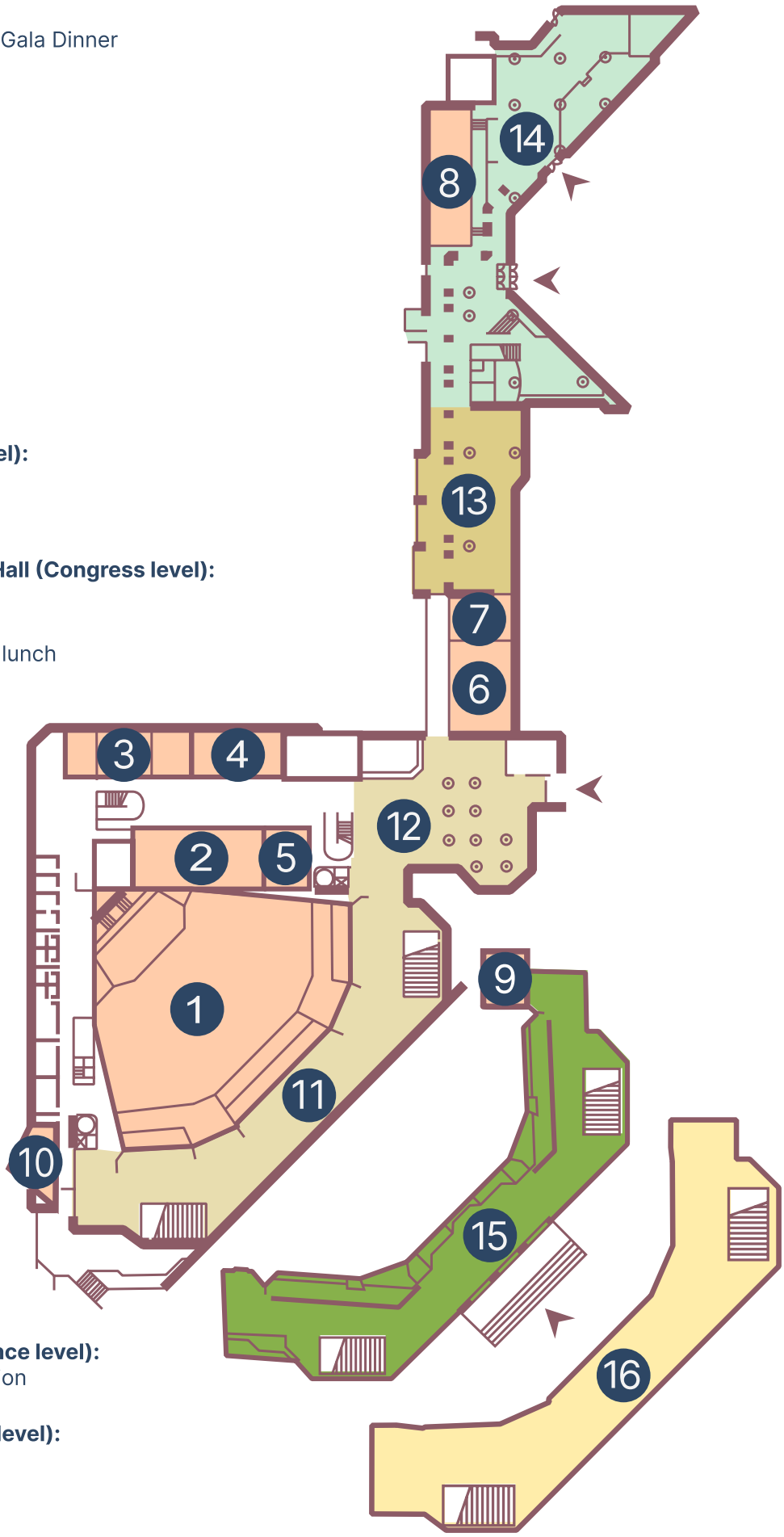
The Steering Committee of the Water Science Programme is currently working actively to promote adaptation to climate change and strengthen resilience. Its future strategic priorities include key issues such as sustainable solutions for landscape and riverbed water retention, the water quality and water replenishment challenges facing our major lakes (Lake Balaton, Lake Velence, Lake Tisza), as well as reducing network losses in municipal water management and drinking water utilities.

The Programme's primary resource and value lie in its extensive and effective network of partnerships, built upon the knowledge base of domestic research institutes and universities. This broad professional background makes it possible to quickly reach and engage the Hungarian research and scientific community, whether to provide a professional foundation for legislative and decision-making processes or to offer effective scientific support during water management emergencies.

MTA
HUNGARIAN WATER SCIENCE
PROGRAMME

Map of the venue

1. **Pátria Hall:**
   Plenary, parallel sessions, Gala Dinner
2. **Bartók Hall:**
   Parallel sessions
3. **Lehár Hall:**
   Parallel sessions
4. **Brahms Hall:**
   Parallel sessions
5. **File upload room**
6. **Liszt I. Hall:**
   Parallel sessions
7. **Liszt II. Hall:**
   Parallel sessions
8. **Mozart Hall:**
   Parallel sessions
9. **Kodály Hall (Entrance level):**
   Parallel sessions
10. **Fortuna Hall:**
    Meeting room
11. **Mirror Corridor of Pátria Hall (Congress level):**
    exhibition, coffee break
12. **Aula:**
    registration, coffee break, lunch
13. **Arcade Restaurant:**
    lunch
14. **Côté Jardin Restaurant:**
    lunch

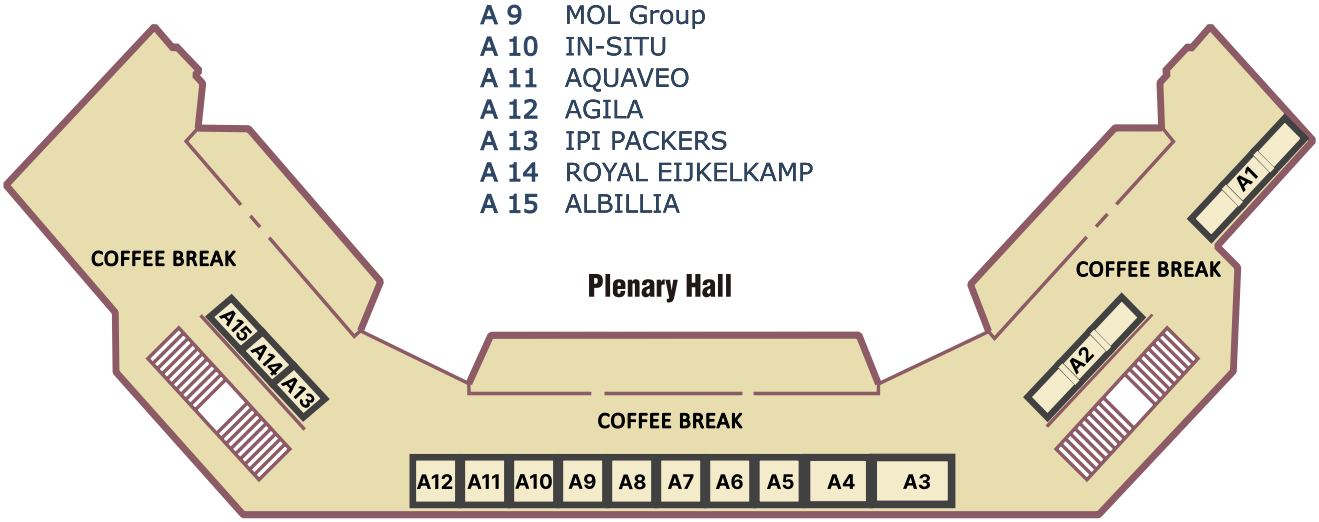


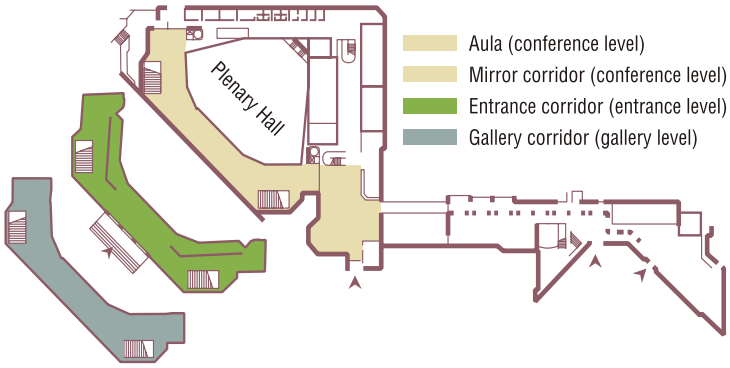
15. **Entrance Corridor (Entrance level):**
    poster session, art exhibition

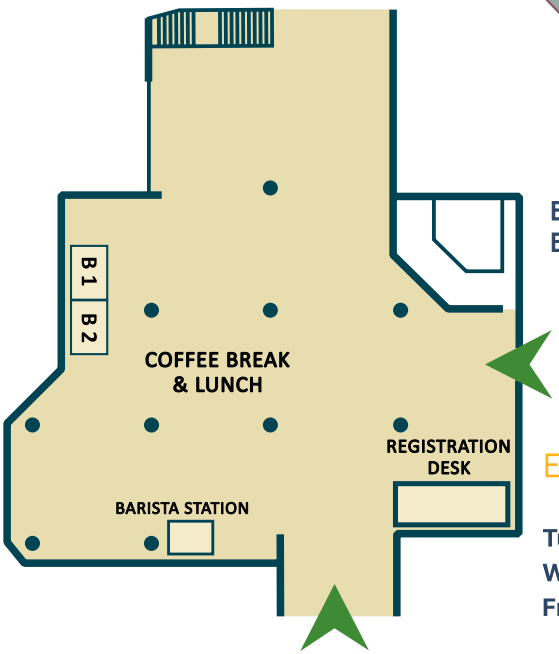
16. **Gallery Corridor (Gallery level):**
    poster session

Exhibitors' map

A 1	ROTAQUA Geological-,Mining-,Researcher and Deep Driller Ltd.
A 2	SARA/Hungarian Geothermal Cluster
A 3	NATIONAL WATERWORKS HUNGARY
A 4	GEOHIDROTERV
A 5	International Association of Hydrogeologists
A 6	DHI
A 7	TRAQUA & AGT
A 8	SciEngineer
A 9	MOL Group
A 10	IN-SITU
A 11	AQUAVEO
A 12	AGILA
A 13	IPI PACKERS
A 14	ROYAL EIJKELKAMP
A 15	ALBILLIA







B 1	General Directorate of Water Management
B 2	SGS Beta

Exhibition hours

Tuesday	08:00–17:00	15 September 2026
Wednesday–Thursday	08:30–19:00	16–17 September 2026
Friday	08:30–15:00	18 September 2026

IAH 2026

World Groundwater Congress

53rd Congress of the
International Association
of Hydrogeologists

14-18 September 2026
Budapest Congress Center



Presenter Abstracts

LID 0001
A multi-tracer approach to demonstrate groundwater inflows to a soda lake experiencing water-level decline in Hungary

Anita Erőss[1*], Ákos Horváth[2], Fanni Luca Bujbáczi[1], Eleonora Benà[3], Petra Baják[1,4], Katalin Hegedűs-Csondor[1], András Hidas[5], György Czuppon[6], Bálint Izsák[7,8], Márta Vargha[7], Henrietta Dulai[9]

[1] ELTE Eötvös Loránd University, Institute of Geography and Earth Sciences, Department of Geology, József and Erzsébet Tóth Endowed Hydrogeology Chair, Budapest, Hungary
[2] ELTE Eötvös Loránd University, Institute of Atomic Physics and Astronomy, Department of Atomic Physics, Budapest, Hungary
[3] University of Padova, Department of Geosciences, Padova, Italy
[4] Università degli Studi di Milano, Department of Earth Sciences "Ardito Desio" (DiSTAD), Milan, Italy
[5] HUN-REN Centre for Ecological Research, Institute of Aquatic Ecology, Budapest, Hungary
[6] HUN-REN Research Centre for Astronomy and Earth Sciences, Institute for Geological and Geochemical Research, Budapest, Hungary
[7] Public Health Directorate, National Center for Public Health and Pharmacy, Budapest, Hungary
[8] Faculty of Health Sciences, Department of Public Health Sciences, Semmelweis University, Hungary
[9] University of Hawaii, Department of Earth Sciences, Honolulu, United States
* eross.anita@ttk.elte.hu

Keywords: soda lake, natural tracers, water management, climate change, radon

Lake Velence is a shallow soda lake, the third largest natural lake in Hungary. Although it is a protected aquatic ecosystem, it is simultaneously exposed to various anthropogenic pressures, such as commercial and recreation activities. In recent years, the water level of the lake has decreased dramatically, resulting in declining water quality and conflicts over its multiple uses.

Although groundwater mapping in the area has shown that the lake is in the discharge area of local groundwater flow systems, only the surface-water components and precipitation are considered among the lake inflow components. A numerical model has indicated that groundwater contributes an annual average of 5% of Lake Velence's inflows. Considering that the watercourses flowing into the lake are groundwater-fed, the total share of groundwater in the lake's inflow may reach as high as 56%. We assessed surface water-groundwater interactions in the catchment area using natural tracers to provide further evidence of the significance of this connection. Water samples were analysed for stable isotopes of oxygen and hydrogen, as well as natural radioactive isotopes of uranium, radium, and radon. Additionally, these geochemical tracers were mapped across the lake, offering a spatial signal of groundwater inflow in the entire water body.

The results provided physical proof of groundwater inflow into Lake Velence and its inflowing streams. Radon concentrations were detected even by liquid scintillations technique (1-6 Bq/L) in both the lake and the streams. Measurements with the RAD7 showed values between 0.017 and 4.72 Bq/L. Uranium concentrations ranged from 96 to 498 mBq/L. All isotopes together provide unequivocal evidence that groundwater contributes substantially to lake's water budget and that groundwater management has to be reconsidered to improve lake water levels and water quality. Revisiting water management practices in the area is necessary for the local ecosystem and tourism industry.

The research was supported by the János Bolyai Research Scholarship of the Hungarian Academy of Sciences. This work has been implemented by the National Multidisciplinary Laboratory for Climate Change (RRF-2.3.1-21-

2022-00014) project within the framework of Hungary's National Recovery and Resilience Plan supported by the Recovery and Resilience Facility of the European Union.

LID 0002
Strengthening groundwater knowledge in Rwanda: Gaps, challenges, and opportunities for improved resource assessment

Jean Pierre Karekezi[1]*

[1] University of Brawijaya, Malang City, Indonesia
* k.jeanpierre1998@gmail.com

Keywords: groundwater assessment, aquifer monitoring, water security, hydrogeological data, Rwanda

Groundwater plays a central role in ensuring water security in Rwanda, particularly for domestic supply in rural communities and drought-prone regions. However, the understanding of aquifer behavior, water quality conditions, and long-term availability remains limited due to fragmented data collection and insufficient monitoring coverage. This study reviews the current status of groundwater assessment in Rwanda and examines key limitations affecting effective groundwater resource evaluation and management.

The analysis draws on existing national monitoring initiatives, published groundwater studies, and institutional reports to evaluate the adequacy of groundwater level observations, water quality surveillance, and hydrogeological characterization. Results indicate that groundwater observation points are unevenly distributed and that routine monitoring focuses on a narrow set of physical indicators, with limited inclusion of chemical and microbiological parameters. As a result, the capacity to identify temporal trends related to recharge variability, contamination risks, and human pressures on aquifers is constrained. Furthermore, weak linkage between groundwater observations and rainfall or surface water monitoring restricts interpretation of aquifer responses to climate variability and land surface processes.

The study emphasizes the importance of developing a more comprehensive groundwater assessment framework that integrates hydrogeological mapping, expanded monitoring networks, and coordinated data management systems. Enhancing groundwater knowledge through systematic observation and analysis is essential to support sustainable water supply planning, climate adaptation strategies, and long-term groundwater protection in Rwanda and similar data-scarce environments.

LID 0008

Quantitative and qualitative assessment of groundwater recharge in natural region of Casamance – South of Senegal: Application of potential recharge zone mapping, groundwater flow, empirical formula, isotopic and chloride masse balance methods

Mouhamet M. Diaw[1]*, Edgar Yvon Terence Benam Beltoungou[1], Djim ML Diongue[2], Aguibou Ba[1], Mathias Diedhiou[1], Ibra Dieng Gueye[1], Kamel Zouari[3], Serigne Faye[1]

[1] Department of Geology, Cheikh Anta Diop University of Dakar, Senegal
[2] Ecole Nationale Supérieure des Mines et de la Géologie, Cheikh Anta Diop University of Dakar, Sénégal
[3] Laboratory of Radio-Analysis and Environment, National School of Engineers of Sfax, Sfax, Tunisia
* mouhamet93.91@outlook.fr

Keywords: groundwater recharge, water isotopes, chloride mass balance, analytic hierarchy process, Casamance, Senegal

The scarcity of groundwater resources, exacerbated by climate change, necessitates sustainable management to meet population needs. This study provides the first comprehensive, regional-scale assessment of groundwater recharge in Casamance, integrating a GIS-based Analytic Hierarchy Process (AHP) with multiple empirical and natural tracer methods to reduce uncertainty. The qualitative approach involved piezometric analysis and the identification of potential recharge areas, while the quantitative approach utilized empirical formulas and natural tracers (δ^2H, $\delta^{18}O$, and Cl). Results from the qualitative methods reveal a piezometric dome in the Sédhiou–Marsassoum sector and a divergent flow system in eastern Kolda, identifying these as areas with very high to high recharge potential, covering an area of 8,167 km² (30 %) and 8,467 km² (37 %), respectively. Areas with moderate and low potential cover 7,808 km² (29 %) and 2,759 km² (10 %) respectively and are more localized in the north and east towards the crystalline basement. These results are corroborated by tritium concentrations < 1 TU measured in groundwater. Recharge rates estimated using the Chaturvedi method range from 36 to 46 mm/year. In contrast, the Thornthwaite and Turc methods yield higher averages, between 38 and 744 mm/year, which are higher values. The combined results from Chloride Mass Balance and $\delta^{18}O$ methods, validated by tritium data, are considered the most reliable, indicating an average recharge of approximately 26-78 mm/year, representing 19-26 % of annual rainfall. The δ2H isotope gives an estimated recharge rate of between 20 and 34 mm/year, a value that is higher than that obtained using other methods.

LID 0010
Addressing PFAS contamination in the groundwater abstraction site 'Heverlee Abdij'(De Watergroep, Belgium): Monitoring, challenges, and strategic responses

Jeroen November[1]*, Bo Van Limbergen[1], Simon Six[1]

[1] De Watergroep, Brussels, Belgium
* jeroen.november@dewatergroep.be

Keywords: PFAS, drinking water supply, protection zones, adaptive management, well field optimisation

Per- and polyfluoroalkyl substances (PFAS) are an increasing challenge for groundwater-based drinking water supplies due to their persistence, mobility, and evolving regulation. This contribution presents the Abdij groundwater abstraction site operated by De Watergroep in Flanders (Belgium), where PFAS contaminations have been identified in raw groundwater.

Screening campaigns and targeted investigations revealed elevated concentrations of several PFAS compounds. The site is characterised by multiple abstraction sites, historical waste disposal activities, an industrial site complicating the hydrogeological setting. Long-term monitoring combined with targeted PFAS analyses revealed the presence of multiple PFAS signals. The observed contamination pattern can be traced back to historical point sources in combination with complex local hydrogeological conditions. The presence of multiple PFAS signatures further complicates risk assessment and long-term resource management.

Rather than relying solely on end-of-pipe treatment, De Watergroep has adopted an integrated, system-based management strategy. This includes advanced PFAS monitoring, improved hydrogeological understanding of the aquifer system, and operational optimisation of groundwater abstraction. Dynamic well operation and blending with other water sources are used to control PFAS levels in raw water while maintaining supply reliability and compliance with current and future European standards.

In parallel, proactive source control and remediation-oriented measures are being explored, including evaluation of groundwater protection zones, collaboration with environmental authorities on source attribution, and evaluation of targeted treatment technologies.

The Abdij case demonstrates how PFAS challenges can be managed through the integration of hydrogeology, monitoring, operational flexibility, and regulatory foresight, providing transferable lessons for groundwater professionals and groundwater-dependent utilities.

LID 0012
Investigating groundwater flow in a buried valley and bedrock aquifer system (Kurikka, Finland) using hydrochemistry and environmental tracers (^{3}H, ^{14}C)

Marie-Amélie Pétré[1,2]*, Niko Putkinen[1], Timo Ruskeeniemi[1], René Lefebvre[3]

[1] Geological Survey of Finland (GTK), Espoo, Finland
[2] Now at Bureau de Recherches Géologiques et Minières (BRGM), Orléans, France
[3] Institut National de la Recherche Scientifique, Centre Eau Terre Environnement, Quebec City, Canada
* marieamelie.petre@gmail.com

Keywords: buried valley aquifer system, hydrochemistry, groundwater age

Increasing groundwater demand in western Finland has drawn attention to a regional network of buried valleys with strong potential for domestic and municipal water supplies. This study aims at understanding the groundwater flow in the buried valley and bedrock aquifer system using hydrochemical data and residence time indicator (^{3}H, ^{14}C). The study area (600 km^{2}) encompasses 4 buried valleys connected to the main Kyrönjoki valley. Historical geochemical data (56 samples, 2011-2021) were completed in 2023 by a groundwater sampling campaign (42 samples) from production and observation wells in sediments, bedrock boreholes, and springs, across the study area. A multivariate statistical analysis (Hierarchical Clustering on Principal Components) revealed six water groups reflecting the origins and different stages of groundwater geochemical evolution. Overall, a modern groundwater component (<60 yr) in an active flow system is present in all parts of the system. Longer residence times are found deep within the buried valleys (tritium-free waters) and at greater depth in a few locations in the bedrock (radiocarbon ages > 5000 years). The occurrence of geochemically evolved waters in the deeper, downgradient areas in buried valleys indicates suitable (in quantity and quality) and safe (low vulnerability) water supply relative to demand. More broadly, the multi-tracer approach provides insights into the geochemical evolution of groundwater, revealing groundwater flow conditions related to geological history and aquifer unit composition. Residence time indicators also illustrate the relative hydraulic isolation of buried valleys from the surface but their lateral connection with bedrock, which has implications on vulnerability and sustainable exploitation. To fully clarify the exchanges between bedrock and granular aquifer, a sampling scheme with locations deep beneath the Paloluoma and Kyrönjoki valleys would be necessary. This study will support the development of a numerical model of the aquifer system and contributes to informing future management decisions.

The work was made in collaboration with Vaasan Vesi, Kurikan Vesihuolto Oy, GTK and Etelä-Pohjanmaan ELY-keskus.

LID 0013
BioFLOWLAND From mining to living landscapes: Biodiversity and water resilience across borders

Julia Azovskaja[1], **Abdelrahman Ahmed Ali Abdelrahman**[1]*, Eva Šabec Korbar[1], Irina Engelhardt[1]

[1] Technical University of Berlin, Department of Hydrogeology, Berlin, Germany
* abdelrahman@tu-berlin.de

Keywords: groundwater modelling, post-mining landscapes, cross-border water management

BioFLOWLAND is a German–Polish research project developing an integrated hydrological–ecological understanding of post-mining landscapes to support water quality protection, biodiversity conservation, and water resilience following the phase-out of lignite mining. The project aims to establish a shared knowledge base and harmonised data infrastructure for sustainable, coordinated water management in the German–Polish border region.

BioFLOWLAND combines hydrological, hydrogeochemical, ecological, and water-management approaches to analyse cross-border interactions between mining legacies, water quality, biodiversity, and landscape processes. The research focuses on five pilot areas of high ecological and cultural value, including the Spreewald and Branitzer Park in Germany and the Nysa Valley, Łuk Mużakowa Landscape Park, and Gubiskie Mokrada in Poland. These sites serve as real-world laboratories for monitoring, modelling, and stakeholder engagement. A central component of the project is the harmonisation of datasets, methods, and monitoring strategies, alongside the development of targeted measurement campaigns to address data gaps, particularly on the Polish side. Based on this foundation, high-resolution process-based models (including soil–plant–water and groundwater flow models) and robust surrogate models are developed to predict water availability, material transport, and sulphate dynamics.

Key outputs include a jointly developed data infrastructure, predictive modelling tools, a toolkit for sustainable water management, an advanced sulphate remediation strategy, and an action plan for optimising environmental monitoring. Through close cooperation between universities, authorities, municipalities, and NGOs, BioFLOWLAND supports evidence-based decision-making and lays the groundwork for long-term cooperative water and landscape management in Ltia and neighbouring Polish regions.

LID 0015
Assessing shallow aquifer heterogeneity with geophysical and numerical modelling in an atoll island setting

N. Tobon[1]*, G. Masselink[1], T. J. O'hare [1], R. Bates[2], F. K. J. Oberle[3], C. D. Storlazzi[3], D. C. Conley[1]

[1] Coastal Processes Research Group, University of Plymouth, United Kingdom
[2] Coastal Resources Management Group, University of St Andrews, United Kingdom
[3] U. S. Geological Survey, Pacific Coastal and Marine Science Center, Santa Cruz, United States
* nidia.tobonvelazquez@plymouth.ac.uk

Keywords: atoll islands, groundwater, morphological variability

This study examines the spatial variability of shallow groundwater on Dhigelaabadhoo Island using electromagnetic induction surveys, groundwater monitoring, and sediment analyses. The research reveals how variations in island morphology, such as differences in elevation, reef flat width, and sediment composition, affect the spatial distribution of groundwater lens and the overall aquifer dynamics. Saltwater intrusion is especially pronounced in low elevated areas, with narrow reef flats and areas where higher hydraulic conductivity, driven by the presence of coarser sediments, is observed, whereas regions characterized by finer sediments, higher elevation, and wider reef flats tend to support more symmetric and less saline groundwater lenses. The geophysical investigations reveal that tidal oscillations alter groundwater movement by markedly changing water levels and conductivity, thereby underscoring the need to account for temporal dynamics in atoll coastal aquifer systems, and the importance of integrating tidal dynamics into the aquifer zone. The findings highlight the significant role of intrinsic morphological and external hydrodynamic factors in shaping groundwater distribution on atoll islands, offering critical insights for sustainable freshwater resource management.

Based on this geophysical interpretation and geological characterization, a second stage of the project involves steady-state numerical simulations to reproduce aquifer geometry under varying conditions of elevation, reef flat width, hydraulic conductivity and recharge, allowing isolation of the key parameters governing the freshwater lens development. This approach provides a process-based understanding of how morphological heterogeneity influences aquifer geometry and establishes a foundation for future simulations assessing groundwater sensitivity to different sea level rise scenarios, accounting for the non-uniform nature of atoll islands.

LID 0016
Understanding PFAS in MAR systems – Insights into seasonal variations, mobility, and local sources

Tabea Mumberg[1,2]*, Lutz Ahrens[3], Dolly Kothawala[4], Philip Mccleaf[5], Britt-Marie Pott[6], Vera Franke[5], Svante Rehnstam[3], Philipp Wanner[1,2]

[1] Department of Earth Sciences, University of Gothenburg, Gothenburg, Sweden
[2] Centre for Future Chemical Risk Assessment and Management (FRAM) in Gothenburg, University of Gothenburg, Gothenburg, Sweden
[3] Department of Aquatic Sciences and Assessment, Swedish University of Agricultural Sciences (SLU), Uppsala, Sweden
[4] Department of Ecology and Genetics - Limnology, Uppsala University, Evolutionary Biology Centrum (EBC), Uppsala, Sweden
[5] Uppsala Water and Waste Ltd., Uppsala, Sweden
[6] Southern Sweden Water Supply Ltd., Malmö, Sweden
* tabea.mumberg@gu.se

Keywords: PFAS, managed aquifer recharge (MAR), surface water

Per- and polyfluoroalkyl substances (PFAS) are compounds that severely affect the environment and human health at low ng L-1 concentrations. Surface waters often contain elevated concentrations of PFAS that can migrate into groundwater systems, especially when used for managed aquifer recharge (MAR). However, research on PFAS distribution and seasonal variation of PFAS in MAR systems remains limited. We therefore (a) monitored seasonal variations in surface water PFAS concentrations over two years, (b) determined the annual PFAS load entering groundwater systems via MAR, and (c) assessed whether MAR systems act as a source or sink for PFAS by investigating possible precursor transformation, PFAS mobility in the subsurface, and local point sources.

Throughout the year, we observed highly variable PFAS concentrations in surface waters used for infiltration ranging from 0.25 ng L^{-1} to 63.0 ng L^{-1}, which enabled, for the first time, a more precise estimation of PFAS infiltrated at MAR sites of between 77 g and 141 g $\sum_{29}$PFAS. Moreover, we show that during MAR passage, PFAS can be influenced by sorption-driven accumulation within the top sand layer, subsequent remobilization, and episodic contributions from local point sources. To evaluate the impact of the infiltrated surface water on groundwater quality at MAR sites and to understand if different MAR sites act as PFAS source or sink, we analysed ten years of stable water isotope ratio data ($\delta^{18}O$ and $\delta^{2}H$) to track the relative contribution of the artificially infiltrated water to the natural groundwater system. These data were then correlated with PFAS concentrations and composition profiles downstream of the MAR site, to provide insight into the annual PFAS load contributed by artificial infiltration.

The findings highlight the high mobility and dynamic behavior of PFAS in the subsurface, underscoring the need for improved treatment strategies, optimized MAR system design, and regular, standardized PFAS monitoring.

The study was financially supported by the FORMAS Early Career Grant awarded to Dr. Philipp Wanner (grant number 2021-00510) and the FORMAS Securing Future Water Supply Through Sustainable Management Grant awarded to Prof. Dr. Lutz Ahrens (grant number 202202108). We thank Uppsala Water and Waste Ltd. and Southern Sweden Water Supply Ltd. for the access to the sampling sites and Uppsala Water and Waste Ltd. for sharing historic isotope and flow data.

LID 0018
The effect of saltwater pumping on the natural dynamics of a coastal aquifer

Fernando Sola[1]*, Antonio Montero[1], Angela Vallejos[1]

[1] Department of Biology and Geology, University of Almeria, Almería, Spain
* fesola@ual.es

Keywords: groundwater discharge, hydrodynamic barrier, desalination plant

Since ancient times, humans have regulated surface water resources by modifying or blocking the natural flow of rivers in order to store and manage these resources efficiently. In this way, demand was met even in times of shortage due to occasional droughts, especially in arid and semi-arid areas. In coastal regions, this regulation has commonly consisted of preventing the natural discharge of these resources into the sea. Today, problems related to water needs have increased as a result of population density and economic development. This has led to a relentless search for new resources, including not only surface water but also groundwater and alternative resources such as seawater desalination. The flow of freshwater that naturally drains into the sea linked to groundwater is volumetrically greater than that of surface resources. However, little or no effort has been made so far to try to slow down this flow and prevent the loss of these underground resources.

This paper presents a case study in which the discharge of fresh water into the sea is slowed down by creating a negative hydraulic barrier. This is the aquifer of the Andarax River delta (SE Spain), where a series of boreholes supply water to a desalination plant by capturing the saline wedge that penetrates the aquifer, acting as a hydrodynamic barrier. This barrier not only prevents the advance of marine intrusion into the aquifer, but also reduces the loss of fresh water to the sea. The effectiveness of this barrier has been proven by records of the electrical conductivity and physicochemistry of the water monitored over time in piezometers located landward.

This research has been funded through project PID2023-148816OB-I00.

LID 0019
The effect of desalinated seawater infiltration on the isotopic signal of an aquifer

Angela Vallejos[1]*, Fernando Sola[1], Juan Reca[2]

[1] Department of Biology and Geology, University of Almeria, Almería, Spain
[2] Department of Agronomy, University of Almeria, Almería, Spain
* avallejo@ual.es

Keywords: non-conventional water resources, desalination, environmental isotopes

The hydrological cycle is a system for transferring water resources across the planet, involving not only the distribution of mass and a change in the state of water, but also an isotopic redistribution of the atoms that compose it. When seawater evaporates, its oxygen and hydrogen isotopes undergo a process of depletion that causes the isotopic signature of the freshwater present in an aquifer to be distinctly different from that of seawater. This does not occur when seawater is transformed into freshwater through a reverse osmosis desalination process. In this case, the permeated freshwater retains the same isotopic signature as the original seawater. In this study, an aquifer was studied from an isotopic point of view in order to elucidate the effect of desalinated seawater infiltration on the isotopic signature of the aquifer as a whole.

The Níjar aquifer (SE Spain) is located in one of the most arid regions of Europe, where rainfall does not exceed 150 mm/year. It is an unconfined detrital aquifer on which, since the 1960s, intensive agriculture under plastic has been practised, traditionally supplied with water from wells that draw on this aquifer. As a result of intensive water exploitation, piezometric levels have fallen and the salinity of the aquifer has increased. In order to alleviate this situation, a desalination plant that takes water directly from the sea came into operation in 2005, which partially supplies a large part of the water needed for irrigation in the area.

This study evaluates the effect of desalinated water recharge from irrigation return flows in the Níjar aquifer. Given the notable difference between the isotopic signature of desalinated water and the water characteristic of the aquifer, it has been calculated that approximately 25% of the water present in the aquifer comes from the infiltration of desalinated water. This research shows how the isotopic composition of an aquifer can be anthropically modified.

This research has been funded through project PID2023-148816OB-I00 and contract UAL-CUCN (Ref. 001752 - article 60 LOSU).

LID 0020
Integrated Hydrogeological Assessment for Sustainable Groundwater Management in the Siwa Oasis, Egypt

Mohamed Hamdy Eid[1,2]*, Viktória Mikita[1], Attila Kovács[1], Péter Szűcs[1]

[1] Institute of Environmental Management, Faculty of Earth Science, University of Miskolc, Miskolc-Egyetemváros, Hungary
[2] Geology Department, Faculty of Science, Beni-Suef University, Beni-Suef, Egypt
* mohamedhamdy@science.bsu.edu.eg

Keywords: groundwater salinization, mixing model, numerical modeling, sustainable management

The Siwa Oasis in Egypt faces a critical water crisis due to unsustainable groundwater abstraction, leading to resource depletion and severe salinization. This study presents an integrated framework for sustainable management by combining remote sensing, advanced geochemical modeling, and numerical simulation. Multi-temporal satellite imagery analyzed with a Support Vector Machine (SVM) model revealed a 270% increase in hypersaline lake surface area, directly linked to agricultural expansion. To identify recharge origins and salinization pathways, a comprehensive geochemical model was developed using isotopic tracers (δ^2H, $\delta^{18}O$, ^{14}C, $^{87}Sr/^{86}Sr$). Inverse (NETPATH) and forward (Faure) mixing models quantified that the shallow Tertiary Carbonate Aquifer (TCA) receives 63-87% of its recharge from upward leakage from the deep Nubian Sandstone Aquifer (NSSA) via fault systems, while hypersaline lakes contribute 0.6-4%, acting as a primary source of salinization. A calibrated FEFLOW numerical model, constrained by these findings, predicted a critical water level decline of 30-70 meters by 2100, confirming the system's unsustainable trajectory. As a practical solution to combat water quality degradation, a novel zeolite/geopolymer membrane was synthesized from local materials, achieving 99.5% salt rejection. This holistic approach, from diagnosing the problem to developing a technological solution, provides a robust and transferable template for sustainable groundwater management in arid regions worldwide.

We would like to thank the sustainable development and technologies national program of the Hungarian Academy of Science (FFT NP FTA) for funding this research work.

LID 0021
Heavy metal contamination assessment and source attribution in the vicinity of an iron slag pile in Hechi, China: Integrating multi-medium analysis

Hongxia Hu[1,2]*, Hongguang Zheng[1], Fengping Liu[2], Zhenyu Ding[2], Aizhong Ding[1]

[1] College of Water Sciences, Beijing Normal University, Beijing, China
[2] China Academy of Environmental Planning, Beijing, China
* huhx@caep.org.cn

Keywords: heavy metal pollution, ecological-health risk, positive matrix factorization, Monte Carlo simulation

Heavy metals, such as mercury, cadmium, and nickel, may contaminate human inhabited environments, with critical consequences for human health. This study examines the health impacts of heavy metal pollution from an iron slag pile in Hechi, China, by analyzing heavy metal contamination in water, sediment, soil, and crops.

Here, the Nemerow pollution index (NI) indicated severe pollution at most sampling sites, the mean NI of groundwater, and surface water had reached 594.13 and 26.79, respectively. Bioaccumulation of mercury (Hg), cadmium (Cd), and nickel (Ni) was noted in crops, cucumbers showed comparatively lower risk levels. Logarithmic surface water-sediment partition coefficient calculations indicated that heavy metals such as chromium (Cr), ferrum (Fe), zinc (Zn), copper (Cu), Ni, arsenic (As), and lead (Pb) tend to accumulate in sediments. There was a high risk in groundwater (67.48–6590.54) and surface water (13.73–2500.85). Variably influenced by rainfall, these metals can be diluted and mobilized from surface water and sediments, thereby changing the contamination levels and ecological risks. Probabilistic health risk assessments indicated that health risks were higher in children than in adults, the mean total carcinogenic risk values of soil, groundwater, and surface water, were 6.79E-04, 4.20E-06, and 1.15E-6 for children, respectively. A Positive Matrix Factorization model attributed over 60% of the pollution to slag stacking.

Biotechnologies, solidification/stabilization techniques, field management, and institutional controls, driven by principles of green, low-carbon, and economic efficiency may mitigate. These findings contribute to the management of heavy metal pollution in iron slag pile areas.

LID 0022

The pollutants distribution profiles and health risks of groundwater and soil around the waste landfills: A study of 12 waste landfills in Guangxi province, China

Fengping Liu[1], **Zhenyu Ding**[1]*

[1] China Academy of Environmental Planning, Beijing, PR China
* dingzy@caep.org.cn

Keywords: waste landfill, groundwater, soil, heavy metal pollution, health risk assessment

The waste landfill disposes of a large amount of urban garbage, and the harmful substances in the waste have serious impacts on the ecological environment of the landfill and its surroundings.

To systematically investigate the pollution mechanisms and associated health risks posed by landfills, we conducted a comprehensive study in Guangxi Province, China by collecting water, soil, and leachate samples from 12 operational landfill sites. These samples were analyzed using inductively coupled plasma mass spectrometry and ultraviolet-visible spectroscopy to quantify concentrations of 18 priority pollutants, including heavy metals and nutrients. Geostatistical analysis revealed moderate spatial clustering of pollutants in soils and groundwater, with significant positive correlations observed between Mn, Cd, and Pb concentrations across leachate-soil-groundwater systems. Notably, as exhibited 2.3-fold higher carcinogenic risk values compared to Cd, while Zn demonstrated the highest non- carcinogenic hazard quotient among all studied pollutants. Contaminant transport pathways were evaluated through correlation models, revealing that Cu and Hg in leachate significantly influenced groundwater quality around landfills.

These findings provide critical insights for implementing site-specific pollution control strategies and optimizing health risk management protocols in landfill-impacted regions.

LID 0025
Managed aquifer recharge in confined multi-layer aquifers: A methodological framework for drought-resilient water management

Abdelrahman Ahmed Ali Abdelrahman[1], Hagen Koch[2], Mobarok Hossain[1], Ronjon Heim[3], Clara Hauke[4], **Irina Engelhardt**[1]*

[1] Technische Universität Berlin, Berlin, Germany
[2] Potsdam Institute for Climate Impact Research, Potsdam, Germany
[3] Adelphi Research gGmbH, Berlin, Germany
[4] Freie Universität Berlin, Berlin, Germany
* irina.engelhardt@tu-berlin.de

Keywords: managed aquifer recharge, ASTR, confined aquifers, drought indices, MCDA

Confined multi-layer aquifers represent a largely untapped resource for Managed Aquifer Recharge (MAR) in Central Europe, yet methodological frameworks for systematically assessing Aquifer Storage, Transfer and Recovery (ASTR) feasibility remain limited. This study presents a scalable, process-based framework that integrates hydroclimatic drought analysis, spatial site selection, and surface-water availability constraints to support groundwater management.

Meteorological and groundwater drought dynamics are quantified using the Standardized Precipitation Evapotranspiration Index (SPEI-12) and the Standardized Groundwater Index (SGI) derived from long-term climate and groundwater monitoring data (1980–2024). Cross-correlation analysis is applied to identify lag times between atmospheric forcing and groundwater response. A GIS-based multi-criteria decision analysis (MCDA) is then implemented to delineate suitable ASTR locations within a confined aquifer system, incorporating aquifer thickness, depth to aquifer, hydraulic conductivity, land use, proximity to surface-water sources, and groundwater abstraction wells.

Surface-water availability for recharge is assessed using daily discharge records at 27 gauging stations and two ecological flow-threshold approaches: (i) a permissive hydroecological limit combined with a fixed abstraction fraction, and (ii) a restrictive multi-threshold method allowing abstraction only during high-flow events. These approaches enable quantification of temporally and spatially available surface water for MAR while maintaining environmental flow requirements.

Application to the Berlin–Brandenburg region reveals a consistent 3–6-month lag between SPEI-12 and SGI, defining an operational window for anticipatory recharge. The MCDA identifies 55% of the assessable area (1,337 km^2) as suitable for ASTR. Aggregated mean annual divertible surface-water volumes range from 18 to 23 million m^3 per catchment, with site-specific potentials to substitute a large amount of local groundwater abstraction. The framework provides a transferable methodological blueprint for evaluating ASTR in confined sedimentary aquifers under increasing drought stress.

LID 0027
Quantifying anthropogenic impacts on urban groundwater dynamics: A machine learning and causal inference approach in Seoul, South Korea

Ho-Rim Kim[1]*, Kyoung-Ho Kim[2], Soonyoung Yu[1], Dong-Woo Ryu[1]

[1] Korea Institute of Geoscience and Mineral Resources, Daejeon, South Korea
[2] Korea Environment Institute, Sejong, South Korea
* honeius@kigam.re.kr

Keywords: urban groundwater, machine learning, infrastructure-induced drainage

Urban subsurface infrastructure increasingly modifies groundwater systems, yet quantitative frameworks linking anthropogenic pressures to groundwater dynamics remain limited. This study develops an integrated machine learning and causal inference approach to identify drivers of groundwater level changes in the Seoul metropolitan area.

We quantified cumulative anthropogenic pressure using the Subsurface Human Modification Index (SHMI), revealing that infrastructure-induced drainage (IID) accounts for 75% of total groundwater loss (63×10^6 m^3/yr), exceeding registered well abstraction by threefold. Dynamic time warping clustering classified 109 monitoring wells into three response patterns: delayed-response (45.9%), immediate-response (38.5%), and persistent decline (15.6%). To overcome limited training data, we employed CTGAN to generate synthetic groundwater time series. Gradient-boosting classifiers trained on synthetic data achieved AUC values of 0.86–0.98 when validated against real monitoring wells. SHAP analysis identified that terrain attributes dominated the delayed-response model, while anthropogenic factors—particularly subway depth and infrastructure density—dominated the persistent decline model. Causal network analysis using backdoor-adjusted average treatment effects identified significant drivers: subway depth (ATE=+0.153) and closed depressions (ATE=+0.152) promoted groundwater decline, while river density (ATE=−0.145) and aged water pipes (ATE=−0.311) were associated with stability. This framework provides a transferable methodology for urban groundwater management, demonstrating how synthetic data generation and causal inference can advance understanding of complex human-groundwater interactions.

This work was supported by the basic research project of the Korea Institute of Geoscience and Mineral Resources (KIGAM), funded by the Ministry of Science and ICT of Korea under 26-3415.

LID 0028
Denoising of Array InSAR 3D point clouds for high-precision detection of surface deformation induced by groundwater dynamics

Fangfang Ji [1,2], **Jie Yu**[1*], Lin Zhu[1]

[1] College of Resources Environment and Tourism, Capital Normal University, Beijing, China
[2] Chinese Academy of Surveying and Mapping, Beijing, China
* fzzj1027@163.com

Keywords: Array InSAR, 3D point cloud, denoising, surface deformation

Groundwater extraction and recharge processes often lead to surface deformation. High-precision detection of the spatial distribution of surface deformation provides an important basis for studying the interaction between groundwater level dynamics and surface responses. Array Interferometric SAR (Array InSAR) is capable of acquiring three-dimensional spatial information over large areas in all-weather conditions, generating point clouds with sub-centimeter accuracy. This offers a high-precision means for detecting surface deformation induced by groundwater dynamics. However, raw Array InSAR point clouds are typically affected by complex noise, making dedicated denoising processing essential for achieving high-precision surface deformation detection.

To address the coexistence of outlier noise and multipath interference, an anomaly point identification method combining statistical feature analysis and spatial clustering is proposed to effectively remove outlier noise. Meanwhile, a multipath interference identification and filtering approach based on planar geometric fitting constraints is developed, successfully distinguishing true scattering points from pseudo points caused by multiple reflections, thereby significantly improving point-cloud purity and structural continuity.

Experimental results demonstrate that, after denoising, point-cloud noise is markedly reduced, spatial structure becomes more stable, and geometric continuity is clearly enhanced. The processed point clouds can more clearly depict surface deformation associated with groundwater activity, providing reliable data support for groundwater monitoring and related analyses.

Therefore, the array interferometric SAR method provides an effective means for high-precision ground deformation detection. The results of high-precision ground deformation detection serve as a basis for analyzing the interaction between groundwater level dynamics and ground deformation.

LID 0029
Strontium enrichment patterns and source dynamics in karst underground river sediments: Comparative case studies from Guizhou, China

Changsong Zhou[1,2,3,4]*, Shengzhang Zou[1,3], Kebuzi Jiqin[2], Li Lu[1], Zhiheng Wang[1], Jia Wang[1], Xianyu Wei[1], Wei Zhang[1]

[1] Institute of Karst Geology, CAGS/Key Laboratory of Karst Dynamics, MNR & GZAR/International Research Center on Karst under the Auspices of UNESCO, Guilin, China
[2] Karst Water Resources and Environment Academician Workstation of Guizhou Province, Zuny, China
[3] Pingguo Guangxi, Karst Ecosystem, National Observation and Research Station, Baise, China
[4] School of Environment Science and Spatial Informatics, China University of Mining and Technology, Xuzhou, China
* zhouchangsongsx@163.com

Keywords: karst underground river, sediment, strontium, forms

Karst underground river systems are critical reservoirs of strontium (Sr), yet their enrichment mechanisms and environmental risks remain complex under anthropogenic and geological influences. This study integrates two cases—Dingqi and Longtankou underground rivers in Guizhou, China—to explore Sr distribution, speciation, and sources through elemental analysis, Tessier sequential extraction, and 87Sr/86Sr isotopic tracing. In Dingqi, sediment Sr concentrations (189.9–1402.2 mg/kg, avg. 662.4 mg/kg) exceed control soils (112.7 mg/kg) and regional counterparts, correlating with proximity to a strontium chemical plant. Residual Sr (SrRES) dominates (55–80%), but subsystem variability in speciation order (e.g., SrEXC > SrCAB > SrOXI) highlights anthropogenic impacts from industrial "three wastes" discharge. Longtankou sediments exhibit lower Sr levels (188–656 mg/kg, avg. 411.8 mg/kg): Sr enrichment (GRS > SRS > CSD > FS) reflects rainwater-driven migration from farmland and cave deposits. Speciation prioritizes carbonate-bound Sr (SrCAB, 127.58 mg/kg) and ion-exchangeable Sr (SrEXC, 123.42 mg/kg), linked to T2g2 limestone dissolution (87Sr/86Sr evidence), with SrRES at ~10%. Comparative analysis reveals dual drivers: anthropogenic dominance in Dingqi versus natural geological processes in Longtankou. RES dominance in Dingqi suggests long-term retention, while active SrCAB in Longtankou implies higher bioavailability. Findings underscore region-specific strategies—pollution control versus sustainable utilization of geogenic Sr resources. This work advances multi-technique source apportionment and provides a framework for balancing ecological restoration and resource development in karst regions.

LID 0030
Potential trace metal release during chemolithotrophic denitrification – a comprehensive study of pyrites from Northern German aquifers

Georg J. Houben[1]*, Leonard Stoeckl[1], Maria A. Sitnikova[1]

[1] Federal Institute for Geosciences and Natural Resources (BGR), Hannover, Germany
* georg.houben@bgr.de

Keywords: denitrification, pyrite, trace elements

Nitrate contamination is one of the most widespread problems affecting the hydrochemical quality of aquifers worldwide. Chemolithotrophic denitrification via pyrite (FeS2) naturally present in the aquifer matrix is one of the most important processes counteracting the spreading of nitrate.

The reaction involves the release of sulphate and iron but also of potentially harmful trace metals contained in the pyrite, either present in the crystal lattice, adsorbed or as nano-sized metal sulphide inclusions. The process has been studied in a few single site studies but it remains unclear how representative these results are on a regional scale.

Therefore, we collected fresh drill core material from 30 sites in unconsolidated aquifers distributed all over Northern Germany. The pyrite was extracted using density separation and analyzed for both its crystal habitus via electron microscopy and trace metal content via electron microprobe and laser ablation (LA-ICP-TOFMS).

Regarding the different aquifer types, the shallow marine Cenozoic and upper Cretaceous aquifers generally contained more pyrite than the fluvio-glacial Quaternary aquifers, probably a reflection of the higher sulphate concentration of seawater.

Regarding the crystal habitus, four types of pyrites could be distinguished: (1) fine-grained framboidal aggregates, (2) coarse-grained single framboids, with mostly octahedral sub-crystals, (3) euhedral crystals, with octahedral and cubic habitus, or combinations thereof, (4) pyritized microfossils, both of plant (fibers, cell structures) and animal (sponge spicula) origin. Euhedral crystals are assumed to from via the recrystallisation of framboids. The simultaneous presence of all four types in some samples suggests that the pyrites do not form in a single event but rather in stages or continuously.

The trace metal contents turned out to be very heterogeneous, even within one sample and within individual crystals, ranging from below detection limit up to 3 weight-%. This again indicates that the pyrites did not form in a single event from a homogeneous pore fluid. Arsenic, nickel and cobalt were present in basically all samples, at roughly similar concentrations (As > Ni > Co). Other elements, such as lead, zinc, copper and uranium were more unevenly distributed and absent in some samples. The analysis of individual pyrites with LA-ICP-MS revealed that the trace element distribution can be quite heterogeneous, with distinct zones of enrichment.

LID 0031
Springs as sentinels of hydroclimatic variability: Discharge dynamics in the Wied il-Bużbież catchment

Christa M. Pisani[1]*, Michael Schembri[1], Julian A. Mamo[2]

[1] The Energy & Water Agency, Qormi, Malta
[2] Institute of Earth Systems, University of Malta, Msida, Malta
* christa-marie.pisani@gov.mt

Keywords: spring discharge, hydroclimatic variability, sentinel springs, perched aquifers, groundwater abstraction, Mediterranean

Perched aquifers in the Maltese Islands develop within the Upper Coralline Limestone, a highly fractured formation that strongly controls permeability and groundwater flow, where it overlies the impermeable Blue Clay layer. Owing to their limited storage and rapid hydraulic response, these aquifers are particularly sensitive to both climatic forcing and abstraction. This study evaluates their combined influence on spring discharge dynamics at the Wied il-Bużbież spring using high-frequency discharge monitoring and event-based rainfall analysis.

Rainfall-driven discharge responses were rapid but highly variable, reflecting strong climatic control on recharge processes within a shallow perched system. At the beginning of the hydrological year, following the dry summer period characterised by intensive groundwater abstraction, pumping activity commonly masked rainfall-induced discharge responses, limiting the visibility of early-season recharge signals. In contrast, Storm Harry produced one of the most pronounced discharge responses of the monitoring period, with a rapid increase in flow occurring within 10 hours of rainfall onset and elevated discharge persisting for several days.

Concurrent groundwater abstraction removed approximately 16% of the total annual spring discharge during a hydrological year. These results demonstrate how intense rainfall events and sustained abstraction interact to shape spring discharge dynamics in perched aquifers. The clear yet transient response of the Wied il-Bużbież spring to a Mediterranean cyclone highlights the value of perched springs as sensitive sentinels of hydroclimatic variability, while also showing that strong anthropogenic signals can obscure climatic responses. This study supports policy objectives related to water balance assessment, abstraction control, and the protection of groundwater-dependent ecosystems, and is particularly relevant for island environments facing increasing pressure on limited groundwater resources.

LID 0032
Assessing climate- and urbanization-driven changes in stream–groundwater recharge using a coupled SLEUTH–SWB modeling framework: A case study of Daejeon, Korea

Dong-Woo Ryu[1]*, Byeongju Jung[1]

1 Korea Institute of Geoscience and Mineral Resources (KIGAM), Daejeon, South Korea
* dwryu@kigam.re.kr

Keywords: urban growth, stream-aquifer system, climate change, SSP, SLEUTH, SWB2

Urbanization and climate change are jointly reshaping metropolitan hydrology by increasing impervious cover, modifying evapotranspiration demand, and altering runoff–infiltration partitioning. These shifts directly influence stream–aquifer interactions through changes in groundwater recharge and surface runoff. This study quantifies the individual and combined effects of climate pathways and urban expansion on key water-balance components, and evaluates whether development constraints (e.g., slope-based restrictions) can mitigate adverse impacts.

We built an integrated framework linking SSP-based climate projections, the SLEUTH 3.0 cellular automata urban growth model, and the USGS SWB2.0 distributed water-balance model. SLEUTH was calibrated with multi-temporal land-use/land-cover maps (1989–2019) and then used to generate long-term urban-growth scenarios. SWB2.0 was forced with climate- and land-cover scenarios to estimate spatially explicit groundwater recharge, surface runoff, and evapotranspiration. Four scenario combinations were assessed by crossing two climate pathways (SSP1–2.6 vs. SSP5–8.5) with two urban assumptions (fixed recent land cover vs. projected urban growth), alongside slope-restriction options.

Simulations indicate sustained urban expansion with associated reductions in forest/green areas; slope-based restrictions reduce forest loss and moderate growth patterns. Scenario comparisons show that climate change tends to reduce recharge while increasing evapotranspiration and runoff, whereas urban growth consistently decreases recharge (and evapotranspiration) and increases runoff. Under the same urbanization condition, SSP5–8.5 yields lower recharge than SSP1–2.6 by ~20 mm/yr in the early period (2023), with the gap diminishing over time. By contrast, under the same climate pathway, the recharge deficit attributable to urban growth grows to ~50 mm/yr by 2100 (urban growth vs. no-urban-growth). For surface runoff, the urbanization signal is stronger: by 2100, runoff increases by ~200 mm/yr under urban growth compared with no-urban-growth, and the spread between high- and low-runoff years widens.

Overall, results suggest urbanization is the dominant driver of recharge reduction and runoff amplification in the study area, while climate change further elevates hydrologic stress. The proposed SSP–SLEUTH–SWB2 workflow provides a transferable, scenario-based decision-support approach for groundwater-sensitive urban planning and integrated surface–groundwater management. Rapid urban expansion and climate change jointly alter the hydrologic cycle by reshaping land-surface permeability and modifying precipitation–evapotranspiration regimes, with direct implications for groundwater recharge and stream–aquifer conditions. This study develops an integrated modeling framework that couples (i) SSP-based climate projections, (ii) an urban growth model (SLEUTH 3.0 cellular automata), and (iii) a distributed water-balance model (USGS SWB2.0) to quantify future changes in key water-cycle components in the Daejeon metropolitan region, Korea. SLEUTH was calibrated using multi-temporal land-use/land-cover maps (1989–2019) and driver layers (e.g., slope, transportation network, and

development exclusion constraints) and then used to simulate long-term urban growth (up to 2119), including alternative development-restriction settings (e.g., slope-based constraints) as a mitigation option. SWB2.0 was forced with scenario climate inputs and land-cover outputs to estimate spatially distributed groundwater recharge, surface runoff, and evapotranspiration. Four scenario combinations were evaluated: SSP1–2.6 vs. SSP5–8.5, each with and without projected urban growth. Results indicate substantial urban-area expansion and associated decreases in natural/vegetated cover, while slope-development restrictions reduce forest loss and slow outward urban growth. Climate projections show increasing annual precipitation toward the late century, with the high-emission scenario (SSP5–8.5) exhibiting a marked increase relative to a recent baseline. Across scenarios, urbanization consistently reduces groundwater recharge and increases surface runoff, whereas climate change intensifies temporal variability and raises evapotranspiration demand, together amplifying hydrologic stress under the combined “urban growth + SSP5–8.5” condition. The proposed framework supports groundwater-sensitive urban planning by enabling scenario-based evaluation of land-management and development controls under uncertain climate futures.

LID 0033
openKARST: From detailed karst conduit dynamics to simplified hydraulic flow descriptions

Jannes Kordilla[1]*, Marco Dentz[1], Juan Hidalgo[1]

[1] Institute of Environmental Assessment and Water Research (IDAEA-CSIC), Department of Geosciences, Barcelona, Spain
* jannes.kordilla@csic.es

Keywords: karst conduit hydraulics, mixed free-surface and pressurized flow, hydraulic simplification and upscaling

Karst aquifers exhibit highly dynamic flow behavior governed by complex conduit networks that transition between free-surface and pressurized conditions during recharge and flooding events. In this work, we demonstrate how openKARST, an open-source modeling framework designed to simulate transient and steady-state flow and transport in large karst conduit systems under mixed hydraulic conditions. The model resolves free-surface and pressurized flow using the 1D Saint-Venant equations and represents turbulent resistance through Darcy-Weisbach friction. Tracer transport and travel-time dynamics can be analyzed via particle tracking and advection-diffusion modules. Model verification against analytical solutions and applications to large-scale cave systems demonstrate numerical robustness across a wide range of hydraulic regimes. Building on these capabilities, we introduce a steady-state analysis workflow in order to reduce complex network-scale simulation results to compact, physically interpretable hydraulic metrics. Using conduit-specific Reynolds numbers and friction factors derived from high-fidelity simulations, we quantify how effective hydraulic resistance evolves with discharge, conduit diameter, viscosity, and the transition from partially filled to pressurized flow conditions. Furthermore, we propose a simplified steady-state approximation in which the longitudinal water surface is represented by a generalized depth profile, while cross-sectional hydraulics follow circular partial-filling geometry. This reduced description allows computation of conduit-averaged Reynolds numbers and friction factors and yields hydraulic profiles that can be directly compared to detailed numerical results, including regimes affected by pressurization. Overall, the approach provides a practical link between detailed karst conduit hydraulics and simplified predictive relationships for upscaling in karst hydrogeological studies.

LID 0034
Intregating geophysics and numerical modeling to predict groundwater storage change in region with thick vadose zone

Jeeban Panthi[1]*

[1] Kansas State University, Department of Geology, Manhattan, KS, United States
* jeebanp@ksu.edu

Keywords: groundwater storage, GRACE, vadose zone, integrated modeling

Groundwater-dependent agricultural regions are undergoing persistent declines in water levels due to intensive pumping and increasing hydroclimatic variability, underscoring the need for improved monitoring and assessment of subsurface water storage. In regions such as western Kansas, groundwater dynamics are particularly difficult to resolve because of deep water tables and a thick unsaturated (vadose) zone that stores, delays, and attenuates infiltrating water before recharge reaches the aquifer. This vertically distributed storage creates pronounced time lags between precipitation, deep percolation, and groundwater response, limiting the ability of surface observations or satellite products alone to accurately capture groundwater availability. While NASA's GRACE and GRACE-FO missions provide valuable estimates of total water storage change at monthly scales, their application to groundwater assessment in deep vadose-zone settings is constrained by the lack of direct measurements of unsaturated-zone water content. As a result, vadose-zone storage cannot be reliably separated from groundwater signals, leading to large uncertainties in groundwater storage change and drought characterization in many semi-arid aquifers worldwide.

We develop an integrated framework that combines subsurface geophysics, vadose-zone hydrologic modeling, and satellite remote sensing to improve groundwater storage estimation in deep aquifer systems. Borehole nuclear magnetic resonance (NMR) measurements are used to directly characterize depth-resolved water content and hydraulic properties within the vadose zone, providing physically based constraints that are rarely available at field scale. These geophysical observations are used to parameterize Hydrus-1D simulations of vertical water fluxes and time-varying vadose-zone storage across the High Plains Aquifer in Kansas, supported by high-resolution OpenET evapotranspiration data and shallow soil moisture observations. Quantified vadose-zone storage dynamics are then incorporated into GRACE data processing to isolate groundwater-specific storage anomalies. The resulting groundwater storage estimates are evaluated using long-term water-level observations from an extensive monitoring well network maintained by the Kansas Geological Survey. This geophysics-informed modeling approach advances the interpretation of satellite-based water storage signals and strengthens groundwater assessment in regions with thick vadose zones and limited direct recharge observations.

LID 0038
Seasonal-driven redox dynamics: Unravelling geogenic and anthropogenic Fe-Mn coupling in shallow alluvial aquifers

Sebastián Correa-Varela[1]*, Matías Taucare[1], Linda Daniele[1], Renata Martínez-Barros[1], Antonio Delgado[2], Christian Antileo[3]

[1] Departamento de Geología, Facultad de Ciencias Físicas y Matemáticas, Universidad de Chile, Santiago, Chile
[2] Instituto Andaluz de Ciencias de la Tierra (CSIC-Universidad de Granada), Armilla, Granada, Spain
[3] Departamento de Ingeniería Química, Universidad de La Frontera, Temuco, Chile
* sebastian.correa.v@ug.uchile.cl

Keywords: trace metals, water quality, groundwater pollution, redox sequence, hydrogeochemistry, multivariate statistical analysis

Shallow groundwater is a critical resource for rural communities in southern Chile, where water supply depends directly on local aquifers. Yet, groundwater often exceeds national quality standards for Fe and Mn, compromising water quality, infrastructure, and long-term supply reliability. Understanding the processes controlling Fe-Mn mobilisation is then essential to ensure safe and sustainable rural water provision.

Although the thermodynamic stability of Fe-Mn minerals is well known, the complex interplay among seasonality, geogenic background, and anthropogenic inputs triggering their mobilisation remains poorly constrained. This study investigates the mechanisms governing Fe-Mn dynamics in a shallow alluvial aquifer using seasonal hydrogeochemical data from 26 groundwater samples, complemented by isotopic (δ18O, δ2H) and multivariate statistical analyses.

Results reveal a seasonal redox control on groundwater quality. In winter, precipitation-driven recharge introduces anthropogenic nitrate and soil organic matter, keeping oxidising conditions that suppress metal mobility. In contrast, summer conditions, characterised by higher groundwater temperatures and declining groundwater levels, enhance organic matter degradation, promoting a redox sequence that includes aerobic respiration, denitrification, and the reductive dissolution of Fe-Mn oxides. These processes lead to important mobilisation events, with Fe^{2+} peaking at 12 mg/L under these conditions.

We propose a conceptual model of seasonal synchrony in which agricultural inputs fuel biogeochemical reactions, which are kinetically regulated by climate-driven variations in temperature and recharge. Our findings underscore the vulnerability of shallow aquifers to shifting precipitation patterns, as warming amplifies the mobilisation of redox-sensitive elements. This study provides a scientific basis for the design and management of rural drinking water supply systems that rely on vulnerable groundwater resources.

LID 0040
Possible solutions for the extreme water management situations in Hungary

Péter Szűcs[1]*, Tibor Bíró[2], Sándor Baranya[3], László Bozó[4] Endre Dobos[5], Nándor Fodor[6], Zsolt Szekeres[7], Gábor Nyiri[1]

[1] University of Miskolc, Institute of Water Resources and Environmental Management, Miskolc-Egyetemváros, Hungary
[2] Ludovika University of Public Service, Budapest, Hungary
[3] Budapest University of Technology and Economics, Department of Hydraulic and Water Resources Engineering, Budapest, Hungary
[4] HungaroMet Hungarian Meteorological Service, Budapest, Hungary
[5] University of Miskolc, Institute of Geography and Geoinformatics
[6] HUN-REN Centre for Agricultural Research, Martonvásár, Hungary
* peter.szucs@uni-miskolc.hu

Keywords: climate change, decreasing groundwater levels, MAR managed aquifer recharge

Climate change and extreme weather conditions have very significant impact on various elements of the earth's water cycle, i.e. the hydrological cycle, in Hungary as well. The time series of Hungary's annual and seasonal average temperatures showing an increase is in line with global trends. The long-term average of precipitation is not changing significantly for the time being, but its spatial and temporal distribution is changing rhapsodically. Due to drier and deteriorating soil conditions, a general decrease in the natural precipitation supply that feeds groundwater is expected. This will be most pronounced in the Great Plain, which is also reflected in the significant decrease in groundwater levels there. The average groundwater level has decreased by several meters in many places over the past three decades.

The situation of surface and groundwater in Hungary is currently being shaped by climate-driven risk increases, human pressure and institutional and management deficiencies. The solution options given below take this complexity into account. It is important to understand that a substantial improvement of the current situation on a regional scale is only possible with a professionally coordinated national action plan and a longer time horizon of at least 10-15 years, using significant amount of water. The magnitude of the challenge is evident in the fact that in an area of about half the size of Hungary, 50,000 km^2, which also includes the Great Plain, approximately 10 km^3 of water would be needed to raise the groundwater level by 1 meter, i.e. a captured water volume equivalent to about five Lake Balaton. The coordinated national program may have several elements of minor and major importance.

The possible solutions can be classified into six groups. MAR Managed Aquifer Recharge projects, improvement of soil water storage capacity and innovative dewatering are among the possible complex solutions, which are explained in a detailed manner in the presentation.

The research was funded by the Sustainable Development and Technologies National Programme of the Hungarian Academy of Sciences (FFT NP FTA).

LID 0043
Characterizing effluent residence times in a large-scale Soil Aquifer Treatment (SAT) system: Insights from a multi-tracer field experiment at the Shafdan site

Sigal Brody[1*], Ran Gabay[1], Ido Negev[1], Daniel Kurtzman[2], German Rudnik[2,3], Ido Nitzan[2]

1 Mekorot, National Water Company, Tel Aviv, Israel
2 Soil Water and Environmental Sciences, Volcani Institute, Rishon LeZion, Israel
3 Tel Aviv University, Israel
* sbrody@mekorot.co.il

Keywords: Soil Aquifer Treatment (SAT), tracer test, residence time, water reuse, bromide, uranine

The Shafdan system is Israel's largest managed aquifer recharge (MAR) operation, where approximately 130 million m^3 of secondary effluents are recharged annually through Soil Aquifer Treatment (SAT) and recovered through 150 wells for unrestricted irrigation. A primary regulatory concern is the subsurface residence time from infiltration to recovery. To address this, a large-scale tracer experiment was initiated in July 2024 within a 5.25 hectare segment of the Shafdan SAT system. This study presents a direct field based quantification of effluent travel time distributions from the soil surface to a first ring of production wells (200500 m laterally and 40-80 m vertically).

The experiment utilized a multi-tracer approach: the conservative anion Bromide (Br^-), the fluorescent dye Uranine (Na-fluorescein), and Electrical Conductivity (EC) as a precursor. A total of 54.5 tons of salts (NaBr, NaCl, $CaCl_2$) and 75 kg of Uranine were uniformly applied across the basins. Results revealed complex transport dynamics; Uranine's low detection limit enabled the observation of early arrivals at shallow observation wells however, in the main breakthrough peaks, Uranine exhibited progressive retardation (10-70 days) relative to Bromide.

The first tracer arrival (Br^-) in the closest production well (220 m laterally) occurred 164 days post tracer injection, significantly exceeding the 90 day regulatory threshold. Peak concentrations at the primary recovery wells were observed after approximately 400 days. Only ~10% of the tracer mass was recovered after 386 days, indicating that over 90% of the effluent remains in the subsurface for more than a year. The tracer experiment has been monitored for over 560 days and remains ongoing. These findings demonstrate that actual residence times are substantially longer than previously estimated by older models. The high degree of mixing and dilution observed enhances the effectiveness of the SAT's biochemical purification processes, providing critical validation for the safety and sustainability of large-scale water reuse.

LID 0045
Machine learning–assisted hydrochemical analysis of seawater intrusion in karst aquifers: Insights from Apulia, SE Italy

Mostafa F. Mostafa[1]*, Isabella Serena Liso[1], Avihu Burg[2], Mario Parise[1]

[1] Earth and Environmental Sciences Department, University Aldo Moro, Bari, Italy
[2] Geological Survey of Israel, Jerusalem, Israel
* mostafa.mohammed@uniba.it

Keywords: karst aquifer, seawater intrusions (SWI), mixing lines, machine learning (ML), random forest (RF)

Karst aquifers complicate seawater intrusion (SWI) diagnosis because salinity signals can reflect seawater mixing, water–rock interaction, and anthropogenic inputs. In south-eastern Italy, the Apulia carbonate aquifers provide a representative Mediterranean case. We integrate hydrogeochemical and isotopic evidence with supervised learning to assess SWI using major-ion chemistry, ionic ratios, mixing lines, and machine-learning classification/regression. The approach was applied to 44 sampling sites across two carbonate units on Apulia's Adriatic side, combining historical and recent observations. Most samples plot along a freshwater–Adriatic seawater mixing line, consistent with dominant seawater–freshwater mixing, with secondary effects attributable to agricultural inputs and water–rock interaction. A Random Forest classifier achieved 96% overall accuracy and reliably identified freshwater samples; misclassifications mainly occurred near the mixed–seawater boundary, indicating sensitivity to the guideline used to define classes. For SWI regression, linear and nonlinear models were evaluated with 95% confidence intervals; residuals were largely unbiased and unstructured, although slight under-prediction at the highest chloride levels suggests room for refinement at extreme salinity. Overall, combining geochemical tracers with data-driven models yields a decision-relevant diagnosis of SWI while making uncertainty explicit through model performance. At the same time, results expose a persistent definitional gap: thresholds separating salinity regimes remain ambiguous and can dominate classification error. Addressing this will require time-resolved monitoring and updated, auditable criteria to improve transferability of predictive SWI assessments.

LID 0046
Spatial-temporal dynamics of surface water-groundwater interactions in a fragmented alpine headwater stream, Taiwan

Yung-Chia Chiu[1]*, Ting-Xing Pan[2], Cheng-Han Wu[1], Tzung-Yu Lee[3], Shao-Yiu Hsu[4]

[1] Institute of Earth Sciences, National Taiwan Ocean University, Keelung, Taiwan
[2] Advanced Geology Research Center, Sinotech Engineering Consultants Inc., Taipei, Taiwan
[3] Department of Geography, National Taiwan Normal University, Taipei, Taiwan
[4] Department of Bioenvironmental System Engineering, National Taiwan University, Taipei, Taiwan
* ycchiu@mail.ntou.edu.tw

Keywords: FO-DTS, hyporheic exchange, river fragmentation, Formosan Landlocked Salmon, thermal refugia alpine hydrology

Alpine headwater catchments are critical for downstream water availability and ecosystem health. In Taiwan's Yusheng Creek, river fragmentation and flow cessation have led to a 90% decline in the endangered Formosan landlocked salmon population. Understanding the dynamics of surface water-groundwater (SW-GW) interactions and hyporheic exchange (HE) is essential for restoring these thermally sensitive habitats. This study utilized Fiber Optic Distributed Temperature Sensing (FO-DTS) to monitor stream temperatures at high spatio-temporal resolution. Statistical z-tests were employed to identify cold-water inflow locations, while an energy balance approach quantified the magnitude of groundwater discharge (GD) and HE during contrasting hydrological seasons. Stream fragmentation initiated in high-permeability reaches and propagated longitudinally during the dry season. Downstream upwelling stabilized baseflow and significantly reduced daily temperature fluctuations from 2°C to 0.5°C. Cold-water inflows accounted for 35% of total streamflow (20% GD, 15% HE), with 90% of these inflows occurring downstream during the dry season. Total inflows increased to 50% of streamflow (35% GD, 15% HE) during the wet season. These findings highlight the vital role of groundwater in maintaining thermal refugia and flow connectivity. This research provides a quantitative foundation for river restoration strategies aimed at conserving endangered aquatic species in alpine environments. Future research will integrate high-resolution stream channel geomorphology to determine how bedforms (such as pool-riffle sequences), channel confinement, and sediment distribution control the localization of GD and HE. Understanding these geomorphic drivers will be essential for designing effective river restoration strategies and ensuring the long-term survival of the Formosan landlocked salmon in a changing climate.

LID 0047
Restoration and water quality management of an urban pond supported by nutrient-rich groundwater

Fumi Sugita[1]*

[1] Chiba University of Commerce, Chiba, Japan
* fsugita@cuc.ac.jp

Keywords: urban pond, algal bloom, nutrient-rich groundwater

Urban ponds play an important role as a nexus between nature and city residents and as valuable habitats for wildlife in urban settings. In Japan, many urban ponds rely on nutrient-rich groundwater as their primary water source. Water quality degradation due to eutrophication has often been reported resulting in excessive algal blooms accompanied by unpleasant odors.

This study investigates the sources and controlling factors of nitrate and phosphate concentrations in Pond Junsai, located in a densely populated area approximately 10 km east of Tokyo. The objective is to identify effective strategies for managing water quality and mitigating algal blooms while utilizing locally available, nutrient-rich groundwater. Until 2022, the pond was supplied by shallow groundwater with high nitrate concentrations, resulting in recurrent algal blooms. In March 2023, a new water management strategy was implemented, introducing large volumes of deep groundwater with low nitrate and relatively high phosphate concentrations. In 2024, algal blooms were partially suppressed.

By comparing sources and water chemistry between 2022 and 2024, we found that, overall phosphorus concentrations in 2024 were lower than in 2022, due to reduced phosphorus release from bottom sediments associated with shorter water residence times. In contrast, nitrogen concentrations decreased markedly, leading to the suppression of green algae and diatoms. During winter, however, increased waterfowl activity resulted in substantial phosphorus inputs via fecal deposition. This seasonal phosphorus enrichment lowered the N/P ratio and promoted the growth of cyanobacteria.

These results highlight the potential for managing nitrogen availability and N/P ratios through the selective use of groundwater from different depths depending on the season, thereby mitigating algal blooms in urban ponds supported by nutrient-rich groundwater.

LID 0048
Multi-indicators to investigate the spatio-temporal effect of groundwater-lake interaction on lake development

Xihua Wang[1]*, Zejun Liu[1], Y. Jun Xu[2]

[1] College of Civil Engineering, Tongji University, Shanghai, China
[2] School of Renewable Natural Resources, Louisiana State University, Baton Rouge, LA, United States
* wangxihua342@163.com

Keywords: groundwater-lake interaction, lake development, spatial–temporal characteristics, stable isotopes

Groundwater-surface water (GW-SW) interaction has vital implications on substance and energy cycling in large fresh water lake area. However, the impact of GW-SW interaction on lake development and evolution remains indistinct. In this study, 101 water samples were collected from groundwater and lake water in a floodplain lake region from 2022 to 2023. Statistical analysis, hydrogeochemical analysis, stable isotope mass-balance modeling, in-situ hydraulic tests, lake water budget and remote sensing method were employed to investigate the groundwater-lake water interaction and lake development in Poyang Lake area. Results showed that the hydraulic connectivity in the southern and northern part of the lake was relatively high while was relatively low in the middle part. The hydraulic conductivity varied from 0.0016 m/d to 1.8557 m/d and the transform intensity between GW and SW ranged from 1.28×10^{-6} m/d to 1.71×10^{-2} m/d across the sampling points. GW-SW interaction patterns exhibited spatial and temporal variabilities. Geology and geomorphology affected the GW-SW hydraulic connectivity. Hydrology, meteorology and anthropogenic activities affected the GW-SW transform relationship. The evaporation and inflow ratios (E/I) of the lake changed from 0.0016 to 0.6747 calculated by $\delta^{18}O$ and from 0.0002 to 0.0197 by $\delta^{2}H$ over the study period. E/I had negative correlation with GW-SW transform intensity. Lake area depended on groundwater recharge in the dry season while this effect was small in the wet season. The results will provide crucial references of understanding regional hydrological cycle, water body evolution and their response to the changing environment to international large fresh water lake areas.

LID 0049
Groundwater as a socio-hydrogeological system: Lessons from community-led multiple-use water services in rural South Africa

Shafick Adams[1]*

[1] Water Research Commission RDI, Pretoria, South Africa
* shaficka@wrc.org.za

Groundwater underpins rural water security across South Africa, yet governance approaches remain dominated by technical and infrastructure-led paradigms that insufficiently engage with social realities. This abstract synthesises findings from community-led assessments of six Multiple Use Water Services systems in Limpopo Province to advance a socio-hydrogeological understanding. The MUS systems rely primarily on groundwater and explicitly support multiple water uses, including domestic supply, livestock watering, and small-scale productive activities. Using a multi-dimensional functionality framework, the assessments show that groundwater outcomes are shaped less by hydrogeological potential than by governance capacity, institutional support, and water practices. Access to groundwater was highly socially differentiated, even within similar aquifer settings, mediated by affordability, infrastructure ownership, storage, and norms of sharing. Systems that accommodated multiple uses through storage, reticulation design, and locally negotiated rules consistently outperformed domestic-only systems. Governance capacity emerged as the strongest determinant of sustainability. Community-managed systems with legitimate leadership, transparent financial management, and enforceable rules remained functional despite weak municipal support, while technically adequate systems deteriorated rapidly where governance was ineffective. Informal and self-supply groundwater arrangements played a critical role in system resilience, buffering households against service interruptions and drought, and challenging regulatory narratives that frame informality as failure.

Institutional integration with municipalities and higher authorities was consistently the weakest element across the portfolio, highlighting a systemic lack of post-construction support and long-term oversight. Groundwater insecurity is primarily an institutional and governance challenge rather than a physical scarcity problem. Securing groundwater futures will require a shift from infrastructure-centric delivery towards sustained institutional care, adaptive governance, and explicit recognition of groundwater as a socially embedded, multiple-use resource.

LID 0050
Understanding the roles of climate change, land use and land cover change and water diversion project in modulating water- and carbon-use efficiency in Han River Basin

Feng Yue[1], **Dedi Liu**[1]*

[1] State Key Laboratory of Water Resources Engineering and Management, Wuhan University, Wuhan, China
* dediliu@whu.edu.cn

Keywords: water use efficiency, carbon use efficiency, evapotranspiration, RHESSys, random forest, water diversion project

Water-use efficiency (WUE) and carbon-use efficiency (CUE) are critical indicators of ecosystem function and hydrologic processes, reflecting the water-carbon flux exchange rate. Climatic variables, land use and land cover change (LUCC) and water diversion project (WDP) have altered water-carbon cycle; however, their roles in modulating WUE and CUE remain uncertain. To explore these effects, a framework is proposed and Han River basin (HRB) in China is selected as a case study including the data sets from both remote sensing and in observations during 2000–2020. The process-based Regional Hydro-Ecological Simulation System model and a supervised machine learning model are applied to simulate the impacts of climatic variables, LUCC and WDP on WUE and CUE, which are conducted by designing four experiments. We find that no significant WUE and CUE trends attributed to contrasting trends in the dry (October to March) and wet (April to September) seasons. Temperature variations greatly affect WUE and CUE, with WUE decreasing in the wet season and increasing in the dry season due to minimum temperature changes. LUCC has litter impacts on WUE and CUE changes. From2014 to 2020, the middle route of the South-to-North WDP decreased WUE by 0.22 $gCkg^{-1}H2O$ in the middle-low HRB's wet season, slightly affecting CUE. Seasonal CUE was stable, with the largest decrease of 0.04 in the upper HRB during the wet season. The WDP also increased WUE sensitivities to minimum and maximum temperatures, while CUE sensitivities remained constant. Our case study has proven that the proposed framework is an effective way to understand the roles of climate change and WDP in modulating WUE and CUE.

LID 0052
FracSYS: A pragmatic approach for the explicit conceptualisation of fractured aquifers

Arnauld Malard[1*], Ivann Milenkovic[2,3], Andreas Wassmer[4], Abel Henriot[2], Pierre-Yves Jeannin[1], André Csillaghy[4], Pascal Ornstein[2]

[1] Swiss Institute for Speleology and Karst Studies, La Chaux-de-Fonds, Switzerland
[2] Centre de Recherche pour l'Environnement Alpin, Sion, Switzerland
[3] HydroCarto SA, Genève, Switzerland
[4] Institute for Data Science, FHNW, Windisch, Switzerland
* arnauld.malard@isska.ch

Fractured aquifers represent significant groundwater resources, mainly in mountainous regions but also in bedrock regions (geological cratons). In these regions, hydrogeological flow systems are organised according to (i) an unconsolidated cover or weathering zone that provides a capacitive function and (ii) fracture networks that provide a transmissive function. These aquifer environments have been the subject of numerous studies with the aim, among other things, of proposing conceptual models to explain the main processes of hydrogeological functioning, namely: (i) recharge, (ii) storage and (iii) drainage. These three processes are essential information for hydrogeological characterisation, which in turns enables (i) the exploitation of water resources and (ii) the protection of the aquifer. Although there are numerous hydrogeological characterisation studies in varied geological environments, research has shown that there are no truly 'practical' approaches or accessible tools for establishing explicit conceptual models of these fractured aquifers. This 'gap' often makes it difficult for hydrogeologists to do their work and share their knowledge to managers, stakeholders or decision-makers, i.e. people who do not have the necessary hydrogeological background to form a clear picture of the hydrogeological system and implement the measures for which they are responsible (water supply, natural hazards, civil engineering works, regulations, etc.).

With this in mind, CREALP and ISSKA propose to develop a practical approach for establishing explicit 3D conceptual models of fractured aquifers and their groundwater resources. The development of this approach, called 'FracSYS', is co-funded by the Swiss Federal Office for the Environment and conducted in collaboration with the Institute for Data Science FHNW.

The FracSYS project consists of proposing a 'generic' conceptual model of hydrogeological systems in fractured aquifers and applying it to a number of test sites in the Swiss Alps. The aim of FracSYS is to enable hydrogeologists to document the main hydrogeological processes: recharge, storage and drainage, and to assess (i) the distribution of groundwater resources and (ii) the organisation of the main flows through the unsaturated and saturated zones of the fracture network (hydraulic gradient, flow rate) and to share this information with non-specialists.

The project is currently underway. Intermediate and final results will be available on the website https://fracsys-vitrine.ch/ from the second half of 2026.

LID 0054
Analysis, comparison and review of water policies for governance and management in Sub-Sahara Africa

Joseph Igbinedion[1]*

[1] ELTE Eötvös Loránd University, Faculty of Science, Institute of Geography and Earth Sciences, Department of Social and Economic Geography, Budapest, Hungary
* joigbinedion@student.elte.hu

Keywords: groundwater, policy, Sub-Sahara Africa

In Sub-Sahara Africa, there is abundance of groundwater availability due to it recharge from rainfall, however, of recent there has been decrease in groundwater aquifer recharges as climate change has affected rainfall patterns. Although same cannot be said of groundwater accessibility. This article provides an overview of the current groundwater governance, management and policy literature. Using the Earth System Governance project, I elaborated and analyzed water policy documents on groundwater architecture, its allocation and access, accountability, adaptation and agencies for effective groundwater governance and management.

Drawing from the analysis, I also compared policy documents. I find that groundwater isn't clearly defined but captured generally under water. Governance and management are fragmented and uncoordinated, weak regulation, poor monitoring and evaluation, lack of transparency and implementable sentences. Water governance is a grand challenge problem and has become one of humanity's foremost priorities, however, they can be turned into opportunities in sub-Saharan Africa.

LID 0055
Heavy metals contamination in groundwater and associated human health risk in semi-arid Katsina State, Northwestern Nigeria

Ibrahim Baba Goni[1]*, Baba Musami Sheriff[1], Aisha Abubakar Kana[2], Musa Mallam Aji[1], Ahmad Salisu[3], Yahaya Nazoumou[4], Boukari Issoufou Ousmane[4], Richard G. Taylor[5]

[1] Department of Geology, University of Maiduguri, Nigeria
[2] Department of Geology and Mining, Nasarawa State University, Keffi, Nigeria
[3] Sokoto Rima River Basin Authority, Katsina State, Nigeria
[4] Department of Geology, Abdou Moumouni University, Niamey, Niger
[5] Department of Geography, University College London, United Kingdom
* mubasherr09@gmail.co

Keywords: groundwater, quality, contamination, heavy metals, health risks

Groundwater is the dominant source of perennial water supply in semi-arid regions globally. In Katsina State, northwestern Nigeria it is the source of supply for domestic, agriculture and industrial use. This resource is threatened by heavy metals contamination through geogenic and/or anthropogenic pathways. In the study area, sixty-seven samples from boreholes, handpumps, and dug wells were collected in November 2024 and analyzed using Atomic Absorption Spectrophotometry (AAS). These samples were analyzed for heavy metals (Pb, Cd, Cr, Cu, Hg, and Ni) to assess their levels, sources, and potential health risks. The extent of contaminations are evaluated using standard indices - Heavy Metal Pollution Index (HPI), Metal Index (MI), and human health risk models of hazard quotients (HQ), hazard index (HI), and carcinogenic risk (CR) for both adults and children. The results show that heavy metals contaminations are from weathering of granites, gneisses, migmatites, and Chad Formation sediments, combined with anthropogenic sources from old dumpsites, dye centers, mechanical workshops, soak aways, and wastewater drains, especially pronounced in densely populated areas. The results further show widespread contamination with one-third of the samples indicating high to severe pollution based on HPI, while nearly 90% exceeded the MI safe limits. Hg, Cr, and Cu present the highest non-carcinogenic risks with HQ and HI far above safety thresholds, especially for children. Carcinogenic risks assessment shows that Cr and Cu present relatively higher risk, here again with children more impacted than adults. These findings are the first in the study area to highlight an urgent need for action to protect the groundwater resources of this semi-arid area. Improved waste and sanitation management, regular monitoring, and development of safer alternative water supplies will be critical in reducing exposure to the risks. The findings contribute to groundwater safety knowledge and support the Sustainable Development Goal (SDG) 6 on clean water and sanitation in this semi-arid area.

LID 0056
Groundwater hydrochemical characteristics and human health risk assessment of dispersed karst water sources in Southeast of Chongqing

Shengzhang Zou[1,3]*, Hao Xie[1,2,3,4], Changsong Zhou[1,2,3,4], Lianjie Fan[1,2,3,4], Li Lu[1,2,3,4], Yongsheng Lin[1,2,3,4], Jia Wang[1,2,3,4], Rixin Deng[1,2,3,4], Yeyu Yang[1,2,3,4], Xianyu Wei[1,2,3,4]

[1] Institute of Karst Geology, Chinese Academy of Geological Sciences, Guilin, China
[2] Key Laboratory of Karst Dynamics, Ministry of National Resources, Guilin, China
[3] International Research Center on Karst under the Auspices of UNESCO, Guilin, China
[4] National Center for International Research on Karst Dynamic System and Global Change, Guilin, China
* zshengzhang@mail.cgs.gov.cn

Keywords: Southeast of Chongqing, karst water, hydrochemistry, entropy-weight water quality index (EWQI), health risk assessment, karst

Karst water is the only dispersed water supply source for residents in the karst mountainous areas of southeastern Chongqing. Understanding its hydrochemical composition and genesis, evaluating the quality of groundwater, and assessing the potential risks to human health are of great significance for the rational development, utilization, and protection of karst water. Taking the karst water with dispersed water supply in southeastern Chongqing as the research object, the concentrations of Al, Cu, Pb, Zn, Cr, Cd, Ni, Mn, As, and Hg metal elements in 71 sets of karst water samples were measured. Gibbs plots, multivariate statistical analysis, entropy weight water quality index (EWQI), and human health risk models were used to study the hydrochemical composition and water quality status of groundwater in the region. The spatial distribution of high detection rate metal elements was revealed by using ordinary kriging interpolation method. Multivariate statistical methods and health risk models were applied to analyze the concentration characteristics of metal elements and the health risks caused by them. The results show that: (1) The hydrochemical composition of groundwater from karst water sources with dispersed water supply in southeastern Chongqing is mainly controlled by water rock interaction and human activities, and cation exchange is not significant; (2) The groundwater EWQI results are between 9.82 and 102.17, indicating that the overall water quality in the karst area of southeastern Chongqing is excellent; The overall occurrence of metallic elements in karst water is greatly influenced by spatial scales, especially Ni and As; The concentrations of Cu, Pb, As, Zn, and Cr elements are mainly influenced by the regional geological background, Al and Mn elements are mainly influenced by human industrial, agricultural, and mining production activities, and Ni element is influenced by both natural background and human activities; (3) The total health risk of exposure through drinking is higher than that through skin infiltration, which is the main exposure route for the human body. Children have a higher total health risk of exposure through drinking than adults, while adults have a higher total health risk of exposure through skin infiltration. It is worth noting that Cr element is the determining element that causes total health risk. From the perspective of drinking water safety, local residents need to pay certain attention to the water quality when drinking dispersed karst groundwater, in order to reduce the health risks of the population.

LID 0057
Groundwater dams as a strategy for water supply diversification: Efforts in South Korea

Sang-Il Lee[1*], Seong-Taek Yun[2], Jae Yun Jung[3], Hwan-Ho Yong[4]

[1] Dongguk University, Seoul, South Korea
[2] Korea University, Seoul, South Korea
[3] Dohwa Engineering, Seoul, South Korea
[4] Rural Research Institute, Korea Rural Community Corporation, Ansan, South Korea
* islee@dongguk.edu

Keywords: groundwater dam, water supply, climate change

With climate change intensifying water scarcity and interregional conflicts over water resources becoming increasingly frequent, the importance of diversifying water resources to ensure a stable and reliable supply has been widely recognized. In South Korea, where water supply has heavily relied on surface water, groundwater dams have recently emerged as a promising strategy for securing alternative water sources. They offer distinct advantages over surface water dams, including lower evaporation losses, higher structural stability, and better community acceptance.

Recognizing the potential of groundwater dams to enhance overall water supply security, the Government of South Korea has established a plan to construct 82 medium- and large-scale groundwater dams by 2053, aiming to expand municipal and industrial water supplies. If successfully implemented, this initiative is projected to alleviate water shortages by 36%. To execute this plan, the development and standardization of technologies covering the entire lifecycle are required—encompassing site selection, design and construction, operation and maintenance, integration with existing facilities, and relevant legal and institutional frameworks.

To address these challenges, the Research Consortium for Innovative Groundwater Dam Technologies (IGDT) was recently launched. This presentation provides an overview of the consortium's objectives and research roadmap, along with demonstration plans designed to validate and optimize the proposed technologies. Furthermore, this study highlights key research findings to date, including optimal site selection, performance assessment of deteriorating groundwater dams, functional restoration techniques, and integrated water supply systems that link groundwater dams and bedrock wells.

This work was supported by the Management Technology for Groundwater Dams in Water Supply Vulnerable Areas Program of the Korea Environmental Industry & Technology Institute (KEITI), funded by the Ministry of Environment (MOE) (RS-2025-01842973).

LID 0058
Vertical distribution of PFAS in coastal sediments of Omura Bay: A proxy for long-term anthropogenic contamination from terrestrial sources

Kei Nakagawa[1]*, Zhuolin Li[2], Keisuke Kuroda[3], Minoru Wada[1], Hiroshi Asakura[1]

[1] Institute of Integrated Science and Technology, Nagasaki University, Nagasaki, Japan
[2] Graduate School of Integrated Science and Technology, Nagasaki University, Nagasaki, Japan
[3] Faculty of Engineering, Toyama Prefectural University, Imizu City, Toyama, Japan
* kei-naka@nagasaki-u.ac.jp

Keywords: PFAS, sediment, vertical distribution, Omura Bay, organic carbon, heavy metals, multivariate analysis

This study evaluated the vertical distribution and contamination status of per- and polyfluoroalkyl substances (PFAS) in the seabed sediments of Omura Bay, a semi-enclosed sea in Nagasaki, Japan, which serves as a sink for terrestrial contaminants transported via the hydrological cycle. Given that Nagasaki Airport, the world's first offshore airport, has been operational since 1975, concerns have been raised regarding the environmental impact of firefighting foams, a known source of PFAS in groundwater and runoff, which contain PFOS, PFOA, and PFHxS.

Sediment cores up to 42 cm deep were collected from two sites: the central bay and near the airport. The analysis measured vertical profiles of PFOS, PFOA, and PFHxS, along with Total Organic Carbon (TOC) and heavy metals using LC-MS/MS and XRF analysis. Multivariate analysis, including Principal Component Analysis (PCA) and hierarchical cluster analysis, was performed to characterize contamination patterns and differentiate between natural and anthropogenic inputs.

PFOS, PFOA, and PFHxS were the dominant PFAS. Concentrations peaked in the shallow layers and decreased with depth. Although the values were lower than those in some extreme cases, they exceeded the background levels, confirming anthropogenic contamination. The strong correlation between PFAS and TOC indicates that organic matter facilitates the retention of these chemicals in the sediment. Multivariate analysis classified the samples into four clusters, separating the shallow layers impacted by PFAS and organic matter from the deep layers representing natural crustal components.

The observed vertical decrease in the uppermost layers likely reflects the global phase-out of these chemicals. These results suggest that coastal sediment cores can serve as a historical record of the transport of emerging contaminants from land-based sources, such as airports, providing critical insights into the long-term dynamics of PFAS in integrated groundwater-seawater systems.

LID 0059
Groundwater recharge and deep flow connectivity in Himalayan mountain catchments

Tanveer Dar[1]*, Munair Ahmad Nayak [1]

[1] National Institute of Technology, Srinagar, India
* tdar@es.iitr.ac.in

Keywords: groundwater recharge, isotope hydrology, Himalayan catchments, groundwater connectivity

Understanding groundwater recharge and deep subsurface flow connectivity in mountain regions is critical for assessing water security under changing climatic conditions. Himalayan catchments, characterized by complex geology, steep topography, and strong climatic gradients, remain poorly constrained in terms of groundwater flow depths, recharge pathways, and inter-basin connectivity. This study investigates groundwater recharge mechanisms and subsurface flow systems in selected Himalayan catchments using an integrated isotopic and hydrogeological approach. Stable isotopes of water ($\delta^{18}O$, $\delta^{2}H$, and d-excess), complemented by hydrogeochemical indicators and field-based hydrogeological observations, are used to trace recharge sources, seasonal variability, and groundwater residence characteristics across springs, streams, and wells spanning different elevations and lithological units. Results reveal distinct isotopic signatures between shallow and deeper groundwater systems, indicating the coexistence of rapid, seasonally recharged flowpaths and longer-residence groundwater components sustained by high-altitude recharge zones. Spatial isotope gradients suggest topographically driven flow systems and possible inter-basin groundwater connectivity, particularly across structurally controlled lithological boundaries. Attenuation of seasonal isotope signals in selected springs highlights the buffering role of subsurface storage under hydroclimatic extremes. These findings provide new insights into the internal architecture of Himalayan groundwater systems and demonstrate the value of isotope hydrology for disentangling recharge and flow processes in complex mountain terrains. The results have important implications for spring sustainability, groundwater resilience, and climate-adaptation strategies in Himalayan regions.

LID 0062
New highlights on MAR implementation worldwide from the 2026 update of the Managed Aquifer Recharge (MAR) Portal

Andrew Pearson[1], Elie Gerges[1], Hyacinthe Pauly[1], Claudia Ruz Vargas[1], Feifei Cao[1], Elisabeth Lictevout[1]

[1] International Groundwater Resources Assessment Centre (IGRAC), Delft, The Netherlands
* andrew.pearson@un-igrac.org

Keywords: managed aquifer recharge, artificial recharge, groundwater recharge

Over recent decades, managed aquifer recharge (MAR) projects have been implemented worldwide. Common objectives include increasing groundwater storage, improving groundwater quality, water filtration, raising groundwater levels, supporting groundwater-dependent ecosystems, reducing land subsidence, and minimising seawater intrusion. To inform successful development and implementation of future projects, it is vital to raise the profile of MAR and disseminate results from existing and past projects to decision-makers and stakeholders.

The Global MAR Portal (https://ggis.un-igrac.org/view/marportal/) sits under IGRAC's Global Groundwater Information System (GGIS), and is designed to highlight MAR as a useful tool for groundwater management, increase data accessibility, and to enable regional to global assessments, research, and planning. The Portal consists of a data layer catalogue, an online GIS-based map viewer, and a features panel. The Portal was established in 2017 following a 12-month manual survey of available online literature in eight languages (Catalin and Ansems, 2018). Following the survey, the Portal contained an inventory of over 1,200 case studies from over 50 countries worldwide. Metadata for each MAR project included year of scheme deployment, the source of infiltration water, the final use of abstracted water, as well as the main objectives of the project.

From 2018 to 2026, the MAR Portal was updated on an ad-hoc basis. In 2026 the Portal underwent a systematic update of both new MAR projects implemented since 2017, and projects that were not captured by the 2017 survey (e.g., due to language limitations). In the 2026 update, an automated and manual search of available literature was supported by data mining using manual and AI-assisted text analysis. A validation step was undertaken, whereby we manually checked a subset of results from the AI-assisted text analysis. Additionally, the search was undertaken in several additional languages not used in the 2017 survey. The metadata search was also expanded to include information on budgets, implementing or responsible organisations, estimates of volume recharged, and some result indicators. Here we present the findings from the 2026 update, and provide a global-scale overview of MAR projects.

LID 0064
Adapting to climate extremes using conjunctive management of surface water and groundwater and managed aquifer recharge

Bridget R. Scanlon[1*], Ashraf Rateb[1], John Malito[2], Sarah Fakhreddine[3], Donald R. Pool[4]

[1] Bureau of Economic Geology, Jackson School of Geosciences, University of Texas at Austin, Austin, Texas, United States
[2] Applied Research Labs, University of Texas at Austin, Austin, Texas, United States
[3] Dept. of Civil and Env. Engineering, Carnegie Mellow University, Pittsburgh, Pennsylvania, United States
[4] Hydrogeologist LLC, Tucson, Arizona, United States
* bridget.scanlon@beg.utexas.edu

Keywords: floods, droughts, managed aquifer recharge

Long-term droughts interspersed with intense floods underscores the need to develop water resource management approaches to address these climate extremes. The objective of this analysis was to assess how much flood flow could be captured and stored in depleted aquifers in different regions of the United States. Analysis of high magnitude flows (HMFs, streamflow > 95th percentile) in the state of Texas shows that they averaged ~10% of total flows at basin outlets (~ 4 km^3/yr), representing ~ 20% of water use in Texas (18 km^3). Previous studies estimated ~ 1000 km^3 of depleted aquifer storage in the US, mostly in the semiarid west, exceeding surface reservoir storage. GRACE satellite data also show recent storage declines in many of the major aquifers, particularly during droughts. Most of the depletion is linked to irrigated agriculture. Conjunctive use of surface water during wet periods and groundwater during droughts helps reduce overall groundwater depletion. Examples of successful managed aquifer recharge will be described. Recharge of up to 0.6 km^3/yr in East Snake Plain Aquifer in Idaho provides baseflow during summer. Irrigation districts in the California Central Valley use surface spreading basins to recharge flood waters from atmospheric rivers to provide irrigation during multiyear droughts. Arizona has been operating many managed aquifer recharge systems to store Colorado River water in depleted aquifers to reduce subsidence in Active Management Areas. These examples demonstrate the variety of water management approaches that can be deployed to address seasonal to interannual climate extremes in semiarid regions.

LID 0067
Long datasets for improved understanding, management and protection of groundwater

John Chilton[1*], Stephen Foster[2]

[1] IAH trustee, Reading, United Kingdom
[2] IAH Past President, Oxford, United Kingdom
* johnchilton48@gmail.com

Keywords: long datasets, groundwater monitoring, groundwater management

In a changing world, long datasets have great value for all components of environmental monitoring. This is particularly true for groundwater systems, with their generally slow responses to negative impacts and to management or remedial measures for both quantity and quality. However, there is a global scarcity of such datasets, with few extending beyond 30 years and even fewer to 50 or 100 years, and the reasons for their scarcity are identified. The wide range of hydrogeological investigations and groundwater management activities benefiting from long-term data is listed. Examples of the use of long datasets in some of these investigations for better understanding, management and protection of groundwater are shown. The present generation of hydrogeologists should be grateful to those who initiated their collection, and strive wherever possible to maintain them for the benefit of future generations of hydrogeologists.

LID 0068
Iron and manganese dynamics in groundwater extraction sites influenced by bank filtration

Maria Nygård-Hämäläinen[1,3]*, Kirsti Korkka-Niemi[1,2], Niina Kuosmanen[1]

[1] Department of Geosciences and Geography, University of Helsinki, Helsinki, Finland
[2] Geological Survey of Finland, Espoo, Finland
[3] AFRY Finland Oy, Vantaa, Finland
* maria.nygard-hamalainen@helsinki.fi

Keywords: groundwater quality, bank filtration, Fe and Mn precipitates, redox reactions, water intake well clogging

In Finland, one of the most significant challenges with water intake wells is the precipitation and clogging problems caused by iron and manganese. These elements precipitate in the well structures and the surrounding sediments due to changes in redox environment.

The aim of the study was to investigate the tendency of iron and manganese to precipitate at groundwater abstraction sites in relation to bank filtration, the aquifer's redox environment, and aquifer utilization. The research also examines how changes in the operation of the water plant affect the zoning of aquifer's redox environments. The study was conducted during the summer of 2024 in three aquifers with water intake plants located in postglacial, Quaternary sedimentary deposits in southern Finland. At two intake plants, there is variable bank infiltration into the groundwater extraction wells from the surface water.

To assess the conditions of iron and manganese precipitation, field measurements (oxygen, redox, pH, and temperature) and water sampling (major ions, trace elements, pH, EC, alkalinity, and water stable isotopes) were done from water intake wells, observation wells, and surface waters.

Iron and manganese concentrations in groundwater were high, and oxygen concentrations were low in areas influenced by surface water. The periodicity of pumping indicates that the practice is one factor in the precipitation of iron and manganese. The data also show that bank filtration has a significant impact on the redox conditions of the aquifer and further on the precipitation of iron and manganese.

LID 0070
Groundwater connected art: Practicing arts-based research to enrich how hydrogeology engages people, place and other disciplines

Tom Gleeson [1]*

[1] University of Victoria, Victoria, Canada
* tgleeson@uvic.ca

Groundwater depletion, contamination and governance challenges persist despite decades of research. Scientific methods are crucial yet seem insufficient to inspire the emotional, cultural and community connections needed for real change—groundwater challenges and opportunities may not be reaching enough hearts and minds. This perspective article invites a bold shift: Integrating arts-based research into hydrogeology. Hydrogeologists, in collaboration with social scientists, artists, and communities, might spark more powerful connections to groundwater by blending art forms such as drama, visual art, storytelling, and music with scientific practice. This article unfolds through a series of invitations spanning art, community engagement and learning from related disciplines that have embraced arts-based research. I introduce the concept of *groundwater-connected art* as both process and expression, expanding how groundwater could be represented and understood. Examples across artistic practices exist and could be expanded through expressions of groundwater tastes, smells, sounds, landscapes, cultures and connections in community and into the future. Arts-based research offers methods to bridge gaps across disciplines, strengthen participatory and community-engaged approaches, elevate cultural and relational dimensions of groundwater, and align with emerging priorities in socio-hydrogeology. Integrating art is not without challenges, including questions of role, rigor, ethics and positionality, but creative processes could make hydrogeology more human, equitable and impactful. This article invites hydrogeologists to embrace creativity and collaboration with artists, social scientists, and communities—which could change how we engage with, value and care for this often invisible resource.

LID 0071
Review and update of the hydrogeological map for sustainable groundwater management: Case study of Komani, South Africa

Lindelani Lalumbe[1]*, Robert Fourie[1], Tholoana Mabula[1], Kgotlello Mashishi[1], Tholeka Mafanya[1]

[1] Department of Water and Sanitation, Pretoria, South Africa
* lindelanilalumbe@ymail.com

Keywords: hydrogeological-map, groundwater-yield, aquifer

Hydrogeological information products such as groundwater quality, groundwater yields, water strikes, depth to groundwater levels and related maps are very crucial in the planning and development of groundwater globally. This study objective was to review and update the 1: 500 000 hydro-geological map series and information brochure which was completed in 2002 with recent data to support decisions in terms of sustainable groundwater management. This study combined monitoring data and data sets from various stakeholders that was used in the information products with data from 2003 to 2025 to update parameters such as groundwater levels, quality, yields, recharge, harvest potential, groundwater allocation and abstraction volumes as well as distribution of boreholes. Various statistical analysis was conducted to determine data variations. ArcGIS tool was used to delineate and map various aquifer types and spatial distribution of data points. Piper diagram was used to classify groundwater quality. This study managed to identify new aquifer yield class of > 10 l/s by expansion of yield classes based on new datasets. Reducing of scale led to the map being sub-divided into 4 information products refined to smaller scales for improved understanding of local conditions. This study managed to update the hydro-geological map series and information brochure, where latest hydrogeological information products were delineated based on recent data and information. This study recommended that all hydro-geological information products should be reviewed every 10 years in order to improve groundwater management, planning and decision making. This study is aligned with the Groundwater challenges and opportunities theme as the approach followed of data collection and assessment are within this them.

LID 0072
Influence of lithostructural features on nitrate transport dynamics in the vadose zone of Malta

Gabriella Balacco[1]*, Maria Rosaria Alfio[1], Gaetano Daniele Fiorese[2], Manuel Sapiano[3]

[1] Department of Civil, Environmental, Land, Construction and Chemistry (DICATECh), Polytechnic University of Bari, Bari, Italy
[2] Department of Soil, Plant and Food Sciences (DISSPA), University of Bari Aldo Moro, Bari, Italy
[3] EWA Energy and Water Agency, Hal Luqa, Malta
* gabriella.balacco@poliba.it

Keywords: groundwater, nitrate transport, vadose zone monitoring station

Mediterranean coastal aquifers are under growing pressure from the combined impacts of climate change, intensified agriculture, and increasing water demand. Malta represents an emblematic case. Although the entire island has been designated a Nitrate Vulnerable Zone since 2004 under European legislation and measures have been introduced to limit fertilizer use, groundwater nitrate levels remain high and frequently display upward trends.

To clarify how recharge and nitrate transport are influenced by the vadose zone and by the lithostructural setting of the Mean Sea Level Aquifer (MSLA), the national Energy and Water Agency established a monitoring network of 16 Unsaturated Zone Stations from 2019. Each station is equipped with Time Domain Reflectometry sensors and interstitial water samplers, enabling continuous measurements of soil moisture and chemical and isotopic analyses at multiple depths. This study focuses on two representative stations with contrasting lithostratigraphic and structural contexts.

The research integrates vadose zone observations with hydrological (rainfall and temperature), hydrogeological (piezometric levels), and geochemical (groundwater chemistry) information, framed by a detailed lithological reconstruction. Groundwater strongly correlates with cumulative precipitation (60–360 days) and response times range from months to nearly one year, consistently with low matrix permeability and the presence of low-conductivity layers. Vadose zone data reveal progressive attenuation of moisture fluctuations with depth and very high nitrate concentrations in shallow interstitial waters. This vertical gradient suggests nitrate storage in the vadose zone with delayed release to the aquifer. Isotopic evidence indicates surface evaporation and slow, lithostructurally controlled deep recharge.

These findings highlight the critical importance of long-term vadose zone monitoring for reliable assessments of aquifer vulnerability. An updated conceptual model of the MSLA is proposed, explicitly accounting for lithostructural controls and unsaturated zone processes in recharge and contaminant transport, with implications for sustainable groundwater management under climate change.

LID 0073
Data-driven assessment of groundwater temperature effects on redox-sensitive Fe and Mn in the Israeli Coastal Aquifer: implications under future warming

David Asalu[1]*, Tuvia Turkeltaub[1]

[1] Zuckerberg Institute for Water Research, Hydrology and Water Quality Department, Beersheva, Israel
* asalu@post.bgu.ac.il

Groundwater is an essential freshwater resource increasingly affected by overexploitation, climate change, urbanization, and declining water quality. One important consequence is groundwater warming, which can modify hydrochemistry through reaction kinetics, gas solubility, and redox processes. In coastal aquifers, these changes are relevant because redox-sensitive iron (Fe) and manganese (Mn) can be mobilized under low-oxygen conditions.

Here, three decades of monitoring data from the Israeli Coastal Aquifer were used to evaluate how groundwater temperature relates to dissolved oxygen and Fe–Mn occurrence. The analysis combines long-term trend assessment, urban–rural comparison, exceedance analysis, and interpretable machine-learning models. Groundwater temperature increased over time, with stronger warming in urban wells than in rural wells, while dissolved oxygen declined over the same period. Together, these patterns indicate a shift toward more reducing groundwater conditions favorable for Fe and Mn mobilization.

Random Forest and XGBoost models were developed for Fe and Mn using hydrochemical, climatic, hydrologic, land-use, and soil-related predictors, with model behavior interpreted using Shapley Additive Explanations. The models showed useful predictive skill, particularly for Mn, and identified groundwater temperature, well depth, dissolved oxygen, and urban proximity as important controls. SHAP responses showed that warmer groundwater generally increased predicted Fe and Mn concentrations. Exceedance analysis showed higher Mn exceedance risk in warmer groundwater, supporting temperature as a screening variable.

These results indicate that groundwater temperature is not only a climate-change indicator, but also a process-relevant proxy for redox-sensitive water-quality deterioration. In warming and urbanizing coastal aquifers, temperature monitoring may provide an early-warning tool for identifying wells at increased Fe and Mn mobilization risk.

LID 0074
The Thirsty Knight – groundwater management in historic times

Manuel Sapiano[1]*, Nikolaos A. Skondras[2], Natalino Spiteri[3]

[1] The Energy and Water Agency, Qormi, Malta
[2] Global Water Partnership – Mediterranean, Athens, Greece
[3] GHAJN National Water Conservation Awareness Centre, Rabat, Malta
* manuel.sapiano@gmail.com

Keywords: water conservation, perched aquifer, spring, qanat, aqueduct

The GHAJN National Water Conservation Awareness Centre is an educational centre managed by the Energy and Water Agency which promotes water conservation among school children through engaging, age-appropriate learning. The Centre's educational programme combines short explanations, interactive digital games, and hands-on activities presenting Malta's historical and modern water management practices. These educational tools were developed with the support of Global Water Partnership–Mediterranean and MEdIES under the AlterAqua Programme.

One of the Centre's flagship experiences, The Thirsty Knight, immerses students in water conservation practices during the time of the Knights of Malta. Across four levels, students protect historic water sources from fictional threats while learning about rainwater harvesting cisterns, traditional hand-dug wells (spieri) providing access to shallow groundwater, underground spring tunnels (qanat or mina) in the perched aquifer systems, and aqueducts that supplied water from the high-level springs to the fortified towns. Through challenges and problem-solving, students gain an understanding of how groundwater is accessed, managed, and protected.

The digital experience is supported by an introductory session on Malta's water resources and conservation challenges, group activities such as puppet theatre and role-play, and a take-home interactive booklet that extends learning to schools and families.

The programme also highlights Maltese water heritage by introducing traditional terminology related to groundwater management such as spiera, bir, għajn, and mina, linking environmental stewardship with cultural identity.

Through storytelling, technology, and experiential learning, the Thirsty Knight game helps students understand Malta's groundwater water resources, their vulnerability to contamination and overabstraction, as well as the importance of protecting them for future generations.

The development of the GHAJN National Water Conservation Centre was co-financed through the EEA-Norway Grants 2009-2014.

The Alter Aqua Programme (2011 – 2027) is co-financed by The Coca Cola Foundation (TCCF) and the Energy and Water Agency (EWA) of Malta and managed by Global Water Partnership (Mediterranean).

MEdIES is the long-standing initiative on Education for Sustainable Development (ESD) of the Mediterranean Information Office for Environment, Culture and Sustainable Development (MIO-ECSDE), the legal host of GWP-Med.

LID 0076
Rapid groundwater warming in an Eastern Mediterranean coastal aquifer linked to urbanization

Tuvia Turkeltaub[1]*, Michael Fire[2], Anat Bernstein[1]

[1] The Zuckerberg Institute for Water Research, The Jacob Blaustein Institutes for Desert Research, Ben-Gurion University of the Negev, Sde Boker Campus, Israel
[2] Faculty of Computer and Information Science, Ben-Gurion University of the Negev, Be'er Sheva, Israel
* tuviat@bgu.ac.il

Keywords: groundwater temperature, climate change, urbanization

The rise in groundwater temperature is a growing concern, primarily driven by urbanization and increasing global temperatures. While long-term trends of groundwater warming have been documented in temperate regions, these trends are rarely studied in semi-arid areas. This study aims to quantify three decades of groundwater temperature changes in an Eastern Mediterranean Coastal Aquifer, a critical freshwater resource affected by hydroclimatic variations and rapid urban expansion. Utilizing temperature records from over 1,000 wells and satellite-derived land surface temperatures (LST), the study reconstructs the spatial and temporal patterns of groundwater warming in both urban and rural areas. The results indicate notable changes in both absolute temperatures and spatial structure. In urban areas of the central part of the coastal aquifer, groundwater temperatures have increased significantly by 0.13°C per year, which is much higher than regional air temperature trends and global groundwater warming rates. In contrast, the rural northern and southern regions exhibit groundwater warming rates similar to those of LST trends, ranging from approximately 0.02 to 0.07°C per year. Correlation analyses reveal a shift from natural factors, such as vadose-zone thickness, latitude, and proximity to the sea, to human-induced factors, including declining rural land cover and changes in soil properties associated with urban development. These findings highlight that subsurface warming in semi-arid coastal aquifers is greatly intensified by urbanization, which may have significant implications for groundwater quality.

LID 0078
Evolution of groundwater salinity in the North China Plain: Evidence from lithium, boron, and strontium isotopes

Ying Wang[1]*, Jiang Chen[1]

[1] The institute of Hydrogeology and Environmental Geology, Chinese Academy of Geological Sciences, Shijiazhuang, China
* wy5966@163.com

This study investigated the distribution patterns and formation processes of saline groundwater, as well as the influence of groundwater table depth on the structure, composition, and diversity of plant communities, using a multi-proxy approach. The investigated indicators included:

• Lateral groundwater: hydrochemical indices, ^{14}C, $^{87}Sr/^{86}Sr$, and $\delta^{11}B$;

• Vertical pore water: hydrochemical indices, $\delta^{7}Li$, $^{87}Sr/^{86}Sr$, and $\delta^{11}B$;

• Aquifer sediments: $^{87}Sr/^{86}Sr$ of soluble components and $\delta^{26}Mg$ of adsorbed components;

• Main physicochemical properties of soils in typical areas;

• Species richness, density, and coverage of plant communities under different groundwater table depths, together with soil salinity and moisture content under corresponding community types.

The main conclusions are as follows:

(1) The electrical conductivity (EC) of vertical pore water ranged from 2449 to 34870 µS/cm. High-EC pore water occurred in the shallow aquifers close to the ground surface, and EC gradually decreased with depth. Along the groundwater flow path, EC generally increased downgradient: the recharge zone had the lowest EC and was non-saline, whereas the runoff and discharge zones showed progressively higher EC and were saline. However, a sharp EC decrease occurred in the runoff zone (60–70 km from the upstream reach), where groundwater was non-saline.

(2) The dominant hydrogeochemical processes in the study area were evaporative concentration, mineral dissolution, adsorption, and vertical leakage of shallow groundwater.

(3) Salinity in lateral groundwater was mainly controlled by evaporite dissolution, with an average contribution rate of 0.64. Salinity in vertical pore water was affected by both evaporite dissolution and silicate weathering, with average contributions of 0.64 and 0.36, respectively.

(4) Groundwater salinity was jointly controlled by biotic and abiotic processes. Shallow groundwater salinization was dominated by evaporative concentration, whereas deep saline groundwater was mainly influenced by vertical leakage from shallow saline aquifers. Synergistic microbial processes enhanced the solubility and conductivity of Na^+, Cl^-, and other ions, thereby promoting groundwater salinization.

(5) In coastal wetlands, surface soil water and salt contents decreased significantly with increasing groundwater table depth. Groundwater table depth affected plant community diversity primarily by regulating surface soil salinity, rather than soil moisture content.

The innovation of this study lies in the application of non-traditional stable isotopes to research on saline groundwater migration and deep groundwater quality evolution. This approach improves understanding of the intrinsic links among various water–rock interactions during shallow saline water movement and regional groundwater circulation, and clarifies the migration and transformation of saline groundwater bodies and their response mechanisms to changes in the groundwater environment.

LID 0079
Occurrence of pharmaceuticals and personal care products in groundwater replenished by managed aquifer recharge at the Świerczków well field site (southern Poland)

Kinga Ślósarczyk[1]*, Sławomir Sitek[1], Sabina Jakóbczyk-Karpierz[1], Krzysztof Janik[1]

[1] University of Silesia in Katowice, Katowice, Poland
* kinga.slosarczyk@us.edu.pl

Keywords: PPCPs, MAR, emerging contaminants, surface water-groundwater interactions

The aim of the study was to assess the occurrence of pharmaceuticals and personal care products (PPCPs) in the water environment at the Świerczków well field site (southern Poland). The Świerczków well field is an example of managed aquifer recharge (MAR), where a sandy-gravel Quaternary aquifer is recharged through induced infiltration of water from the Dunajec River and an infiltration ditch system.

Fieldwork was conducted during three sampling campaigns (September 2020, January 2021, and July 2021). Surface waters (the Dunajec River and the infiltration ditch) and groundwater from five production wells and one piezometer were sampled. PPCP analyses covered 109 compounds and were performed using liquid chromatography coupled with tandem mass spectrometry (LC–MS/MS).

A total of 23 PPCPs were identified in surface waters. The dominant compounds were metformin (up to 357 ng/L), caffeine (up to 174 ng/L), and acesulfame (up to 141 ng/L). In groundwater, 23 substances were also detected, with the highest concentrations recorded for caffeine (up to 1130 ng/L), paraxanthine (up to 818 ng/L), and oxypurinol (up to 389 ng/L). The results revealed spatial variability in groundwater quality within the well field with respect to PPCPs. In the north-western part of the site, characterised by the highest contribution of surface water infiltration, the PPCP concentrations (e.g., carbamazepine and acesulfame) were most similar to those of the recharge waters. In contrast, the south-eastern part of the site showed the influence of nearby industrial facilities, manifested by the presence of specific compounds not detected in the Dunajec River, such as fluorosurfactants (PFOS and PFOA). The migration of PPCPs into the aquifer is strongly controlled by their physicochemical properties, as compounds with a high sorption potential did not reached the groundwater. The results confirm that MAR systems are vulnerable to PPCP contamination, highlighting the need for their regular monitoring.

LID 0080
Multi-tracer assessment of nitrate contamination in urban aquifers: The case of Abuja FCT (Nigeria)

M. Mary Etuk[1], **V. Re**[2,3]*, B. Raco[3], S. Viaroli[2], I. Da Prato[2], O. Ibiono[1]

[1] Department of Geology, University of Nigeria, University Road, Nsukka, Nigeria
[2] Dipartimento di Scienze della Terra, Università di Pisa, Pisa, Italy
[3] Istituto di Geoscienze e Georisorse, CNR, Pisa, Italy
* viviana.re@unipi.it

Keywords: CECs, nitrate, isotope hydrology, groundwater

Nitrate contamination is a pervasive groundwater quality issue in rapidly urbanizing regions, posing significant risks to public health and aquatic ecosystems. In Abuja Federal Capital Territory (Nigeria), shallow fractured basement aquifers constitute the primary source of drinking water, yet nitrate concentrations frequently exceed the WHO guideline of 50 mg/L. This study investigates the origin, spatial distribution, and seasonal dynamics of nitrate pollution in the Abuja aquifer system through an integrated hydrogeochemical and socio-hydrogeological approach. Groundwater samples collected during dry and rainy seasons were analyzed for major ions, nitrate isotopes (δ^{15}N-NO_3 and δ^{18}O-NO_3), and contaminants of emerging concern (CECs), and interpreted alongside land-use change analysis and groundwater use surveys. Results show pronounced seasonal nitrate remobilization during the rainy season, with concentrations progressively increasing year after year, suggesting cumulative nitrogen loading rather than dilution effects. Spatial patterns and NO_3^-/Na^+ and Cl^-/Na^+ ratios indicate a dominant contribution from urban and domestic sources. Isotopic signatures (+8 to +30‰ δ^{15}N-NO_3) and CECs are largely consistent with septic and sewage effluents, while limited evidence of soil or fertilizer-derived nitrate suggests only a minor agricultural legacy contribution.

These findings highlight the vulnerability of shallow crystalline aquifers to unregulated urban development and inadequate sanitation infrastructure. The study underscores the need for targeted groundwater protection measures, improved well construction standards, and integrated monitoring strategies to ensure sustainable water resource management in fast-growing Sub-Saharan cities.

LID 0081
Can groundwater flux measurements constrain uncertainties in groundwater flow modelling for Managed Aquifer Recharge assessment?

Lara Speijer[1,2]*, Syed Mustafa[3], Luk Peeters[2], Eric Laloy[4], Goedele Verreydt[5,6], Jef Dams[2,1], Marijke Huysmans[1,7]

[1] Department of Water and Climate, Vrije Universiteit Brussel (VUB), Brussels, Belgium
[2] Vlaamse Instelling voor Technologisch Onderzoek (VITO), Mol, Belgium
[3] Wageningen University and Research (WUR), Wageningen, The Netherlands
[4] SCK CEN, Mol, Belgium
[5] iFLUX, Niel, Belgium
[6] ECOSPHERE, University of Antwerp, Wilrijk, Belgium
[7] Department of Earth and Environmental Sciences, KU Leuven, Leuven, Belgium
* lara.marianne.speijer@vub.be

Keywords: groundwater flux measurements, uncertainty quantification, data worth analysis, sensitivity analysis, parameter inference, model prediction uncertainty

While constraining groundwater model prediction uncertainty is most effective if hydraulic head data are complemented with other information types, such systematic integration and its impact remain understudied. Groundwater flow rate measurements are especially relevant, as they measure a different state variable (flux) than head data (pressure).

In this study, we use data from iFLUX sensors that continuously measure horizontal fluxes in 3 monitoring wells in the vicinity of an agricultural field in the Nete catchment in Flanders (Belgium) where subirrigation is tested as potential Managed Aquifer Recharge technique. The effects on the groundwater system are assessed through a groundwater flow model in MODFLOW, and the impact of additional flux data for model calibration is assessed. First, a sensitivity analysis is carried out using a Monte Carlo ensemble of parameter samples to assess the effect of calibration with (1) hydraulic heads, (2) baseflow at the outlet of a subcatchment and (3) groundwater fluxes on the sensitivity of the parameters. Secondly, most sensitive parameters are used in Bayesian parameter inference using the DREAMzs algorithm to assess the impact of the use of different calibration targets on the posterior distribution of the parameters and predictive uncertainty of the model in terms of Managed Aquifer Recharge impacts.

The uncertainty analysis shows that different model parameters can be sensitive to different calibration targets, which highlights the importance of the inclusion of several types of measurements during calibration. Especially the hydraulic conductivity of the layer in which the flux sensors are located is highly sensitive to groundwater flux measurements while this parameter was relatively insensitive to hydraulic head measurements. Furthermore, the Bayesian inference analysis shows that certain parameters can be inferred with hydraulic head observations, while other posterior distributions remain highly uncertain.

LID 0082
Occurrence and seasonal dynamics of Per- and Polyfluoroalkyl Substances (PFAS) contamination in the Krško aquifer (Slovenia)

Ivana Perović[1]*, Anja Koroša[1]

[1] Geological Survey of Slovenia, Ljubljana, Slovenia
* ivana.perovic@geo-zs.si

Keywords: PFAS, groundwater contamination, intergranular aquifer

The Krško aquifer in southeast Slovenia represents a vital Quaternary intergranular system. Its high hydraulic conductivity and geological vulnerability, combined with diverse land-use pressures that range from intensive agriculture to concentrated urban and industrial centres, make the groundwater highly susceptible to anthropogenic contamination. This study presents a comprehensive monitoring campaign initiated in April 2025 to evaluate the occurrence, spatial distribution and seasonal dynamics of Per- and Polyfluoroalkyl Substances (PFAS). To investigate the transport pathways and connectivity between surface water and the underlying aquifer, data are collected monthly from a network of monitoring boreholes and surface water locations. The analytical suite includes 20 PFAS compounds, including perfluoroalkyl carboxylic acids (C4–C13: PFBA, PFPeA, PFHxA, PFHpA, PFOA, PFNA, PFDA, PFUnDA, PFDoDA, PFTrDA) and perfluoroalkyl sulfonic acids (C4–C13: PFBS, PFPeS, PFHxS, PFHpS, PFOS, PFNS, PFDS, PFUnDS, PFDoDS, PFTrDS). Perfluorobutanoic acid (PFBA) was the most frequent and concentrated PFAS in surface waters. In groundwater, however, perfluorononanoic acid (PFNA) was the most frequently detected, while perfluorooctane sulfonate (PFOS) reached the highest concentrations. Through the analysis of monthly fluctuations and chain-length ratios (short-chain vs. long-chain PFAS), this research seeks to fingerprint primary contamination sources and delineate plume migration through the alluvial deposits. This approach offers critical insights into the chemical status of the Krško aquifer and the delineation of contaminant transport, providing a foundation for more robust groundwater management and protection strategies.

This research was supported by the Slovenian Research and Innovation Agency through research project J1-60003 (GWQualityPath), the PhD work of I. Perović, and research programme P1-0020.

LID 0084
Boundary condition improvements in numerical modeling of tidally forced coastal unconfined aquifers and analysis of solute transport mechanisms

Rui Wu[1]*, Yuhang Lin[1], Xueli Dai[1], Zhiping Ma[1], Junwei Wan[1]

[1] School of Environmental Studies, China University of Geosciences (Wuhan), Wuhan, Hubei, China
* wur36988@gmail.com

Keywords: coastal unconfined aquifer, tidal boundary condition, solute transport, variably saturated flow, numerical modeling

Coastal unconfined aquifers feature fragile hydrogeologic structures and complex hydrodynamic forcing where tides impose periodic sea-level oscillations that significantly influence recharge and discharge, making numerical model predictions highly sensitive to seaward boundary conditions and the treatment of variably saturated processes. However, simplified vertical or saturated-only boundaries often fail to capture the dynamically evolving land-sea interface, seepage faces, and shoreline migration, thereby biasing simulations. We develop a state-based dynamic tidal boundary condition scheme that integrates sea level, topography, groundwater level, and flux to classify boundary nodes as submerged, seepage-face, or unsaturated. This formulation allows the seaward boundary to evolve dynamically in both plan view and cross section, explicitly representing tide-driven saturated-unsaturated transitions. We constructed a two-dimensional coupled model of variably saturated flow and solute transport. Model performance was benchmarked against controlled tracer experiments in a large laboratory flume and in situ field measurements. Results demonstrate that without tides, plumes injected in the unsaturated zone exhibit delayed migration and longitudinal stretching due to reduced permeability. With tidal forcing, frequent hydraulic gradient reversals and intensified seawater exchange shift solute plume trajectories from continuous advancement to a stair-step transport pattern, characterized by alternating horizontal advection and vertical excursions, thereby increasing residence time. Furthermore, tidal fluctuations induce cyclic expansion and contraction of the variably saturated zone, altering transport from horizontally stratified advection under static conditions to tidally driven vertical dispersion. This boundary strategy supports more reliable simulation and risk assessment of solute transport in tidally forced coastal aquifers.

LID 0085
Enhancing geothermal efficiency: Fluorescent tracer testing for Aquifer Thermal Energy Storage (ATES) in fractured aquifers

Sofie De Volder[1]*, Amaël Poulain[1], Mathias Possemiers[2]

[1] Traqua SA, Namur, Belgium
[2] AGT, Kontich, Belgium
* sdv@traqua.be

Aquifer Thermal Energy Storage (ATES) systems use aquifers to transfer and store thermal energy seasonally. In Brussels, AGT uses the Brabant Massif for numerous geothermal projects. The top of the massif is found at depths between 100 and 150 metres, consisting of Palaeozoic sandstones and shales with low to moderate permeability. Groundwater primarily flows through fractures and fault zones, resulting in preferential flow pathways.

The performance and sustainability of geothermal systems depend heavily on geological and hydrogeological conditions, such as aquifer permeability and the presence of fractures. Furthermore, thermal interference can impact system efficiency.

An accurate evaluation of groundwater dynamics is therefore essential to mitigate risks. TRAQUA's fluorescent dye tracing has proven to be a reliable and cost-effective method. The tracer test is performed alongside the injection test in the geothermal doublet within a pressurised, closed system. The tracer is injected at a higher pressure via a plug in the injection well, and its arrival is monitored using TRAQUA's STREAM® fluorometers. These fluorometers are installed in flow cells within a bypass system. The tests provide valuable insights into preferential flows, fractures and potential thermal recycling in real-world conditions by determining groundwater dynamics.

The field data provided AGT insight into the behaviour of solute transport and the hydraulic connectivity between the wells under pumping and injection conditions. Tracer breakthrough data were used to calibrate transport parameters, particularly effective porosity, and to characterise inter-well connectivity within the fractured aquifer. These calibrated parameters were then implemented in the thermal transport model to enhance the accuracy of long-term thermal impact predictions.

This approach reduces operational risks and enhances the overall efficiency and sustainability of geothermal projects in regions with complex hydrogeological conditions.

LID 0087
Nonlinear response of coastal unconfined aquifers to irregular semi-diurnal tides: Field experiments and numerical modeling

Yuhang Lin[1]*, Rui Wu[1], Yulu Li[1], Yunlong Wang[1], Junwei Wan[1]

[1] China University of Geosciences, Wuhan, China
* ned2580@163.com

Keywords: coastal unconfined aquifer, irregular semi-diurnal tides, tidal driving, nonlinear groundwater dynamics, saturated-unsaturated numerical simulation

Coastal unconfined aquifers function as critical conduits for mass transport at the land-ocean interface and represent vulnerable zones where intensive human activity intersects with fragile ecosystems. A robust understanding of groundwater dynamics in these regions is imperative for effective emergency response to environmental hazards and nearshore ecological preservation. While tidal fluctuations constitute the primary forcing mechanism governing flow field evolution, existing literature predominantly relies on idealized models that assume vertical beach faces or simplify complex tidal boundaries into single sinusoidal waves. Such simplifications fail to capture groundwater behavior in unconfined aquifers characterizing the gentle slopes of natural beaches, thereby introducing significant uncertainties into pollution risk assessment. Neglecting these topographic and boundary complexities inevitably leads to erroneous predictions of groundwater flow direction, velocity, and contaminant migration.

Based on field investigations at the silty beach of Xiangshan Bay in Zhangzhou, China, this study constructed a mathematical model of irregular semi-diurnal tidal dynamics through long-term high-frequency monitoring, providing a basis for the quantitative characterization of seawater boundary conditions. It has been observed that the unconfined aquifers exhibit unique multiscale response patterns, under the influence of irregular semi-diurnal tidal boundaries. On the semi-diurnal scale, groundwater level fluctuations showed classic amplitude attenuation and phase lag with increasing distance from the sea. On the semi-monthly scale, groundwater levels did not remain at the mean sea level but displayed oscillating fluctuations varying with the tidal range. During the period of increasing tidal range, driven by irregular semi-diurnal tides, groundwater levels rose in an oscillating manner characterized by alternating large and small amplitudes, reaching a peak when the tidal range was maximum; conversely, during the period of decreasing tidal range, they showed an oscillating decline. This pattern indicates that tidal dynamics alter the groundwater flow field in coastal unconfined aquifers, forming instantaneous hydraulic gradients directed toward the land.

To elucidate the above mechanism, this study used the constructed irregular semi-diurnal tide mathematical model as a dynamic boundary input, combined with in-situ hydrogeological parameters, to establish a 2D saturated-unsaturated flow numerical model based on COMSOL Multiphysics. Simulation results accurately reproduced the field-monitored phenomena and quantified the control mechanism from a flux perspective: the interaction between irregular semi-diurnal tidal driving and the saturated-unsaturated medium leads to flux asymmetry—where inflow exceeds outflow—during the stage of increasing tidal range, causing net water retention in the aquifer and raising the water level.

Combining field monitoring and numerical simulation, this study reveals the groundwater movement mechanism in coastal unconfined aquifers under the action of irregular semi-diurnal tides. The study confirms that ignoring tidal irregularity and the unsaturated characteristics of the medium will lead to

severe misjudgments of groundwater flow direction and velocity. These findings refine traditional hydrodynamic models, providing a scientific basis consistent with actual movement laws for groundwater resource assessment, accurate pollution source tracing, and emergency management in coastal regions.

LID 0088
Challenges of geophysical reports in East and Southern Africa

Tichazvipedza Fadzai Munodawafa[1]*, Brandon Stone[2]

[1] HydroLOGICA, Harare, Zimbabwe
[2] HydroLOGICA, Colorado, United States
* fadzai@hydrologica.com

Keywords: geophysics, groundwater, data quality

Geophysics is widely used in African groundwater development, yet many borehole failures can be traced to geophysical reports that do not meet high quality standards. Poor drilling decisions are therefore made from inaccurate data, whereas there is need for quality data and interpretations to increase the chance of good groundwater during drilling. This paper examines recurring deficiencies in VES datasets encountered during independent technical reviews, focusing on data auditability, reproducibility, and drilling relevance. Using real project reviews from East and Southern Africa, this paper demonstrates how missing or inconsistent raw geophysical parameters undermine the reliability of inversion results and elevate drilling risk. In total, 27 randomly selected geophysical and hydrogeological siting reports were assessed across Kenya, Uganda, Zimbabwe, and Malawi. The reviews apply a consistent, standards-based rubric referencing Water Resource Authority (WRA), and Society of Exploration Geophysicists (SEG)/EAGE expectations for auditable raw data retention, QA/QC, processing transparency, inversion/uncertainty reporting, and defensible decision support. 96% of the 27 geophysical siting reports reviewed lacked essential raw data, QA/QC documentation, and inversion transparency, with only one report (representing 4%), approaching best practice. Further, at least 37% of reports used non-scientific methods such as dowsing or pool finder, about 44% had location coordinate issues, and the majority exhibited significant gaps in equipment and processing disclosure, undermining reproducibility, and traceability. Insufficient data transparency and quality controls in geophysical siting reports significantly undermine the long-term sustainability and reliability of water sources, highlighting the need for robust raw data, QA/QC documentation, and uncertainty-driven decision frameworks to ensure resilient groundwater development. It concludes with clear, practical recommendations for donors, NGOs, consultants, and regulators to shift from “interpretation-led” reporting to evidence-led, auditable decision support.

LID 0089
Unconventional groundwater exploration in Sicily (Italy)

Lorenzo Lipparini[1,2]*, Damiano Chiacchieri[1,2], Daniel Zamrsky[3,4], Enrico Brugaletta[5], Elizabeth Quiroga Jordan[6], Andrea D'Ambrosio[7], Roberto Bencini[8], Aaron Micallef[9,10]

[1] Istituto Nazionale di Geofisica e Vulcanologia (INGV), Rome, Italy
[2] Department of Earth Science, University of Roma Tre, Rome, Italy
[3] IHE Delft Institute for Water Education, Water Resources and Ecology Department, Delft, The Netherlands
[4] Department of Physical Geography, Utrecht University, Utrecht, The Netherlands
[5] Department of Earth Science, University of Bologna, Bologna, Italy
[6] Ruden AS, Oslo Science Park, Oslo, Norway
[7] Eni Upstream & Technical Services, San Donato Milanese (MI), Italy
[8] Department of Industrial Chemistry, University of Bologna, Bologna, Italy
[9] Department of Geosciences, University of Malta, Msida, Malta
[10] Monterey Bay Aquarium Research Institute, Moss Landing, United States
* lorenzo.lipparini@ingv.it

Keywords: groundwater exploration, offshore freshened groundwater, Sicily

Access to water is one of the most pressing global challenges of our time. Water demand continues to increase as a result of rapid population growth, urbanization, and expanding requirements from the agricultural, industrial, and energy sectors. Surface water and groundwater currently represent the primary conventional water resources. However, despite its critical importance, groundwater exploration has largely focused on shallow, onshore aquifers, leaving vast portions of the deeper subsurface and offshore environments insufficiently investigated.

In 2020, the United Nations officially recognized deep onshore and offshore groundwater as unconventional water resources, highlighting their potential role in reducing the growing gap between water supply and demand (UN-Water, 2020). Although recent progress has been made in mapping and modelling offshore groundwater systems, the water sector remains in the early stages of exploring the deep subsurface, both onshore and offshore. In contrast, the oil and gas industry has accumulated extensive subsurface datasets over several decades through sustained investment in exploration and production activities.

This talk presents the outcomes of an international research effort, supported by the OFF-SOURCE COST Action (CA21112), focused on the identification and multi-scale characterization of unconventional deep and offshore groundwater resources in Sicily. By leveraging good-quality industrial datasets and workflows inherited from Oil & Gas exploration, we integrated seismic interpretation with advanced 3D geological, hydrogeological, and thermal modeling. Our results provide a robust assessment of freshened groundwater bodies, highlighting their potential as a future strategic resource for water-scarce Mediterranean regions. Moreover, the study demonstrates the successful transfer of technology from the energy industry to hydro-geosciences.

LID 0090
Emplacement and preservation mechanisms of deep freshened groundwater in the Gela Aquifer (Sicily, Italy)

Lorenzo Lipparini[1,2]*, Damiano Chiacchieri[2,3], Daniel Zamrsky[4,5], Aaron Micallef [5,6]

[1] Istituto Nazionale di Geofisica e Vulcanologia (INGV), Rome, Italy
[2] Department of Earth Science, University of Roma Tre, Rome, Italy
[2] Ricerca sul Sistema Energetico, RSE S.p.A. - Milan, Italy
[4] IHE Delft Institute for Water Education, Water Resources and Ecology Department, Delft, The Netherlands
[5] Department of Physical Geography, Utrecht University, Utrecht, The Netherlands
[6] Monterey Bay Aquarium Research Institute, Moss Landing, United States
[7] Department of Geosciences, University of Malta, Msida, Malta
* lorenzo.lipparini@ingv.it

Keywords: deep groundwater, regional hydrogeological modelling, Sicily

Deep groundwater resources are potential unconventional sources of potable water that can help address water scarcity, particularly in arid or water-stressed regions. One such region, the island of Sicily (Italy) in the Central Mediterranean, has been experiencing drought for decades, leading to increased water scarcity in recent years, and an increased likelihood of drought events due to climate change. A recent discovery of an extensive fresh and brackish groundwater body, buried deep below in the south-east of the island in a carbonate aquifer (the Gela Formation), could provide a crucial new source of potable water. This study presents a comprehensive regional scale groundwater hydrogeological proof-of-concept modeling of this deep aquifer, focusing on improving the understanding of regional hydrogeological conditions, analyzing groundwater emplacement, flow and preservation mechanisms, and the interactions between geological elements and hydro-stratigraphic units across the geological time.

Our results indicate that the emplacement (and preservation) of the identified extensive fresh/brackish groundwater body in the Gela Formation can be attributed to the effect of extreme sea level drop during the Messinian Crisis, approximately six million years ago, combined with local geological and surface conditions. Identifying and quantifying these deep fresh groundwater reserves can have far-reaching consequences for both the Sicilian region and other geologically similar areas in the Mediterranean Basin. This could alleviate regional freshwater scarcity and thus mitigate water deficit and the impacts of future droughts.

LID 0094
Paleoclimate reconstruction in a large delta with groundwater isotopes

Jingjing Su[1,2], **Yueqing Xie**[1,2]*, Jichun Wu[1,2]

[1] Key Laboratory of Surficial Geochemistry, Ministry of Education, School of Earth Sciences and Engineering, Nanjing University, Nanjing, China
[2] Frontiers Science Center for Critical Earth Material Cycling, Nanjing University, Nanjing, China
* yxie@nju.edu.cn

Keywords: groundwater isotopes, river delta, paleoclimate reconstruction, evaporation, seawater mixing, Bayesian inversion

Fossil groundwater that effectively retains the isotopic composition of precipitation is the basis for reconstructing paleoclimate changes in river deltas. However, our compilation of the isotopic composition from global deltas indicates that this assumption is often violated, as the isotopic composition of deltaic groundwater is modified by seawater mixing and evaporation. Paleoclimate changes inferred from this modified isotopic composition of deltaic groundwater may be misinterpreted. Here, we establish a robust framework for interpreting the isotopic composition of precipitation unaffected by evaporation and seawater mixing based on the mass-balance mixing model and the Craig-Gordon isotopic mass balance model. Applying this framework to the northern Yangtze River Delta (YRD), we obtained the isotopic composition of precipitation during three periods, including the Late Pleistocene, the Early and Middle Holocene, and the sub-modern and recent period. Differences in the isotopic composition of precipitation among these three periods indicate climate fluctuations in the northern YRD since the Late Pleistocene. By integrating multiple climatic factors including temperature, precipitation, distance from the shoreline, and seawater isotopic variations, we identify the dominant factors responsible for the isotopic depletion or enrichment of precipitation during each period. This framework provides a transferable approach for paleoclimate reconstruction in river deltas globally.

LID 0095
Hydrogeological characteristics and hydro-chemical environment of a karst aquifer system are determined by the presence of major ions, trace elements, and environmental isotopes

Yongli Guo[1]*

[1] Institute of Karst Geology, Chinese Academy of Geological Sciences / Key Laboratory of Karst Dynamics, MNR and GZAR / International Research Center on Karst under the Auspices of UNESCO / National Center for International Research on Karst Dynamic System and Global Change, Guilin, China

* ylguo89@163.com

Keywords: Sr, environmental isotopes, karstification indicator, hydrodynamic characteristics, hydro-chemical environment

Trace elements, along with major ions and environmental isotopes, serve as valuable tracers in carbonate aquifers. The primary objectives of this study are to evaluate the karstification, hydraulic connections, and hydro-chemical environment within the Yangzhuang karst groundwater basin in North China, which is characterized by a fractured network and significant aquifer thickness. The slope values of ρ(Sr) relative to ρ(SiO_2) in areas with increasing hydraulic conductivity indicate its potential as an indicator of karstification. The slope values of between hydraulic conductivity and major ions, as well as trace elements, demonstrated a rapid decrease from the Shanting fault block to the Yangzhuang fault block. Additionally, ρ(Sr)/ρ(Ca^{2+}) and ρ(Sr)/ρ(Mg^{2+}) ratios increased from upstream to downstream, indicating a heightened degree of karst development and enhanced hydraulic connections between Shanting and Yangzhuang fault blocks. Values of k, ρ(Sr), δD, $\delta^{18}O$, and $\delta^{13}C_{DIC}$ exhibited an increasing trend with groundwater depth. The Sr content exhibited a similar trend in relation to majors and environmental isotopes, both horizontally and vertically. $^{87}Sr/^{86}Sr$ signatures in conjunction with major ions, $\delta^{15}N_{NO3}$, and $\delta^{18}O_{NO3}$, indicate that hydro-chemical environment is influenced by both geological formations and human activities, with chemical fertilizer used in agricultural activities being the primary factor. Sr and its isotopes function similarly to major ions and environmental isotopes in elucidating the hydrogeochemical and hydrodynamic attributes of karst aquifers These insights could improve traditional hydrodynamic methods that have limitations in accurately describing the karstification and hydraulic connections within karst fractured aquifer systems of significant thickness.

LID 0098
Long-term trends and spatial heterogeneity of groundwater levels in Vojvodina: Analyzing the impact of climate change and anthropogenic factors on water management

Katarina Atanasković Samolov[1*], Milan Tomić[1], Tanja Petrović Pantić[1], Nataša Obradović[1], Marina Magazinović[1]

[1] Geological Survey of Serbia, Belgrade, Serbia
[*] katarina.samolov@gzs.gov.rs

Keywords: groundwater, time series analysis, water management

Groundwater in Vojvodina is a vital resource, its dynamics significantly shaped by climatic and anthropogenic factors. This study analyzes long-term groundwater level trends and spatial heterogeneity to understand change drivers and water management implications.

Analysis utilized approximately 85000 daily measurements from 39 piezometers in Vojvodina over a 30-year period. Linear regression quantified trends, while the non-parametric Mann-Kendall test assessed statistical significance ($p<0.05$). Despite typically low R^2 values for seasonal hydrological time series, trend significance was robustly confirmed by Mann-Kendall. Given the long-term focus of the analysis, standard Mann–Kendall test was applied without prewhitening.

Results reveal significant spatial heterogeneity: 23 piezometers showed deepening groundwater levels, 12 raising trends, and 4 no significant trend. Decreasing trends often correlate with prolonged droughts, extreme climate events, reduced natural recharge, and increased groundwater exploitation. Conversely, rising trends in some areas link to specific local hydrogeological conditions, surface water connectivity, or high precipitation periods. The regional average trend was 0.57 cm/year calculated as the arithmetic mean of individual linear regression slopes (median 0.81 cm/year), indicating a weak regional trend but strong localized changes.

The study concludes that regional-scale descriptions of groundwater regime changes are insufficient. Detailed, site-specific analysis of local hydrogeological conditions, aquifer characteristics, and anthropogenic pressures is essential. Understanding this complex dynamic and spatial variability is crucial for sustainable groundwater management and protection in Vojvodina.

LID 0099
The thirst for data – establishing a robust O- and H-isotope record for a water-stressed region in the southern hemisphere

Carla Dodd[1]*, Matthew Forbes[2,3], Lucienne Human[4], Yazeed Van Wyk[5], Gavin Rishworth[1]

[1] Institute for Coastal and Marine Research, Nelson Mandela University, Gqeberha, South Africa
[2] School of Earth, Atmospheric and Life Sciences, University Of Wollongong, NSW, Australia
[3] EMM Consulting, Brisbane, Queensland, Australia
[4] South African Environmental Observation Network, Elwandle Node, Gqeberha, South Africa
[5] Water Research Commission, Pretoria, South Africa
* cdodd49@gmail.com

Keywords: water resources, transitional rainfall zone, semi-arid, isotope geochemistry, groundwater recharge, coastal aquifers

The use of O- and H-isotopes as hydrological tracers provides insights into the water cycle at local and global scales. Applications include constraining the source origin and timing of groundwater recharge. Excellent long-term isotope records exist for summer and winter rainfall regions of semi-arid South Africa. Yet, the transitional rainfall zone, where year-round precipitation creates complex recharge dynamics, remains critically understudied. This data gap limits groundwater management in water-stressed areas experiencing increasingly variable climate patterns.

Here we present our efforts towards a long-term O- and H-isotope record for rainfall and environmental waters in a water-stressed coastal region. Nelson Mandela Bay is an important metropolitan area in the Eastern Cape Province of South Africa and has high socio-economic value for the region. It is interesting from a hydrological perspective as it occurs within the transitional rainfall zone between summer and winter rainfall regions. Furthermore, a variety of hydrological compartments are found within the area, such as rivers, intergranular and fractured rock aquifers, groundwater dependent ecosystems, lakes and the ocean.

Unfortunately, the water supply system is affected by multiple pressures, such as climate extremes (droughts and floods), anthropogenic pollution, increased water demand and political instability. Yet, this region lacks robust isotope records that hydrologists and water resource managers can use for recharge calculations and susceptibility studies. A Water Research Commission project is addressing this gap by establishing a comprehensive four-year record of stable water isotopes ($\delta^{18}O$, $\delta^{2}H$) and tritium in precipitation and environmental waters. To date, the isotope records show signatures consistent with a climatically hot/dry region influenced by humid conditions. Here we discuss further findings and future consequences for groundwater recharge as monitoring is set to continue.

LID 0100
Numerical study on formation of preferential flow paths in non-uniform seepage field using soil erosion model

Masahiko Saito[1]*

[1] Kobe University, Kobe, Japan
* msaito@kobe-u.ac.jp

Keywords: soil erosion model, preferential flow paths, numerical simulations

In conventional seepage flow analyses, hydraulic conductivity is typically assigned as a constant representative value for each soil layer, and its spatial variability or temporal evolution is seldom considered. However, in soils containing a high proportion of fine particles, the application of a large hydraulic gradient can induce localized internal erosion, potentially leading to the formation of preferential flow paths.

This study investigates the temporal evolution of hydraulic conductivity and the resulting macroscopic flow rate in a two-dimensional saturated seepage field subjected to a constant hydraulic gradient. The analysis incorporates a spatial variability model for hydraulic conductivity in non-uniform media, an erosion model for soil, and an estimation model that relates hydraulic conductivity to fines content and void ratio. Numerical simulations were conducted to examine how the degree of initial heterogeneity influences the development of preferential flow and the associated changes in the seepage field.

The results indicate that the progression of preferential flow paths is strongly dependent on the magnitude of the initial variability in hydraulic conductivity. Greater heterogeneity leads to the formation of a larger number of preferential flow paths extending from the upstream to the downstream boundary, thereby exerting a significant influence on the temporal behavior of the overall flow rate.

LID 0101
Hydrogeology education: The role of groundwater engineering

Bruce Misstear[1]*

1 Trinity College Dublin, Ireland
* bmisster@tcd.ie

Keywords: education, groundwater engineering, well design

Recent articles in groundwater journals have expressed concerns that opportunities for hydrogeology education are not as widely available as they need to be. The survey carried out as part of the IAH Congress in Davos, Switzerland in 2024 identified deficits in hydrogeology education and that there were insufficient numbers of hydrogeologists entering the profession. A special issue of *Hydrogeology Journal* is to be published in 2026 which will address some of the key issues for hydrogeology education. The purpose of this talk is to highlight the importance of groundwater engineering as part of postgraduate hydrogeology education programmes (especially taught-course masters). Groundwater engineering in this context includes well design, well construction and pumping systems, all vital topics for the role of a hydrogeologist in developing and maintaining groundwater supplies for drinking water, irrigation schemes and industrial applications. A review of the syllabuses of 30 master's programmes in hydrogeology (or closely related discipline) in North America and Europe found only one example where topics such as well design or well construction were explicitly mentioned in a module title (although, of course, some instruction in these subjects may be included within other, broader modules). Nevertheless, such skills will be needed to meet future demands: there are some two billion people who do not have access to a safely-managed drinking water supply, and most (especially in rural areas) will need to be supplied from groundwater in the future. Again, many of our existing wells do not function efficiently and the failure of pumps has been a major constraint on meeting Millennium Development Goal and Sustainable Development Goal targets over the past 30 years.

LID 0102
Impacts of irrigation on water quality under different agricultural land uses

Anja Koroša[1*], Ivana Perović[1], Vasja Juretič[2], Mojca Mavrič Štrukelj[2], Anka Poženel[2], Matjaž Glavan[3]

[1] Geological Survey of Slovenia, Ljubljana, Slovenia
[2] Agricultural and Forestry Institute Nova Gorica, Nova Gorica, Slovenia
[3] Department of Agronomy, Biotechnical Faculty, University of Ljubljana, Ljubljana, Slovenia
* anja.korosa@geo-zs.si

Keywords: agriculture, irrigation, nitrates, pollutant transport, groundwater, vulnerability

Slovenia is a signatory to the Barcelona Convention, adopted under the United Nations framework, which aims to protect the Mediterranean Sea from pollution. Agriculture is recognised as a significant source of pollution due to its influence on the quality of waters draining into the Mediterranean. In Slovenia, particular attention is given to the Soča River basin, which discharges into the Adriatic Sea. Water from this system is extensively used for irrigation and may increase pressures on water bodies if inadequately managed. Additional risks arise from surplus nutrients and plant protection products that can be leached into surface and groundwater as a result of improper agricultural practices and intense rainfall events. This study presents a monitoring campaign conducted on two agricultural test fields in the lower Vipava River basin, within an irrigated area characterised by existing drainage infrastructure. One test field is cultivated with vegetable crops, while the other is a permanent peach orchard. The aim of the study is to assess the effects of irrigation, fertiliser application and plant protection products on pollutant leaching from the soil profile into drainage water and subsequently into the Vipava River. The selected sites are located in a lowland area with a sub-Mediterranean climate and are equipped with fixed sprinkler irrigation systems, representing intensive agricultural production. Regular water sampling has been carried out from January 2025 to February 2026 at multiple locations upstream and downstream of the fields, within the irrigation system and at drainage outlets. The monitoring programme includes monthly field measurements and analyses of nitrates, water isotopes and microbiological indicators, complemented by occasional analyses of plant protection products.

This research was supported by the Slovenian Research and Innovation Agency through research project V4-2407 (NaKaVo) and research programme P1-0020.

LID 0103
New tools for flow animation and conduit generation in karst aquifers using VisualKarsys

Arnauld Malard[1]*, Pierre-Yves Jeannin[1], Tim Winkelmann[2]

1 Swiss Institute for Speleology and Karst Studies, La Chaux-de-Fonds, Switzerland
2 Naito.one, Boecourt, Switzerland
* arnauld.malard@isska.ch

Visualkarsys is an online tool that allows users to build conceptual and explicit geological and hydrogeological models in 3 dimensions by following the principles of the KARSYS approach [1]. Launched in 2019, this tool has more than 2,000 users worldwide, and new features are regularly implemented with the aim of improving the characterization of karst aquifers and associated flow systems. While the tool is primarily intended for geologists and hydrogeologists with modelling experience, Visualkarsys outputs are designed to best meet the needs of non-specialist users (engineers, administrators, authorities, stakeholders, decision-makers, etc.). The models created can thus be used as a basis for decision-making or evaluation for all types of projects related to the underground environment and water resources: drinking water exploration, construction of underground structures, geothermal energy, natural hazards, protection of water catchments, etc.

In recent years, considerable efforts have been made to increase service stability and reduce model calculation times, thereby (i) facilitating user work, (ii) facilitating the creation of models of higher resolution and (iii) facilitating output transmission. Two specific modules have since been added: (i) the flow animation module [2] and (ii) the 3-dimensional karst conduit generation module based on the “KarsNSim” algorithm[3].

The flow animation module (Fig. 1) allows users to create explicit and dynamic flow scenarios at different time scales (a few days event, a few years or over the long term) based on a few input parameters, mainly the location of rain clouds and precipitation rates. The animation then directly simulates rainfall, runoff, evapotranspiration, percolation through the unsaturated zone, and flow in the saturated zone until the groundwater reemerges at the springs as particles and flowlines. Since 2024, it is possible to explicitly reproduce hydrogeological tracing tests or the assumed trajectories of contaminants injected at a specific point in the catchment area or dispersed over a surface. This animation provides a very clear overview of recharge and discharge mechanisms for complex hydrogeological systems (confined, folded, highly faulted, etc.) and provides insight into the dynamics of contamination from different parts of the catchment area.

The KarstNSim module allows users to generate 3D karst conduit networks online on their own geological and hydrogeological models via a dedicated graphic interface (Fig. 2). Users can modify a few parameters (conduit density, network tortuosity, strength of ‘guidance’ by various discontinuities: faults, overlaps, interlayers, etc.) that constrain the geometry of the conduit network until they obtain one or several scenarios that meet their expectations. This implementation aims to offer a ‘simplified’ tool to the majority of users, providing a limited number of parameters, only those with the greatest impact on the generated network geometry, ensuring optimized calculation times to allow users to ‘test’ different probable scenarios based on their knowledge of the site and their professional experience.

These recent modules enable optimal use of interpretations from 3D conceptual hydrogeological models and facilitate the transmission of this information to non-specialist users who need it for activities within their areas of expertise: work planning, land use planning, water resource protection, natural

hazard protection, etc. Visualkarsys provides accessible and easy-to-understand outputs designed to support various applications in the field.

There are many development prospects for the coming years: (i) implementation of a module for calculating hydrological recharge (based on assessments made as part of the Karst Modeling Challenge [4]), (ii) integration of a hydraulic solver to better simulate flows and hydraulic loads within the conduit network, (iii) improvement of interfaces with other specialized tools (BIM software, hydrogeological flow modeling software, cartographic geoportal, etc.).

These developments will enable users to better document karst aquifers and associated flow systems for better management of hydrogeological environments and water resources in the future.

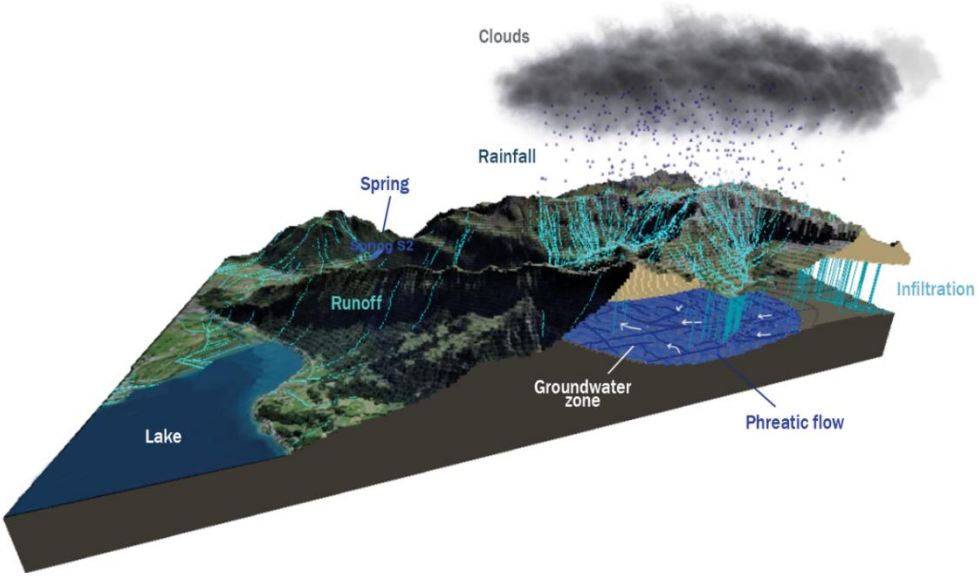


Figure 1. Overview of the flow animation module in visualkarsys. The animation displays the clouds, the rainfall, the runoff and the underground flow through the unsaturated (infiltration and vadose flow) and saturated parts of the aquifer (phreatic flow).

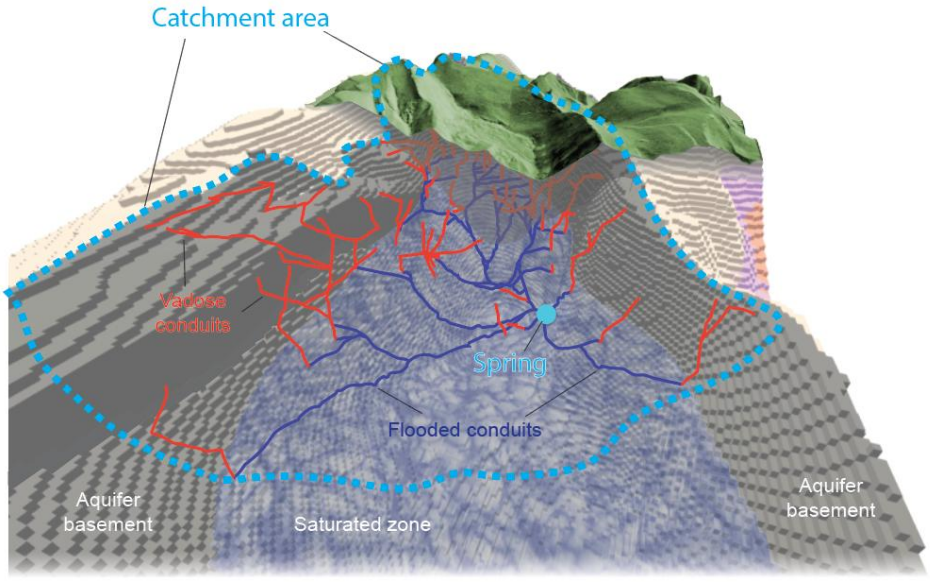


Figure 2. Overview of a generated 3D karst conduit network using the KarstNSim library in Visualkarys

References:

[1] Jeannin, P.Y., Eichenberger, U., Sinreich, M., Vouillamoz, J., Malard, A., Weber, E., 2013. KARSYS: a pragmatic approach to karst hydrogeological system conceptualisation. Assessment of groundwater reserves and resources in Switzerland. Environmental Earth Sciences 69(3), 999–1013. https://doi.org/10.1007/s12665-012-1983-6

[2] Malard, A., Dörfliger, N., Jeannin, P.-Y., Laube, S., 2022. Contribution of the dynamic visualization of a 3D hydrogeological conceptual model to the participatory management of groundwater resources. Comptes Rendus. Géoscience 355, 1–14. https://doi.org/10.5802/crgeos.152

[3] Gouy, A., Collon, P., Bailly-Comte, V., Galin, E., Antoine, C., Thebault, B., Landrein, P., 2024. KarstNSim: A graph-based method for 3D geologically-driven simulation of karst networks. Journal of Hydrology 130878. https://doi.org/10.1016/j.jhydrol.2024.130878

[4] Jeannin, P.-Y., Artigue, G., Butscher, C., Chang, Y., Charlier, J.-B., Duran, L., Gill, L., Hartmann, A., Johannet, A., Jourde, H., Kavousi, A., Liesch, T., Liu, Y., Lüthi, M., Malard, A., Mazzilli, N., Pardo-Igúzquiza, E., Thiéry, D., Reimann, T., Schuler, P., Wöhling, T., Wunsch, A., 2021. Karst modelling challenge 1: Results of hydrological modelling. Journal of Hydrology 600, 126508. https://doi.org/10.1016/j.jhydrol.2021.126508

LID 0105
Hydrogeology and hydrogeochemistry of selected potentially medicinal waters of the Sudetes (SW Poland, NE Bohemian Massif)

Maciej R. Kłonowski[1]*, Linda Chudzik[1], Anna Krzonkalla[1]

[1] Polish Geological Institute – National Research Institute, Lower Silesian Branch, Wrocław, Poland
* maciej.klonowski@pgi.gov.pl

Keywords: medicinal waters, water hydrogeochemistry, Sudetes

The Sudetes are the mountains shared by Czechia, Poland and Germany and constitute the north-eastern marginal part of the Bohemian Massif, one of the major geotectonic unit of Central Europe. The area is rich in medicinal and potentially medicinal waters, though the wealth of these resources have still not yet been sufficiently identified nor analysed. The Sudetes are characterised by occurrence of extensive fractured and fractured-porous aquifers, significant depth of groundwater infiltration and coexistence of fresh, medicinal and thermal waters. These often mix with each other under various geological and hydrogeological conditions, which results in complex groundwater chemistry.

In the Sudetes 10 sites with medicinal water have been officially authorized as spas. In this study hydrogeological and hydrogeochemical properties of potentially medicinal waters, i.e. radon, carbonic and acidulous ones, were analysed. Investigation covered eight currently unused prospective areas. Physicochemical parameters of sampled groundwater were measured in situ in winter 2023 and 12 new samples were taken for laboratory analysis. Most of studied fractured-porous aquifers are formed by Cretaceous sedimentary rocks. Groundwater shows relatively high mineralisation and in some places increased concentration of CO2 and ferrous ions. Groundwater in fractured aquifers built of Upper Carboniferous and Paleozoic and Proterozoic igneous crystalline bedrock shows much lower mineralisation and often elevated content of radon 222Rn isotope.

The results were compared to historical hydrogeological and hydrochemical datasets derived between 1968 and 2022. They help to better understand the conditions of occurrence of potentially medicinal waters in the Polish Sudetes, and to some extent in the proximal parts of the Bohemian Massif showing similar geological and hydrogeological settings, including the hard-rock crystalline massif environment and the Bohemian Cretaceous Basin.

The research was a part of the task of the Polish Geological Survey entitled: “Assessment of the resources of the initially identified deposits of medicinal waters, together with indication of prospective areas for their extraction and application. The Sudetes” carried out by the Polish Geological Institute – National Research Institute by an or der of the Ministry of Climate and Environment and financed by the National Fund for Environmental Protection and Water Management (Agreement no 304/2021/Wn-07/FG-godn/D from April 21st, 2021).

LID 0106
FloodWatch: A mobile application to monitor floods in karst areas

Cyril Mayaud[1,2]*, Žan Kafol[1,2,3], Žiga Kokalj [4,5,6]

[1] ZRC SAZU Karst Research Institute, Postojna, Slovenia
[2] UNESCO Chair on Karst Education, University of Nova Gorica, Vipava, Slovenia
[3] Kafol.NET, Postojna, Slovenia
[4] ZRC SAZU Institute of Anthropological and Spatial Studies, Ljubljana, Slovenia
[5] Postgraduate school ZRC SAZU, Ljubljana, Slovenia
[6] University of Vienna, Wien, Austria
* cyril.mayaud@zrc-sazu.si

Keywords: FloodWatch, mobile application, citizen science, karst floods

Floods are probably the most frequent hazard occurring in karst regions, covering large areas underwater for periods that can be relatively long. Usually, they are monitored by the monitoring network that is already installed on the field. However, accurately monitoring every area prone to flood is not always possible due to budget and time restrictions. Therefore, their characterization might remain considerably limited. In addition, the return period of the most extreme events might often be too long to justify the installation of a monitoring station in some areas. In many cases, the only available data relies solely on visual observation of the flood made by local citizens and environmental activists witnessing the event. However, such valuable information remains often rather qualitative (i.e. without any measure of the water level) and only known by the event direct observers, preventing its diffusion to a wider audience.

To remedy this situation, a citizen-science mobile application aiming to monitor floods in karst areas has been developed. FloodWatch is able to record the flood level in an accurate way with the use of a simple smartphone. Along with water-level measurements, the application is also computing approximate flooded surfaces, depths and volumes. The measurements done with the application have been compared to the data collected by several automatic monitoring stations installed in three Slovenian intermittent karst lakes. The results were rather similar to the water level measured automatically. FloodWatch should be seen as an easy-to-use tool to monitor floods in karst areas in a pedagogic way. Its final aim is to foster science and raise the awareness on karst floods to the wider public by building a reactive community of citizen scientists ready to go out and measure when a flood occurs.

This work has been funded by the Slovenian Research and Innovation Agency (ARIS) within the frame of the project “Evaluate the impact of climate change on the groundwater reserves and ecology of a karst aquifer flooding intermittently: the Upper Pivka Valley” (J1-60004) and the program Karst Research (P6-0119), with additional funding from funded by the EU Research Infrastructure projects eLTER ERIC and LifeWatch ERIC.

LID 0107
Metal contamination in groundwater in Umaria Coalfield of Madhya Pradesh, India

Ashwani Kumar Tiwari[1]*, Abhay Kumar Singh[2]

[1] School of Environmental Sciences, Jawaharlal Nehru University, New Delhi, India
[2] CSIR-Central Institute of Mining and Fuel Research, Dhanbad, India
* ashwani.enviro@gmail.com

Keywords: groundwater, seasonal variation, source identification, human health risk, GIS

The Sustainable Development Goals (6, 2022) intend to increase the proportion of the global population with access to safe drinking water by 2030. In mining regions, groundwater is primarily utilised for potable purposes; hence, its quality is a significant global concern due to mining and associated activities. Therefore, the aim of the present study is to investigate the spatial and temporal variation of metals (Al, As, Ba, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, Se, Sr, and Zn) in the groundwater of the Umaria coalfield, along with statistical source identification of the metals. The risk to human health due to the intake of metals through groundwater is also estimated. One hundred groundwater samples were collected during the post-monsoon season (n=50) and pre-monsoon season (n=50) from various locations in the Umaria Coalfield. The results show that Al, Fe, and Mn concentrations exceeded the Indian drinking water quality standards in 26%, 38%, and 12% of samples in the post-monsoon season, and in 38%, 40%, and 14% of samples in the pre-monsoon season. Metal concentrations were higher in the pre-monsoon season than in the post-monsoon season. Principal component analysis suggests that geogenic attributes, coal mining activities and vehicular load are the primary sources of the metals in the groundwater of the study area. The risk assessment to human health indicated a considerable risk to the local population using groundwater for drinking. The present study's findings can assist policymakers in implementing remediation strategies and ensuring safe drinking water for the local population.

LID 0108
Influence of groundwater in compound flooding: A case study of the Conwy Estuary in Wales

Ankita Bhattacharya[1,2]*, Andrew Barkwith[1], Peter Robins[2]

[1] British Geological Survey, Nottingham, United Kingdom
[2] School of Ocean Sciences, Bangor University, United Kingdom
* ankitabhatta31@gmail.com

Compound flooding results from the interaction of multiple flood drivers, producing impacts that exceed those generated by individual processes acting independently. Low-lying estuaries and deltas are particularly vulnerable due to the combined influence of storm surges, tides, river discharge, intense rainfall, sea-level rise, and antecedent hydrological conditions. While surface-water drivers of compound flooding are increasingly well understood, the role of groundwater remains comparatively under-represented, despite growing evidence of rising groundwater levels and enhanced coastal aquifer vulnerability under climate change.

This study investigates the contribution of groundwater dynamics to compound flooding in the Conwy Estuary, North Wales, UK, a flashy, tide-dominated catchment with a long history of flood events. A fully coupled catchment–groundwater modelling framework (CAESAR–Lisflood–GW) is used to explicitly simulate interactions between fluvial, coastal, pluvial, and groundwater processes. The model is calibrated using observed river discharge, tidal water levels, and groundwater heads, and is applied to reproduce flooding during Storm Ciara (February 2020), when intense rainfall, elevated river flows, and high storm tides caused widespread inundation. Sensitivity analyses are performed to quantify the influence of key hydrogeological parameters, including hydraulic conductivity and specific yield, on groundwater response, baseflow contribution, and flood behaviour. Results indicate that groundwater levels play a significant role in modulating flood timing, duration, and persistence, particularly under high antecedent saturation conditions, thereby amplifying compound flood impacts. The findings demonstrate that groundwater is a critical but often overlooked component of estuarine flood risk.

This work highlights the importance of explicitly representing groundwater–surface water interactions in compound flood risk assessments and climate adaptation planning for estuarine environments.

LID 0109
Integrating hydrogeological models and water balance into an interactive GIS for Central Apennines aquifers

Alessia Di Giovanni[1]*, Sergio Rusi[1]

[1] University "G. d'Annunzio" of Chieti - Pescara, Chieti, Italy
* alessia.digiovanni@collaboratori.unich.it

Keywords: carbonate aquifer, GIS, water balance

Insights into groundwater circulation are essential for supporting groundwater exploitation management and promoting sustainable water use. The existing hydrogeological maps of the Central Apennines (Italy) provide a regional characterization of the principal springs, dominant groundwater flow directions, and overall water balance. Within this framework, the POA Acquacentro project enabled the systematic updating and detailed refinement of the hydrogeological conceptual models of eight carbonate aquifers in Central Italy.

The aquifers considered are characterized by permeability controlled by karstification and fracturing, resulting in high hydraulic conductivity, and are underlain by almost impermeable marl or clay formations and groundwater discharge occurs predominantly through basal springs with minimum flows of approximately 50 L/s.

The results of seasonal spring monitoring, field investigations, and water balance calculations were synthesized into hydrogeological maps, which can be interactively explored through a GIS-based project. This project contains, for each aquifer, detailed information on hydrogeological complexes, mean annual springs' discharge, principal groundwater flow directions, and major river systems. A six-year water balance was computed using GIS-based spatialization methods with regression analyses built for rainfall values, together with snow cover data, and for evapotranspiration; the resulting infiltration can be accessed interactively by selecting individual aquifers within the project. Infiltration values can be easily compared with springs' discharges for each aquifer, thereby allowing a preliminary assessment of the balance between inputs (infiltration) and outputs (springs).

The strength of this work lies in the interactive functionality of the GIS-based project and in the ability to extract and visualize all embedded information in the form of thematic maps.

LID 0110
A dual perspective on soil heavy-metal ecological risk: Parallel pathways of intrinsic intensity and spatial spillover

Yuchen Zhu[1]*

[1] Institute of Hydrogeology and Environmental Geology, CAGS: Chinese Academy of Geological Sciences, Xiamen, China
* zhuyuchen413@163.com

Keywords: dual perspective, soil heavy metals, graph neural network, spatial spillover, landscape connectivity

Conventional soil heavy-metal ecological risk assessments rely mainly on concentration-based indices that capture local risk intensity but overlook spatial spillover governed by environmental mobility and landscape connectivity, leading to underestimation of risks in connected or down-gradient areas at the regional scale. We propose a dual perspective that conceptualizes ecological risk as the coupling of two parallel pathways: an intrinsic risk pathway, representing site-specific hazard intensity, and a spillover risk pathway, representing the potential for lateral migration and spatial propagation across the landscape. This explicitly distinguishes risk generation from risk transmission. For the intrinsic pathway, a landscape-aware Graph Neural Network (GNN) learns non-linear relationships between heavy-metal concentrations and multi-source environmental predictors while encoding spatial adjacency and linear landscape structures, directly producing a continuous intrinsic risk surface without geostatistics. For the spillover pathway, we first diagnose drivers of metal mobility (terrain-controlled movement, soil permeability, proximity to linear corridors, and land-use disturbance). These are integrated into a landscape resistance surface, followed by least-cost path and network diffusion analyses to delineate probable spillover routes and exposure hotspots. The two pathways are synthesized into a bivariate risk typology (high intrinsic–low spillover, low intrinsic–high spillover, and high–high risk) to support differentiated management. A subtropical metal-impacted region shows that areas with moderate contamination but strong landscape connectivity can exhibit elevated spillover risk that is missed by concentration-only approaches.

LID 0112
Informing conjunctive water management with groundwater–spring modelling in a sand and gravel catchment

Paul Wilson[1]*, Rebecca Ní Chonchubhair[1]

[1] Geological Survey of Northern Ireland, British Geological Survey, Belfast, Northern Ireland, United Kingdom
* paul2@bgs.ac.uk

Keywords: spring, sand, gravel, catchment, flow, conjunctive

Increasingly frequent high-demand periods for public water supply are driving a shift toward conjunctive water management. In Northern Ireland, where over 99% of raw water comes from surface water sources, interest in groundwater is growing to enhance system resilience. However, integrating groundwater abstractions while protecting environmental flows requires a clear understanding of groundwater–surface water interactions.

Anney's Well is a major spring discharging from a glaciofluvial sand and gravel aquifer south of Lough Fea, forming the headwaters of the Lissan Water. Groundwater exploration in this area has identified a significant resource that could support abstraction for public supply, but any pumping would directly affect flows from Anney's Well. This study aimed to quantify the spring's flow regime, delineate its zone of contribution, estimate recharge, and assess sustainable abstraction levels.

A suite of complementary methods was applied, including monthly dilution-gauging measurements, groundwater-level monitoring, groundwater-flow mapping, the Water Table Fluctuation method, spatial recharge estimation using infiltration coefficients, and lumped conceptual modelling using AquiMod2.

Spring discharge ranged from 2 to 4.5 ML/d. Annual recharge estimates were 516–756 mm. The zone of contribution was calculated as 2.414 km^2, with an estimated average potential resource of 3.4–5 ML/d. AquiMod2 simulations indicated aquifer throughflow of 2.5–4.5 ML/d, consistent with Anney's Well being the primary discharge point. With a spring Q95 of 2.05 ML/d, maintaining at least 1.025 ML/d should allow approximately 2.3 ML/d to be abstracted without adversely impacting flows.

LID 0113
Groundwater assessment in volcanic island arc: Hydrogeochemistry and groundwater quality of Ngazidja's aquifer systems

Ayouba Mmadi[1,5]*, Huguette Christiane Emvoutou[1,2], Mathias Diedhiou[1], Kossitse Venyo Akpataku[1,3,4], Serigne Faye[1]

[1] Department of Geology, Faculty of Sciences and Techniques, University Cheikh Anta Diop, Dakar, Senegal
[2] Department of Earth science of faculty of sciences, University of Douala, Cameroon (LGRNE)/FS/U-Do)
[3] Laboratory of Organic Chemistry and Environmental Sciences, Department of Chemistry, University of Kara, Kara, Togo
[4] Laboratory of Applied Hydrology and Environment, Faculty of Science, University of Lome, Lome , Togo
[5] Sustainable Development Géophysics (SDG) Lab, University Cheikh Anta Diop, Dakar, Senegal
* mmadi.ayouba@ucad.edu.sn

Keywords: Ngazidja, hydrogeochemistry, volcanic aquifers, marine intrusion, water quality indices

This study presents the first integrated assessment of the hydrogeochemistry and groundwater quality of Ngazidja's aquifer systems, highlighting their potential and vulnerabilities. While most groundwater complies with WHO standards, localized exceedances of major ions and trace elements (Na^+, K^+, Mg^{2+}, SO_4^{2+}, HCO_3^-, Cl^-, Br^-, NO_3^-, Fe, Mn, Pb) occur, particularly in coastal zones, reflecting the combined influence of marine intrusion and geogenic inputs. The water quality indices (WQI) indicate that 18.92% of the samples exhibit poor to very poor quality; according to the LS-Index, 64.87% of the waters are highly aggressive toward hydraulic infrastructures, while the Kelly's Ratio (KR) reveals that 73% are unsuitable for irrigation due to elevated sodium concentrations. Multivariate statistical analyses identified three distinct groundwater types: coastal waters affected by marine intrusion, weakly mineralized waters under atmospheric influence, and silica-rich waters indicative of enhanced water–rock interaction. Hydrochemical facies vary seasonally, with Na–Cl and Mixed–HCO3 dominating during the dry season, and Na–Cl, Mixed–Cl, Na–HCO3, and Mixed–HCO3 prevailing in the rain season. The Na^+/Cl^- ratio proves to be a key tracer for source identification and the evolution of flow paths. These findings emphasize the critical role of aquifer recharge and the urgent need for Integrated Water Resources Management (IWRM).

LID 0115
ecological and hydrological effects of vegetation restoration in karst peak-cluster depression system

Fang Guo[1,2]*, Guanghui Jiang[3]

[1] Key Laboratory of Karst Dynamics, MNR/GZAR, Institute of Karst Geology, Chinese Academy of Geological Sciences, Guilin, China
[2] International Research Centre on Karst Under the Auspices of UNESCO, National Center for International Research on Karst Dynamic System and Global Change, Guilin, China
[3] College of Civil Engineering and Architecture, Guangxi University, Nanning, China
* gfkarst@126.com

Keywords: bicarbonate, rock desertification, vegetation restoration, CO_2 partial, karst spring

Carbonate rock weathering actively participates in the global carbon cycle, yet its weathering process is highly sensitive to environmental changes. The IPCC Climate Change Assessment Reports have explicitly confirmed the existence of a geological carbon sink derived from the chemical weathering of carbonate rocks, with its timescale defined as 10^3–10^4 years. However, the carbon sink associated with carbonate rock chemical weathering also exhibits significant positive manifestations at interannual, seasonal, and even single rainfall event timescales.

Since 2008, China has implemented a series of major ecological projects, including rocky desertification control and the ecological protection and restoration of key ecological zones. These initiatives have achieved initial positive results in ecological restoration, with vegetation cover showing an overall increasing trend. Existing studies have indicated that vegetation restoration can enhance soil CO_2 concentrations, thereby promoting rock dissolution and increasing carbon sequestration. In contrast, evidence regarding the impact of vegetation restoration on runoff remains contradictory.

In this study, we examine an experimental site with over 40 years of spontaneous vegetation restoration to evaluate how changes in spring alkalinity reflect shifts in hydrology and bicarbonate-mediated carbon export. Results indicate that spring discharge remains predominantly rainfall-controlled, exhibiting similar annual flow patterns before and after restoration. Rainfall events increase flow while transiently diluting ion concentrations, indicative of unsaturated flow influenced by vegetation cover and surface morphology. Vegetation recovery attenuates runoff velocities and extends the residence time of unsaturated flow in contact with bedrock, promoting greater mineral saturation. Therefore, by evaluating shifts in the proportional contribution of unsaturated runoff, we can indirectly quantify the hydrological impacts of vegetation recovery. End-member mixing analysis reveals contributions from unsaturated flow ranging from 3–36% under low Ca^{2+} concentrations and from 4–51% under high Ca^{2+} concentrations. Long-term monitoring demonstrates that HCO_3^- and Ca^{2+} concentrations have increased by 24.7% and 14.5% since the 1980s, following a slow–fast–stabilizing trend. Concurrently, the variability in these concentrations and the proportion of unsaturated flow have declined, underscoring the growing ecohydrological influence of vegetation. Although carbon export via unsaturated flow is diminishing, overall carbon flux is projected to increase with ongoing vegetation restoration under stable precipitation conditions. The results also suggest that vegetation restoration amplifies carbon export in karst systems, but this effect may stabilize as ecosystems mature and soil CO_2 concentrations reach equilibrium.

The financial support of National Natural Science Foundation of China (42272303，42172287), Guangxi Key Technologies R&D Program (Guike AB24010054) are gratefully acknowledged.

LID 0116
Monitoring fresh–salt groundwater interface in a land-subsided coastal aquifer using a vertical ERT approach

Jiawei Li[1]*, ChiSan Tsai[1], Jiaqi Liu[1], and Tomochika Tokunaga[1]

[1] The University of Tokyo, Graduate School of Frontier Sciences, Department of Environment Systems, Kashiwa, Japan
* lijiaweiwin@163.com

Keywords: coastal aquifer, fresh–salt water interface, land subsided area

Land-subsided coastal aquifers are highly vulnerable to seawater intrusion. Understanding the characteristics of fresh–saltwater interface is crucial for analyzing the dynamics of groundwater salinity in subsided coastal areas. This study presents the application of vertical Electrical Resistivity Tomography (ERT) to characterize the fresh–saltwater interface in a subsided coastal aquifer in Chiba, Japan.

A 64-electrode array was vertically deployed in a borehole to a depth of around -20 m, with 30 cm interval. Two nearby monitoring wells (shallow -4 m and deep -17 m) recorded continuous groundwater level and salinity for hydrogeological interpretation. Hourly ERT measurements were conducted over a 27-hour period under contrasting seasonal conditions (summer and winter). Data inversion was performed in PyGIMLi, an open-source Python-based geophysical inversion framework. The deep transition zone shows relatively stable resistivity between the seasons, whereas the near-surface sandy layers show seasonal variations.

The results indicate that the integrated field experiment and inversion-based analysis developed in this study provide a reliable framework for hydrogeophysical monitoring of the fresh–saltwater interface in subsided coastal aquifers. Future work will integrate density-dependent numerical simulations and controlled pumping experiments. Numerical simulations will guide the design of pumping experiments, followed by field investigations to quantify interface dynamics and evaluate aquifer response under hydraulic stress.

LID 0117
Spatial distributions of microplastics and PFAS at the streambed interface near a wastewater effluent outfall in Korea

Eunju Jeong[1]*, Jin-Yong Lee[1], Gahee Lee[1], Sungbeen Lee[1], Hye-Yeon Jeon[1]

[1] Department of Geology, Kangwon National University, Chuncheon, Korea
* jej8377@kangwon.ac.kr

Keywords: microplastics, PFAS, streambed interface, WWTP effluent

Effluent-impacted urban rivers may facilitate the transfer of emerging contaminants into shallow streambed sediments, yet field evidence describing their distribution across the streambed–subsurface interface remains limited. This study investigates the spatial distribution of microplastics (MPs) and per- and polyfluoroalkyl substances (PFAS) between stream water and shallow porewater (30–40 cm below the sediment surface) in an urban river receiving wastewater treatment plant effluent. Upstream, midstream, and downstream sections were compared, with additional evaluation of bank-side and channel-center locations. MP concentrations, dominated by PP, PE, and PET, were markedly elevated in midstream surface water adjacent to the effluent discharge (48–56 items/L) compared to upstream and downstream sections (≤14 items/L). In contrast, MP abundances were substantially lower in porewater, suggesting limited vertical infiltration of particulate contaminants into the underlying porous sediments. PFAS were detected at all sites, with a localized maximum of total PFAS (ΣPFAS = 115.8 ng/L) observed in porewater near the effluent discharge. Unlike MPs, dissolved PFAS concentrations were higher in porewater than in stream water at this location, indicating solute transport into the shallow subsurface. These results demonstrate contrasting transport behavior of particulate and dissolved contaminants across the streambed interface and highlight the importance of incorporating shallow subsurface compartments in groundwater-related assessments of effluent-impacted urban systems. This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIT) (RS-2024-00352562).

LID 0118
Conductivity as a proxy to understand spatial and temporal nitrate concentration in groundwater – Beauce area, France

Laurence Gourcy[1]*, Nicolas Surdyk[1], Eline Malcuit[1], Gilles Braibant[1], Mohamed Boujoudar[2]

[1] BRGM, Orleans, France
[2] ISTO/CNRS, Orleans, France
* L.gourcy@brgm.fr

Keywords: groundwater, nitrate, conductivity

The Beauce is a flat area with wide, dry valleys covering 9,000 km^2, stretching across two regions (Ile de France and Centre Val de Loire). The Beauce aquifer in the broad sense (s.l.), is a hydrogeological unit structured by lacustrine limestones that were deposited from the Middle Eocene to the beginning of the Miocene. The upper layers, more vulnerable to contamination, were composed by the Pithiviers and Etampes calcareous aquifers separated in a heterogeneous way by marls. Recent studies undertaken within the JUNON project demonstrated that, in the northern part of the Loire River the two upper layers have a similar hydrogeological behaviour. It was also shown that chemical composition of both layer is similar except in term of nitrate concentration. Nitrate concentration in groundwater varies from lower than the limit of quantification in captive areas up to 93 mg.l^{-1} as an interannual average.

Initially a study of nitrate concentration and conductivity measured irregularly but no more than 4 times per year all over the Beauce aquifer was carried out. As the aim of the JUNON project was to build a digital twin of the Beauce region, it was necessary to have a regular, high-density monitoring of groundwater quality in the Beauce region. Three nitrate probes were therefore installed in two wells and a river just at the outlet of the aquifer. For one site, the experimental O'ZNS site, conductivity is also monitored every hour since.

The correlation between nitrate concentration and conductivity at the experimental site is very good as the main parameter explaining temporal variability of electric conductivity is nitrate content. Therefore, spatial correlation between these two parameters was also tested with the objective to improve conductivity monitoring as a proxy of nitrate concentrations in groundwater.

LID 0119
Overlooked sedimentary heterogeneity as a control on advective groundwater transport: Insights from Triassic sandstones, Eastern France

Lucas Bofill[1,2]*, Gerhard Schäfer[2], Gulherme Bozetti[2], Mathieu Schuster[2], Jean-François Ghienne[2]

[1] Azerbaijan State Oil and Industry University, French Azerbaijani University, Baku, Azerbaijan
[2] Université de Strasbourg, Strasbourg, France
* lucasbofill@yahoo.com.br

Keywords: sedimentary heterogeneity, advective transport, upscaled anisotropy

Predicting advective transport in sandstone aquifers remains challenging due to unresolved sedimentary heterogeneity at decimetre- to metre-scale. Even in the absence of mudstone interbeds or marked granulometric contrasts, depositional architecture and diagenetic processes can generate permeability variability that strongly influences solute transport in groundwater.

This study investigates the Lower Grès Vosgien Formation (Lower Triassic, eastern France), a major aquifer hosting drinking water and lithium-rich geothermal brines in the Upper Rhine Graben. Using a digital outcrop model combined with high-resolution sedimentary facies analysis, we developed a two-dimensional conceptual model to evaluate how different representations of heterogeneity affect advective transport simulations.

Six progressively simplified hydrostratigraphic models were tested to assess their impact on particle residence times, breakthrough curves, longitudinal macrodispersivity, and upscaled anisotropy. Results demonstrate that distinguishing between fluvial- and aeolian-formed sandstones significantly alters advective flow patterns. Models that fail to discretise individual fluvial facies, or that rely on deterministic hydraulic conductivity assignments, underestimate preferential flow pathways and delay the prediction of first particle arrivals. Furthermore, the degree of facies discretisation substantially influences anisotropy upon upscaling.

These findings highlight that small-scale sedimentary heterogeneity in sandstones, controlled by primary sedimentary processes, exerts an important control on advective transport, with direct implications for predicting geothermal brine circulation and contaminant transport in sandstone aquifers.

LID 0120
Use of soft sensors to provide real-time sanitary risk assessment in karst springs captured for drinking water supply

Jaime Fernández-Ortega[1]*, Juan Antonio Barberá[1], Bartolomé Andreo[1]

[1] Department of Geology and Centre of Hydrogeology, University of Malaga (CEHIUMA), Malaga, Spain
* jaimeortega@uma.es

Keywords: karst, drinking water, faecal contamination

Supplying safe drinking water from karst aquifers is particularly challenging because these systems are highly vulnerable to contamination, often leading to rapid and abrupt changes in water quality and subsequent interruptions of groundwater capture. Conventional methods for assessing faecal bacterial contamination rely on laboratory cultures, which are time-consuming and require expensive laboratory reagents that may delay the detection of ongoing pollution events. To solve these analytical constraints, this study presents an innovative methodology for real-time water quality assessment based on the indirect detection of faecal bacteria using Machine Learning (ML) models.

Fieldwork was conducted in a binary karst aquifer in southern Spain over three hydrological years (2020/21–2022/23). Continuous monitoring of discharge, electrical conductivity, turbidity and tryptophan-like fluorescence was combined with groundwater sampling for *Escherichia coli* determination at the two main springs. Three supervised ML models—Gaussian Processes, Neural Networks and Naïve Bayes—were evaluated to infer five sanitary risk levels defined by WHO which are derived from *E. coli* activity using continuous sensor data, forming the basis of the soft-sensor approach.

Results show that combining two water parameters provided the most reliable predictions at both springs, although the optimal parameters combination differed according to hydrogeological features and contaminant transport. Gaussian Processes and Naïve Bayes showed a better performance when linear relationships existed between bacterial activity and water parameters, whereas Neural Networks were more effective under complex sediment transport lacking free living bacteria. Overall, the proposed methodology demonstrates the strong potential of soft sensors as early-warning tools for real-time sanitary risk assessment, offering a valuable approach to protect drinking water sources worldwide from microbial contamination.

LID 0121

Unraveling the interactions between shallow and deep aquifers analysing groundwater chemical trends: Insights from a case study in the piedmont Po Plain (NW Italy)

Daniele Cocca[1]*, Manuela Lasagna[1], Elena Egidio[1], Domenico Antonio De Luca[1]

[1] University of Turin, Earth Sciences Department, Turin, Italy

* daniele.cocca@unito.it

Keywords: deep aquifers, groundwater quality, chemical trends

Deep aquifers are essential for human activities, and their exploitation has intensified in recent years. Indeed shallow aquifer generally exhibit a higher occurrence of contaminants compared to deep aquifers. The aim of this study was to investigate the interactions between shallow and deep aquifers using hydrochemical approaches, considering the distribution and trends of main physicochemical parameters, heavy metals, pesticides and specific indexes in deep aquifers over the 2000–2021 period in Piedmont (NW Italy). In the Piedmont Po Plain, a shallow phreatic aquifer hosted in fluvial deposits overlies deep confined and semiconfined aquifers, hosted in transitional and marine complexes. Results highlight (1) an increase in physicochemical parameters concentrations; (2) increased input of pollutants, such as pesticides; (3) increased CO_2 levels, leading to increased concentrations of some major ions and decreased concentrations of Fe and calcite SI; and (4) intensified ion exchange processes. In conclusion, the increasing trends in physicochemical parameters and the other hydrochemical approaches confirm an increase in the recharge of deep aquifers from the overlying shallow aquifer, likely driven by the intensified exploitation of deep groundwater resources. This work represents one of the first regional studies of deep aquifers to analyze both physicochemical trends and the significant role of interactions with shallow aquifers, providing a valuable tool for local authorities, particularly as deep aquifers are expected to be increasingly exploited in future for agricultural and drinking water purposes.

LID 0122
Identifying critical groundwater systems through the use of an analytical methodology in Limpopo, in South Africa

Nando Mathabela[1]*, Fanus Fourie[1]

[1] Department of Water and Sanitation, Pretoria, South Africa
* mathabelana@dws.gov.za

1. Introduction: Over the years, groundwater has been seen as a sustainable source of water in helping to ease the high demand of water within societies and aiding in securing water security and efficiency. However, recent studies have displayed unpredictable rainfall patterns which result in inconsistent recharge quantities and over-abstraction norms which lead to total depletion of groundwater systems [1]. This brings about a shortage in water supply to communities around the country, with little to no resolution to mitigate the effects as they worsen with time. As part of the new plans, DWS has launched a full-scale study across the Limpopo province, with the goal of identifying groundwater systems that display critically low groundwater levels over the years and mitigating the impacts on the identified geosites. The Department of Water and Sanitation supervises water levels at more than 2000 geosites, with monitoring intervals varying from monthly to biannually. This nationwide data analysis helps identify groundwater level patterns, allowing the department to make prompt decisions to reduce harm and protect lives and livelihoods, especially during droughts. Through the application of an analytical methodology and technical tools, geosites stations were identified and the most affected stations were isolated and further analysed. Upon completion of the analysis, information in regard to functions and usage of the isolated geosites was studied and hypothetical assumptions backed by pre-existing reports were drawn. This information was pivotal in formulating the implementation plan of rehabilitating the affected geosites.

2. Methodology: The Groundwater Level Status and Risk Percentile methodology was utilized as a diagnostic and data analysis tool due to its simplicity in interpreting groundwater level data and its efficiency in demonstrating fluctuations in groundwater levels. This method aided in bettering the understanding of groundwater level data of geosites across the province over an extended period of time. The method uses a graphical simulated approach that combines groundwater level data and groundwater status calculated in percentages to analyse and navigate the trajectory and patterns of the fluctuations of groundwater levels over a set period of time for each particular system. The method classified groundwater level data into seven classes that revealed the overall status of the geosites with time. The classes are categorized as, Very Low Risk (>P90), Low Risk (P75-P60), Normal Risk (P60-P40), Below Normal Risk (P40-P25), High Risk (P25-P10), and Very High Risk (<P10). The bottom classes (low percentile) signify a high-risk status, while the top classes (high percentile) denote a low-risk status of groundwater level. The fluctuations in the graph are a subject of mainly changes in rainfall patterns and the abstraction rates and quantities over the geosites [2].

3. Results: The Risk Percentile graph provided a visual presentation that indicated the groundwater systems underlying conditions. The method revealed a graphical overview drastically declining groundwater levels over time. The status of the groundwater systems was then obtained, and seven geosites were identified to be severely impacted as a result of unmonitored over abstraction patterns. The identified critically affected groundwater systems were then placed on high priority for further analysis and investigation. The Groundwater Level Status methodology also allowed for the comparison of groundwater level data across different geosites with each other on the same scale. The averages of the

groundwater level statuses were then plotted on a map, classed into ranges and the risk profiles displaying intensities of the over-abstraction impacts were developed for decision makers.

4. Conclusion: Ground truthing and site-visitation are yet to be completed in the next phase upon completion of data acquisition and analysis. The site exploration will form part of a geophysical survey that will be completed in cooperation with the DWS Limpopo Provincial Office.

References:

[1] Maluleke, N.V., 2023. Investigating groundwater abstraction impacts on surface water levels and surface water–groundwater interaction with analytical and numerical models.

[2] Fourie, F 2018. National Overview of Groundwater Level Trends for the period: August 2016 - August 2018. GH4300 report number. Department of Water and Sanitation, Pretoria, South Africa. pp 1-15.

LID 0123
Tackling high nitrate concentrations near a drinking water abstraction site through isotopic analysis and environmental stakeholder management

Bo Van Limbergen[1]*, Simon Six[1]

[1] De Watergroep, Brussels, Belgium
* bo.van.limbergen@dewatergroep.be

Keywords: LIFE BELINI, nitrate in groundwater, isotopic analysis, environmental stakeholder management

Since 2016 De Watergroep, the largest drinking water company in Flanders, has participated in the European LIFE Integrated Project "BELINI". This Belgian initiative aims to make a leap forward to a good qualitative, quantitative and ecological status for surface water and groundwater, in collaboration with various cross-border partners from the Flanders, Walloon and Brussels region. The project runs for 10 years and is almost at its end.

De Watergroep's project involves determining the origin of high nitrate concentrations in the groundwater at a drinking water extraction site. Over a short period the values have risen to levels approaching and surpassing the drinking water standard, reducing the capacity of the well site. Groundwater samples were collected from a large series of wells, allowing for concentration analyses at various distances and depths to determine the extent and severity of the spread. Isotopic analyses were carried out in collaboration with the University of Liège to determine the nitrate origin through stable isotopes (δ15N, δ18O, δ34S, δ11B). This was coupled with a groundwater age determination through environmental tracers (Tritium, CFC’s and SF6).

Results revealed that nitrates are linked to agricultural practices over a long period of time, with the highest concentrations in the younger groundwater. The focus went to environmental stakeholder management with local farmers. In collaboration with an agricultural organization active in the region, the farmers were contacted to raise awareness, explore potential partnerships, and find ways to improve current agricultural practices to reduce nitrate seepage into the subsoil. The collaboration has generated a lot of valuable information and connections, but also presented challenges. With the project's near completion, a summary can be made of 10 years of study work, stakeholder management, do’s and don’ts, and determining future steps.

LID 0124
From CT scans to flow models: Enhancing aquifer characterization in complex bioturbated carbonates

Husam Musa Baalousha[1,2]*, Ataur Rehman[1], Marwan Fahs[3]

[1] Department of Geosciences, College of Petroleum Engineering and Geosciences, King Fahd University of Petroleum and Minerals (KFUPM), Dhahran, Saudi Arabia
[2] Interdisciplinary Research Center for Membranes and Water Security, King Fahd University of Petroleum and Minerals, Dhahran, Saudi Arabia
[3] Institut Terre et Environnement de Strasbourg, Université de Strasbourg, CNRS, ENGEES, Strasbourg, France
* husam.baalousha@kfupm.edu.sa

Characterizing groundwater flow in bioturbated carbonate formations is very challenging because of the high heterogeneity and anisotropy introduced by extensive burrow networks, which can act as super-permeable pathways. This study presents an integrated, physics-based workflow that combines high-resolution X-ray computed tomography (CT) imaging with pore-scale numerical flow simulation to accurately model groundwater movement in such complex media. Using a bioturbated limestone sample from the Upper Cretaceous Member (Aruma Formation) in central Saudi Arabia as an analogue, CT-derived 3D models were constructed to explicitly represent connected burrow networks. Steady-state, single-phase flow simulations were carried out in COMSOL Multiphysics across three progressively smaller model domains to evaluate scale-dependent hydraulic properties. Results reveal that connected burrow networks dominate flow, creating preferential pathways within a low-permeability matrix. A systematic increase in permeability with decreasing model volume reveal the scale-dependent nature of hydraulic characterization in such systems. The non-linear relationship between applied pressure gradient and average velocity confirms flow becomes non-Darcian across various scales. The proposed approach enables building a robust approach for characterizing effective permeability and flow behavior in highly heterogeneous bioturbated aquifers. These results have direct implications for improved groundwater resource assessment, contaminant transport prediction, and reservoir characterization in carbonate systems worldwide.

LID 0125
Assessing the effect of cable orientation in active-DTS derived groundwater fluxes

Alice Sai Louie[1]*, Corentin Moullec[1], Benjamin Belfort[2], Hugo Reiller[1], Anthony Julien[2], Stephane Mace[1], Olivier Bour[1]

[1] Univ Rennes, CNRS, Géosciences Rennes, Rennes, France
[2] ITES, University of Strasbourg, CNRS, ENGEES, Strasbourg, France
* alice-jean.sai-louie@univ-rennes.fr

Keywords: active-DTS, fibre optic, groundwater flux, hydrogeophysics

Traditional groundwater monitoring techniques lack the capabilities to measure groundwater fluxes at high spatial resolution over large distances. Breakthrough work by [1] enabled the quantification of groundwater fluxes at high spatiotemporal resolution using actively heated fibre optic Distributed Temperature Sensing (A-DTS), establishing this as a promising hydrogeophysical method. However, current A-DTS interpretation methods, such as the analytical solution used to process A-DTS data, assume that groundwater flux is perpendicular to the cable. Yet, many field-based applications of A-DTS violate this assumption due to the multi-dimensional nature of groundwater flow. This study aims to characterise the effect of fibre optic cable orientation on the interpretation of groundwater fluxes, and determine the minimum angle for which the method remains applicable.

This study presents methodological advancements to A-DTS by characterising how cable orientation relative to flow direction affects groundwater flux estimates in a controlled environment. A large-scale experiment was conducted at the *Site Contrôlé Expérimental de Recherche pour la réhabilitation des Eaux et des Sols* (SCERES) platform in Strasbourg, France. This 25×12×3 m experimental tank represents an ~1000 m^3 artificial porous aquifer designed to reduce potential boundary effects. This study allowed us to test some of the assumptions underlying the A-DTS method. A hybrid cable containing fibre optic strands and a steel armour for heating, was installed in a configuration with five sections at different orientations relative to the flow direction though the horizontal plane. The cable was buried within the saturated porous medium and different flux rates were imposed to establish the critical angle thresholds for reliable groundwater flux estimation. We will discuss the advantages and limitations of A-DTS for high-resolution groundwater flux monitoring under controlled yet field-representative conditions.

Reference:

[1] Simon, N., Bour, O., Lavenant, N., Porel, G., Nauleau, B., Pouladi, B., ... & Crave, A. (2021). Numerical and experimental validation of the applicability of active-DTS experiments to estimate thermal conductivity and groundwater flux in porous media. Water Resources Research, 57(1), e2020WR028078.

LID 0126
Spatial temperature distribution inferred from borehole logging and OF DTS measurements. Results of OptiSGE project

Maciej R. Kłonowski[1]*, Anders Nermoen[2], Peter J. Thomas[2], Urszula Wyrwalska[1], Weronika Pratkowiecka[1], Agnieszka Ładocha[1], Kirsti Midttømme[2], Paweł Brytan[1], Anna Krzonkalla[1], Adrianna Maćko[1], Karol Zawistowski[1]

[1] Polish Geological Institute – National Research Institute, Lower Silesian Branch, Wrocław, Poland
[2] NORCE Norwegian Research Centre, Bergen, Norway
* maciej.klonowski@pgi.gov.pl

Keywords: borehole temperature logging, distributed temperature sensing, south-western Poland

Borehole temperature logging and optical fibre distributed temperature sensing (OF DTS) were applied to assess spatial distribution of subsurface temperatures in south-western Poland. The research was carried out between 2023-2024 in the boreholes representing various climatic, geological, tectonic and hydrogeological settings and showing diverse technical construction.

Results of temperature logging showed characteristic depth-dependent features. Daily, seasonal and yearly temperature changes occur in the near surface zone at different depths, changing from one borehole to the other. These depended mostly on external factors including climate, weather and type of land use. Beneath, in the so-called zone of neutral temperatures, the subsurface temperature was close to the average yearly air temperature at a given location. Deeper, an inflection point occurs below which temperature depends strictly on the local geothermal gradient.

The above patterns were most noticeable in fully cased boreholes. There, the influence of lateral groundwater flow was altered by grouting and casing and the effect of natural thermal convection and conduction causing gradation of water temperature, was still observed. In such boreholes, conditions within the water column showed, to some extent, a tendency to be stagnant. In the uncased fragments of boreholes, higher temperature variations were observed, depending on such factors as groundwater flow and thermal conductivity of rocks. In the case of groundwater inrush through the uncased walls of the borehole or through the screen, temperature change often coincides with a change of water electroconductivity. Temperature measurements in the urban and industrial areas confirmed the occurrence of anthropogenic thermal anomalies in subsurface caused by the presence of infrastructure and effects of subsurface urban heat island. The applied methods also proved to be an effective tool for assessment of the technical condition of the boreholes.

The research on distributed temperature sensing and borehole temperature logging is the result of the project “Optimization of Shallow Geothermal Energy Resources for Green Transition (OptiSGE), which received support from the Fund for Bilateral Relations of the European Economic Area Financial Mechanism 2014–2021 and Norwegian Financial Mechanism 2014–2021, under the terms of the Open Call for Bilateral Initiatives in the Area of Green Transition between Poland and Norway, Grant no. FWD-Green-2.

LID 0127
Assessment of salinity and geogenic fluoride and vanadium contamination of a deep aquifer system in Northern Namibia

Sibel Melisa Gürsoy[1]*, Roland Bäumle, Georg J. Houben

[1] Federal Institute for Geosciences and Natural Resources (BGR), Hannover, Germany
* SibelMelisa.Guersoy@bgr.de

Water scarcity is a widespread problem in semiarid climate zones of southern Africa. In the Ohangwena Region of northern Namibia, groundwater from a deep aquifer system is utilized as a resource for drinking water and agriculture. The aquifer system is located in mostly unconsolidated, Cenozoic sediments of a paleo-megafan, the Cubango megafan. It consists of the deep aquifer KOH-2, the overlying aquifer KOH-1 and local appearances of a perched aquifer KOH-0. The aquifers are characterized by regional variations in salinity and trace element concentrations. Fluoride concentrations of up to 30 mg/l and vanadium concentrations that often exceed 1.0 mg/l, as well as high salinities, can restrict the groundwater utilization and pose health risks to local communities. To expand the knowledge about the groundwater system and its quality, a sampling campaign was conducted in the Ohangwena Region in August and September 2025. Hereby, groundwater samples from 24 different wells were collected, including samples for the general hydrochemistry, stable isotopes (^{18}O, ^{2}H), excess nitrogen and radiocarbon (^{14}C). Additionally, 20 noble gas samples were collected in copper tubes. With the first results from the sampling campaign, a more precise determination of the salinity and trace element distribution of the groundwater can be achieved. In addition to radiocarbon age dating, excess nitrogen and noble gas data give information about groundwater age and the environmental conditions during the time of its infiltration. The new groundwater data can be correlated with mineralogical and geochemical data of a 400 m deep sediment core from the study area, giving further insights into the origin of the high fluoride and vanadium concentrations and the associated mobilisation processes. Therefore, the contents and distribution of the problematic elements were analysed in different potential source minerals, including heavy minerals and the clay fraction.

LID 0128
Model emulation made simple with pyEMU

Rui Hugman[1]*, Jeremy White[2]

[1] INTERA Geosciences, Faro, Portugal
[2] INTERA Inc, Fort Colins, United States
* rthugman@gmail.com

Keywords: uncertainty quantification, surrogate, decision-support modelling

The computational expense of high-fidelity environmental models frequently renders uncertainty quantification and optimization unfeasible within standard project timelines. While surrogate modelling (emulation) offers a viable path to computational efficiency, widespread adoption is hindered by a lack of standardized tooling, often forcing practitioners to rely on brittle, ad-hoc scripts to bridge the gap between models and algorithms. To address this barrier to entry, we introduce the Emulator module within the open-source pyEMU package, designed to standardize and automate the construction and deployment of surrogates. The module provides a streamlined architecture for implementing methods such as Gaussian Process Regression (GPR) and Data-Space Inversion (DSI). A critical feature of this framework is its ability to integrate directly into existing PEST++ based data assimilation and optimization workflows, allowing users to seamlessly transition between physics- and emulator-based workflows. By automating the necessary infrastructure, including non-Gaussian data transformations and the generation of PEST interface files, the framework allows trained surrogates to function as seamless "drop-in" substitutes for physics-based models. This capability enables users to leverage the robust methods available in the PEST++ suite without refactoring their familiar workflows. We demonstrate the framework's utility through a benchmarking optimization case and a history-matching application involving a synthetic groundwater model.

LID 0129
Towards a plan for managing abandoned wells in Slovenia – experiences and surprises

Nina Rman[1]*, Andrej Lapanje[1], Nika Pišek Szillich[1], Mitja Janža[1], Ana Burger[1]

[1] Geological Survey of Slovenia, Ljubljana, Slovenia
* nina.rman@geo-zs.si

Keywords: inactive well, data management, methane regulation, well repurposing, geothermal well

The number of boreholes in Slovenia reaches several tens of thousands, however, only about 608 are deeper than 500 m. This is a non-legislative threshold that defines „deep boreholes”. Most were drilled in mid-to-late previous century, about one third for hydrocarbon exploration, one third for coal and metal mine exploration, and the rest for groundwater and thermal water capture. Only about half of these boreholes still exist. Metadata on 265 boreholes is freely accessible on a Viewer of 3D geothermal model of NE Slovenia (https://geo3d.pgi.gov.pl/Slovenia/index.html), still, this data package is limited due to data confidentiality.

Since more than 90% of boreholes are older than 20 years, they may pose an environmental risk or hazard to human health. Recently, there were two accidents: a CO_2 blowout in 2023 and a thermomineral water outflow in 2025. Hands-on mitigation protocols and research of *in situ* fluid and borehole status were challenging and initiated the Ministry of Natural Resources and Spatial Planning towards a systematic approach to prepare a management plan for abandoned wells in Slovenia. This initiative was also supported by the requirements of new regulation on evaluation of methane emissions. Simultaneously, the Central Europe project TRANSGEO, in which Slovenia participates, developed a Transnational Strategy for the structural transition of fossil fuel producing regions to geothermal – focused on how to repurpose old hydrocarbon wells for geothermal use.

We will present taken and foreseen steps towards designing a management plan for abandoned wells, where we face several challenges: limited data availability, inconsistent terminology, dispersed databases, inconsistent legislation, lack of intersectoral cooperation, and other issues.

The research is supported by the Slovenian Research and Innovation Agency through research projects N1-0347 InnoGeoPot, GC-0006 GeoAI, and research core funding P1-0020; and a successor of the EEA project INFO-GEOTHERMAL. The IGCP project 636 Geothermal resources for energy transition fosters knowledge exchange. The Ministry of Natural Resources and Spatial Planning supports it through financing advisory support for managing water concessions.

LID 0130
Using monthly stable-isotope datasets of the Sava River water cycle for investigation of pollutant transport pathways

Nina Rman[1]*, Katja Koren Pepelnik[1], Anja Koroša[1], Klara Žagar[2], Polona Vreča[2], Urška Pavlič [3], Marina Gacin[3]

[1] Geological Survey of Slovenia, Ljubljana, Slovenia
[2] Jožef Stefan Institute, Ljubljana, Slovenia
[3] Slovenian Environment Agency, Ljubljana, Slovenia
* nina.rman@geo-zs.si

Keywords: oxygen and hydrogen isotopes, precipitation, groundwater recharge, time-series, Slovenia

The Quaternary alluvial aquifer in Krško basin is bounded by two rivers – Sava in the north and Krka in the south, both in dual role along its length - as recharge and discharge hydraulic boundaries. The area is sensitive to droughts, agricultural and urban pollution. Moreover, it is where Nuclear power plant Krško and four hydropower plants at Lower Sava are situated, also affecting the aquifer recharge. Several numerical models of groundwater flow try to simulate flow directions and velocities.

Regular monthly monitoring of isotopic composition of oxygen and hydrogen at Sava River – Ljubljana-Šentjakob station started in 2020 by JSI. Monitoring of precipitation, surface and groundwater along the Sava River was extended in 2021 by GeoZS: close to Julian Alps in Radovljica, in Ljubljana, and in Krško. Two springs of the Krka River which flows into the Sava River are also monitored. Five-year datasets carry signals of extreme events and of a positive isotope shift in latest years. To understand variability of the Krka River along its 94 km long flow path, as only the springs are regularly sampled, a one-day snap-shot sampling was performed at app. 20 points and 10 tributaries in April 2024. In 2025, four seasonal sampling campaigns were performed at 15 groundwater wells in Krško basin.

The isotope results were supplemented with tritium-helium dating and groundwater level measurements to investigate the recharge characteristics and mixing ratios of different water end-members. Time-series were used to support interpretation of groundwater recharge with less expressed seasonal effect and to predict possible pathways for contaminant transport between surface and groundwater.

The research is supported by the Slovenian Research and Innovation Agency by research project J1-60003 GWQualityPath, research core fundings P1-0020 and P1-0143 and by IAEA TC projects (RER7017, RER7013, NC 7001). The research at Krško basin in 2025-2026 is supported by the Slovenian Environment Agency.

LID 0131
Use of open-access tools to construct and calibrate a groundwater delta-scale model

Ludovic Schorpp[1*], Nina Egli[1], Philippe Renard[1]

[1] Center for Hydrogeology and Geothermics, University of Neuchâtel, Neuchâtel, Switzerland
* ludovic.schorpp@unine.ch

Keywords: geological heterogeneity, groundwater modeling, calibration, inverse modeling

Arsenic (As) is a major contaminant of groundwater, particularly in Southeast Asia, where more than 100 million people are regularly exposed to As. Geogenic arsenic exhibits a complex spatial and temporal distribution that cannot be fully understood by considering only surface data, such as the probability of flooding or surface geology. Complex redox reactions that trigger the release of arsenic are strongly controlled by subsurface variables such as organic matter content and lithology. Therefore, subsurface heterogeneity must be considered to understand the release of As in groundwater.

To test this approach, the DeltAs project was initiated at two key sites in Vietnam: The Red River and Mekong deltas. These are two highly populated areas that are known to have high levels of arsenic in their groundwater. This study focused on the Mekong Delta.

To accomplish this, we have developed a framework that uses only open-source, accessible, and scriptable tools. First, we build a geological model using ArchPy, a Python library that enables the rapid, semi-automated generation of stochastic, heterogeneous models. These models serve as the basis for constructing an ensemble of MODFLOW 6 models using ArchPy2Modflow and FloPy. The groundwater model is then calibrated using PEST++. The parameters considered are the horizontal and vertical hydraulic conductivity and the abstraction rate per province and for each model layer.

Particle tracking is then performed on the calibrated models at each water sampling location to trace the lithology encountered by the water as it arrives at the well. This is done for each final member of the ensemble to better account for the resulting uncertainty from the calibration. The results show the proportions of the different lithologies at each water sampling point. In the future. These results will be used to improve our understanding of the factors that contribute to the release of arsenic in underground environments.

LID 0133
Multidisciplinary characterization of a Mediterranean island hydrogeosystem

Stylianos Voudouris[1,2]*, Youri Hamon[1,3], André Fourno[1] , Nathalie Collard[1], Konstantinos Chalikakis[2]

[1] IFP Energies nouvelles, Rueil-Malmaison Cedex, France
[2] Avignon Université, UMR 1114 EMMAH (AU-INRAE), Avignon, France
[3] BRGM-Service géologique national, Orléans, France
* stylianos.voudouris@ifpen.fr

Keywords: Mediterranean islands, Chios, springwater, insular aquifers, karst

Mediterranean islands are experiencing water pressure due to climate change and human activities. In this context, enhancing the hydrogeological understanding of the critical groundwater resources necessitates synergistic studies. To adress this issue, a holistic approach was employed, integrating geology, hydrochemistry and stable isotope hydro(geo)logy. Chios island, an ideal pilot case, represents an intricate hydrogeosystem, which includes the existence of a thermal spring. Springs are recognized as natural outlets for this hydrogeosystem. The main aquifer corresponds to the intensely karstified Triassic plateau where numerous springs are located at the contact between the Paleozoic and Mesozoic formations, forming a strong permeability contrast. In the Paleozoic unit, the springs are associated with olistoliths and minor faults. Remnants of an allochthonous nappe overlying the autochthonous basement are visible in several places across the island and are associated with an alignment of springs. According to Piper diagram, springwaters are classified into two primary hydrochemical facies: Ca^{2+} - HCO_3^- - Mg^{2+} (carbonate signature) and Na^+ - Cl^- (brakish water). However, geology, minor ions and $\delta^{18}O$ and δ^2H composition indicate the presence of multiple aquifer types. The findings of this multidisciplinary work have the potential to provide valuable insights to other Mediterranean islands for sustainable groundwater resource management, if disseminated.

LID 0134
Groundwater as a hidden driver of persistent aquatic pesticide pollution in the Western Cape, South Africa

Gert-Jan Blom[1], Reynold Chow[1,2]*

[1] Soil Physics and Land Management Group, Wageningen University & Research, Wageningen, The Netherlands
[2] Department of Earth Sciences, Stellenbosch University, Stellenbosch, South Africa
* reynold.chow@wur.nl

Keywords: pesticide pollution, groundwater–surface water interaction, passive sampling

Agricultural catchments in the Western Cape, South Africa show persistent pesticide pollution, with several compounds detected year-round despite limited seasonal application. Understanding the role of groundwater in sustaining this pollution is essential for effective management in semi-arid, agriculturally intensive regions. Our study integrates two 14-day passive sampling campaigns at three river sites with nine groundwater grab samples from connected aquifers, which enables a combined assessment of surface and subsurface transport pathways. No significant rainfall occurred during the study period, reducing the likelihood of runoff-driven pathways. Twenty-eight pesticides were analyzed using LC-MS/MS.

Preliminary results reveal widespread detections across both sampling rounds, with multiple compounds occurring in several catchments. Groundwater samples contained mobile and persistent pesticides also found in surface water—most notably imidacloprid—supporting the hypothesis that groundwater acts as a sustained source to surface water, particularly outside main application periods. Cross-catchment overlap further suggests regional persistence and transport rather than isolated local inputs. Sampling artefacts in round one, where PES membranes did not detach properly at two sites, likely led to underestimation of concentrations; however, cumulative detections remain substantial.

Risk screening against Environmental Quality Standards indicates that multiple sites contain several pesticides that approach or exceed thresholds, underscoring concerns about chronic exposure. The combined use of passive samplers and groundwater monitoring provides a powerful framework for disentangling pesticide sources in data-scarce regions. These findings highlight the need to explicitly incorporate groundwater–surface water interactions into pesticide monitoring, modelling, and mitigation strategies in vulnerable agricultural landscapes.

LID 0135
Enhancing groundwater resilience to drought through integrated modelling, Earth Observation and managed aquifer recharge: Insights from the AQUIGROW project

Reynold Chow[1,2]*, Matteo Camporese[3], Alex Furman[4], Claire Lauvernet[5], Christian Massari[6], Adam Szymkiewicz[7]

[1] Department of Earth Sciences, Stellenbosch University, Stellenbosch, South Africa
[2] Soil Physics and Land Management, Wageningen University & Research Wageningen, The Netherlands
[3] Department of Civil, Environmental and Architectural Engineering, University of Padua, Padua, Italy
[4] Civil and Environmental Engineering, Technion – Israel Institute of Technology, Haifa, Israel
[5] UR RiverLy, National Research Institute for Agriculture, Food and the Environment (INRAE), Lyon, France
[6] Research Institute for Geo-Hydrological Protection, National Research Council (CNR), Perugia, Italy
[7] Faculty of Civil and Environmental Engineering, Gdańsk University of Technology, Gdańsk, Poland
* reynold.chow@wur.nl

Keywords: managed aquifer recharge, groundwater resilience, integrated hydrological modelling

Increasing drought frequency and intensity, combined with land-use change and rising water demand, are placing growing pressure on groundwater resources. Managed aquifer recharge (MAR) and soil–aquifer treatment (SAT) offer promising nature-based solutions to enhance groundwater storage and protect water quality, yet their effectiveness remains highly site-specific and insufficiently quantified across contrasting hydroclimatic conditions.

The AQUIGROW project addresses this challenge by integrating field observations, Earth Observation (EO) data, laboratory experiments and numerical modelling to assess groundwater recharge and quality in aquifer systems in Italy, Poland, Israel and South Africa. Integrated surface–subsurface hydrological models (CATHY, HydroGeoSphere) and coupled vadose-zone–aquifer frameworks (HYDRUS–MODFLOW/MT3DMS) are used to quantify recharge dynamics, groundwater responses and contaminant transport under current and future climate and management scenarios. EO-derived irrigation, evapotranspiration and soil-moisture products support recharge estimation and model calibration in data-scarce regions.

Mid-term results show that physics-based models constrained by EO data can reproduce spatial and temporal recharge patterns across climatic gradients. At an Air-SAT site in Israel, field evidence and modelling indicate that extended or continuous flooding can more than double recharge volumes compared to conventional operations, with limited impacts on most water-quality indicators. At a MAR site in South Africa, monitoring indicates that most contaminants of emerging concern are effectively attenuated; however, PFAS compounds remain an issue, requiring dedicated monitoring and treatment.

Overall, AQUIGROW delivers transferable tools and comparative insights to support risk-informed groundwater management and the design of MAR systems that enhance groundwater resilience under increasing drought risk.

LID 0136
Creating the first global hazard map of manganese contamination of groundwater

Joel Podgorski[1]*, Michael Berg[1]

[1] Eawag, Swiss Federal Institute of Aquatic Science and Technology, Dübendorf, Switzerland
* joel.podgorski@eawag.ch

Keywords: manganese (Mn), groundwater hazard, global prediction, machine learning

Although manganese (Mn) is an essential element for human nutrition, exposure to excessive amounts of Mn may be detrimental to health, with drinking water representing a substantial source of dietary Mn. The World Health Organization (WHO) has recently lowered its health-based guideline for Mn in drinking water from 400 µg/L to 80 µg/L, citing new evidence of the health effects on infants.

In order to identify the regions affected by groundwater Mn contamination and the number of people exposed, we have compiled a dataset of nearly 300,000 groundwater Mn measurements along with various environmental parameters to create a global prediction map of high geogenic Mn concentrations using state-of-the-art machine learning. These results were combined with population and groundwater usage rates to estimate that about 200 million people worldwide are at risk from consuming >80 µg/L Mn in drinking water. Although this large number of affected people is comparable to that for the more widely regarded geogenic contaminants of arsenic and fluoride, Mn generally receives much less attention.

In addition to providing insights about the geogenic conditions under which high concentrations of Mn can accumulate in groundwater, this global map provides novel comprehensive information for water and health authorities at regional to national scales where this is important for identifying safe groundwater sources.

LID 0137
Assessing groundwater vulnerability to nitrate contamination in a rice-growing district (Northern Italy) using generalized linear regression models

Petra Baják[1]*, Marco Masetti[1], Arianna Facchi[2], Giulio Gilardi[2], Daniele Pedretti[1], Lorenzo Sangalli[1], Darya Tkachenko[2], Alessandro Sorichetta[1]

[1] Università degli Studi di Milano, Department of Earth Sciences "Ardito Desio" (DiSTAD), Milan, Italy
[2] Università degli Studi di Milano, Department of Agricultural and Environmental Sciences – Production, Landscape, Agroenergy (DiSAA), Milan, Italy
* petra.bajak@unimi.it

Keywords: nitrate contamination, agricultural land use, generalized linear regression models

Despite strict regulations, nitrate contamination of groundwater is a global environmental concern, especially in agricultural areas. The cultivation of rice represents a specific case, as it is traditionally conducted under flooded conditions that favor denitrification and typically result in low nitrate concentrations in groundwater.

This study was carried out in the Lomellina region, a major rice-growing district in Northern Italy, where traditional water seeding with continuous flooding has increasingly been replaced by dry seeding followed by delayed flooding or by an alternation of flooding and dry periods. Despite the advantages that dry seeding has brought to farmers (reduction in working time and use of wheeled vehicles), this conversion has led to several problems, one of which is an increased risk of nitrates leaching into the underlying phreatic aquifer. The objectives of this study were to use geospatial statistical methods to model groundwater nitrate concentrations, identify the main factors controlling their distribution, and ultimately assess groundwater vulnerability to nitrate contamination.

Groundwater was sampled at 27 locations during 13 monitoring campaigns conducted between June 2024 and December 2025. A spatial database of 102 environmental and anthropogenic independent variables was compiled and used to explore statistically significant relationships with the observed nitrate concentrations. Multivariate generalized linear regression models were developed and evaluated using leave-one-out cross-validation.

The best-performing model (adjusted R^2 = 0.75, AICc = 203.3, mean absolute error = 7.92) identified groundwater table depth, groundwater velocity, vertical hydraulic conductivity, soil type, and soil protection capacity as the most influential variables. Based on this model, a groundwater nitrate vulnerability map was produced for the entire study area, indicating that most of the region falls within very low to low vulnerability classes.

The study was carried out in the context of the projects: i) "Applicazione di metodi di statistica spaziale per la valutazione della vulnerabilità e disponibilità della risorsa idrica sotterranea in diversi contesti idrogeologici", funded by the Piano di Sostegno alla ricerca (PSR Linea 4) by the University of Milan, and ii) “PROMEDRICE project (https://promedrice.org/; PRIMA-Section2-2022)” funded, for the Italian partners, by MUR (Italian Ministry of University and Research).

LID 0138
Estuaries as amplifiers of coastal salinization: Implications for soil, groundwater, and agriculture

Hayden Tackley[1]*, Craig Lake[1], Barret Kurylyk[1]

[1] Department of Civil and Resource Engineering & Centre for Water Resources Studies, Dalhousie University, Halifax, Canada
* hayden.tackley@dal.ca

Keywords: estuary, saltwater intrusion, flooding

Climate change is expected to intensify storminess, drought, and sea-level rise, leading to increased salinity and flooding in many estuaries worldwide. While the vulnerability of groundwater along marine coastlines has been widely studied, comparatively little attention has been given to soil and groundwater systems adjacent to estuaries, where highly variable surface water salinity, tidal forcing, and sediment dynamics create complex subsurface responses. This presentation synthesizes results from multi-year field investigations, numerical modeling, and global analysis to assess how estuarine processes may drive soil and groundwater salinization in areas not traditionally considered at risk.

Field studies conducted in a macro-tidal estuary in Atlantic Canada, at the site of a managed dike realignment, demonstrate that episodic flooding by brackish water can rapidly salinize surficial soils, even when groundwater salinity remains buffered by low-permeability sediments. Geophysical surveys, groundwater monitoring, and sediment analyses show that vertical salinization driven by overland flooding and saline sediment deposition can persist long after floodwaters recede, with geomorphological variability strongly controlling salinization patterns. Complementary numerical modeling indicates that increases in estuary salinity associated with sea-level rise may expand subsurface saline plumes laterally, while short-term salinity fluctuations due to drought have more limited groundwater impacts in low-permeability settings.

A global synthesis further reveals that extensive agricultural land and major population centers are located in low-elevation coastal zones near estuaries, highlighting the disproportionate exposure of estuary-adjacent soils and aquifers to compounding climate stressors. Together, these findings show that estuaries act as hydraulic and geochemical amplifiers of coastal salinization, underscoring the need to explicitly consider estuary-adjacent groundwater systems in climate adaptation, land-use planning, and water resource management.

LID 0139
Automated operation of a rural stormwater-based MAR scheme

Lea Augustin[1]*, Thomas Baumann[1]

[1] Technical Universtiy of Munich, School of Engineering and Design, Munich, Germany
* lea.augustin@tum.de

Keywords: stormwater-based MAR, operational control, conformity testing

Managed Aquifer Recharge (MAR) using stormwater sources offers a promising approach for decentralized areas to enhance groundwater resources sustainably. The MAR pilot site in Hüll (Bavaria, Germany) is a blueprint for such schemes using direct infiltration via a well. A comprehensive monitoring framework ensures long-term sustainability, while the systematic collection of high-resolution data proved critical for reducing uncertainties related to system performance and clogging behavior.

While laboratory analyses remain the standard for MAR permitting and compliance, their long processing times limit applicability for operational decision-making. Furthermore, stormwater recharge requires rapid water-quality assessment immediately following rainfall events. To bridge this gap, this work presents an automated control concept that integrates multiparameter online monitoring with laboratory-derived knowledge and contextual information (e.g., weather forecasts) using a qualitative, clustering-based decision framework. Beyond qualitative control, the framework incorporates a technical tier to maintain recharge within hydraulic limits and site-specific operational constraints.

By combining continuous monitoring, targeted laboratory analyses, and catchment-scale contextual data, the proposed control system supports anticipatory MAR operation and contributes to sustainable groundwater management in rural environments. This real-world operational framework provides transferable insights for practitioners and researchers and highlights key lessons for the design, monitoring, and management of stormwater-based MAR schemes.

LID 0140
Activation of reactive zones in aquitards for the mobilization and degradation of persistent and emerging contaminants

Diana Puigserver[1]*, Alberto Millan[1], Jofre Herrero[1], Pasqual Martín[1], Cristina Villanova[1], Alberto Saez[2], Joaquim Farguell[3], Joaquim Vila[4], Xavier Santos[5], Encarnación Moyano[5], Amparo Cortes[6]

[1] Department of Mineralogy, Petrology and Applied Geology, Faculty of Earth Sciences, University of Barcelona (UB), Water Research Institute (IdRA-UB), Barcelona, Spain
[2] Department of Earth and Ocean Dynamics, Faculty of Earth Sciences, University of Barcelona (UB), Barcelona, Spain
[3] Department of Geography, Faculty of Geography and History, University of Barcelona (UB), Water Research Institute (IdRA-UB), Barcelona, Spain
[4] Department of Genetics, Microbiology and Statistics, Faculty of Biology, University of Barcelona (UB), Water Research Institute (IdRA-UB), Barcelona, Spain
[5] Department of Chemical Engineering and Analytical Chemistry, Faculty of Chemistry, University of Barcelona (UB), Water Research Institute (IdRA-UB), Barcelona, Spain
[6] Department of Biology, Health and Environment, Faculty of Pharmacy, University of Barcelona (UB), Water Research Institute (IdRA-UB), Barcelona, Spain
* puigserverdiana@ub.edu

Keywords: aquitard remediation, biotic and abiotic chloroethene degradation, emerging contaminants

Dense Non-Aqueous Phase Liquids (DNAPL) of chlorinated solvents commonly accumulate in basal aquitards, where low hydraulic conductivity, matrix diffusion and limited advective transport promote long-term persistence. Although aquitards are often considered barriers to remediation, internal textural heterogeneities such as interbedded coarse sands and fine gravels may locally increase transmissivity, generating redox transition zones where coupled biotic and abiotic processes occur.

This study evaluates an in situ strategy to activate these reactive zones in a DNAPL-impacted aquitard south of Figueres (Catalonia, Spain), affected by perchloroethylene (PCE), trichloroethylene (TCE), cis-dichloroethylene (cDCE) and selected emerging contaminants. Detailed characterization based on continuous core drilling allowed delineation of DNAPL distribution, lithological contrasts, mineral phases and indigenous microbial communities, identifying sandy–gravelly interlayers where natural attenuation is enhanced.

A low-pressure injection approach combining zero-valent iron (ZVI) and a bioestimulant (EHC® Reagent) was applied in selected intervals to stimulate reductive dichlorination while preserving formation structure. The intervention promoted bioactive domains with redox oscillations and coexisting aerobic and anaerobic conditions, stimulating *Dehaloccoides* spp. and favoring precipitation–dissolution cycles of neoformed Fe and Mn minerals contributing to abiotic degradation.

Post-injection monitoring using continuous coring and multilevel CMT piezometers assessed reagent distribution and groundwater quality evolution. Results show that low-permeability layers can be transformed into reactive zones through minimally invasive actions, supporting aquitards as Nature-Based Solutions for DNAPL source management and sustainable remediation of persistent and emerging contaminants.

The authors would like to thank the European Commission and Agencia Española de Investigación (AEI), for funding in the frame of the collaborative international consortium ClimEx-PE financed under the 2022 Joint call of the European Partnership 101060874 — Water4All.

LID 0141
Puerto Rico's submarine groundwater discharge characterization: North Coast Limestone Aquifer System

Jobel Y. Villafañe Pagán[1]*, Henrietta Dulai[1], Melody Cosme Morales[1]

[1] University of Hawaii at Manoa, Honolulu, United States
* jyvilla@hawaii.edu

Keywords: Submarine Groundwater Discharge, Coastal Aquifer, Karst hydrogeology

The North Coast Limestone Aquifer System in Puerto Rico (PR) is a hydrostratigraphically complex, karst-dominated groundwater system that favors Submarine Groundwater Discharge (SGD) along the coast. It has been proven that SGD directly impacts coastal water quality, nutrient supply, temperature, and salinity regulation. This study advances the detection and characterization of SGD in PR by integrating thermal infrared (TIR) drone imagery with detailed geochemical sampling. TIR drone technology was utilized to map SGD by detecting temperature anomalies where colder groundwater interacted with warmer marine waters. Field sampling was strategically performed during low tide to ensure targeted data collection from critical SGD zones. Mass balance calculations based on salinity, and silicate were employed to quantify SGD fluxes. Nutrient, trace metal, and contaminant of emerging concern (CEC) concentrations observed in springs were then multiplied by the estimated SGD rates to calculate solute fluxes. Maps depicting identified springs, seepage areas, and thermal signatures were produced, and summarized SGD fluxes and associated nutrient and metal concentrations at seven study sites. We find that dissolved inorganic nitrogen is highly elevated in SGD in PR, while phosphate concentrations are at ambient levels, producing extreme DIN:DIP ratios threatening the nutrient balance of coastal ecosystems. This comprehensive SGD study provided an in-depth assessment of SGD's impact on coastal water quality in Puerto Rico.

LID 0144
Analytical hydrogeology of unconfined Dupuit-type aquifers

Romain Chesnaux[1]*

[1] Université du Québec à Chicoutimi, Saguenay, Canada
* romain_chesnaux@uqac.ca

Keywords: groundwater flow, analytical solutions, Dupuit-type unconfined aquifers

Analytical solutions still have a crucial role to play in hydrogeology on a global scale, and should be viewed as an equally powerful and complementary collaborator along with advanced numerical tools. In parallel with the most recent numerical modeling programs enriched by artificial intelligence learning models, analytical solutions using closed-form equations are still being developed and perfected. Analytical solutions are not only relevant for solving problems, but they can be useful for process understanding. They are still being used and perfected by hydrogeologists to solve groundwater problems and should always be considered an efficient tool available in the toolbox of hydrogeologists. This presentation focuses on compiling and presenting a series of analytical solutions for solving practical problems in unconfined Dupuit-type flow systems for both inland and coastal aquifers. These closed-form solutions can be used to improve knowledge of quantitative hydrogeology and to solve practical problems at an academic and professional level. Solving analytical solutions usually requires low-cost, low-tech, back-of-the-envelope calculations or a simple Excel spreadsheet.

Illustrations are given for solving groundwater flow, groundwater velocity and transit time, groundwater recharge, and groundwater volume equations in unconfined Dupuit-type aquifers. A specific application is proposed for assessing seawater intrusion and the impacts of climate change for different scenarios, specifically in Dupuit-type coastal and island aquifers.

The proposed solutions are intended for practitioners in hydrogeology, for undergraduate and graduate students in Earth sciences/hydrogeology or civil/environmental engineering, as well as for academic researchers.

LID 0146

Spatial variability of groundwater nitrate and fecal sterol signatures in an intensively farmed area of Western Japan

Zhuolin Li[1], Kei Nakagawa[2]*, Yuji Takao[2], Ronny Berndtsson[3,4]

[1] Graduate School of Integrated Sciences and Technology, Nagasaki University, Nagasaki, Japan
[2] Institute of Integrated Science and Technology, Nagasaki University, Nagasaki, Japan
[3] Division of Water Resources Engineering, Lund University, Lund, Sweden
[4] Centre for Advanced Middle Eastern Studies, Lund University, Lund, Sweden
* kei-naka@nagasaki-u.ac.jp

Keywords: groundwater nitrate pollution, fecal sterols, agriculture

Groundwater nitrate contamination in agricultural regions is a long-standing challenge. In an intensively farmed area of western Japan, groundwater NO_3–N shows pronounced spatial variability with localized hotspots, making source identification challenging. The study area was the Shuso Plain in Saijo City, Ehime Prefecture. The Shuso Plain is an alluvial plain formed along the lower reaches of the Nakayama River, with rice paddies accounting for 60% of its area. Fruit orchards are spread out in the hinterland, and livestock farms are dispersed throughout the region.

In this study, we collected 17 groundwater samples and measured NO_3–N concentrations along with fecal sterols (coprostanol, cholestanol, cholesterol, and β-sitosterol). Source interpretation was supported by land use and local livestock information. We also applied a sterol ratio index based on coprostanol and cholestanol and classified fecal impact levels.

NO_3–N concentrations ranged from 0.8 to 8.0 mg/L, indicating strong spatial heterogeneity. Fecal sterols were widely detected, with coprostanol ranging from 22.3 to 219.3 ng/L and cholestanol from 86.4 to 527.6 ng/L, whereas cholesterol was consistently high across all samples (599.4–2,788 ng/L). In contrast, β-sitosterol showed a wide range (6.7–456.5 ng/L), suggesting potential inputs from plant-derived materials or manure associated with herbivorous livestock. The sterol ratio ranged from 0.06 to 0.43, and several samples exceeded 0.30, approaching the commonly used threshold indicative of fecal influence. Overall, the combined patterns of NO_3–N, sterol composition, and sterol ratios suggest that nitrate contamination in the study area is not spatially uniform but is jointly controlled by the intensity of agricultural activity, land use configuration, and groundwater transport processes. Sterol indicators provide complementary evidence for identifying fecal-source influences and interpreting localized NO_3–N hotspots.

LID 0147
Migration of emerging contaminants at two riverbank filtration sites located in the Warta river valley (Poland) – Results of the one-year monitoring

Krzysztod Dragon[1]*, Roksana Kruć-Fijałkowska[1], Marcin Siepak[1]

[1] Adam Mickiewicz University in Poznań, Faculty of Geographical and Geological Sciences, Institute of Geology, Hydrogeology and Water Protection Research Unit, Poznań, Poland
* krzysztof.dragon@amu.edu.pl

Keywords: emerging contaminants, riverbank filtration, contaminants migration

Emerging contaminants, such as pharmaceuticals, personal care products, drugs, or pesticides, have been increasingly detected in aquatic environments over the last few decades. The most apparent sources of pharmaceutical contamination in river water are wastewater treatment plant effluents discharged into the rivers. Special emphasis on investigations of emerging contaminants is important for riverbank filtration systems (RBF), due to the strong dependence of extracted water quality on the river (source) water quality. Riverbank filtration systems can effectively remove these contaminants from polluted river water; however, removal efficiency varies and depends on multiple environmental factors, including: aquifer lithology, permeability, aquifer thickness, hydraulic gradients, quality of source water, etc. The construction features of the well fields, including well-screen locations, distances of wells from the river, and pumping rates, are also important.

The two RBF sites in the Warta River valley (Poland) were examined for the occurrence of pharmaceuticals: the Śrem waterworks, located upstream of the Poznan agglomeration, and the Gorzów waterworks, located downstream of the agglomeration. The water samples for pharmaceuticals investigation (114 substances in total) were collected four times during the hydrological year of 2025 (in quarterly intervals) from the river and from continuously pumped wells at each site. In the Śrem waterworks, it was possible to select two wells located at a close distance from the river (40 m), and two wells located at a greater distance from the river (70 m), while in the Gorzów waterworks, one well was selected for investigation, which is located 70 m from the river. On both sites, the observation wells located between the river and the extraction wells were included for investigation.

A visible increase in pharmaceutical concentrations was observed along the river. The sum of pharmaceutical concentrations ranges from 7735 to 15601 ng/l at the Śrem location, whereas at the Gorzów location it ranges from 8087 to 16914 ng/l. Most likely, this increase is attributable to the influence of treated sewage effluent from the Poznań agglomeration and from towns and villages along the river.

A substantial difference in the removal rate of pharmaceuticals was observed in the extraction wells. At the Śrem site, the sum of pharmaceutical concentrations (SPC) in well XII (where using strontium isotopes, the lowest contribution of the river water in total water balance was documented - 30%), the SPC varied between in range163-916 ng/l. In contrast, in well XIII, where the highest contribution of river water was detected (82%), the SPC ranged from 3850 to 3920 ng/L. At the Gorzów site, SPC in the well ranged from 205 to 354 mg/l, with one event at 5243 ng/l (most likely due to secondary contamination).

The research presented demonstrates markedly different rates of pharmaceutical removal across sites with similar hydrogeological conditions and underscores the need for monitoring, particularly at groundwater strongly influenced by river-water contamination (e.g., at RBF sites).

This work has received funding from the National Science Centre of Poland (grant no. 2021/41/B/ST10/00094).

LID 0148
A new approach for assessing geothermal reservoir potential in South-Eastern Serbia

Tanja Petrovic Pantić[1]*, Marina Magazinović[1], Norbert Caldera[2], Ignasi Herms[2], Katarina Atanasković Samolov[1]

[1] Geological survey Serbia, Belgrade, Serbia
[2] Institut Cartogràfic i Geològic de Catalunya, Spain
* tanja.petrovic@gzs.gov.rs

Keywords: geothermal energy, heat in place/heat storage potential, radiogenic heat

The south-eastern part of Serbia represents a highly prospective geothermal area, in which five geothermal reservoirs have been identified. Thermal waters are associated with the granitoid massifs of the Surdulica, Bujanovac, Jastrebac and Lece andesite massif, as well as with faults and fracture systems within metamorphic rocks. The area is classified as an extensional-domain geothermal play type. Natural spring temperatures reach up to 82°C, while borehole-produced water temperatures reach up to 111°C. Groundwaters are predominantly mineralized, while low-mineralized waters occur mainly within the andesites. The dominant hydrochemical facies are HCO_3-Na and HCO_3-SO_4-Na.

To assess the potential for deep geothermal energy utilization, the Heat in Place (HIP) and Heat Storage Potential (HSP) were calculated with 1D HIP/HSP Calculator which is developed in the framework of the Pan-EU Atlas SGC, Geological Service for Europe (GSEU) project co-funded by Horizon Europe.

The total HIP of the investigated area is estimated at 96,322 PJ. The Surdulica reservoir has the largest value, with an estimated HIP of 82,500 PJ. These results are supported by radiogenic heat production values of the Surdulica granitoid, ranging between 2.8 and 3.44 $\mu W/m^3$.

The HIP of the Sijarinska crystalline schists reservoir is 7,690 PJ, while lower values were calculated for the Jastrebac metamorphic reservoir (768 PJ) and Bujanovac reservoir within granitoid gruss (754 PJ). The Lece andesite reservoir shows a lower HIP (4,610 PJ) compared to its estimated HSP (7,650 PJ). The heat storage potential of the granitoid massifs and reservoirs in metamorphic rocks is partly limited by high water temperatures, increased TDS, and dense fracture systems, which may enhance heat losses.

This study refines previous geothermal investigations in the south-eastern part of Serbia and confirms the high heat potential of the Surdulica massif, as well as the significant heat storage potential of the Lece massif.

LID 0149
Forest–groundwater interactions across scales controlling groundwater dynamics in the Weierbach Experimental Catchment, Luxembourg

Laurent Gourdol[1]*, Núria Martínez-Carreras[1], Stanislaus Schymanski[1], Viola Huck[1], Jean-François Iffly[1], Jérôme Juilleret[1], Cyrille Tailliez[1], Christophe Hissler[1]

[1] Luxembourg Institute of Science and Technology, Belvaux, Luxembourg
* laurent.gourdol@list.lu

Keywords: forest headwater catchment, slate bedrock, groundwater dynamics

Forests, as major carbon sinks, play a crucial role in climate regulation, yet their health and carbon-storage capacity are increasingly threatened by multiple stressors. In Europe, droughts are becoming longer and more intense, with low soil-moisture conditions now extending into winter. Drought has even surpassed wind as the continent's primary forest disturbance. During periods of limited soil water availability, groundwater can be an essential water source for trees. A better understanding of the controls and dynamics of this deeper water store is therefore key for predicting the resilience of forest ecosystems under climate change. This study investigates how geological, topographic, soil, and vegetation-related factors jointly regulate groundwater responses in the Weierbach Experimental Catchment (WEC), a slate forested headwater in Luxembourg (0.45 km^2). We rely on an integrated observational approach, leveraging a dense monitoring network consisting of 26 piezometers, 33 soil moisture sensors, and 4 stream gauges, together with records of multiple climatic variables. To bridge the gap between point-scale observations and catchment-scale architecture, we integrate geophysical surveys – including electrical resistivity tomography and borehole logging – to characterize soil-to-bedrock subsurface heterogeneity, with LiDAR and aerial photography data to define ground and canopy features. Besides responses of the groundwater table to precipitation inputs, we examine feedbacks between forest ecosystem water demand and groundwater depletion during summer baseflow periods. By correlating local topography and vegetation characteristics with soil-moisture and piezometric fluctuations, this research aims to refine our understanding of how groundwater supports the resilience of the WEC forest ecosystem, and how tree water use affects groundwater resources.

LID 0151
Three-dimensional inter-basin groundwater flow toward a groundwater-fed stream: Identification, partition, and quantification

Peng-Fei Han[1]*, Li Wan[1], Xu-Sheng Wang[1], Xiao-Wei Jiang[1]

[1] China University of Geosciences, Beijing, China
* pfhan@cugb.edu.cn

Keywords: inter-basin groundwater flow, divide, numerical model

Inter-basin groundwater flow (IGF), defined as groundwater flows across the topographic divides, occurs in nature as a common phenomenon, and seriously affect water balance and solute transport in a basin. Although the existence of IGF has been checked in drainage basins with indirect methods, such as using information of hydrogeochemistry, few studies are conducted to directly identify and quantify the IGF in the three-dimensional (3D) space using numerical modeling of groundwater flow. In this study, we identify, partition and quantify IGF based on a regional-scale 3D groundwater flow model covering several traditional surface water basins. The investigation is focused on the Hailiutu River, a groundwater-fed stream in the Ordos Plateau, China. It is the first time that the source zones and 3D paths of IGF as well as its contribution to the streamflow are fully captured for a groundwater-fed stream. Results indicate that the IGF contributes 36%~59% to the baseflow and 32%~52% to the streamflow of the Hailiutu River, through different groups of circulation paths with the maximum depth up to ~ 1000 m. Uncertainty analyses of the model show that the contribution of IGF to the streamflow is positively correlated to the infiltration recharge and hydraulic conductivities of the aquifer media. Several indirect methods are also checked for comparison, but they could only be used to assess the potential contribution of IGF, not the IGF paths. This study will facilitate in deeply understanding the evolution mechanism of the inter-basin groundwater circulation and the interaction between surface water and groundwater.

LID 0153
Quantifying the geothermal impact of sedimentary heterogeneity through stochastic reservoir modeling: Sergnano Gravel Formation (Late Messinian), Po Basin, NW Italy

Georgios Pantopoulos[1]*, Luca Colombera[1], Daniel Barrera-Acosta[1], Giovanni Toscani[1], Andrea Di Giulio[1]

[1] University of Pavia, Department of Earth and Environmental Sciences, Pavia, Italy
* georgios.pantopoulos@unipv.it

Keywords: geothermal energy, Po Basin, sedimentary heterogeneity

The Sergnano Gravel Formation (late Messinian) in the subsurface of the Po Basin (Italy) is a significant yet underexplored target for medium- to low-enthalpy geothermal resources, with expected temperatures of 40-60°C at reservoir depths. This study investigates the impact of sedimentary heterogeneity on geothermal potential through stochastic geological modeling and numerical reservoir simulations over an area around Treviglio, ~30 km east of Milan, Lombardy.

A 3D static geological model extending to a depth of 1800 m was developed, accounting for two major paleogeographic domains inherited from the Messinian sea-level drawdown, consisting of paleohighs and paleovalleys with distinct depositional environments and lithological assemblages. Using Sequential Indicator Simulation (SIS), 20 facies realizations (10 per domain) with three categorical facies were generated, employing both equidimensional and anisotropic variograms, with the latter capturing the presumed elongation of alluvial-fluvial sedimentary bodies sourced from the Southern Alps. TOUGH2 fluid flow and heat transport simulations were performed for each static model realization under two scenarios of permeability anisotropy (Kh/Kv = 1 and Kh/Kv = 10), to assess thermal behavior and fluid flow characteristics of geothermal doublet operation.

The results demonstrate that sedimentary heterogeneity, controlled by Messinian paleotopography, significantly influences heat distribution, fluid circulation patterns, and overall geothermal potential. Older stratigraphic units on paleohighs exhibit enhanced reservoir quality compared to younger units representing paleovalley infills, with permeability anisotropy playing a critical role in vertical heat transfer. This study provides a methodological framework for assessing geothermal resources in similar heterogeneous clastic formations and highlights the importance of detailed paleogeographic reconstruction in geothermal exploration and production.

LID 0154
Construction of groundwater vulnerability maps in a river basin with few data on groundwater and pressure in the Dominican Republic

Laurence Gourcy[1]*, Nicolas Surdyk[1], Alexandre Brugeron[1], M. Delaunay[1], A. Gutierrez[1], Berenice Marte[2], Antonio Mendez[3]

[1] BRGM, Orleans, France
[2] MIMARENA, Dominican Republic
[3] INDRHI, Dominican Republic
* L.gourcy@brgm.fr

Keywords: groundwater, nitrate, pesticides

The Dominican Republic is divided by 8 hydrogeological basins. The Yaque del Sur Basin is one of the largest with 4972 km^2. Two mountain ranges shape the landscape; the central mountain range, with heights of over 2000 m, composed of low permeability hard-rock aquifer and the Neiba mountain range composed of carbonated rocks with medium to high permeability. Between these two mountain ranges lie vast plains, San Juan and Neiba valley, that allow for the development of agriculture. The development of the agriculture is based mainly on the use of surface water, stored in dams and brought to plots via a network of canals.

Groundwater resources are nevertheless significant in the Yaque del Sur Basin but are currently used mainly only for drinking water supply. Therefore, the need to protect groundwater resources and monitor their quality has not yet been incorporated into management practices.

Agriculture is varied, ranging from small-scale traditional farming to intensive sugar cane cultivation for international export. Even though pesticide use is often limited by costs, inputs to the soils of the main valleys exert significant pressure on the resource. The project to study the impact of agricultural pressures on aquifers has been hampered by a lack of knowledge about aquifers and their vulnerability, as well as about agricultural practices in terms of fertilizer and pesticide use.

Data on the agriculture practises were collected from various sources and local practices were collected from local associations. The maps were discussed during meetings to ensure validation by local stakeholders and to take uncertainties in the calculations into account for the final maps. The two maps of nitrate and pesticides vulnerability were confronted with the few field data. The challenge remains for the authorities to take into account the significance of the pressures on the resource reflected in the thematic maps produced with the AFD/BRGM project.

LID 0155
Forecasting yields from public water supply boreholes

Kirsty Upton[1]*, Matt Arran[1], Chris Jackson[2], Setareh Nagheli[2], Ben Marchant[2]

[1] British Geological Survey, Edinburgh, UK
[2] British Geological Survey, Keyworth, UK
* kirlto@bgs.ac.uk

Keywords: groundwater, yields, forecasting

Public water supply providers need to understand how much groundwater can be pumped reliably during droughts. In the UK this is based on historical observations of pumping rates and groundwater levels in boreholes, considered alongside the physical characteristics of sources, e.g., the depths of boreholes, pumps, and inflow horizons. However, this approach does not provide information about how groundwater yields will respond during potentially more extreme future droughts. We present a modelling framework that simulates the water level in groundwater supply boreholes in response to pumping and regional groundwater levels without the need for a regional groundwater model.

The SPIDERR modelling code – a 3D distributed radial groundwater flow model – represents local hydrogeological processes in and around an abstraction borehole. The boundary condition of this model is driven by the AquiMod code, which simulates the groundwater level at a point in the regional aquifer by linking simple algorithms of soil drainage, unsaturated zone flow, and groundwater flow. This simple modelling framework is shown to accurately and efficiently simulate the time-varying water level in a pumped borehole, reproducing the results of a much more complex regional groundwater model.

To complement this modelling framework and provide a useful tool for operational groundwater supply management, an emulator was developed using a recurrent neural network, which was trained on the input-output relationship of the AquiMod-SPIDERR model. This was able to accurately model the water level in a borehole in response to pumping, rainfall, and potential evapotranspiration, allowing multiple scenarios of abstraction and climate to be explored very quickly.

We demonstrate the application of this framework to forecast the behaviour of a UK groundwater supply source over seasonal to multi-decadal timescales.

LID 0156
A risk-based approach to groundwater governance in West Africa

Kirsty Upton[1*], Laura Holliday[1], Raghav Patel[2], Tom Heath[3], Alejandro Jimenez[3], Antoine Delepiere[3], Franck Bouvet[4], Fiona Ward[4]

[1] British Geological Survey, Edinburgh, United Kingdom
[2] British Geological Survey, Keyworth, United Kingdom
[3] IVL Swedish Environmental Research Institute, Stockholm
[4] UNICEF

Keywords: governance, management, risk

Effective groundwater governance and management attempts to balance the socio-economic benefits of groundwater resource development with environmental sustainability and protection. This is imperative to secure the long-term availability and quality of groundwater resources while safeguarding their vital ecological functions. We present a risk-based approach to support the development of effective governance systems, which focuses on groundwater management actions that directly address groundwater quality and quantity risks.

This work forms part of a broader governance tool, which is being developed through a collaboration between BGS, BGR, IVL and UNICEF. The tool, which aims to enable government agencies to develop tailored groundwater governance systems, considers three key components: the hydrogeological system; the institutional landscape; and water users. The tool is designed to be widely applicable, but has been developed within the context of West Africa.

For the hydrogeological system, a risk-based approach to groundwater management is presented based on a risk framework, which considers groundwater quality and quantity risks as a result of exposure to natural or anthropogenic hazards. The translation of hazards into risk is dependent on the nature of the hazard and the vulnerability of the groundwater system to that hazard. We focus on the groundwater system as the primary receptor for risk but also consider cascading impacts that could result from groundwater depletion or contamination, particularly risks to the wider environment. Four phases of assessment are presented to guide users towards an overall definition of risk for which proportionate management actions can be defined.

The risk assessment is broadly illustrated for the hydrogeological context of West Africa, and we present provisional results from a pilot of the governance tool in Chad.

LID 0157
Quantifying the impact of climate drivers on groundwater dynamics in diverse environmental settings and heterogeneous time series data – a method comparison

Annemarie Bäthge[1]*, Robert Reinecke[1]

[1] Johannes Gutenberg - University Mainz, Institute of Geography, Mainz, Rhineland-Palatinate, Germany
* a.baethge@uni-mainz.de

While critical to humans and ecosystems, groundwater accessibility is threatened by climate change, which alters groundwater recharge and can lead to water table decline. However, quantifying groundwater response to climatic changes remains highly uncertain. Modeling efforts are constrained by the oversimplification of processes, a lack of data for calibration and validation, and an uncertainty regarding processes and state variables. Improving our understanding of hydrological systems requires better quantification of the relationship between individual system inputs (climate signals) and outputs (groundwater table). However, this task is challenging, as groundwater is an integral part of the Earth system, where complex feedback mechanisms and multiple interacting factors and drivers (confounders) complicate the investigation of single processes. Topography, for example, is a core driver of groundwater flow and determines water table depth as well as where recharge and discharge areas develop. Geological properties like permeability and porosity strongly influence groundwater flow, response time, and storage capacity. Infiltration from surface waters is often the main source of groundwater recharge in drylands and may blur the direct influence of precipitation. Consequently, the nature and strength of the climate-groundwater connection are likely to vary across different environmental contexts. In particular, the subsurface's damping effect complicates a climate-groundwater analysis. Damping is described as the delay and smoothing of an output signal (i.e., water table) in a system compared to the input signal (i.e., precipitation). This effect is not only dependent on static subsurface characteristics but also nonstationary and nonlinear. Finding a relationship between precipitation and groundwater time series with classical correlation analysis remains, therefore, often unsuccessful. Here, we propose analyzing in situ groundwater time series and other groundwater-associated variables using statistical methods that account for confounders and damping. We compare the performance and feasibility of methods like (1) partial cross-correlation, (2) deconvolution, (3) clustering of pulse-response functions (a byproduct from deconvolution), (4) clustering functional relationships between climate variables and groundwater, and (5) causal interference methods (i.e., PCMCI–CMI). We give an overview of the advantages and disadvantages of every tested method. We aim to provide clarity in a landscape of numerous available methods and to offer practical guidance for holistic analyses that encounter similar challenges.

LID 0158
Contaminants of emerging concern in circular water reuse: Evidence from a treated-wastewater managed aquifer recharge scheme in South Africa

Maposholi Mokhethi[1], **Reynold Chow**[1,2]*

[1] Department of Earth Sciences, Stellenbosch University, Stellenbosch, South Africa
[2] Soil Physics and Land Management Group, Wageningen University & Research, Wageningen, The Netherlands
* reynold.chow@wur.nl

Keywords: managed aquifer recharge, contaminants of emerging concern, groundwater quality

Managed aquifer recharge (MAR) using stormwater and treated wastewater is a key strategy for improving water security in water-stressed regions. In the Atlantis Aquifer, MAR has operated for more than four decades, yet concerns remain about contaminants of emerging concern (CECs) entering the system and their implications for groundwater quality. Our study investigates the sources, distribution and attenuation of CECs in the Atlantis MAR scheme using samples collected in 2019, 2021 and 2023 from treated wastewater, stormwater, naturally recharged groundwater and MAR-impacted groundwater.

Across the three campaigns, between 127 and 649 compounds were analyzed, including pharmaceuticals, pesticides, industrial chemicals and PFAS. MAR-impacted groundwater consistently showed higher CEC detections and concentrations than naturally recharged groundwater, confirming treated wastewater and stormwater as the dominant sources. However, detections of pesticides and PAHs in naturally recharged groundwater also indicate contributions from atmospheric deposition linked to surrounding agricultural and urban land uses. Along the MAR flow path, most CECs decreased due to dilution and biodegradation, while PFAS concentrations increased, reflecting their persistence and mobility.

The results highlight both the benefits and limitations of MAR as a climate-resilient water supply option. While natural attenuation reduces many CECs, persistent compounds such as PFAS accumulate along the flow path, suggesting that post-abstraction treatment may be required to ensure safe drinking water. These findings provide critical insights for the design and management of MAR schemes in South Africa and other semiarid regions facing similar water scarcity challenges.

LID 0159
Groundwater warming in Switzerland: Trend analyses, seasonal dynamics, and hydrogeological controls

Christian Moeck[1,2]*

[1] Eawag – Swiss Federal Institute of Aquatic Science and Technology, Dübendorf, Switzerland
[2] CH-GNet: Swiss Groundwater Network, Dübendorf, Switzerland
* christian.moeck@eawag.ch

Keywords: groundwater temperature trends, climate change, hydrogeological controls

A groundwater temperature dataset from >100 monitoring sites across Switzerland, including springs, piezometers, and abstraction wells, was evaluated for the period 1990 to early 2025. Trends were analyzed using non-parametric methods and linear regression, complemented by seasonal and hydrogeological meta-information.

The results indicate significant groundwater warming at nearly all stations. Since the 1990s, deviations from the long-term mean have steadily increased, with the 2020s representing the warmest decade within the observation period. Approximately 52% of the stations exhibit statistically significant trends, with warming rates ranging between 0.2 and 0.8 K per decade. Seasonal analyses reveal that warming occurs in all seasons, albeit with varying magnitudes. Comparison with air temperature trends shows that in about two-thirds of the cases, air temperatures exhibit stronger trends than groundwater temperatures. At the same time, observed time lags and attenuation effects reflect the thermal inertia of the subsurface. These findings allow inferences regarding flow paths, retardation processes, and groundwater residence times in aquifers.

In addition, site-specific factors (e.g., aquifer type, land use, thickness of the unsaturated zone, elevation, and number of snow-cover days) were examined to explain the spatial heterogeneity of trends. The study demonstrates that groundwater warming in Switzerland is a widespread phenomenon closely linked to climate change, yet modulated by local hydrogeological characteristics. These findings have far-reaching implications for drinking water supply, ecosystem protection, and the sustainable use of geothermal resources.

LID 0160
Downscaling GRACE data for physically consistent monitoring of groundwater storage changes and associated land subsidence

Sebastian Walczak[1]*, Artur Guzy[1]

[1] AGH University of Krakow, Faculty of Geo-Data Science, Geodesy and Environmental Engineering, Krakow, Poland
* walczak@agh.edu.pl

Keywords: GRACE downscaling, groundwater depletion, land subsidence, PINNs

Groundwater extraction is a major driver of land subsidence in densely populated delta regions, arid areas, and post-mining basins worldwide. Declining groundwater heads lead to aquifer-system compaction, infrastructure damage, and increased flood vulnerability, posing long-term environmental and socio-economic risks. Effective monitoring at local scales remains challenging, particularly where in situ observations are sparse or discontinuous.

The GRACE (Gravity Recovery and Climate Experiment) mission provides information on terrestrial water storage changes at continental to regional scales. However, its coarse spatial resolution (~300 km) prevents direct application for monitoring groundwater dynamics in small, high-risk areas. Existing machine learning-based downscaling approaches improve spatial detail but frequently neglect physical consistency, leading to violations of mass conservation and hydrological balance.

This study presents a prototype downscaling framework based on Physics-Informed Neural Networks (PINNs), designed to enhance the spatial resolution of GRACE-derived signals while explicitly enforcing physical constraints. The proposed architecture integrates governing hydrological relationships into the training process, ensuring consistency with water balance principles. Groundwater storage variations are isolated using GLDAS (Global Land Data Assimilation System) outputs and validated against independent high-resolution datasets, including numerical hydrogeological models, monitoring wells, piezometric records, and InSAR-derived vertical displacement measurements.

The expected outcome is a transferable, reproducible methodology for physically consistent GRACE downscaling applicable to vulnerable environments worldwide. By bridging satellite gravimetry with local-scale hydrogeological processes, the proposed approach supports groundwater management and risk assessment in areas exposed to groundwater-induced land subsidence.

This research was carried out within the framework of the Excellence Initiative – Research University programme at AGH University of Krakow. The study was supported by the AGH University of Krakow grant system for research projects carried out with the participation of doctoral students (Action D4), under the competition "Minigranty uczelniane na prace badawcze realizowane przez doktorantów AGH – edycja VII" (Application No. 17297, decision date: 25 March 2026).

LID 0161
Hydrogeological monitoring of water resources during Kéré drought events in Androy, Southern Madagascar (1991 and 2015)

Miora Harivony Rakotondrabe[1,2*], Felaniaina Rakotondrabe[3], Ononamandimby Antsonantenainarivony[1]

[1] University of Vakinankaratra, Antsirabe, Madagascar
[2] Ministery of Public Health, Antananarivo, Madagascar
[3] UNESCO, Antananarivo, Madagascar
* rakmiora@gmail.com

Keywords: Kéré, drought, water

Kéré, a drought-induced famine, represents a major systemic challenge for water security in the semi-arid Androy region of southern Madagascar. In a context of low and highly variable rainfall, groundwater constitutes the primary and often the only perennial water resource for rural populations. Extreme droughts, combined with chronically insufficient water infrastructure, deforestation and high socio-economic vulnerability, intensify pressure on both shallow and deep aquifers.

This study presents a comparative hydrogeological analysis of two major Kéré crises separated by a quarter century: 1991 (SOS-Sud) and 2015. The objective is to assess the evolution of groundwater stress, resource failure mechanisms and the effectiveness of monitoring practices. The methodology is based on a retrospective analysis combining reconstructed rainfall and piezometric time series, socio-hydrological data, and cartographic analyses of arid zone expansion, spatial distribution of water abstraction points and changes in cultivated areas. Electrical conductivity and chloride concentrations were analysed to characterise groundwater mineralisation dynamics during periods of intensive pumping.

Results show that in 1991, with annual rainfall below 300 mm, the water crisis was primarily driven by an absolute rainfall deficit, leading to a collapse of alluvial aquifers (up to −70% of piezometric levels) and early depletion of traditional wells (ketsa). In 2015, despite slightly higher rainfall (~450 mm), the prolonged duration of drought (18 months) and increased anthropogenic pressure caused faster and deeper groundwater drawdown, accompanied by chemical degradation linked to lateral saline intrusion in coastal sedimentary aquifers.

The comparison highlights a critical transition in monitoring practices, from sporadic manual measurements to the emergence of instrumented monitoring networks and GIS-based tools. The study emphasizes the need to shift from reactive crisis management to permanent and automated groundwater monitoring integrated into early warning systems, as a key lever for strengthening water security and resilience to Kéré droughts in southern Madagascar.

LID 0163
Natural attenuation of emerging and biological contaminants during Managed Aquifer Recharge (MAR) of coastal aquifers using reclaimed water

Diana Puigserver[1]*, Laura Rincon[1], Alberto Millan[1], Humbert Salvado[2], Samuel Hernandez[2], Marta Rusiñol[3], Silvia Bofill[3], Jofre Herrero[1], José Francisco Garcia[4]

[1] Department of Mineralogy, Petrology and Applied Geology, Faculty of Earth Sciences, University of Barcelona (UB), Water Research Institute (IdRA-UB), Barcelona, Spain
[2] Department of Evolutionary Biology, Ecology and Environmental Sciences, Faculty of Biology, Water Research Institute (IdRA-UB), Barcelona, Spain
[3] Department of Genetics, Microbiology and Statistics, Faculty of Biology, Water Research Institute (IdRA-UB), Barcelona, Spain
[4] Department of Chemical Engineering and Analytical Chemistry, Faculty of Chemistry, Water Research Institute (IdRA-UB), Barcelona, Spain
* puigserverdiana@ub.edu

Keywords: Managed Aquifer Recharge, natural attenuation, emerging contaminants

Managed Aquifer Recharge (MAR) using reclaimed water is increasingly applied to enhance groundwater availability and resilience to climate change in water-stressed regions. In coastal aquifers, MAR can help control seawater intrusion; however, concerns remain regarding potential impacts on groundwater quality and submarine groundwater discharge. These risks have traditionally been addressed through advanced reclaimed water treatment, often involving high operational costs due to the presence of emerging contaminants and microbial indicators.

Many aquifers exhibit an intrinsic capacity for natural attenuation of contaminants through coupled physical, chemical and biological processes. Characterizing these processes at laboratory and field scales is essential to support risk-based MAR design and to optimize treatment requirements.

This study investigates natural attenuation processes in the alluvial aquifers of the Lower Muga basin (NE Spain). Boreholes with continuous core recovery were drilled, and microcosm experiments were conducted using sediments from the upper unconfined and lower confined aquifers, groundwater, and different proportions of reclaimed water. Attenuation of selected emerging contaminants (including pharmaceuticals such as carbamazepine, diclofenac, venlafaxine and benzotriazoles) and biological indicators (*E. coli, enterococci, Clostridium* perfringens and human adenoviruses, HAdV) was evaluated.

In parallel, a pilot-scale MAR test was monitored using CMT (Solinst) multilevel piezometers to assess the spatial and temporal evolution of groundwater quality. Results indicate that MAR with reclaimed water is feasible in this coastal aquifer, contributes to limiting seawater intrusion, and may support the protection of groundwater-dependent ecosystems under conditions of groundwater overexploitation and increasing climate variability.

The authors would like to thank the European Commission and Agencia Española de Investigación (AEI), for funding in the frame of the collaborative international consortium ClimEx-PE financed under the 2022 Joint call of the European Partnership 101060874 — Water4All.

LID 0164
Coastal processes and groundwater response: Long-term climate change impacts on a sandy barrier island

Valentina Uribe Jaramillo[1]*, Perry De Louw[2], Arjen Luijendijk[2], Tess Davids[3], Peter Vermeulen[3], Vince Kaandorp[3]

[1] Deltares & Delft University of Technology, Delft, The Netherlands
[2] Deltares & Wageningen University, Utrecht, The Netherlands
[3] Deltares, Utrecht, The Netherlands
* valentina.uribejaramillo@deltares.nl

Keywords: salinization, freshwater lens, sea level rise

As global temperatures increase and sea levels rise, low-elevation coastal areas face climate impacts such as coastal flooding, shoreline erosion, and groundwater salinization. Coastal aquifers are especially sensitive to these impacts because they are located at the land–sea interface, where multiple processes interact and influence groundwater conditions. We examined how interactions between coastal and groundwater processes influence coastal aquifers, focusing on key drivers like recharge variability, sea-level rise, tidal forcing, and morphological changes.

A variable-density groundwater model in iMOD-WQ was used to assess the long-term effects of climate change and morphological processes in a typical low-lying coastal area with a sedimentary aquifer, using the island of Terschelling as a case study. Future scenarios were based on projections from KNMI (2023), including dry and wet conditions, as well as sea-level rise of 0.38m by 2050 and 1.24m by 2100. We assessed relative changes in groundwater depth, freshwater lens depth, total freshwater volume, seepage, and salt load accumulation.

Results show that both coastal and groundwater processes play key roles in controlling the thickness of the freshwater lens and salinity levels. Higher recharge expands the freshwater lens, whereas sea-level rise and coastal morphological changes (smaller island) promote lens shrinkage; together, these mechanisms result in an overall shrinking of the freshwater lens. Sea-level rise drives long-term salinity patterns, whereas ignoring tidal variability can lead to underestimation of groundwater levels near the coast. Different areas of the island respond differently: drainage- controlled areas are mainly affected by recharge, while nearshore areas react quickly to changes in sea level and tides. Overall, the interplay of coastal and groundwater processes tends to decrease freshwater availability, especially under scenarios of reduced recharge.

The authors acknowledge support from the European NBRACER project (Horizon Programme under grant agreement 101112836).

LID 0166
Tracing recharge and flow redistribution in alluvial fans of the Northern Apennines (Italy): Implications for sustainable groundwater abstraction

Maria Filippini[1]*, Erica Tamagnini[1], Paolo Severi[2], Marco Marcaccio[3], Alice Palazzi[4], Marco Rotiroti[4]

[1] Biological, Geological and Environmental Science Department, Alma Mater Studiorum University of Bologna, Italy
[2] Regione Emilia-Romagna – Geology, Soil and Seismic Risk, Bologna, Italy
[3] Arpae Emilia-Romagna, Technical Direction, Bologna, Italy
[4] Department of Earth and Environmental Sciences, University of Milano-Bicocca, Italy
* maria.filippini3@unibo.it

Keywords: alluvial fan recharge, mixing analysis, integrated groundwater assessment

Alluvial fans along the Northern Apennine foothills represent a key recharge interface for the confined aquifers of the southern Po Plain, which sustain a large share of groundwater abstractions in northern Italy. However, despite substantial regional-scale knowledge on recharge processes and groundwater exploitation, the relative importance of recharge sources and the effects of long-term groundwater pumping remain only partially constrained. This study investigates recharge mechanisms and groundwater dynamics in an Apennine pilot area encompassing the Reno-Lavino, Savena, and Idice alluvial fans in the city of Bologna, focusing on year 2024-25.

An integrated framework combined hydrochemical and isotopic tracers (δ^2H, Cl/Br), endmember mixing models, differential river discharge measurements, physically based recharge estimates, and groundwater budget calculations. Recharge is mainly controlled by streambed infiltration and local precipitation, whereas a direct contribution from mountain block groundwater is negligible. Mixing results also indicate a persistent pumping-induced component consistent with intrabasin flow capture from downgradient or deeper aquifer sectors, so part of the abstracted groundwater does not originate exclusively from local recharge.

Integrating mixing results, physical estimates, and groundwater budgets shows that abstractions should be balanced against local recharge, pumping-induced inflow, and downgradient groundwater outflow. Despite positive storage variations in all three fans during the investigated high-recharge year, downstream outflow contrasts among fans: it exceeds abstractions in the Reno fan but remains lower than pumping rates in the Savena and Idice fans. These results suggest that explicit quantification of downgradient groundwater outflow is essential to assess abstraction sustainability in alluvial fan systems. The proposed research provides a reproducible framework for such quantification in similar systems.

This work is part of the AMBRA project (Assessing Alpine and Apennine mountain-front recharge to Po Plain alluvial aquifers), funded by the European Union – Next Generation EU – PRIN 2022.

LID 0167
Tracking regional scale aquitard permeability using fully coupled groundwater flow models in the Central Pannonian Basin

Brigitta Czauner[1]*, Márk Szijártó[2,1], Attila Galsa[2,3], Judit Mádl-Szőnyi[1]

[1] József & Erzsébet Tóth Endowed Hydrogeology Chair, Department of Geology, ELTE Eötvös Loránd University, Budapest, Hungary
[2] Department of Geophysics and Space Science, ELTE Eötvös Loránd University, Budapest, Hungary
[3] HUN-REN Institute of Earth Physics and Space Science, Sopron, Hungary
* czauner.brigitta@ttk.elte.hu

Keywords: numerical flow simulation, aquitard permeability, thermohaline effects

Assigning permeability values to regional-scale hydrostratigraphic units or groups is a notoriously difficult task, while these parameters can significantly control groundwater flow systems, the extent of thermohaline effects, the interaction of shallow and deep groundwater resources, and thus sustainable water and geothermal energy management considerations. This study examines all these aspects in the case of the Algyő Aquitard (AAT), which is the most significant basin-scale aquitard unit in the Neogene basin fill of the Central Pannonian Basin (CPB), Hungary. It controls overpressure dissipation in the deeper basin parts and penetration depth of the topography-driven groundwater flow systems. However, literature data based on measurements and theoretical calculations of AAT permeability show differences of 6-7 orders of magnitude, also raising questions about the origin of deep overpressure (i.e., non-equilibrium compaction vs. lateral tectonic compression). The present study carried out fully coupled numerical simulations along a 2D section to examine the effect of changing permeability of the AAT (10^{-15}–10^{-21} m^2) on the groundwater flow pattern, salinity and temperature distribution, and efficiency of buoyancy forces. The modeling results were then compared with evaluations based on measured data. As a result, the permeability values determined from measurements for the AAT and used in previous models (10^{-15}–10^{-14} m^2) are too high, while according to the criteria examined, there is no significant difference between the effects of permeability values of 10^{-20} and 10^{-21} m^2. A significant change in the flow pattern, i.e., where the overpressure-induced upwelling no longer reaches the surface, can be observed at the permeability value of 10^{-17} m^2. In addition, no significant thermohaline effect can be detected in the Neogene siliciclastic basin fill of the CPB, while the compaction origin of the overpressure has been confirmed.

The research was supported by the National Multidisciplinary Laboratory for Climate Change RRF-2.3.1–21-2022–00014 project, and the National Research, Development and Innovation Office (grant no. PD 142660); and by the Papp Simon Foundation, Hungary.

LID 0168
A lightweight proxy model for underground thermal energy storage: Predicting thermal recovery and breakthrough risk using MODFLOW-based simulations

Hawkar Ali Abdulhaq[1,4]*, István Vass[2], János Szanyi[3,4]

[1] Department of Atmospheric and Geospatial Data Sciences, University of Szeged, Szeged, Hungary
[2] MOL Hungary, MOL Plc, Algyő, Hungary
[3] Department of Geology, University of Szeged, Szeged, Hungary
[4] HUNREN TKI Rybach Research Center, Hungary
* hawkar.ali.abdulhaq@szte.hu

Keywords: Underground Thermal Energy Storage (UTES), proxy modeling, thermal breakthrough risk, MODFLOW-based simulation

Underground Thermal Energy Storage (UTES) in clastic aquifers is promising for integrating renewable heat, but design screening commonly relies on computationally intensive heat-transport simulations and is sensitive to subsurface heterogeneity that controls thermal breakthrough. This study develops a lightweight proxy model to rapidly predict UTES thermal performance and thermal breakthrough risk using a training dataset generated from a calibrated, regional-scale MODFLOW groundwater flow model extended for cyclic heat injection and extraction. The framework is designed for large-area applicability and is demonstrated in the Nyírség region (Hungary). A simulation ensemble is built by varying key geological properties, operational parameters, and a simple heterogeneity/connectivity indicator representing preferential flow pathways. The proxy predicts thermal recovery efficiency and classifies breakthrough risk into operational categories, enabling rapid comparison of candidate well pairs and operating strategies with minimal computational cost across a broad domain. Model evaluation demonstrates accurate reproduction of simulation-derived performance metrics and reliable identification of high breakthrough-risk scenarios. The proposed approach provides a practical screening tool that reduces dependence on full numerical simulation during early-stage planning while explicitly addressing heterogeneity-driven breakthrough uncertainty.

LID 0169
Building a groundwater data factory for faster decisions, lower risk, and compliance by design

Hawkar Ali Abdulhaq[1,4]*, János Szanyi[2,4], Róbert Hegyi[3,4]

[1] Department of Atmospheric and Geospatial Data Sciences, University of Szeged, Szeged, Hungary
[2] Department of Geology, University of Szeged, Szeged, Hungary
[3] General Directorate of Water Management (OVF), Budapest, Hungary
[4] National Laboratory for Water Science and Water Safety, Hungary
* hawkar.ali.abdulhaq@szte.hu

Keywords: groundwater monitoring, data factory, data quality (QA/QC), data governance, regulatory reporting

Groundwater authorities and geological surveys increasingly rely on heterogeneous data streams—monitoring wells, field measurements, laboratory results, drilling and geological logs, and model outputs—to support operational decisions and meet regulatory reporting obligations. However, fragmented workflows, inconsistent formats, and manual quality control can delay decision-making, increase uncertainty, and elevate compliance risk.

This project proposes to scale a Groundwater Data Factory concept—already demonstrated at pilot scale—into an operational, repeatable, and auditable capability for end-to-end groundwater data management. The Data Factory implements standardized pipelines for data ingestion, harmonization, validation, and publication. It introduces quality control by design through automated rule-based checks combined with human-in-the-loop review. Automated validations prioritize and flag exceptions, while domain experts confirm, correct, and approve records via defined workflows. The project will deliver: (1) a configurable data pipeline framework that integrates key groundwater datasets across programs; (2) a shared quality and metadata model enabling transparent QA/QC, audit trails, and traceable data lineage; and (3) analytics, dashboards, and visualization tools to accelerate risk-based decision support (e.g., trends, threshold exceedances, anomaly detection, and situation awareness for operational response).

Success will be measured through operational metrics such as reduced time from data acquisition to validated availability, increased completeness and consistency of core datasets, fewer reporting corrections, and improved responsiveness to emerging groundwater risks.

LID 0170
Securing water supply for agriculture with storm-water based managed aquifer recharge

Anne Schultze[1]*, Thomas Baumann[1]

[1] Technical University of Munich, TUM School of Engineering and Design, Chair of Hydrogeology, Munich, Germany
* anne.schultze@tum.de

Keywords: managed aquifer recharge, agriculture, water availability and needs

Climate change challenges the water supply as decreasing groundwater recharge meets increasing water demand for agriculture, drinking water, and industry. Managed aquifer recharge (MAR) is widely used as a countermeasure to maintain groundwater levels and quality. However, increasing rainfall intensity and prolonged drought periods reduce the availability of surface runoff for MAR, while river discharge becomes more dynamic and flashy. This requires systems with very high infiltration capacities, rapid treatment processes, and adaptive discharge control. Our study area, the “Gäuboden” in Lower Bavaria is characterized by rich soils of loess covering fluviatile quaternary sediments. The area is intensively farmed, mainly with corn, sugar beet, and potatoes.

A broad water quality assessment analyzes pesticide loads and their spatial distribution in streams and groundwater. Continuous monitoring of two small streams is conducted to identify patterns in potential water sources during heavy precipitation events and to determine suitable infiltration periods with respect to the growing season of cultivated crops. A very fast response of the streams to heavy precipitation with water levels and turbidity increasing sharply is indicated, while total dissolved solids (TDS) are diluted in thunderstorms. During low-flow conditions in summer, riverbed sediments become anoxic and are strongly disturbed by flash floods. Although surface water quality reflects intensive agriculture, it is generally superior to groundwater quality. The environmentally sustainable abstraction potential from surface waters — considering minimum ecological flows — is quantified and compared to local irrigation demands. Conceptual design and modeling suggest that the aquifer’s long-term storage capacity is limited but can be enhanced through upstream infiltration.

LID 0171
Analysis of aquifer heterogeneity as a risk factor for geothermal wells based on theoretical and field-based numerical simulations

Bence Molnár[1,2]*, István Garaguly[2], Attila Galsa[1,3]

[1] Department of Geophysics and Space Science, Institute of Geography and Earth Sciences, ELTE Eötvös Loránd University, Budapest, Hungary
[2] MS Energy Solutions Ltd., Eger, Hungary
[3] Institute of Earth Physics and Space Science, HUN-REN, Sopron, Hungary
* molbenc@student.elte.hu

Keywords: aquifer heterogeneity, risk factor, mass and heat transport

The aquifer heterogeneity strongly influences the groundwater flow and associated mass and heat transport processes; therefore, it should be considered as a risk factor in geothermal exploration. In this study, synthetic and field-based numerical models were developed to investigate the effect of permeability heterogeneity on (i) the protection zone (PZ) size to be delineated around geothermal well doublet and (ii) the thermal performance of the geothermal system. Both the solute protection zone (SPZ) and thermal protection zone (TPZ) were defined separately at different times based on the time-of- travel (TOT=20 d, 180 d, 5 yr, 50 yr), where SPZ and TPZ size was characterized by monitoring the position of the solute and thermal front. The former is important because of potential contamination, while the latter is essential due to the positioning of geothermal wells. The thermal performance was evaluated as a function of time as well.

The aquifer heterogeneity was characterized by stochastically heterogeneous permeability distributions, which were generated by sequential Gaussian simulations. Among the synthetic simulations, the effects of the heterogeneity scale, the different dimensional approaches, and thermal retardation were examined in detail. In the second part of the study, the findings of the synthetic simulation were applied in a real geothermal project area in Hungary, where heterogeneity scale was derived based on seismic attributes and geophysical logs.

The results reveal how the PZ size and extractable heat performance vary with the heterogeneity scale. By evaluating numerous realizations, probabilities can be assigned to the extractable heat performance for each heterogeneity scale, and probability maps can be created for the PZ size, facilitating risk assessment. The real-life model demonstrates not only a case study, but also offers a universal, novel workflow for modeling heterogeneity in porous geothermal reservoirs.

Project no. KT-2023-900-I1-00000975/0000003 has been implemented with the support provided by the Ministry of Culture and Innovation of Hungary from the National Research, Development and Innovation Fund, financed under the KDP-2023 funding scheme.

LID 0172
Groundwater management and governance framework by the Saudi Geological Survey: The case of Wadi Ibrahim and Wadi Utaibia, Makkah City, KSA

Bandar Al-Tunsi[1]*, Abdulrahman Al-Zahrani[1], Ahmad Hames[1]

[1] Saudi Geological Survey, Jeddah, Saudi Arabia
* Tunsi.ba@sgs.gov.sa

Keywords: aquifer, replenish, sustainability, recharge

The Saudi Geological Survey (SGS), within its statutory responsibilities, plays a central role in managing and governing groundwater aquifers in Wadi Ibrahim and Wadi Utaibia, Makkah Al-Mukarramah. These areas are located in sensitive groundwater aquifers taht are considered strategic water resources. To ensure long-term sustainability for these aquifers, SGS has established regulatory policies aimed at conserving aquifers both quantitatively and qualitatively.

The adopted framework includes enforceable controls such as restricting construction below groundwater levels, preventing the use of environmentally harmful materials within aquifer extents, and implementing adaptive abstraction limits and operational management programs to maintain stable hydrogeological conditions. These measures are actively applied throughout the two wadis as part of an integrated groundwater governance strategy.

Among the key technical strategies enforced under this regulatory framework is the implementation of Rainwater Harvesting (RWH) systems to replenish aquifer recharge. Technical components such as rooftop collection systems, attenuation tanks for flow regulation and sediment control, and recharge trenches are evaluated according to site-specific geological settings, including alluvial deposits and fractured rock in aquifers commonly found in arid environments.

A brief discussion of SGS policies, examples of major projects on which these policies have been enforced, and implemented methods are presented in this work.

LID 0173
Alluvial fans as hydraulic connectors between coastal aquifer and a declining base level: Insights from long-term monitoring along the Dead Sea shore

Yehuda Levy[1]*

[1] Geological Survey of Israel, Jerusalem, Israel
* yudalv@gmail.com

Keywords: groundwater base level, Dead Sea, alluvial fans

Groundwater recharged in Mediterranean-climate highlands flows toward the Dead Sea coast and discharges through several large springs, the major ones being Einot Zuqim, Einot Kane, and Einot Samar. Over the past 50 years, the Dead Sea level has steadily declined and is currently dropping at a rate of approximately 1.1 m/year. The shoreline is composed of highly permeable alluvial fans, separated by lower-permeability lacustrine deposits (clay and marl). As the lake level falls, the coastal hydrogeological system undergoes continuous adjustment.

For the past two decades, systematic monitoring of spring discharge and groundwater levels has been conducted. This long-term dataset, combined with the rapid base-level decline, makes the Dead Sea coastal system a unique natural laboratory for directly observing aquifer response to a falling base level.

The observations indicate that base-level decline alters the regional flow field. Rather than exhibiting simple seaward discharge, groundwater flow is increasingly focused through the high-conductivity alluvial fans, which function as preferential drainage pathways. This reorganization is expressed by a reduction in the number of active discharge points, the coalescence of multiple outlets into main channels, stabilization or even local rise of groundwater levels in some piezometers, and localized salinity trends—particularly at Einot Kane and Einot Zuqim. At Einot Samar, discharge points are migrating southward toward the Dragot alluvial fan, where permeable gravel units remain hydraulically connected to the lake. Continuous hydraulic head monitoring further reveals distinct response behavior between the permeable alluvial fans and the lower-conductivity units separating them.

These findings provide insight into aquifer adjustment to rapid base-level decline and may serve as an analogue for hydrological system responses to large-scale shoreline and sea-level changes over geological timescales.

LID 0174
A hybrid geostatistical–machine learning framework for three-dimensional hydrogeological structure estimation

Hua-Ting Tseng[1]*, Chia-Lun Wang[1], Su-Yi[2], Hwa-Lung Yu[1]

[1] Department of Bioenvironmental Systems Engineering, National Taiwan University, Taipei, Taiwan
[2] CECI Engineering Consultants, Inc., Taipei, Taiwan
* d13622006@ntu.edu.tw

Keywords: hydrogeological characterization, XGBoost, 3D lithology estimation

Hydrogeological characterization is frequently constrained by sparse borehole information due to the high cost of drilling. Such data scarcity propagates uncertainty into downstream analyses, such as physically based groundwater flow modeling. Conventional geostatistical approaches (e.g., kriging) are widely used to interpolate subsurface properties; however, they often rely on linearity and Gaussian assumptions that may be violated in heterogeneous lithologic settings and non-Gaussian systems.

Here, we propose an integrated framework that combines Bayesian Maximum Entropy (BME) and machine learning to construct a probabilistic three-dimensional hydrogeological structure model under limited hard data. BME provides a flexible geostatistical inference approach that does not require Gaussianity or linearity and can incorporate uncertainty while integrating information from multiple sources. To strengthen the lithological information used in BME, we develop an XGBoost-based model that learns relationships between expert-interpreted geological cross sections and physiographic predictors (e.g., watershed attributes, spatial location, and DEM-derived slope). By integrating expert knowledge with exogenous, geology-relevant variables, the model produces an informative initial lithology probability field that provides additional spatial constraints for the BME estimation. BME then integrates this probability field with the available borehole observations to infer the final probabilistic 3D hydrogeological structure.

We demonstrate the proposed framework in the Yilan Plain, Taiwan, where borehole coverage is sparse and lithologic heterogeneity is pronounced. The results indicate that coupling a machine-learning-derived lithology probability field with BME offers a flexible and scalable approach for multi-source subsurface structure modeling, providing a practical pathway to reduce uncertainty in 3D hydrogeological reconstruction under data-limited conditions.

LID 0175
Why are there so many irregular wells in Brazil?

Ricardo Hirata[1]*, Antonio Pinhatti[1]

[1] CEPAS|USP Centro de Pesquisas de Águas Subterrâneas, Universidade de São Paulo, São Paulo, Brazil
* rhirata@usp.br

Keywords: irregular well, water management, groundwater governance

Brazil extracts more than 600 m^3/s from over 3 million tubular wells and another 2 million dug wells, making it the ninth-largest user of this resource. However, this importance is not accompanied by good management and governance. More than 70% of wells are irregular (clandestine and unknown to public authorities), and only 1% have permits. These numbers are similar in several other Latin American countries. To understand why so many irregular wells exist in Brazil and to define mitigation measures, an opinion survey was conducted with the participation of 275 respondents, distributed among: i) technicians from well drilling companies; ii) selected users; iii) government technicians; iv) academic researchers; and v) members of Water Basin Authorities. The reasons identified were: i) lack of oversight by government control bodies; ii) drillers who execute wells without a permit to reduce costs and construction time; iii) lack of user knowledge about groundwater, both in technical and legal aspects; iv) short-sighted and individualistic user perspective seeking economic advantage and reducing construction time; and v) lack of ethics on the part of users and drillers who consider an illegal well a minor offense or believe that the groundwater is their property. Inspection is the main mitigation measure, but state agencies have low operational capacity in the field and a lack of political will to penalize users. One cause of this inaction is that the "conflict is not apparent": the user, not understanding how the aquifer works, does not recognize that the problem with their well stems from other illegal users competing for water, and does not pressure the agency responsible for management. Without such pressure, the State is “not obliged” to intervene effectively. Thus, there must be support for management agencies to conduct inspections, but above all, a program to raise awareness among users, well-drilling professionals, managers, and government officials.

The authors thank FAPESP (São Paulo Research Foundation) for its support of the SACRE Project (www.projeto.sacre.org). Proc. 2020/15434-0, and the CAPES (Brazilian Federal Agency for Support and Evaluation of Graduate Education) for the second author’s PhD scholarship.

LID 0176
Sedimentary architecture of the Mezőberény geothermal aquifer and its control on doublet performance (SE Hungary)

Soma Budai[1]*, Cees J.L. Willems[2], Luca Colombera[1], Rob Westaway[3]

[1] University of Pavia, Pavia, Italy
[2] HVC groep, Alkmaar, The Netherlands
[3] James Watt School of Engineering, University of Glasgow, Glasgow, United Kingdom
* soma.budai@unipv.it

Keywords: geothermal, aquifer sedimentology, aquifer modeling

Evaluating and quantifying the static connectivity of geothermal aquifers is key in the assessment of risks of pressure communication loss between production and injection wells.

In this study a workflow is proposed that combines sedimentological and sequence stratigraphic analyses with stochastic 3D aquifer modelling techniques to assess the likely static connectivity between production and injection wells. The workflow was applied to a geothermal doublet drilled in Mezőberény (SE Hungary) and targeting a deltaic aquifer succession. Geological analogs were utilized to assess the planform dimension of mouth-bar and fluvial channel bodies forming the sand-rich aquifer geobodies. The analogues were selected based on thickness statistics of sedimentary bodies interpreted on gamma-ray logs of the well doublet and nearby hydrocarbon wells. In total ten different sets of reservoir-model input parameters were established, considering five scenarios of mouth-bar geometry and two scenarios of fluvial channel geometry; fifty object-based realizations were constructed. For ten selected realizations Sequential Indicator Simulations were used to model sandstone distributions within the geobodies. Connected-volume analysis indicates that the sandstone content of the aquifer is located within vertically segmented fluvial channel and mouth-bar bodies separated by muddy prodelta deposits. This architectural configuration, in combination with low net-sandstone fractions, hinders well-to-well connectivity. Across the 10 stochastic realizations, the sandstone volume connecting injection and production wells is ~4% of the total aquifer volume, on average.

This study shows that simplified reservoir models can lead to over-estimations of the connectivity across geothermal wells. The proposed workflow enables predictions of sandstone connectivity for deltaic geothermal reservoirs by combining sedimentological analysis and 3D modelling supported by geological analogues.

LID 0178
Seasonal stream level raising as Managed Aquifer Recharge: A case study from the Eastern Netherlands

Evi Derks[1]*, Anouk Sprong[1], Rogier Van Der Velde[1]

[1] Vitens N.V. , Zwolle, The Netherlands
* evi.derks@vitens.nl

Keywords: Managed Aquifer Recharge (MAR), groundwater-surface water interaction, coupled flow and heat transport modelling

Worldwide Managed Aquifer Recharge (MAR) is applied to enhance groundwater availability and reduce impacts of abstractions. Water replenishment is a common MAR strategy, and involves adding water to the tertiary surface water system during winter when precipitation is in surplus. This aims to recover groundwater drawdowns and alleviate summer drought. However, the effectiveness of this buffering is only partially understood. It remains, for example, uncertain how much and how long water can be stored, and how far the effects may reach spatially. This study addresses these questions by analyzing measurements of both temperature profiles and hydraulic heads collected in the east of the Netherlands.

A field campaign is conducted in an agricultural setting where the water authority and drinking water company experiment with water replenishment to mitigate the effect of the nearby drinking water abstraction. The infrastructure includes three transects perpendicular to watercourses at distinct positions within the water system. Each transect is equipped with three 8-m deep piezometers, and three 10-m vertically inserted fiber-optic cables at distances of 1 m, 10 m and 20 m from the watercourse. Groundwater levels are monitored continuously. Vertical temperature profiles are measured every two months in the piezometer with a precise thermometer using a ‘stop-and-go’ method and Distributed Temperature Sensing (DTS) equipment via the fiber-optic cables.

Initial measurements suggest a rapid aquifer response to the supplied surface water. A coupled Darcy flow and heat transport model (COMSOL Multiphysics) is developed and constrained using the field data to quantify groundwater flow and travel times. The results from this study will support evaluate the water replenishment program and serve as showcase for the potential of water replenishment as MAR strategy to strengthen the sustainability of drinking water abstractions in a changing climate.

LID 0180
Using grain size distribution data to constrain hydraulic conductivity estimates in groundwater flow models: Varaždin aquifer case study

Igor Karlović[1*], Kosta Urumović[1], Mitja Janža[2], Tamara Marković[1]

[1] Croatian Geological Survey, Zagreb, Croatia
[2] Geological Survey of Slovenia, Ljubljana, Slovenia
* ikarlovic@hgi-cgs.hr

Keywords: grain size, hydraulic conductivity, groundwater flow model

A thorough understanding of subsurface flow is essential for sustainable water resource management, with the spatial distribution of hydraulic conductivity (K) representing a key parameter in groundwater flow modeling. Grain-size analysis offers a practical, cost-effective approach for estimating K in unconsolidated sediments. In this study, such analyses were employed to refine hydraulic conductivity assignments for a numerical flow model of the Vinokovščak wellfield in the Varaždin alluvial aquifer. Hydraulic conductivity values were estimated from grain-size distribution curves of core samples from eight observation wells. A comprehensive dataset comprising both grain-size analysis data and pumping test results enabled validation of the estimated K values against field measurements. The estimated K values effectively captured the broad range of sedimentological heterogeneity observed in the aquifer and showed reasonable agreement with pumping test results. In addition to improving initial parameter assignment, the approach provided upper and lower bounds for automatic calibration of the groundwater flow model, addressing a key limitation of relying solely on pumping test data. This methodology offers a transferable framework for integrating sedimentological data into groundwater model parameterization, particularly in data-sparse or early-stage site investigations.

This research was conducted in the scope of the internal research project NITROVERT at the Croatian Geological Survey (funded by National Recovery and Resilience Plan 2021–2026 – NextGenerationEU, monitored by the Ministry of Science, Education and Youth of the Republic of Croatia), and mobility programme of the Croatian Science Foundation (MOBODL-2023-08-4470).

LID 0183
Enhancements in Large-Scale Subsurface Flow Modeling

Léo Agelas[1], Benoit Chauveau[1], **Sébastien Erdocio**[1]*, Martin Parisot[2], Arnaud Pujol[1]

[1] IFPEN, Rueil Malmaison, France
[2] Team CARDAMOM, Inria Bordeaux Sud-Ouest, Talence, France
* sebastien.erdocio@ifpen.fr

Keywords: groundwater, capillary pressure, saturation, Richards equations, Dupuit-Forchheimer, infiltration modeling

The general context of this work is the development of a numerical strategy to improve the modelling of the hydrological response of a catchment on a multi-decadal scale. At the spatial and temporal scales considered, surface runoff cannot be accurately described by surface processes alone, due to its active coupling with subsurface flow (the groundwater system) (camporese_surfacesubsurface_2010). To successfully integrate these couplings, it is necessary to correctly describe the variables that will control the exchanges. That is the reason why it is crucial to simulate not only the groundwater system, but also the dynamics of the unsaturated zone. However, modeling groundwater flow involves complex interactions between infiltration processes and aquifer dynamics. Richards' equation accurately models both unsaturated and saturated flow, including infiltration processes, but is computationally expensive when applied over large three-dimensional domains, particularly due to the strong non-linearity of the equations (cockett_efficient_2018). Therefore, the objective of this work is to enhance the computational efficiency of subsurface water flow modeling at large temporal and spatial scales. The core idea of this research is, through a set of reasonable assumptions, to divide the two dominant physical processes: the infiltration and the aquifer dynamic, where the first one is described by a one-dimensional congested Richards equation in the vertical direction (z-axis) (brenner_improving_2017), and the second one by the Dupuit-Forchheimer type equation in the horizontal plane ((x,y)-axes). This decomposition assumes that flow in the unsaturated zone is predominantly vertical, while flow within the saturated aquifer is considered primarily horizontal, which is justified by a low shallowness number. These two models are then coupled through a source term that ensures mass conservation. It has to be kept in mind that this approach may lead to some limitations in accurately representing few complex hydrogeological configurations, but this approach approximates well the three-dimensional groundwater flow using a multi-directional framework, which is computationally very efficient.

LID 0184
Random forest predictions of groundwater salinity across the United States

Katherine J. Knierim[1]*, Paul E. Stackelberg[2], Blaine M. Mccleskey[3], Charles Cravotta[4], Kenneth Belitz[5], Courtney D. Killian[6]

[1] U.S. Geological Survey, Lower Mississippi-Gulf Water Science Center, Little Rock, Arkansas, United States
[2] U.S. Geological Survey, Water Mission Area, Troy, New York, United States
[3] U.S. Geological Survey, Water Mission Area, Boulder, Colorado, United States
[4] Cravotta Geochemical Consulting, Bethel Pennsylvania, United States
[5] U.S. Geological Survey, retired
[6] U.S. Geological Survey, Pennsylvania Water Science Center, Bridgeville, Pennsylvania, United States
* kknierim@usgs.gov

Keywords: groundwater, salinity, random forest

Groundwater salinity affects water availability for drinking, irrigation, and other uses. Salinity can be expressed as the total dissolved solids (TDS_{SOC}), computed as the sum of inorganic constituents. An understanding of where groundwater with high TDS_{SOC} occurs is important for quantifying freshwater resources and identifying brines with potential mineral commodities. Groundwater TDS_{SOC} was predicted across the continental United States (CONUS) at multiple depths using a random forest (RF) model trained on >138,000 groundwater samples with calculated TDS_{SOC}. Features hypothesized to be important for predicting salinity were mapped across the entire model domain and used to train the RF model. The input TDS_{SOC} concentrations ranged from 1 to 539,600 milligrams per liter (mg/L) and about 53% of the dataset had TDS_{SOC} less than the secondary maximum contaminant level (SMCL) for drinking water of 500 mg/L. The input dataset was dominated by samples collected from the drinking water zone (86%). Observations of TDS_{SOC} generally increased with depth. The RF model made accurate predictions (r^2 >0.85) for holdout data that were not used in model training. Important features for predicting TDS_{SOC} included the elevation of the bottom of the well screen relative to the bottom of the drinking water zone and the dominant hydrochemical facies of the groundwater sample, especially calcium-magnesium-bicarbonate versus chloride dominated water. Similar to observed samples, predicted TDS_{SOC} across the CONUS generally increased with depth. TDS_{SOC} was predicted to be greater than the SMCL across 38% of the CONUS at the bottom of the drinking water zone. At approximately 300 meters below the bottom of the drinking water zone, moderately saline groundwater (>3,000 mg/L TDS_{SOC}) was predicted across about 25% of the CONUS. Mapped predictions of TDS_{SOC} across the CONUS and with depth provide a way to calculate the volume of groundwater available at various salinity thresholds.

LID 0185
Modelling groundwater flow and temperature using forward and multi-parameter inverse numerical methods for improving geothermal potential exploration

Tamara Tóthi[1,2,3]*, Juan Carlos Afonso[2], Eszter Békési[1], Kristóf Porkoláb[1], Tibor Rubóczki[1], Márk Szijártó[3], Mark Van Der Meijde[2]

[1] HUN-REN Institute of Earth Physics and Space Science, Sopron, Hungary
[2] University of Twente, Faculty of Geo-Information Science and Earth Observation, GAIA Department, Enschede, The Netherlands
[3] Eötvös Loránd University, Institute of Geography and Earth Sciences, József and Erzsébet Tóth Endowed Hydrogeology Chair, Budapest, Hungary
* tothi.tamara@ttk.elte.hu

Keywords: geothermal energy, geophysical inversion, hydrogeological simulation

This PhD research aims to enhance geothermal exploration by developing an integrated hydrogeological–geophysical workflow that reduces uncertainty in subsurface characterisation. Therefore, the study combines conventional hydrogeological approaches—hydraulic data processing and forward groundwater flow modelling—with conductive heat transport modelling, geophysical approaches (e.g., magnetotellurics - MT) and multi-parameter inversion techniques.

The Zala Basin (Hungary), located in the Pannonian Sedimentary Basin, serves as a pilot area. Two main geothermal targets are investigated: the Miocene basin-fill sediments and the underlying Mesozoic carbonate basement. The primary objective is to identify target zones for geothermal exploration by mapping regional and local groundwater flow systems and recharge/discharge areas, and by understanding dominant heat transfer mechanisms and heat sources characteristics.

The reliability of heat transport models strongly depends on the conceptual model and boundary conditions. This research integrates MT data analysis and multi-parameter inversion techniques to constrain the input parameters of heat transport models, towards the improved characterisation of geothermal targets. Preliminary results indicate that MT resistivity models, and multi-parameter inversion, provide valuable constraints on the geometry and physical properties of hydrostratigraphic units, thereby improving the definition of model boundaries and parameter distributions.

By integrating complementary datasets and methodologies, the proposed workflow aims to improve the efficiency and cost-effectiveness of geothermal assessment. The results contribute to reducing exploration risk and support the sustainable utilisation of geothermal resources, with direct relevance to basin-scale hydrogeological studies.

This study is supported by the National Research, Development and Innovation Office (NKFIH) under the Research Grant Hungary (RGH) Programme, project no. RGH_L_151351.

LID 0186
Tracing hydrological mixing and flow paths in precipitation, rivers, and groundwater of the Nepal Himalaya using seasonal $\delta^{18}O$ lapse rates and CFC-age dating

Emma Davies[1]*, Camille Bouchez[1], Anne-Catherine Pearson-Wickmann[1], Christoff Andermann[1]

[1] Géosciences Rennes, University of Rennes, Rennes, France
* emma.davies@univ-rennes.fr

Keywords: isotopes, tracers, Himalayas

The hydrogeological interactions of the Himalayas are shaped by steep terrain, fault systems and a pronounced monsoon. Stable water isotopes are useful tracers as signatures change with topography, seasons and mixing. In data-scarce areas like Nepal, synthesizing isotope data characterizes the regional water cycle. This study uses $\delta^{18}O$ and $\delta^{2}H$ data from 38 studies to derive regional seasonal altitude-$\delta^{18}O$ lapse rates for rain, rivers and groundwater (50–8020m). CFC ages from 20 springs are used to further constrain residence time.

Altitude-$\delta^{18}O$ trends in pre-monsoon rain are more enriched than the monsoon, yet have similar lapse rates (1.3-1.5‰/km). This indicates a consistent altitude effect but shifts in moisture sources. The groundwater lapse rate is 2.3‰/km, reflecting heterogeneous sources compared to rain. Groundwater was generally more enriched than monsoon rain, indicative of pre-monsoon recharge despite previous assumptions of evaporative losses. Groundwater altitude-$\delta^{18}O$ trends don't exhibit seasonal differences, suggesting long mixing times that dampen variable input signals. CFC-11 & CFC-12 piston-flow groundwater ages in the Kaligandaki catchment support this, ranging from 36.5-56 years.

Groundwater >2500m in the Kaligandaki negatively deviate from the regional δ18O-altitude trend, but conform to the d-excess-altitude trend, likely from the Himalayan rain-shadow effect under a shared moisture source. Conversely, groundwater from the Dudh Koshi conforms to the $\delta^{18}O$-altitude trend but has low d-excess, consistent with recharge from glacial melt that underwent non-equlibrium procceses (e.g., refreezing).

Regional isotopic trends were identified despite catchment heterogeneity. Deviations from trends correspond to hydrological extremes. Results suggest long groundwater mixing times. Future work will apply end-member mixing models and refine groundwater age estimates. These tools evaluate the resilience of high-mountain water resources under climate change.

LID 187
The importance of recharge and capture processes in modelling climate resilient groundwater development in tropical drylands

Nurudeen Oshinlaja[1], **Mark Cuthbert**[1*], Brenda Mndolwa[2], Boukari Ousmane[3], Pragya Pradhan[4], Baba Musami Sheriff[5], Arjuna Srinidhi[4], Innocent Masukwedza[6], Monzer Abdalah[6], Andrés Quichimbo[1], Alan Macdonald[7], Richard Taylor[8,9]

[1] Cardiff University, Cardiff, United Kingdom
[2] Sokoine University of Agriculture, Morogoro, Tanzania
[3] Abdou Moumouni University, Niamey, Niger
[4] WELL Labs, Bengaluru, India
[5] University of Maiduguri, Maiduguri, Nigeria
[6] University of Sussex, Brighton, United Kingdom
[7] British Geological Survey, Edinburgh, United Kingdom
[8] University College London, London, United Kingdom
[9] University of Toronto, Toronto, Canada
[*] cuthbertm2@cardiff.ac.uk

Keywords: drylands, recharge, capture

Groundwater plays a key role in water supply and supporting livelihoods in tropical drylands, home to some of the world's poorest and most marginalized communities. Understanding the response of groundwater systems to climate change and adaptive human behaviour is thus critical for climate-resilient development strategies. Under the CLARITY research consortium, integrated hydrological models have been developed to quantify the sensitivity of groundwater systems in contrasting catchments in peninsular India, the central Sahel of Niger and Nigeria, and central Tanzania, to a range of projected changes in climate, landuse and water use pathways.

Central to the utility of such models is the inclusion of conceptually robust groundwater recharge processes. A conceptual model was first developed of each system before a numerical code, DRYP, was chosen to allow for the explicit inclusion of focused recharge, identified as a key hydrological process. Models were evaluated over a 40-year historical period and the best performing models were then tested for their response to possible future pathways in respect of adaptive land use and abstraction/irrigation behaviour changes under a range of projected climate forcing scenarios.

Our findings highlight (1) the challenge of managing groundwater in systems where recharge is dominated by multi-decadal return-period of extreme wet years which are poorly constrained in climate models (2) the importance of explicitly including sensitivity to rainfall extremes and focused recharge from ephemeral streams for the dryland water balance (3) the need for integrated modelling to allow all possible components of capture to be addressed, including the response of recharge and evapotranspiration to pumping. Applying the same modelling strategy across three diverse socio-hydrogeological contexts also enabled the dominant controls on potential resilience to be highlighted in each case, to support ongoing climate-resilient water management.

LID 0188
What is groundwater? Finding a way back to the source of a modern abstraction

Mark Cuthbert[1]*

[1] Cardiff University, Cardiff, United Kingdom
* cuthbertm2@cardiff.ac.uk

Keywords: socio-hydrogeology, history of hydrogeology, philosophy of science

Since the birth of modernity, participatory ways of perceiving and knowing groundwater have largely given way to increasingly abstract, propositional modes of knowledge. For all the apparent progress this has enabled, it is also a maladaptive trap: the abstract mode of perception habituated in the modern mind has stripped the world of interiority and separated us, for the first time in our evolutionary history, from an embodied sense of connectedness with groundwater.

Applying an evolutionary hermeneutic to explore how groundwater has come to be perceived, understood and defined within a particular, WEIRD (western, educated, industrialised, rich, democratic), cultural evolutionary pathway, this paper will discuss new narratives for understanding the evolution of 'modern groundwater' in the context of evolution more broadly, including the evolution of consciousness. By considering the co-evolution of four aspects of human-groundwater development - behaviour, systems, psychology and culture – it proposes a metamodern framework which we may explore to find a new and wiser relationship with groundwater, and more effective responses to the predicaments of the Anthropocene.

This framework encourages us to reflect on our own, potentially hidden, worldviews, and asks of us what becoming more conscious of these cultural lenses might mean for our future, collective, relationship with groundwater. If we have lost ourselves in this modern abstraction, how can we find our way back to its source?

LID 0189
From abstraction to subsidence: Sentinel-1 InSAR and 3-D groundwater modelling for infrastructure risk screening in Tema, Ghana

Owusu-Korkor Asante[1]*, Richard Asumadu[1]

[1] Ghana Hydrological Authority, Accra, Ghana
* owusu.asante@hydro.gov.gh

Keywords: Sentinel-1 InSAR, land subsidence, coastal aquifers

The rapid rate of urban development and industrial growth is leading to major unregulated abstraction of groundwater in Ghana's Tema coastal area. The current situation raises significant concerns that the compaction of the coastal aquifer system may be contributing to land subsidence and increasing the vulnerability of essential infrastructure, including Tema Port and the Sakumono Sea Defence. This study develops a comprehensive coastal-aquifer monitoring and numerical simulation approach to map displacement, establish a defensible groundwater baseline and deliver infrastructure-focused subsidence risk screening for a data-limited urban setting.

Sentinel-1 InSAR data have been processed to corridor-scale vertical displacement GeoTIFFs to identify displacement hotspots and support model calibration. A three-dimensional conceptual model, developed from historical hydrogeological, climatological, and hydraulic data as well as prior research, is converted into a numerical MODFLOW model in Aquaveo GMS. Rivers and engineered drains are modeled using RIV and DRN packages, whereas lagoons, wetlands, and dams are represented as constant-head (CHD) features. A steady-state simulation has been executed and calibrated to accurately reflect baseline head patterns and water-budget dynamics.

Initial results suggest groundwater flows from the north-west to the south-east, with discharge directed towards the coast. The next stages involve simulating transient conditions, adjusting abstraction stresses, and integrating aquifer-system compaction using MODFLOW-SUB package. Subsidence will then be calibrated using InSAR data and validated with targeted geodetic leveling at key assets. The anticipated subsidence will be incorporated with infrastructure designs within GIS to generate vulnerability and exposure screening maps. These maps will guide focused monitoring, abstraction regulations, and risk-informed groundwater management, contributing to sustainable coastal development.

This research is being conducted under the Coalition for Disaster Resilient Infrastructure (CDRI) Fellowship Programme (2025–2026).

LID 0190
Unravelling the complexity of recharge mechanisms and mixing processes in mountainous aquifers

Renata Martínez-Barros[1]*, Matías Taucare[1], Sebastián Correa-Varela[1], Antonio Delgado[2], Linda Daniele[1]

[1] Departamento de Geología, Facultad de Ciencias Físicas y Matemáticas, Universidad de Chile, Santiago, Chile
[2] Instituto Andaluz de Ciencias de la Tierra (CSIC-Universidad de Granada), Armilla, Granada, Spain
* renata.martinez@ug.uchile.cl

Keywords: end-members mixing analysis, compositional data analysis, multivariate statistical analysis, environmental tracers, mountain hydrogeology

Recharge quantification is challenging because groundwater reflects mixing among multiple sources. Lowland sedimentary aquifers in mountainous regions exemplify this issue, as they represent the meeting point of local (mountain-front) and allochthonous (high-mountain) inputs. We integrate environmental tracers (hydrogeochemistry and water stable isotopes) with advanced data treatment: compositional data analysis (CoDA), factor analysis (FA), geostatistics, and end-member mixing analysis (EMMA). The intermountain San Felipe aquifer in the semiarid Central Chile was selected as a case study, where 30 samples were collected from wells, mountain-front springs and high-mountain rivers. Results show springs are dominated by HCO3-Ca facies with δ18O values of -11.9--9.7‰, whereas rivers are characterised by SO4-Ca and more depleted signatures (δ18O ≈-15.0‰). Wells span intermediate chemical and isotope compositions, suggesting mixing between these sources. Compositional data were treated using additive log-ratio transformation (alr). FA identifies 3 factors: (F1) SO4, Ca, Ni, and Sr, interpreted as volcanic rock dissolution by H2SO4; (F2) HCO3, Na, and SiO2, interpreted as volcanic rock dissolution by H2CO3; and (F3) NO3 attributed to agricultural inputs. Geostatistical mapping shows that F1 has high scores throughout the aquifers, F2 peaks near the mountain front, and F3 increases as hydraulic head declines toward the aquifer outlet. All samples plot below the local δ18O-elevation gradient, suggesting that diffuse/direct recharge from local precipitation is a negligible mechanism. Pyrite at high elevations supports a sulphate-rich high-mountain component as the allochthonous end member, while bicarbonate springs represent local inputs. EMMA based on δ18O indicates the local contribution ranges from 3-96% (average 48%). These results highlight that recharge estimation requires an explicit definition of recharge sources and their mixing proportions prior to quantification.

Project ANID ATE220029 y 21251574 National PhD grant.

LID 0191
Bridging numerical modeling and field tracer testing in the unsaturated zone of decommissioned mining sites

Wilfredo Puelles-Ramírez[1*], Valerie Plagnes[1], Pierre L'hermite[2], Michael Descostes[2], Mathieu Lacorde[3], Benoit Reilé[4], Jamel Benmamar[1], Anne Jost[1]

[1] Sorbonne University, CNRS, EPHE, METIS, Paris, France
[2] ORANO Mining, Environmental R&D Department, Châtillon, France
[3] ORANO Mining, HSE&R Department, Bessines-sur-Gartempe, France
[4] Cabinet REILÉ, Beure, France
* segundo-wilfredo.puelles_ramirez@sorbonne-universite.fr

Keywords: uranium, tailings piles, groundwater flow, solute transport, unsaturated conditions, tracer testing

The former uranium mine Le Cellier, located in France, offers a valuable natural laboratory to study groundwater flow and solute transport under unsaturated conditions in a tailings pile generated by heap leaching operations (1970-1990). Two-dimensional (2D) numerical simulations were performed to characterize groundwater flow dynamics within one of the tailings piles, whereas non-reactive solute transport was simulated using a one-dimensional (1D) approach. While validation of the hydrogeological model was based on flow rates measured at the outlet of the pile, we do not yet have validation parameters for the solute transport model. With this objective in mind, artificial tracer tests were conducted.

Conceptual models of the pile were implemented in HYDRUS-1D to simulate variably saturated flow and non-reactive solute transport, supporting tracer injection design. The model generates breakthrough curves exhibiting similar temporal dynamics regardless of the injected tracer concentration. Sensitivity analyses indicate that hydraulic conductivity and longitudinal dispersivity strongly influence solute migration: higher values accelerate transport and result in shorter restitution times. Increased rainfall further reduces restitution times and produces higher and sharper concentration peaks compared to dry conditions, suggesting that tracer experiments should preferably be conducted during wet periods.

Comparison of the 1D simulations with the first artificial tracer experiment revealed significant discrepancies. The model failed to accurately reproduce the timing of tracer arrival, indicating that the current 1D representation does not fully reflect the complexity of solute transport processes in the unsaturated zone at the site. These findings underscore the need to move toward higher-dimensional approaches to better represent the tracer transport dynamics and optimize the upcoming artificial tracer experiments.

LID 0192

A national-scale preliminary overview study of poly- and perfluoroalkyl substances (PFAS) occurrence in aquatic environments of England, UK

Raghav J. Patel[1*], Daren C. Gooddy[2], Ben Marchant[1], Dan J. Lapworth[1], Alun James[3], Martin Cook[3], Kirsty Darby[4], Tim Besien[5]

[1] British Geological Survey, Keyworth, Nottinghamshire, United Kingdom
[2] UK Centre of Ecology and Hydrology, Wallingford, Oxfordshire, United Kingdom
[3] Environment Agency, National Laboratory Service, Starcross Laboratory, Exeter, Devon, Starcross, United Kingdom
[4] Environment Agency, West Bridgford, Nottingham, United Kingdom
[5] Environment Agency, Tewkesbury, United Kingdom
* rpatel@bgs.ac.uk

Keywords: poly- and perfluoroalkyl substances (PFAS), groundwater, surface waters, coastal waters, national, occurrences, distribution

Perfluoroalkyl and Polyfluoroalkyl Substances (PFAS) are emerging contaminants, where some are known to harm ecological and human health. Due to their widespread use, PFAS have become commonly detected in aquatic environments, which serve both as pathways and as reservoirs for these pollutants. This study provides the first full quantitative national overview of 41 PFAS compounds in English waterbodies (surface water, groundwater, coastal, and estuarine; n = 850), using High-Performance Liquid Chromatography-Triple Quadrupole Mass Spectrometry (HPLC-QQQ). Individual PFAS concentrations at 475 sites ranged from <LOD to 480 ng/L while ΣPFAS concentrations per site ranged from 0.18 to 2021 ng/L. Monitoring detected the highest concentrations near large distinct urban areas, though PFAS were also present in rural and undeveloped regions, highlighting the importance of detections across different land use. PFOA was one of the most frequently detected PFAS across all waterbodies, consistent with other studies. No clear correlations were found between PFAS physiochemical properties (chain length and functional group) and concentrations, this may be due to the sampling approach focused which focused on an assessment of background concentrations, rather than point source, pollution. However, shorter chain PFAS compounds dominated detections in surface waters compared to groundwater. Physical properties and PFAS exposure in waterbodies may play a large role in PFAS detections, as higher concentrations were found in surface water relative to groundwater. Future research should explore PFAS trends over time, consider groundwater sampling depths, examine a broader range of land uses, and assess transboundary PFAS transport to better understand PFAS flux in aquatic systems.

LID 0193
Response of groundwater levels to interactions between recharge and irrigation in a changing climate (Seewinkel, Austria)

Steffen Birk[1]*

[1] University of Graz, Department of Earth Sciences, NAWI Graz Geocenter, Graz, Austria
* steffen.birk@uni-graz.at

Keywords: groundwater abstraction, irrigated agriculture, evapotranspiration

While irrigation accounts for the majority of global freshwater use, the share of irrigation in the total water amount is still low in Austria. Yet, the irrigation demand varies greatly from year to year. An increase in frequency and severity of droughts, as expected under climate change, further exacerbates the volatility of the demand. Moreover, summer precipitation is expected to decrease, suggesting increasing irrigation demand particularly in the low-precipitation eastern part of Austria. Groundwater recharge is governed by similar processes and drivers. Unfortunately, however, these act in the opposite direction, that is, recharge will likely be low in time periods with high irrigation demand. Understanding how changes in recharge and irrigation demand interact thus is crucial to the management of groundwater resources in irrigated areas. As these interacting processes affect groundwater-land surface connections, their understanding also contributes to concepts and modelling approaches in the context of Earth system modelling.

This work examines how groundwater levels respond to the interaction in recharge and irrigation. To this end, irrigation is integrated into a lumped-parameter model coupling a soil-water balance model, yielding evapotranspiration and seepage from the root zone, to a linear storage, representing groundwater storage and discharge. While the soil-water balance model determines recharge and irrigation demand, the groundwater abstraction needed to meet the demand is considered in the linear storage. The model is tested for the case of the shallow Seewinkel aquifer (Austria), which is almost exclusively used for irrigation.

The results of the calibrated model agree very well with the observed groundwater levels, and the average groundwater abstraction obtained from the model calibration is reasonable when compared with available irrigation estimates. Running the calibrated model without irrigation enables an assessment of the impact of irrigation withdrawals on groundwater levels. The model results suggest that the depletion of groundwater levels resulting from irrigation withdrawals varies depending on the hydrological conditions. Following the European drought 2003, for example, the depletion appears to be around twice as high as in wet years, illustrating the amplifying effect of low groundwater recharge and high irrigation demand.

LID 0194
Reconstructing groundwater age and vertical flow paths in a former coal mining area using multi-tracer analysis

Tano Kivits[1]*, Nienke Kamstra[1], Willem Jan Zaadnoordijk[1], Jelle Buma[1], Jürgen Sültenfuß[2]

[1] TNO Geological Survey of the Netherlands, Utrecht, The Netherlands
[2] University of Bremen, Bremen, Germany
* tano.kivits@tno.nl

Keywords: groundwater age dating, mine-water flow system, vertical hydraulic connectivity

Since the closure of the Dutch coal mines in the 1970s and the ending of groundwater pumping in the early 1990s, hydraulic heads have recovered significantly, in some places rising by several meters per year. The rising mine water poses risks, such as ground uplift, and may also negatively impact groundwater quality in the overlying aquifers of the region. The long history of intensive pumping and subsequent recovery has created a highly altered flow regime with potentially complex age distributions. Rising mine water may originate from Carboniferous strata, infiltrating meteoric groundwater from the upper aquifers, or from a mixture of both, each with different implications for future groundwater-quality developments. To determine these contributions, we applied a multi-tracer groundwater dating approach, including tritium-helium, noble gases, CFCs, radio- and stable carbon isotopes, and methane isotopes. In addition to the isotope measurements, an analysis was made of the groundwater composition in both the Carboniferous and overlying aquifers. Sampling included multi-level groundwater wells with filters in the Carboniferous strata as well as in the overlying Quaternary, Tertiary, and Cretaceous formations, allowing interpretation of vertical patterns in groundwater age distributions and identification of possible short-circuit flow between the deep and shallow subsurface. Comparison of tracer-derived age distributions and groundwater quality data across the system allowed assessment of the likelihood, direction, and scale of vertical exchange reaching the deep Carboniferous strata. The results reveal new insights into groundwater-mixing processes in this anthropogenically altered system and show how legacy mine dewatering continues to influence present-day flow, and possible future developments in groundwater quality in the region.

LID 0196
Beyond streamflow: Managing tradeoffs between economy and ecology in high-capacity well evaluation

Michael Fienen[1]*, Aaron Pruitt[2], Ty Ferre[3], Howard Reeves[4]

[1] U.S. Geological Survey, Upper Midwest Water Science Center, Madison, Wisconsin, United States
[2] Wisconsin Department of Natural Resources, Madison, Wisconsin, United States
[3] University of Arizona, Tucson, Arizona, United States
[4] U.S. Geological Survey, Upper Midwest Water Science Center, Lansing, Michigan, United States
* mnfienen@usgs.gov

Keywords: groundwater, optimization, management

In the Great Lakes region of North America, water is abundant. Streamflows and lake levels, however, are often in a tenuous balance with the shallowest portion of the groundwater system. Small reductions in groundwater levels may leave plenty of water volume in place but may interrupt supply to streams and lakes. This condition motivates US states in the region to use surface water impacts as key legal considerations when evaluating requests for high-capacity well withdrawals for public supply, industry, and agriculture. The cumulative effect of multiple wells in a watershed can be estimated using superposed analytical solutions. The python package pycap-dss implements analytical solutions and can simulate many wells in a watershed efficiently, enabling multi-objective formal optimization that quantifies a Pareto frontier, delineating the tradeoff between the amount of pumping in managed wells and the streamflow response in a river. Using the Little Plover River in Wisconsin, USA as a test case, we demonstrated the use of this analysis. Additionally, we converted streamflow to brook trout probability of occurrence and quantified the agriculture receipts in US Dollars as supported by agricultural pumping. These Pareto tradeoffs compare model results with management options in terms that are relevant to the societal decisions at hand. Such tradeoffs have the potential to enhance understanding and negotiations about responsible water use serving all needs. We adapted this modeling framework to develop a Masters-level curriculum project at the University of Arizona. We also discuss insights, challenges, and results from the participating students.

LID 0197
Conceptualisation of contaminant pathways in the Lomagundi dolomite aquifer, Zimbabwe

Moses Souta[1,2]*, Kay Knoeller[2,3], Ronald Krieg[2], Hodson Makurira[1], Alexander Mhizha[1]

[1] Department of Construction And Civil Engineering, University of Zimbabwe, Harare, Zimbabwe
[2] Catchment Hydrology Department, Helmholtz Centre for Environmental Research, Halle, Germany
[3] Institute of Applied Geosciences, Technical University of Darmstadt, Germany
* msouta6@gmail.com

Keywords: conceptual models, contaminant pathways, karst aquifers

Contaminant transport models are widely used to assess vulnerability to pollution in karst aquifers. However, contaminant pathways in these systems are often poorly constrained. Limited or fragmented field data in many karst systems translate into unreliable conceptualisation of contaminant pathways. Despite the widespread use of groundwater for irrigation in semi-arid karst regions, few studies have examined its influence on contaminant sources, mobilisation, degradation and transport. The study integrated multi-isotopes, pumping tests, long-term groundwater levels, rainfall patterns and hydrochemistry to develop a process-based understanding of contaminant pathways in the Lomagundi Dolomite aquifer, Zimbabwe. Groundwater chemistry was dominated by water-rock interactions with dolomite dissolution controlling ionic composition. Elevated nitrate concentrations in groundwater was observed in areas near intensive irrigation with $\delta^{15}N_{NO3}$ and $\delta^{18}O_{NO3}$ indicating mixed fertilizer and manure sources. Nitrate attenuation was limited and spatially localised. Groundwater levels declined rapidly in response to intensive pumping but recovered quickly during the wet season. Stable water isotopes ($\delta^{18}O$ and $\delta^{2}H$) were slightly enriched relative to local rainfall is suggestive of evaporation prior to infiltration common in semi-arid regions and enhanced by contributions from delayed irrigation return flow. Tritium indicated predominantly modern recharge with evidence of mixing with older groundwater in some locations likely due to intensive abstraction. Transmissivity and storage properties were spatially variable and indicative of heterogeneity in fracture matrix flow. Relatively rapid recharge and contaminant mobilisation possibly occurs through preferential pathways within the dolomitic rock matrix. Integrating multiple datasets could potentially improve conceptualisation of contaminant transport in vulnerability assessments and support monitoring and management strategies in groundwater irrigation dominated karst aquifers.

LID 0199
Seawater intrusion in a Mediterranean coastal aquifer under climatic and drought stress conditions

Mohamed Neji[1,2], Ghassen Benzid[1,2], Malek Drissi[1,2], Sameh Chargui[1], Olivier Grunberger[3], Fethi Lachaal[1], **Isabel Margarida Antunes**[4]*

[1] Georesources Laboratory, Water Research and Technology Centre, Tunisia
[2] University of Tunis El Manar, Faculty of Sciences of Tunis, Tunisia
[3] LISAH, University Montpellier, INRAE, IRD, SupAgro, Montpellier, France
[4] ICT | Institute of Earth Sciences, University of Minho, Braga, Portugal
* imantunes@dct.uminho.pt

Keywords: groundwater salinization, piezometric decline, aquifer vulnerability

Coastal aquifers in semi-arid Mediterranean regions are increasingly threatened by groundwater overexploitation, prolonged drought, and seawater intrusion. The Plio-Quaternary aquifer of the Lebna plain (Cap Bon Peninsula, northeastern Tunisia) has experienced severe salinization during the 2020–2023 drought period.

This study integrates piezometric monitoring and major-ion hydrogeochemistry to assess current hydrodynamic conditions and to identify the main processes controlling groundwater mineralization. Groundwater levels measured in 100 wells reveal the development of a pronounced depression cone downstream of the Lebna Dam, with hydraulic heads locally reaching 10 m below sea level. These conditions generate reverse hydraulic gradients that promote inland migration of seawater.

Electrical conductivity values range from 1.2 to 21.3 mS/cm, indicating strong mineralization in coastal areas. Hydrochemical results show the dominance of Na–Cl and Ca–Na–Cl–SO_4 water facies, with progressive chloride and sodium enrichment toward the coastline. This chemical evolution follows groundwater flow directions and reflects active seawater–freshwater mixing combined with inverse cation exchange processes.

The findings confirm that modern seawater intrusion is the primary driver of groundwater salinization, significantly intensified by intensive pumping and reduced recharge during prolonged drought. Although the Lebna Dam provides localized recharge, its buffering effect is spatially limited and insufficient to offset regional hydraulic decline.

This study highlights the pronounced vulnerability of Mediterranean coastal aquifers to combined climatic stress and human pressures, highlighting the need for integrated hydraulic and hydrogeochemical monitoring to support adaptive and sustainable groundwater management.

LID 0200
Data-driven geothermal groundwater potential using integrated GIS–machine learning approaches

Najeh Bouarrouj[1,2], Bilel Abdelkarim[2,3], Yahya Moumni[1,4], Mohamed Haythem Msaddak[1], Nabil Abaab[5], Fadoua Hamzaoui Azaza[6], **Isabel Margarida Antunes**[2]*

[1] LR01ES06, Laboratoire des Géoressources et Environnement, Faculté des sciences de Tunis, Université de Tunis El Manar, Tunis, Tunisia
[2] ICT | Institute of Earth Sciences, University of Minho, Braga, Portugal
[3] Laboratory of Applied –Hydrosciences, University of Gabes, Tunisia
[4] Department of Earth Sciences, Faculty of Sciences of Bizerte, University of Carthage, Bizerte, Tunisia
[5] Le Mans Université, Géosciences Le Mans, Le Mans, France
[6] Laboratory of Sedimentary Basins and Petroleum Geology (SBPG) LR18 ES07 University of Tunis El Manar Faculty of Sciences of Tunis, Tunis, Tunisia
* imantunes@dct.uminho.pt

Keywords: renewable energy, self-organizing map, Mediterranean region

Geothermal groundwater represents a strategic resource for renewable energy development and sustainable water management in tectonically active Mediterranean regions. This study presents an integrated spatial framework for delineating geothermal potential zones in northern Tunisia by combining Geographic Information Systems (GIS), Multi-Criteria Decision-Making (MCDM), Principal Component Analysis (PCA), and Kohonen Self-Organizing Maps (SOM).

Twelve thematic layers were integrated, representing geomorphological, geological, hydrogeological, structural, and climatic controls. Key parameters included lithology, aquifer depth, fault and lineament density, slope, elevation, precipitation, surface temperature, soil type, land cover, drainage density, and runoff. These variables were standardized and weighted within a structured MCDM framework to generate a geothermal potential index. PCA was applied to identify dominant controlling factors, while SOM clustering enabled unsupervised classification of geothermal domains and detection of nonlinear spatial patterns.

Results reveal pronounced spatial variability in geothermal favorability. Approximately 48% of the study area falls within favorable to very favorable classes, with 22% classified as “very good” and 26% as “good.” High-potential zones are concentrated along the Tell–Atlas structural corridor, characterized by high fault density, fractured carbonate lithologies, deep aquifer systems, and enhanced hydrothermal circulation. In contrast, low-potential areas correspond to compact sedimentary units, limited structural complexity, and reduced permeability. The strong correspondence between PCA-derived factors, SOM clusters, and the geothermal index confirms the robustness of the integrated GIS–PCA–SOM methodology.

The proposed methodology constitutes a reproducible, data-driven approach for geothermal resource assessment, facilitating sustainable groundwater management and strategic renewable energy planning in tectonically active settings.

LID 0201
3D chronostratigraphic mapping of the Murray Basin and Australia's groundwater systems

Caleb Bishop[1]*, Nadege Rollet[1], Catherine Norton[2], Carey Hannaford[3], John Vizy[1], Penny Kilgour[1], Steven Lewis[1]

[1] Geoscience Australia, Canberra, Australia
[2] Catherine Norton, Adelaide, Australia
[3] MGPalaeo, Adelaide, Australia
* caleb.bishop@ga.gov.au

Keywords: chronostratigraphy, hydrostratigraphy, Cenozoic, Murray Basin, south-east Australia, national-scale groundwater systems, 3D model

Australia is the world's driest inhabited continent, with approximately 70% of the mainland being arid or semi-arid. Groundwater supplies around 30% of national water use and is often the only reliable source for many inland communities. Yet groundwater is finite, with accurate 3D hydrogeological models serving as important tools to support effective groundwater management, constraining aquifer geometry, connectivity and storage volumes at regional scales. These models depend on robust 3D stratigraphic frameworks. Conventional 3D geological models are commonly based on lithostratigraphic correlation. However, lithostratigraphic units are often diachronous, causing problematic assumptions when correlated over regional scales and across jurisdictional boundaries. Geoscience Australia has therefore adopted a chronostratigraphic framework that anchors 3D stratigraphic surfaces to geologic time rather than lithology, standardising stratigraphic nomenclature and aligning geoscientific and hydrological datasets to enable nationally consistent data integration. This provides regional and holistic insights into geological basin architecture, aquifer connectivity, and groundwater flow systems, and lays the groundwork for a national 3D groundwater atlas of Australia. As part of this nation-wide project, we recently reviewed and integrated stratigraphic picks from 2,431 boreholes with palynological data from 227 boreholes into a single sequence- and chronostratigraphic framework to better define the groundwater systems of the Cenozoic Murray Basin in south-east Australia. The Murray Basin's multi-layered groundwater systems are critical for agricultural, environmental, industrial and community water supply. However, they also contain extensive saline aquifers that, without effective management, risk impacting water quality in the Murray River. We provide the first regional-scale cross-jurisdictional 3D chronostratigraphic and hydrostratigraphic models of the Murray Basin, using a novel workflow with ongoing refinement and multi-agency collaboration. These 3D mapping efforts provide a robust regional framework that significantly improves understanding of the distribution, depth, thickness and connectivity of one of Australia's major aquifer systems, supporting more sustainable groundwater management and demonstrating the benefits of a chronostratigraphic approach.

LID 0203
Finding contaminants in unexpected places: Explaining the occurrence of synthetic chemicals in deep groundwater

Matthew Currell[1*], Agustin Cabrera[1], Phoebe Lewis[2], Oliver A. H. Jones[3], Pacian Netherway[2], Dioni Cendon[4], Dongmei Han[5]

[1] Australian Rivers Institute, Griffith University, Brisbane, Australia
[2] EPA Science, Environment Protection Authority, Melbourne, Australia
[3] Australian Centre for Research on Separation Science (ACROSS), School of Science, RMIT University, Bundoora, Australia
[4] ANSTO (Australian Nuclear Science and Technology Organisation), Lucas Heights, Australia
[5] Institute for Geographical Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing, China
* m.currell@griffith.edu.au

Keywords: contamination, PFAS, pesticides, deep groundwater, tracers

Traditional conceptual models of aquifer systems assume that the transport of water and contaminants from the surface into deep, confined aquifer layers is minimal, and that increasing aquifer depth and confinement should therefore provide significant protection against water quality threats. This research presents contaminant and environmental isotope data spanning multiple regions, aquifer types, and time periods, which indicate that this assumption is not always valid. Frequent detection of PFAS, nutrients and a range of pesticides in groundwater wells that are > 50 m depth (and in some cases > 100 m deep), together with tritium – a tracer of relatively young water input - show that deep groundwater wells are not always safe from being contaminated from surface activities, and that the contamination pathway is relatively rapid (e.g., transporting contaminants to deep groundwater within years or decades at most). These data and findings have important implications for human and environmental health, because deep groundwater supplies drinking water in many regions of the world, and it sustains unique biota both within aquifers (stygofauna) and in their discharge areas (e.g. springs). Understanding the pathway(s) and timescales of deep groundwater contamination with synthetic chemicals, and the most important controlling factors - e.g. groundwater extraction rates, well construction methods and well condition, geological heterogeneities, transient vertical hydraulic loading - is therefore a crucial challenge for the hydrogeology community. Understanding and addressing this issue will be vital for protecting public health and groundwater ecosystems into the future.

LID 0204
Overcoming uncertainty: Machine learning and probabilistic modelling for groundwater exploration in data-scarce areas

Claire Corthier[1]*

[1] Douglas Partners Pty Ltd, Sydney, Australia
* claire.corthierfrachot@gmail.com

Keywords: groundwater supply, machine learning, probabilistic modelling, Bayesian, Gaussian process, uncertainty

Water scarcity is an increasing challenge across most of Australia. In some remote areas, groundwater is the main reliable resource available to supply communities, agriculture and industry.

This challenge is intensified where mining occurs. Australia is one of the world's leading critical minerals producers, and mining has long been a major economic driver of the country's development. However, much of this activity is undertaken in water-scarce remote regions. As extraction and processing require significant volumes of water, identifying reliable groundwater supplies without impacting communities and groundwater-dependent ecosystems can be a critical constraint to project viability.

To make matters worse, groundwater exploration in these regions is inherently uncertain due to sparse hydrogeological datasets and complex subsurface geology. Identifying prospective groundwater supplies can be challenging, and human interpretation alone may overlook subtle data relationships when datasets are limited. Probabilistic machine learning (ML) methods, such as Gaussian processes, can be highly effective under these conditions, enabling spatial relationships to be identified and quantified where they are not readily apparent.

This talk (and forthcoming paper) demonstrates how ML-enabled probabilistic modelling was used to delineate a large, highly productive palaeovalley aquifer system near Lake George, New South Wales, and to map its groundwater supply probability for a nearby gold mine.

The results show how probabilistic mapping can convert uncertainty into a measurable and defensible decision-making tool. The approach provides a practical framework for groundwater exploration in data-scarce areas, particularly where conventional deterministic methods are not sufficient on their own.

LID 0205
A real-time monitoring and prediction study on the establishment of an AI-based drinking groundwater quality and quantity management system

Do Hwan Jeong[1]*, Jeonga Kim[1], Yu-Yeon Jeong[1], Tae Kwon Lee[2], MoonSu Kim[1]

[1] Soil and Groundwater Division, National Institute of Environmental Research, Incheon, South Korea
[2] Department of Environmental Engineering, Yonsei University, Wonju, South Korea
* jungdh93@korea.kr

Keywords: groundwater quality & quantity, AI-based, monitoring & prediction

These days, interested in clean and safe drinking groundwater is increasing, continuous and sustained management of groundwater has not yet been carried out in a systematic manner. There are not immediate response to temporary, seasonal fluctuations in groundwater quality and quantity occurring during some drinking groundwater production processes. It is need for a structured preventive management system to ensure drinking groundwater safety. This study aimed to ensure the safety of drinking groundwater that utilizes groundwater as its source and to establish a systematic management framework through research on real-time monitoring and assessment based on AI(artificial intelligence).

To achieve this objective, the study was organized into five major components. First, a comprehensive literature review was carried out to examine domestic and international research trends related to AI-based characterization of groundwater quality and quantity (groundwater level). Second, a pilot study area (one monitoring well) was selected by considering geological conditions, well depth, the operational status of bottled water companies, and potential policy linkages, and an ICT(Sensor–IoT)-based real-time monitoring system was established. Third, to verify the accuracy and calibration of real-time monitoring data, more than six field surveys, including on-site water quality measurements, were conducted, along with corresponding laboratory-based water quality analyses. Fourth, real-time monitoring data and laboratory analysis results were systematically accumulated and managed through integration with the National Institute of Environmental Research's "AI-Based Groundwater Contaminant Monitoring and Prediction System" . Finally, through expert consultations involving specialists in AI and groundwater, and by applying AI techniques, a foundational framework was established for predicting groundwater quality and quantity (groundwater level) of drinking water sources.

To identify the hydrochemical characteristics of groundwater, a piper diagram analysis was conducted, and the results indicated Ca-Mg-HCO_3 type. In addition, comparative analysis of groundwater quality data showed no significant difference across monitoring periods and seasons. Furthermore, advanced data quality control procedures including outlier removal and correction using AI model were used for real-time monitoring sensor data. When various statistical and AI models were compared for groundwater level prediction, the LSTM model with Bayesian Optimization showed the best predictive performance(R^2 > 0.91). In addition, a groundwater quality fluctuation prediction using a variational Autoencoder(VAE)-based anomaly detection approach, trained on normal pattern learning, was proposed. The results of the VAE model indicated that 96.7% of the entire data were evaluated as stable, and the average groundwater quality stability score was 0.88. Through this, it was confirmed that the water quality of drinking groundwater in pilot area is generally excellent.

LID 0206
reframing groundwater monitoring strategies for nuclear facilities: Hydrogeological gaps and future directions from Korean cases

Jeongwon Lim[1]*, Seung-Gyu Hyun[1], So-Beom Jin[1]

[1] Korea Institute of Nuclear Safety, Daejeon, Korea
* lim.jw@kins.re.kr

Keywords: groundwater monitoring, hydrogeochemistry, risk-informed management

Groundwater monitoring at nuclear power plants and radioactive waste disposal facilities plays a critical role in environmental safety assurance. However, current monitoring practices often prioritize regulatory compliance over hydrogeological understanding. Based on Korean cases, this study examines structural limitations of existing monitoring systems and proposes a revised conceptual framework tailored to facility-specific characteristics.

At nuclear power plants, groundwater has not historically been treated as a primary environmental concern. Nevertheless, elevated tritium concentrations are periodically reported in on-site monitoring wells. In many cases, source identification remains unresolved, and limited off-site impact has led to minimal corrective action. The lack of integrated hydrogeological and hydrogeochemical interpretation constrains the ability to delineate flow paths, identify leakage sources, and evaluate transport mechanisms.

For radioactive waste disposal facilities, monitoring challenges are fundamentally different. The temporal framework extends from hundreds to tens of thousands of years, yet monitoring programs are typically designed within short-term operational perspectives. Current analytical targets frequently focus on gamma-emitting radionuclides and tritium, while limited attention is given to broader hydrogeochemical indicators that control long-term groundwater evolution and radionuclide mobility.

This study analyzes these gaps and proposes a hydrogeologically informed monitoring approach incorporating site-specific conceptual models, multi-parameter hydrogeochemical characterization, and process-based interpretation strategies. By shifting from compliance-driven observation to system-based understanding, the proposed framework aims to enhance early detection capability, improve source attribution, and strengthen long-term safety assessment for nuclear-related facilities.

LID 0207
Hydraulic connectivity of deep granite fracture zones at the KURT site: Site characterization for solute transport experiments

Jiwon PARK[1], Seong-Chun JUN[1], Jeong-Yong CHEON[1], Jun-Young AHN[1]*

[1] GeoGreen21 Co., Ltd., Seoul, South Korea
* junyoung@geogreen21.com

Keywords: high-level radioactive waste, natural barrier, KURT, long-term solute migration experiment, pumping test

Deep geological disposal of high-level radioactive waste relies on natural barriers to restrict groundwater inflow and retard radionuclide migration. However, construction-induced migration of the redox front may compromise the long-term stability of the disposal system. Therefore, precise characterization of site hydraulic properties is essential to mitigate geochemical perturbations associated with redox front advancement. This study aims to select optimal test boreholes for subsequent long-term solute transport experiments through hydraulic connectivity testing conducted across GE-series boreholes installed at the Korea Atomic Energy Research Institute Underground Research Tunnel (KURT) site and to incorporate these results into the design of the long-term solute transport test system.

Cross-hole pumping tests were conducted to evaluate the hydraulic connectivity. The tests involved pumping from one borehole while monitoring drawdown in the surrounding boreholes. The results indicated that boreholes GE-1 and GE-3 exhibited relatively high transmissivity, on the order of approximately 10^{-5} m^2/s. The distinct drawdown response observed between these two boreholes demonstrates the presence of well-developed fracture zones and strong hydraulic connectivity within the tested interval. Consequently, GE-1 and GE-3 were identified as the optimal zones for simulating long-term solute migration.

The hydraulic connectivity characteristics determined in this study provide critical design parameters for the specialized long-term solute transport test system. Future in-situ experiments injecting fluorescein as tracers and oxygenated water as redox-altering agent will focus on quantitatively assessing physical transport pathways and the redox buffering capacity of the host rock, thereby contributing to the safety assessment and design of high-level radioactive waste repositories.

This research was supported by the National Research Foundation of Korea(NRF) under the project 'Development of Core Technologies for the Safety of Used Nuclear Fuel Storage and Disposal; RS-2021-NR056203.

LID 0208
Integrated approach to simulating radionuclide migration: Coupling infiltration tests in unsaturated–saturated zones

Kyuyoung Park[1], Jong-Hwa Yi[1], Myeong-Jae Yi[1], Jun-Young Ahn[1]*, Chang-Wook Park[2]

[1] GeoGreen21 Co., Ltd., Seoul, South Korea
[2] OCEANIC C&T Co., Ltd., Seoul, South Korea
* junyoung@geogreen21.com

Keywords: Conceptual Site Model(CSM), in-situ infiltration test, radionuclide transport prediction

As nuclear facilities in Korea approach permanent shutdown and decommissioning, advanced quantitative contamination assessment technologies are essential to support site release. Conventional concentration-based investigations must evolve toward process-based evaluation frameworks that incorporate site-specific geological and hydrogeological characteristics. This study proposes a methodological framework for a coupled unsaturated–saturated solute infiltration test, capable of simulating and evaluating radionuclide migration behavior under leakage scenarios, based on a site-specific Conceptual Site Model (CSM) developed for the Korea Research Reactor (KRR) site in Seoul.

Prior investigations, including borehole drilling, stratigraphic analysis, and hydraulic testing, were conducted to construct a three-dimensional geological model and define the spatial hydraulic conductivity distribution. Unsaturated hydraulic parameters were determined and integrated with a saturated groundwater flow model to establish a comprehensive CSM that reflects the site-specific hydrogeological conditions.

The proposed infiltration test simulates radionuclide behavior under surface leakage scenarios by controlling infiltration flux and solute concentration within an engineered pond. Simultaneously, hydrogeological and hydrochemical responses are monitored across both the vadose and saturated zones. Sensor-based monitoring enables the quantification of key transport parameters governing radionuclide migration. The system is designed to reproduce various leakage scenarios under differing boundary conditions, allowing for the experimental validation of coupled infiltration-recharge-transport processes. Ultimately, the study results will be used to the development of a radionuclide transport prediction model.

This study was also supported by a National Research Foundation of Korea (NRF) grant (No. RS-2023-00243600) funded by the Korean government, Ministry of Science, and ICT.

LID 0210
Microplastics in multiple environmental media along a land-sea continuum

Yaci Liu[1]*

[1] The Institute of Hydrogeology and Environmental Geology, CAGS, Shijiazhuang, China
* liuyaci11@163.com

Keywords: microplastic, surface water, groundwater, sediment, estuary

Microplastic pollution is widely distributed from surface water to sediments to groundwater vertically and from land to the ocean horizontally. This study collected samples from surface water, groundwater, and sediments from upper to lower reaches and then to the estuary in 16 typical areas in the Jinjiang River Basin, Fujian Province, China. Afterward, it determined the components and abundance of the microplastics and analyzed the possible microplastic sources through principal component analysis (PCA). As a result, seven main components of microplastics were detected, i.e., polyethylene (PE), polypropylene (PP), polyvinyl chloride (PVC), polyethylene terephthalate (PET), polyformaldehyde (POM), nylon 6 (PA6), and polystyrene (PS). Among them, PE and PP were found to have the highest proportion in the surface water and sediments and in the groundwater, respectively. The surface water, groundwater, and sediments had average microplastic abundance of 1.6 n/L, 2.7 n/L, and 33.8 n/kg, respectively. The microplastics in the sediments had the largest particle size, while those in the groundwater had the smallest particle size. Compared with water bodies and sediments in other areas, those in the study area generally have medium-low-level microplastic abundance. Three pollution sources were determined according to PCA, i.e., the dominant agriculture-forestry-fishery source, domestic wastewater, and industrial production. This study can provide a scientific basis for the control of microplastics in rivers.

LID 0216
Potential groundwater pollution from fluorine in fertilizers

Hiroki Amano[1]*, Kei Nakagawa[2]

[1] School of Humanities and Science, Tokai University, Kumamoto, Japan
[2] Institute of Integrated Science and Technology, Nagasaki University, Nagasaki, Japan
* amano.hiroki.k@tokai.ac.jp

Keywords: groundwater pollution, fluorine, fertilizer

The chronic consumption of high concentrations of fluorine in drinking water can cause health problems. Therefore, in countries that use groundwater for drinking purposes, fluorine pollution of the groundwater is a major concern.

Fluorine pollution is primarily caused by natural factors, such as leaching from rocks and the effects of volcanic gases, though human factors, such as coal combustion and fertilizers, are also suspected. Regarding fertilizers, analyses of raw materials have already revealed that phosphate fertilizers contain fluorine. Consequently, groundwater pollution from fertilizers is anticipated in agricultural areas. However, studies quantifying the fluorine content in fertilizers are currently extremely scarce.

Therefore, this study focused on Kumamoto Prefecture, where fluorine pollution of groundwater used for domestic purposes has been confirmed, in an attempt to quantify fluorine levels in fertilizers used within the prefecture. Specifically, leaching test using pure water were conducted on dozens of types of fertilizers. The solution was analyzed using ion chromatography and the fluorine content was quantified.

The leaching test confirmed fluorine from all fertilizers. Furthermore, differences in the amount of fluorine were observed between different fertilizers.

LID 0218
Hydrologic controls on arsenic contamination of rice and groundwater: Insights from Cambodia

Mason Stahl[1]*, Keith Lawless[1], Devin Snyder[1], Amelia Casassa[1], Samnang Phin[2], Kongkea Phan[2], Samrach Phan[2], Eva Coleman[3], Daniel Sousa[3], Eden Halpert[4], Benjamin Bostick[4]

[1] Union College, Department of Geosciences, Schenectady, United States
[2] Water Innovation Lab, Kampong Cham, Cambodia
[3] San Diego State University, Department of Geography, San Diego, United States
[4] Columbia University, Lamont Doherty Earth Observatory, New York, United States
* stahlm@union.edu

Keywords: arsenic, rice, soil

Exposure to arsenic (As) through contaminated drinking water and food, particularly rice, affects more than 100 million people globally. A large proportion of the affected population resides in South and Southeast Asia, with Cambodia being heavily impacted through exposure to high levels of As in their groundwater and rice crops. The release of As from soils, sediments, and rocks is strongly dependent on a range of environmental factors, many of which are heavily influenced by hydrologic processes. Characterizing the hydrologic processes as water moves through soils and sediments (e.g., irrigation amount and source, soil moisture levels, and flooding frequency) is critical to understanding what drives As concentrations in groundwater, soil water, and rice (which can take up As from these water sources).

To address these questions, we sampled over 150 rice fields across Cambodia and have multiple harvest years of data for many of these fields. Here we present measurements of rice grain As and stable isotopes (C, N, O) along with field-based and remotely sensed measurements of soil moisture and flooding to identify how hydrologic conditions influence As mobilization and uptake into rice. Notably, our field sampling reveals that rice paddies which have experienced frequent flooding in recent decades have substantially less year-to-year variability in rice grain As than those flooded less frequently. We also present results for a large set of rice paddy soil incubation experiments that have allowed us to identify key soil physical and chemical properties that are predictive of the soils' potential for As mobilization and the generation of high As soil water, groundwater, and rice. Our field sampling together with our laboratory incubation experiments allows us to better separate the hydrologic drivers of As mobilization from the underlying soil/sediment characteristics that influence the potential for As mobilization.

LID 0220
Modelling groundwater flow and thermal regimes in the Ljubljana urban aquifer

Mitja Janža[1]*

[1] Geological Survey of Slovenia, Ljubljana, Slovenia
* mitja.janza@geo-zs.si

Keywords: shallow geothermal energy, urban aquifer, modelling

Intensive thermal use of groundwater can alter its natural thermal balance and reduce long-term renewability. To ensure efficient and sustainable use of groundwater for heating and cooling, it is essential to understand how thermal plumes form and evolve in the subsurface. In many urban areas, geothermal potential remains underused due to limited knowledge of subsurface hydraulic and thermal conditions. With growing pressures on the subsurface, groundwater management is becoming increasingly challenging.

Sustainable groundwater management strategies require tools capable of simulating natural and anthropogenically altered hydraulic and thermal regimes. Numerical groundwater-flow and heat-transport models at the urban scale are increasingly recognized as powerful decision-support instruments for evaluating plume propagation and optimizing geothermal system design. These models help address key challenges, including maximizing heat-exchange performance, minimizing costs, and reducing interference between neighboring geothermal installations or impacts on other groundwater users.

Geological, hydrogeological, and thermal datasets derived from monitoring networks, field investigations, and regional hydrogeological knowledge were integrated to develop a groundwater-flow and heat-transport model for the Ljubljana area. The model is intended to support planning of new geothermal systems by enabling simulations of thermal plume development and providing guidance for the sustainable and efficient use of this shallow geothermal resource.

The research was supported by the Slovenian Research and Innovation Agency through the research project N1-0347 InnoGeoPot, and through the UNESCO project IGCP 636 - Geothermal resources for energy transition.

LID 0221
Springs are crucibles of biodiversity connecting groundwater and surface water ecohydrology

Monica Esmond[1]*, Mark De Bruyn[2,3], Joseph Dibattista[4,5], Harald Hofmann[6], Matthew Currell[1]

[1] Australian Rivers Institute, Griffith University, Nathan, QLD, Australia
[2] Australian Research Centre for Human Evolution, Griffith University, Nathan, QLD, Australia
[3] School of Environment and Science, Griffith University, Nathan, QLD, Australia
[4] School of Environment and Science, Griffith University, Southport, QLD, Australia
[5] Australian Museum Research Institute, Australian Museum, Sydney, NSW, Australia
[6] Environment, Commonwealth Scientific and Industrial Research Organisation (CSIRO), Dutton Park, QLD, Australia
* monica.esmond@griffithuni.edu.au

Keywords: springs, eDNA, groundwater, surface water, isotopes

Freshwater springs worldwide are recognised for their biodiversity and ecological specialisation. However, their role in the hydrologic continuum between aquifers and surface water environments is rarely considered in catchment management and has to date been scarcely documented. This study employs microbial environmental DNA and environmental isotope tracers to investigate the ecohydrology of springs in aquifer-spring-surface water systems in Australia's largest groundwater reservoir, the Great Artesian Basin. Through analysis of prokaryotic and microeukaryotic DNA, we confirm that springs host the greatest microbial diversity throughout the system. By integrating the eDNA and isotopic datasets, we demonstrate that springs are also the key link by which sub-surface microbial ecosystem diversity and function is transmitted into surface water bodies. Springs that form headwaters or contribute to surface water flows in the Great Artesian Basin sustain unique ecological and cultural values well beyond their relatively small geographic extent, and this is consistent with other spring systems worldwide. These hydrologic systems are threatened by increasing development pressures and thus this research addresses a critical and timely need for methods to characterise groundwater-spring-surface water connectivity and ecological diversity, to inform evidence-based conservation and management strategies.

LID 0222
Assessment of small-scale Managed Aquifer Recharge (MAR) in India

Mohammad Faiz Alam[1], Navneet Sharma[1]*, Paul Pavelic[2], Alok Sikka[1]

[1] International Water Management Institute, New Delhi, India
[2] International Water Management Institute, Lao, PDR
* navneet.sharma@cgiar.org

Keywords: managed aquifer recharge, pond-based recharge, groundwater monitoring, community participation, India

Groundwater underpins India's food and water security but is increasingly overexploited. This study evaluates the hydrologic performance of Managed Aquifer Recharge (MAR) interventions implemented under government programs, in the context of India's plan to construct 14 million recharge structures, to inform more effective recharge design. Focusing on the groundwater-stressed Ramganga basin of the Ganges basin, the study draws on three years of participatory monitoring of 23 recharge structures. Using topographic surveys, staff gauge installations, daily water-level records maintained by trained community members, and water-balance methods, the study captures nearly 300 recharge events and quantifies associated recharge volumes. Results show that recharge performance remain consistently below its potential and consistently declines over time. Across all sites, the ratio of recharge volume to pond storage averaged 1.75 in 2023 but fell to around 0.8 in 2024 and 2025, far below those reported in a nearby recharge pilot (values of 5–12 times storage). Substantial variability in performance was observed across recharge structure types and seasons. Declining recharge rates over time were linked to siltation, lack of maintenance, and site-specific hydrogeological constraints. Pond water availability (averaging ~140 days per season) was not the primary constraint; instead, low infiltration rates—mostly below 40 mm day^{-1}—emerged as the dominant limiting factor. High evaporation losses (~28% of pond storage) further reduced effective recharge. These findings highlight the need to move beyond simply establishing infrastructure towards creating incentives for performance-based MAR planning, linking MAR sites with watershed measures and regular O&M for managing siltation. Additional recommendations include incorporating context-specific designs (especially in multipurpose ponds) and participatory monitoring for building local ownership and capacity. The study provides a rich evidence base to improve the effectiveness of large-scale recharge investments in India and offers transferable lessons for groundwater-stressed regions globally.

LID 0223
Groundwater depletion in India's food bowl: Assessing aquifer limits and the effectiveness of policy interventions

Mohammad Faiz Alam[1*], Anton Urfels[2], Vartika Singh[3], Proloy Deb[2]

[1] International Water Management Institute, New Delhi, India
[2] International Rice Research Institute, Los Baños, Philippines
[3] International Food Policy Research Institute, New Delhi, India
* m.alam@cgiar.org

Keywords: groundwater sustainability, aquifer depletion, Ganges Basin, energy–water nexus, demand-side management

Groundwater underpins India's food and water security, supplying irrigation to nearly two-thirds of cultivated land and meeting most rural drinking water needs. This reliance enabled the Green Revolution and national food self-sufficiency, but decades of intensive and un-regulated abstraction have pushed aquifers toward physical limits, particularly in the north-western India. Nearly one-fifth of assessed groundwater units in India are now classified as overexploited or critical, raising concerns about the long-term viability of irrigated agriculture and rural livelihoods. This study examines the sustainability of groundwater-based irrigation systems in the Ganges basin, with a focus on north-western India, by synthesizing hydrogeological evidence, irrigation demand, and the performance of policy and management interventions. It assesses how aquifer storage, crop water demand, and declining water tables interact with cropping choices, and demand management interventions to shape future groundwater trajectories. A stylized, data-driven assessment for a representative district in central Punjab indicates that the productive unconfined aquifer has already lost nearly ~ 30% of its dynamic storage. The analysis shows that while demand management measures such as irrigation efficiency interventions can slow depletion, they are insufficient to reverse long-term declines in heavily stressed aquifers. Under current depletion rates (~0.6 m yr^{-1}), binding constraints emerge within decades, with borewell deepening in mkahoring of wells and energy requirement for pumping doubling by mid century, and aquifer desaturation by ~2070s. Mainstream demand-side measures such as AWD and DSR will extend aquifer life by only 2–5 years, largely reducing energy use through irrigation water savings rather than consumptive depletion. The findings underscore the need to reassess groundwater management and policy solutions in the backdrop of aquifer physics and time-bound thresholds for long-term sustainable management.

LID 0224
Mapping the vulnerability of groundwater to drought using ensemble-based reconstructed groundwater level time series

Philip Schuler[1]*, Joan Campanyà[2], Henning Moe[2], Monika Kabza[2], David Tynan[2], Colin Fitzgerald[2], Béhinn Anders[2], Jon Hunt[2], Oisín Ó Briain[3], Ted Mccormack[3]

[1] CDM Smith SE, Berlin, Germany
[2] MKO, Galway, Ireland
[3] Geological Survey Ireland, Blackrock, Ireland
* philip.schuler@cdmsmith.com

Keywords: groundwater drought, vulnerability, groundwater level modelling, time series analysis, climate change adaptation

Geological Survey Ireland (GSI) is investigating Groundwater Forecasting and Climate Change Impacts. The investigation quantifies groundwater vulnerability to climatic drought in Ireland. Here, we define the 'vulnerability of groundwater to drought' as the predisposition of groundwater flow systems to be adversely affected by climatic drought.

Vulnerability refers to the magnitude of water level or SGI below a moving quantile threshold. Key variables for characterising drought include groundwater memory as proxy for storage; resilience and resistance; frequency; average drought length; and time lag, the latter describing the delayed response of groundwater levels to climatic events or conditions using the cross-correlation function.

The applied method makes use of an Ireland-wide long-term dataset of reconstructed (modelled) groundwater levels and derived time series of the Standardised Groundwater Index (SGI), which were prepared using three hydrological models: Pastas; AquiMod2; and UISCEmod. The data set covers climatic and topographic variability and represents the major hydrogeological characteristics of different 'aquifer types' (fractured bedrock, karst, and sands and gravels) that define Irish hydrogeology. Hence, the data set represents a wide range of settings that control the propagation of meteorological drought into hydrological droughts of different magnitude, duration and frequency. Principal Component Analysis and clustering analysis facilitate understanding drought characteristics, and map them across Ireland.

The related workflow uses open-source tools only, and is applicable to other regions. The characterisation of groundwater drought and associated vulnerability will be available to stakeholders. The intent is to assist water suppliers and water management agencies with climate change adaptation planning and to enhance groundwater user resilience related to specific droughts.

LID 0225
Assessment of artificial recharge impact on groundwater using groundwater modelling in Ban Dong Khwang, Sakon Nakhon Province, Thailand

Sirilack Duangsong[1]*, Kriangsak Pirarai[1], Ocpasorn Occarach[1], Okke Batelaan[2]

[1] The Department of Groundwater Resources, Bangkok, Thailand
[2] Flinders University, Adelaide, Australia
* ppgeol49@gmail.com

Keywords: managed aquifer recharge, groundwater modelling

Groundwater scarcity in northeastern Thailand has worsened due to climate variability, reduced rainfall, and rising water demand in agricultural communities. Managed Aquifer Recharge (MAR) has emerged as a promising strategy to improve groundwater availability and resilience. This study assesses the effectiveness of a MAR system in Ban Dong Khwang, Sakon Nakhon Province, using field observations, hydrogeological data, and numerical groundwater modelling.

A conceptual hydrogeological model was developed based on lithological logging, geophysical surveys, and groundwater monitoring data. This conceptualisation was translated into a transient numerical groundwater flow model using MODFLOW via the ModelMuse interface. Model calibration used observed groundwater levels before and after MAR construction, with parameter optimisation via PEST.

Groundwater conditions were simulated over ten years with and without Managed Aquifer Recharge (MAR). MAR implementation increased total recharge from 3.4 million cubic meters to 7.4 million cubic meters, adding 3.96 million cubic meters. The groundwater level rose by about 0.57 m, affecting flow over 1.3 km^2 and reaching up to 2.7 km southeast. The system provides an additional 12,310 m^3 of water annually, supporting 684 residents' domestic and agricultural needs during dry seasons, confirming MAR as a sustainable strategy for drought-prone areas.

This study demonstrates the importance of numerical groundwater modelling as a tool for assessing MAR performance and guiding water resource planning. The findings support the implementation of MAR systems in Thailand for climate adaptation and groundwater sustainability, highlighting the need for ongoing monitoring and model refinement to manage uncertainties in hydraulic properties and climate projections.

LID 0227
Warming up the subsurface: How buildings shape underground temperatures in changing urban environments

Nele Hastreiter[1,3]*, Thomas Vienken[2,1]

[1] Helmholtz Centre for Environmental Research – UFZ, Department Monitoring and Exploration Technologies, Leipzig Germany
[2] Weihenstephan-Triesdorf University of Applied Sciences, TUM Campus Straubing for Biotechnology and Sustainability, Geothermal Energy, Straubing, Germany
[3] Technical University of Munich, Campus Straubing for Biotechnology and Sustainability, Geothermal Energy, Geothermal Energy, Straubing, Germany
* nele.hastreiter@ufz.de

Keywords: subsurface warming, anthropogenic thermal footprints, groundwater temperature dynamics

Urban environments are subject to continuous changes in built infrastructure and human activities. In the subsurface, these effects alter the thermal regime and subsurface temperatures, often leading to the formation of subsurface urban heat islands (SUHIs). Understanding and predicting subsurface temperature changes is highly relevant for the sustainable management of groundwater resources, groundwater quality monitoring, protection of dependent ecosystems, the use of groundwater as a renewable source for heating and cooling, and for making our cities more resilient to the effects of climate change.

Subsurface thermal footprints are yet rarely explicitly considered in urban groundwater management approaches, as their variety and development under changing conditions are hard to disentangle.

Focusing on the influence of buildings, we investigate the historical development of groundwater temperatures beneath a peri-urban study area in great spatial and temporal detail. Buildings of different types and construction periods are considered, as well as temporal changes in building density and renovation measures within the building stock. The analysis is based on long-term surface and subsurface temperature observations combined with a well-parameterized numerical heat and groundwater flow model.

The results show how the cumulative thermal footprint of buildings varies in intensity and extent, depending on building characteristics and transformation processes. The presented study contributes to a more realistic assessment and reconstruction of urban subsurface temperatures and supports the understanding and sustainable management of groundwater resources in changing urban environments.

LID 0228
Groundwater for emergency water supply: Evidence from the 2024 Noto Peninsula earthquake, Japan

Takahiro Endo[1]*, Takashi Kakimoto[2], Makoto Taniguchi[2]

[1] College of Environmental Studies, Rikkyo University, Japan
[2] Environmental Geotechnology Group, Center for Environmental Science in Saitama, Japan
[3] Research Division, Research Institute for Humanity and Nature, Japan
* endotak01@gmail.com

Keywords: groundwater, disaster, emergency water supply

Although the importance of groundwater during post-disaster water outages has been frequently mentioned in public discourse, empirical evidence on how local wells are actually used remains limited. This presentation examines the case of Nanao City, Ishikawa Prefecture, Japan, where both formal water supply points operated by local governments using water trucks and informal water supply points based on private wells were used following the 2024 Noto Peninsula Earthquake.

In addition to participant observation during the water outage period, we employed a transdisciplinary, mixed-methods approach that integrates qualitative and quantitative data, combining questionnaire surveys with residents (n = 522) and private well owners (n = 28) to examine the temporal and spatial distribution of privately owned wells accessible to the public..

The results show that groundwater played an important role as an alternative water source because it was locally available, could be accessed quickly, and was distributed across the affected area. These features allowed groundwater to complement formal emergency water supply systems, particularly for non-potable uses such as washing and toilet flushing.

However, the case study also reveals several limitations. Groundwater is not always suitable for drinking due to water quality concerns, carrying water can impose a physical burden, and information on well locations is not always well shared within communities. Based on these findings, this study suggests policy measures including the combined use of multiple water sources, volunteer-based support for water transportation, and the pre-registration of local wells for emergency use.

LID 0229
Hydrogeological monitoring for the assessment of Managed Aquifer Recharge (MAR) Techniques: A case study in the Alban Hills region (Rocca Priora, Rome, Italy)

Lucia Mastrorillo[1], Stefania Passaretti[2], Claudio Mineo[2], Eleonora Boscariol[2], Simona Battaglia[2], Alberto Trotta[2], **Marco Petitta**[1*]

[1] Department of Earth Sciences, Sapienza University, Rome, Italy
[2] ACEA ATO2 SpA, Department of Water Resources Engineering, Rome, Italy
* marco.petitta@uniroma1.it

Keywords: managed aquifer recharge, sustainable water resource management, groundwater resilience

Over the past three decades, in Mediterranean area, many aquifers have been affected by a progressive reduction in groundwater availability due to the combined impact of prolonged droughts and increasing withdrawals driven by demographic and economic growth. Research institutions, water utilities and other stakeholders recognize the need to explore innovative groundwater management strategies to enhance long-term resource sustainability and restore hydrogeological balance. In this context, controlled aquifer recharge - known as Managed Aquifer Recharge (MAR) and regulated in Italy by Ministerial Decree No. 100/2016 - offers a promising approach to addressing water scarcity. In this study, a hydrogeological monitoring plan has been implemented as a preliminary step toward evaluating a MAR system at the “Pantano della Doganella” site (in the municipality of Rocca Priora, Rome). The site is located within the caldera rim of the Alban Volcanic Complex and it is characterized by multiple superimposed aquifers. It also hosts a wetland significantly modified by historical anthropic activities but naturally re-establishing during periods of intense rainfall. Its proximity to the Doganella drinking wellfield has provided access to long-term groundwater level records and detailed stratigraphic data. By developing a site-specific conceptual hydrogeological model based on hydrogeochemical characterization and water budget analysis, this research aims to identify the most suitable MAR technique for the site and to assess its technical and environmental feasibility. Within this framework, adopting MAR represents a key mitigation and adaptation measure to enhance groundwater resilience under changing climatic conditions, with direct impact on the restoration of hydrological budget in areas affected by necessary drinking water supply.

The research was funded through the agreement “Hydrogeological monitoring activities aimed at identifying the recharge technique under controlled conditions in the area of Pantano della Doganella” between ACEA Ato2 SpA and Department of Earth Sciences Sapienza University (Rome, Italy).

LID 0231
Integrating geophysical surveys and groundwater potential assessments in salt dome areas of Northeastern Thailand for sustainable water security

Anuwat Surinthip[1]*, Kriangsak Pirarai[1], Paranee Buarapa[1], Bunyasit Kiwduangta[1], Sattaya Intanum[1]

[1] Department of Groundwater Resources, Bangkok, Thailand
* surinthip.a@gmail.com

Keywords: salt dome, geophysical surveys, water security

In Northeastern Thailand, water shortage is a persistent challenge due to complex geographic and geological structure limitations, which is characterized by unpredictable and irregularly shaped and deep rock salt deposits. Study area covers approximately 250 km^2 which is representing a deep underground salt dome located in Ban Dung District, Udon Thani Province. The area is impacted by brine extraction at depths of 70 meters for the salt farming industry. This study integrates magnetotelluric (MT), gravity, and resistivity (1D and 2D) surveys to delineate salt dome boundaries and identify the freshwater-saline groundwater transition.

MT and gravity surveys effectively delineated regional N-S structural anomalies, though their vertical resolution remains limited. This limitation is refined by 1D and 2D resistivity surveys, to enhance depth profile resolution for drilling site selection. The analysis results align with well data, revealing shallow aquifers in the central region (40–60 meters) and increasing depths towards the W-E edges (84–90 meters), respectively. Integration of the data enabled the mapping of a freshwater–saline transition zone, effectively outlining a 75 km^2 N-S trending salt dome within the central area. A 75-hour constant-rate pumping test confirmed sustainable yields of 3–25 m^3/h, providing critical data for safe abstraction and saline intrusion prevention. Strategic drilling should target N-S anomalies at depths of 40–90 m, while maintaining abstraction rates within the 3–25 m^3/h range.

The study emphasizes that future exploration should adopt a multi-scale geophysical approach, utilizing gravity/MT for regional targeting and 1D/2D resistivity for depth precision to optimize borehole completion. This framework provides a vital database for informed policymaking, ultimately enhancing water security in salt dome regions.

LID 0232
Temperature-depth profiles at Vitens' riverbank filtration site: Engelse Werk

Anouk Sprong[1]*, Rogier van der Velde[1]

[1] Vitens, Zwolle, the Netherlands
* anouk.sprong@vitens.nl

Keywords: temperature depth profiles, groundwater abstraction, travel time estimations

Engelse werk is a groundwater abstraction site for drinking water production that is positioned between the river IJssel and the city of Zwolle, the Netherlands. The well field abstracts approximately 14 $Mm^3\ y^{-1}$, of which 2 Mm^3 from a deep aquifer and 10 Mm^3 from a middle deep aquifer. Groundwater quality at this location is increasingly influenced by anthropogenic pressures, originating both from the river and from the urbanized area to the north. These influences pose risks for maintaining the required drinking water quality standards, especially for the water abstracted from the middle deep aquifer.

Current risk assessments rely on a combination of monitoring and regional numerical groundwater models. Although these models incorporate all available hydrogeological data, uncertainties remain significant due to assumptions regarding hydraulic conductivity, aquifer heterogeneity, boundary conditions, and river–aquifer interaction. These uncertainties propagate into the estimates of groundwater travel times to the abstraction wells. To improve these estimates new information is needed.

This research focuses on investigating the possibilities of using groundwater temperature as a natural tracer to characterize the origin of the abstracted water and ultimately quantify travel times. Temperature depth profiles (TDPs) were collected in existing monitoring wells using a precise thermometer (0.002°C), recording temperature at 1 m. Measurements were conducted along two transects: (1) a transect located between the river IJssel and the well field, and (2) an transect located between the city center and the well field. Profiles were repeatedly measured over multiple seasons to capture temporal variations in thermal propagation.

First results show a clear thermal signal originating from the IJssel towards the well field. Along the river transect, a gravel layer exhibits strong temporal variability, reflecting seasonal river-temperature cycles.

LID 0233
Characterising spatial groundwater recharge heterogeneity using transfer-function modelling in a fractured rock aquifer in Wellington (NSW, Australia)

Muqing Dong[1]*, Martin S. Andersen[1], Gabriel C. Rau[2]

[1] Water Research Laboratory, School of Civil and Environmental Engineering, UNSW Sydney, Australia
[2] Earth Sciences, School of Science, The University of Newcastle, Callaghan, Australia
* muqing.dong@student.unsw.edu.au

Keywords: groundwater recharge, spatial heterogeneity, transfer function modelling

For estimation of groundwater recharge spatiotemporal heterogeneity remains a challenge. This study applies a transfer function method to model groundwater level responses to precipitation through convolution of a non-linear soil moisture balance model and Gamma response function using the python package Pastas (Collenteur et al., 2019). The model is tested and evaluated with data from the Wellington Critical Zone Observatory located in semi-arid region of NSW Australia, using eighteen groundwater level time series from monitoring bores located in a heterogeneous fractured rock aquifer.

Groundwater level time series from each location is fitted with the model to characterise its response to precipitation events. Three groundwater response types are identified. The fast, intermediate, and slow groups have a mean precipitation-to-peak response times of <1, 39, and 122 days. This corresponds to mean alluvial deposit thicknesses of 3.0 m, 4.6 m, and 10 m on top of the fractured rock, respectively. Deep soil moisture monitoring (to nearly 8 m) within the slow response region shows that moisture related to rainfall events do not penetrate beyond 0.8 m, indicating that matrix pathways may not drive recharge in this region.

Two conceptual models can account for the spatially variable groundwater responses. Recharge may occur locally via vertical transport in vadose zone with variable alluvial thickness and macropore structures. Alternatively, recharge may occur through preferential paths originated from bedrock outcrops and the head rise laterally propagate to the observation bores. Validation or disproval of either conceptual model will require further analysis.

The results demonstrate that transfer function modelling can characterise groundwater level responses under geologically heterogeneous conditions in efficient and robust manner and provides an effective conceptualisation strategy for groundwater recharge processes and regional management.

LID 0235
Decision support tool in GoldSim for managing and optimizing remediation activities

Tamás Olasz[1]*, Zoltán Bőthi[1]

[1] WSP Hungary Consulting Zrt., Budapest, Hungary
* tamas.olasz@wsp.com

Keywords: remediation, decision support model, uncertainty management

Selecting, designing and optimizing remediation technologies of contaminated areas is one of the major challenges world-wide. A new decision support tool is developed in GoldSim which supports these activities by providing an easy to use, yet sophisticated modelling environment.

The developed model can be used as a predictive tool to simulate natural attenuation and the expected effects of various remediation technologies, but also as a backwards simulation to determine the possible source characteristics based on historical data. The model focuses on organic contaminants including CHC, PAH, TPH, BTEX and other common compounds, but has the capability to be extended to other contaminant groups such as toxic metals or PFAS. Multi-phase flow and advective-diffusive transport calculations are the basis of the model, which incorporate processes such as seasonal weather effects, sorption on organic and inorganic materials, the accumulation and transport of DNAPL and LNAPL phases, microbial degradation processes, and chemical decay series, all driven by spatially and temporally varying physical and chemical conditions. The overall flexibility of the model allows it to be tailor-made for different contaminated areas and to investigate the differences between specific remediation technologies. The applied GoldSim modelling environment provides the user with graphical user interfaces for simple model setup and visual cost-benefit analysis, along with the built-in Monte Carlo capabilities to consider uncertainties of input parameters and end results, which are often overlooked in traditional models.

The developed novel modelling approach allows for a realistic, yet high-level investigation of contaminant fate, linked to a cost-benefit based decision support system to optimize potential remediation technologies. This makes the tool unique and applicable in a large range of remediation related use cases, which can be used during the whole lifecycle of the project.

LID 0236
Identifying relative sources of groundwater recharge in the Indus Alluvial Aquifer using a new canal module within a coupled VIC–groundwater model

Setareh Nagheli[1]*, Johanna Scheidegger[1], Christopher Jackson[1], Andrew Hughes[1], Alan Macdonald[2]

[1] British Geological Survey, Nottingham, UK
[2] British Geological Survey, Edinburgh, UK
* snagheli@bgs.ac.uk

Keywords: Indus Basin, link canal system, Variable Infiltration Capacity (VIC) model

The Indus Basin is one of the world's most intensively irrigated regions, supported by a vast canal network that delivers large volumes of water to agriculture. Alongside these irrigation supplies, major link canal systems move water from the western rivers, such as the Chenab, towards eastern tributaries to help meet increasing domestic and agricultural demands. These transfers change the spatial pattern of surface-water availability and influence how groundwater is recharged across the alluvial aquifer. Despite this, many large-scale hydrological models still treat canal–aquifer interactions in a simplified way or exclude them entirely.

To address this gap, we developed a new canal–groundwater interaction module within an enhanced version of the Variable Infiltration Capacity (VIC) model, coupled to a two-dimensional lateral groundwater-flow component. The module allows canal flows to be routed dynamically, includes stage-dependent leakage, and enables irrigation water to be drawn flexibly from both groundwater and surface-water sources. Canal–aquifer exchanges are calculated using a head-dependent flux approach, allowing both gaining and losing conditions to be represented within complex branching canal systems.

We demonstrate how the new module behaves using a simplified representation of the Indus link canal system. This initial setup allows us to explore how canal routing, irrigation withdrawals, soil processes, and groundwater flows interact within the coupled framework, and how different recharge sources – precipitation, canal seepage, river leakage, and irrigation return flow – contribute to the groundwater balance. The results are preliminary, and full calibration and quantitative assessment are still in progress.

LID 0237
Combining AI-based data mining and 3D interpolation for groundwater salinity models

Jude King[1,2]*, Gualbert Oude Essink[1,2], Marta Faneca Sànchez[1], Guilherme Emidio Horta Nogueira[1]

[1] Deltares, Utrecht, The Netherlands
[2] Utrecht University, Utrecht, The Netherlands
* jude.king@deltares.nl

Keywords: groundwater salinity, 3D modelling, AI data mining

Advances in AI-based data mining now enable rapid extraction of groundwater salinity information from previously unusable sources such as scanned PDFs, images, and undigitised borehole logs. Using multimodal Large Language Models (LLMs) and bespoke agentic architectures, new routines have been developed that automatically identify, classify, and digitise salinity-relevant text and figures, reducing the time and cost typically associated with large-scale data compilation. These methods build on recent improvements in LLM-driven hydrogeological digitisation, and demonstrate how AI can help address established challenges of regional groundwater modelling: data scarcity and reliable data.

To explore how such AI-derived datasets can support model development and validation, a 3D salinity interpolation workflow was implemented using the Python package ArchPy. ArchPy enables geostatistical simulation within stratigraphically constrained geological models, allowing AI-extracted point data to be combined with deterministic surfaces and variogram-based interpolation routines. By integrating global datasets for surface and subsurface geometry, a reproducible three-layer model was constructed and Sequential Gaussian Simulation (SGS) was applied to generate continuous 3D salinity fields. Even with limited observations, the workflow illustrates how modern open-source tools can produce transparent, transferable, and data-driven regional groundwater models.

Together, these developments highlight a promising direction for groundwater modelling in data-scarce environments. AI-assisted digitisation offers an opportunity to build regional (or even global) salinity databases, while packages such as ArchPy provide a framework for transforming these datasets into spatially coherent 3D datasets that can support model validation and management decisions. This work forms part of the UNESCO-GEF project “Management of Coastal Aquifers and Related Ecosystems in the Mediterranean.”

LID 0238
20,000 years underground, today in your glass: Turning groundwater age into a public awareness movement in Southwest France

Mélanie Erostate[1]*, Emilie Laurent[1], Bruno De Grissac[1]

[1] SMEGREG – Syndicat mixte d'étude et de gestion de la ressource en eau du département de la Gironde, Bordeaux, France
* melanie.erostate@smegreg.org

Keywords: groundwater residence time, public awareness, science communication

Groundwater residence times are a fundamental hydrogeological parameter - yet they rarely reach public consciousness. In the Gironde department (Southwest France), where 97% of drinking water comes from aquifers averaging 20,000 years old - locally exceeding 50,000 years - a unique initiative transformed this scientific data into a large-scale public awareness movement.

For the first time in France, groundwater age became the core message of a territorial communication campaign, not just a technical parameter in reports. The slogan "*20 000 ans sous Terre, aujourd'hui dans votre verre*" (20,000 years underground, today in your glass) bridges deep time and everyday experience, making abstract residence times tangible and emotionally resonant while reframing drinking water as a millennial heritage rather than an ordinary utility.

The campaign combined scientific credibility with creative storytelling through a two-tiered approach. At the regional scale, a woolly mammoth mascot symbolizing deep time and slow renewal cycles anchored a department-wide campaign deployed via displays, animated videos, and web platforms. At the local scale, each drinking water service received customized communication tools - including territory-specific posters displaying the actual age of their distributed water with period-appropriate visuals (Cro-Magnon figures, hunter-gatherers, medieval knights) - allowing them to tell the unique story of "their" water and reinforce territorial ownership.

By revealing that today's tap water infiltrated during the last glaciation, the campaign fundamentally shifts perceptions: groundwater is no longer seen as endlessly renewable but as a slowly renewable and shared inheritance. As deep aquifers face overexploitation pressure, this narrative supports demand management policies and strengthens public acceptance of conservation measures.

The authors acknowledge the research projects DEESAC and PaléEaux, as well as the University of Corsica, for providing groundwater dating data and chemical analyses.

LID 0239
Advancing data sharing, dissemination, collaboration and global-scale analysis through the Global Groundwater Monitoring Network

Claudia Ruz Vargas[1]*, Andrew Pearson[1], Elie Gerges[1], Feifei Cao[1], Arnaud Sterckx[1,2], **Elisabeth Lictevout**[1]

[1] International Groundwater Resources Assessment Centre (IGRAC), Delft, The Netherlands
[2] Independent Researcher, Rome, Italy
* claudia.ruz-vargas@un-igrac.org

Keywords: groundwater monitoring, in-situ observations, data accessibility

Groundwater is the largest store of liquid freshwater on Earth and supports water and food security, ecosystems, and climate resilience. It supplies around 40% of irrigation water globally and drinking water for billions of people. Yet in many regions, groundwater depletion has become widespread due to unsustainable extraction and climate impacts. Monitoring groundwater levels is essential to understand these changes and manage the resource sustainably. Moreover, analysing groundwater at continental to global scales using monitoring data can improve understanding of large-scale hydrological processes, refine estimates of groundwater storage, and support international collaboration in water management.

This presentation introduces recent developments of the Global Groundwater Monitoring Network (GGMN) (https://ggis.un-igrac.org/view/ggmn/), a global database and platform designed to improve access to in situ groundwater data. Operating as a network of networks, the GGMN collates, harmonises, and disseminates groundwater data from national and subnational monitoring programmes worldwide.

As of December 2025, the GGMN contains over 111 million groundwater level observations from more than 134,000 wells and over 5 million groundwater quality measurements from 66,000 locations, representing 218,670 monitoring points across 50 countries, contributed by 66 organisations. GGMN data are increasingly used for global groundwater trend assessments, research and international reporting.

Here, we will highlight the current data coverage, processing and harmonisation approach, recent improvements towards FAIR data (findable, accessible, interoperable, and reusable), and key applications, including status assessments and trend analyses. By providing harmonised, accessible groundwater data globally, the GGMN supports the transformation of isolated datasets into coordinated information that can inform sustainable groundwater management and enable evidence-based action.

LID 0241
Collaborative groundwater modelling for Northern Uganda

Rebekah Hinton[1]*, Dor Fridman[1], Barbara Willaarts[1], Silvia Artuso[1], Wycliffe Tumwebaze[2], Winfred Kintu[2], Kerudong Pascal[2], Kamusiime Brosom[2], Taher Kahil[1]

[1] International Institute for Applied Systems Analsysis (IIASA), Laxenburg, Austria
[2] Ministry of Water and Environment (MWE), Kampala, Uganda
* hinton@iiasa.ac.at

Keywords: groundwater, adaptation, hydrological modelling

We present a collaborative approach to modelling groundwater resources in the Upper Nile Water Management Zone (UNWMZ) of Uganda, advancing integrated water resources assessment and planning. The Community Water Model (CWatM) is applied across the UNWMZ and coupled with MODFLOW 6 to simulate basin-scale surface-groundwater interactions, enabling development of a fully integrated hydrological modelling framework.

Implementing a stakeholder-engaged modelling approach including stakeholder workshops focused on participatory mapping exercises, major water demand sectors and pressures were identified and collaboratively mapped. Additional data-sources such as household survey data were further used to refine the spatial representation of domestic water demand, a critical consideration in Uganda where approximately 74% of the population relies directly on groundwater abstraction from boreholes, shallow wells, and springs to meet daily water needs.

Through ongoing collaborative modelling process between scientists and practitioners, the process represents a collaborative modelling approach in which stakeholders are engaged in model development. Calibration and validation draw on multi-source observations, including streamflow records and groundwater level time series from monitoring wells distributed across the UNWMZ.

This work provides the first integrated systems model of groundwater storage and dynamics for the UNWMZ. The coupled framework enables improved assessment of recharge, abstraction impacts, and surface-groundwater feedbacks. Through the co-development of scenarios with stakeholders, the modelling process supports exploration of plausible future pathways and identification of emerging threats under climatic change. The results provide an evidence base to inform future groundwater policy and planning in the UNWMZ. The approach demonstrates the value of combining physically based modelling with stakeholder-informed data to strengthen groundwater management in data-limited environments.

The work is undertaken through the GEF sponsored Groundwater for advancing Resilience in Africa, G4DR project. GEF ID 10970

LID 0242
Climate change impacts on groundwater recharge in the Mitchells Plain West Catchment of the Cape Flats Aquifer

Miriam Arinaitwe[1]*, John Okedi[2]

[1] Department of Civil Engineering, University of Cape Town, Rondebosch, South Africa
* arnmir003@myuct.ac.za

Keywords: groundwater recharge, climate change, coastal aquifer

Groundwater recharge in sandy coastal aquifers is highly sensitive to climate change, yet remains poorly constrained in many semi-arid regions due to limited long-term monitoring. In South Africa, rising temperatures, changing rainfall characteristics, and increasing urban pressures are expected to significantly modify recharge processes, with implications for longterm water security. The Cape Flats Aquifer, a shallow unconfined coastal aquifer underlying Cape Town, provides an important drought buffer but is particularly vulnerable due to its reliance on rainfall-driven recharge and high evapotranspiration losses. This study assesses climate change impacts on groundwater recharge within the Mitchells Plain West Catchment of the Cape Flats Aquifer. It addresses three questions: how do climate change drivers, like altered rainfall and rising temperatures, influence groundwater recharge; how can Internet of Things (IoT)-based groundwater monitoring, remote sensing, and physically based hydrological modelling be integrated to improve recharge assessment and reduce uncertainty; and how can controlled experimental data support model validation and inform future groundwater sustainability. These questions are addressed by evaluating recharge sensitivity using an integrated approach that combines climate data, satellite-derived land surface indicators, IoT-based groundwater observations and controlled experimental infiltration data within a hydrological model under baseline and future climate scenarios. The study advances understanding of groundwater recharge responses to climate change in a coastal aquifer within an urbanised setting and demonstrates that integrating monitoring, experimental validation, and modelling can meaningfully reduce recharge uncertainty in data-scarce environments. The findings strengthen the evidence base for climate-resilient groundwater management in urban catchments.

LID 0243

Characterisation of spatially and temporally varying surface water and groundwater interaction processes at a MAR site using environmental tracers

Kai Meiselbach[1,3]*, Diana Burghardt[1], Thomas Fichtner[1], Stephan Beil[2], Paul Franke[3], Bernd Bauer[3], Zhao Chen[1]

[1] Dresden University of Technology (Institute of Groundwater Management), Dresden, Germany
[2] Dresden University of Technology (Institute of Water Chemistry), Dresden, Germany
[3] Stadtwerke Görlitz AG, Görlitz, Germany
* kai.meiselbach@tu-dresden.de

Keywords: groundwater-surface water interaction, MAR, environmental tracers

The drinking water supply for the city of Görlitz is mainly based on groundwater abstraction and the local groundwater resources are increased through managed aquifer recharge activities. In the context of changing regional climate conditions, the frequency of droughts and floods is expected to increase in the future. This would significantly impact the quantity and quality of available groundwater resources, increasing the risk to the local drinking water supply of the city of Görlitz. To strengthen the resilience of the future drinking water supply, strategies and adaptation measures are required. This study focuses on characterising the interaction between surface waters and the shallow aquifer used for Görlitz's drinking water supply, as it varies spatially and temporally, using environmental tracer monitoring during different hydrological flow conditions. The monitoring data, which are resolved in space and time, demonstrate the high dynamic interaction of the various flow components: landside groundwater inflow; riverbank filtrate from the Lusatian Neisse; and managed aquifer recharge from infiltration ponds. An additional relevant aspect is that the study area is regularly flooded. Individual flood events reveal clear physical and chemical parameter signals in the continuously monitored groundwater observation and abstraction wells. This indicates the direct influence of infiltrated floodwater through the partially permeable cover layer of the aquifer. As part of the ongoing CRossWATER project, which is funded by the EU Interreg Poland-Saxony 2021–2027 programme, further detailed investigations and experiments are being designed based on the findings, and the local monitoring network is being optimised to improve the monitoring and understanding of the influence of surface water on groundwater in terms of quantity and quality.

LID 0244
Assessing the energy storage potential of abandoned Longwall Coal Mines: A coupled hydro-thermo-geomechanical approach in Wallonia (Belgium)

Guillaume Vandelois[1]*, Olivier Kaufmann[1], Nicolas Dupont[1], Thiérry Martin[1], Bertrand François[1], Pascal Goderniaux[1]

[1] University of Mons, Mons, Belgium
* guillaume.vandelois@umons.ac.be

Energy storage systems will play a central role in achieving the European Union's objective of climate neutrality by 2050. Among emerging solutions, the reuse of abandoned underground coal mines as subsurface energy storage reservoirs represents a promising opportunity, particularly in former mining regions.

In Wallonia (South Belgium), underground coal mining ceased in the late 1980s after more than a century of intensive exploitation, based on the longwall mining method. This technique implies controlled roof collapse behind the mining front, generating highly disturbed zones known as goafs, characterized by fractured and compacted rock with complex hydraulic, thermal, and mechanical properties. These zones, as groundwater systems, may provide significant storage and heat exchange potential, but their properties are poorly documented.

This research aims to characterize the hydro-thermal and geomechanical properties of a goaf system and to evaluate its suitability for subsurface energy storage using a geomechanical model and a 3D groundwater flow and heat transfer model. The first step consists of reconstructing the mine geometry and coal seams using historical mining plans and cross-sections from archival documents. This 3D geological and mining model forms the structural basis for future simulations.

Five boreholes were drilled to intersect three mined coal panels. A geophysical logging program was carried out, including gamma-ray, spectral gamma-ray, induction, electrical resistivity, and flowmeter logs. In addition, cross-hole seismic tomography was performed between selected boreholes. These investigations aimed to characterize the geological structure, delineate the spatial extent of the goaf and associated fractured zones, and precise their structural and hydraulic heterogeneity.

A geomechanical model is being developed to simulate goaf formation and post-mining deformation, allowing estimation of permeability and porosity fields within collapsed and fractured zones. These fields are then integrated into a coupled groundwater flow and heat transport model to assess the storage capacity, thermal recovery efficiency, and long-term performance of the system.

This multidisciplinary workflow provides a quantitative framework to evaluate abandoned coal mines as large-scale, low-carbon energy storage systems and contributes to the sustainable re-use of post-mining subsurface infrastructures.

LID 0245

Assessment of nitrogen-bearing compound sources in the Lomellina rice-paddy area through nitrogen and oxygen isotope analysis in the local phreatic aquifer

Lorenzo Sangalli[1]*, Daniele Pedretti[1], Petra Baják[1], Marco Masetti[1], Neus Otero[2,3], Arianna Facchi[4]

1 Università degli Studi di Milano (UNIMI), Dipartimento di Scienze della Terra 'Ardito Desio' (DISTAD), Milan, Italy
2 Universitat de Barcelona (UB), Departament de Mineralogia, Petrologia i Geologia Aplicada, Facultat de Ciències de la Terra, Barcelona, Spain
3 Serra Hunter Fellowship, Generalitat de Catalunya, Spain
4 Università degli Studi di Milano (UNIMI), Dipartimento di Scienze Agrarie e Ambientali – Produzione, Territorio, Agroenergia (DiSAA), Milan, Italy
* lorenzo.sangalli@unimi.it

Keywords: nitrate in groundwater, isotope geochemistry, rice-paddy agroecosystems

Nitrate pollution in groundwater represents a global issue, with significant impacts on water resource quality. Despite its relevance, few studies have investigated the origin and transformation processes of nitrate derived from nitrogen-based fertilizers in European rice-paddy contexts such as the Lomellina area, within the main rice-producing district in Italy.

This study aims to systematically apply $\delta^{15}N$-$\delta^{18}O$ dual isotope analysis of nitrate in the phreatic aquifer of the Lomellina area, where groundwater depth ranges from less than 1 m to about 15 m, in order to trace the sources and transformations of nitrogen-bearing compounds in this rice-paddy district.

Between June 2024 and December 2025, thirteen geochemical monitoring campaigns were conducted at 25 monitoring points tapping the phreatic aquifer. Data obtained from the dual isotopic analysis of nitrates in groundwater (represented using a version of the Kendall Plot adapted to local conditions) were integrated with nitrate concentration, land use data and details on the type of fertilizers applied in the study area.

The results suggest that although nitrate concentrations in groundwater (measured up to 164.49 mg/L) mainly originate from $NH4^+$- based inorganic fertilizers ($\delta^{15}N$ between -5 and +15‰; $\delta^{18}O$ between 0 and +5‰), significant contributions also come from the natural nitrogen cycle in soil and from atmospheric deposition. In some samples, nitrate concentrations of approximately 5-15 mg/L can be interpreted as a mixture of these different sources, whereas in others, anomalous $\delta^{15}N$ and $\delta^{18}O$ values in nitrate prevent the clear identification of nitrogen-bearing compound sources.

The study's findings provide a solid basis for future monitoring activities and for the sustainable management of fertilizers, both within the study area and in other regions where it is necessary to identify the contribution of nitrogen-based fertilizers to groundwater nitrate.

This study was carried out in the context of the PROMEDRICE project (https://promedrice.org/; PRIMA-Section2–2022) funded, for the Italian partners, by MUR (Italian Ministry of University and Research).

LID 0247
Sensitivity and uncertainty analyis of soil-water dynamics through a bucket-model approach

Catalina Zapata Barra[1]*, Giovanni Porta[1], Gabriele Chiogna[2]

[1] Dept. of Civil and Environmental Engineering, Politecnico di Milano, Milan, Italy
[2] GeoZentrum Norbayern, Friedrich-Alexander-Universität, Erlangen, Germany
* catalina.zapata@polimi.it

Keywords: soil-water nexus, global sensitivity analysis, bucket-model calibration, uncertainty quantification

This study investigated soil water interactions in a peri urban area in the South-East of Milan to assess infiltration and groundwater recharge in a highly heterogeneous setting. A bucket-type model was developed to simulate soil moisture and groundwater recharge dynamics using meteorological data and soil/aquifer parameters. Different sensitivity analysis methods, including Monte Carlo simulation, global sensitivity analysis (AMA indices) and Sobol indices computed in the wavelet domain (DWT) were used to determine the dominant model parameters controlling two quantities of interest, i.e. soil moisture and recharge. All three methods identified evapotranspiration zone thickness (ETD) as the most influential parameter on mean and variance for both quantities. In addition, field capacity (FC) greatly influenced recharge and, to a lesser degree, soil water content. The wavelet-based analysis allowed understanding the impact of each parameter separately on different frequencies embedded in the time series. DWT showed that ETD is relevant at low frequencies while FC at higher ones. A hybrid optimisation process was used to optimise the sensitive model parameters using soil moisture observations (circa 1 year) to then estimate recharge. Parameter search was initialized through an algorithm suitable for complex/multi-modal data and finalized by a local refinement with a gradient-based optimization approach. This significantly improved agreement between model results and observed soil moisture, yielding robust parameter estimates as well as their confidence bounds. Post-calibration results showed plausible recharge fractions (20% of precipitation on average), consistent with global literature values, nonetheless soil moisture peaks remained underestimated. Overall, this work demonstrated that simple bucket-type models, when properly parametrized and calibrated, can provide reliable and computationally efficient insights into complex hydrogeological systems.

Many thanks to Andrea Galli and Giacomo Marrazzo for the provision of soil water content data.

LID 0248

Combined impact of climate and seismic activity on shallow-to-deep groundwater systems by monitoring hydrogeochemistry in the Eastern Southern Alps, Italy

Francesca Gori[1]*, Adriana Damato[1], Mario Anselmi[2], Ilaria Baneschi[3], Marino Domenico Barberio[2], Maurizio Barbieri[4], Andrea Billi[5], Tiziano Boschetti[6], Manuel Curzi[1], Giorgia Lucianetti[7], Matteo Salvadori[3], Alessandra Sciarra[2], Marco Petitta[1]

[1] Department of Earth Sciences, Sapienza University of Rome, Rome, Italy
[2] Istituto Nazionale di Geofisica e Vulcanologia, Sezione Roma 1, Rome, Italy
[3] National Research Council, CNR-IGG, Pisa, Italy
[4] Department of Chemical Engineering and Environmental Materials, Sapienza University of Rome, Rome, Italy
[5] National Research Council, CNR-IGAG, Rome, Italy
[6] Department of Chemistry, Life Sciences and Environmental Sustainability, University of Parma, Parma, Italy
[7] Regional Agency for Environmental Protection and Prevention of the Veneto, ARPAV, Belluno, Italy
* francesca.gori@uniroma1.it

Keywords: hydrogeochemistry, climate, seismicity

Groundwater systems commonly involve interactions between shallow and deep flowpaths, whose dynamics may be modulated by external natural factors, such as climatic extremes and seismic activity. This study investigates their combined influence on groundwater hydrogeochemistry in the Eastern Southern Alps (northern Italy), a tectonically active compressional region, integrating hydrogeological, hydrogeochemical, isotopic, and seismological data. Between May 2022 and May 2024, thirteen springs were monitored through annual surveys, with five selected springs sampled monthly for chemical-physical parameters, major ions and trace elements, dissolved gases, and isotopic compositions. Most springs show a Ca-HCO_3 facies, typical of shallow circulation in karst/carbonate aquifers. In contrast, two springs (Canal and Colesei) display a Ca-SO_4 facies, higher temperatures, and elevated Na-Cl contents, indicating contributions from deeper sources. Stable isotopes of water and dissolved gases confirm a meteoric origin for all springs, while trace elements, $^{87}Sr/^{86}Sr$ isotopes, and geothermometers provide constraints on deep inputs for Canal and Colesei. Multivariate statistical analyses (PCA and CPD) applied to hydrogeochemical time series reveal transient geochemical changes possibly associated with (i) a prolonged drought period, which reduced recharge and enhanced ion contents, and (ii) seismic activity, including a M_w 5.8 earthquake occurring ~245 km from the study area, potentially affecting mixing between shallow and deep groundwater systems. The results demonstrate that deep-shallow groundwater interactions can occur and vary over time even in compressional tectonic environments, highlighting the value of integrated, long-term monitoring for assessing groundwater vulnerability under combined climatic and tectonic forcing.

LID 0249
Reactive transport modelling revealed the key role of methane oxidation in a groundwater hydrocarbon plume

Davide Sartirana[1]*, Chiara Zanotti[1], Alice Palazzi[1], Rasmus Jakobsen[2], Andrea Franzetti[1], Tullia Bonomi[1], Marco Rotiroti[1]

[1] Department of Earth and Environmental Sciences, University of Milano-Bicocca, Milan, Italy
[2] Geological Survey of Denmark and Greenland, Copenhagen, Denmark
* davide.sartirana@unimib.it

Keywords: reactive transport modelling, LNAPL, plume fringe

Reactive transport models are effective tools for supporting groundwater management at contaminated sites, as they enable understanding the main hydrogeochemical processes taking place within the aquifer. In this context, a 1D reactive transport model was developed using PHREEQC to study the long-term evolution of a shallow aquifer affected by LNAPL contamination.

A 1 km transect was spatially discretized into 25 cells, each 40 m. The temporal resolution was organized into 216 time steps of 100 days each (e.g. 60 years), simulating a spill in the first cell with the intensity gradually diminishing over time. Model calibration was performed considering only data collected in 2023 from 8 monitoring wells, as historical information was subject to a strong variability.

The hydrogeochemistry was modelled by simulating the (1) oxidation of selected hydrocarbons (octane, hexadecane, benzene and xylene) through first-order kinetics, (2) the reduction of different electron acceptors (oxygen, nitrate, manganese and iron oxides, sulfate, and carbon dioxide) through the partial equilibrium approach, and (3) precipitation/dissolution of mineral species approaching equilibrium (e.g. rhodochrosite, siderite and iron sulphides).

Calibrated model results showed that transformation of hydrocarbons to methane and CO2 took place within the first 0.2 km, followed by the anaerobic oxidation of methane coupled to iron-oxide reduction up to 0.9 km. Aerobic oxidation of methane only occurred in the plume fringe, between 0.9 and 1 km.

Enhancing natural attenuation by adding oxygen could prevent intense methane formation and successive oxidation, limiting the plume extension. In this regard, a simulation was performed, showing that an air sparging system could reduce methane concentrations by almost half within 5 years.

LID 0250
Integrated analysis of Cr(VI) contaminant plume originating from multiple sources

Janja Svetina[1*], Joerg Prestor[1], Mihael Brenčič [2,1]

[1] Geological Survey of Slovenia, Ljubljana, Slovenia
[2] Faculty of Natural Sciences and Engineering, University of Ljubljana, Ljubljana, Slovenia
* janja.svetina@geo-zs.si

Keywords: groundwater contamination, hexavalent chromium, alluvial aquifer

Identifying groundwater contamination sources is particularly challenging where multiple contaminant plumes overlap spatially. This is characteristic of the Ljubljansko polje alluvial aquifer, where hexavalent chromium [Cr(VI)] has been present in groundwater since the 1980s. The main objective of this study was to evaluate whether depth-discrete sampling can improve three-dimensional delineation of contamination and support differentiation among individual sources contributing to the contaminant plume. The study also aimed to assess Cr(VI) transport characteristics at the field scale (>10 km) in a thick alluvial aquifer with high groundwater velocity and predominantly oxidising redox conditions. An integrated approach was used, combining borehole logging with an impeller flowmeter, depth-discrete sampling using a double-packer system, statistical analysis of long-term monitoring data (> 35 years), and groundwater modelling. Borehole logging revealed strong ambient intraborehole flows (IBFs) of up to 2.1 L/s, substantially exceeding the pumping rates used during conventional sampling (≤0.2 L/s). Under these conditions, concentrations obtained by conventional sampling deviated by up to 50% from actual formation values due to IBF-induced vertical mixing. Depth-discrete sampling proved valuable for obtaining representative samples and for identifying characteristic depth-dependent variations in Cr(VI) distribution. These variations provided crucial insights into the potential proximity of different sources and revealed the complex and intertwined impacts of past and present Cr(VI) sources. The impact of past contamination sources was reconstructed using analytical modelling based on time delays between elevated concentrations in different monitoring wells. A field-scale derived retardation factor for Cr(VI) in a highly productive alluvial aquifer was estimated to be around 9.5, with a corresponding soil partition coefficient between 1.06 and 1.33 L/kg.

LID 0251
Time-series clustering to assess trend reversals in groundwater nitrate concentrations at a regional scale

Chiara Zanotti[1]*, Tullia Bonomi[1], Mariachiara Caschetto[1], Carlo Riparbelli[2], Simone Bruno[1], Davide Sartirana[1], Marco Rotiroti[1]

[1] Department of Earth and Environmental Sciences, University of Milano-Bicocca, Italy
[2] Regional Agency for Services to Agriculture and Forestry of Lombardy, Italy
* chiara.zanotti@unimib.it

Keywords: nitrate contamination, groundwater monitoring, time series analysis

Nitrate contamination poses a serious threat to groundwater quality worldwide. In Europe, since the 1990s, the EU Nitrate Directive has pushed toward the implementation of mitigation measures to reduce nitrate concentrations in aquifers. Nevertheless, assessing their effectiveness over time is difficult due to the long hydrogeological response times.

This study investigates nitrate concentration time series at a regional scale to assess the effectiveness of mitigation measures over time. The study area is the shallow alluvial aquifer of the Po Plain, in the Lombardy Region (N Italy), characterized by intensive agricultural activity. Nitrate concentration time series (2006–2020) from 67 monitoring wells were analyzed using statistical techniques including trend analysis, reversal point analysis and time-series clustering.

Results show an overall improving picture. The analysis identifies 10 temporal clusters, with 88% of the wells falling into 6 main clusters with specific time profiles: one stationary, four with a trend reversal from increasing to decreasing concentrations, and one increasing (6 wells). The remaining 4 clusters represent local situations (1 to 3 wells each), 3 stationary and 1 decreasing. Wells in the cluster characterized by a stationary trend exhibit concentrations below 35 mg/L, far below the regulatory limit of 50 mg/L. Wells with values exceeding the 50 mg/L threshold fall in clusters characterised by a trend reversal.

Available groundwater dating data allowed for the reconstruction of the time frame of the mitigation measures potentially responsible for the observed trend reversals, which range from the 90’s up to the early 2000s. Finally, the analysis of the trend following the reversal point shows that wells with higher concentrations exhibit greater decrease rates compared to wells with lower concentrations, which reach a stabilization. This suggests that, in the absence of denitrification processes, concentrations can hardly fall below certain thresholds.

This work was supported by the Regional Agency for Services to Agriculture and Forestry of Lombardy Region (ERSAF) [scientific collaboration with the University of Milano-Bicocca number 2021-NOECO-0129]

LID 0253
Hydrodynamic behavior of riverbank filtration systems: A review of Hungarian experiences

Gábor Nyiri[1]*, Zsombor Fekete[1], Andrea Tóth[1], Tamás Madarász[1], Balázs Zákányi[1], Péter Szűcs[1]

[1] University of Miskolc, Institute of Water Resources and Environmental Management, Miskolc, Hungary
* gabor.nyiri1@uni-miskolc.hu

35-40% of Hungary's drinking water supply is based on riverbank filtered (RBF) water bases. In addition, Budapest's water supply also relies heavily on the RBF water bases. In our work RBF systems were investigated. One of the most important task of our work was to know what happens between the river and the production wells. Our goal was to get more information about the hydrodynamic conditions of these systems. This investigation process was carried out by the staff of the Institute of Water Resources and Environmental Management of the University of Miskolc. In this study, we would like to present the results of different kinds of investigations, and experiences related to the main hydrodynamic parameters, like hydraulic gradient, transit time, and the river-background contribution ratio. With the help of field measurements and modelling activity we can get an image of the subsurface flow conditions, and we can follow the effect of flood events. The hydrodynamic models were performed using the MODFLOW code, which can help us to get a picture about the behavior of this complex hydrological system. As a result of this investigation, water level, contribution ratio, hydraulic gradient and transit time changes could be calculated in a daily resolution.

The research was funded by the Sustainable Development and Technologies National Programme of the Hungarian Academy of Sciences (FFT NP FTA).

LID 0254
Conceptual hydrogeological model testing and refinement using numerical modelling in a complex glaciated environment

John Mosquera[1]*, Mitchell Brown[1], Carl Mendoza[1], Trevor Crozier[1]

[1] BGC Engineering Inc, Vancouver, Canada
* jmosquera@bgcengineering.ca

Keywords: calibration, PEST, Modflow-USG, multi-aquifer

The development of a robust conceptual hydrogeological model (CHM) is a critical step in groundwater modelling and provides the framework for numerical implementation in a groundwater flow model (GWM). This study presents the iterative development, testing, and refinement of a CHM through construction and calibration of a MODFLOW-USG model. The models were evaluated based on their representation of shallow-aquifer/surface-water interactions, an artesian intermediate aquifer, and trans-valley flow in a deep aquifer.

The Site is in a mountainous area with deep valleys infilled by multiple episodes of glaciation. The groundwater system is characterised by strong lateral and vertical heterogeneity resulting in perched, unconfined, and confined aquifers, with confined units being both flowing artesian and subject to active groundwater abstraction. The heterogeneity leads to highly uncertainty aquifer continuity, hydraulic connectivity, and vertical leakage between shallow and deep groundwater systems. These uncertainties in the CHM were addressed by systematically testing alternative interpretations of hydrostratigraphy, hydraulic properties, and boundary conditions using the GWM.

Model calibration to observed hydraulic heads and pumping responses was used as the primary means of evaluating conceptual model assumptions. Additional targets included measured surface flows, observed gradients, the presence of perched zones, and observations of groundwater discharge zones. The iterative refinement of the CHM and GWM resulted in improved representation of groundwater flow across both shallow and deep systems, reduced uncertainty in key parameters, and increased confidence in the model's suitability for predictive simulations. The study demonstrates how modelling can be effectively used as a tool for CHM improvement and GWM representation in complex multi-aquifer environments with incomplete field data.

LID 0255

Comparative analysis of the impacts of mechanical weathering on the physicochemical transformation and lead adsorption of polypropylene and polyvinyl chloride microplastics

Tae-Jung Ha[1]*, Minjune Yang[2, 3]

[1] Division of Earth and Environmental System Sciences-Major of Earth & Environmental Sciences, Pukyong National University, Busan, South Korea
[2] Division of Earth and Environmental System Sciences-Major of Environmental Geosciences, Pukyong National University, Busan, South Korea
[3] Wible Inc., Busan, South Korea
* taejung_ha@pukyong.ac.kr

Keywords: microplastics, heavy metals, adsorption

Mechanical weathering alters the physicochemical properties of microplastics and influences the role of these particles as vectors for heavy metals. This study compares the transformation of Polypropylene (PP) and Polyvinyl Chloride (PVC) subjected to mechanical weathering for 1 h and 3 h. Transitions in surface morphology were evaluated via SEM and BET analysis. Concentrations of major elements were measured using an Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES, Optima 7000DV, PerkinElmer) installed at the Integrated Analytical Center for Earth and Environmental Sciences of Pukyong National University. Furthermore, chemical changes were examined through FTIR and XPS to evaluate the evolution of functional groups. The results showed that the BET surface area of PP increased from 17.42 to 38.63 m2/g, which was an increase of 121%, while the surface area of PVC increased by a relatively modest 13.1% from 24.58 to 27.81 m2/g. The O/C ratio of PVC surged from 0.36 to 0.51, which was an increase of 40.3% and indicated that the oxidation rate of PVC was more rapid than the rate of PP. Analysis via 2D Correlation Spectroscopy revealed that structural variations in PP were dominated by hydrocarbon deformation followed by the formation of functional groups that contain oxygen. In contrast, the evolution of PVC began with changes in structures related to C-Cl bonds, followed by the development of species that contain oxygen. Adsorption of Pb2+ was best described by the Sips model (R2 > 0.99), reflecting increased surface heterogeneity. The maximum adsorption capacity reached 0.69 mg/g for HW-PP and 0.33 mg/g for HW-PVC. These findings suggest that the adsorption of PP is driven by physical surface expansion, whereas PVC relies on chemical oxidation. specific to the polymer are essential for accurate risk assessments of microplastics.

This research was supported by Global - Learning & Academic research institution for Master's·PhD students, and Postdocs(LAMP) Program of the National Research Foundation of Korea(NRF) grant and Basic Science Research Program through the National Research Foundation of Korea(NRF) funded by the Ministry of Education (No. RS-2023-00301702, No. RS-2025-25415424).

LID 0256
Evaluation of surface – groundwater interaction using stable isotopes and geochemical composition for water management purposes in arid zone

Oleg Bogdevici[1]*, Aurel Persoiu[2], Elena Culighin[1], Elena Nicolau[1]

[1] Institute of Chemistry, Moldova State University, Chisinau, Republic of Moldova
[2] Emil Racoviță Institute of Speleology, Romanian Academy, Cluj Napoca, Romania
* oleg.bogdevici@sti.usm.md

Keywords: stable isotopes, surface water, groundwater

Understanding the water cycle and groundwater formation can provide information for integrated water resources management under water scarcity. Environmental indicators such as stable oxygen ($\delta^{18}O$) and hydrogen ($\delta^{2}H$) as well as geochemical parameters, are useful for studying the water cycle, water balance formation, and surface-groundwater interactions. The stable isotope technology can provide a better understanding of the groundwater recharge capacity. Stable isotope technology can provide a better understanding of groundwater recharge capacity. This study presents an assessment of surface-groundwater interactions for the Moldovan artesian basin and an evaluation of water balance formation in a dry climate for the period 2021–2025. The isotopic composition of precipitation, surface water bodies (rivers and lakes), and major aquifers was studied. WISER stable isotope data for precipitation were used for five GNIP stations. Surface waters were sampled at 15 lake stations and 6 river stations. Seven major aquifers were studied at 111 sampling points (37 springs and 74 wells). Geochemical composition and stable isotopes were analysed using an ICS DIONEX6000 ion chromatography system and a PICARRO laser analyser, both provided by the IAEA under the National Technical Project (NTP) in 2020–2023. The obtained results demonstrate the isotopic composition of oxygen and hydrogen ($\delta^{18}O$, $\delta^{2}H$) taking into account the effect of evaporation in rivers, lakes, and unconfined aquifers. Deep confined aquifers have a lighter isotopic composition and a similar regression line to the GMWL. Small rivers, as well as the studied lakes, receive their main supply from groundwater during dry periods. The results of isotopic analysis in such systems can be used to assess water balance and spatial modelling. As a result, water deficit zones were identified. Analysis of the interactions between surface and groundwater can be used to validate a conceptual model for groundwater flow modelling.

LID 0257
Systematic compilation and analysis of regional groundwater age data in a fractured aquifer system in Central Germany

Roland Bäumle[1]*, Karsten Osenbrück[1], Robert Kringel[1]

[1] Federal Institute for Geosciences and Natural Resources (BGR), Germany
* roland.baeumle@bgr.de

Keywords: groundwater age, mixing, fractured aquifer

This multi-tracer study investigates the characteristics of groundwater age in regional fractured aquifers of the Buntsandstein in Germany based on a comprehensive compilation of radioactive isotope tracers obtained from state geological surveys and literature.

The study area covers over 37,500 square kilometres, encompassing parts of the federal states of Hesse, Bavaria and Baden-Württemberg, and includes the East Hesse Highlands within the Central European Highlands as well as the Odenwald and Spessart mountains of the Southwest German Highlands. Geologically, the study focusses on the regionally significant fractured aquifers of the Middle and Lower Buntsandstein Formation from the Triassic Period. Other aquifers, included in the study for comparison, occur in the arenaceous sediments and limestone of the Triassic Keuper and Muschelkalk groups, the marine carbonate and anhydrite rocks of the Permian Zechstein Group, the clastic rocks of the Permian Rotliegend Group, and in rocks of Devonian age.

The newly compiled relational groundwater database contains approx. 600 sets of hydrochemical analyses, and 922, 203 and 35 results for tritium (^{3}H), radiocarbon (^{14}C) and krypton-85, respectively.

We investigated the unique dataset to determine residence times and mixing ratios of groundwater of different ages. For tritium, reliable ages (and uncertainties) could be determined for wells with repeated measurements, or for wells with multi-age tracer information (esp. ^{3}H together with ^{85}Kr) applying the dispersion model. Initial results indicate widespread mixing of young and older groundwater components even in deep wells. This regional study places particular emphasis on the factors controlling the observed mixture of modern to old (tritium-free) groundwater such as the topographical location along flow paths, the proximity to known faults, the thickness of the overburden, and the abundance of fracturing.

LID 0258
Multi-level data systems for risk mitigation, management and visualization in support geothermal exploration in Hungary

Nóra Gál[1]*, András Cégény[1], Zoltán Friedl[1]

[1] Supervisory Authority for Regulatory Affairs, Geological Survey, Budapest, Hungary
* nora.gal@sztfh.hu

Keywords: thermal water, webmap system, data service

Comprehensive data acquisition and analysis are fundamental to ensuring sustainability and equity in the management of groundwater and geothermal energy. Within the domain of hydrogeological exploration, the rigorous processing and interpretation of datasets serve as a primary risk mitigation instrument. To facilitate informed decision-making and reduce investment uncertainty, the Geological Survey is developing a sophisticated, three-tier data infrastructure compliant with FAIR principles (Findable, Accessible, Interoperable, Reusable).

The first tier consists of a continuously maintained thematic arrangement of existing databases, primarily providing metadata through an ArcGIS-based public webmap system. The second tier offers curated data packages designed to support the expansion of district heating systems by enhancing geological knowledge through publicly accessible information. The third tier introduces a secure, in-house 'data room' service. This platform centralizes geological, geophysical, and hydrogeological data within a scalable PostgreSQL database. To meet the demand for advanced visualization and selection, the system integrates industrial interpretation tools with inhouse developed programs into Geographic Information System. By leveraging both professional applications and open-source frameworks, this multi-level architecture establishes a robust foundation for the long-term viability of geothermal energy projects.

LID 0260
Numerical investigation of the effectiveness of managed surface water infiltration through surface canals in semi-arid areas

Márk Szijártó[1,2,3]*, Adél Petneházy[1,2], Szilvia Simon[3], Judit Mádl-Szőnyi[3]

[1] Department of Geophysics and Space Science, ELTE Eötvös Loránd University, Budapest, Hungary
[2] Institute for Geological and Geochemical Research, HUN-REN Research Centre for Astronomy and Earth Sciences, Budapest, Hungary
[3] József & Erzsébet Tóth Endowed Hydrogeology Chair, Department of Geology, ELTE Eötvös Loránd University, Budapest, Hungary
* mark.szijarto@ttk.elte.hu

Keywords: groundwater flow system, unsaturated zone, canal network

The decline in groundwater levels resulting from a combination of different processes (e.g., climate change, overpumping, and canalisation) has led to serious problems across agriculture, ecosystems, and drinking water supply in the Danube-Tisza Interfluve region. Two-dimensional numerical modelling was carried out to investigate local-scale hydraulic responses/effects in the near-surface groundwater flow system caused by surface water infiltration through canals. The time-dependent simulations were performed in synthetic models, where (i) the depth of the water table, (ii) the water level in canals, (iii) the hydraulic conductivity of the near-surface porous media, and (iv) the shape of the water table were varied between the values characteristic for the study area.

We found the thickness of the unsaturated zone to be a crucial parameter, in which vertical flow predominates until infiltrating water reaches the water table. After the initial transient period (1 week–1 yr), infiltrating water raises the water table, thereby changing the original flow system. After 20 years of continuous infiltration, the water table rises by at least 5 cm, and this hydraulic effect extends up to a maximum of 300 m distance from the canal. Of course, this critical distance varies in space and time depending on the hydraulic conductivity. For example, the critical distance reaches 160 m with a hydraulic conductivity of 10^{-4} m/s, after 1 year of infiltration. However, a twofold reduction in hydraulic conductivity can significantly decrease the critical distance and/or increase the operation time of the infiltration system. Accounting for topography-driven groundwater flow can enhance the efficiency of the infiltration system.

This project was supported by the János Bolyai Research Scholarship of the Hungarian Academy of Sciences. The research was supported by the National Multidisciplinary Laboratory for Climate Change, RRF-2.3.1–21-2022–00014 project.

LID 0261
Predicting the age of baseflow across the conterminous United States with process-based and random forest modeling

Paul Stackelberg[1]*, Kenneth Belitz[2], Wes Zell[3], Ward Sanford[4]

[1] U.S. Geological Survey, Troy, NY, USA
[2] U.S. Geological Survey – emeritus, Carlisle, MA, USA
[3] U.S. Geologial Survey, Reston, VA, USA
[4] U.S. Geological Survey – emeritus, Reston, VA, USA
* pestack@usgs.gov

Keywords: baseflow, process-based modeling, random forest modeling

Understanding the proportion of baseflow that is relatively young can provide insight into the susceptibility of streams to both recent and legacy changes in management activities across the land surface. Although it is possible to use process-based models to estimate baseflow ages at local to regional scales, it would be computationally prohibitive to do so for the entire conterminous United States (CONUS, 8M km^2). Here we describe a hybrid approach whereby a random forest (RF) model was used to leverage output from MODFLOW/MODPATH (MF/MP) models. A total of 1,975 MF/MP models were generated at the HUC12-scale (~100 km^2, 50m cell size). The HUC12-scale models are a modified subset of 75 previously developed HUC4-scale MF models (~100K km^2, 250m cell size) which collectively represent CONUS. The 1,975 HUC12-scale models represent the range of climate, landscape, and hydrogeologic settings across CONUS, and consist of 22,699 catchments which are a subset of the more than 800,000 catchments that comprise the CONUS. The target variable in the RF model is the proportion of baseflow less than 10 years old in a catchment, denoted here as P10. The predictor variables include input data common to the HUC4 and HUC12-scale models, output data from the HUC4-scale models, and other relevant hydrogeologic data. Preliminary results indicate that the median value of P10 is ~30%. Catchments with P10 exceeding 50% are predominantly located in the humid Pacific Northwest and northeastern United States. In contrast, catchments with P10 <10% are predominantly located in more arid settings of the west. Comparison of RF model predictions with HUC12-scale MF/MP estimates indicate close agreement; R^2 exceeds .90 for both training (80% of the catchments) and testing (20% of the catchments).

LID 0262

Integrated hydrogeochemical and isotopic investigation of the Budapest Thermal Karst system, Hungary: Implications for groundwater system understanding

Zsóka Szabó[1]*, Nóra E. Gál[1], Andrea Szűcs[1], Eszter Tihanyiné Szép[1], Zoltán Vári[1], Eszter Sendula[1], Teodóra Szőcs[2], Anita Erőss[3], József Deák[4], István Fórizs[5], Éva Kun[1]

[1] Supervisory Authority for Regulatory Affairs, Geological Survey, Budapest, Hungary
[2] Ludovika University of Public Service, Institute for Environmental Sustainability, Budapest, Hungary
[3] Eötvös Loránd University, Institute of Geography and Earth Sciences, Budapest, Hungary
[4] GWIS Ltd., Veszprém, Hungary
[5] HUN-REN Research Centre for Astronomy and Earth Sciences, Institute for Geological and Geochemical Research, Budapest, Hungary
* zsoka.szabo@sztfh.hu

Keywords: thermal water, water–rock interaction, multivariate analysis

The thermal karst system of Budapest forms a unique urban hydrogeological environment, supporting both historic balneological use and emerging geothermal exploitation. While decades of archival hydrochemical and isotopic data have provided valuable insights into its complex groundwater flow system, these datasets are often heterogeneous in time, methodology, and completeness.

To overcome these limitations, a comprehensive water sampling campaign was recently conducted at selected wells and springs representing contrasting hydrogeological and lithological settings. The campaign was designed to obtain a quasi-simultaneous dataset including major ions, trace elements, stable and radioactive isotopes, dissolved and separated gases, as well as samples for noble gas analyses, thereby enabling a holistic characterization of the system. The dataset is evaluated using comparative and spatial analyses, complemented by multivariate statistical methods to identify consistent geochemical trends and internally coherent patterns. Particular emphasis is placed on hydrochemical ratios and trace element distributions, with cation exchange processes representing an important mechanism shaping compositional variability. The integrated interpretation of major ions, trace elements, and isotopes further constrains regional differences and deviations from dominant trends.

This integrated approach provides insights into water–rock interactions, the degree of mixing between distinct water components, regional differences and anomalous sites, and helps the delineation of spatially distinct groundwater flow domains within the karst system. The results contribute not only to a more detailed conceptual model of the groundwater system but also provide a robust basis for the sustainable utilization and management of groundwater resources.

LID 0263
From sink to spring: How do microplastics behave in a show-cave karst aquifer?

Syeda Maria Zainab[1,2,3]*, Alexandra Howard[2], Richard Cross[2], Dan Lapworth[3], Kathy Pond[1], Monica Felipe-Sotelo[4], John Gunn[5], Barry Townsend[3], Raghav Patel[3], Louise Maurice[3]

[1] University of Surrey, School of Engineering, Guildford, United Kingdom
[2] UK Centre for Ecology & Hydrology, Wallingford, United Kingdom
[3] British Geological Survey, Keyworth, Nottingham, United Kingdom
[4] University of Surrey, School of Chemistry and Chemical Engineering, Guildford, United Kingdom
[5] University of Birmingham, School of Geography, Earth and Environmental Sciences, Birmingham, United Kingdom
* s.zainab@surrey.ac.uk

Keywords: microplastics, karst groundwater, show-cave, stream sink, spring

Microplastic pollution of karst aquifers remains under-characterised due to the extensive global distribution of karst; complex flow pathways and rapid hydrological responses; and difficulties in accurately measuring microplastics. This study investigates microplastic concentrations and polymer composition within the UK Carboniferous limestone system of Poole's Cavern, Derbyshire, a show cave, to address two research questions: how microplastic abundance and characteristics vary along the subsurface pathway, and to what extent tourism activities may influence observed concentration patterns. Duplicate water samples were collected from two stream sinks feeding the cave, two points within the cave stream, and two springs (cave-fed and non-cave-fed). Samples were analysed using state of the art FTIR (Fourier-Transform Infrared) spectroscopy to evaluate spatial differences in microplastic presence within the system.

Microplastics were detected in all samples, with varying concentrations across the system. Lower concentrations were generally observed within the stream sinks and cave stream, while higher concentrations were recorded at both springs. Despite differences in flow pathways, total microplastic concentrations were broadly similar between the cave-fed and non-cave-fed springs, suggesting no clear difference in overall microplastic loads attributable to the tourist cave system. Polymer composition was largely consistent across stream sinks, cave water, and springs, with frequently detected polymers including silicone, polyvinyl chloride, and polyurethane, reflecting common environmental microplastics. Their presence across most sample types suggests transport from catchment sources through the system, although minor differences may reflect selective retention, dilution, or additional inputs along the flow path.

These findings demonstrate that microplastics are transported through karst systems, highlighting the vulnerability of groundwater to microplastic pollution.

LID 0264
Continuous in situ groundwater flux monitoring in dynamic aquifer systems: Validation of the iFLUX sensor

Niels Van Putte[1,2]*, Goedele Verreydt[1,2]

[1] iFLUX, Niel, Belgium
[2] ECOSPHERE research group, University of Antwerp, Antwerp, Belgium
* niels@iflux.be

Keywords: groundwater flux sensor, autonomous monitoring, microfluidic sensing

In low-gradient or highly dynamic systems such as wetlands, managed aquifer recharge projects, and coastal aquifers, the lack of autonomous, low-power approaches for direct groundwater flux measurement limits reliable long-term monitoring and constrains informed management decisions.

We present the novel iFLUX horizontal flux sensor, which measures groundwater flux magnitude and direction in real time by using two low-power microfluidic flow chips, representing the first in situ hydrogeological application of this technology. The sensor is designed for use in fully saturated, non-cohesive porous media and is installed in a dedicated prepack filter to ensure correct orientation and hydraulic contact.

First, we evaluated the sensor's magnitude and directional accuracy in a controlled laboratory sand tank experiment. Furthermore, we calibrated the sensor for flow field distortion across varying hydraulic conductivities using numerical modelling. The performance of the sensor was subsequently validated in a managed aquifer recharge system, where flux estimates were compared with Darcy-based triangulation methods.

Within the imposed flow range of 1 – 35 cm/day, measured flux magnitude followed the imposed flux with an RMSE of 1.15 cm/day and R^2 of 0.99, while directional accuracy was 4.55° (RMSE). Field evaluation further demonstrated the sensor's ability to resolve rapid changes in groundwater flux magnitude and direction under dynamic conditions.

Overall, its low power demand, fast response and high accuracy at low flux compared to established methods, demonstrate that the iFLUX sensor enables robust, continuous in situ groundwater flux monitoring in systems where accurate flux information is essential for informed management.

LID 0265
Groundwater level forecasting for climate change adaptation in Ireland

Joan Campanyà[1*], Philip Schuler[2], Henning Moe[1], Jon Hunt[1], Owen Naughton[3], Barry Coonan[4], Ted Mccormack[5]

[1] MKO, Tuam Road, Galway, Ireland
[2] CDM Smith SE, Berlin, Germany
[3] Department of the Built Environment, South East Technological University, Ireland
[4] Met Éireann, Dublin, Ireland
[5] Geological Survey Ireland, Blackrock, Ireland
[*] jcampanya@mkoireland.ie

Keywords: groundwater, drought, flood, level modelling, forecasting, climate adaptation, water resources

Climate change is increasing the frequency and magnitude of meteorological extremes in Ireland, affecting the severity and occurrence of groundwater drought and flood events. Accurate forecasting of these events is essential to support climate change adaptation, water security, and evidence-based governance. In response, Geological Survey Ireland (GSI) has embarked on the *Groundwater Forecasting and Climate Change Impacts* project (2023–2027), which has resulted in the creation of an operational system for forecasting groundwater levels.

The forecasting system is implemented at over 30 monitoring sites across Ireland's main aquifer types, including boreholes and seasonal groundwater lakes. It provides forecast from days to several months ahead, with forecast skill varying by forecast horizon and hydrogeological setting. Forecasts results are generated using a hybrid approach combining Dynamic Forecasting (DF) and Ensemble Hydrological Forecasting (EHF). DF forecasts up to seven months ahead using past and predicted climate data and groundwater level observations, while EHF projects beyond seven months based on historical climate variability. The results are presented as probabilistic groundwater level categories relative to long-term conditions and as continuous time series, with contextual thresholds and historical events.

Historical and forecast climate data, including precipitation and evapotranspiration, are sourced from the Irish Meteorological Service and the Copernicus Climate Change Service (C3S) at daily intervals, while groundwater observations originate from the Environmental Protection Agency (EPA) and GSI. The forecast uses three independent hydrological models, AquiMod, PASTAS, and UISCEmod, to simulate future groundwater levels.

This system represents a significant advance in translating climatic forecasts into actionable groundwater information to support water resource management, drought and flood preparedness, and climate change adaptation in Ireland.

LID 0267
Disentangling geological and parametric contributions to predictive uncertainty in groundwater flow models: A variance-based framework

Saman Moghimi Benhangi[1]*, Ludovic Schorpp[2], Zhao Chen[1]

[1] Institute of Groundwater Management, Technische Universität Dresden, Dresden, Germany
[2] Centre for Hydrogeology and Geothermics, University of Neuchâtel, Neuchâtel, Switzerland
* saman.moghimi_benhangi@tu-dresden.de

Keywords: hydrogeological uncertainty, 3D stochastic underground modelling, variance decomposition, numerical groundwater flow modelling

Understanding the relative impact of geological and parametric uncertainty is essential for transparent and robust groundwater modeling. This work presents a variance decomposition–based experimental framework designed to quantify how different sources of hydrogeological uncertainty contribute to variability in model outputs, using the sedimentary aquifer system of Görlitz, Germany, as a case study. The study builds on an extensive borehole dataset and a stochastic 3D geological model generated using ArchPy. Three hierarchical levels of geological complexity are explored: (1) geological unit configurations, (2) lithofacies architectures within each unit, and (3) distributed hydraulic conductivity (K) fields conditioned on facies. From this, a large ensemble of MODFLOW 6 steady-state models is generated. For each level, parametric uncertainty is introduced through randomized K values and, in later stages, through additional stress boundary parameters. To address convergence and runtime constraints, the uncertainty contribution analysis focused on lateral flow through a simplified single-layer framework, maintaining representative spatial discretization. The design enables structured variance decomposition, applied stepwise to assess the contribution of each uncertainty source to key outputs such as simulated heads and water budget components. The approach illuminated how the importance of uncertainty sources shifts with increasing geological detail and boundary complexity. Of particular interest is how transitioning from regional-scale homogeneity to local-scale heterogeneity influences not only total predictive uncertainty but also the relative role of structural versus parametric components. The methodology offers a scalable blueprint for hydrogeological uncertainty analysis and supports modelers in prioritizing data collection and parameter treatment strategies when dealing with incomplete knowledge and process ambiguity.

LID 0269

Toward a transboundary groundwater flow model for the Görlitz–Zgorzelec Aquifer: Integrating 3D stochastic geological modeling and transient groundwater simulation

Saman Moghimi Benhangi[1]*, Krzysztof Janik[2], Sławomir Sitek[2], Agnieszka Patrzałek[3], Bernd Bauer[4], Paul Franke[4], Zhao Chen[1]

[1] Institute of Groundwater Management, Technische Universität Dresden, Dresden, Germany
[2] Institute of Earth Sciences, Faculty of Natural Sciences, University of Silesia in Katowice, Poland
[3] Przedsiębiorstwo Wodociągów i Kanalizacji “NYSA” Sp. z o.o. in Zgorzelec, Poland
[4] Stadtwerke Görlitz AG, Germany
* saman.moghimi_benhangi@tu-dresden.de

Keywords: stochastic underground modeling, transboundary aquifer, numerical groundwater flow modeling, Görlitz–Zgorzelec

Transboundary aquifers present unique challenges for groundwater modelling due to the need for harmonized data, consistent geological interpretation, and integrated resource management. As part of the EU-funded CRossWATER project (Interreg Poland–Saxony 2021–2027 programme), a transient numerical groundwater model is being developed for the shared Görlitz–Zgorzelec aquifer, which underlies both the German and Polish sides of the twin cities and serves as a key drinking water source. The modelling framework integrates geological and hydrogeological data from both countries to construct a cross-border subsurface model. Borehole datasets from German and Polish geological institutions were compiled and harmonized for use in ArchPy, a hierarchical stochastic modelling tool, to generate a 3D representation of subsurface structures. This geologically informed model supports the refinement of aquifer boundaries and defines the hydrostratigraphic architecture used in the numerical simulation. The transient flow model is implemented in MODFLOW 6, using an unstructured grid to represent both regional and local dynamics with variable resolution. Boundary conditions are formulated to represent surface water–groundwater interactions and spatially variable lateral inflows within the transboundary system. Preliminary configurations demonstrate the feasibility of a harmonized, data-driven approach to simulating cross-border flow systems. This work presents the ongoing development process and highlights the methodological steps taken to integrate multi-source geological data and numerical modelling across administrative boundaries. The model is intended to support joint groundwater management strategies and scenario assessments for climate and usage impacts in the Görlitz–Zgorzelec region.

LID 0271
Hydrogeologically diverse aquifers converge surface-derived dissolved organic matter into a persistent molecular core

Arina Ivanova[1,2]*, He Wang[2], Martina Herrmann[2], Robert Lehmann[2], Kirsten Küsel[2], Kai Uwe Totsche[2], Gerd Gleixner[1]

[1] Max Planck Institute for Biogeochemistry, Jena, Germany
[2] Friedrich Schiller University Jena, Jena, Germany
* aivanova@bgc-jena.mpg.de

Keywords: dissolved organic matter, subsurface carbon cycling, high-resolution mass spectrometry

Dissolved organic matter (DOM) is ubiquitous in groundwater and shapes subsurface biogeochemistry; however, its molecular composition across contrasting aquifers remains understudied. As groundwater DOM integrates surface inputs, microbial processing, and hydrogeological conditions, it can serve as a tracer of interactions within groundwater system.

We studied 155 groundwater samples collected over four years from two Central European aquifer archetypes: a fractured-karstic carbonate system with highly varying residence times and redox states, and a fractured-porous siliciclastic aquifer. Molecular DOM composition was analyzed by high-resolution mass spectrometry, microbial communities were characterized by 16S rRNA gene sequencing, and radiocarbon age of DOM - by accelerator mass spectrometry.

Across wells, we identified a set of ubiquitous molecules (present in all wells and ≥60% of samples per well) that represents a minority of molecular diversity (19% of all formulae), but accounts for 82-97% of total signal intensity and exhibits reduced structural diversity. The relative abundance of this ubiquitous pool increases with residence time and anoxia in the carbonate aquifer, and with DOM aging under oxic conditions in the siliciclastic aquifer, indicating convergence of diverse surface-derived inputs into a persistent molecular core. This ubiquitous pool shows stronger co-variation with bacterial community composition (partial Mantel $r=0.39$, $p<0.001$) than the total DOM pool does ($r=0.15$, $p<0.001$), suggesting ecological coupling to an abundant and persistent carbon source.

These results show that interacting groundwater systems converge heterogeneous DOM towards a shared microbially coupled molecular core, linking hydrogeology and redox history. Complementary tandem mass spectrometry helps to distinguish whether ubiquitous compounds have identical molecular structures across aquifers, improving our understanding of DOM transformation in diverse settings.

LID 0272
Climate Collaboratorium: Transdisciplinary groundwater modelling to support community-based climate change adaptation, case study of the mining region of Rietschen (Görlitz, Germany)

Tania Agudelo Mendieta[1]*, Zhao Chen[1], Kwok Pan Chun[2], Diana Ayeh[3], Sina Leopold[3], Andreas Hartmann[1]

[1] TU Dresden, Germany
[2] University of the West of England, United Kingdom
[3] Helmholtz Centre for Environmental Research – UFZ, Germany
* Tania_stefania.agudelo_mendieta@tu-dresden.de

Climate change is increasing pressure on regional water resources and requires adaptive, integrated water management strategies that consider hydrogeological processes alongside socio-economic and land use changes. Addressing these challenges requires integrated approaches that combine hydrogeological modelling with stakeholder knowledge to support adaptive and locally relevant decision-making. The Climate Collaboratorium is a multilateral project involving partners from Canada, the United Kingdom, and the United States, aiming to provide such an approach through the integration of numerical modelling and participatory scenario development.

The German contribution to the project focuses on the region of Rietschen in the Lausitz area (Germany), where centuries of landscape modification, including fishpond systems and intensive lignite mining, have significantly altered natural hydrological conditions. With the ongoing coal phase-out and landscape transformation into post-mining lake systems, future water management must account for combined effects of anthropogenic change and projected climate trends such as longer dry periods and reduced groundwater recharge.

This research presents the development of a steady-state numerical groundwater model representing the hydrogeological conditions of the unconfined aquifer system and its dominant natural and anthropogenic controls. The methodological framework comprises three main steps. First, a conceptual hydrogeological model was established using geological data, monitoring records, and regional maps to define system boundaries, properties, and groundwater–surface water interactions. Second, climate change scenarios were implemented using recharge projections derived from downscaled global climate models from the Central German Core Ensemble (Mitteldeutsches Kernensemble, MDK). Third, water management scenarios were incorporated based on stakeholder workshops with mining operators, rehabilitation authorities, local industries, municipalities, and community representatives. Participatory theatre-based approaches are planned to further enhance stakeholder engagement and communication of modelling outcomes.

The steady-state model provides the basis for subsequent transient simulations to evaluate the combined impacts of climate change and water management strategies on groundwater availability and regional water budgets. Preliminary results indicate strong system sensitivity to both climate-driven recharge changes and water management decisions, particularly regarding water allocation strategies. Thus, highlighting the need for integrated, scenario based approaches to support decision-making and secure future water availability across sectors. These findings contribute directly to the broader objectives of the Climate Collaboratorium by supporting the development of transferable methodologies for community based water management. Beyond the Rietschen case study, comparable studies are being

implemented in other regions to test and demonstrate the applicability of this transdisciplinary approach across diverse socio-cultural and environmental contexts.

LID 0273
Compositional PCA and t-SNE radar signatures toward an integrated hydrogeological assessment of PFAS in a fractured chalk aquifer

Anthony Mahieu[1]*, Guillaume De Schepper[2], Nicolas Devau[3], Fabio Cogliandro[1], Tanguy Robert[2], Pascal Goderniaux[1]

[1] University of Mons – Polytech Mons – Geology and Applied Geology, Mons, Belgium
[2] VIVAQUA – Production Department – Water Resources Management, Brussels, Belgium
[3] BRGM – French Geological Survey, Orléans, France
* anthony.mahieu@umons.ac.be

Keywords: PFAS, compositional PCA, t-SNE, radar signature, groundwater, chalk aquifer

The assessment of PFAS contamination in groundwater is crucial for safeguarding drinking water resources and ensuring their long-term sustainability. A hydrogeochemical investigation conducted at a groundwater abstraction site in Wallonia (southern Belgium) highlighted the presence of multiple contamination sources, including diverse PFAS compounds. A dedicated statistical framework combining compositional data analysis, t-distributed Stochastic Neighbor Embedding (t-SNE), and radar signature plots was implemented to characterize PFAS pollution facies and their spatial organization. A compositional Principal Component Analysis based on centered log-ratio transformation was first applied to identify distinct contamination signatures independently of absolute concentration levels. Ternary diagrams using grouped PFAS improved the visualization of compositional trends, while t-SNE coupled with radar plots enabled refined cluster discrimination and intuitive interpretation of chemical fingerprints. This multivariate strategy provides valuable insight into the behavior and potential origins of PFAS in groundwater systems, and represents a novel integration of compositional PCA with t-SNE for this purpose. Special attention was paid to the rigorous application of compositional assumptions, which significantly enhanced the discrimination of PFAS pollution signatures, an approach rarely applied in similar studies. The investigated site, characterized by an exceptionally high density of monitoring points, provided a unique opportunity to resolve spatial heterogeneity and validate the compositional framework. Three major facies were distinguished: a low-level PFOS-dominated group, a highly contaminated sulfonic-rich group mainly driven by PFBS, and a third ensemble related to surface water and to a 2019 motorway accident. Ongoing work aims to complement this approach with flux measurements, advanced piezometric monitoring, extended hydrochemical surveys, and the development of a groundwater flow and transport model, whose results will be presented if available.

LID 0275
A game-theoretical approach to sustainable groundwater management: application to a heavily impacted volcanic aquifer

Vincenzo Piscopo[1], **Chiara Sbarbati**[1]*, László Székely[2], Zoltán Varga[2]

[1] Department of Ecological and Biological Sciences, University of Tuscia, Viterbo, Italy
[2] Department of Mathematics and Modelling, Institute of Mathematics and Basic Science, Hungarian University of Agriculture and Life Sciences, Gödöllő, Hungary
* chiara.sbarbati@unitus.it

Keywords: game theory, conflict resolution, groundwater management

Groundwater is vital for food security, public health and ecosystems, however its overexploitation could undermine long-term sustainability. Managing this resource requires integrating complex hydrogeological, socio-economic and environmental data; to this end, different methodological approaches were developed. Among these, game theory enables the optimization of sustainable groundwater withdrawal rates in conflicting resource demands framework.

This study applies game-theoretical approach to the Colli Albani volcanic aquifer (central Italy), a system heavily impacted by multi-user abstraction. The model integrates groundwater sustainability constraints with the optimization of economic returns for diverse stakeholders.

The hydrostructure was subdivided into four major basins, each assigned a groundwater residual discharge to safeguard springs, rivers, dependent ecosystems and to maintain a sufficient flow towards bordering aquifers. Groundwater demands for potable use, industry, and irrigation were quantified to define current consumptions and the potential economic utility of various uses. Integrating these data with hydrogeological constraints, a cooperative solution of a normal form game was adopted, identifying citizens, agriculture and industries sectors as the players of the game.

Scenario analyses, conducted by changing player weights, offer a wide range of sustainable abstraction configurations. In all scenarios, citizens' water demand was prioritized. The results generally reveal that the industrial sector incurs the most significant economic trade-offs to satisfy the sustainability constraints of the basins.

Despite the incomplete hydrogeological and economic dataset, the implemented algorithm allows wide possibilities for varying both hydrogeological constraints and socio-economic strategies. This integrated sustainability approach provides a valuable tool for guiding decision-making in the framework of conflict groundwater management scenarios.

LID 0276
Dissolution effects of increased thermal spread in geothermal operations in the North Alpine Foreland Basin

Marlis Hegels[1]*, Thomas Baumann[1]

[1] Technical University of Munich, Chair of Hydrogeology, Munich, Germany
* marlis.hegels@tum.de

Keywords: geothermal energy, rock matrix dissolution

Deep geothermal systems in the North Alpine Foreland Basin (NAFB) play a key role in decarbonizing district heating in Bavaria. To date, more than 25 facilities exploit the Upper Jurassic reservoir in doublet or multilateral configurations. Current efforts to expand and optimize geothermal capacity include transitioning from high-temperature to low-temperature heating networks, constructing new plants, and enhancing thermal sweep efficiency by reducing injection temperatures.

Hydrogeochemical models predict further undersaturation of the injected thermal water with regard to the carbonates, thereby promoting dissolution of the rock matrix along preferential flow paths. We hypothesize that this process can lead to a heterogeneous heat extraction, accelerated thermal breakthrough, and thus incomplete exploitation of the heat-in-place.

In this study, we quantify the hydrogeochemical effects of reduced return-flow temperatures for representative geothermal sites in the NAFB using hydrogeochemical models. Simulations indicate that decreasing the injection temperature from, e.g., 60 °C to 40 °C increases rock matrix dissolution by approximately 50%. The spatial distribution of the dissolution depends on the kinetics and the existing fracture network. Here, hydraulic models have to inform hydrogeochemical models with regard to local flow velocities. In turn, the hydrogeochemical models feed changes in the fracture widths back to the hydraulic models.

LID 0278
Development of a conceptual model of the groundwater–river interaction under changing climate conditions by using hydrochemical and isotopic parameters

Ivana Benčić[1]*, Igor Karlović[1], Jasna Kopić[2], Tamara Marković[1]

[1] Croatian Geological Survey, Zagreb, Croatia
[2] Vinkovački vodovod i kanalizacija d.o.o., Vinkovci, Croatia
* ibencic@hgi-cgs.hr

Keywords: conceptual model, river-groundwater interaction, hydrochemical parameters

Alluvial aquifers represent strategically important groundwater resources due to their high productivity and strong hydraulic connection with surface waters, but they are also vulnerable to climate variability and anthropogenic pressures. Understanding interactions between alluvial aquifers and river water is essential for sustainable groundwater management.

Within the scope of the Interreg InnoWATCCH project, a conceptual model of the interaction between the Sava River and the associated alluvial aquifer will be developed, focusing on hydrochemical parameters to better understand groundwater–river interactions and governing processes, which significantly influence groundwater quantity and quality. Groundwater samples were collected from wells and piezometers, while river water was sampled at two locations along the river. Precipitation was also sampled to provide information on recharge and isotopic composition. Hydrochemical analyses include major ions, nutrients, total organic carbon and total nitrogen. These data are complemented by stable water isotopes ($\delta^{18}O$ & $\delta^{2}H$), radon measurements and noble gas analyses. Together, these methods provide a basis for assessing hydraulic connection and exchange processes between the river and the alluvial aquifer.

The conceptual model will improve understanding of hydraulic connection and exchange processes between the Sava River and the alluvial aquifer, providing a scientific basis for sustainable groundwater management. Furthermore, the findings may support the design and implementation of Managed Aquifer Recharge (MAR) strategies to enhance groundwater availability, improve water quality and increase the resilience of alluvial aquifer systems to climate variability and anthropogenic pressures.

This work is supported by the Innovative Water Retention for Climate Change Mitigation, Sustainable Agriculture and Flood Protection (InnoWATCCH) project and the Croatian Science Foundation (HRZZ) through the DOK-2025-02-2429 programme.

LID 0279
Investigating MIKAS and Sentinel springs in Denmark

Klaus Hinsby[1]*, Christian N. Albers[1], Rasmus, Jakobsen[1], Bertel Nilsson[1]

[1] Geological Survey of Denmark and Greenland (GEUS), Copenhagen, Denmark
* khi@geus.dk

Keywords: spring, monitoring, groundwater-dependent ecosystems

We present initial results from Danish springs discharging from karst and fractured chalk aquifers in Himmerland, Denmark. Evidence of karstification in the chalk aquifer connected to one of the springs and a dependent stream has previously been demonstrated by differences in nitrate concentrations between agricultural and natural areas, and by characteristic EC time-response to rain events in and around the spring[1]. Seven of ten investigated springs were recently included among the world's most important karst aquifer springs (MIKAS). All ten springs are being investigated in the project “SentinelSprings –springs as sentinels of climate change and sustainability of aquatic ecosystems” within "Water4All-Water Security for the planet".

Real-time groundwater quantity (discharge) and quality (nitrate, conductivity, temperature) monitoring data, along with preliminary results for groundwater age indicators ($^{3}H/^{3}He$ and TFA), inorganic chemistry, and stable isotopes, are presented. All the investigated springs contain nitrate, and most show a clear impact of agricultural pollution. Spring discharge varies between approximately 10 and 100 l/s. All springs contain TFA, indicating that the discharging groundwater was recharged within the last five decades. Some springs contain only traces of TFA, whereas others have modern concentrations, indicating different sources and ages of groundwater discharging to the springs. This will be further investigated by $^{3}H/^{3}He$ dating. PhreeqC modelling shows carbonate supersaturation in five of the springs. Two of these, with $SI_{calcite} > 0.26$, show tufa deposition. Stable water isotopes (^{2}H, ^{18}O) are similar in all springs and show no signs of evaporation, indicating similar infiltration conditions. Egebæk spring has higher F^{-} and Sr^{2+} concentrations, indicating geochemical variations in the chalk. More information on the investigated springs, ecology and access to real-time data is available on the EGDI Spring Information Platform.

The project SentinelSprings has received national funding from Fundação para a Ciência e a Tecnologia-I.P. (FCT-Portugal), Agence Nationale de la Recherche (ANR-France), Ministero dell’Università e della Ricerca (MUR-Italy), Narodowe Centrum Badań i Rozwoju (Poland), Innovation Fund Denmark (Denmark), Ministry for the Environment, Energy and Public Cleanliness (MEEC-Malta) and the European Union’s Horizon Europe Programme under the 2023 Joint Transnational Call of the European Partnership Water4All (Grant Agreement n°101060874)

Reference:

[1] Nilsson, B., Li, F., Chen, H., Sebok, E., & Henriksen, H. J. (2023). Evidence of karstification in chalk and limestone aquifers connected with stream systems and possible relation with the fish ecological quality ratio in Denmark. Hydrogeology Journal, 31(1), 53–70. https://doi.org/10.1007/s10040-022-02565-7

LID 0280

Is the Emilia-Romagna Region (Italy) aquifer system resilient to combined climatic and anthropogenic stresses? A comparison of physics-based and machine learning models

Ilaria Delfini[1]*, Daniel Zamrsky[2,3], Alberto Montanari[1]

[1] Department of Civil, Chemical, Environmental, and Materials Engineering (DICAM), Alma Mater Studiorum – University of Bologna, Bologna, Italy
[2] Department of Physical Geography, Utrecht University, Utrecht, The Netherlands
[3] IHE Delft Institute for Water Education, Water Resources and Ecology Department, Delft, The Netherlands
* ilaria.delfini2@unibo.it

Keywords: groundwater recovery, drought, anthropogenic impact

The Emilia-Romagna region (northeastern Italy) makes wide use of groundwater to meet water demand, particularly during drought periods, which have become more frequent and severe in recent years. As surface water availability declines during droughts, groundwater becomes an increasingly critical resource; however, aquifer systems recovery after drought events is still poorly quantified.

This study analyzes the combined influence of climate change and human activities on a portion of the Emilia-Romagna region multi-layered aquifer system, investigating its response and recovery times to different drought events. The main objective is to evaluate the system's resilience to prolonged droughts and to outline potential guidelines for long-term sustainable groundwater management. To do so, a numerical groundwater flow model and a random forest algorithm are applied and compared in simulating historical and future groundwater head values.

After calibrating both models, a scenario analysis is carried out considering different climatic conditions and groundwater abstraction regimes. The aim is to assess how climatic stressors and anthropogenic pressures influence groundwater head decline and post-drought recovery in the study area, and to clarify their respective roles in shaping future groundwater security.

Results indicate that the aquifer system is vulnerable to future droughts, and that pumping regime can exert a dominant control on system behavior and its recovery times. While the random forest model accurately reproduces system dynamics under conditions similar to the calibration period, its reliability decreases under extreme scenarios.

Overall, these findings emphasize the importance of considering both climatic variability and anthropogenic pressures when assessing future groundwater resilience, and highlight the benefit of integrating complementary modeling approaches to support sustainable groundwater management amid increasing hydroclimatic uncertainty.

LID 0281
Multi-exponential retention of pathogens during subsurface transport

Veerle Troelstra[1]*, Anna Störiko[1], Gertjan Medema[2,1], Boris Van Breukelen[1]

[1] Department of Water Management, Faculty of Civil Engineering and Geosciences, Delft University of Technology, Delft, The Netherlands
[2] KWR Water Research Institute, Nieuwegein, The Netherlands
* v.troelstra@tudelft.nl

Keywords: pathogen transport, multi-exponential retention, Bayesian inference

Groundwater contamination by pathogenic microorganisms remains a significant contributor to waterborne disease outbreaks worldwide. Ensuring microbial safety of drinking water produced from groundwater or infiltration water requires reliable predictions of pathogen transport and removal in the subsurface. Such predictions underpin risk assessments, guide the design of setback distances between contamination sources and wells, and support optimisation of managed aquifer recharge systems. Regulatory and modelling frameworks typically assume that pathogen concentrations decrease exponentially with distance from the source. However, many field studies report retention profiles that deviate from this behaviour and show a multi-exponential profile, defined by strong initial removal followed by a more gradual decline.

We investigated multiexponential retention through a systematic meta-analysis of published field studies. Using a Markov Chain Monte Carlo approach, we evaluated whether each retention profile was better described using an exponential (log-linear) or bi-exponential model. Bi-exponential models represent systems in which a fraction of the microbial population is removed more rapidly than the remaining fraction. Across all profiles best described by a bi-exponential model, the fast-attaching fraction was consistently high, indicating that pronounced deviations from log-linear behaviour may arise from a relatively small fraction that undergoes slower removal. This pattern could be ascribed to a range of possible mechanisms.

Recognising and characterising multi-exponential retention at the field scale provides a basis for incorporating this behaviour into assessments of pathogen removal, and enables the development of guidance on how to account for it at existing sites and in the design of future groundwater protection measures.

LID 0282
Hydrodynamics of Morro da Água Quente geothermal system and mining feasibility at Fazendão Mine, Quadrilátero Ferrífero, Southeastern Brazil

Maria Luiza Ramos[1]*, Thiago Elias Silva[2], Paulo Scudino[2], Carlos Cantarutti[2], Ana Caroline Trindade[2]

[1] Vale S.A., Belo Horizonte, Brazil
[2] Watergeo Solutions, Belo Horizonte, Brazil
* maria.luiza.ramos@vale.com

Keywords: hypothermal springs, thermodynamic, mine dewatering

This study investigates the hydrodynamics of the hypothermal springs (29 °C) in Raul Neuenschwander Park, adjacent to the Fazendão mine (Vale S.A.) in Catas Altas-MG, Brazil. The springs have been impacted by anthropogenic changes since the 19th century, contributing to their cooling. An integrated approach combining geological-structural, hydrochemical, isotopic, and thermodynamic analyses was applied for a hydrogeological assessment to evaluate the impact of iron ore mining and dewatering operations on the integrity of hypothermal springs. These springs are associated with an alluvial aquifer overlying a geothermal system linked to the Moeda Formation (fractured quartzitic aquifer) and the Cauê Formation (itabiritic aquifer, unconfined with secondary porosity under dewatering).

Major ionic constituents and silica (SiO_2) content were analyzed, along with isotopic and thermodynamic parameters. Stable isotopes (Deuterium, ^{2}H, and Oxygen-18, ^{18}O) indicate a paleometeoric origin of the thermal waters and isotopic differentiation between the Moeda and Cauê aquifers. The radioisotope Tritium (^{3}H) in the Cauê aquifer indicates a cold-water age near 70 years, while Carbon-14 (^{14}C) suggests a thermal groundwater age of 10^3 years and an estimated permeability of 2×10^{-5} cm s^{-1}.

A mixing geothermometric model based on SiO_2 content, enthalpy, and temperatures of cold and thermal groundwaters, as well as thermal conductivity and heat flow, estimated a convection geotemperature of 150 °C at a depth of 3.55 km. The model indicates an 8% contribution of hot water from deep circulation (Moeda Aquifer) and a 92% contribution from cold water of shallow circulation (Cauê Aquifer) for the springs.

The results suggest a positive effect of mining operations, as dewatering the Cauê Aquifer should invert the hydraulic gradient, reduce cold-water mixing, and promote a medium to long-term increase in springs temperatures, which was probably higher than the current 29°C in previous times.

LID 0283
Evaluation the effect of comprehensive control measures on groundwater over-exploitation in Beijing

Xia Wu[1]*, Binghua Li[1], Peng Dou[1]

[1] Beijing Water Science Technology Institute, Beijing, China
* wux082020@outlook.com

Keywords: groundwater over-exploitation, control measures, groundwater level, Beijing

Implementing groundwater overdraft control is urgently required to protect groundwater resources, improve the ecological environment, ensure public livelihood, and achieve sustainable development. Since the launch of the "Beijing Comprehensive Action Plan for Groundwater Over-extraction Management" in 2019, Beijing has adopted a comprehensive "one reduction, one increase" management and control strategy, focusing on advancing six key governance tasks—namely, control, management, conservation, diversion, replacement, and supplementation—and has carried out the governance work in an orderly manner. Based on a historical analysis of groundwater development and utilization in Beijing, this study employed geostatistical and water-level dynamics methods to evaluate the effectiveness of various over-extraction control measures implemented from 2018 to 2021, with respect to changes in groundwater levels and the spatial extent of over-exploitation zones. The results indicate that the groundwater level rose from 23.03 meters to 16.39 meters, groundwater storage increased by 3.32 billion cubic meters, and the area of groundwater over-extraction zones shrank from 4,134 km^2 to 1,200 km^2, representing a reduction of 71%. Nevertheless, Beijing's overall water resource situation remains in a state of "tight balance." Therefore, continued implementation of stringent management measures remains essential to address groundwater over-extraction and to achieve sustainable development.

LID 0284
Chemical hydrogeology of freshened groundwater offshore New England

Boris Van Breukelen[1*], Verena Heuer[2], Laura Wehrmann[3], Karen Johannesson[4], Holly Michael[5], Sophie Ten Hietbrink[6,7], Ellie Miller[8], Thomas Müller[9], Mojgan Soleimani[10], Bryce Mitsunaga[11], Jeremy Everest[12], Margaret Stewart[12], Rebecca Robinson[13], Brandon Dugan[14,15], IODP[3]-NSF Expedition 501 Science Team

[1] Department of Water Management, Delft University of Technology, Delft, The Netherlands
[2] MARUM, University of Bremen, Bremen, Germany
[3] Stony Brook University, Stony Brook, United Sates
[4] University of Massachusetts, Boston, United Sates
[5] University of Delaware, Delaware, United Sates
[6] Department of Geological Sciences, Stockholm University, Stockholm, Sweden
[7] Bolin Centre for Climate Research, Stockholm University, Stockholm, Sweden
[8] Department of Geology and Geological Engineering, Colorado School of Mines, Golden, CO, United Sates
[9] GEOMAR, Kiel, Germany
[10] CNRS, Montpellier, France
[11] Harvard University, Boston, United Sates
[12] British Geological Survey, Edinburgh, United Kingdom
[13] Graduate School of Oceanography, University of Rhode Island, Kingston, RI, United Sates
[14] Department of Geophysics, Colorado School of Mines, Golden, CO, United Sates
[15] Hydrologic Science and Engineering, Colorado School of Mines, Golden, CO, United Sates
* b.m.vanbreukelen@tudelft.nl

Keywords: offshore freshened groundwater, biogeochemistry, radiocarbon dating, isotope hydrology, coastal aquifers

Offshore freshened groundwater is currently being studied with an unprecedented level of interdisciplinarity and detail through IODP3-NSF Expedition 501 (www.ecord.org/expedition501/). Expedition 501 tightly links the research fields of hydrogeology, geology, sedimentology, (isotope) tracer hydrology, noble gas geochemistry, groundwater dating, inorganic and organic (isotope) biogeochemistry, and environmental microbial ecology, to ultimately provide enhanced and comprehensive insights on the global phenomenon of offshore freshened groundwater.

Boreholes drilled in May-August 2025 along the Atlantic continental shelf offshore New England, Massachusetts, USA allowed collection of sediments to depths of nearly 400 meters below seafloor at three sites up to 60 km offshore the island Nantucket. Groundwater was collected every few meters in millilitre quantities by squeezing or extraction from sediment cores, and in cubic meter volumes during several groundwater pumping tests, targeting both saline and near-fully freshened groundwater horizons (salinity as low as ± 2‰ at the least offshore site). During the onshore phase of the Expedition (January-February 2026) the cores were analysed at MARUM in Germany, and expedition data collection was completed.

In this presentation, possible mechanisms and timing of offshore fresh groundwater emplacement will be briefly discussed based on water isotopes and radiocarbon dating. This presentation will focus on main biogeochemical processes occurring in the submarine hydrogeological system: cation-exchange patterns in relation to freshening and salinization; mineral dissolution and precipitation; and redox processes (iron-reduction, sulphate-reduction, methanogenesis) in relation to decomposition of organic matter, and

production of dissolved greenhouse gases and nutrients. The potential relevance of these processes on geological time scales, and for offshore freshened groundwater as resource, will be briefly discussed.

LID 0285

A new database for stable isotopes and tritium in precipitation, surface water and groundwater – German Isotope Network

Paul Koeniger[1*], Stephan Braune[1], Robert Kringel[1], Eric Habiryayo[1], Martin Leistner[1], Aixala Gaillard[2], Johannes A.C. Barth[2], Andreas Neuner[2], Blake Walker[2], Andreas Wagner[2], Sarah Jelinski[2], Dominik Kremer[2,3], Jessica Landgraf[4], Axel Schmidt[4], Michael Heidinger[5], Heinrich Eisenmann[6], Philip Schuler[7], Robert Van Geldern[2]

[1] Federal Institute for Geosciences and Natural Resources (BGR), Hannover, Germany
[2] Friedrich-Alexander-University Erlangen-Nürnberg (FAU), Erlangen, Germany
[3] Leibniz Institut für Länderkunde (IFL), Leipzig, Germany
[4] Federal Institute of Hydrology (BfG), Koblenz, Germany
[5] HydroIsotop, Schweitenkirchen, Germany
[6] Isodetect, Leipzig, Germany
[7] CDM Smith SE, Berlin, Germany
* paul.koeniger@bgr.de

Keywords: isotopes, isotope database, isoscapes, GIN

Isotope compositions of precipitation, surface water and groundwater are only available through a limited number of international or national databases. These offer access to measured and published isotope data for interested users. Examples are the Global Network of Isotopes in Precipitation (GNIP-WISER) of IAEA [1], or on a national level, the Austrian and Swiss Isotope Networks (ANIP and ISOT). Within a research project (LURCH-IsoGW) financed by the German Federal Ministry of Research, Technology and Space (BMFTR) data on stable water isotopes (δ^2H, $\delta^{18}O$) and tritium (^3H) in precipitation, surface water and predominately groundwater were compiled for Germany. Additionally new measurements were conducted and complemented by meta information on ownership, analytical methods and data access, and was re-organized for the German Isotope Network (GIN) website (isotopes-gin.de). Now a set of more than 16,000 groundwater samples exists all over Germany. This data was assembled from state authorities, water suppliers, published research work, companies and an additional approximately 5,000 samples were collected and measured during sampling campaigns in 2024 and 2025 at locations where no previous data were available within the project. Precipitation and surface water stations of the German Federal Institute of Hydrology (BfG) and the German Meteorological Service (DWD) are collected monthly since the late 1970s and up to now count about 40,000 samples (approx. 15,000 precipitation and 24,000 surface water) [2,3]. For the generation of groundwater isotope maps (isoscapes), all data were queried from a IsoGW/GIN designed SQL database and transferred into GIS-layers and via web-feature-service https protocols for exchange to partners for interpolation. Original data, managed on AQUA, allow users to choose appropriate excerpts and add new results. We demonstrate the current status of the database, its usability on the website and related activities of GIN.

References:

[1] Terzer-Wassmuth S., Wassenaar L.I., Welker J.M., Araguás-Araguás L.J. (2021): Improved high resolution global and regionalized isoscapes of $\delta^{18}O$, δ^2H and d-excess in precipitation. Hydrological Processes. DOI:10.1002/hyp.14254.

[2] Schmidt A., Frank G., Stichler W., Duester L., Steinkopff T., Stumpp C. (2020): Overview of tritium records from precipitation and surface waters in Germany. Hydrological Processes (2020); DOI:10.1002/hyp.13691.

[3] Koeniger P., Schmidt A., Stumpp C. (2022): Stable isotope patterns of German rivers with aspects on scales, continuity and network status. Isotopes in Environmental and Health Studies 58 4-6, 363-379. DOI:10.1080/10256016.2022.2127702.

LID 0287

Integrating isotopes, hydrogeochemistry, and the watersociety nexus to evaluate coastal aquifer salinization and water security under hydroclimatic and socioeconomic stress: insights from the Indian Sundarbans

Mijanur Mondal[1]*, Kousik Das[1]

[1] Department of Environmental Science and Engineering, SRM University-AP, Amaravti, Andhra Pradesh, India
* mijanurmondal.geo@gmail.com

Keywords: stable water isotopes, SW-GW interaction, water security

The Indian Sundarbans, a densely populated sector of the tide-dominated Ganges delta adjoining the Bay of Bengal, is experiencing acute freshwater stress due to climate variability, anthropogenic pressure, and changing socio-economic conditions. This study evaluates the hydrogeochemical and isotopic characteristics of deep groundwater—the only reliable freshwater source—across inland to near coastline aquifers, and assesses surface water–groundwater (SW–GW) interaction and solute mobilization using stable isotopes ($\delta^{18}O$, $\delta^{2}H$) and salinity. The hydrogeological assessment is integrated with a household survey (n = 300) to examine the water–society nexus and drinking water dependency patterns. Groundwater levels have declined significantly over the past decade, likely reflecting delayed aquifer response to rainfall recharge. Inland aquifers exhibit wide salinity (0.7–9 PSU) and $\delta^{18}O$ (−2.8 to −0.5‰) variability, whereas near-coastline aquifers show narrower ranges (0.8–1.2 PSU; −2 to −0.6‰). Groundwater samples plot along the GMWL and LMWL, indicating dominant meteoric recharge, supported by mean d-excess values (inland: −2 ± 1.7‰; near-coastline: −2 ± 1‰). Elevated river salinity (24 PSU) suggests fluvial intrusion as a primary source of inland salinization, while seawater influence (33 PSU) governs salinity in near-coastal aquifers. Isotopic depletion inland indicates monsoonal recharge with limited maritime influence, whereas relative enrichment near the coast suggests vertical mixing. These findings delineate active SW–GW interaction pathways contributing to groundwater vulnerability. Socio-economic analysis reveals that ~70% of households depend on agriculture and wage labor, and approximately 65% rely on deep tubewells and 15% on surface water, increasing exposure to salinity-related health risks. Over 60% perceive declining water availability, consistent with observed groundwater trends. Estimated annual water demand (~6.85 mcm) exceeds extractable groundwater availability (~3.6 mcm), intensifying stress on deep aquifers and raising sustainability concerns. Overall, the integrated isotopic, hydrogeochemical, and socio-economic framework provides a robust decision-support basis for sustainable groundwater management, strategic use of intermediate aquifers, and community-centered adaptation measures to enhance water security in the Indian Sundarbans and advance SDG-6.

LID 0288
Diffusion-controlled isotope transport and implications for dating fossil groundwater in the Milk River Aquifer (Canada–USA)

Stephanie L. Musy[1,2,3]*, Roland Purtschert[2], Neil C. Sturchio[4], Linnea J. Heraty[4], Peter Mueller[5], Jeremy Lantis[5], Michael N. Bishof[5], Christof Vockenhuber[6], Avadhoot Date[7], Bernhard Mayer[7], Reika Yokochi[8]

[1] University of Basel, Basel, Switzerland
[2] University of Bern, Bern, Switzerland
[3] University of Oulu, Oulu, Finland
[4] University of Delaware, Newark, United States
[5] Argonne National Laboratory, Lemont, United States
[6] ETH Zurich, Zurich, Switzerland
[7] University of Calgary, Calgary, Canada
[8] University of Chicago, Chicago, United States
* stephanie.musy@gmail.com

Keywords: groundwater dating, ^{81}Kr, ^{36}Cl, matrix diffusion, fossil aquifers

Krypton-81 ($t_{½}$ = 229 kyr) and chlorine-36 ($t_{½}$ = 301 kyr) are among the few tracers capable of constraining groundwater residence times on 10^5–10^6 year timescales. However, in sedimentary aquifer systems bounded by low-permeability units, diffusive solute exchange may alter tracer systematics and bias apparent ages. We investigate these processes in the transboundary Milk River Aquifer (Canada–USA), a regionally important fossil groundwater resource affected by long-term chloride enrichment.

New measurements of ^{81}Kr, ^{36}Cl/Cl, δ^{37}Cl, and ^{14}C were combined with two-dimensional advection–diffusion transport modeling to quantify the role of matrix diffusion across aquifer–aquitard interfaces. Observations show a systematic downgradient decrease in ^{36}Cl/Cl accompanied by increasing chloride concentrations and enrichment in δ^{37}Cl. Numerical simulations reproduce these coupled trends and demonstrate that the evolution of the chlorine isotope system is dominated by diffusive influx of Cl-rich, ^{36}Cl-depleted water from adjacent shales rather than by radioactive decay alone.

In contrast, ^{81}Kr activities are substantially less sensitive to diffusive exchange. Model results indicate that diffusion accounts for ~90% of the reduction in ^{36}Cl/Cl at distal locations, but only ~20% of the reduction in ^{81}Kr relative to a diffusion-free scenario. Neglecting diffusion would lead to strong overestimation of ^{36}Cl apparent ages, whereas ^{81}Kr remains a comparatively robust chronometer for very old groundwater.

Our results highlight the importance of integrating stable and radioactive chlorine isotopes with noble-gas tracers and explicit transport modeling to distinguish decay from transport effects. The combined tracer–modeling framework provides a quantitative basis for interpreting groundwater ages in diffusion-dominated fossil aquifer systems worldwide.

LID 0289
Multi-scale modelling of geothermal heat transport in the Budapest Thermal Karst and the Pannonian Basin

Éva Kun[1]*, Katalin Székvölgyi[1], János Kiss[1], László Zilahi-Sebess[1]

[1] Supervisory Authority for Regulatory Affairs, Geological Survey, Budapest, Hungary
* eva.kun@sztfh.hu

Keywords: multi-scale modelling, density-dependent flow, conductive heat transport

Heat transport in geothermal systems is governed by processes operating at markedly different spatial extents, from density-driven groundwater flow within thermal karst aquifers to conductive heat transfer across the lithosphere. This study presents a multi-scale modelling framework that links a density-dependent groundwater and heat transport model of the Budapest Thermal Karst (4,477 km^2) to a conductive heat transport model of the Pannonian Basin (~228,000 km^2).

The Budapest geothermal model was developed using FEFLOW to simulate coupled groundwater flow and heat transport in karstified carbonate formations under natural and production conditions. The model accounts for density-driven flow, thermal convection and conduction, and was calibrated against hydraulic heads, spring discharge and subsurface temperature data. Although the model reproduces the observed thermal patterns and convective flow structures, the estimation of the regional geothermal heat flux remains uncertain due to limited deep observations and the masking effect of convection.

To address this limitation, a purely conductive, single-phase heat transport model was constructed for the Pannonian Basin, extending from the surface to the lithosphere–asthenosphere boundary (LAB). The model incorporates lithology-dependent thermal conductivity and radiogenic heat production. Results from the first modelling approach were compared with measured bottom-hole temperatures (BHT > 30 °C) from more than 5,000 thermal wells across the basin. The average RMS error is consistent with the intended resolution of the conductive model and reflects the dominant control of lithospheric structure and internal heat production.

The heat flux distribution provided by the conductive model can be used as a boundary condition at any selected depth within the model domain in subsequent regional or local simulations. Future work will address parameter sensitivity and further refinement of the conductive model.

LID 0290
3D framework for integrated urban groundwater management

Mohammad Reza Hajizadeh Javaran[1]*, Fabien Glatting[1], Hannes Hemmerle[2], Peter Bayer[2], Philipp Blum[1], Kathrin Menberg[1]

[1] Karlsruhe Institute of Technology (KIT), Institute of Applied Geosciences (AGW), Karlsruhe, Germany
[2] Department of Applied Geology, Institute of Geosciences and Geography, Martin Luther University Halle-Wittenberg, Germany
* mohammad.javaran@kit.edu

Keywords: urban groundwater management, subsurface urban heat island, shallow geothermal energy, groundwater ecosystems

Urbanisation has intensified the use of urban subsurface, altering quality, quantity and thermal state of urban aquifers, which are habitats for groundwater ecosystems and a source of drinking water and geothermal energy. Thus, there is a need for coordinated groundwater use that accounts for potential conflicts among different uses. Hence, this study aims to develop a framework for 3D groundwater management, which can integrate groundwater protection, use and existing management policies, using the city of Berlin as case study.

The subsurface of Berlin is divided into 3D blocks of similar size (500 m × 500 m × 50 m), and parametrised using hydrogeological and thermal conditions. For selected groundwater purposes, i.e. ecosystem functions, thermal use, and provision of infrastructure space, a multi-criteria decision analysis is carried out to assess the qualitative suitability for each purpose. Various types of interaction, such as exclusion, competition and accompaniment of specific purposes and uses, are evaluated considering water protection zones and regulations for shallow geothermal energy.

While 26% of the assessed blocks are suitable for a single purpose (7% ecosystem protection, 19% geothermal use), around 74% are suitable for multiple purposes, indicating potential conflicts of use. The competitive use of subsurface space for infrastructure and geothermal use accounts for a high share of potential conflicts (30%). In contrast, accompaniment between water protection zones and groundwater ecosystem protection is identified for 7% of the blocks, highlighting the potential for mutual benefits even in dense urban areas. Overall, the identified competitions and accompaniments underline the need for comprehensive groundwater management in urban areas, such as Berlin. The proposed framework can support decision-making to balance groundwater utilisation and preservation, and can be refined by adding case-specific criteria for advanced subsurface planning.

LID 0292
Integrated surface geophysics and borehole logging for characterizing heterogeneity in a shallow alluvial aquifer

Seho Hwang[1]*, Seungho Jeong[1], Jihun Choi[1], Jehyun Shin[1], Soonyoung Yu[1], Dongkyu Park[1]

[1] Korea Institute of Geoscience and Mineral Resources, Deajeon, South Korea
* dreaminghwang@gmail.com

Keywords: groundwater availability, surface geophysics, borehole logging, aquifer characterization, climate change

Recent severe droughts along the eastern coast of Korea highlight the increasing need for climate-resilient groundwater management. Securing sustainable groundwater resources under climate variability requires reliable characterization of aquifer structure and hydraulic properties. This study presents an integrated investigation combining surface geophysical surveys and borehole logging to assess groundwater availability in a shallow alluvial aquifer. The study area (approximately 200,000 m^2) has a shallow water table (~1.5 m). The weathered zone begins around 8 m depth with spatial variability. Seismic refraction surveys delineated subsurface velocity structures, and seismic velocities were converted to porosity using nearby borehole logging data to estimate hydrogeological properties. Variations in refractor geometry were interpreted in relation to paleo-channel distribution. Electrical resistivity tomography identified two fractured weak zones beneath the weathered layer, interpreted as potential preferential groundwater pathways. Four boreholes (depth ~15 m) penetrated fill, sand, silt, and gravel layers. Temperature logs showed typical geothermal gradients in two boreholes, whereas two exhibited temperature decreases below 8–9 m, indicating groundwater flow. Fluid electrical conductivity ranged from 120 to 370 µS/cm. Natural and spectral gamma logs reflected heterogeneous depositional environments; higher Th/K ratios were observed in the upper weathered zone, while uranium concentrations remained relatively constant. Density and neutron logs acquired within 50 mm PVC casing were calibrated to estimate total porosity. Integrated field investigation results indicate that the shallow alluvial aquifer is highly heterogeneous due to weathering, paleo-channel development, and fractured zones. These findings underscore the need for systematic and integrated investigation planning to reduce uncertainty and improve the efficiency of groundwater development under climate stress.

LID 0294
Data-scarce recharge estimates from wadi flows in Yemen

Sarah Alexander[1]*, Michelle Rygus[2], Alastair Black[3], Luciano Marquetto[2], Geraint Burrows[2]

[1] Groundwater Science, Edinburgh, United Kingdom
[2] Groundwater Relief, Totnes, United Kingdom
[3] Groundwater Science, Shrewsbury, United Kingdom
* s.alexander@gwscience.co.uk

Keywords: recharge modelling, wadi flows, water resources

Yemen is a highly water-stressed country due to the ongoing conflict, lack of infrastructure, changing population densities, unregulated drilling, and saline intrusion, with groundwater an important resource for both agricultural and domestic users.

Surface hydrology in the region is controlled by wadi systems that flow from upland regions towards the coast. Where the flows pass across the Quaternary-age alluvial plain, there is enhanced recharge to the aquifer. The Tihama Plain along the Red Sea is one of the key agricultural areas in the country, and is heavily dependent on irrigation from both groundwater and diverted wadi flows.

SWAc, a spatially distributed runoff-recharge model, is used to simulate recharge across Yemen's Al-Mokha district and associated wadi catchments as part of a UNICEF-funded project. The model includes geological, geomorphological, land use and climatic inputs, in addition to crop-specific parameters accounting for local cropping calendars.

The recharge outputs from SWAc reflect distributed infiltration recharge to the aquifer, which is typically low due the high rate of evapotranspiration. Surface water routing within SWAc directs runoff towards the wadi network, which is simulated in MODFLOW 6. The streamflow package from MODFLOW 6 is used to estimate the surface water-groundwater interactions in the wadis, and this flux is combined with the SWAc diffuse recharge outputs.

Due to the political instability in the country, as well as the difficulties of collecting data during peak wadi flows, there is limited flow data for model calibration. An irrigation survey of farmers in the Tihama Plain is used to provide point data for model calibration, informing where wadi flows are fully depleted before reaching the sea.

The resultant mapping provides a new spatial recharge estimate for water resource planning, as well as a baseline for climate scenarios.

LID 0296
Introducing slow hydrology as a nature-based water balance tool

Peter van der Keur[1*], Miguel Joaquim Fernandes Potes[2], Maria Helena Novais[2], Ana Isabel Da Silva Mendes[2], João Filipe Fragoso dos Santos[2], Helene Müller[3], Johann Peter Rauch[3], Magdalena von der Thannen[3], Albert Scrieciu[4], Andrei Toma[4], Marina Bergen Jensen[5], Peter Stubkjær Andersen[5], Thomas Balstrøm[5], Rikke Munck Petersen[5], Amalie Laursen[5], Ida Karlsson Seidenfaden[1], Maria Ondracek[1], Emma Gaitán Fernández[6], Jaime Ribalaygua[6], Klaus Hinsby[1], Malin Ingemarsson[7]

[1] Geological Survey of Denmark and Greenland (GEUS), Copenhagen, Denmark
[2] University of Evora, Evora, Portugal
[3] BOKU University, Vienna, Austria
[4] Romanian National Institute of Marine Geology and Geoecology (GeoEcoMar), Bucharest, Romania
[5] University of Copenhagen, Denmark
[6] Meteogrid, Madrid, Spain
[7] Stockholm International Water Institute (SIWI), Sweden
* pke@geus.dk

Keywords: slow Hydrology, biodiversity, landscape restoration

Climate change intensifies existing disparities in water quantity and quality across European river basins, reinforcing the need for management approaches that rebalance the dual role of freshwater in sustaining terrestrial and aquatic ecosystems as well as supporting human demands. The Water4All–INTERLAYER project introduces Slow Hydrology as a conceptual framework for nature-based solutions to realign this balance in European river basin management under future climate extremes. Slow Hydrology is proposed as a structured approach to identify and evaluate measures that enhance water storage through detention and retention, thereby regulating and slowing flow velocities across the landscape. These measures are designed to not only deliver flood and drought resilience but also multiple co-benefits, including improved biodiversity through, for example, reforestation and landscape restoration, enhanced surface water quality, recharge of shallow groundwater to mitigate drought impacts, and the preservation of cultural landscapes. The framework is demonstrated in four contrasting Living Labs in Austria, Portugal, Romania, and Denmark. For each basin, key ecological and resource-related challenges—such as low-flow conditions requiring restoration, flooding linked to channel morphology, reconnection of wetlands to river systems, and trade-offs between ecological flow requirements and consumptive water use—are identified and addressed using Slow Hydrology-based strategies. The analysis integrates GIS-based bluespot screening with conceptual and physically based hydrological modelling and targeted monitoring to support robust assessment and validation of proposed interventions.

INTERLAYER project has received funding from the European Commission programme Water4All (Water4All-2022-00261). The content does not necessarily reflect the views of the European Commission. The European Commission is not liable for any use that may be made of the information contained herein.

LID 0297
Aquifer storage, transport and recovery for water reuse: A case study of the NATALIE project in Belgium

Marylidia Villagrán Marroquín[1]*, Miguel Moreno Gomez[1], Marijke Huysmans[1]

[1] Department of Water and Climate, Vrije Universiteit Brussel, Brussels, Belgium
* marylidia.villagran.marroquin@vub.be

Keywords: MODFLOW, aquifer storage, transfer and recovery, nature-based solutions, Cretaceous aquifer, chalk

The south-eastern part of Flanders (Belgium) relies on the Cretaceous Aquifer, a strategic deep groundwater aquifer for drinking water production. This aquifer is of utmost regional importance, with a total annual drinking water production of about 30 Mm^3. In addition to drinking water, it also provides resources for agriculture and industry. However, increasing demand due to economic growth, population pressures, and climate change, combined with limited infrastructure connectivity and tightening abstraction regulations, threatens the sustainability of this resource.

This case study investigates the feasibility of Aquifer Storage, Transport and Recovery (ASTR) as a Nature-Based Solution to enhance groundwater sustainability. ASTR involves the seasonal storage, transport and recovery of treated water. It aims to recharge the aquifer, ensure high-quality water recovery, and support indirect water reuse. To assess the potential of the aquifer, the study has been divided into two phases: In phase one, a three-dimensional MODFLOW model (MODFLOW) was developed to design the ASTR system and evaluate different scenarios with injection/extraction rates ranging from $10m^3/h$ to $100m^3/h$. This modelling guided the selection of the location of injection, extraction, and monitoring wells, which were subsequently drilled. Field tests, including pumping and tracer tests, and laboratory analyses were conducted to characterise aquifer permeability, discharge, hydraulic conductivity, porosity and dissolution. Subsequently, the MODFLOW model was refined and calibrated considering all acquired field and lab data. In the second phase, the new model was used to simulate the potential for water reuse. In the near future, RO (reverse osmosis) water will be injected into the aquifer to evaluate injection capacity, clogging risk, and chemical transformations of the injected water.

This case study is part of the Horizon Europe NATALIE project (https://www.natalieproject.eu/). It promotes several nature-based solutions across eight European demonstration sites, integrating different European biogeographical regions. The Belgian case study is implemented by a consortium of De Watergroep (problem owner and future operator), KWR (research mentor), Vrije Universiteit Brussel (modelling and scientific validation), Aquafin (site provider), and AGT (hydrogeological and ASTR expert).

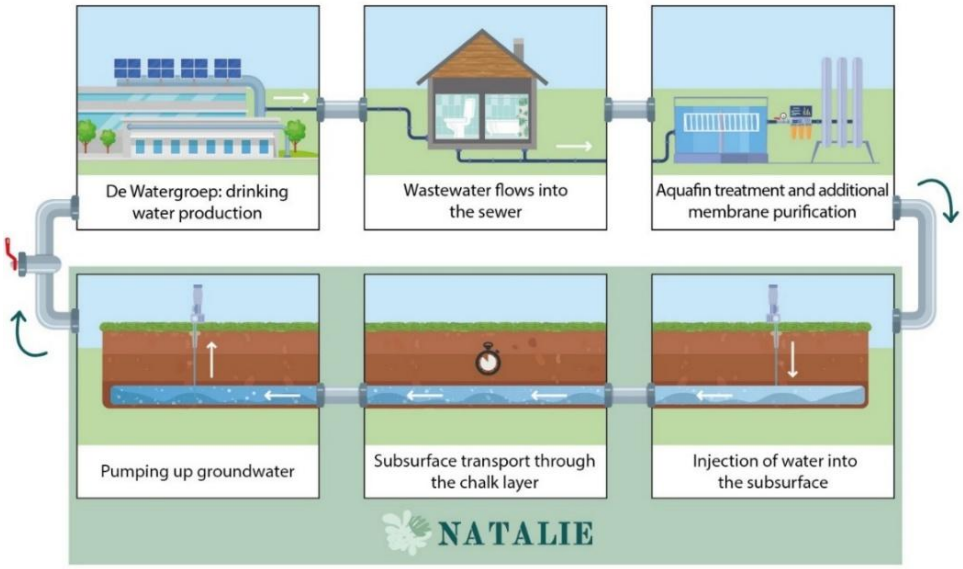


Figure 1. ASTR for water reuse

LID 0298
Pore-scale observation of the enhanced remediation of residual DNAPLs under co-solvents flushing

Huirong Guo[1]*, Boyang Ruan[1], Aiguo Zhou[1], Qin Shuai[1], Zhaohui Tang[1]

[1] China University of Geosciences, Wuhan, China
* elsieguo@126.com

Keywords: pore-scale observation, residual DNAPLs, co-solvents flushing

Groundwater contaminated by dense non-aqueous phase liquids (DNAPLs) such as chlorinated hydrocarbons is difficult to remediate. The removal efficiency of residual DNAPLs is usually limited by the mass transfer process in the pore-scale. Combinations of xanthan, cyclodextrin (CD) and ethanol during co-solvents flushing can enhance the mass transfer and increase the remediation efficiency. We simulated the co-solvents flushing and dissolution processes in 2D heterogeneous porous micromodels and real rock-microfluidics, acquiring spatially resolved fluid velocity fields with microscopic particle image velocimetry, monitoring the concentration of solvents and contaminants by using in-situ Raman spectroscopy, to reveal the effects of shear-thinning fluids and co-solvents on the flow and dissolution in the porous media. It was found that the mixed CD-ethanol solutions have a synergistic solubilization effect on the dissolution of PCE dissolution, and the dissolution rate of residual PCE in unconnected pores is influenced by several factors, including the water phase flow rate, the cross-sectional flux(Q) within the pore, the angle (α) between the direction of pore opening and the direction of water phase flow, and the flux gradient (F). Increasing the injection rate and the ethanol concentration of flushing floods improves the mass transfer rate of PCE. A larger Q corresponds to a higher renewal rate of the water phase in pore channels near unconnected pores, leading to an increased dissolution rate of residual PCE. When α is larger (α>90°), more flushing fluid enters the unconnected pores, further enhancing the dissolution rate of residual PCE. On the other hand, a larger F leads to a faster attenuation of the vertical component of the water phase flux entering the unconnected pores, lower flow velocities near the interface and slower dissolution rate of residual PCE.

LID 0299
Assessing the sensitivity of lowland springs to climate variability and anthropogenic pressures through integrated monitoring

Elena Egidio[1]*, Daniele Cocca[1], Damiano Saponaro[1], Domenico Antonio De Luca[1], Chiara Richiardi[2], Concita Daniela Spada[2], Simone Ciadamidaro[2], Maria Rita Minciardi[2], Manuela Lasagna[1]

[1] University of Torino, Earth Sciences Department, Torino, Italy
[2] ENEA, National Agency for New Technologies, Energy and Sustainable Development, Biodiversity and Ecosystems Laboratory, Saluggia, Italy
* elena.egidio@unito.it

Keywords: springs, climate change, Water4All, ecohydrology

Springs are pivotal in the connection between groundwater and surface water ecosystems. SentinelSprings project develops integrated monitoring protocols for springs across Europe, combining hydrogeological, ecological and climatic data to assess their resilience to global change.

Ten lowland springs, known as “fontanili”, were selected in the heavily anthropised Po Valley as Italian pilot sites.

Hydrogeological monitoring included quarterly campaigns at all sites to measure in situ parameters (temperature, pH, electrical conductivity, TDS), discharge rate and major ions. In two springs a data logger was installed to continuously record water level, temperature, and electrical conductivity. At these same sites, annual isotopic and pesticide analyses were also conducted to evaluate recharge areas and agricultural pressures.

Ecological monitoring, to assess biodiversity, ecosystem status and ecosystems services, consisted of two annual field surveys of aquatic and riparian vegetation, stream macroinvertebrate communities and odonates. Further, changes in the territory were assessed using Earth Observation data, such as multi-temporal land use and land cover maps and satellite indexes trends.

Early results showed that biological communities’ composition is linked to land use, water chemistry, discharge patterns and human maintenance activities. Intensively managed springs showed reduced ecological integrity, simplified communities, loss of sensitive species, and greater alien plant cover. Also, biological communities benefit from channels with larger dimensions and higher flow velocity.

The integration of climate, hydrogeological and ecological data highlighted the high sensitivity of springs to climate variability. The first year of data demonstrates that combining continuous high-frequency measurements with seasonal sampling and annual specialised analyses provides a robust dataset for assessing spring ecosystems in highly anthropised landscapes.

The project SentinelSprings has received national funding from Fundação para a Ciência e a Tecnologia-I.P. (FCT-Portugal), Agence Nationale de la Recherche (ANR-France), Ministero dell’Università e della Ricerca (MUR-Italy), Narodowe Centrum Badań i Rozwoju (Poland), Innovation Fund Denmark (Denmark), Ministry for the Environment, Energy and Public Cleanliness (MEEC-Malta) and the European Union’s Horizon Europe Programme under the 2023 Joint Transnational Call of the European Partnership Water4All (Grant Agreement n°101060874).

LID 0300
Model comparison to evaluate the implementation of adjustable weirs in agricultural drainage ditches for groundwater management in Belgium

Marylidia Villagrán Marroquín[1]*, Lise Piepers[2], Karsten Jensen[3], Torben Sonnenborg[4,3], Jan Diels[5], Marijke Huysmans[1,5]

[1] Department of Water and Climate, Vrije Universiteit Brussel, Brussels, Belgium
[2] Flemish envomental Agency, Brussels, Belgium
[3] Department of Geosciences and Natural Resources Management, University of Copenhagen, Copenhagen, Denmark
[4] Geological Survey of Denmark and Greenland (GEUS), Copenhagen, Denmark
[5] Department of Earth and Environmental Sciences, KU Leuven, Leuven, Belgium
* marylidia.villagran.marroquin@vub.be

Flanders is characterised by low-lying, flat terrain, where agricultural drainage is essential for managing excess groundwater. However, during severe drought periods in 2011, 2017–2020, 2022, and most recently in 2025, groundwater levels declined significantly, affecting natural ecosystems, agriculture, and the drinking water supply. In response, several Managed Aquifer Recharge (MAR) systems have been implemented to increase groundwater recharge. One key method involves installing weirs in agricultural drainage ditches to slow down groundwater outflow and raise groundwater levels. This strategy has been implemented in the Dommel and Bollisenbeek Catchment, located in the Province of Limburg. There have been 13 adjustable operational weirs since 2015.

Modelling the impact of weirs on groundwater levels is not straightforward, as weirs are not a standard feature of many hydrological or groundwater models, and as each model has different degrees of complexity to model surface water and groundwater interaction. To assess the impact of these weirs on groundwater levels and river discharge, a model comparison study between MODFLOW and MIKE SHE (coupled with MIKE+) was performed. These two fully distributed physical models were calibrated against groundwater heads, and additionally, MIKE SHE was calibrated against river discharge. The calibrated models were then used to quantify the extent of the weirs' impact on groundwater levels and to calculate their contribution to the overall water balance. Furthermore, scenario analyses were performed to compare different configurations, varying the number and location of weirs within the sub-catchments. This research identifies the strengths and limitations of these two hydrological models to optimise strategies for managing groundwater on agricultural landscapes, which are facing increasing water scarcity and climate-related challenges.

LID 0301
Assessing and comparing subsurface urban heat island intensity across European cities: Towards a harmonised framework

Elena Egidio[1]*, Verena Dohmwirth[2], Susanne A. Benz[2], Ashley M. Patton[3], Manuela Lasagna[1]

[1] University of Torino, Earth Sciences Department, Torino, Italy
[2] Karlsruhe Institute of Technology (KIT), Institute of Photogrammetry and Remote Sensing (IPF), Karlsruhe, Germany
[3] British Geological Survey, Cardiff, United Kingdom
* elena.egidio@unito.it

Keywords: subsurface urban heat island (SubSUHI), groundwater temperature, groundwater monitoring, European cities

The subsurface urban heat island (SubSUHII) intensity is increasingly recognised as a key indicator of anthropogenic impacts on groundwater (GW) systems. Despite growing evidence of GW warming in urban areas, there exists no consistent framework for quantifying and comparing SubSUHII across cities. A robust assessment of subsurface thermal anomalies is essential to understand urbanisation implications for GW resources, ecosystem functioning and shallow geothermal potential.

This contribution aims to define a conceptual and methodological framework for quantifying SubSUHII by analysing temperature differences between urban and rural GW conditions, taking into consideration the monitoring depth, hydrogeological setting, urban boundary definition and a selection of appropriate rural thermal references. The framework is designed to be compatible with approaches used in atmospheric urban heat studies, enabling interdisciplinary exchange and supporting a more comprehensive understanding of urban heat across different layers.

Moreover, the study expands comparative analysis of SubSUHII patterns across multiple cities in Europe (Karlsruhe (Germany), Turin (Italy) and Cardiff (UK)) using the updated global GW temperature dataset by Benz et al. (2024), complemented by additional observational data. These new case studies explore how SubSUHII varies with local climate zones, GW monitoring depth, aquifer type and urban morphology.

Results provide insights into the SubSUHII magnitude and spatial variability within and between cities, considering also the influence of urban structure and infrastructure and the role of climatic and hydrogeological conditions. By integrating local-scale analyses with broader inter-city comparison, this study identifies recurring patterns and key drivers of subsurface thermal anomalies, advancing towards a harmonised framework for assessing SubSUHII and supporting sustainable GW management.

Reference:

Benz, S.A. et al., 2024. Global groundwater warming due to climate change. Nat. Geosci. 17, 545–551. https://doi.org/10.1038/s41561-024-01453-x

LID 0302
Groundwater reservoirs as central components of a sponge city: Basic principles, concepts and new approaches

Florian Hirsch[1]*, Christopher Conrad[2], Peter Bayer[1]

[1] Martin-Luther-University Halle, Department of Applied Geology, Halle, Germany
[2] Martin-Luther-University Halle, Department of Geoecology, Halle, Germany
* florian.hirsch@geo.uni-halle.de

Keywords: water storage, integrated water management, sponge city

Urban water management requires responding to long-term changes in both natural and anthropogenic conditions. Water use, along with water availability, is subject to constant change, leading to an increased need for adaptive, multifunctional water management and supply strategies, particularly in complex urban areas. Specific interest to our work are integrated approaches such as the sponge city concept, in which temporary excess water – for example, intensive rainwater – is stored, infiltrated and evaporated on site in a controlled process to prevent flooding and simultaneously improve the urban climate. Storage as groundwater is not only the most straightforward solution here, but also often the most cost-effective.

Despite considerable progress in planning and implementation, there are scientific and practical gaps in the research and implementation of the sponge city concept, e.g. with regard to the economic perspective, standardised indicators and monitoring protocols. Ideally, the focus should not only be on individual neighbourhoods, but on the expansion to an entire city or a large catchment area. Our research is currently focused on an initial geographical and nominal analysis of the current status of urban water management systems. The aim is to address the subsoil as a primary storage medium in the sponge city concept and to make quantitative statements about its function through a parameter analysis. Furthermore, the spatial and temporal boundaries of the sponge city concept will be examined, and its favourable application window in comparison to conventional water management practices.

LID 0304
Integrated near-surface geophysics for characterizing river–aquifer interactions in a transboundary aquifer: The Vipava/Vipacco River, Soča/Isonzo Basin (Slovenia–Italy)

Veronika Iván[1]*, Gaia Travan[1], Flavio Accaino[1], Alessandro Affatato[1], Ilaria Dreossi[1], Michela Giustiniani[1], Oziel Souza De Araujo[1], Luigi Sante Zampa[1], Goran Vižintin[2]

[1] OGS, National Institute of Oceanography and Applied Geophysics, Trieste, Italy
[2] University of Ljubljana, Ljubljana, Slovenia
* vivan@ogs.it

Keywords: river-aquifer interactions, transboundary aquifer, near-surface geophysics

Effective management of transboundary aquifers requires comprehensive hydrogeological understanding, especially in case of complex geological settings. The impacts of climate change further complicate the picture, increasing uncertainty and the need for robust, forward-looking management strategies. Characterizing the connection between surface and groundwater systems is one of the key elements to ensure adequate water quality and quantity.

Our study site is located on the Slovenian–Italian border, around the confluence of Vipava River with the Isonzo. The Vipava crosses a contact zone between a karst aquifer and alluvial aquifers, separated by low-permeability flysch units, while the banks of the Isonzo are characterized by alluvial deposits extending up to the Torre River, representing a natural hydrodynamic boundary. To assess the subsurface architecture and the hydraulic connection between the Vipava and the aquifers, an integrated near-surface geophysical approach is applied on a smaller subset of the hydrogeological modeling area. Near Miren (Slovenia), two field campaigns were conducted in February and August 2025, allowing to capture seasonal variations. The applied methodology combined high-resolution P- and S-wave seismic reflection and tomography, Electrical Resistivity Tomography (ERT), Self-Potential (SP) method, and gravimetry.

Integrated geophysical results reveal a system with gently northward-dipping carbonate bedrock of variable depth, overlain by alluvial deposits of heterogeneous permeability. Based on the obtained geophysical data characterizing the hydraulic boundary between the alluvial plain and the karst, a 3D hydrogeological model was refined in FeFlow and calibrated in PEST. The results indicate limited exchange between the Vipava and the alluvial aquifer under current conditions in Slovenia, and demonstrate the effectiveness of combining multiple geophysical methods to provide key input data for refining conceptual hydrogeological models.

This research was supported by the WABIN project (Transboundary river basin water balance with integrated methodologies and adaptation to climate change), co-financed by the European Union under the Interreg VI-A Italy-Slovenia Programme 2021–2027.

LID 0305
Sustainability of managed wetlands in semi-arid agricultural coastal areas transitioning from traditional to modern irrigation practices

Christian Montoro-Paredes[1]*, Sachin Karan[2], María Luisa Calvache[1], Ana Susino-Súnico[1], Carlos Duque[1]

[1] Department of Geodynamics, University of Granada, Granada, Spain
[2] Department of Geochemistry, The Geological Survey of Denmark and Greenland, Copenhagen, Denmark
* chr.montoro@ugr.es

Keywords: unmanaged aquifer recharge, wetlands

Traditional irrigation practices represent a type of unmanaged aquifer recharge that reinforce the long-term resilience of groundwater resources. Irrigation practices are transitioning to less water-consuming technologies, from gravity to localised irrigation, boosted by water managers aiming to increase the available water resources for higher demands. This transition from traditional to modern irrigation practices in agricultural semi-arid areas may also have a negative impact on the sustainability of groundwater-related ecosystems, such as wetlands. In coastal areas, this thread is higher because of the risk of saltwater intrusion. The objective of this study is to assess the impact of changing traditional to modern irrigation practices on managed wetlands in semi-arid agricultural areas based on the Motril-Salobreña aquifer (Southern Spain) case study. The study area is characterised by the presence of several lagoons in the Charca de Suárez wetlands. The water of the lagoons proceeds from managed surface water inflows due to irrigation surplus waters distributed with a complex irrigation network of small ancient ditches that supply water extracted from a river. The regional evolution of the aquifer has been assessed over the last two decades through the analysis of land cover and water balance changes integrated in a hydrogeological numerical model with variable density. The predictive simulations that include both climate and irrigation changes show impacts on groundwater heads, water balance and salinity. The changes in irrigation system generate drawdowns of up to 0.12 m in the wetlands area with a direct impact on lagoon infiltration rates and an increase of up to 8% in salinity in the groundwater. Maintaining the wetland as it is today would require an additional managed surface water inflow 18-43% higher. The sustainability of the Charca de Suárez wetlands does not depend only on the management of the lagoons with surface water because the infiltration rates are limited to the lagoon bed permeability and geometry. Therefore, the hydrogeological setting and the hydraulic characteristics play a significant role for the sustainability of wetlands.

LID 0306
Addressing the groundwater gap: Harmonizing UNFC E-axis evaluations for mining projects

Peter van der Keur[1]*, William Nibbs[2], Tania Martins[3], Rahul Dasgupta[4], Abraham Nunbogu[5], Éva Kun[6], Hashim Carey[7], Hendrik Falck[8,9], Erika Ingvald[10], Aaron Johnson[11], Kevin Parks[12]

[1] Geological Survey of Denmark and Greenland (GEUS), Copenhagen, Denmark
[2] University of Glasgow, Glasgow, Scotland
[3] Manitoba Geological Survey, Winnipeg, Canada
[4] Independent geochemist, India
[5] United Nations University Institute for Water, Environment and Health, Richmond Hill, Ontario, Canada
[6] Geological Survey of the Supervisory Authority of Regulatory Affairs, Budapest, Hungary
[7] Geoscience Australia, Canberra, Australia
[8] Geoscientists Canada, Ottawa, Canada
[9] Canadian Institute of Mining and Metallurgy, Quebec, Canada
[10] United Nations Economic Commission for Europe, Geneva, Switzerland
[11] American Institute of Professional Geologists, Northglenn, United States
[12] Independent groundwater consultant, Alberta, Canada
* pke@geus.dk

Keywords: groundwater, mining, resource management

The secure and sustainable supply of metals, rare earth elements, and other critical raw materials is essential for achieving the United Nations 2030 Sustainable Development Goals (SDGs), particularly the transition to affordable clean energy. Mining activities commonly interact with groundwater systems through abstraction, diversion, and contamination risks, over a variety of time frames from immediate impacts to long-term legacies from waste and tailings. These interactions, together with legacy groundwater overdraft, land-use change, and climate-related pressures, can affect mining project viability, including social acceptance and access to resources.

The United Nations Framework Classification for Resources (UNFC) provides a globally applicable system to assess environmental–socio-economic viability, technical feasibility, and degree of confidence for resource projects. However, the application of the UNFC environmental–socio-economic (E) axis to groundwater-related impacts and constraints remains inconsistent, particularly where impacts extend beyond the project boundary to the aquifer or watershed scale. Preliminary gap analysis indicates the absence of a clear, harmonised approach for integrating mine-scale water management practices, basin-scale groundwater assessments, and regulations within UNFC evaluations.

This contribution presents the rationale, scope, and objectives of a dedicated Task Force established under the UNECE Expert Group on Resource Management to address this gap. The Task Force aims to extend the preliminary gap analysis to develop a practical roadmap capable of supporting qualified, evidence-based E-axis evaluations of mining projects that impact, or are impacted by, groundwater resources. This includes guidance on translating common water management reporting standards into E-axis classifications. The outcomes are expected to improve the consistency and transparency of UNFC classifications, and supporting SDGs.

LID 0307
Discriminating seawater intrusion from other salinization sources in the Algarve sedimentary basin: Insights from environmental isotopes

Paula M. Carreira[1*], Luis Ricardo Costa[2], José Paulo Monteiro[3], Dina Nunes[1], Susana Gomes[1], Pedro Valério[1], José Manuel Marques[4], Edite Reis[2]

[1] Centro de Ciências e Tecnologias Nucleares (C²TN), Departamento de Ciências e Engenharia Nuclear (DECN), Instituto Superior Técnico, Universidade de Lisboa, Bobadela, Portugal
[2] Divisão de Planeamento e Informação, ARH do Algarve – Agência Portuguesa do Ambiente, Faro, Portugal
[3] CERIS IST/ UALG; Faculdade de Ciências e Tecnologia, Universidade do Algarve, Faro, Portugal
[4] Centro de Recursos Naturais e Ambiente (CERENA), Departamento de Engenharia de Recursos Minerais e Energéticos (DER), Instituto Superior Técnico, Universidade de Lisboa, Lisboa, Portugal
* carreira@ctn.tecnico.ulisboa.pt

Keywords: environmental isotopes, salts dissolution, seawater intrusion

With an area of 3,837 km², the Algarve basin hosts over 300,000 inhabitants, mainly concentrated along the coastal zones. Groundwater resources in this basin have been overexploited to meet increasing demands from domestic use, agriculture, and tourism. Shallow aquifers are particularly affected by the continuous input of nitrates, derived from both synthetic fertilizers and manure, as well as by emerging organic contaminants. This study aims to identify and characterize the main anthropogenic and natural pressures affecting groundwater resources in Quarteira–Fuseta area (Algarve Basin, S-Portugal). Groundwater samples were collected to determine major ions, trace elements, water isotopes, and emerging contaminants, together with in situ physicochemical parameters. The overarching goal is to support sustainable groundwater management in these coastal systems.

The collected groundwater samples were analyzed and compared, using isotopic, physical, and chemical data, with previous datasets from earlier projects to assess the temporal evolution of groundwater quality. The available data were used to: (i) classify groundwater samples based on chemical similarity, identifying hydrogeochemical facies; (ii) determine the main factors controlling groundwater salinization processes; and (iii) estimate the mean residence time of groundwater, considering both natural geochemical processes and anthropogenic influences.

Sampling campaigns were carried out to identify, through geochemical and isotopic hydrology approaches, the main causes and sources of groundwater degradation in coastal areas. More than 40 groundwater samples were collected for isotopic analysis. The isotopic composition ranged from −4.83 ‰ to −0.40 ‰ for $\delta^{18}O$ and from −27.7 ‰ to −6.46 ‰ for $\delta^{2}H$. The $\delta^{18}O$ data of groundwater, was used to define the freshwater–seawater mixing line and to estimate mixing proportions, providing insights into the extent of seawater intrusion in the study area.

This research was funded by the FCT-PRIMA Project/0003/2023 (WATER4MED – Innovative Strategies for Climate-Resilient Water Management in the Mediterranean). The authors from C2TN/IST acknowledge the support of FCT through the strategic project UID/04349/2025 (doi.org/10.54499/UID/04349/2025). The authors from CERENA/IST acknowledge the support provided through the projects FCT-UIDB/04028/2025 and FCT-UIDP/04028/2025. The authors from CERIS/IST/APA/UALG acknowledge the support provided through the project funded in whole or in part by the FCT, I.P. (FCT, https://ror.org/00snfqn58), UID/06438/2025 (https://doi.org/10.54499/UID/06438/2025) of the CERIS research unit.

LID 0308
Column experiments for comparing microplastic and conservative tracer transport in saturated porous media

Gahee Lee[1]*, Jin-Yong Lee[1], Eunju Jeong[1], Maimoona Raza[1]

[1] Department of Geology, Kangwon National University, Chuncheon, South Korea
* ghee7397@kangwon.ac.kr

Keywords: microplastic, conservative tracer, column experiment

Microplastics (MPs) are emerging as a critical contaminant in groundwater systems; however, the mechanisms governing their transport and retention in saturated aquifer media remain insufficiently understood. This study quantitatively evaluates MP transport behavior by interpreting MP breakthrough curves (BTCs) in direct comparison with those of a conservative NaCl tracer. To simulate subsurface environments, soil-packed columns (10 cm diameter, 40 cm length) were prepared and fully saturated with deionized (DI) water for 24 hours to establish stable hydrodynamic conditions. Conservative NaCl tracer tests (4,000 µS/cm) were conducted to define hydraulic transport characteristics independent of particle-specific interactions. Effluent electrical conductivity was continuously monitored until steady-state conditions were achieved, and tracer BTCs were normalized as a function of pore volume (PV). Red polypropylene (PP) fragments (10–100 µm) were injected in separate experiments to represent MP contamination. MP transport behavior was evaluated relative to the NaCl tracer BTC, which provided a conservative hydraulic reference for interpreting MP transport under saturated conditions. These findings improve the understanding of MP transport behavior and provide a basis for evaluating processes influencing MP mobility and retention under saturated groundwater conditions. This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIT) (RS-2024-00352562).

LID 0309
Unravelling response times in regional groundwater systems: Implications for the past and the future

Carlos Felipe Marin-Rivera[1]*, Alexandre Pryet[1], Julio Goncalves[2]

[1] Univ. Bordeaux, CNRS, Bordeaux INP, EPOC, UMR 5805, France
[2] Aix Marseille Univ., CNRS, IRD, INRA, Coll France, CEREGE, Aix-en-Provence, France
* cmarinriver@bordeaux-inp.fr

Keywords: hydraulic response times, sustainability, confined aquifers, climate change, groundwater-surface water interactions

Hydraulic response times link past and future groundwater dynamics. They govern how paleoclimatic signals persist and define the time scales over which aquifer systems adjust to new stresses, such as climate change and groundwater abstraction. Additionally, they are becoming a central metric in assessing system vulnerability, renewability, and sustainable use.

In unconfined systems, the role of surface water–groundwater interactions in controlling response times is well established. In contrast, confined systems are commonly treated as hydraulically isolated, with response times estimated under the assumption of impermeable confining units and negligible leakage.

We argue that this assumption can significantly overestimate response times under certain conditions. This study investigates response times in regional multilayer systems using numerical simulations across a wide range of hydraulic diffusivities. Our results indicate that hydraulic response times are controlled by the interplay between pressure propagation along stratigraphic units and diffusion across them. In regions with strong surface water-groundwater connectivity, vertical diffusion through semi-permeable layers enhances communication between deeper confined units and surface boundaries, shortening response times.

Our findings suggest that the influence of paleoclimatic conditions on present-day flow dynamics might have been overestimated in some regional groundwater systems. When response times are shorter than assumed, system behaviour reflects current forcing more strongly than its paleoclimate history. In any case, shorter response times do not imply negligible dynamics. They remain relevant within management planning horizons and must be considered in assessments of vulnerability, renewability, and sustainable use. We illustrate this by showing that sustainable abstraction volumes can be quantified as a function of planning horizons, using constrained optimization approaches. This provides a practical framework to support regional-scale sustainable management.

LID 0310
Quantifying mountain-front recharge in urban areas: the case study of Brescia (N Italy)

Alice Palazzi[1]*, Chiara Zanotti[1], Tullia Bonomi[1], Maria Filippini[2], Marco Rotiroti[1]

[1] Università degli Studi di Milano-Bicocca, Milano, Italy
[2] Biological, Geological and Environmental Science Department, Alma Mater Studiorum University of Bologna, Bologna, Italy
* alice.palazzi@unimib.it

Keywords: urban aquifer, aquifer recharge, mixing models

Urban areas deserve a great deal of attention because natural and anthropogenic recharge processes combine here to generate complex hydrogeological systems. This complexity increases for cities located in piedmont areas, where mountain front recharge (MFR) can be significant. One example is the city of Brescia in northern Italy. This work aims at quantifying recharge processes in the semiconfined conglomeratic aquifer beneath the city of Brescia, which is located at the mouth of an Alpine valley (Val Trompia), surrounded by carbonate Alpine reliefs and crossed by an Alpine river (the Mella River).

Over the course of one year, water samples were collected bi-monthly from the Mella River and a secondary stream, and six-monthly from 6 piedmont wells, 2 mountain wells, 1 Val Trompia well, and 1 mountain spring. Rainwater was also continuously collected during the same year. Samples were analysed for water stable isotopes, Cl/Br ratio, and major ions. In addition, the discharge of the Mella River was measured in different sections to calculate infiltration rates through a water balance method.

Ternary endmember mixing models based on δ^2H and Cl/Br showed that recharge to piedmont wells originated from a) focused mountain block recharge (fMBR) from the Val Trompia (47%), b) diffuse mountain block recharge (dMBR) from the surrounding Alpine reliefs (16%) and c) surface mountain front recharge (sMFR) from the Mella River (37%). Local precipitation was found to be irrelevant for aquifer recharge likely due to its drainage by the urban stormwater sewage system.

The Mella River infiltration rates were then used together with mixing model results to derive recharge flowrates for each recharge process. Results indicated that flowrates were 22.1 Mm^3/y for sMFR from the Mella River, 27.6 Mm^3/y for fMBR and 9.4 Mm^3/y for dMBR. This work highlighted the key role of MFR in piedmont aquifers, confirming the negligible contribution to recharge of local precipitation in urban areas.

This work was funded by the European Union – Next Generation EU – PRIN 2022.

LID 0312
Improved methods for assessing microplastic transport in groundwater: The GWMicroPlast Project

Nina Mali[1]*, Elvira Colmenarejo Calero[1], Manca Kovač Viršek[1,2]

[1] Geological Survey of Slovenia, Ljubljana, Slovenia
[2] National Institute of Biology, Ljubljana, Slovenia
* nina.mali@geo-zs.si

Keywords: microplastics, groundwater, sampling, tracing experiment, unsaturated zone

Microplastics (MPs) have recently been recognised as an emerging class of contaminants in groundwater, yet their occurrence, transport pathways, and sources remain insufficiently understood. The GWMicroPlast project addresses this knowledge gap by advancing the study of MPs in groundwater through integrated field monitoring, methodological innovation, and experimental research under natural conditions. The project provides the first systematic assessment of MP occurrence in Slovenian groundwater. Groundwater was sampled at twenty locations. A network of pilot sites was established across both intergranular and karst aquifers, enabling representative coverage of diverse hydrogeological settings.

A key achievement is the development and patenting of a novel groundwater sampling device designed to minimise contamination risks and improve the reliability of MP detection. The device enables the collection of large water volumes through cascade filtration, followed by visual and spectroscopic identification of MP particles. This technological advancement enhances the accuracy, reproducibility, and comparability of MP quantification in groundwater studies.

To better understand MP transport processes in the unsaturated zone of gravel aquifers, field lysimeter experiments were conducted. Tracer tests under natural hydrological conditions allowed evaluation of migration behaviour for different MP shapes, offering new insights into their mobility, retention, and potential pathways towards groundwater.

Initial results confirm the presence of MPs in various groundwater sources and underscore the critical role of rigorous sampling methodology and experimental design. The integrated approach of GWMicroPlast establishes a scientific foundation for future research on MP transport in subsurface environments and supports the development of standardised monitoring protocols for the protection of groundwater resources.

This work was supported by the Slovenian Research and Innovation Agency (ARIS) under the project Improved Methods for Determining Transport Processes and the Origin of Microplastics in Groundwater Resources (GWMicroPlast) (J1-50030).

LID 0313
Data-driven conceptual modelling of complex highland-lowland hydrological interactions in the Ethiopian Rift Valley

Michel Frem[1,2]*, Tibor Stigter[1], Boris Van Breukelen[2], Gretchen Gettel[1,3], Graham Jewitt[1,2], Tilahun Azagegn[4], Binyam Tesfaw[4], Abdalmajeed Ibrahim[1], Elie Gerges[5]

[1] IHE Delft Institute for Water Education, Delft, The Netherlands
[2] TU Delft, Delft, The Netherlands
[3] Aarhus University, Aarhus, Denmark
[4] Addis Ababa University, Addis Ababa, Ethiopia
[5] IGRAC - International Groundwater Resources Assessment Centre, Delft, The Netherlands
* m.frem@un-ihe.org

Keywords: highland-lowland interactions, surface water-groundwater interactions, groundwater recharge

The development of a data-driven understanding of the hydrological dynamics of geologically complex highland-lowland systems is essential for formulating strategies that address water-related challenges in East Africa. The overarching objective of this study is to develop a conceptual understanding of the hydrological functioning of the Wondo Genet water tower system in the Ethiopian Rift Valley, built up of volcanic rock and volcano-lacustrine sediments. To achieve this, we installed sensors for continuous monitoring of water levels in rivers and wells, and of climatic variables, conducted discharge measurements, and carried out hydrochemical measurement and sampling surveys of rainwater, surface water, and groundwater. This allowed us to employ a multi-method approach and perform an integrated analysis of the collected data, including hydrograph separation, groundwater recharge estimation, and various water quality analyses. Average groundwater recharge is estimated at approximately 22.5 ± 9.6% of rainfall. While results show slightly higher recharge in the highlands, this pattern is not as pronounced as in other highland-lowland systems. Around 89% of streamflow originates from baseflow, and the latter is an order of magnitude higher than what could be assessed so far from contributing springs, further highlighting the importance of subsurface flow along faults and fractures. Additionally, chemical and isotopic signatures suggest that the lowlands receive significant groundwater contributions from the highlands. Water balance calculations indicate that a relatively large portion of net rainfall (P-ET) is not discharging at the catchment outlet, suggesting that a substantial fraction may contribute to deep percolation and lateral subsurface outflow beyond the catchment boundary, along fracture networks. The improved conceptual hydrological understanding is essential for the area, given the significant use of groundwater for agricultural and domestic purposes.

LID 0314
Statistical insights from long-term time-series of radon and hydrogeochemical signatures in groundwater of the Matese Region, Central-Southern Italy

Adriana Damato[1*], Francesca Gori[1], Marino Domenico Barberio[2], Maurizio Barbieri[3], Mariachiara Caschetto[4], Valerio Comerci[5], Marco Petitta[1]

[1] Department of Earth Sciences, Sapienza University of Rome, Rome, Italy
[2] Istituto Nazionale di Geofisica e Vulcanologia, Sezione Roma 1, Rome, Italy
[3] Department of Chemical Engineering and Environmental Materials, Sapienza University of Rome, Rome, Italy
[4] Department of Civil and Environmental Engineering, Politecnico di Milano, Milano, Italy
[5] Istituto Superiore per la Protezione e la Ricerca Ambientale-ISPRA, Roma, Italy
* adriana.damato@uniroma1.it

Keywords: hydrogeochemistry, time-series, STL analysis

Understanding groundwater responses to tectonic and hydrological forcing is crucial in seismically active regions. Long-term hydrogeochemical monitoring provides an effective approach to study the interactions between groundwater dynamics and seismic activity. This study examines groundwater variability in the Matese area (Central–Southern Italy) to assess processes controlling hydrogeochemical behavior and to distinguish recharge signals from deeper fluid contributions within a carbonate aquifer. Since 2018, a multiparametric monitoring network has been developed at the Matese Massif, focusing on four major springs (Capovolturno, Biferno, Telese Terme, and Grassano). The network integrates monthly hydrogeochemical surveys with continuous in-situ measurements of physicochemical parameters and dissolved ^{222}Rn, allowing high-resolution temporal monitoring of groundwater dynamics. The combined dataset enables the investigation of groundwater behavior across short- and long-term temporal scales. Time series were statistically analyzed using decomposition techniques to identify trends, seasonal patterns, and residual variability, allowing the separation of recharge-driven processes from deeper contributions. Rio Freddo and Grassano springs, selected for continuous radon monitoring, represent different discharge areas and hydrogeological settings. Seasonal–Trend decomposition using LOESS (STL) revealed distinct temporal dynamics of radon and hydrogeological parameters, reflecting different flow paths, circulation depths, and subsurface interactions. Overall, the study highlights the effectiveness of long-term, integrated monitoring and advanced statistical approaches for improving the understanding of groundwater dynamics in tectonically active carbonate aquifers, providing relevant insights for water resource management and seismic hazard assessment.

LID 0315
Efficient adjoint analysis for estimation of stream capture to support groundwater abstraction management in the UK

Kath Standen[1]*, Stefan Bramer[1], Rui Hugman[2], Jeremy White[3]

[1] INTERA Geosciences (UK) Ltd, London, United Kingdom
[2] INTERA Geosciences Pty Ltd, Faro, Portugal
[3] INTERA Incorporated, Fort Collins, United States
* kstanden@intera.com

Keywords: adjoint, sensitivity, stream-capture, sustainability

The UK water sector faces increasing pressure to deliver environmentally sustainable abstraction while maintaining resilient public water supplies. The UK Environment Agency (EA) is seeking to reduce groundwater abstraction by almost 40% (2,200 Ml/d) across England to meet environmental flow objectives. These values have been estimated using a precautionary, GIS-based screening method that applies simplified assumptions of how much streamflow is captured by groundwater abstraction using spatial relations. Water companies and other abstractors now need to undertake more detailed, site-specific investigations to confirm / refute these findings.

MF6-ADJ (Hayek et al., 2025) is an open-source, non-intrusive tool that uses the adjoint method to efficiently compute sensitivities of a wide-range of important input-output relations within any MODFLOW 6 model using the MODFLOW API. It computes sensitivities of important input-output relations but only requires a single forward model run per output of interest, enabling rapid, fine-grained diagnostic analyses with little computational cost.

We demonstrate the use of MF6-ADJ on a stochastic regional groundwater model of the Vale of Clwyd; a Permo-Triassic Sandstone aquifer where river flows are influenced by groundwater abstraction. We demonstrate how this tool can quickly calculate transient stream depletion with explicit attribution to multiple existing / potential groundwater abstraction locations with just one additional simulation, compared to the thousands of model runs needed for traditional stream-capture analysis. Uncertainty is considered by applying the adjoint method across an ensemble of calibrated models.

We demonstrate that at a regional scale, the relative impacts of each abstraction on surface water flows can be reliably estimated, potentially allowing more targeted abstraction schemes to meet water demand while minimising impacts on surface-water flows.

LID 0316
Impact of climate change on the river flow dynamics over recent decades on a tropical volcanic island: The Northeast of Martinique

Emile Gros[1,2]*, Benoit Vittecoq[1], Sophie Violette[2,3], Jérôme Fortin[2]

[1] BRGM, Fort-de-France, Martinique
[2] CNRS, UMR.8538 – Laboratoire de Géologie, ENS-PSL Research University, Paris, France
[3] SU, UFR.918, Paris
* e.gros@brgm.fr

Climate change is already causing significant modification and extreme events in all regions of the world, and the islands of the Lesser Antilles are not spared. Understanding long-term changes in the hydro-system functioning is a priority in Martinique.

Unfortunately, the lack of complete flow series for many stations makes it difficult to assess hydrological trends. To fill these gaps, we compiled rainfall and surface-water flow data over the period 1987-2024 (38 years). Stations with older historical surface-water flow series were included to extend the analysis period to 45 years. Next, we simulated the total continuous surface-water flow for ten stations using the GR4J model. These time series were used to estimate the contribution of base flow to total flow. Base flow contributions were then analysed using graphical (local minima) and numerical (Eckhardt model) separation methods. The local minima approach mainly captures groundwater contributions with longer residence times, whereas the Eckhardt method is less restrictive and includes a fraction of more recent, shallow groundwater.

Our results indicate that precipitation has remained stable since the 2000s, whereas temperature and evapotranspiration have increased significantly, especially during the wet season. These trends mainly influence the reduction in runoff while base flow remains relatively stable. Our results show that agricultural watersheds located in low-lying topographical areas are more vulnerable. In contrast, high elevation forest watersheds are moderately affected, underlining the regulating role of primary forests. The stability of base flow is explained by recharge distributed at higher elevations, where it exceeds the infiltration capacity of the aquifers. If base flows still appear to be relatively resilient to climate change, the decline in surface runoff could compromise water supplies, particularly in small coastal watersheds.

LID 0317
Hydrogeology of Kilwa Kisiwani: An island world heritage site in coastal East Africa

Belay Molla Sisay[1]*, Jean-Christophe Comte[1], Edward Pollard[2], Elgidius Ichumbaki[3], Joshua Wright[1], William Megarry[4], Simon Melchioly[3]

[1] University of Aberdeen, Aberdeen, United Kingdom
[2] The Discovery Programme, Dublin, Ireland
[3] University of Dar es Salaam, Dar es Salaam, Tanzania
[4] Queen's University Belfast, Belfast, United Kingdom
* belaymolla2009@gmail.com

Keywords: coastal groundwater, freshwater lens, seawater intrusion, East Africa

Groundwater is the primary source of freshwater in coastal East Africa, but is under increasing pressure from population growth, climate and land-use changes. Groundwater salinity driven by saltwater intrusion and shallow water table evapotranspiration is a major concern. The aim of this study is to provide critical insights into the factors affecting the quality and availability of groundwater and inform future sustainable management in Kilwa Kisiwani (KK) Island, a World Heritage Site holding evidence of past groundwater mismanagement and climate impacts. To evaluate KK's hydrogeology and groundwater dynamics, we employed geological analysis, seasonal well surveys, automatic water-level and salinity monitoring, and 2D electrical resistivity tomography (ERT).

The geology of the region comprises recent unconsolidated sediments and Mid-Eocene to Quaternary coral limestones and marine claystones. Groundwater has long been extracted from wells tapping the shallow aquifer. Seasonal surveys show average EC ranges from 2-12 mS/cm. Automatic monitoring data indicate groundwater level fluctuates by ~2.5 m annually, with additional semi-diurnal tidal signals and short-term drawdown from abstraction. Spectral and wavelet analyses revealed the dominant tidal component and allowed estimation of aquifer diffusivity using tidal propagation. Statistical analyses showed a very high correlation between water level and tides, with a time lag of 1.2 hr. Recharge estimated using the water table fluctuation method represents about 21% of total rainfall. ERT surveys further delineated a thin (~ 10-15 m) freshwater lens overlying saline groundwater.

Findings confirm the thin, shallow and dynamic nature of the freshwater system and its vulnerability to salinisation. Further analysis of climatic and environmental change data will inform long-term numerical modelling of the freshwater lens to unravel the possible natural or anthropogenic reasons for well failure and predict future changes.

LID 0318
Assessment of sea impact on a mediterranean coastal water system and its evolution over time

Angela Volpe[1]*, Rita Masciale[1], Maria Clementina Caputo[1]

[1] CNR National Research Council, IRSA Water Research Institute, Bari, Italy
* angela.volpe@cnr.it

Keywords: coastal aquifer, coastal freshwater lake, hydrochemical indicators

A hydrogeochemical study was performed on a coastal water system comprising a carbonate aquifer that feeds a freshwater lake. The interpretation of water quality data was based on a set of hydrochemical indicators that reflect the mechanisms controlling groundwater chemistry, with special attention to seawater intrusion. Given the lake's origin, indicators were also used to compare lake chemistry to that of the feeding groundwater, and the factors determining the compositional differences were analysed.

Chemical data were collected during two different time frames, ten years apart. Comparing the corresponding hydrochemical indicators allowed assessing the changes in water quality over time.

Results showed that the dissolution of calcium carbonate was the main factor controlling groundwater chemistry in the studied coastal aquifer. During the first monitoring period, ion exchange mechanisms and seawater mixing did not play a significant role. However, groundwater composition in the monitored coastal wells exhibited slightly higher chlorine salinity than that of inland wells. A clear seasonal pattern also characterized the coastal wells. Such features were not ascribable to direct seawater mixing caused by intrusion. In addition, the lake samples were also affected by seasonality and exhibited higher chlorine salinity than groundwater. Neither of these features was consistent with the salinization of the incoming groundwater.

The sea impact on the system was associated with factors other than seawater intrusion, i.e., the intake of sea salts through both the incorporation of sea spray into rainfall and the dissolution of salt deposits on land during runoff.

The data discussed above were compared to those collected ten years later. The analysis of hydrochemical indicators suggested that an incipient seawater intrusion had occurred in a restricted portion of the aquifer close to the coastline. Such a change did not affect the composition of the groundwater-fed lake.

LID 0319
Effect of salt concentration on osmotic potential in the dry range of the water retention curve of porous rock

Maria Clementina Caputo[1*], Andrea Colaleo[2], Mert Cetin Ekiz[1], Antonietta Celeste Turturro[2]

[1] CNR National Research Council, IRSA Water Research Institute, Bari, Italy
[2] University of Ferrara, Ferrara, Italy
* mariaclementina.caputo@cnr.it

Keywords: dew point method, salt-affected rock, modeling

Understanding the processes that occur in the vadose zone is crucial for quantifying the water stored, its transport timing, and its availability for aquifer recharge and plant uptake.

Hydraulic characterization, which consists of determining the water retention and hydraulic conductivity functions, is mandatory to assess the behaviour of the fluid as it crosses the unsaturated subsoil.

Particularly, the rocks constituting the unsaturated portion of the coastal aquifer are often crossed by water containing salt derived from marine spray. In addition, the capillary rise of seawater by the intrusion implies an increase in salt concentration of the water circulating in the pores of the rocks.

Because of these two processes, the objective of this work was to experimentally determine the salinity effect on water retention curves of calcarenite, the sedimentary rock that widely represents the unsaturated part of the Apulian coastal aquifer.

Experimental wetting water retention curves for two lithotypes of calcarenite have been determined using five solutions with different salt concentrations. The dew point method, using the WP4-T psychrometer, has been applied to measure retention data. It measures water potential as the sum of matric and osmotic components. LABROS Soil-View Analysis software was used to fit the experimental data with the unimodal van Genuchten model.

The curves of both lithotypes have shown different retention characteristics due to saline concentration and, consequently, to the osmotic component of water potential.

The results confirm that in the coastal aquifer, the salt concentrations of the water that cross the unsaturated calcarenite lead to higher water retention in the rock's pores, impacting the timing of aquifer recharge and freshwater-saltwater interaction.

In addition, this result suggests considering, for numerical modeling, retention functions specifically determined with saline solutions representative of the real ones.

LID 0320
Managed aquifer recharge and volumetric water benefit accounting for sustainable water management in Northeast Italy

Mara Meggiorin[1]*, Domenico Fracchiolla[1], Fabio Colombo[1]

[1] Ramboll Italy srl, Milan, Italy
* mmeggiorin@ramboll.com

Keywords: MAR, VWBA, sustainable water management, infiltration pond

Managed Aquifer Recharge (MAR) is an innovative and sustainable response to the water challenges posed by climate change and human overexploitation. Ramboll and Sanpellegrino have collaborated on a local project along the Brenta River in northeast Italy within the Venetian Plain, aimed at replenishing the hydrological cycle through the construction of two artificial basins.

Sanpellegrino aims to achieve a water positive target by 2025 using the globally recognized Volumetric Water Benefit Accounting (VWBA) methodology developed by the World Resources Institute. VWBA is at the forefront of innovative water management, offering a practical avenue for companies and communities to restore the local water balance. This approach quantifies and compares the benefits of various initiatives within the same exploited basin. It includes the approval by an external panel of experts, ensuring transparency and providing advantages to local communities and ecosystems.

The project addresses the progressive depletion of local aquifers caused by climate change, which complicates water supply and distribution, especially for agricultural purposes during the summer months. The final project aims to infiltrate more than 750,000 cubic meters of water into the highly permeable alluvial aquifer below, through the installation of an infiltration pond and a pre-sedimentation/bioretention basin. These basins serve a dual purpose: recharging the aquifer during the winter months, when water is abundant, and providing a water reserve for agricultural activities in the summer.

This example of private sector involvement underscores the relevance and effectiveness of such initiatives in sustainable water resource management amidst global climate challenges. Cooperative and responsible approaches like this are vital for climate change adaptation, promoting lasting positive change in water-stressed regions and demonstrating how local actions can contribute to solving global problems.

LID 0321
Integrating hydrochemical, isotopic, gaseous, pharmaceutical, and eDNA tracers to detect active subrosion of intrastratal halite

Eric Zechner[1*], Jakob Zopfi[1], Yama Tomonaga[1,3], Adrian Auckenthaler[2], Jannis Epting[1]

[1] Department of Environmental Sciences, University of Basel, Basel, Switzerland
[2] Office of Environmental Protection and Energy Canton Basel-Country, Liestal, Switzerland
[3] Entracers GmbH, Duebendorf, Switzerland
* eric.zechner@unibas.ch

Keywords: subrosion, multi tracer, environmental DNA (eDNA)

This study applies a multi-tracer approach in a regional Middle Triassic aquifer-aquitard-evaporites system in Northwestern Switzerland and aims to delineate areas where observed land subsidence can be linked to active subrosion of intrastratal halite. In the regional aquifer, naturally occurring mixing has been intensified by anthropogenic alteration of the groundwater flow field by large-scale artificial groundwater recharge for drinking water purposes in combination with groundwater pumping.

A total of 63 groundwater wells reaching depths between 12 m and 273 m were sampled for hydrochemistry (major ions), isotopes (^{18}O, ^{2}H, ^{3}H, ^{13}C,^{14}C), dissolved gas composition (CH_4, N_2, H_2, O_2, Ar, CO_2, He, Kr), pharmaceutical compounds (tramadol), and microbiology (environmental DNA/eDNA).

Methods for groundwater age determination (^{13}C,^{14}C, ^{3}He, ^{4}He) revealed that large parts of the regional aquifer have been subjected to mixing between very recently infiltrated rainwater, artificial recharge of Rhine water, and older groundwater. Highest chloride concentration with up to 100 g/l were found in two wells recently drilled to the top of the halite, where hydraulic measurements indicated the presence of an evaporitic karst at about 150 m depth. Data of water isotopes and tramadol taken from the recent wells show an important amount of artificially recharged water, which supports the hypothesis of an active subrosion process. Increased dissolved helium gas contents in the evaporitic karst, but also in other wells suggest possible upwelling from basement rocks along faults. Analysis of eDNA by high throughput sequencing revealed a significant presence of halophile microorganisms such as Halanaerobiaeota in the evaporitic karst. Multivariate statistical analysis of data from major ions, water isotopes, gas composition, and eDNA analyses revealed consistent trends among the presented tracer methods, and delineate the sampling locations under influence of the active subrosion.

LID 0322
Isotope analysis at an Italian coastal industrial site to detect sewer system leakage

Mara Meggiorin[1]*, Domenico Fracchiolla[1], Daniele Susanni[1]

[1] Ramboll Italy srl, Milan, Italy
* mmeggiorin@ramboll.com

Keywords: isotope analysis, sewer system leakage, industrial site

This study assessed potential contamination from the sewer system at an Italian coastal industrial site using oxygen ($\delta^{18}O$) and hydrogen ($\delta^{2}H$) isotopes. The objective was to determine if wastewater from the sewer system had contaminated other water resources, such as the aquifer and seawater.

Water samples were collected from rain, the sewer system, the aquifer, and seawater. The site's complexity stems from its geology and proximity to the shoreline, resulting in the mixing of various water contributions. The stratigraphy and hydrogeological setup reveal three main geological units: superficial fill materials with low mobility water, a sandy-silty horizon acting as an aquitard, and Miocene calcarenites forming the main aquifer with tectonic discontinuities providing preferential flow paths. Groundwater flows towards the sea, but hydraulic barrier systems at the plant lower the piezometric level upstream, creating a stagnation zone influenced by saline wedge intrusion.

Isotopic analysis was conducted using mass spectrometry techniques, tracing distinctive isotopic signatures of different water sources. The application of stable isotopes ($^{18}O/^{16}O$ and $^{2}H/^{1}H$) in hydrogeology aids in understanding groundwater recharge mechanisms and flow. Our analyses show significant isotopic differences between sources. The sewer system exhibits a unique isotopic signature, identifying wastewater contributions relative to other natural sources. Some samples indicated seawater intrusion with isotopic ratios progressing towards those of seawater. This analysis allows identification of different water sources within this complex site, enabling a better understanding of the conceptual model on-site, discerning between various water contributions.

This study demonstrates the effectiveness of isotope analysis as a diagnostic tool for monitoring and evaluating water systems interactions, not only at a regional scale for large water basins, but also in coastal complex industrial areas.

LID 0324

Refined geological and hydrogeological models to resolve surface and underground impacts of the Einstein Telescope facility in the Euregio – Meuse Rhine (EMR) region

Dwight Baldwin[1*], Alberto Román Gessa Fernández[1], Philippe Orban[2], Hossein Parsasadr[2], Marijke Huysmans[1], Daniel Drimmer[3]

[1] Department of Water and Climate, Vrije Universiteit Brussel, Brussels, Belgium
[2] Urban & Environmental Engineering Unit, University of Liège, Liège, Belgium
[3] Tractebel Engineering, Bruxelles, Belgium
* dwight.baldwin@vub.be

Keywords: tunnel engineering, groundwater modelling, geological modelling

The Einstein Telescope is a proposed underground facility that will serve as a third-generation gravitational waves observatory. The Euregio – Meuse Rhine (EMR) bid proposes the construction of a triangular array with 30 km of tunnels and caverns at depths between 250 and 400 meters below ground surface. A large underground facility such as this can cause significant environmental impacts as groundwater would drain into the tunnels and caverns and would need to be removed. Previous regional modelling estimated that drawdowns in the shallow aquifer could be up to 20 meters.

The EMR area is located in the border region between Belgium, the Netherlands and Germany and the subsurface of the area is complex, containing faulted, fractured and folded sedimentary rocks. Heterogeneity in hydraulic parameters spans widely within the same stratigraphic units. Based on first regional simulations, initial drainage estimates range from 380 to 48,500 m3/day. To address this uncertainty, refined models have been built based on newly acquired geological and hydrogeological data.

Locally refined groundwater and geological models are built in concert with each other advancing the hydrogeological interpretation of the subsurface. Refinement of the FEFLOW model discretization is done to handle calculation of pore pressure and tunnel inflow and subsequent impacts on hydraulic head in all aquifers. It has been developed through detailed interpretations of new and existing data obtained from public sources and within the Einstein Telescope project. Additionally, the mesh for the Einstein Telescope underground infrastructure has been enhanced, improving the solution at the boundary condition and increasing the ability of the model to handle different parameters. Mitigations including grouting around the tunnels and Managed Aquifer Recharge (MAR) are tested in our model to address impacts contributing to feasibility of the project bid.

LID 0325

Tracing anthropogenic versus geogenic sources of groundwater pollution using multi-isotope fingerprints: The case study of the Sarigkiol Basin, Western Macedonia

Eleni Vasileiou[1]*, Panagiotis Papazotos[2], Maria Perraki[1]

[1] National Technical University of Athens, School of Mining and Metallurgical Engineering, Department of Geosciences, Athens, Greece
[2] Hellenic Survey of Geology and Mineral Exploration, Acharnae, Greece
* elvas@metal.ntua.gr

Keywords: sources of pollution, fingerprint, water rock interaction

In regions with complex and varied environmental pressures, distinguishing between anthropogenic and geogenic sources of contamination is essential for selecting and applying the appropriate remediation method.

In the Sarigkiol basin, Western Macedonia, Greece, various anthropogenic activities occur, including mining, farming, livestock rearing, and industrial operations. Geogenic factors, such as geological and hydrogeological conditions, also significantly influence the qualitative characteristics of groundwater. The most severe groundwater quality issue in this basin is the elevated concentration of chromium, reaching up to 180 μg/L.

A methodology was developed to identify the origin of chromium in the region, combining field data with chemical and multi-isotope analyses. Six water samples were collected from springs, water wells, and mine waters, along with twelve solid samples comprising soil, rocks, fertilisers, and fly ash. Comprehensive physico-chemical analyses (pH, electrical conductivity, temperature, dissolved oxygen, redox potential, major ions, and potentially toxic elements) were performed on all water samples and leachates from leaching tests. In addition, stable isotope analyses of Pb, Sr, Cr, B, and N were conducted on all water and leachate samples to trace pollution sources in the Sarigkiol basin. Each of these stable isotopes represented a specific pollution source.

The isotope analyses of $\delta^{53}Cr$ and $\delta^{11}B$ in groundwater indicated mobilisation of geogenic chromium. The $^{87}Sr/^{86}Sr$ and Pb isotope ratios further supported the geogenic origin of chromium, identifying water–rock interaction as a crucial factor controlling groundwater quality, while $\delta^{15}N$ highlighted impacts from agricultural activities. The combining evaluation of the results revealed that the geogenic factors play a dominant role to the water quality in the study basin.

LID 0326
Groundwater stress and emerging solutions in the U.S. High Plains Aquifer

Sam Zipper[1,2]*, Maria Elena Orduña Alegría[3,1], Annick Anctil[4], James Bingaman[4], Micah Cameron-Harp[5], Jennifer Ifft[5], Anthony Kendall[4], Hannah Parker[5], Jacob Stid[4], Hanna Szydlowski[1], Blake B. Wilson[1], Geoffrey C. Bohling[1], Donald O. Whittemore[1], James J. Butler Jr[1]

[1] Kansas Geological Survey, University of Kansas, Lawrence, United States
[2] Department of Geology, University of Kansas, Lawrence, United States
[3] Oregon State University, Corvallis, United States
[4] Michigan State University, East Lansing, United States
[5] Kansas State University, Manhattan, United States
* samzipper@ku.edu

Keywords: solutions, food-energy-water nexus, governance, High Plains aquifer, water management

Aquifers in agricultural areas around the world are experiencing stress due to groundwater extraction for irrigation. The High Plains Aquifer covers parts of 8 states in the central U.S. and supports a multi-billion dollar agricultural economy. However, the aquifer has been depleted by over 50% in places and has localized areas that can no longer support large-scale groundwater extraction, resulting in negative impacts on agriculture, ecosystems, and the regional economy. This presentation will provide an overview of the status and trajectory of groundwater resources in the region and highlight two emerging solutions to the groundwater depletion challenge that have the potential to benefit other aquifers around the world.

First, we will focus on the Local Enhanced Management Area (LEMA) program, a novel governance structure developed in 2012 in the state of Kansas. A LEMA region in northwestern Kansas has been highly effective, leading to >20% reductions in groundwater withdrawals and slowing groundwater decline rates by >60%. Key governance characteristics related to its success, including a unique hybrid approach in which rules are developed by irrigators and enforced by the state; a multi-year cap on pumping that reduced overall extraction rates while providing flexibility for irrigators to experiment and adapt; and the relatively consistent social and environmental conditions within the LEMA region, which ensured irrigators in the region faced a relatively common set of conditions. One key environmental condition driving effectiveness is the near-constant aquifer net inflow observed across the High Plains Aquifer in Kansas, which allows us to assess impacts of pumping changes and chart paths toward a more sustainable future for aquifers supporting irrigated agriculture in Kansas and beyond.

Second, we will discuss a technological solution focused on developing water-energy-food-environment synergies. We have developed an on-farm solar photovoltaic array situated in a low-productivity corner of a center pivot field and instrumented with rain collection systems to enhance groundwater recharge while generating energy. While this solution is still in the early stages, preliminary results from the first year of installation indicate that these systems can reduce farm energy costs while enhancing infiltration of water past the root zone without displacing productive agricultural land. Ongoing work will include hydrological, energy, and economic monitoring and modeling to assess the scalability of this potential solution.

Combined, these two solutions illustrate both soft (governance) and hard (technological) solutions to the growing challenge of global groundwater depletion in agricultural landscapes, using the High Plains Aquifer as a data-rich case study.

LID 0327
Assessing the impact of adjustable weirs on groundwater availability and crop performance in Flanders, Belgium

Erika Rodríguez[1]*, Yves Sauter[1,3], Jan Diels[1], Sarah Garré[2], Marijke Huysmans[3,4]

[1] Division of Soil and Water, Department of Earth and Environmental Sciences, KU Leuven, Leuven, Belgium
[2] Flanders research institute for Agriculture, Fisheries and Food (ILVO), Plant Unit, Merelbeke-Melle, Belgium
[3] Department of Water and Climate, Vrije Universiteit Brussel, Brussels, Belgium
[4] Division of Geology, Department of Earth and Environmental Sciences, KU Leuven, Leuven, Belgium
* erika.lucia.rodriguez@kuleuven.be

Keywords: weir management, groundwater-crop interactions, MODFLOW 6, SWAP, lowland agriculture

In some agricultural areas in Flanders (Belgium), drainage ditches have been used to prevent waterlogging in the root zone and guarantee optimal crop growth in rainfall periods. However, in drought periods, this continuous drainage has resulted in lowered groundwater levels in the phreatic aquifer, reducing the crop water availably. To mitigate this, weirs can be installed in the ditches to retain water for a longer period. During the main growing season (mid spring to end October), farmers manage weir levels to prevent crop damage and allow field trafficability. They typically raise the weir level when no field operations are required, lower it before ploughing/planting, and then raise it again afterward. Despite their extensive implementation across Flanders, the impacts of weirs on groundwater and crop performance have not been quantified. In this study, a field area located in the village of Kasterlee was selected to quantify the impacts of weirs on groundwater and crops. The aquifer system consists of the Quaternary and Campine aquifers, which together serve as important shallow groundwater reservoir. First, the groundwater flow model MODFLOW6 (MF6) was used to quantify the effects of weirs on groundwater levels. Second, the 1D Soil-Water-Atmosphere-Plant (SWAP) model was applied to assess the impacts of weirs on crop performance. Both models were calibrated using observations from piezometers and soil moisture sensors. To assess the effects of weir management, groundwater levels simulated with MF6 are compared between scenarios with and without weirs to quantify the increase of groundwater level and its spatial extent. The resulting groundwater level time series are used as lower boundary conditions in the SWAP model to evaluate impacts on crop water use. This study gives new insights into the groundwater-crop responses to weir management in lowland agricultural landscapes.

LID 0328
Island aquifers challenges: Insights from Rapa Nui (Easter Island, Chile)

Linda Daniele[1]*, Matías Taucare[1], Angela Vallejos[2], Marcos Macchioli-Grande[1,3]

[1] Departamento de Geología-FCFM Universidad de Chile, Santiago, Chile
[2] Departamento de Biología y Geología, Universidad de Almería, Almeria, Spain
[3] Instituto de Ciencias Agroalimentarias, Animales y Ambientales, Universidad de O'Higgins, San Fernando, Chile
* ldaniele@uchile.cl

Keywords: groundwater management, isolated aquifers, groundwater quality

Water scarcity and climate change exert unprecedented pressure on global water resources. Environmental, economic, and socio-ecological impacts are particularly intense in vulnerable areas, such as islands and semiarid zones that depend on groundwater.

Islands are unique settings for analysing hydrogeological and water management issues, given their limited surface and water resources. They face similar hydrogeological challenges, including limited freshwater, seawater intrusion, and vulnerability to climate change. Thus, they are singular settings for assessing and promoting management practices able to deliver global learning on adaptation to scarce water scenarios.

The aim of this study is to evaluate the impact of temporal changes and assess the sustainability of Rapa Nui's groundwater system by updating hydrogeochemical and isotopic data. Its unique geological history, limited freshwater resources, and rich cultural heritage make it a fascinating case study for understanding groundwater dynamics, water management practices, and cultural resilience. The island's hydrological system has been well-understood and adapted by locals through historical practices, but today's challenges pose a threat to its sustainability.

Results show an increase in salinity (up to 8,170 µS/cm) in Hanga Roa coastal area, with a salinity factor of 10%. In contrast, Rano Kau and Vaitea wetlands show no salinisation (below 260 µS/cm). Combining yield data and ionic composition, seawater intrusion emerges as the main process degrading groundwater quality. Since 2003, EC has increased by over 3,000 µS/cm and the saline factor by 7%. Thus, growing water demand and tourism (~70.000 visitors/y) are compromising groundwater quality. The situation requires innovative, nature-based solutions that respect the island's cultural heritage.

Rapa Nui is an excellent example of addressing the challenges posed by limited freshwater resources in a way that can be applied to other similar isolated settings.

The project ANID-ATE220029 "Water-Energy-Food nexus for urban areas in Central Chile" funded this research.

LID 0329
Hydrogeological settings of the Yaque del Sur Basin – Knowledge update

Alexis Gutierrez[1*], Matthieu Delaunay[1], Alexandre Brugeron[1], Antonio Mendez[2], Bérénice Marte[3], Ricardo Gonzales[4], Australia Ramirez[5], Laurence Gourcy[1]

[1] BRGM, Orléans, France
[2] INDRHI, Santo Domingo, Dominican Republic
[3] MIMARENA, Santo Domingo, Dominican Republic
[4] INAPA, Santo Domingo, Dominican Republic
[5] SGN, Santo Domingo, Dominican Republic
* a.gutierrez@brgm.fr

Keywords: basin scale groundwater flow, groundwater-surface water interaction

The Yaque del Sur basin, is the third basin by size of Dominican Republic. The main stream (Yaque del Sur) is 500 km long and its mean discharge is 45 m^3/s. It appears at 3000 m of elevation and ends in the sea, close to Barahona airport. The Yaque del Sur and its tributaries are crossing mainly four hydrogeological units.

The Cordillera unit is a system with high precipitation but low permeability hard rocks, except in alluvial valleys and the Constanza graben.

The Vallee de San Juan unit and the Vallee de Neiba unit are graben systems filled by detrital and basaltic formations separated by the Sierra de Neiba horst.

Field campaigns show that the aquifer formations in the Constanza valley are highly vulnerable and contaminated with various chemical elements of anthropic origin including pesticides. The San Juan valley forms a large aquifer benefiting from run off coming from the cordillera (north) and the Sierra de Neiba (south). The flat bottom of the large valley and its sediments facilitate infiltration, which is enhanced by leakages from irrigation canals.

The monitoring of groundwater levels and the measurement of major dissolved elements revealed valuable insights into the aquifer dynamics and geochemical processes. Notably, the analysis of pesticide presence in the Constanza valley highlighted the need for sustainable management practices. The study's findings have important implications for groundwater availability and quality in the region, ultimately affecting the population's access to this vital resource. By advancing our understanding of the Yaque del Sur basin's groundwater systems and favoring collaboration between clustered institutions, this research contributes to the development of effective management strategies, ensuring the long-term sustainability of groundwater resources for the benefit of the local population.

LID 0330
Hydrogeology beyond the textbook - Verifying deep aquifer potential in Arid Somalia

Harmen Van Den Berg[1]*, Theo Kleinendorst[1], Daniela Benedicto Van Dalen[1]

[1] Acacia Water, Gouda, The Netherlands
* harmen.vandenberg@acaciawater.com

Keywords: deep groundwater exploration, conceptual hydrogeological modelling, groundwater development, water security

In 2024-2025, four deep exploration boreholes (ranging from 540 –750 m depth) were drilled in Somaliland and Puntland in northeastern Somalia, to assess groundwater potential and quality of deep sedimentary aquifers within the Auradu Limestone and Jessoma Sandstone formations.

An integrated approach combined conventional hydrogeological investigations with groundwater suitability mapping, conceptual hydrogeological modelling, and socio-economic assessments to identify target areas. Ground truthing, well inventories and surface geophysics (VES and AMT surveys) refined the conceptual models and guided site selection and target depths for exploration drilling.

Drilling results indicate encouraging deep groundwater potential in this arid, drought-prone region. Lithological descriptions and borehole geophysical logs largely confirmed the conceptual understanding of the deep aquifer system and demonstrated the value of deep-penetrating AMT in rarely explored settings.

Field implementation, however, revealed a pronounced “theory–practice gap.” Well success depended not only on hydrogeological targeting but also on remote logistics, contractor capacity and drilling performance; operational factors beyond hydrogeologists’ control. Water quality assessments also differed markedly between textbook standards and local perceptions of usability.

These findings show that deep groundwater exploration cannot be evaluated solely on hydrochemical thresholds or aquifer characteristics. Socio-economic context, operational constraints, contractor performance and stakeholder priorities fundamentally shape outcomes. In addition, the high costs of investigation and deep well construction must be weighed against expected yields and long-term sustainability. This contribution reflects on how textbook hydrogeology can be more effectively integrated with the realities of groundwater development in complex hydrogeological and operational environments.

LID 0332
Hydrogeochemical responses to urbanisation in an estuarine aquifer: Insights from Río Valdivia Estuary (Southern Chile)

Matías Taucare[1]*, Daniele Tardani[2], Linda Daniele[1], Fernanda Álvarez-Amado[3], Marcos Macchioli-Grande[2], Josefa Sánchez[3], Marco Taussi[4], Daniele Pinti[5], And Linda Godfrey[6]

[1] Departamento de Geología, Facultad de Ciencias Físicas y Matemáticas, Universidad de Chile, Santiago, Chile
[2] Instituto de Ciencias de la Ingeniería, Universidad de O'Higgins, Rancagua, Chile
[3] Departamento de Ciencias de la Tierra, Facultad de Ciencias Químicas, Universidad de Concepción, Concepción, Chile
[4] Dipartimento di Scienze Pure ed Applicate, Universitá degli Studi di Urbino Carlo Bo, Urbino, Italy
[5] GEOTOP and Département des Sciences de la Terre et de l'Atmosphère, Université du Québec à Montréal, Montréal, Canada
[5] Department of Earth and Planetary Sciences, Rutgers University, Piscataway, United States
* matias.taucare@gmail.com

Keywords: estuarine-related aquifers, urban impact, hydrogeochemistry, isotopy, compositional data analysis

Urbanisation of estuarine plains can destabilise aquifers through intensified pumping and land-use changes, but its impacts on groundwater quality remain poorly constrained. We combine piezometry, hydrogeochemistry and O-H-Li-B-Sr isotopes to address this issue in the Valdivia River estuary (Southern Chile). Currently, groundwater abstractions reach >6.8 hm^3, with major pumping located ~1 km inland. The piezometric map shows three cones of depression that distort natural NE-SW flow and promote losing conditions in inland rivers. $\delta^{18}O$-$\delta^{2}H$ suggests a common origin for these rivers and groundwater from local precipitation, even for samples collected at considerable depths. Electrical conductivity (EC) spans 99 to 7,166 $\mu S.cm^{-1}$ (median=234 $\mu S.cm^{-1}$), from fresh to brackish salinities. EC profiles detect downward inputs from surficial saline sources and constrain the freshwater-saltwater transition zone at -40 m a.s.l. Hydrochemistry is vertically structured. Above -20 m a.s.l., HCO_3^- facies dominate, with elevated NO_3^- (0.3-24.9 $mg.L^{-1}$) and potential toxic elements (PTEs; 19.8-944.9 $\mu g.L^{-1}$), associated with urban soil leaching. At depth, Cl^- facies prevail with higher contents of B (3.5-171.6 $\mu g.L^{-1}$) and Fe-Mn (49.6-1285.0 $\mu g.L^{-1}$). A chloride-based saline fraction and an isometric log-ratio balance (Cl^--SiO_2) separate two regimes at 0.35%, coincident with an order-of-magnitude increase in ionic strength (from $9.8x10^{-4}$ to $7.8x10^{-3}$). $^{87}Sr/^{86}Sr$ (0.70404-0.70975) follows a mixing line between estuarine- and continental-derived inputs. However, $\delta^{7}Li$ (5.00-29.69‰) and $\delta^{11}B$ (12.22-43.34‰) depart from simple mixing and typical Rayleigh behaviour, supporting a coupled mixing-reactions setting in which small estuarine inputs trigger non-linear geochemical responses. Our findings highlight that urban growth overlaps the natural boundary conditions and increases the aquifer's vulnerability, emphasising the requirement for sustainable urban planning to mitigate environmental impacts.

LID 0333
Enhancing water supply through MAR systems at Jijiga, Somali Region, Ethiopia

Alexis Gutierrez[1]*, Jérôme Perrin[1], Alexandre Brugeron[1], Thomas Klinka[1], Antoine Pecastaing[1], Nicolas Guillot[2], Nibret Adula[3]

[1] BRGM, Orléans, France
[2] ECORESIL, Montpellier, France
[3] MOWE (Ministry of Water and Energy), Addis Ababa, Ethiopia
* a.gutierrez@brgm.fr

Keywords: groundwater resource management, Managed Aquifer Recharge (MAR), pilot site, Ethiopia

Groundwater constitutes the main reliable water resource in eastern Ethiopia, where semi-arid climate, high evapotranspiration and strong interannual rainfall variability constrain surface water availability. Rapid population growth and expanding irrigation around Jijiga have increased abstraction from shallow alluvial and sedimentary aquifers, leading to declining water levels and risks of overexploitation. Managed Aquifer Recharge (MAR) was therefore investigated as a climate-adaptation measure to enhance storage, buffer seasonal variability and secure long-term supply.

A regional assessment first mapped MAR suitability using hydrogeological, geomorphological and climatic criteria. Spatial analysis integrated geology, aquifer type, depth to groundwater, permeability, slope, surface water occurrence, recharge potential and land use to identify favorable zones for infiltration or injection. Field verification refined these results and guided the selection of two representative pilot sites supplying Jijiga: the Fafen alluvial aquifer and the Jerer sedimentary aquifer.

Prefeasibility investigations combined hydrogeological surveys, borehole data review, groundwater-level monitoring, infiltration testing, water-quality analyses, and conceptual and numerical groundwater modeling. For the Fafen valley, the thick permeable alluvium and seasonal river flows support simple MAR options such as infiltration basins. Modeling indicates that distributed recharge can mitigate drawdown, stabilize heads and improve resilience under future demand and climate scenarios. In the Jerer valley, a deeper and heterogeneous fissured aquifer requires recharge wells and additional characterization; simulations show potential benefits but highlight higher uncertainty and the need for phased implementation.

Socio-economic appraisal compared projected water demand, abstraction reductions and MAR costs, confirming that recharge schemes could enhance supply security while remaining technically and economically viable.

The study demonstrates that Jijiga’s water resources may be sustained by targeted MAR.

LID 0334
Salinization, redox shifts, and metal release in coastal groundwater systems

Nicole Leroux[1]*, Clare Robinson[2], Barret Kurylyk[1]

[1] Department of Civil and Resource Engineering, Dalhousie University, Halifax, Canada
[2] Department of Civil and Environmental Engineering, Western University, London, Canada
* nicole.leroux@dal.ca

Keywords: saltwater intrusion, metal mobilization, coastal groundwater

Nearly 40% of the world's population resides within 100 km of the coastline, where freshwater aquifers provide a critical source of drinking water. These systems are increasingly stressed by climate-driven sea-level rise and intensifying coastal storm activity. Along Canada's Atlantic coast, projected relative sea-level rise is among the highest nationally, coinciding with widespread reliance of rural, coastal communities on groundwater resources. Landward encroachment of seawater, also know as saltwater intrusion (SWI), alters the physical and geochemical conditions of coastal aquifers. Changes in salinity and redox state can destabilize aquifer sediments and promote the release of naturally occurring metals into groundwater.

This research explores the connection between SWI and arsenic contamination at Rainbow Haven Beach, Nova Scotia, where metal concentrations in groundwater consistently exceed drinking water guidelines. A multidisciplinary field program includes continuous monitoring of groundwater levels, temperature, electrical conductivity, oxidation–reduction potential, and dissolved metals, combined with geophysical surveys spanning the beach to the inland dune system. Preliminary results indicate a seasonally dynamic freshwater lens approximately 3 m thick. Tidal propagation into monitoring wells and elevated heads following storm events confirm strong hydraulic connectivity between the ocean and aquifer. Pronounced vertical and lateral redox transitions occur across the freshwater–saltwater interface.

Ongoing work will link field and modeling approaches and contribute to a better understanding of how coastal hydrodynamics, aquifer legacy, and geochemical reactions interact to regulate the mobility of geogenic metals. Improved understanding of these coupled processes will support risk assessment and adaptive management of groundwater resources in climate-vulnerable coastal regions.

LID 0335
Natural asset management framework for aquifers in the regional municipality of Peel, Canada

Victor Marcucci[1]*, Luis Lasso[2]

[1] Watermark Environmental Ltd, Ontario, Canada
[2] Regional Municipality of Peel, Ontario, Canada
* vmarcucci@watermarkenv.ca

Keywords: conjunctive water management, sustainability, governance, asset management, groundwater resource management, anthropogenic effects, groundwater/ecosystem services

The Regional Municipality of Peel (Region of Peel) owns and operates drinking water systems that supply potable water to over 1.6 million customers across three lower-tier municipalities in Ontario, Canada. One of these municipalities is entirely groundwater-reliant and the Region of Peel has identified an opportunity to consider its' source water aquifers as natural assets within the context of infrastructure and asset management practices.

The Region of Peel, with Watermark Environmental Ltd. and Amethyst Infrastructure Management, are developing an asset management framework focused on aquifers, emphasizing the aquifers' service role and ability to deliver ecosystem services to dependent communities. The Region of Peel believes that treating aquifers as natural assets will ensure a more comprehensive and resilient approach to water resources management.

The objective of the project was to outline a natural asset management planning roadmap, enabling the Region of Peel to recognize, value, and manage aquifers as critical service-delivering assets in alignment with the asset management pillars of Risk, Cost, and Service. Key to this roadmap is the development of a condition assessment for aquifers, assessing them both by how the asset is influenced by land uses and by the physical attributes of the asset. This includes aquifer attributes such as transmissivity, historical water levels and water quality, as well as land use and soil permeability. The program also integrates aquifer assets within the Region of Peel's existing asset management systems, allowing the aquifers to be documented using the same structural logic as other infrastructure, to support data consistency, and system-wide reporting, analysis, and decision-making. Finally, applying the condition assessment within the scope of asset performance standards, the Region of Peel can better assess the asset within their strategic objectives, operational activities, and long-term financial planning.

LID 0336
Strengthening post-graduate groundwater education through a joint, applied, interdisciplinary and inclusive approach

Tibor Y. Stigter[1]*, M. Teresa Condesso De Melo[2], Rodrigo Oliveira[2], Christian Bernhofer[3], Peter Krebs[3], Judith Poeschmann[3], Karen Rojas[3], Andreas Hartmann[3], Brindha Karthikeyan[1]

[1] IHE Delft Institute for Water Education, Department of Water Resources and Ecosystems, Delft, The Netherlands
[2] Instituto Superior Técnico, Universidade de Lisboa, CERIS - Civil Engineering Research and Innovation for Sustainability, Lisboa, Portugal
[3] TU Dresden, Faculty of Environmental Science, Department of Hydro Sciences, Dresden, Germany
* t.stigter@un-ihe.org

Keywords: groundwater education, joint, applied, interdisciplinary, inclusive

Safeguarding groundwater, a vital resource in adaptation to global change, yet increasingly under pressure, requires robust knowledge and capacity. While strong foundations in hydrogeology remain indispensable, groundwater education at postgraduate level can benefit from a joint, applied, interdisciplinary and inclusive approach, to tackle the global interconnected challenges that define today's groundwater landscape. These vary from socioeconomic and climate-related pressures to political and transboundary complexities, the water-food-energy nexus and the delicate balance between groundwater's ecological and economic value. The Joint Master's Programme "Groundwater and Global Change – Impacts and Adaptation" was launched a decade ago and bridges theory and practice, integrates multiple perspectives across borders and disciplines, and is accessible to BSc graduates worldwide. Accredited as a joint degree at the European level, the programme brings together institutions in Portugal, the Netherlands and Germany, with a global network of associated partners. Close partnership and exchange are considered key, as joint programme delivery allows the partners to capitalise on their strengths, while learning from each other, broadening perspectives and fostering a sense of community among staff and students. Interdisciplinarity is achieved by linking education and research, anchored in fundamental groundwater science, to the thematic fields of climate, society and ecosystems. Academic learning is linked to professional experience and societal impact by integrating practical skills, internships and applied thesis research. Inclusiveness in the programme is reflected in the 50 nationalities represented among its students and alumni to date, 75% of whom from developing countries. By addressing financial and other barriers, the programme ensures equal opportunities and empowers intrinsically motivated individuals irrespective of their background.

We would like to acknowledge the EU Erasmus+ programme (https://erasmusplus.ec.europa.eu/) for co-funding GroundwatCh (https://www.groundwatermaster.eu/).

LID 0337
Fire-driven groundwater recharge vulnerability and recharge-zone protection: A pilot case in the municipality of San José de Chiquitos, Bolivia

Mónica Guzman-Rojo[1]*, Marijke Huysmans[2]

[1] Research Center for the Sustainable Development of Eastern Bolivia (CIDOR), Universidad Católica Boliviana "San Pablo" (UCB), Santa Cruz de la Sierra, Bolivia
[2] Department of Water and Climate, Vrije Universiteit Brussel (VUB), Brussels, Belgium
* mguzman@ucb.edu.bo

Keywords: wildfire, groundwater recharge, vulnerability mapping, governance, tropical dry forest, Bolivia

Wildfires are intensifying in Bolivia's Chiquitania lowlands, where dry-season water security relies strongly on springs and groundwater. However, post-fire impacts on recharge are rarely incorporated into local land-use planning and fire management, partly because subsurface change is difficult to observe and decisions are often made under uncertainty. This study uses the El Sutó spring catchment (San José de Chiquitos) as a model-to-policy pathway linking post-fire hydrological change with actionable recharge-zone protection.

We applied a process-based, daily soil-water balance model to estimate potential recharge under baseline conditions and under plausible post-fire scenarios. Fire effects were represented through scenario adjustments consistent with ash deposition and burn-related changes in infiltration capacity and near-surface water storage. Modelling was complemented by field monitoring and participatory fieldwork with local water users, farmers, and municipal staff to support interpretation of recharge timing, spring reliability, and feasible protection measures.

Scenario results indicate a pronounced short-term contraction of effective recharge, with first-year reductions of approximately 40%, followed by partial recovery that still suggests an average deficit of about 10% after two years. These findings show that vulnerability is shaped not only by burned area, but also by where recharge concentrates during short wet-season windows and where communities depend on specific springs and wells. In decentralised, participatory municipal governance settings, such evidence can be translated into locally feasible rules. In San José de Chiquitos, the results informed a municipal law to protect water sources and recharge areas, illustrating how forward-looking simulations combined with field-based monitoring can strengthen accountable groundwater governance after fire.

LID 0338
Design principles and early evaluation of science communication resources for post-wildfire groundwater resilience in Bolivia: A pilot case in the Chiquitania lowlands

Mónica Guzman-Rojo[1]*, Roberto Pizarro[2], Sixto Angulo[3], Huáscar Azurduy[3], Bruno Dominguez[4], Saraí Sirpa[5], Ana Carolina Roncal[5], Natalia Acebey[5], Miguel Mealla[5], Ana Luisa Unzueta[5], Paola Alvizuri[6], Miguel Moreno[7], Marijke Huysmans[7]

[1] Research Center for the Sustainable Development of Eastern Bolivia (CIDOR), Universidad Católica Boliviana “San Pablo” (UCB), Santa Cruz de la Sierra, Bolivia
[2] Environmental Hydrology Technology Center, Faculty of Forest Sciences, Universidad de Talca, Talca, Chile
[3] Foundation for the Conservation of the Chiquitano Forest (FCBC), Santa Cruz de la Sierra, Bolivia
[4] Department of Law, Universidad Católica Boliviana “San Pablo” (UCB), Santa Cruz de la Sierra, Bolivia
[5] Design Research Center, Universidad Católica Boliviana “San Pablo” (UCB), La Paz, Bolivia
[6] Research Center in Water, Energy and Sustainability (CINAES), Universidad Católica Boliviana “San Pablo” (UCB), La Paz, Bolivia
[7] Department of Hydrology and Hydraulic Engineering, Vrije Universiteit Brussel (VUB), Brussels, Belgium
* mguzman@ucb.edu.bo

Keywords: fire, groundwater, science communication, governance, water security, Bolivia

Groundwater underpins dry-season water security in fire-prone regions of Bolivia, yet it remains weakly represented in public debate—particularly among urban audiences that influence policy priorities, funding, and accountability. After wildfire, surface impacts are highly visible, whereas subsurface consequences evolve less observably and are therefore frequently misunderstood. A diagnostic-informed approach is presented to translate post-wildfire groundwater realities into integrated resources designed to improve societal understanding and support evidence-informed governance.

The methodological core is a structured territorial diagnostic capturing how wildfire–water interactions are experienced, narrated, and acted upon in the Bolivian lowlands. Semi-structured interviews, contextual documentation, and field-informed accounts were analysed using qualitative thematic coding to identify recurrent constraints, misconceptions, causal framings, and decision bottlenecks shaping post-wildfire water security. Results were synthesised into a concise message architecture that preserves scientific accuracy while reflecting local meanings and decision contexts.

Diagnostic outputs informed the design of integrated resources—including short-format audiovisual materials and an interactive learning tool—by guiding narrative structure, visual language, and explicit cause–effect chains. Early formative evaluation was conducted with local actors directly involved in post-wildfire water and land management to assess fidelity to the underlying science, clarity, and perceived actionability prior to broader testing with urban publics. Strengthening the public information environment is expected to support more accountable groundwater governance after wildfire by enabling citizens, media, and decision-makers to recognise groundwater risks and demand effective measures.

This work was developed in collaboration with the REMA Network (CYTED) — Red Iberoamericana para la Restauración y Fortalecimiento del Manejo de los Acuíferos en Paisajes Afectados por Incendios (Ibero-American Network for the Restoration and Strengthening of Aquifer Management in Fire-Affected Landscapes).

LID 0339
Numerical assessment of long-term contaminant migration risk and management strategies at a redeveloped heavy-metal smelting site

Litang Hu[1,2]*, Dingwei Qi[1,2]

[1] College of Water Sciences, Beijing Normal University, Beijing, China
[2] Engineering Research Center of Groundwater Pollution Control and Remediation of Ministry of Education, Beijing Normal University, Beijing, China
* litanghu@bnu.edu.cn

Keywords: contaminant transport, long-term migration risk, early warning, numerical modeling, monitoring network design

Groundwater contamination is costly to remediate, so early prevention is critical. Risk management for redevelopment projects is particularly challenging when engineering controls are not yet in place and field data remain limited. The study site covers ~0.5 km^2, but its groundwater system is hydraulically connected to regional flow from adjacent mountain catchments. To reduce boundary-condition artifacts, we apply an in-house three-dimensional groundwater flow and solute-transport code with nested grids and expand the model domain to ~14 km^2. The model is constrained using early-stage soil and groundwater investigations. We identify potential leakage pathways associated with the planned workshop expansion and simulate heavy-metal transport under representative hydrogeological conditions. Sensitivity analyses quantify the influence of key transport parameters on predicted concentration patterns, including hydraulic conductivity, dispersivity, sorption, and reaction kinetics. We then use an entropy-based criterion to select robust long-term monitoring locations under worst-case scenarios. The proposed framework links real-time monitoring with model-based forecasting to support early warning, guide mitigation, and reduce future remediation costs. Results delineate plausible worst-case migration pathways, inform targeted management actions, and underscore the need for sustained groundwater-quality monitoring and effective governance.

LID 0343
Non-rainfall water enhances the survival of *Artemisia ordosica* under drought stress

Zaiyong Zhang[1]*, Chengcheng Gong[2], Bin Ran[1], Wanyu Zhang[1]

[1] Chang'an University, Xi'an, China
[2] State Key Laboratory of Ecological Safety and Sustainable Development in Arid Lands, Northwest Institute of Eco-Environment and Resources, Chinese Academy of Sciences, Lanzhou, China
* zaiyongzhang@126.com

Keywords: non-rainfall water, *Artemisia ordosica*, Mu Us Sandy Land

Dryland ecosystems are increasingly threatened by water deficits under global climate change. However, field-based evidence for the role of non-rainfall water (NRW) in alleviating water stress for desert shrubs remains scarce, especially regarding whether foliar-absorbed NRW is transported to roots and contributes to soil water. We investigated if and how *Artemisia ordosica* (*A. ordosica*) utilizes NRW as a survival strategy during soil water stress in the Mu Us Sandy Land, China, using an integrated approach of weighing lysimeters, micro-lysimeters, isotopic labeling, and soil core sampling. We found that *A. ordosica* experienced prolonged soil water stress even in climatically wet years, indicating rainfall alone is insufficient to offset seasonal soil deficits. Crucially, our results reveal a multi-faceted survival strategy: *A. ordosica* absorbs nocturnal NRW via its foliage, with subsequent downward transport through the xylem to rehydrate shallow, dry soil layers. This process is facilitated by a well-developed shallow root system (>70% of root mass density in the upper 0-40 cm), which also intercepts upward soil vapor flux from deeper layers. Concurrently, daytime stomatal closure minimizes transpiration. These integrated strategies enable *A. ordosica* to survive under severe water limitation. This study provides direct evidence underscoring the ecological importance of NRW for desert shrub survival and offers novel insights for dryland restoration strategies.

LID 0344
Enhanced groundwater remediation using integrated groundwater circulation well and pump-and-treat methods in heterogeneous aquifer

Chengcheng Gong[1]*, Zaiyong Zhang[2], Yu-Li Wang[3], Bin Ran[2], Chuanqi Zhang[4]

[1] State Key Laboratory of Ecological Safety and Sustainable Development in Arid Lands, Northwest Institute of Eco-Environment and Resources, Chinese Academy of Sciences, Lanzhou, China
[2] Key Laboratory of Subsurface Hydrology and Ecological Effect in Arid Region of the Ministry of Education, Chang'an University, Xi'an, China
[3] Department of Bioenvironmental Systems Engineering, National Taiwan University, Taibei, China
[4] Liaoning LGJ Environmental Protection Technology Co., Ltd, Shenyang, China
* gcc895470127@163.com

Keywords: groundwater circulation well, pump-and-treat, groundwater remediation, heterogeneous aquifer

Remediating contaminated groundwater in heterogeneous aquifer remains a major challenge due to the spatial variabilities of subsurface hydraulic properties and contaminant distributions. Prior research suggests that integrating groundwater circulation wells (GCWs) with pump-and-treat (P&T) systems can create a more dynamic hydraulic regime, expand the radius of influence, and enhance remediation efficiency. However, the influence of several critical factors, including aquifer properties, well spacing, and operational strategies, on overall remediation performance remains inadequately characterized. This knowledge gap restricts the broader implementation of integrated P&T-GCW remediation strategies. Therefore, this study investigates and optimizes the performance of an integrated GCW-P&T system within complex, heterogeneous aquifer settings. We employed a comprehensive suite of numerical simulations to systematically evaluate the effects of hydraulic conductivity (K) and porosity variability, diverse well network configurations, and various operational strategies on contaminant removal. The results demonstrate that the variance in ln$K$ significantly impacts remediation performance. Specifically, strategically positioning GCWs near low K zones enables the integrated GCW-P&T system to surpass the performance of standalone P&T or GCW methods, leading to a substantial improvement in contaminant removal within these zones. Moreover, while well spacing and the GCW operational mode (continuous versus periodic) influence remediation efficiency in low K zones, they do not significantly alter the overall remediation performance across the entire aquifer. Our findings indicate that well spacings less than 1.5 times the GCW's radius of influence are most effective for remediation. Based on these findings, we propose a detailed guideline for designing effective integrated GCW-P&T systems to maximize remediation efficiency. These results underscore the critical importance of considering site-specific heterogeneity in the design of GCW-P&T systems and provide practical guidelines for well network design to improve the implementation of these systems at contaminated sites.

LID 0347
Seasonal variations in groundwater and surface water quality and implications for water resource management in an urban-rural mixed area

Yebin Lee[1,2]*, Hanna Choi[1,2]

[1] Geo-Environment Research Division, Korea Institute of Geoscience and Mineral Resources, Daejeon, South Korea
[2] University of Science and Technology, Geological Science, Daejeon, South Korea
* yebinwk@gmail.com

Keywords: urban–rural mixed area, groundwater–surface water interaction, dissolved organic matter (DOM), seasonal variation

Urban–rural mixed cities are influenced by urban–industrial activities and agricultural nonpoint source pollution, which makes water quality assessment more complex. A representative urban–rural mixed area in South Korea, Daejeon Metropolitan City, was selected for this study to evaluate the seasonal water quality characteristics of groundwater and surface water. Groundwater and surface water samples were collected during the wet (n = 32) and dry (n = 39) seasons and analyzed for field parameters, major ions, isotopes, and fluorescent dissolved organic matter (DOM). The hydrochemical facies were predominantly classified as the $CaHCO_3$ type, indicating that groundwater and surface water share a similar geochemical background. Groundwater exhibited relatively stable water quality with limited seasonal variation, whereas surface water showed pronounced seasonal changes influenced by rainfall dilution and external non-point source pollution. In particular, nitrate–nitrogen and chloride concentrations reflected contamination inputs associated with land-use types. DOM analysis revealed that surface water showed relatively minor seasonal variation in dissolved organic matter sources, whereas groundwater presented distinct seasonal differences. During the dry season, groundwater was increasingly influenced by recently produced, microbially derived organic matter, likely associated with enhanced microbial activity within the aquifer. These findings suggest that groundwater and surface water exhibit seasonal interactions. This study provides insight into seasonal water quality variability and supports integrated water resource management in urban–rural mixed cities under ongoing climate and land-use change.

This study was supported by the Basic Research Project (26-3411) of the Korea Institute of Geoscience and Mineral Resources (KIGAM), funded by the Ministry of Science and ICT (MSIT).

LID 0348
Long-term stabilization of chromite ore processing residue via elemental sulfur disproportionation for groundwater contamination mitigation

Yali He[1,2], **Yuanyuan Sun**[1], Mingxia Zheng[1]*, Jing Su[1]

[1] State Key Laboratory of Environmental Criteria and Risk Assessment, and State Environmental Protection Key Laboratory of Simulation and Control of Groundwater Pollution, Chinese Research Academy of Environmental Sciences, Beijing, China
[2] College of Resources and Environment, University of Chinese Academy of Sciences, Beijing, China
* zhengmx@craes.org.cn

Keywords: groundwater overexploited areas, industrial pollution, chromite ore processing residue, abiotic disproportionation of elemental sulfur, long-term stabilization

Groundwater recharge zones are characterized by complex hydrochemical conditions. Fluctuating hydraulic regimes and strong surface-groundwater interactions pose significant challenges to the stability of legacy industrial wastes. In industrialized regions within overexploited zones, historical stockpiles of chromite ore processing residue (COPR) remain potential sources of chromium release. In this study, a novel stabilization strategy driven by the abiotic disproportionation of elemental sulfur (S^0) was developed to achieve efficient and durable detoxification of COPR. The raw COPR, collected from an industrial waste site, exhibited strong alkalinity (pH 11.38) and a high Cr(VI) content (7.76 mg/g). Under hydrothermal conditions (80°C), S^0 disproportionated facilitated by the alkaline conditions provided by COPR. Reductive sulfur species generated in this process, promoting the reduction of Cr(VI) to Cr(III). At a molar ratio of S^0:Cr(VI) of 5:1, the residual Cr(VI) content decreased to 0.07 mg/g, meeting the treatment standards in China. To further enhance the stabilization performance of S^0 for COPR, a nucleophilic reagent S^{2-} was introduced into the reaction system. When the hydrothermal temperature was lowered to 25℃, even with the addition of a small amount of S^{2-}, the stabilization effect of elemental sulfur toward COPR was significantly enhanced. The content of Cr(Ⅵ) decreased by 27.2% compared with the system without S^{2-} addition. Column experiments further demonstrated this method provided a superior long-term stability compared with conventional ferrous sulfate treatment, without particle expansion or “re-yellow” phenomenon. It was attributable to the sustained release of reductive sulfur species, which enabled the continuous reduction of residual Cr(VI) within the internal lattice structure. The strategy in this study offers an effective approach for mitigating groundwater contamination risks posed by COPR in recharge zones of overexploited aquifers.

LID 0349

Using a novel chain of models to mimic potential source aquifer depressurisation impacts across the Doongmabulla Springs Complex, Queensland, Australia

Anne Gibson[1]*, Richard Cresswell[2], Jarrah Muller[3], Samantha Capon [4], Rebekah Grieger[4], Penn Lloyd[5], David Stanton[6], Miles Yeates[7], Sophie Pyrke[8]

[1] Eco Logical Australia, Canberra, Australia
[2] Eco Logical Australia, Sydney, Australia
[3] EMM Consulting, Adelaide, Australia
[4] Griffith University, Brisbane, Australia
[5] Biodiversity Assessment and Management Ecological Consultants, Australia
[6] Watermark Ecohydrology, Australia
[7] Essence Environmental, Australia
[8] Eco Logical Australia, Adelaide, Australia
* anne.gibson@ecoaus.com.au

Keywords: groundwater dependent ecosystems, modelling, wetlands

The Doongmabulla Springs Complex (DSC) is a cluster of groundwater-dependent wetlands located in central Queensland, Australia, with over 160 individual springs. The supported endemic flora species are adapted to the unique physico-chemical characteristics of groundwater discharge. The DSC is a listed Threatened Ecological Community and protected under Australia's State and Commonwealth Environmental legislation.

Mine dewatering to the east of the springs has potential to threaten spring biodiversity in the future should aquifer depressurisation reduce groundwater discharge. Assessing the likelihood and possible magnitude of these threats requires a multi-disciplinary modelling approach to address the complex groundwater–surface water–ecosystem interactions to 1) define groundwater pressure change probabilities; 2) simulate likely wetland response and 3) evaluate potential ecological impacts. Once this modelling chain is in place, impact mitigations may be assessed and evaluated at each stage of the chain.

Regional numerical groundwater modelling (MODFLOW) generates potential groundwater pressure change responses relevant to the DSC which can be fed into a wetland water balance model (GoldSim) to describe wetland persistence, size and seasonality. Water balance outputs were spatially translated to predict spring hydrology (TUFLOW) that is compared to historical wetland data and used to predict suitable habitats for key flora species using maximum entropy species distribution modelling (MaxEnt).

Outputs from a range of scenarios, including mining-related groundwater depressurisation and climate change are combined with a multiple-lines-of-evidence approach to spring conceptualisations (Cresswell, et al., these proceedings) to inform a revised impact assessment for the potential impacts of mine dewatering on the unique vegetation communities at the DSC and enables development of targeted mitigation approaches for individual wetlands and species.

LID 0350
Karst springs as cold refuges in a warming world

Jean-Christophe Marechal[1,2]*, Vincent Bailly-Comte[1,2], Enzo Bronnec-Castanet Desages[1,2], Yvan Caballero[1,2], Jean-Baptiste Charlier[1,2], Bernard Ladouche[1,2], Adrien Selles[1,2]

[1] BRGM, Univ Montpellier, Montpellier, France
[2] G-EAU, UMR 183, INRAE, CIRAD, IRD, AgroParisTech, Institut Agro, BRGM, Montpellier, France
* jc.marechal@brgm.fr

Keywords: groundwater, aquatic ecosystem, temperature

Karst aquifers are key regulators of groundwater-dependent ecosystems (GDEs) because their springs supply large, sustained discharges and thermally buffered waters that stabilize ecological conditions. In regions where hydrological variability and climate extremes are intensifying, these groundwater inputs act as ecological stabilizers that support biodiversity and enhance ecosystem resilience. This study investigates how karst groundwater controls thermal and ecological dynamics in surface ecosystems using two complementary case studies: (i) the Argens River in Provence region (France), monitored within the ESTHER project, where the Bouillidoux spring system generates persistent cold-water refuges during summer low flows; and (ii) the Lez karst spring system near Montpellier (France), investigated under the SentinelSprings initiative as a “sentinel” of long-term environmental trends, where drinking-water abstractions compete with the baseflow required to sustain aquatic habitats (iii) the Loue river in Jura mountains where karst springs sustain the river baseflow in which water quality is a key factor for fishes community and associated leisure activities.

At these sites, high-frequency monitoring networks (continuous temperature, electrical conductivity, and dissolved oxygen) were deployed in springs and river reaches, enabling the construction of detailed thermal budgets that elucidate how groundwater inflows create thermal refugia and regulate stream metabolic conditions. Joint analysis of hydrological and thermal signals supports refined conceptual models of groundwater–surface water interactions and allows the potential impacts of climate change on spring-fed thermal regimes and river corridor resilience to be quantified. The results demonstrate that karst groundwater inputs sustain critical habitats, reduce the sensitivity of river corridors to warming, and provide natural buffering capacities that function as nature-based solutions for climate-change adaptation, thereby informing the identification, assessment, and long-term management of GDEs.

The project SentinelSprings has received national funding from Fundação para a Ciência e a Tecnologia-I.P. (FCT-Portugal), Agence Nationale de la Recherche (ANR-France), Ministero dell’Università e della Ricerca (MUR-Italy), Narodowe Centrum Badań i Rozwoju (Poland), Innovation Fund Denmark (Denmark), Ministry for the Environment, Energy and Public Cleanliness (MEEC-Malta) and the European Union’s Horizon Europe Programme under the 2023 Joint Transnational Call of the European Partnership Water4All (Grant Agreement n°101060874).

LID 0351
Practical implications of urban modelling for open-loop geothermal systems: A MODFLOW 6-FEFLOW 10 comparison from an Italian case study

Alessandro Berta[1,2]*, Mara Meggiorin[2], Luca Ziliani[2], Daniele Susanni[2]

[1] Politecnico di Torino, Department of Energy, Turin, Italy
[2] Ramboll Italy, Site Solution Team, Milan, Italy
* alessandro.berta@polito.it

Keywords: urban open-loop geothermal systems, MODFLOW 6–FEFLOW 10 comparison, groundwater modelling

Open-loop groundwater heat pump (GWHP) systems constitute an increasingly relevant low-enthalpy geothermal resource for urban areas, where shallow aquifers offer stable temperatures suitable for high-efficiency heating and cooling. As their deployment grows, particularly in densely urban environments, the assessment of cumulative hydraulic and thermal interactions becomes essential to ensure sustainable long-term operation and to support informed urban geothermal planning. Numerical modelling plays a central role in this context, providing a quantitative basis for evaluating thermal plumes, system interference and suitable well configurations. A comparative benchmark is presented for the city-scale GWHP system of Turin (Italy), where a finite-difference model developed in MODFLOW 6 has been translated into an equivalent finite-element model in FEFLOW 10. Both models have been calibrated using PEST-based parameters and share identical conceptual hydrostratigraphy, boundary conditions, parameter fields and operational input data. The case study includes more than 150 geothermal wells within an 11×11 km urban domain and focuses on realistic operational scenario. Model outputs are then compared in terms of groundwater heads, thermally affected zone (TAZ) evolution, numerical stability and computational efficiency. A dedicated sensitivity analysis assesses the influence of key hydraulic and thermal parameters on model response, highlighting differences in how finite-difference and finite-element formulations capture thermal plume dynamics in densely exploited systems. Beyond the quantitative comparison, the study evaluates modelling workflows and graphical interfaces, outlining strengths and limitations. The analysis identifies the most suitable modelling solution depending on user needs and objectives, including researchers, consultants, regulators, planners and system designers involved in geothermal resource assessment and decision-making.

LID 0352
Pan-European groundwater assessment enabled by the European Groundwater Monitoring (EUGM) Database

Mariana Gomez[1], Héctor Aguilera[2], Julian Koch[3], Georgina Arno[4], Montse Colomer[4], Benjamin Marchant[5], Bentje Brauns[5], **Stefan Broda**[1*], Julie Lions[6], Birgitte Hansen[3], David Pulido-Velázquez[7], Peter van der Keur[3], Klaus Hinsby[3]

[1] Federal Institute for Geosciences and Natural Resources (BGR), Berlin, Germany
[2] Geological Survey of Spain (IGME-CSIC), Spain
[3] Geological Survey of Denmark and Greenland (GEUS), Copenhagen, Denmark
[4] Cartographic and Geological Institute of Catalonia (ICGC), Barcelona, Spain
[5] British Geological Survey (BGS), Keyworth, United Kingdom
[6] Bureau de recherches géologiques et minières (BRGM), Orléans, France
[7] Geological Survey of Spain (IGME-CSIC), Granada, Spain
* stefan.broda@bgr.de

Keywords: groundwater monitoring, data harmonization, pan-European database

We present the main features of the European Groundwater Monitoring (EUGM) database, developed within the Geological Service for Europe (GSEU) project, based on harmonized groundwater quantity and quality data provided by participating national and regional geological surveys.

For groundwater quantity, we compiled 18,850 groundwater level records spanning a wide range of sampling intervals, record lengths, continuity, and data quality, with uneven spatial coverage across Europe. To increase usability and comparability, the dataset is processed through a quality assurance workflow that includes the detection of stagnation periods, outlier screening, and the imputation of missing values. After this workflow, the current EUGM release contains 12,797 groundwater level time series, including 1,119 near real time (NRT) monitoring points with expected monthly updates.

For groundwater quality, we collected hydrochemical data from 120,484 monitoring points, covering 73 parameters from 1991 to 2024 and comprising more than 50 million chemical values. An integrated data management framework combining GIS-based, statistical, machine-learning, and geochemical methods enables mapping, temporal analysis, regulatory assessment, and groundwater protection. Building on this framework, a comprehensive EU-wide dataset encompassing natural and anthropogenic compounds is being developed through harmonized site selection, data integration protocols, and processing workflows to assess trends (e.g., nitrate) and to estimate the spatial distribution of natural trace elements such as arsenic and fluoride.

Overall, the EUGM database provides a consistent observational basis for cross-border assessment, modelling, drought monitoring, and forecasting of groundwater levels, and it establishes a foundation for ongoing efforts to expand and improve pan-European groundwater data products. The results are intended for integration into the European Geological Data Infrastructure (EGDI) platform to enable Europe-wide access, comparison, and operational use.

LID 0354
Deep learning-driven 3D hydrogeological modeling and transient groundwater flow modeling in complex, heterogeneous multi-aquifer systems

Abdelrahman Ahmed Ali Abdelrahman[1]*, Andrea Cominola[1,2], Alberto Guadagnini[3], Robert Bussert[1], Martin Sauter[4], Irina Engelhardt[1]

[1] Technische Universität Berlin, Berlin, Germany
[2] Einstein Center Digital Future, Berlin, Germany
[3] Politecnico di Milano, Milan, Italy
[4] University of Göttingen, Göttingen, Germany
* abdelrahman@tu-berlin.de

Keywords: 3D hydrogeological modeling, artificial neural networks, saltwater upconing, groundwater management, multi-aquifer systems

Groundwater management in large, structurally and stratigraphically complex, heterogeneous multi-aquifer systems requires hydrogeological models that preserve stratigraphic continuity and support predictive simulations. We develop and validate a generalizable workflow that builds high-resolution 3D hydrogeological models from boreholes and interpreted cross-sections, and identifies key features that control flow and storage, including aquifer thickness, unsaturated-zone thickness, depth to aquifer tops, lateral continuity, and the distribution of confined versus unconfined conditions. Lithostratigraphic information on sediment age and grain size is encoded as multiclass labels for hydrogeological units and mapped to unit-based hydraulic properties for forward groundwater simulation.

We benchmark traditional geostatistical methods (inverse distance weighting, nearest neighbor, kriging) against machine-learning algorithms (decision trees, random forest, AdaBoost, XGBoost, k-nearest neighbors, support vector machines) and deep learning-based artificial neural networks (ANNs). Most methods struggled with stratigraphic continuity and structural complexity (e.g., fractures, faults, overdeepened valleys, overturned layers), whereas ANNs replicated complex subsurface architecture more consistently, achieving a test accuracy of 0.97 and a weighted F1 score of 0.98 under an 85/15 split with cross-validation, and outperformed the other evaluated approaches.

We translate the hydrogeological model to a transient groundwater flow and transport model and assign unit-based hydraulic properties to preserve heterogeneity at modeling scales, enabling analysis of groundwater dynamics, Managed Aquifer Recharge, and salinity-risk assessments. Collectively, these results indicate that deep learning provides a robust pathway for hydrogeological modeling in complex heterogeneous multi-aquifer systems, with direct applicability to basin-scale groundwater modeling and management.

LID 0356

Reconstruction of the hydrogeological structure of the Po river basin (Northern Italy) for modeling purposes to support sustainable groundwater management

Simone Bruno[1*], Chiara Zanotti[1], Letizia Fumagalli[1], Simone Varisco[2], Marco Masetti[2], Domenico Antonio De Luca[3], Manuela Lasagna[3], Daniele Cocca[3], Giovanni Pigozzi[3], Alessandro Gargini[4], Maria Filippini[4], Laura Landi[4], Maria Elena Cavallini[6], Riccardo Pinardi[5], Andrea Chahoud[7], Marco Marcaccio[7], Addolorata Palumbo[8], Paolo Severi[8], Filippo Battaglini[9], Cesare Vasini[9], Tullia Bonomi[1]

[1] Department of Earth and Environmental Sciences, University of Milano-Bicocca, Milan, Italy
[2] Dipartimento di Scienze della Terra "Ardito Desio", Università degli Studi di Milano, Milan, Italy
[3] Department of Earth Sciences, University of Turin, Turin, Italy
[4] Department of Biological, Geological and Environmental Sciences, Alma Mater Studiorum University of Bologna, Bologna, Italy
[5] Department of Chemistry, Life Sciences and Environmental Sustainability, University of Parma, Parma, Italy
[6] Provincia di Ferrara, Servizio Pianificazione Territoriale e Urbanistica, Ferrara, Italy
[7] Regional Agency for Prevention, Environment and Energy of Emilia-Romagna, (Arpae), Technical Directorate, Bologna, Italy
[8] Environmental Protection and Circular Economy Sector, Water Protection and Management Area, Emilia-Romagna Region, Bologna, Italy
[9] Po River Basin District Authority (ADBPO), Parma, Italy
* simone.bruno@unimib.it

Keywords: hydrostratigraphy, aquifer characterization, GIS, groundwater management, Po Plain

Hydrogeological modeling at the basin scale is essential for the sustainable management of groundwater resource. This study presents a framework for reconstructing the subsurface geology by harmonizing fragmented datasets in the Po Plain (Northern Italy) from four administrative regions: Piedmont, Lombardy, Emilia-Romagna, and Veneto. The modeling workflow processed an extensive database including, stratigraphic logs, regional hydrogeological surfaces, maps and geological cross-sections, to build a unified basin-scale framework.

The resulting 12-layer model (depths up to 800 m b.s.l.) represents the main aquifer groups: A (Holocene), B and C (Pleistocene), and D (Pliocene). The architecture alternates aquifer units, with thicknesses averaging from 14 to 100 m, and aquitards, typically measuring between 7 and 12 m. In depocenters, Group B can reach up to 400 m, while Group C and D averages 100 m. Harmonization was achieved using GIS interpolation processes and "median surfaces" to resolve boundary conflicts between regions. An R-based automated scripting workflow was implemented to generate 3D visualizations, ensuring stratigraphic continuity across the entire basin.

Hydraulic characterization was based on lithological zonation, deriving parameters from textural analysis (gravel, sand and silt/clay). Horizontal conductivity (K_h) was calculated as an equivalent value based on textural proportions, ranging from 10^{-3} m/s (gravels) to 10^{-7} m/s (clays). Vertical conductivity (K_v) was derived using a reduction factor (F = 0.10–0.60) based on the permeable lithological fraction. Storage coefficients were based on literature values linked to hydraulic conductivity classes.

The results reveal significant spatial variability in aquifer properties, underscoring the necessity of a large-scale, integrated approach. This model provides a robust foundation for interregional groundwater management strategies and a more comprehensive understanding of complex aquifer systems.

Acknowledgements to Modello idrogeologico delle Acque Sotterranee del distretto idrografico del fiume Po-MidAS-Po (Fondo per lo Sviluppo e la Coesione 2014-2020).

LID 0357
Modelling of combined variably saturated and density-dependent flow and salinity dynamics in coastal agricultural systems under controlled drainage

Fatima-Ezzahra Riakhi[1]*, Mark Bakker[1], Edo Abraham[1], Boris M. van Breukelen[1]

[1] Delft University of Technology, Faculty of Civil Engineering and Geosciences, Department of Water Management, Delft, The Netherlands
* f.e.riakhi@tudelft.nl

Keywords: coastal agriculture, variably saturated and density-dependent flow, controlled drainage, root-zone salinity

Freshwater availability in low-lying coastal agricultural areas of the Netherlands is constrained by the presence of saline groundwater at shallow depth and by drainage systems that rapidly remove rainfall-derived freshwater. Crop growth in these systems relies primarily on rainfall, which forms shallow rainwater lenses that supply moisture to the root zone and control root-zone salinity. Increasing climatic variability, combined with freely discharging drainage, may intensify root-zone moisture stress and salinisation, particularly where surface water is too saline for irrigation during dry periods.

While previous modelling studies of fresh-salinity dynamics in Dutch coastal systems focused on fully saturated conditions, this study investigates how level-controlled drainage and subsurface irrigation modify groundwater and root-zone interactions using an integrated variably saturated and density-dependent modelling approach that explicitly accounts for root-zone processes and crop water demand. Level-controlled drainage is implemented by imposing dynamic groundwater-level thresholds that regulate drainage outflow, while subsurface irrigation is represented as controlled inflow using an external freshwater supply.

The modelling framework is applied to a representative coastal field setting based on previously collected data from a level-controlled and subsurface-irrigated field. The model is subsequently used to explore system behaviour under contrasting hydrogeological conditions, climatic variability, and crop characteristics. The analysis focuses on diagnosing (i) seasonal root-zone moisture availability, (ii) salinity evolution in the root zone and shallow groundwater, and (iii) sensitivity of rainwater-lens persistence to drainage control and subsurface inflow. The results advance understanding of freshwater retention and moisture-salinity dynamics in coastal agricultural systems.

LID 0359
Isotopic fingerprints of stibnite oxidation: unraveling water-rock interactions in mine groundwater systems

Xiaoqian Li[1], **Aiguo Zhou**[1]*, Shu Li[1], Chengjie Huang[1], Ningjie He[1]

[1] School of Environment Studies, China University of Geosciences, Wuhan, China
* lxq511030@163.com

Keywords: water-rock interaction, stable sulfur and oxygen isotopes, antimony mobilization, mine groundwater

The mobilization of antimony (Sb) from stibnite weathering poses a significant threat to groundwater quality in mining areas, yet the water-rock reaction mechanism governing Sb mobilization remain unclear. To elucidate the interaction between groundwater and sulfide minerals in mine groundwater system, aerobic abiotic batch experiments were conducted to simulate stibnite oxidation with varying $\delta^{18}O_{H2O}$ values over 15-300 days. The sulfur isotope fractionation factor ($\Delta^{34}S_{SO4\text{-}stibnite}$) values decreased from 0.8‰ to -2.1‰ during the first 90 days, and increased to 2.6‰ at the 180 days, indicating the dominated intermediate sulfur species such as $S_2O_3^{2-}$, S^0, and H_2S (g) involved in Sb_2S_3 oxidation processes. The incorporation of O into sulfate derived from O_2 (~100%) indicated that the dissociated O_2 was only directly adsorbed on the stibnite-S sites in the initial stage (0-90 days).The proportion of O incorporation into sulfate from water (27%-52%) increased in the late stage (90-300 days), which suggested the oxidation mechanism changed to hydroxyl attack on stibnite-S sites promoted by nearby adsorbed O_2 on stibnite-Sb sites. The new insight of stibnite oxidation pathway contributes to the understanding of sulfide oxidation mechanism and helps to interpret field data. These findings provide novel mechanistic basis for interpreting isotopic data in antimony-contaminated aquifers and refining our understanding of sulfur cycling in groundwater environments.

LID 0360
Quantifying pumping-induced vertical groundwater fluxes using transient temperature–depth profiles

Victor F. Bense[1]*, Jelte G.H. de Bruin[1]

[1] Hydrology and Environmental Hydraulics, Department of Environmental Sciences, Wageningen University, Wageningen, The Netherlands
* victor.bense@wur.nl

Groundwater temperatures in unconsolidated sedimentary aquifer systems are increasingly being altered by regional surface warming, yet the extent to which these thermal signals are modified by groundwater abstraction remains poorly constrained. In this study, repeated temperature–depth profiles collected between 2016 and 2026 near a long-operating groundwater abstraction station in the Netherlands are analyzed to quantify the combined effects of surface warming and pumping-induced groundwater flow. A characteristic downward propagating thermal signal associated with atmospheric warming is observed in the shallow subsurface, producing transient C-shaped temperature–depth profiles with progressively deepening thermal inflection points. It is shown that the depth of the thermal inflection point increases toward the pumping station, indicating enhanced downward advection of recently recharged groundwater into the pumped aquifer. Estimates derived from the position of the inflection point suggest that vertical downward groundwater fluxes near the abstraction wells are approximately three times greater than those observed several kilometers away.

At greater depths, curvature in temperature–depth profiles across the lower aquitard is interpreted using a thermal Peclet number framework. Upward groundwater fluxes from the deeper aquifer into the pumped interval are thereby inferred to exceed downward fluxes from the shallow aquifer by up to an order of magnitude. These results demonstrate that groundwater abstraction substantially modifies vertical exchange fluxes between shallow and deep aquifers and exerts a measurable control on subsurface thermal structure. It is further suggested that transient groundwater temperature data can provide a quantitative and practical alternative to groundwater age tracers for assessing the relative contributions of modern and old groundwater to abstraction wells. The findings highlight that continued surface warming will progressively overprint present-day cooling effects associated with enhanced downward flow, ultimately leading to rising temperatures of abstracted groundwater. Even modest temperature increases may have implications for groundwater quality and ecosystem functioning, underscoring the importance of integrating thermal monitoring into groundwater resource management.

LID 0361
Deep-seated gravitational slope deformations control on groundwater flow and spring dynamics in the Northern Apennines (Italy)

Erica Tamagnini[1*], Stefano Segadelli[2], Laura Landi[1], Kei Ogata[3], Luigi Guerriero[4], Maria Filippini[1]

1 Biological, Geological and Environmental Science Department - Alma Mater Studiorum University of Bologna, Italy
2 Geological, Seismic and Soil Survey, Emilia-Romagna region, Bologna, Italy
3 Department of Earth, Environmental and Life Sciences – DISTAV, Genova, Italy
4 Department of Earth, Environmental and Resource Sciences, Napoli, Italy
* erica.tamagnini@studio.unibo.it

Keywords: DSGSDs, Groundwater flow, Northern Apennines

Deep-Seated Gravitational Slope Deformations (DSGSDs) are widespread along the Northern Apennines in Italy, where the combination of lithological – particularly the rheological contrasts of the fractured lithoid rock mass above plastic substrates - structural and geomorphological settings promote large-scale slope deformation. While their geomorphological significance is well documented, their hydrogeological role remains poorly explored.

Building on previous investigations, this study presents an improved and spatially extended assessment of the relationship between DSGSDs and groundwater discharge across the entire Northern Apennine chain. A regional-scale analysis was performed by optimizing and comparing existing landslide and spring databases within a GIS-based framework. Enhanced spatial analysis was applied to evaluate the distribution, density, and magnitude of springs in relation to DSGSDs.

The results highlight a persistent spatial association between DSGSDs and springs. High-yield springs frequently occur within or in close proximity to DSGSD bodies, with variations depending on lithology, areal extent, and typology of the deformation. Results suggest that DSGSDs play a key role in groundwater storage and transmission by restructuring subsurface flow systems through deformation-induced fracturing and increased secondary permeability, ultimately controlling spring location, discharge magnitude, and hydrogeological characteristics.

These findings highlight the hydrogeological relevance of DSGSDs in the investigated setting, emphasizing their role as reliable mountain water reservoirs and strategic resources under increasing climatic and hydrological stress.

LID 0363
Assessment of groundwater potential and productivity variability through exploratory boreholes in Tseri, Cyprus

Gerasimos Yoxas[1,2]*, Triantafyllia Samara[1]

[1] AQUASCIENCE – Consulting Geologists, Pallini, Greece
[2] University of Western Macedonian, Department of Mineral Resources Engineering, Kozani, Greece
* yoxas@aquascience.gr

Keywords: groundwater resources, borehole productivity, hydrogeological investigation, spatial variability, Tseri, Cyprus

Groundwater resources in stressed environments are frequently characterized by pronounced hydraulic fluctuations controlled by complex geological and hydrogeological conditions.

This study presents the results of an exploratory drilling program conducted in the broader area of Tseri, Central Cyprus, comprising eleven boreholes of variable depth, aimed at assessing groundwater potential and spatial productivity variability.

The investigation included geophysical surveying, lithological logging, groundwater level monitoring and step-drawdown pumping tests. Borehole yields ranged between 1 and 7 m^3/h, revealing significant heterogeneity over short spatial scales. Additional infiltration measurements were performed during different hydrological periods using the variable-head (Maag) method.

The geological setting consists of a heterogeneous Quaternary–Neogene sedimentary succession with units of low to moderate hydraulic conductivity. Groundwater occurrence is mainly associated with discontinuous permeable horizons and locally developed secondary porosity, while stratigraphic complexity exerts primary control on hydraulic behavior.

Results demonstrate that hydraulic response is governed by the geometry and connectivity of discontinuities, lithological transitions and secondary flow pathways rather than by assumptions of an equivalent porous medium. Productivity variability reflects the behavior of a discontinuous system in which secondary porosity forms locally enhanced but spatially restricted hydraulic zones. Such an approach can significantly improve productivity forecasting and reduce uncertainty in groundwater development planning and sustainable resource management.

This study provides a practical framework for groundwater investigation in comparable sedimentary environments, emphasizing the critical role of hydrogeological testing for reliable aquifer characterization.

LID 0365
Emerging organic contaminants in the karst aquifer of Yucatán, Mexico: Assessing the urban impact of Mérida

Flor Árcega Cabrera[1], Marta Inés Llamas Dios[2]*, Ismael Oceguera Vargas[1], Elizabeth Lamas Cosío[1], Iñaki Vadillo Pérez[2]

[1] Unidad de Química-Sisal, Facultad de Química, Universidad Nacional Autónoma de México (UNAM), Mexico
[2] Department of Geology, Faculty of Science, University of Málaga, Spain
* mllamasd@protonmail.com

Keywords: water quality, emerging contaminants, Yucatán, karst

The Yucatan Peninsula (SE Mexico) is one of the largest coastal karst regions worldwide. Due to intense karstification and predominant flat topography, surface runoff is extremely limited, and the population relies almost entirely on groundwater. The city of Mérida, located 20 km inland in the northern part of the peninsula, is the largest urban center in the region, with 1.1 million inhabitants. Wastewater management in Mérida is primarily conducted via septic tanks. Given the high aquifer permeability and the thin to absent soil cover, vulnerability to contamination represents a major concern.

A groundwater monitoring campaign (28 samples) was conducted in July 2023 to evaluate water quality in Mérida and surrounding areas, including general hydrochemical analyses and the screening of 134 emerging organic contaminants (EOCs).

The hydrochemical composition is predominantly influenced by seawater intrusion, with salinity increasing toward the shoreline. The spatial distribution of nitrate concentrations clearly reflects urban influence on groundwater, reaching up to 76.4 mg/L.

Fifty-nine EOCs were detected at least once, including personal care products, artificial sweeteners, drugs of abuse, and pharmaceuticals. Twenty-two compounds were consistently detected in all samples. The spatial distribution of total EOC concentrations did not reveal a clear pattern. However, specific compounds (e.g., ibuprofen, carbamazepine) were primarily detected in samples with nitrate concentrations above 20 mg/L, i.e., within the city limits. The drugs of abuse, largely represented by a metabolite associated with alcohol consumption, showed increasing concentrations north of the city, downstream of urban influence.

The results obtained represent the first environmental baseline of EOCs in Yucatán, highlighting the urgent need for continuous monitoring and the modernization of sanitation infrastructure in the region to prevent adverse impacts on human health and ecosystem integrity.

LID 0366
Influence of hydraulic conductivity zone placement on preferential flow in a saturated heterogeneous gravel column

Margaret E. Stevenson[1]*, Alraune Zech[2], Alexander Eder[3], Peter Strauss[3]

[1] Institute of Hydraulic Engineering and Water Resources Management, TU Wien, Vienna, Austria
[2] Department of Earth Science, Utrecht University, Utrecht, The Netherlands
[3] Institute for Land and Water Management Research, Federal Agency of Water Management, Petzenkirchen, Austria
* stevenson@waterresources.at

Keywords: heterogeneity, preferential flow, modelling methods

Connectivity in heterogeneous porous media plays a critical role in determining flow and transport behaviour, yet the influence of hydrofacies placement at the metre scale is still poorly understood. This study examines how the spatial arrangement and connectivity of hydrofacies with contrasting hydraulic conductivity values govern preferential flow paths and solute transport in a 4 m high saturated gravel column using bromide as a conservative tracer. Experiments were run by pouring the bromide solution on the free surface at the top of the column and taking samples at 5 different depths, as well as at the outlet at the bottom. Modelling was done using Hydrus 1D and 2D, using various configurations of hydraulic conductivity, including stochastic distributions as well as the traditional zonation method. The placement and connectivity of high and low permeability zones were systematically varied to assess the relative importance of low versus high hydraulic conductivity zones. Our experiments show that, at the metre scale, relatively low permeability regions exert dominant control on flow, producing asymmetric breakthrough curves with pronounced tailing that reflect mass exchange and delayed release from less mobile zones. In contrast to regional-scale studies in the literature, where connectivity of high permeability bodies governs large-scale flow patterns, our results demonstrate that the geometry and spatial placement of low permeability blocks are the primary determinants of flow dynamics and transport at intermediate (metre) scales. Achieving satisfactory results required one to two orders of magnitude contrast between adjacent hydrofacies, which could not be reproduced using a purely stochastic distribution of hydraulic conductivity values or grain-size derived estimates. The work highlights that solute tailing and late-time breakthrough curve behaviour provide an indicator of low permeability zone placement.

LID 0367
Assessment of groundwater level trends and drought based on the European EUGM database

Willem J. Zaadnoordijk[1,2]*, Bentje Brauns[3], Mariana Gomez[4], Stefan Broda[4]

[1] TNO – Geological Survey of the Netherlands (GDN), Utrecht, The Netherlands
[2] TU Delft – Department of Water Management (CEG), Delft, The Netherlands
[3] British Geological Survey (BGS), Nottingham, United Kingdom
[4] Federal Institute for Geosciences and Natural Resources (BGR), Berlin, Germany
* willem_jan.zaadnoordijk@tno.nl

Keywords: groundwater, timeseries, GSEU-CSA

National and regional European geological surveys work together to develop pan-European harmonised data and information services for the subsurface. Groundwater dynamics is one of the focus topics. The basis for the assessment of the groundwater levels is the European groundwater monitoring database, EUGM.

Currently, 26 countries have delivered groundwater level data to the EUGM. The data have been checked and harmonized with respect to frequency, units and metadata. All series have been converted to a monthly frequency if necessary. Gaps have been filled by means of imputation using a linear mixed model. So far, this resulted in more than seven thousand timeseries in 18 countries that cover at least a common recent period of 25 years.

For each timeseries, the groundwater levels have been converted to values of the standardized groundwater index (SGI). Moreover, a trend analysis has been performed on the groundwater level series using the non-parametric Mann-Kendall test and Sen's slope for the common 25-year period and two 15-year periods, that cover the same 25 years with 5 years overlap. Also, various other signatures have been computed, like autocorrelation and seasonality.

These results are combined to detect spatial and temporal patterns. E.g. k-means clustering of the monitoring locations shows areas with similar behaviour of the groundwater levels. Heatmaps of the SGI-series per cluster provide the associated different temporal patterns.

These results and the continued collection and evaluation of data in the EUGM database will enable better management of the water resources in Europe, which are indispensable for many aspects of a healthy society.

LID 0368

A new multidisciplinary approach to assess well clogging issues in an open-loop groundwater heat pumps system integrated with metagenomic analysis

Casati Tommaso[1]*, Girolamini Luna[1], Greggio Nicolas[1], Caligaris Laura[1], Cristino Sandra[1], Dinelli Enrico[1], Gargini Alessandro[1]

[1] Department of Biological, Geological, and Environmental Sciences, Alma Mater Studiorum University of Bologna, Bologna, Italy

* tommaso.casati2@unibo.it

Open-loop groundwater heat-pump (GWHP) systems are increasingly adopted as low-carbon solutions, but their durability is often limited by progressive clogging of abstraction and reinjection wells. Clogging typically results from concurrent physical particulate retention, geochemical mineral scaling and biologically mediated biofouling. Conventional diagnostics and rehabilitation frequently restore specific capacity only temporarily. This study investigates the well clogging processes of an open-loop GWHP plant cooling a high-performance data centre in Italy. A multidisciplinary workflow was applied integrating (i) operational records and hydraulic testing to quantify performance decline and define critical and optimum discharge rates, (ii) detailed hydrochemical characterisation to assess scaling propensity and redox-driven precipitation potential, and (iii) metagenomic sequencing to profile microbial communities and functional potential. Samples and measurements were collected comparatively along the full abstraction–heat-exchange–reinjection chain. The results show that no single mechanism explains the impairment: hydrochemical signatures and hydraulic behaviour indicate coupled scaling / particulate processes, while metagenomic profiles reveal taxa and metabolic pathways consistent with biofilm development and iron cycling, which can promote ferric oxyhydroxide precipitation. By explicitly linking microbiological evidence with hydrogeological and geochemical indicators, the approach constrains the dominant drivers and their distribution across the system. The proposed framework supports targeted rehabilitation and preventative operational protocols (e.g., optimum discharge rates, well conditioning, injection strategy and treatment selection) and offers a transferable template to enhance the long-term efficiency of open-loop GWHP systems.

LID 0369
Utilizing ensemble-based uncertainty analysis for potential observation well locations in the Pwales Aquifer, Malta

Mert Çetin Ekiz[1], Maria Clementina Caputo[1]*, Lorenzo De Carlo[1], Antonietta Celeste Turturro[1], Manuel Sapiano[2], Luke Galea[2], Michael Schembri[2]

[1] CNR-Water Research Institute, Bari, Italy
[2] The Energy and Water Agency, Qormi, Malta
* mariaclementina.caputo@cnr.it

Keywords: uncertainty, pyEMU, groundwater

In coastal aquifers, a main objective of groundwater management is often to determine sustainable pumping rates that avoid seawater intrusion and well salinization. Numerical models can be used to model the aquifers and forecast the highest pumping rate without salinization. A necessary step for modeling is calibration, and such a process contains uncertainty. Uncertainty in the model can be reduced by new observation types and locations. One of the most common observation types is groundwater head observation in an observation well. However, the number of observation wells is limited by constraints, such as budget and zoning. For highly parametrized and non-linear models, Linear Uncertainty Analysis can be time-consuming. Therefore, the EVA (Ensemble Variance Analysis) and DSI (Data Space Inversion) approach was chosen for data worth analysis considering parameter and observation uncertainty. It was implemented in a real-world island aquifer in the Pwales CA (Malta). The flow model was developed using MODFLOW6, and Uncertainty analysis was done via PEST. EVA and DSI were conducted, aiming to find optimum groundwater head observation locations to reduce forecast uncertainty. The workflow used scripts for reproductibility and it adapted to a high-dimensional model.

LID 0370
Optimizing monitoring effort for numerical modelling of fractured sedimentary aquifers

Elettra Cavana[1]*, Marco Bianchi[2], Maria Filippini[1], Alessandro Gargini[1]

[1] Alma Mater Studiorum – University of Bologna, Bologna, Italy
[2] British Geological Survey (BGS), Keyworth, United Kingdom
* elettra.cavana2@unibo.it

Keywords: fractured aquifers, data reduction, groundwater modelling

In the context of climate change and increasing drought frequency across the Mediterranean region, sedimentary, non-karst aquifers are being increasingly evaluated for water supply. In the region of the Northern Apennines (Italy), fractured arenitic and turbiditic aquifers, although traditionally considered of minor hydrogeological relevance due to their relatively low accessible yields, are now recognized as a strategic climate-resilient resource for local water supply, especially for integrating supply during dry periods.

Because these sedimentary aquifers are generally poorly investigated, the application of modelling tools to support water resource assessment and management is challenging given the scarcity of characterization data and monitoring observations. To understand the minimum amount of field data required to implement sufficiently robust groundwater flow models in these settings, a numerical experiment was performed starting from relatively well characterized case studies. In particular, the temporal resolution of spring discharge observations used for model calibration was reduced: instead of continuous monthly time series, only selected representative spring discharge values were retained for calibration. This approach allowed an evaluation of how monitoring frequency affects model performance and optimized parameterization.

By applying automatic calibration using PEST, the parameters obtained were compared with those derived from complete monitoring records to assess the impact on model reliability. The results provide insight about monitoring strategies that minimize effort while maintaining acceptable accuracy in parameter estimation and groundwater resource assessment.

The proposed methodology provides a practical framework to extend quantitative hydrogeological analysis to multiple small fractured sedimentary aquifers under limited monitoring conditions, supporting groundwater management strategies in climate-sensitive regions.

LID 0371
Evaluation of the temporal evolution of groundwater levels from repeated spatial interpolation for prediction of land subsidence

Willem J. Zaadnoordijk[1,2]*, Aris Lourens[1], Martijn D. Van Leer[1], Thibault G.G. Candela[1]

[1] TNO – Geological Survey of the Netherlands (GDN), Utrecht, The Netherlands
[2] TU Delft – Department of Water Management (CEG), Delft, The Netherlands
* willem_jan.zaadnoordijk@tno.nl

Keywords: spatio-temporal, timeseries, data-driven

Land subsidence connected to deformation of the upper meters of the subsurface is strongly related to evolution of phreatic groundwater levels. In the TNO Climate Adaptation Programme, a data-driven approach has been adopted for groundwater levels because of the lack of a reliable physics-based groundwater model with enough resolution and accuracy (and the effort, time and information needed to establish one). The groundwater levels are input of a physically based subsidence workflow. The workflow uses an ensemble approach and assimilation with land surface movement from InSAR data.

A pilot area has been selected in the Dutch Province of Friesland. Here, land subsidence is occurring due to peat oxidation, soil compaction and gas extraction. The peat oxidation and soil compaction are linked to groundwater levels in combination with the lithology. The voxel model GeoTOP is used for the lithology. Measurements of the groundwater levels in the area are available from 1524 monitoring wells of which 567 are good enough to create a time series model that can be used for predictions using precipitation and evaporation from climate change scenarios from the Royal Dutch Meteorological Institute KNMI.

The groundwater levels on the 28th of each month are interpolated by kriging with a trend. The trend surfaces for the kriging are determined using the average high and average low groundwater levels from the Groundwater table depth map of the Dutch Key Registry of the Subsurface (BRO). The average high and low levels are linearly interpolated in time assuming a seasonal variation determine a trend surface for each month.

The interpolations per month are carried out independently. This raised the question how realistic the temporal changes are. This has been evaluated.

The improvement of the temporal consistency of groundwater levels will foster better prediction of the subsidence both for hindcasting and forecasting under climate change.

LID 0373
Long-term environmental impacts of historical gold mining on soil and water: A comparison between Italian and Portuguese case studies

Linda Zaniboni[1]*, Manuela Lasagna[1], Giovanna Antonella Dino[1], Isabel Margarida Horta Ribeiro Antunes[2], Domenico Antonio De Luca[1]

[1] University of Turin, Department of Earth Sciences, Turin, Italy
[2] ICT, University of Minho, Braga, Portugal
* linda.zaniboni@unito.it

Keywords: gold mining, environmental impacts, potentially toxic elements

Historical gold mining sites represent a long-term source of environmental contamination. This study compares the impacts on soil, surface water (SW) and groundwater (GW) in two post-mining contexts: the gold mines of Crocette and Pestarena (NW Italy), and the Jales gold mine (NE Portugal), based on soil and water sampling conducted in 2024.

At the Italian sites, mining activities ceased in 1961, leaving substantial volumes of extractive waste (EW) deposited near adits and treatment plants, partly confined and partly dispersed across mining areas. Soils show high As and other Potentially Toxic Elements (PTEs: Co, Cr, Cu, Pb, Zn, Hg and CN) concentrations, exceeding the Italian contamination threshold (D.Lgs. 152/2006). Water samples are classified as Ca–HCO_3 and Ca–SO_4 facies, with the latter reflecting both sulfide-bearing mineralized rocks and oxidized sulfides in EW. Arsenic contamination occurs in 75% of SW and GW (up to 70 µg/L). While other PTEs are low in SW, threshold values are exceeded in GW at Pestarena, downstream of EW and contaminated soils, for Al, Fe, Mn, Ni, and Pb.

At the Portuguese site, mining activities ceased in 1992. In the early 2000s, remediation actions were implemented, including the capping of EW deposits and the treatment of drainage waters through constructed wetlands. Soils display elevated As concentrations and other PTEs (Cr, Cu, Pb and Zn) exceeding the natural background values of the local lithologies. Waters are mainly Ca–SO_4 facies; while Na–Cl facies occur in SW upstream of the mining complex and GW from horticultural areas. The highest As concentrations (up to 57 µg/L), associated with high Fe and Mn, are detected in underground drainage water and persist in SW downstream of the wetlands.

The results show that contamination may persist long after mine closure. This highlights the need for effective remediation, and long-term management and monitoring of historical mining activities to mitigate their environmental impact.

LID 0374
Comparative analysis of the impacts of gold mining on surface and groundwater at a global scale

Linda Zaniboni[1]*, Domenico Antonio De Luca[1], Elena Egidio[1], Giovanna Antonella Dino[1], Manuela Lasagna[1], Isabel Margarida Horta Ribeiro Antunes[2] , Abhishek Pandey Bharat[3], Maria Perraki[4], Ashwani Tiwari[5], Eleni Vasileiou[4], Zhikai Wang[6]

[1] University of Turin, Department of Earth Sciences, Turin, Italy
[2] ICT - Institute of Earth Sciences, University of Minho, Braga, Portugal
[3] Gautam Buddha University, Department of Environmental Sciences, School of Vocational Studies & Applied Sciences, Greater Noida, India
[4] National Technical University of Athens, School of Mining and Metallurgical Engineering, Athens, Greece
[5] Jawaharlal Nehru University, School of Environmental Sciences, New Delhi, India
[6] University of Science and Technology Beijing, School of Civil and Resources Engineering, Beijing, China
* linda.zaniboni@unito.it

Keywords: gold mining, water pollution, mine water management

Gold mining has played a fundamental socioeconomic role, with underground, open-pit and alluvial mining operations contributing to regional development across various historical periods and geographical contexts. However, despite its importance, substantial environmental degradation has been linked with gold mining operations, both during active mining and after mine closure.

A systematic literature review is being conducted using the Web of Science and Scopus databases, from which 281 articles have been collected and evaluated from Africa, America, Asia, Europe and Oceania. The aim is to synthesise current knowledge on the impacts of gold mining on water resources, identify and compare the applied methodologies in human health risk assessment.

This research records the status of surface and groundwater, affected by gold mining activities, focusing the hydrogeochemical characteristics and physicochemical parameters that primarily control the water quality (e.g., pH, Electrical Conductivity, Total Dissolved Solids and Potentially Toxic Elements, PTEs). It identifies the main sources of contaminants as well as their spatial and temporal distribution. Additionally, this work addresses the effects of mine waters on aquatic ecosystems and human health, also considering the changes to natural hydrogeological systems and water consumption.

This review provides a comparative analysis of the impacts of mining activities on water resources worldwide, considering active, inactive, abandoned, and remediated sites. It aims to highlight research gaps and underrepresented regions, compare the extent of studies on surface versus groundwater, and identify the challenges of such comparisons due to non-standardised parameters and different regulatory frameworks. Finally, the review identifies key shortcomings in mine water management strategies and the lack of an effective and uniform legislation for mine waters.

LID 0375
A novel groundwater sampling framework incorporating hydrogeological characterization and dynamic purging

Francesco Maria De Filippi[1]*, Yu He[2], Giuseppe Sappa[3]

[1] Department of Wellbeing, Health and Environmental Sustainability (BeSSA), Sapienza University of Rome, Italy
[2] State Key Laboratory of Hydraulics and Mountain River Engineering, Sichuan University, Chengdu, China
[3] Department of Civil, Environmental and Construction Engineering (DICEA), Sapienza University of Rome, Italy
* francescomaria.defilippi@uniroma1.it

Keywords: low-flow sampling, groundwater monitoring, aquifer characterization

The initial stagnant water in a monitoring well may have undergone geochemical changes and is therefore non-representative of the surrounding groundwater quality. Consequently, a sufficient well purge is required before collecting a sample that accurately reflects local hydrogeochemical conditions. Recent studies indicate that sufficient well purge is governed by the coupled effects of well storage depletion and wellbore mixing, characterized by the dimensionless variables η_q [-] and η_c [-]. These processes are influenced by well geometry and hydrogeological settings, resulting in different purge times and volumes across wells and regions. Current sampling strategies often apply a relatively fixed purge duration (5-30 minutes) or volume (3-5 well volumes) in case of low-flow or volumetric method, respectively. Indiscriminate application of standard procedures without taking into account local hydrogeological and construction conditions may lead to unreliable data and high uncertainties in groundwater contamination analyses.

To address this issue, the present study proposes a novel groundwater sampling framework that integrates hydrogeological characterization with dynamic purge. Low-flow conditions during purging and sampling have already proven to be effective for determining key hydraulic parameters, such as conductivity and storativity. Using the obtained hydrogeological information, the storage–mixing model can applied to calculate well-specific purge times and volumes. Dynamic purge criteria prevent over-purge (unnecessary costs) and under-purge (non-representative samples). In high-yield aquifers or large, deep wells, wellbore mixing controls the required purge time, whereas in low-yield or shallow, small wells, storage depletion is the limiting factor. This framework provides a systematic procedure for obtaining accurate hydrogeological parameters and representative groundwater samples across wells with varying geometries and aquifer conditions.

LID 0376
Linking analytical solutions and geospatial modeling to map patterns of aquifer vulnerability to saltwater intrusion and coastal groundwater flooding

Barret Kurylyk[1]*, Nicole Leroux[1], Ryan Malley[1], Bay Berry[1], Rob Jamieson[1]

[1] Department of Civil and Resource Engineering, Dalhousie University, Halifax, Nova Scotia, Canada
* barret.kurylyk@dal.ca

Keywords: seawater intrusion, water table rise, vulnerability mapping

Domestic water systems in rural areas rely on private wells and onsite wastewater treatment (septic) systems. In coastal communities, sea-level rise threatens wells and septic systems through saltwater intrusion (SWI) and groundwater flooding, respectively. These processes and their impacts can be assessed using physics-based analytical or numerical models, or empirical, parametric methods implemented within geospatial frameworks (e.g., GALDIT). While numerical models provide detailed simulations, their regional application is often constrained by data availability and computational capacity. Analytical solutions are simple and scalable but rarely incorporated into geospatial decision-making tools, whereas empirical approaches integrate easily but rely on subjective weighting and lack predictive capability.

Here, we propose a hybrid framework to combine the strengths of analytical models (transparency, efficiency) and geospatial approaches (compatibility with existing risk assessments and spatial datasets). We demonstrate the approach for Nova Scotia, Canada, where nearly half of residents depend on private wells and septic systems. We adapt the Strack solution and later applications to estimate SWI vulnerability in confined aquifers and groundwater flooding in unconfined aquifers under sea-level rise. Unlike previous analytical studies focused on localized areas, we apply the method along the entire 13,300 km coastline. ArcGIS toolboxes are used to derive hydrogeological inputs from public data and compute vulnerability indices along the gridded coastline. Results show strong spatial variability controlled by coastal forcing and subsurface parameters. The southern coast exhibits the highest SWI vulnerability, while Annapolis County shows the greatest potential impacts on septic systems and road infrastructure. These results provide a first-order assessment of relative risk and support the identification of priority areas for detailed investigation and adaptation.

LID 0377
Subsurface heat-island anomalies beneath a small city as tracers of heterogeneous lateral groundwater flow toward a near-urban groundwater abstraction

Victor F. Bense[1]*, Jelte G.H. de Bruin[1]

[1] Hydrology and Environmental Hydraulics, Department of Environmental Sciences, Wageningen University, Wageningen, The Netherlands

* victor.bense@wur.nl

Subsurface urban heat islands (SUHIs) are well documented beneath large cities, where the strongest thermal signals occur beneath city centers and lateral heat flow toward fringes smooths the near-surface imprint. SUHIs beneath small cities are rarely described because their signals are weaker and receive less attention for urban heat-storage applications. Here we demonstrate that thermal anomalies associated with a small city can nonetheless be sufficiently distinct to act as passive tracers of preferential lateral groundwater flow toward a nearby phreatic abstraction. The study site is a few kilometres north of Ede (the Netherlands), where a phreatic groundwater abstraction for domestic supply is located in a forested area underlain by a glacial moraine of strongly heterogeneous unconsolidated sediments. Between 2016 and 2026 we collected annual temperature–depth profiles at 1 m intervals using an RBRsoloT logger in ~10 piezometers positioned along a transect from the city limits toward the abstraction site. Profiles extend to up to ~80 m depth and reveal a decadal warming trend in groundwater temperature; superimposed on this trend are distinct, persistent positive thermal anomalies of order ~0.1°C at depths that coincide with coarse sand and gravel units in borehole logs. The spatial coherence of these subtle anomalies along the transect and their depth correspondence with permeable lithologies are consistent with focused lateral groundwater pathways conveying urban-derived heat toward the abstraction area. This thermal evidence complements routine chemical monitoring: screened piezometers provide discrete samples only at screen depths and may miss preferential flow intervals where no screens are present, whereas continuous temperature–depth profiles resolve vertical intervals of enhanced connectivity. We discuss alternative explanations (local geothermal variability, shallow anthropogenic heat sources, logging artefacts) and argue that the combined spatial, lithologic and temporal patterns support a lateral groundwater-flow interpretation. Our results indicate that even modest SUHIs beneath small cities can be exploited as continuous, depth-resolved tracers to identify preferential flow and potential contaminant pathways, informing targeted monitoring and protection strategies for near-urban water supplies.

LID 0380
Integrating monitoring network data and machine learning for groundwater level prediction: A case study in the Euganean Geothermal Field, Veneto Region, NE Italy

Pietro Maniero[1]*, Diego Di Curzio[1], Paolo Fabbri[1]

[1] Department of Geosciences, Università degli Studi di Padova, Italy
* pietro.maniero@studenti.unipd.it

Keywords: Euganean Geothermal Field, monitoring network, machine learning

The Euganean Geothermal Field (EGF), located in the Veneto Region (NE Italy), represents one of the most significant low-enthalpy geothermal systems in Europe. Geological evidence indicates that thermal water circulation has been active for at least several thousands of years and its exploitation for therapeutic purposes dates back to Roman times, reaching maximum anthropogenic pressure during the 20th century. Thermal waters, with temperatures between 63°C and 87°C, are intensively exploited for balneotherapy, supporting one of the largest spa districts in Europe. Due to this intensive exploitation, a monitoring network was established in the 1970s to ensure sustainable resource management and prevent further depletion. In 2024, the TREASURE project restored and upgraded the monitoring network for potentiometric levels and temperature, which currently includes 14 automatic monitoring stations, representing a fundamental tool for balanced resource management and the evaluation of its potential for future energy use.

Long time series from monitoring networks are often affected by missing data due to interruptions and instrumental issues, limiting their reliability for analysis and forecasting. The main objective of this study is to develop a machine learning approach to reconstruct missing data and, above all predict potentiometric level variations as a function of thermal water withdrawals.

The machine learning approach integrated historical data and new measurements from the TREASURE monitoring network. Iterative imputation techniques were applied for gapfilling, and predictive models were developed to simulate the relationship between withdrawals and groundwater levels.

This methodology provided a valuable tool to support sustainable geothermal resource management and improve decision-making for future exploitation scenarios.

LID 0382
Subsurface thermal patterns

Verena Dohmwirth[1]*, Susanne A. Benz[1]

[1] Karlsruhe Institute of Technology, Institute for Photogrammetry and Remote Sensing, Germany
* verena.dohmwirth@kit.edu

Groundwater temperatures (GWT) are shaped by a complex interplay of atmospheric conditions, hydrogeological settings, and human activities. Especially in urban areas, subsurface thermal regimes are altered by built infrastructure and anthropogenic heat inputs, with potential implications for groundwater quality, ecosystem functioning, and geothermal use. However, thermal anomalies are also found under isolated structures of human activities. While a growing body of work describes the general warming of groundwaters due to urbanization and climate change, disturbances in their seasonal patterns due to anthropogenic activities are so far understudied.

Accordingly, this study analyses more than 1,000 observed GWT time series collected across Austria between 2018 and 2022 by the *Federal Ministry of Agriculture and Forestry, Climate and Environmental Protection (BMLUK)* to investigate patterns, and deviations thereof, in seasonal subsurface thermal dynamics. I.e. we assess the depth dependent correlation and phase shifts between air temperature and GWT. Air temperature time series are provided by *GeoSphere Austria* for the same period. By linking these data with information on the lithological setting, we are able to identify groundwater wells in which seasonal temperature dynamics deviate from direct atmospheric forcing. These sites are analysed to determine whether they exhibit attenuated seasonal amplitudes, delayed phase responses, or fundamentally altered thermal regimes.

Finally, we explore potential drivers of such deviations, including urban land use, proximity to surface water bodies, and the presence of subsurface infrastructure. By linking seasonal phase shifts to hydrogeological and environmental characteristics, this study improves the understanding of how GWTs are controlled and the conditions under which atmospheric control weakens or is overridden by local influences.

Overall, the results highlight that groundwater thermal regimes are frequently modified beyond what can be explained by climate alone, both in urban centres and surrounding areas. By integrating seasonal dynamics, this study contributes to a more comprehensive understanding of the drivers and patterns of groundwater temperature variability.

LID 0383
Integrating field, numerical and analytical methods to characterize the unsaturated zone in Milan, Italy

Claudia Medina Montecinos[1]*, Charles J. Paradis[2], Daniel Feinstein[2], Luca Alberti[1]

[1] Department of Civil and Environmental Engineering, Politecnico di Milano, Milan, Italy
[2] Department of Geosciences, University of Wisconsin-Milwaukee, Milwaukee, United States
* claudia.medina@polimi.it

Keywords: unsaturated zone, time series modeling, numerical modeling

Piezometric data from the metropolitan area of Milan reveal complex spatiotemporal patterns in groundwater dynamics, indicating that local factors such as variations in unsaturated zone thickness strongly influence groundwater behaviour. Characterizing the unsaturated zone remains challenging due to heterogeneous soils and diverse land uses. Yet this zone plays a crucial role in delaying aquifer response to recharge, especially where the water table lies tens of meters deep. These delays could introduce uncertainty into ongoing basin-scale groundwater modeling efforts.

To better understand the influence of the unsaturated zone, we investigated an agricultural field where the shallow water table makes the aquifer relatively responsive to precipitation. Infiltration tests were conducted to characterize the topsoil, while a granulometric analysis of sediments collected from a piezometer described soil composition down to the water table. A 1-D numerical model was developed using the VSF package of MODFLOW-2000 to simulate vertical infiltration through the soil column with Richards' equation. Hydraulic conductivity was calibrated by matching infiltration test data and the aquifer response time estimated through time-series modeling with PASTAS.

Results show that in this area the unsaturated zone leads to an aquifer response time of approximately one day. This is unlikely to be representative of other parts of Milan with different soil properties and unsaturated thickness. Extending these combined methods to additional sites could allow the identification of areas where delayed responses occur, improving the reliability of future basin-scale groundwater models. This study provides a simple and transferable framework to estimate unsaturated-zone hydraulic properties and associated aquifer response delays.

LID 0384
Hydrogeological exploration for groundwater management: Case studies of Donpradoo and Pakpayoon subdistricts, Pakpayoon District, Phatthalung Province

Tusneem Kusaman[1]*, Dawruang Sukarawat[1], Khemmarat Somsing[1], Pitchaporn Intamol[1]

[1] Department of Groundwater Resources, Bureau of Groundwater Resources Regional 12 (Songkhla), Songkhla, Thailand

* kustus211@gmail.com

Keywords: meta-sedimentary aquifer, groundwater management, hydrogeological exploration

Many areas in southern Thailand continue to face water insecurity due to rainfall variability, dry-season shortages, seawater intrusion, and groundwater quality issues, limiting domestic water supply. Similar conditions occur in Donpradoo and Pakpayoon Subdistricts. Terrain consists of mountainous areas in the central zone, sloping eastward toward Songkhla Lake. Surface water and groundwater sources in the area are affected by brackish and saline conditions. Groundwater development in this region is made difficult by meta-sedimentary aquifers and issues of iron contamination and salinity in aquifers. This study aimed to assess groundwater potential in terms of quantity and quality to establish appropriate development and management strategies.

The methodology included compilation and analysis of geological and hydrogeological data, geophysical surveys, exploratory drilling, pumping tests, and groundwater quality analysis. The study revealed that the area is underlain by chert, shale, shale interbedded with limestone, and sandstone. Groundwater occurs within fractured and weathered rock at depths of 30–300 m. The central zone shows high potential with yields of 14–25 m^3/h, while the northern and southern zones exhibit low to moderate potential (2–5 m^3/h). Groundwater quality generally meets standards; however, iron concentrations of up to 1.8 mg/L were detected in some locations, requiring treatment prior to consumption. The estimated water balance in the system is 16.07 MCM/year, with a safe yield of 4.3 MCM/year. Groundwater use is about 1.5 MCM/year (30% of safe yield), indicating sufficient potential for further development.

Based on the assessment of groundwater potential, water demand, and village distribution, three groundwater management approaches were proposed. A groundwater supply system in the high-potential central area is proposed to serve 11 villages and 7,310 people (70% of affected residents), as a model for sustainable groundwater management.

LID 0386
Assessment of groundwater recharge by irrigation tanks in weathered hard rock regions

Isabelle Schmidt[1]*, Stephan Schulz[2], Kristina Gumgowski[2], Juan Carlos Richard-Cerda[2,3], **Brindha Karthikeyan**[1,4], Michael Schneider[5]

[1] Institute of Geological Sciences, Freie Universität Berlin, Berlin, Germany
[2] Institute of Applied Geosciences, Technical University of Darmstadt, Darmstadt, Germany
[3] Helmholtz Centre for Environmental Research, Halle, Germany
[4] Department of Water Resources and Ecosystems, IHE Delft Institute for Water Education, Delft, The Netherlands
[5] Department of Applied Geosciences, German University of Technology in Oman, Oman
* i.schmidt@fu-berlin.de

Keywords: Hydrus 2D, unsaturated zone, satellite images, water management, semi-arid region

Surface water storage structures known as ‘tanks’ are used in India to store rainwater for irrigation for millennia. However, their importance diminished over time as groundwater increasingly replaced tank water as the primary source of irrigation in the 20th century, thereby reducing the need for tank maintenance. As India's agricultural sector increasingly relies on groundwater for irrigation, depletion of groundwater resources is recorded in various parts of the country. Thus, recent revitalization measures aim to improve the functioning of tanks, resulting in increased water availability and groundwater recharge, which supports sustainable livelihoods.

The recharge process of irrigation tanks remain insufficiently quantified. Therefore, this study assesses their effectiveness in enhancing groundwater recharge in hard rock aquifers through numerical modelling using HYDRUS-2D. Tank water levels were reconstructed using weekly high-resolution satellite images from Planet Labs. Soil samples were taken to a priori parametrize the model. The results confirm that irrigation tanks contribute to groundwater recharge, particularly when embedded in a cascade system. Cascades of tanks are supplied by rivers, and within, water flows from upstream to downstream tanks, resulting in tanks that are almost constantly filled with water. This causes recharge throughout the year, except on some days in the dry season. Recharge rates strongly depend on both the aquifer properties and the characteristics of the tank floor. Model runs with modified conditions of the tank floor reveal the effect of measures such as the removal of accumulated sediments and thus provide insights to improve the tanks' dual function as reservoirs for irrigation as well as aquifer recharge structures.

LID 0387
Research on key areas of major aquifers and groundwater reserves in China

Fengying Liu[1,2]*, Yasong Li[1,2], Jingtao Liu[1]

[1] The Institution of Hydrogeology and Environmental Geology, CAGS, Xiamen, China
[2] Fujian Key Laboratory of Water Cycling and Eco-Geological Processes, Xiamen, China
* 20704285@qq.com

Keywords: national major aquifers, groundwater reserves, storage volume

As a strategic resource for responding to extreme climate events and water pollution accidents, groundwater offers unique advantages such as widespread distribution, minimal impact from seasonal variations, and strong multi-year regulation capacity. It plays an irreplaceable role in maintaining regional social stability and ensuring sustainable economic development. China is a water-scarce country, with its per capita water resources accounting for only one-fourth of the global average. In particular, the North China Plain, the northwest region, and numerous large and medium-sized urban agglomerations have long suffered from severe water shortages and groundwater overexploitation. There is an urgent need to establish a national drinking water supply security system to address regional emergencies, such as extreme climate events or water pollution incidents. The delineation of national groundwater reserve areas is a key measure for constructing a drinking water supply security system in China's major economic development zones and densely populated urban agglomerations. It is a forward-looking foundational effort aimed at enhancing the country’s capacity to ensure emergency drinking water supply in response to major incidents.

Based on systematically conducted national groundwater assessments (three rounds), the first national groundwater pollution survey and evaluation, and other systematic efforts, this study systematically delineated the major aquifers and key national groundwater reserve areas in China. The main achievements are as follows: First, 46 national major aquifers (systems) were delineated, clarifying the spatial pattern of groundwater resources in China, which is characterized by "abundance in the south and scarcity in the north, more in the east and less in the west." The recoverable resources of Quaternary pore water, karst water, and fissure water account for 47.80%, 24.67%, and 27.53%, respectively. Second, 38 key national groundwater reserve areas were delineated, with a total emergency recoverable volume of approximately 111.5 billion cubic meters. This includes 50.4 billion cubic meters in the northwest region, 39.5 billion cubic meters in the north region, 8.2 billion cubic meters in the northeast region, and 14.0 billion cubic meters in the southern region. Third, an evaluation system for the storage capacity of reserve areas was established, assessing the current storage volume of each reserve area at approximately 500 billion cubic meters, with an additional recharge capacity of about 50 billion cubic meters. Fourth, a groundwater security pathway was proposed, encompassing "utilizing existing sources, exploring new sources, fostering cooperation, and establishing reserves," along with a comprehensive set of measures for the protection, utilization, and restoration of reserve areas. These findings fill the gap in the national-level planning of groundwater reserve areas and provide a scientific basis for constructing a national water security system.

This study has achieved multiple innovations in theoretical methods: First, it established a theoretical system for groundwater reserve area delineation, proposing the fundamental principle of "conservation during normal times, activation during emergencies, and recovery within 3-5 years," while defining the technical requirements of "ensuring effective recharge, reliable storage, substantial emergency reserves,

and good water quality." Second, it developed a quantitative evaluation method for storage capacity, creating GIS-based models for calculating current storage volume, potential recharge increments, and emergency recoverable volume, thereby achieving spatial and quantitative assessment results. Third, it innovated evaluation methods for karst water reserve areas, addressing the heterogeneity of karst development by incorporating parameters such as karstification rate, runoff belts, and high-intensity runoff zones to improve assessment accuracy. Fourth, it established an environmental risk assessment technology for reserve areas, developing a water level threshold control system for land subsidence, karst collapse, and underground engineering safety to ensure the security of groundwater reserves.

LID 0388

From science to policy: An action plan to adopt Agricultural Managed Aquifer Recharge as a drought adaptation measure in Lombardy, Italy

Claudia Medina Montecinos[1]*, Paolo Colombo[1], Luca Alberti[1]

[1] Department of Civil and Environmental Engineering, Politecnico di Milano, Milan, Italy

* claudia.medina@polimi.it

Keywords: science-policy interface, agricultural managed aquifer recharge, drought adaptation

The severe 2022 drought in Lombardy caused substantial unmet irrigation demand across the agricultural areas of the metropolitan area of Milan. Although future climate projections do not indicate clear trends in drought frequency and intensity, the recurrence of dry conditions during the irrigation season highlights the need to enhance the sector's climate resilience. In this context, the underlying aquifer represents a strategic resource for storing excess water during wet periods.

Over three consecutive winters, we tested Agricultural Managed Aquifer Recharge (Ag-MAR) by diverting water through the dense canal network to a selection of agricultural fields, where it infiltrates into the aquifer. To characterize the system and quantify water fluxes, we developed a pilot-area groundwater model. Both field monitoring and model simulations showed clear rises in piezometric levels in response to Ag-MAR, and the model identified the factors controlling the magnitude and persistence of these increases. We then implemented Ag-MAR in a basin-scale groundwater model to evaluate how widespread adoption could influence the aquifer system.

Building on these results and supported by collaboration with key stakeholders, we proposed Ag-MAR as a drought adaptation measure to be integrated into regional planning. Using the Climate-ADAPT Regional Adaptation Support Tool and creating collaborative spaces such as workshops and a national conference, we developed a structured action plan. This instrument provides guidelines for the technical implementation and monitoring of Ag-MAR and addresses key management aspects, including subsequent groundwater abstraction, economic and regulatory barriers, and integration into regional policy. These efforts created a clear pathway for the uptake of Ag-MAR as the first aquifer-based drought adaptation measure in Lombardy, while offering a replicable framework for regions with similar environmental and societal characteristics.

This research was carried out as a Pilot Action for the MAURICE Interreg project (CE0100184).

LID 0389
Enhancing groundwater recharge projection INSIGHTS by learning from the past

Frédérique M. Mourot[1,2]*, Dylan J. Irvine[1,2], Tomas A. Remenyi[3], Lindsay B. Hutley[1], Russell S. Crosbie[4], Catherine R. Moore[5], Sarah Chapman[6]

[1] Research Institute for the Environment and Livelihoods, Charles Darwin University, Northern Territory, Australia
[2] National Centre for Groundwater Research and Training, Adelaide, Australia
[3] Acclimatised Pty Ltd, Hobart, Australia
[4] CSIRO, Environment, Waite Campus, Adelaide, Australia
[5] Earth Science New Zealand, Lower Hutt, New Zealand
[6] Queensland Government, Brisbane, Australia
* frederique.mourot@cdu.edu.au

Keywords: climate change, hydrological projections, decision-making

The extensive archives of climate variables from more than 100 Global Climate Models (GCMs) of the Coupled Model Intercomparison Project Phase 6 (CMIP6) offer unique opportunities to explore future hydrological projections. However, developing hydrological projections that meet decision-makers' needs is often time-consuming, complex, and requires expertise in climate and hydrological modelling as well as effective communication. Consequently, hydrologists often use climate projections available at a suitable scale as input data for their model(s), without fully validating that these projections are appropriate for the targeted application.

We highlight the benefits of exploring climate and hydrological "hindcasts" (i.e., past projections) to enhance insights for future hydrological projections. Specifically, we investigate the potential impacts of climate change on groundwater recharge (GWR) in a northern Australian case study where agricultural development is being pursued. We force a daily time-step, lumped recharge model (LUMPREM) with climate projections from a multi-model ensemble (MME) of 60 simulations downscaled and bias-adjusted from CMIP6-GCMs. We use projections for three Shared Socio-economic Pathway scenarios: SSP1-2.6, SSP2-4.5, and SSP3-7.0. First, we benchmark rainfall, evapotranspiration, and GWR hindcasts to build more robust projections. Then we project future GWR out to 2100.

Our hindcasts-vs-observations analysis (for 15 downscaled and bias-adjusted simulations) provides valuable insights into GCM members' ability to represent locally important climatic and hydrological drivers. In addition, GCM-member specificity is identified (e.g., dry/wet), yielding more application-ready information than when solely focusing on the MME mean or median. We show that the initial characterisation of climate and hydrological hindcasts and MME members provides key elements to develop, interpret, and inform future hydrological projections to support water security.

LID 0390
Nanoplastic mobility in agricultural soils: A risk for groundwater quality

Swagatam Chakraborty[1*], Chaksika Prematunga[1], Philipp Wanner [1,2]

[1] Department of Earth Sciences, University of Gothenburg, Gothenburg, Sweden
[2] Centre for Future Chemical Risk Assessment and Management (FRAM) in Gothenburg, University of Gothenburg, Gothenburg, Sweden
* swagatam.chakraborty@gu.se

Keywords: groundwater, nanoplastic, contaminant transport

Agricultural soils are one of the major sinks for plastic materials because of the use of mulch films, application of microplastic contaminated sewage sludge as fertilizers and manure, and irrigation water. These plastics tend to fragment into smaller particles generating nanoplastic particles (NPs <100 nm). Vertical movement of nanoplastic particles through agricultural topsoil is a potential threat to groundwater quality. However, the mobility of NPs in agricultural soils remains largely unknown.

Here, we determined the transport of NPs with a size of 90 nm, in agricultural soils under *in situ* conditions by using an innovative NP gold-core tracer method and an advanced lysimeter setup. We revealed that NPs can migrate through agricultural soils, potentially acting as long-term contamination sources for underlying groundwater systems. Somewhat counterintuitively, the NP mobility was higher (higher mass recovery) in fine grained silty-clayey soils compared to coarse-grained sandy agricultural soils, suggesting that the smaller area of air–water interface in clayey soils reduces NP retention. Additionally, simulated extreme rainfall events, increasingly expected under climate change, showed an enhanced NP mobility, indicating that NPs would become more mobile in the future in agricultural soils.

Overall, these novel findings highlight the importance of considering NP mobility in agricultural soils when assessing global groundwater contamination risks, especially in clayey soils and under changing climate conditions with intensified rainfall.

LID 0392

Enhancing baseflow resilience through managed aquifer recharge: Quantifying groundwater system response to ecological water replenishment In The North China Plain

Zhengyan Li[1]*, Aizhong Ding[1]

[1] College of Water Sciences of Beijing Normal University, Beijing, China
* 202431470001@mail.bnu.edu.cn

Keywords: ecological baseflow, baseflow resilience, SWAT-LSTMMODFLOW, groundwater-surface water interaction, managed aquifer recharge

In the North China Plain, decades of intensive groundwater extraction have severely depleted aquifers and degraded the essential hydrological connectivity for sustaining ecological baseflow. Large-scale Ecological Water Replenishment (EWR) projects aim to reverse this trend; however, a quantitative understanding of how managed recharge enhances the resilience of baseflow—the system's capacity to maintain baseflow under stress—remains limited. This study uses an advanced SWAT-LSTM-MODFLOW coupled modelling framework to analyse the response of the groundwater system to EWR and its implications for baseflow sustainability. The model integrates the semi-distributed hydrological model SWAT, the three-dimensional groundwater flow model MODFLOW and Long Short-Term Memory (LSTM) networks. It is rigorously calibrated using multi-decadal data from the China Geological Environment Monitoring Network. When applied to a region that is critically over-exploited, the model simulates the spatiotemporal evolution of the groundwater flow field and storage recovery following EWR events. The study focuses on quantifying two key aspects: (1) the increased contribution of groundwater to ecological baseflow and (2) improvements in baseflow resilience indicators, such as dry-season flow reliability and recovery rate. This groundwater-to-baseflow analysis directly links aquifer recovery to ecological outcomes. The results elucidate how engineered replenishment alters interacting groundwater systems and enhances the aquifer's buffer capacity, thereby providing a mechanistic basis for climate change adaptation strategies. By offering a predictive framework to optimise recharge schemes, this work contributes to the development of next generation solutions for the sustainable management of groundwater.

LID 0393
From global datasets to risk maps: An integrated framework for 3D modelling of coastal groundwater salinity

Guilherme Emidio Horta Nogueira[1], Daniel Zamrsky[2], Gualbert Oude Essink[1,2], Marta Faneca Sànchez[1], **Jude King**[1,2]*

[1] Deltares, Utrecht, The Netherlands
[2] Utrecht University, Utrecht, The Netherlands
* jude.king@deltares.nl

Keywords: groundwater salinity, 3D modelling, coastal vulnerability

Global datasets and expedite computing power enables a fast, first-order assessment of coastal aquifers vulnerability to salinization, especially important in data-scarce areas. This works presents the development and application of the “MedSWI” framework, a large-scale, 3D variable-density groundwater modelling framework to assess salinization risk across six Mediterranean coastal areas. The framework integrates open global datasets, reproducible python-based tools (flopy, iMOD-python), and parallel computing to efficiently simulate 3D salt transport at both regional (5×5 km^2) and national (1×1 km^2) scales. Key components include harmonized hydrogeological databases, paleo-reconstruction of groundwater salinity , and scenario exploration using climate change, sea-level rise, and groundwater abstraction projections. AI-based extraction of borelog data further enhances subsurface characterization in data-scarce areas and enhance model representativeness.

Validated model outputs for 2020 indicate varying freshwater–saltwater interface (FSI) and salinity distributions, with hotspots around heavily pumped or geomorphologically vulnerable areas. Future simulations (2120) reveal significant shallowing of FSI and increased salinization at shallow aquifers. Risk analyses integrating aquifer vulnerability and thresholds for drinking water, agriculture, and ecosystems highlight priority zones where salinization threatens water security and locations where mitigation measures can enhance freshwater availability.

The framework demonstrates the use of large-scale models to support coastal climate-change adaptation, by identifying main salinization drivers, estimating trends, and assessing potential of mitigation measures. While results are indicative, comparison with local data show the potential of large-scale models for coastal salinity assessment.

This work forms part of the UNESCO-GEF project “Management of Coastal Aquifers and Related Ecosystems in the Mediterranean.”

LID 0394
Century-scale spring discharge trends under climate change in the Southern Apennines (Italy)

Claudia Pensa[1]*, Tommaso Casati[1], Daniele Invernizzi[1], Giosuè Bergami[1], Donato Sollitto[2], Giuseppe D'alonzo[2], Stefano Savino[2], Gennaro Capasso[2], Vera Corbelli[2], Alessandro Gargini[1]

[1] Department of Biological, Geological and Environmental Sciences, Alma Mater Studiorum Università di Bologna, Italy
[2] Basin Authority of the Southern Apennines District, Caserta, Italy
* claudia.pensa2@unibo.it

Keywords: climate change, water management plan, groundwater bodies

Systematic surveys of springs in Southern Italy were conducted at the beginning of the twentieth century, resulting in the monograph series *Le Sorgenti Italiane* (Italian Springs), published by the National Hydrographic Service (1920s–1960s). These volumes provided the first comprehensive documentation of spring discharge, establishing a valuable hydrogeological dataset. Over recent decades, Mediterranean groundwater systems have proved highly sensitive to climate change, with reduced recharge linked to more frequent and severe droughts. Robust assessment of climate-driven impacts on groundwater therefore requires temporally comparable datasets capable of capturing multi-decadal variability in aquifer discharge. In this context, groundwater monitoring has been strengthened under the Water Framework Directive (2000/60/EC) and the Groundwater Directive (2006/118/EC). The Southern Apennines River Basin District Authority (SADA) has prioritised the standardisation and expansion of monitoring networks to support updates to the Water Management Plan. Accordingly, an extensive field census and hydrogeological survey of springs used for public water supply was carried out by the University of Bologna hydrogeology research group across the entire district. For the first time since the 1960s, a homogeneous district-scale spring dataset has been achieved. Where reliable correspondence could be established, contemporary spring discharge measurements were compared with historical records, enabling a century-scale assessment. The results reveal multi-decadal differences in spring discharge and a spatially heterogeneous aquifer response. Several groundwater bodies exhibit significant discharge declines consistent with climate-change impacts, whereas others remain stable. These findings underscore the importance of long-term, standardised spring monitoring to support climate adaptation, drought-risk mitigation, and sustainable groundwater management under increasing water scarcity.

LID 0395
Hydrogeological modelling of the Nord–Artois–Picardie Chalk hydrosystem for sustainable water management: Multidisciplinary approach for conceptual and structural controls

Guillemoto Quentin[1*], Arnaud Luc[1], Meire Baptiste[1], Aka Brou Carl[1], Parmentier Marc[1], Guillaumot Luca[1], Aissat Ryma[1], Manlay Adrien[1], Tison Louis[1], Hallouin Thibault[1], Buscarlet Etienne[1], Manceau Jean-Charles[1], Amraoui Nadia[1], Picot-Colbeaux Géraldine[1]

[1] French Geological Survey (BRGM, France)
* q.guillemoto@brgm.fr

Following the general need of French river basin management schemes for the quantification of sustainable groundwater abstraction volumes, regional water authorities have expressed a strong demand for hydrogeological investigations and numerical modelling in order to provide decision-support tools for future projections of groundwater management. The study is based on the investigation of the Chalk aquifer, which represents the main groundwater resource within the Artois–Picardie basin (northern France).

A large multidisciplinary effort has been undertaken to characterise the geology and groundwater flow dynamics of the complex Chalk aquifer system in this region, especially in the Authie catchment (4,300 km^2, Hauts-deFrance). One of the main challenges lies in the strong spatial heterogeneity of geological facies and hydrodynamic properties (hydraulic conductivity and storage parameters) of the Chalk, driven in particular by fracturing processes, near-surface dissolution, depositional conditions of the geological units, and the structural history of the area, controlling groundwater recharge, preferential flow paths, groundwater storage, and groundwater–river exchanges.

Within this study, we developed a comprehensive characterization of the chalk lithostratigraphy and hydrodynamic parameters, and available piezometric time series across the Authie catchment with the aim of integrating this knowledge into a regional transient, distributed groundwater flow numerical model. Initial analyses of national databases combined with targeted data acquisition highlight strong relationships between hydrodynamic properties and (i) the thickness of the unsaturated zone and (ii) past tectonic events. An extensive geological modelling effort resulted in the construction of a 3D geological model describing 18 lithostratigraphic units ranging from the Quaternary, Paleogene to the Cretaceous and Palaeozoic, based on data from 1,244 boreholes across the area. Time series analyses on groundwater levels, through cyclicity and spatial analysis, also showed a spatial link between hydrogeological responses and variations with thickness of the unsaturated area, distance to the watershed outlet, and the fracturing of the Chalk layer. These multidisciplinary characterization efforts converge towards the formulation of a conceptual groundwater flow model, which guides the subsequent implementation of a regional numerical model.

The study highlights the existence of multiple plausible geological and hydrogeological representations of the Chalk system, reflecting both conceptual and structural uncertainties. The modelling strategy therefore seeks a balance between geological and hydrogeological simplification, ensuring acceptable computational for preserving the key processes and for further scenario analysis, optimisation procedures, and calibration algorithms. A series of geometrical assumptions through modelling sensitivity tests is conducted to quantify the impact of structural assumptions on model calibration and predictive responses.

Beyond providing decision-support tools for local water authorities, this work also contributes to testing and refining through hydrogeological modelling, the conceptual hypotheses regarding the complex hydrogeological functioning of Chalk aquifer systems in northern France, in order to better address future groundwater management challenges.

LID 0399
Participatory groundwater management in a subsidence-prone region: from focus groups to scenario workshops in Yunlin, Taiwan

Shih-Yao Lee[1]*, Hwa-Lung Yu[1], Jean-Daniel Rinaudo[2]

[1] National Taiwan University, Taipei, Taiwan
[2] BRGM France, Montpellier, France
* f08622011@g.ntu.edu.tw

Keywords: participatory groundwater management, land subsidence, agriculture

Groundwater plays a critical role in global water security, particularly for agriculture, yet long-term overuse has led to severe impacts such as aquifer depletion, water quality degradation, and land subsidence. While many countries have adopted groundwater management policies, their effectiveness is often constrained by governance challenges and limited stakeholder engagement. In Taiwan, although groundwater abstraction is legally regulated, weak enforcement has induced widespread unregistered pumping, especially for irrigation. Yunlin County, one of Taiwan's major agricultural regions, hosts more than 150,000 wells and has experienced progressive land subsidence, shifting from coastal aquaculture areas to inland agricultural zones over recent decades.

This study presents one of the first attempts in Taiwan to integrate stakeholder participation into groundwater management in a subsidence-prone region. We designed and implemented a two-stage participatory process consisting of Consensus Workshops and Scenario Workshops. Three parallel stakeholder groups were engaged in each stage: central-level policymakers, local administrators and experts, and local farmers. The Consensus Workshops synthesized key groundwater and land subsidence issues identified through prior interviews and focus groups, facilitating cross-group dialogue on issue importance and perceived solvability. Building on these outcomes, the Scenario Workshops introduced alternative groundwater management pathways and supported discussions on feasible actions, implementation timelines, and stakeholder preferences.

The participatory process clarified critical governance and water-management challenges while revealing both divergences and convergence among stakeholder perspectives. By fostering mutual learning and co-developing actionable strategies, this study offers a practical participatory framework for groundwater management in Taiwan.

LID 0400
Watershed and ecosystem resiliency in Napa County, California: Adaptation, collaboration, and conservation as a way of life

Vicki Kretsinger Grabert[1]*, Nick Watterson[1], Nick Newcomb[1], Jamison Crosby[2]

[1] Luhdorff and Scalmanini, Consulting Engineers (LSCE), United States
[2] Napa County, United States
* vkretsinger@lsce.com

Climate change brings global implications for water supply availability, resiliency, and ecosystem health. Actions to improve future water resources conditions, decrease susceptibility to drought effects, address public trust interests, and facilitate conjunctive surface water and groundwater management require ongoing attention regardless of water year type. In spring 2023, following recurring dry years, hotter temperatures and diminished recharge, Napa County embraced “Conservation as a Napa Way of Life.” Regardless of future weather patterns that bring drought or deluge, Napa County has incorporated this philosophy in its climate, drought, and sustainability planning efforts and implementation. However, stakeholders hold the notion that when the rains come, or drought has ceased, that conditions are “normal” again. Ongoing outreach and public engagement are critical to support numerous interrelated programs that rely on conservation, stewardship, adaptation, and resiliency, especially because of the importance of interconnected surface water and groundwater. Comprehensive ecologic, streamflow, and groundwater monitoring and an actionable water management framework are required to characterize and quantify the urban, agricultural, and environmental water needed to sustain all beneficial uses, including ecosystem services. The new, transformative framework includes an integrated approach to land use and water management that achieves watershed-wide water supply security and protects and enhances ecosystems. Among other objectives, the Napa Valley Subbasin Groundwater Sustainability Plan supports the new framework that includes protective well siting and construction standards and water conservation measures for domestic, agricultural, commercial and community water systems, to reduce streamflow depletion. Community collaborations are underway to encourage conjunctive water management strategies that accelerate groundwater recharge and demand management measures.

LID 0401
The role of carbonate aquifers in the circum-Mediterranean region as a storage reservoir in the context of water resources management strategies

Martin Sauter[1]*, Stephan Theobald[1], Ali Kavousi[1], Yakov Livshitz[1], Yossi Guttman[1], Bernd Rusteberg[1]

[1] LIAG-Institut für Angewandte Geophysik, Hannover, Germany
* martin.sauter@liag-institut.de

Carbonate aquifers are widely distributed across the Mediterranean and the Middle East and constitute important water resources. As a result of their high hydraulic conductivity, low storage coefficient, and therefore low storage capacity they are highly vulnerable to drought conditions. The management of these resources requires knowledge of the stored volume of water as well as information on the temporal variability of the available resources. Water is stored either in the phreatic zone as groundwater or in the vadose zone as vertical flux. The volume of the latter can be substantial, especially in thick vadose zones, such as those that developed above the carbonate aquifers. The temporal variability of the available groundwater resources is determined by the variability in weather and climate, and particularly affected by extreme events. Variability of vertical water flux is driven by preferential and matrix flow. Variability of groundwater flow dynamics of carbonate aquifers is determined by a dual flow system, consisting of the draining conduit network and the adjacent matrix blocks. The assessment and prediction of the available groundwater resources requires knowledge on all of these components and prediction of their behavior needs superposition of all their individual dynamics.

Employing a coupled sat-unsat double continuum numerical model, historic 70 yearlong records of spring discharge and groundwater heads were successfully modelled for the transboundary 9000km^2 Western Mountain Aquifer (WMA) of Israel / West Bank to show that the relevant system components as well as their event and seasonal dynamics can be represented.

Based on this numerical model, the response of the groundwater system to extreme recharge events, expected as a result of climate change effects, was simulated. The results show that exceptionally wet winter seasons can contribute to elevated discharge for time periods even longer than five years after the wet season.

Furthermore, employing the WMA-model we could show that despite their unfavourable hydraulic characteristics (high hydraulic diffusivity; high hydraulic conductivity / low porosity) even karst aquifers can act as efficient and economically viable water storage systems in Managed Aquifer Recharge operations (MAR) with desalinated sea water as injected recharge during periods of low demand. Here, the importance of the role of the vadose is highlighted, contributing up to 40% of the total groundwater storage volume.

LID 0402
A data-driven approach for estimating groundwater availability under management targets for agricultural irrigation

Shih-Yao Lee[1]*, Hwa-Lung Yu[1], Hua-Ting Tseng[1]

[1] National Taiwan University, Taipei, Taiwan
* f08622011@g.ntu.edu.tw

Keywords: data-driven, groundwater availability, agriculture

Groundwater management in Taiwan is primarily based on management water levels, yet water level alone does not directly represent the quantity of groundwater available for irrigation. This study develops a data-driven framework to estimate groundwater availability by integrating time-series analysis, water balance, and management targets. The study area is the Choushui River alluvial fan in central Taiwan, where intensive agricultural pumping has led to groundwater decline and subsidence. Long-term groundwater level observations are used to estimate aquifer storage parameters and spatiotemporal pumping and recharge amounts based on signal-analysis and transfer-function approaches. These results are incorporated into a groundwater water-balance framework that quantifies recharge, pumping, discharge, and storage variation at irrigation management-unit scale.

Groundwater availability is defined under two conditions: (1) long-term sustainability, where recharge equals pumping and discharge, and (2) management-constrained availability, where groundwater levels must remain above predefined management thresholds. By converting water-level thresholds into volumetric storage limits through estimated storage coefficient, the framework translates level-based regulation into quantity-based management. The estimated available groundwater amounts are further integrated into a conjunctive surface–groundwater allocation model (WEAP) to evaluate irrigation supply scenarios under quantity-control strategies. Results demonstrate that the proposed framework provides spatially explicit, management-oriented groundwater availability estimates and supports the transition from water-level-based control to quantity-based groundwater management in agricultural regions.

LID 0404
Are the groundwater levels recovering in the IGB?

Pratibha Mishra[1,2]*, Simon Moulds[1,2], Donald John MacAllister[2], Johanna Scheidegger[3], Alan MacDonald[2]

[1] School of Geosciences, University of Edinburgh, Edinburgh, Scotland, United Kingdom
[2] British Geological Survey, Edinburgh, Scotland, United Kingdom
[3] British Geological Survey, Nicker Hill, Keyworth, Nottingham, United Kingdom
* pratibha.mishra@ed.ac.uk

Keywords: Indo-Gangetic Basin, groundwater, machine learning

The Indo-Gangetic Basin (IGB) is a large transboundary aquifer system supporting one of the world's largest agrarian populations. Expansion of groundwater irrigation through shallow–medium tubewells has reduced dependence on monsoon rainfall enabling food security and improved rural livelihoods. While the fertile plains of the Indo-Gangetic basin accounts for nearly 25% of global groundwater abstraction, patterns of groundwater use are not uniform across the IGB. Nevertheless, previous studies have largely advanced a narrative of uniform groundwater decline across the IGB. In reality, the IGB is a complex, heterogeneous aquifer system that responds differently to climatic variability and anthropogenic pressures. Here, we analyse groundwater dynamics at basin and sub-basin scales for 1998–2024 using a novel, quality-controlled dataset of quarterly groundwater levels from 5,877 wells, complemented with meteorological and land-use data.

Mann–Kendall analysis for 1998–2010 across 2,585 wells indicates predominantly declining groundwater levels, associated with proliferation of deep tubewells (>70 m) in the Indus and Rajasthan inland basins and shallow-medium tubewells (<70m) in the Ganges basin. After 2010, groundwater trends diverge spatially. In the Ganges, groundwater levels have largely stabilised, despite some variability at sub-basin scale with the median rate of 3.9 cm/year, post 2010. Elsewhere, groundwater levels have continued to decline despite increased rainfall and a prolonged multi-annual wet anomaly. The rate of decline has stabilised in the Indus from -9.18cm/year until 2010 to -3.16cm/year post 2010 but continue to accelerate in the Rajasthan inland basin.

To attribute these contrasting patterns, we quantify the relative roles of hydro-meteorological variability, land-use change and irrigation practices. Overall, our analysis challenges simplified narratives of uniform groundwater decline and supports more targeted groundwater management across the IGB.

LID 0405
Groundwater flow modeling in urban areas: A case study of N'Djamena in Chad (Central Africa)

Tidjani Bahar[1]*, Djimadjimbaye Eraste[1]

[1] École Nationale Supérieure des Travaux Publics (ENSTP), N'Djamena, Chad
* tidjanibahar@yahoo.fr

Keywords: MODFLOW 6, groundwater flow modeling, N'Djamena

Groundwater flow modeling in urban areas is of great importance in the context of water level depletion due to the high population and industrial growth. A numerical modeling approach could be implemented in order to get information in data-scarce locations and with limited resources. The movement of groundwater in the city of N'Djamena is not well known because of the scarcity of hydrogeological data in this complex aquifer, and under these conditions, a study through numerical modeling approaches is mandatory to fully understand this issue.

The goal of this work is to analyze changes in the urban groundwater level of N'Djamena using the well-known MODFLOW 6 model. In this work, we combine field studies and modeling in order to reach this goal. The field studies consist to measure water level of around 200 urban wells located in the N'Djamena city. In parallel, the differential equation of groundwater flow movement using the MODFLOW 6 is solved numerically to obtain results in terms of 3D groundwater surface cross-sections, groundwater head, and water balance plots. Comparison of fields data and MODFLOW 6 results will be reported and discussed.

LID 0408
Irrigation practice changes versus meteorological drought: A numerical modeling assessment of aquifer depletion

Agnese Redaelli[1]*, Tullia Bonomi[1], Davide Sartirana[1], Gianfranco Sinatra[2], Daniel T. Feinstein[3], Randall J. Hunt[4], Marco Rotiroti[1], Chiara Zanotti[1]

[1] Department of Earth and Environmental Sciences, University of Milano-Bicocca, Milan, Italy
[2] Acque Bresciane S.r.l. SB, Rovato, BS, Italy
[3] Department of Geoscience, University of Wisconsin-Milwaukee, Milwaukee, WI, United States
[4] Department of Geoscience, University of Wisconsin-Madison, Madison, WI, United States
* agnese.redaelli@unimib.it

Keywords: groundwater recharge, climate change, water management

Groundwater availability is increasingly threatened by a changing climate. This study provides a quantitative assessment of the major drivers of potential aquifer depletion in a highly human-influenced system with significant agricultural activity. The focus is on modelling direct and indirect effects of climate change, such as hydrological droughts and shifts to more efficient irrigation practices in response to reduced surface water availability.

A 3D groundwater flow model was developed to simulate the 2015-2017 period in an area of ≈ 2,000 km^2 in the Po Plain (N Italy), representative of a complex hydrogeological setting in which irrigation return flow dominates recharge. To quantify and compare the effects of meteorological conditions and irrigation management changes on the system, the calibrated model was used to run two synthetic future scenarios of practical interest: (S1) a two-year meteorological drought, using the dry 2022 conditions as a reference, and (S2) a transition from surface-water irrigation to the more efficient drip irrigation technique.

Results indicated that the S1 scenario reduces recharge processes but preserves seasonal groundwater dynamics observed under baseline conditions, resulting in a total groundwater storage loss of 2.34×10^5 m^3/d. Conversely, the S2 scenario disrupts the seasonal pattern and leads to larger groundwater storage losses of 2.77×10^5 m^3/d with critical impacts on lowland springs and connected surface water bodies. These findings highlight the central role of surface-water irrigation return flow in maintaining the groundwater balance in intensively cultivated areas, suggesting that adaptation measures taken to mitigate climate-induced surface-water scarcity may have a greater impact on groundwater systems than climate change itself.

LID 0410
Transforming spontaneous to ordered conjunctive management: A pilot case from the Kamishkurgan Aquifer, Western Fergana

Shammy Puri[1]*

[1] Department of Hydrogeology, University of Warsaw, Warsaw, Poland
[2] Centre for Sustainable Solutions with Practical Hydrogeology, United Kingdom
* ShammyPuri@practicalhydrogeology.co.uk

Keywords: spontaneous conjunctive management, aquifer buffering, irrigation modernisation, drainage, waterlogging, salinity, governance retrofit, Western Fergana Valley, Syr Darya river basin

Over the past few decades, unreliable irrigation-water delivery in semi-arid irrigated regions in the global South has driven water users to turn to local aquifers as a reactive coping mechanism, referred to as ‘spontaneous’ conjunctive use. While this reaction does help to stabilise agricultural production, it evolves without operational rules, monitoring or coordinated drainage control. The consequences are persistent inefficiency, waterlogging and salinity risks re recurring. This presentation develops and applies a novel practical diagnostic approach in the Western Fergana Valley, Asht–Syr Darya irrigated area, underlain by the Kamishkurgan alluvial aquifer.

Using a coupled conceptual framework of canal delivery, irrigation return flow, drainage management and groundwater abstraction, supported by an appropriately simplified (lumped-parameter) interpretation of groundwater-level fluctuations and basic hydrochemical data, the analysis identifies the dominant feedbacks that lead to reactive pumping behaviour and shallow groundwater level rise in discharge areas. Results indicate that irrigation drainage is a first-order control on groundwater levels and increases in salinity. Additionally, high cost energy lift irrigation reinforces a feedback loop in which surface-water unreliability triggers groundwater pumping, thus increasing overall energy intensity.

The presentation proposes a ‘retrofitting’ approach to move from spontaneous to planned conjunctive management, in defined stages. To kick start the process, pilot-scale intervention is developed, that links the limited monitoring and threshold-based operating rules. A joint institutional-operational coordination linking surface water, drainage and groundwater responsibilities is also proposed. The approach and pilot logic are transferable to similar irrigation economies where data scarcity and institutional fragmentation constrain conjunctive management.

LID 0412
Navigating challenges and strengthening groundwater education and sustainable progress in Tajikistan

Brindha Karthikeyan[1*], Jenniver Sehring[1], Marian Szymanowicz[2], Aminjon Abdulloev[2], Andamiyon Rajabali Shams[3], Anushervon Pochoev[4], Andrew Pearson[5]

[1] IHE Delft Institute for Water Education, Delft, The Netherlands
[2] Helvetas Swiss Intercooperation, Dushanbe, Tajikistan
[3] Department of Hydrogeology and Engineering Geology of the Geological Faculty of Tajik National University, Dushanbe, Tajikistan
[4] Mining-Metallurgical Institute of Tajikistan, Buston, Tajikistan
[5] International Groundwater Resources Assessment Centre (IGRAC), Delft, The Netherlands
* b.karthikeyan@un-ihe.org

Keywords: hydrogeology, curriculum development, advanced tools, digital mode

The Groundwater Management Project is focused on the Sughd Region of Tajikistan and funded by the Swiss Agency for Development and Cooperation (SDC). Parts of Sughd region are dominated by intensive agriculture, leading to declining groundwater levels and impacts on groundwater quality in some aquifers. The project aims to improve rural livelihoods and enhance resilience to climate change and water stress through conjunctive water management, with a strong focus on improving groundwater governance. The initiative seeks to establish sustainable, climate-resilient and participatory groundwater management in the Syr Darya Basin, targeting all water users.

A key project output is the development of groundwater-related expertise within academic and educational institutions, as well as state institutions involved in the groundwater sub-sector. Groundwater education, research and institutional capacities are strengthened through targeted capacity development activities. A systematic needs assessment approach is used to identify skill gaps and tailor interventions to the specific requirements of institutional staff.

Government departments are a major focus of the project, with the development of groundwater-specific training modules and professional training programmes. Emphasis is placed on the use of digital tools, supporting the national agenda for improving groundwater monitoring systems and advancing data digitisation across the country. Another important output is the development of a hydrogeological dictionary in the local language(s), aimed at improving technical understanding and communication within the sector.

Academic institutions are supported through institutional strengthening of key educational organisations offering hydrogeology programmes in Tajikistan. This support includes enhancement of laboratory and library facilities, alongside continuous improvement of staff technical knowledge and teaching capacities. The project adopts a step-by-step, integrated approach to capacity development, ensuring long-term sustainability and alignment with national groundwater management priorities.

LID 0413
The use of long-term monitoring data to delineate natural background levels for the assessment of groundwater contamination

Chris Cammaer[1]*, Eric Smolders[1], Valérie Cappuyns[2], Marijke Huysmans[1]

[1] KU Leuven, Department of Earth and Environmental Sciences, Campus Arenberg, Belgium
[2] KU Leuven, Centre for Economics and Corporate Sustainability, Campus Brussels, Belgium
* chris.cammaer@kuleuven.be

Keywords: hydrogeochemical properties, groundwater background levels, long-term monitoring, groundwater contamination, trace metals and major anions

The analysis of extensive datasets of physical and chemical parameters obtained from long-term groundwater monitoring facilitates the detection of contamination and the derivation of natural background levels of contaminants. Establishing reliable background levels is essential for accurately interpreting contamination and setting appropriate remediation targets. The study focuses on constituents that occur naturally but may also originate from anthropogenic activities, e.g. coal mining and non-ferro industry in the Flemish region of Belgium (trace metals and major anions).

This study presents an approach for estimating natural background groundwater quality from a regional long-term monitoring dataset (1985-2025). The approach involves the implementation of spatial filtering, a technique that involves the extraction of observations situated at a sufficient distance from known contamination sources. Additionally, the methodology incorporates the concept of hydrogeological stratification, which refers to the layering of the earth's water bodies based on their age, composition, and depth. The data are subdivided according to aquifer, and further classified according to redox conditions and groundwater confinement (phreatic versus confined). It is acknowledged that background chemistry is primarily controlled by water-rock interaction and local hydrogeological context.

The resulting background concentration ranges are subsequently utilised as reference conditions to assess groundwater quality within impacted areas. The approach demonstrates how a single monitoring network can simultaneously support background characterisation and contamination assessment, while accounting for spatial heterogeneity and hydrogeochemical variability. This framework provides a practical foundation for better interpreting groundwater quality data in regions with legacy pollution and evolving environmental conditions.

LID 0415

Drought in the Central American Dry Corridor: A comparative regionalism perspective on impacts and the need for transboundary groundwater-based solutions

Miguel Moreno[1,2]*, Nidhi Nagabhatla[2,3], Marijke Huysmans [1]

[1] Department of Water and Climate, Vrije Universiteit Brussel, Brussels, Belgium
[2] Institute on Comparative Regional Integration Studies, United Nations University, Brugge, Belgium
[3] Department of Economics and Business Administration, Ghent University, Ghent, Belgium
* miguel.moreno@vub.be

Keywords: drought, groundwater, regionalism

The Central American Dry Corridor (CADC), extending from Guatemala to Panama, is among the most climate-vulnerable regions in the world. Severe drought events, increasing in duration and intensity, aggravate regional challenges such as agricultural yield losses, food insecurity, groundwater stress, rural poverty, and forced migration. Despite the transboundary nature of droughts and regional vulnerability patterns, responses across the CADC remain fragmented and reactive and, in many cases, constrained within national borders. Since drought impacts, food systems, and aquifers are not restrained by administrative boundaries, the implementation of groundwater-based solutions to increase drought resilience depends heavily on the strength and type of regionalism.

A comprehensive analysis of the intensifying drought crisis in the CADC examines the barriers posed by different sectors, helping to explain why long-term resilience strategies remain limited. The analysis adopts a comparative regionalism approach to assess how transboundary integration mechanisms, governance frameworks, and institutional capacities address multi-sectoral drought challenges, as well as the potential for implementing regional mitigation strategies.

The assessment highlights persistent barriers to coordinated action, including uneven monitoring capacity and weak cross-border groundwater governance, driven by limited information on regional aquifers. We argue that drought in the CADC should be reframed not only as a climatic hazard but as a regional, multi-sectoral risk requiring sustained transboundary cooperation. Groundwater-centred regionalism is presented as both a technical and political pathway to strengthen regional integration. Shared drought-monitoring networks, open-source groundwater modelling, coordinated management strategies, and joint capacity-building can support a shift from crisis response to long-term resilience planning.

LID 0416
Drought and Managed Aquifer Recharge (MAR) in Mexico: Priority framework to increase drought resilience

Farah Matar[1], **Miguel Moreno**[1]*, Adrián Pedrozo [2] José Breña[2], Marco López[2], Catalin Stefan[3], Marijke Huysmans [1]

[1] Department of Water and Climate, Vrije Universiteit Brussel, Brussels, Belgium
[2] Instituto de Ingeniería, Universidad Nacional Autónoma de México, Mexico City, Mexico
[3] Research Group INOWAS, Technische Universitat Dresden, Dresden, Germany
* miguel.moreno@vub.be

Keywords: MAR, Mexico, drought, groundwater

The impacts of climate change and anthropogenic practices on ecosystems, societies and natural resources are becoming increasingly critical due to the rising intensity and frequency of extreme events such as droughts. In addition to climate change, anthropogenic factors affecting drought propagation and aquifer recovery in various regions of Mexico include deforestation, urbanization, and increasing groundwater extraction rates, whether for human consumption, industry, or agriculture. Considering current groundwater overexploitation trends in central and northern Mexico, the occurrence of more severe and frequent drought events makes these aquifers more vulnerable, significantly decreasing their resilience potential.

Managed Aquifer Recharge (MAR) comprises a series of techniques designed to enhance aquifer recharge and resilience to drought. For the successful implementation of MAR, it is necessary to identify suitable locations by balancing technical feasibility, potential water sources, and local needs. However, the spatial distribution of drought and the limited budgets in developing countries make it necessary to integrate new concepts into MAR suitability analyses.

This work proposes a comprehensive Drought Priority Framework (DPF) to identify critical areas where interventions should be implemented. It integrates hydrogeological and climatic factors by correlating groundwater storage anomalies and meteorological drought indices yielded from Earth Observation (EO) data to determine the time of onset of groundwater drought; by incorporating intrinsic aquifer characteristics, priority areas are determined. The DPF will identify critical areas for intervention to improve resource allocation and maximize the benefits of MAR implementations.

The proposed framework will benefit stakeholders, policymakers, and water managers by providing recommendations for future MAR projects, maximizing benefits and minimizing drought impacts on human livelihoods and ecosystems.

LID 0417
Geological and hydrogeological modeling of the Red River Delta to understand the origin of dissolved Arsenic

Nina Egli[1*], Ludovic Schorpp[1], Philippe Renard[1], Michael Mcglade[2,3], Lenny Winkel[2,3]

[1] Center for Hydrogeology and Geothermics, University of Neuchâtel, Neuchâtel, Switzerland
[2] Institute of Biogeochemistry and Pollutant Dynamics, ETH Zurich, Zurich, Switzerland
[3] Department of Water Resources and Drinking Water (W+T), Eawag, Dübendorf, Switzerland
* nina.egli@unine.ch

Keywords: arsenic, stochastic-modelling, inversion

Arsenic (As) contamination of groundwater is persistent throughout South and Southeast Asia, affecting the low and flat floodplains of rivers draining the Himalayas. This geogenic contamination exposes over 100 million people to As through their drinking water, posing a major health hazard.

Two affected areas are the Red River and Mekong deltas in Vietnam, where growing population and climate change combine with natural arsenic occurrence to form unpredictable spatiotemporal patterns of groundwater contamination. The sedimentological context of the area leads to highly heterogeneous deposits, which increase the difficulty in identifying these patterns.

To understand As variability in these environments, we develop a detailed ensemble of 3D geological models for the Red River delta using ArchPy, an automated, hierarchical method for stochastic geological modelling. The model includes 15 stratigraphic units and 5 main lithologies. An ensemble of models is generated using gaussian random fields for the unit boundaries and sequential indicator simulations for the lithologies. These geological models show that the shallower sediments are more clayey while the deeper ones are richer in gravels and sands.

This ensemble of geological models is then used to define the range of petrophysical properties used as input for MODFLOW 6 groundwater flow models. The horizontal and vertical conductivity, and abstraction multipliers, which account for the main sources of uncertainty in this area, are identified by matching the simulated groundwater levels against measurements using the parameter estimation software PEST.

The resulting models are then used to trace back the possible origin of water from sampling locations. The lithologies encountered along the flow path serve as an input for further statistical analysis to identify their possible links with As concentrations.

This framework investigates the role of geological heterogeneity in determining the origin of As in groundwater.

LID 0418
Assessing microplastic fate in riverbank filtration systems via large-volume sampling and Laser Direct Infrared (LDIR) Analysis

Jiaxing Ding[1]*, Thomas Grischek[1]

[1] University of Applied Sciences Dresden, Division of Water Sciences, Dresden, Saxony, Germany
* jiaxing.ding@htw-dresden.de

Groundwater is increasingly reported to be contaminated with microplastics (MP), yet results vary across different aquifers due to limited sampling volume (<20 L) and procedures. It is prone to artifact from wellbore materials and initial purging effect. This study investigates whether large-volume filtration on site can provide a more accurate assessment of MP contamination in the subsurface by mitigating these sampling-induced biases.

We implemented two on-site filtration cascades to compare the sampling efficiency between industrial-grade angled strainers and precision coupling cascades. Both systems were utilized to process at least 200–500 L of groundwater per sample. This large volume was identified as a critical threshold to achieve sample homogeneity and effectively avoid the overestimation typically associated with low-volume methods. Characterization was performed using Laser Direct Infrared (LDIR) spectroscopy, a high-throughput infrared technique that allows for rapid identification of polymers types and size distribution down to 20 µm. The methodology was applied across unconfined alluvial aquifers in the Elbe River catchment in Germany, representing riverbank filtration (RBF) sites with permeable sand and gravel (K 10^{-4} to 10^{-3} m/s) and bankfiltrate residence times from 10–60 days.

This study demonstrates a combination of high-volume on-site cascades with advanced LDIR detection, which is essential for characterizing MP transport dynamics and ensuring data integrity in managed aquifer recharge systems.

LID 0420
New perspectives on recharge and water quality from integrated groundwater and cave monitoring on the raised coral atoll Niue

Sebastian N. Höpker[1,2,3]*, Haden Talagi[4], Clinton Chapman[5], Grizelda Mokoia[6], Rossylynn Mitiepo[7], Adam Hartland[8], Andrew Pearson[9], Theo Sarris[10], Daryn Magatogia[11], Richard Siataga[12], Jeffrey Lang[8], Franziska A. Lechleitner[13], Sebastian F.M. Breitenbach[14], Bernat Oró-Nolla[1], Lukas Nerlich[1], Jule Werner[1], Christian Zwiener[1], Christiane Zarfl[1,2], Kira Rehfeld[1,2]

[1] Department of Geosciences, Geo- and Environmental Research Center (GUZ), University of Tübingen, Germany
[2] Cluster of Excellence (EXC 3121): TERRA – Terrestrial Geo-Biosphere Interactions in a Changing World, University of Tübingen, Germany
[3] Te Aka Mātuatua - School of Science, University of Waikato, Hamilton, Aotearoa New Zealand
[4] Niue Department of Environment, Alofi, Niue
[5] Niue Department of Utilities, Alofi, Niue
[6] Niue Department of Health, Alofi, Niue
[7] Niue Meteorological Service, Alofi, Niue
[8] Lincoln Agritech Ltd, Hamilton, Aotearoa New Zealand
[9] International Groundwater Resources Assessment Centre (IGRAC), Delft, The Netherlands
[10] New Zealand Institute for Public Health and Forensic Science (PHF Science), Christchurch, Aotearoa New Zealand
[11] Niue Department of Agriculture, Forestry & Fisheries, Alofi, Niue
[12] Niue Department of Justice, Lands, Survey & Community, Alofi, Niue
[13] Swiss Federal Institute for Forest, Snow and Landscape Research (WSL), Birmensdorf, Switzerland
[14] School of Geography and Natural Sciences, Northumbria University, Newcastle upon Tyne, United Kingdom
* sebastian.hoepker@uni-tuebingen.de

Keywords: observation, water chemistry, contaminants

Effective water management is, in many Small Island Developing States, hindered by a lack of comprehensive assessment and high vulnerability to natural and anthropogenic pressures on water quantity and quality. On the South Pacific raised atoll of Niue, groundwater dynamics are not yet well characterised. At the same time, extreme weather events and several sources of surface contamination threaten the aquifer's water quality. These challenges are exacerbated by highly corrosive conditions that accelerate infrastructure deterioration, as well as strong seasonal and inter-annual variability in local rainfall that complicate the management of water extraction and storage.

We address key knowledge gaps regarding Niue's freshwater resources, quantifying spatio-temporal recharge patterns and thresholds, and contributing to water quality assessments. Specifically, we test for known parameters negatively impacting water usability in island settings (e.g., salinity), as well as emerging contaminants (e.g., PFAS). We leverage Niue's limited size and its tropical karst geology, integrating continuous borehole monitoring with observations of potential recharge from several limestone caves within the island's vadose zone.

Supported by measurements of cave drip rates and chemical tracers in infiltrating water collected over the preceding six years, we discuss first results of our new island-wide hydrological monitoring campaign launched in late 2025. Our data further include preliminary analyses of water quality and natural tracers (e.g., stable water isotopes) from rainwater, caves and freshwater chasms, as well as groundwater bores and selected infrastructure (e.g., village reservoir tanks). Altogether, our findings already contribute to new temporal and spatial actionable knowledge for local resource management and public health. Ultimately,

we aim to provide novel insights into the longer-term sensitivity of Niue’s aquifer to regional impacts of global change.

LID 0422
Combining geological knowledge and observations to improve predictions of transport models

Zoé Petitjean[1,2]*, Alexandre Pryet[1], Olivier Atteia[1], Marc Kham[2], Mathieu Couplet[2], Raphaël Lamouroux[2], Frédéric Lalbat[3]

[1] UMR EPOC, Bordeaux INP, Pessac, France
[2] R&D – LNHE, EDF, Chatou, France
[3] Dir. Technique – TEGG, EDF, Aix-en-Provence, France
* zoe.petitjean@bordeaux-inp.fr

Keywords: preferential flow paths, transport models

Connected, highly permeable subsurface features act as preferential flow paths and strongly influence solute transport. Transport models are frequently used for risk assessment and mitigation and should properly account for these connected structures to provide unbiased and informative predictions.

The parameterization of hydraulic properties typically relies on multi-Gaussian distributions and poorly integrate geological knowledge in the prior. They allow for a flexible and efficient data assimilation of process variables (heads, concentrations), but may lead to unrealistic geology and insufficient description of connectivity. Alternatively, detailed descriptions of heterogeneities can be obtained with advanced geostatistical methods. They account for geological knowledge and can be conditioned to geological or geophysical data. However, they are hardly compatible with a data assimilation process and usually fail to match observed data.

To address this issue, we compared several approaches capable of integrating both geological knowledge and observation data. We employed different parameterization strategies by using pilot points, adopting a facies-like representation of the subsurface with truncated Gaussian simulations, or inserting structures whose positions can be adjusted. We also implemented data space inversion, which bypasses parameter estimation and focuses on the link between observations and forecasts.

The approaches are tested with a transport model considering a contaminant leakage scenario in a synthetic alluvial aquifer with permeable channels. The predictions of interest are the mass flow, peak time, and total mass of contaminant reaching the river. We find that, while pilot points can best assimilate observations, focusing on representing facies or structures allows for an easier depiction of connectivity in the prior. Those methods, as well as data space inversion used with detailed geological models, can help models make better predictions.

LID 0423
Machine learning approaches for spring detection in the Northern Apennines (Italy)

Ernesto Pugliese[1]*, Laura Landi[1], Darshan Moktan[1], Erica Tamagnini[1], Elettra Cavana[1], Stefano Segadelli[2], Maria Filippini[1], Alessandro Gargini[1]

[1] Department of Biological, Geological and Environmental Earth Sciences, Alma Mater Studiorum – University of Bologna, Bologna, Italy
[2] Geological, Seismic and Soil Survey, Emilia-Romagna region, Bologna, Italy
* ernesto.pugliese2@unibo.it

Keywords: spring detection, machine learning, remote sensing

The identification of springs over a wide area represents the first step toward understanding groundwater circulation patterns. In the absence of historical data regarding spring locations, surveying large territories can become complex and inefficient. Over the past decades, Remote Sensing and Machine Learning techniques have been increasingly applied across a wide range of scientific disciplines, particularly in hydrogeology, where they have substantially enhanced the analysis and interpretation of spatial and environmental data. The detection of springs using these approaches has been widely reported in the literature, particularly in areas characterized by limited data availability.

The Italian Institute for Environmental Protection and Research (ISPRA), responsible for environmental monitoring, land protection, and technical-scientific support to national and regional authorities, is funding the realization of several thematic geological maps. Among these, the hydrogeological thematic sheet No. 218 ”Castelnovo ne’ Monti”, currently being developed by the University of Bologna, covers an approximately 600 km^2 area in the Northern Apennines (Emilia-Romagna Region, Italy).

In the context of this project, after an intensive field survey, a dataset of more than 800 spring locations has been collected. This extensive dataset was used to train a machine learning algorithm in order to develop a prediction model of spring location. Integrating additional data (e.g., Remote Sensing, geological and topographic variables), we could generate spatially continuous prediction maps depicting the probability of spring occurrence. The resulting tool represents a valuable support instrument for similar studies conducted in comparable geological settings and data-scarce contexts.

LID 0424
Beyond status quo: Knowledge-based co-construction labs for climate adaptation in Sud-West Europe's thermal spa towns

Christian Iasio[1], **Victor Klaba**[1*], Georgina Arno Pons[2], Rosa Maria Moreno[2], Jessica Dieguez[3], Queralt Madorell Batlle[3], Isidre Pineda Moncusi[3], Jordi Martins Forns[3], Ana Jorge[4], Elsa Ramalho[5], Joao Carvalho[5], Luis M. Ferreira Gomes[6], Nuno Almeida[7], Ana Ladeiras[8], María Isabel Doval Ruiz[9], Javier Rodriguez-Novoa[10], Carlos Ontiveros Beltranena[11], María Elena Galindo Rodríguez[11], Clement Brunet[1], Cyril Aumar[1], Sylvia Becerra[12], Marion Roussel[13], Eric Brut[13]

1 BRGM-Délégation de Clermont-Ferrand, Aubière, France
2 Institut Cartogràfic i Geològic de Catalunya, Barcelona, Spain
3 Ajuntament de Caldes de Montbui, Caldes de Montbui, Barcelona, Spain
4 Termas de São Pedro do Sul, São Pedro do Sul, Portugal
5 Laboratorio Nacional de Energia e Geologia, Amadora, Portugal
6 Universidade da Beira Interior, Covilhã, Portugal
7 Camara Municipal de São Pedro do Sul, São Pedro do Sul, Portugal
8 Around Europe Advisors, Porto, Portugal
9 Universidade de Vigo, Ourense, Spain
10 Diputación Provincial de Ourense, Ourense, Spain
11 IGME-CSIC, Madrid, Spain
12 GEODE-CNRS, Toulouse, France
13 Thermauvergne, Royat, France

Keywords: energy transition, groundwater management, climate change adaptation, competing uses, collaborative governance, decision aiding systems

Climate change imposes new societal challenges, particularly conflicts over water and energy resources in thermal towns, necessitating a shift from status-quo practices. The ThermEcoWat project, presented at IAH2024, addressed this by supporting decision-making in three pilot sites, Chaudes-Aigues (France), Caldes de Montbui (Spain), and São Pedro do Sul (Portugal). Within the scope of this project, a replicable workflow integrating environmental, socioeconomic, and regulatory dimensions through a co-construction process allowed the joint definition and development of policies via thematic workshops and a knowledge-based decision-aiding tool for robust adaptation strategies.

The methodology structured co-creation around iterative meetings and analytical phases. Key features of the supporting tool included multi-criteria analysis tailored to local contexts. Driving criteria encompassed resource protection, shared governance, geothermal energy deployment, consolidation of therapeutic thermal water uses, and integrated urban planning.

Outcomes from three workgroups, each comprising remarkable stakeholders and decisionmakers, including geoscientists, elected municipal officials, and spa managers, revealed critical insights. First, policy constraints hinder good practices, underscoring needs for modernization. Second, opportunities for sustainable energy supply proved feasible, yet demand enhanced engineering expertise. Third, tensions emerged between long-term objectives/benefits and short-term investment demands, highlighting policymakers' challenges. Finally, knowledge-based tools effectively mitigated conflicts of interest, pointing to further advances in knowledge management engineering (i.e. AI-based information extraction) and transdisciplinary decision-aiding systems.

These climate adaptation labs demonstrate co-construction's potential to foster resilience amid competing uses, offering a scalable model for European thermal sites facing global change pressures.

LID 0425

Integrating thermal and hydrogeological properties in an alluvial aquifer: A comparative approach to TRT using analytical and numerical modelling in the Aconcagua Basin, Central Chile

Benjamín Carriel[1], Alfonso Mohor[1], Gabriele Galassi[2], Linda Daniele[1], **Matías Taucare**[1]*

[1] Departamento de Geología, Facultad de Ciencias Físicas y Matemáticas, Universidad de Chile, Santiago, Chile
[2] Università degli Studi di Urbino Carlo Bo, Dipartimento di Scienze Pure e Applicate, Urbino, Italy
* matias.taucare@gmail.com

Keywords: shallow geothermal energy, thermal response test, groundwater flow

Shallow geothermal energy represents an efficient alternative whose design depends on an adequate characterization of the subsurface hydro-thermal properties. In alluvial aquifers with active groundwater flow, advective processes can significantly affect thermal measurements and, consequently, their interpretation. This study presents an analysis of the thermal properties measured in a 200 m deep borehole drilled in an alluvial aquifer of the Aconcagua Valley, integrating long-term hydrogeological logging, a Thermal Response Test (TRT) using a heating cable and calibrated numerical modelling. The well monitoring reveals a complex dynamic characterized by a well-defined vertical zonation. In the shallow levels (<80 m), electrical conductivity (EC) increases from 300 µS/cm to 750 µS/cm, while temperature decreases from 17.5 °C to 16.5 °C with depth. Between 80 and 155 m depth, temperature and EC remain relatively constant. In the deeper section (>155 m), the presence of warmer groundwater (>19 °C) with lower EC (<600 µS/cm) is identified, indicating the influence of regional flow with advective heat transport. Thermal conductivity was estimated analysing the temperature response recorded during the TRT. The analytical Infinite Line Source (ILS) model, applied to the thermal recovery phase through an automated algorithm, yielded values consistent with the well lithology between 1.7 and 2.46 W/m·K. In contrast, the uncalibrated two-dimensional numerical model developed in FEFLOW significantly overestimated the thermal conductivity, whereas calibration using FEPEST produced values ranging between 1.79 and 2.40 W/m·K. The results highlight the importance of integrating hydrogeological information with robust numerical modelling for the proper interpretation of TRT data, providing technical criteria for the planning and efficient management of shallow geothermal systems.

LID 0426
Decision support tools for scientific story telling

Sorab Panday[1]*

[1] GSI Environmental Inc.
* spanday@gsienv.com

The future of sustainability depends as much on accessibility and communication as on advanced science. As environmental data grows more complex, static reports fall short. Interactive dashboards that convert inputs into real-time calculations and visuals enable managers to tell clear, defensible data stories. GSI's Managed Aquifer Recharge toolkit exemplifies this approach, translating technical evaluations into actionable investment decisions that link cost directly to water security outcomes.

LID 0427
Estimating aquifer dual-porosity transport properties through geoelectrical imaging of road salt plumes

Jean-Christophe Comte[1]*, Olivier Banton[2]

[1] University of Aberdeen, Aberdeen, United Kingdom
[2] University of Avignon, Avignon, France
* jc.comte@abdn.ac.uk

Keywords: aquifer transport properties, dual-porosity, road salt, electrical resistivity tomography

In field-scale studies of contaminant transport and energy storage, aquifers often exhibit dual-porosity behaviour where solutes or heat move rapidly through preferential flow pathways or fracture porosity rather than the bulk matrix. Active tracer tests, which involve tracer injection and recovery, are commonly used to assess seepage velocities and effective transport properties. However, they can be costly, may suffer from poor recovery, and often fail to capture aquifer scale heterogeneity.

An alternative, low-cost approach is presented using near-surface geophysical methods to passively monitor 'naturally' occuring contaminant plumes as tracers. In colder regions, de-icing salts applied to roads in winter leak into underlying aquifers, creating annual saline plumes that move with groundwater flow. This research explores the capability of electrical resistivity tomography (ERT) to detect these road salt plumes and estimate aquifer dual-porosity transport properties.

ERT data collected from two Permo-Triassic sandstone aquifers in Canada – one poorly and one moderately consolidated – revealed series of patches of elevated electrical conductivity downgradient of main roads. These patches are consistent with successions of annual salinity plumes drifting at velocities of 100–250 metres per year.

By calibrating a dual-porosity flow and transport model coupled with resistivity modelling, effective (fracture) porosity values were estimated to approximately 6% and 2% for the poorly and moderately consolidated sandstones, respectively. These figures are significantly lower than laboratory total porosity measurements of 20–30%, which reflect both fracture and matrix pore space. Solute transfer rates between fracture and matrix could also be quantified. The approach offers a cost-effective way to resolve key transport properties, and their heterogeneity when deployed at aquifer scale, essential for well management and thermal storage assessments.

LID 0428
Groundwater storage assessment in Lenasia South, city of Johannesburg, South Africa: A multi-source data approach

Lemogang Mokhosi[1]*, Khuliso Masindi[1], Ndamulelo Mutshafa[1]

[1] University of the Witwatersrand, Johannesburg, South Africa
* lemogangmokhosi@gmail.com

Keywords: aquifer characterisation, urban hydrogeology, sustainable groundwater management

Water scarcity is a growing global concern and cities in semi-arid regions are highly vulnerable because of population growth, urbanisation, and climatic variability. Johannesburg, for example, as South Africa's economic hub and largest city, is increasingly facing water insecurity due to these challenges. This is largely attributed to its reliance on surface water resources whose availability is progressively threatened by pollution, ageing infrastructure, rising demand and high evaporation rates. In response, groundwater has been recognised as a supplementary component of the urban water supply systems in this city.

This study investigates the potential of groundwater as an alternative water source in Lenasia South, an urban area within the City of Johannesburg characterised by expanding informal settlement development. A multi-source data approach was conducted, integrating geological and hydrogeological desktop studies, spatial analysis using GIS and Remote sensing, Electrical Resistivity Tomography (ERT) surveys, drilling and borehole data, pumping test analysis and groundwater geochemistry. ERT profiles were used to delineate aquifer extent and potential saturated zones to identify priority zones for drilling. During drilling chip logging provided information to characterise subsurface properties such as lithologies, stratigraphic sequences and geological structures. Pumping test data provided basis for estimating aquifer hydraulic properties and groundwater storage while hydrochemical analysis was used to assess water quality and treatment requirements.

Preliminary results indicate that groundwater has potential to serve as a complementary and reliable component to strengthen sustainable and climate-resilient urban water management strategies in Johannesburg, while providing a methodological approach transferable to other cities experiencing water insecurity in South Africa and beyond.

LID 0429
Vertical hydraulic gradients and thermal anomalies in the Alpu Basin (Turkiye): Indicators of concealed hydrothermal processes

Hatice Kilic-Germec[1]*, Hasan Yazicigil[1]

[1] Middle East Technical University, Ankara, Türkiye
* hakilic@metu.edu.tr

Keywords: concealed geothermal systems, advective heat transport, depth-dependent groundwater flow

Hydrogeological characterization conducted in mining areas to ensure safe operations and assess potential impacts on surface and groundwater resources generates high-resolution subsurface pressure and temperature datasets. Although these data are primarily used to support operational and environmental decision-making, their integrated evaluation may also reveal depth-dependent groundwater flow and coupled heat transport, potentially indicating concealed hydrothermal processes within sedimentary basins. To examine whether such coupling is reflected in the Alpu Basin (Central Anatolia, Türkiye), vertical hydraulic gradients and thermal anomalies are analyzed together within the lignite-bearing Neogene succession.

The analysis is based on 31 vibrating-wire piezometers installed at depths between 16 and 454 m. Hydraulic heads derived from pore-water pressure measurements were compared to hydrostatic reference gradients to assess vertical flow tendencies, and temperature–depth profiles were evaluated against expected conductive geothermal gradients to identify deviations from equilibrium conditions.

Results indicate persistent upward hydraulic gradients within deeper Miocene units at multiple locations, contrasting with the more dynamic hydraulic response of the shallow aquifer system. Pore-water pressures within the deeper lignite-bearing Miocene units reach up to 5.3 MPa, reflecting confined, overpressured conditions at depth. Temperature–depth profiles exceed the average geothermal gradient reported for Türkiye, reaching 37 °C at 450 m depth, approximately 8 °C above expected conductive estimates.

The spatial association between sustained upward hydraulic gradients and localized departures from conductive temperature profiles suggests that advective heat transport contributes to the observed thermal anomalies. These findings highlight the value of integrated pressure–temperature analysis for identifying vertically coupled flow systems, advancing basin-scale hydrogeological conceptualization, and providing a hydrogeological basis for evaluating concealed geothermal systems in sedimentary basins.

LID 0430
Retrospective and prospective on the use of fluorescent tracers in hydrogeology

Philippe Meus[1]*, Lee Anne Bledsoe[1], Nevila Jozja[1]

[1] European Water Tracing Services srl, Nandrin, Belgium
* ewts@skynet.be

Fluorescent tracers hold a predominant position in the history of artificial tracing in hydrogeology, mainly in karst hydrogeology due to their relative ease of implementation and their performance in terms of detectability. The main catalyst in the development of fluorescent dye tracing was technological advancement in analytical techniques, either using benchtop instruments or field fluorometers. Paradoxically, the panel of fluorescent dyes used has changed very little over several decades, regardless of toxicity concerns and lack of general acceptance as a routine scientific tool (few regulations are found until now, which means that it is holding things up). Moreover, there is a data gap in the characterization of the substances themselves and their analytical specificities. Tracer tests are often conducted as if each hydrogeologist is using their own recipe, adapted from that of another. A consequence is that even with the growing number of tests performed globally and the publishing of cartographic inventories, it seems difficult to define successful experiments and conduct subsequent comparisons between analytical techniques. Evidence of these discrepancies is that the techniques used on different continents appear quite distinct. A good example is the use of passive activated carbon receptors which is not perceived in the same way in the United States and Europe. A shift in the hydrogeological objectives of conventional tracer testing (i.e. in karst hydrogeology defining connections between sinks and springs) towards a need to investigate lesser accessible, hidden parts of an aquifer system, has made fluorescent dye tracing more challenging and somewhat scientifically delayed in consideration of real needs. Specifically, tracer data is needed for hydrogeological/hydrological applications such as drinking water protection, contaminate source tracking, mining, agriculture, artificial recharge, geothermal uses, wastewater management, and major risk prevention. Artificial tracers are sometimes used as a substitute for, or at least to confirm, the results of environmental tracers. We ask “do the techniques we are using nowadays respond to the demand of more precise data and resolution of sophisticated underground questions?”. Through a comprehensive review of the evolution of the techniques and the tracers, we decipher some key points in the prospective use of fluorescent tracers in hydrogeology. Understanding the tracers and finding consensus on the best analytical techniques is emphasized. Examples from the literature and from each of the authors’ own experience illustrate our hypothesis.

LID 0431
Short-and-dense versus long-and-sparse: Trade-offs in groundwater level time series analysis

Mateusz Zawadzki[1]*, Maziar Fekri[1], Marijke Huysmans[1]

[1] Vrije Universiteit Brussel, Department of Water and Climate, Brussels, Belgium
* zawadzkimat@outlook.com

Keywords: timeseries analysis, groundwater level, groundwater recharge, Pastas, SWAP

A growing affordability of sensor-based groundwater monitoring increases the volume of timeseries that cover only a few years of high frequency measurements (short-and-dense) in contrast to traditional manual measurements timeseries spanning decades (long-and-sparce timeseries). Time series decomposition has conventionally required long records to reliably separate deterministic signals from stochastic noise. However, there is potential in utilizing the tools of timeseries analysis for those datasets generated from, e.g., time-limited research projects.

In this work we systematically evaluate the trade-offs between data duration and frequency for estimation of infiltration rates at a managed aquifer recharge site in Kinrooi (Belgium), where treated wastewater is used for sub-irrigation. We utilize groundwater level records from multiple sensors. The dataset is experimentally degraded into two scenarios: (1) full dataset (5 years, monthly resolution) and (2) "short project" (3-year length, hourly frequency). As reference, we use long-term groundwater timeseries from the regional monitoring network. We then systematically assess the ability of the models to extract deterministic signals from the heads response using the open-source Pastas Python package.

Although Pastas already contains a non-linear recharge model which includes root zone reservoir, including it significantly increases the required timeseries length. Therefore, we couple the TFN model with the physically-based vadose zone model SWAP for recharge calculation to reduce the degrees of freedom in the TFN calibration. We aim to uncover which processes' "fingerprints" are lost or gained when moving to short-and-dense dataset and demonstrate how process-based constraints can effectively "substitute" for missing temporal length. The results provide practical guidelines for maximizing the value of contemporary telemetry data in hydrogeological systems analysis.

LID 0432
The mitigating effect of irrigation activities on near-surface groundwater salinization in the subsiding coastal estuary

ChiSan Tsai[1*], Jiaqi Liu[1], Yuka Ito[2], Tomochika Tokunaga[1]

[1] Department of Environment Systems, Graduate School of Frontier Sciences, The University of Tokyo, Tokyo, Japan
[2] Department of Geosciences, Graduate School of Science, Osaka Metropolitan University, Osaka, Japan
* tsaichisan@edu.k.u-tokyo.ac.jp

Keywords: groundwater salinization, low-lying coastal plains, land-use planning

Low-lying coastal plains are subject to saltwater intrusion, particularly where land subsidence occurs. Lowering land elevations caused by land subsidence enhances seawater intrusion into shallow aquifers, threatening freshwater resources. Irrigation in coastal regions through groundwater abstraction often exacerbates salinization, however, the impact of paddy field irrigation on near-surface groundwater salinization needs further investigations. Here, 3D coupled surface-subsurface flow modelling with HydroGeoSphere was used to investigate how paddy field irrigation affects near-surface groundwater salinity in a subsiding coastal estuary. Paddy field management uses a low-permeability paddy soil layer to maintain ponded water during the rice growing season, minimizing rapid infiltration and sustaining surface water retention. The numerical simulation results showed that when irrigation activities were active, continuous freshwater ponding led to the downward hydraulic gradients, pushing saline groundwater slightly deeper and freshening the near-surface zone. The freshening effect primarily occurs in the uppermost part of subsurface layer, indicating that agricultural water management mitigates near-surface salinization driven by tidal influence and land subsidence. These findings suggest that paddy cultivation practices, designed by local farmers to optimize water retention for rice production, potentially provide an unintended but significant benefit of maintaining a thin freshwater lens in salinized coastal aquifers, with implications for land-use planning in subsiding coastal agricultural areas.

LID 0435
Groundwater in the fractured rocks of Chacabuco, Maipo Basin, Central Chilean Andes

Denisse Toro[1,2]*, Matias Taucare[1,2,3], Linda Daniele[1,2,3], Benoit Viguier[4]

[1] Departamento de Geología, Universidad de Chile, Santiago, Chile
[2] Centro Avanzado para Tecnologías del Agua (CAPTA), Universidad de Chile, Santiago, Chile
[3] Centro de Excelencia en Geotermia de los Andes (CEGA), Facultad de Ciencias Físicas y Matemáticas, Universidad de Chile, Santiago, Chile
[4] CNRS, Université Côte d'Azur, Nice, France
* denisse.toro.a@gmail.com

The Water–Energy–Food (WEF) Nexus seeks integrated resource security to support sustainable development under climate change. Water, the focus of this study, is essential to all human activities and has experienced a significant global decline in storage due to unsustainable use [1][2]. Mountain environments, which play a key role in groundwater renewal, remain insufficiently studied [3]. Understanding recharge processes in these complex systems is critical to ensure present and future water availability.

The study area is the Chacabuco–Polpaico basin in Central Chile, located between the Andean foothills, characterized by Cenozoic and Mesozoic volcanic-sedimentary lithologies, and the Central Depression, composed of extensive fluvio-alluvial deposits. The basin is subject to significant anthropogenic pressure, including mining dams and wide distribution of agriculture. An integrated methodology combining hydrogeochemistry, isotopes, sensor monitoring, and geophysics was implemented to study the completeness of the basin. The main objective is to quantify the “Mountain Block Recharge” process [4].

Hydrogeochemical results from 36 groundwater samples (30 from sedimentary fill and 6 from fractured rocks) indicate predominantly HCO_3–Ca water types. Higher mineralization is observed in the mountain front, decreasing along the groundwater flow path toward the valley. Elevated concentrations of trace elements (B, Al, Fe, Mn, Zn, and Sr) are also identified in the water in mountain.

References:

[1] Jasechko, Scott, and Debra Perrone (2021). Global groundwater wells at risk of running dry. Science, vol. 372, No. 6540, pp. 418–21
[2] Famiglietti, J. S., & Ferguson, G. (2021). The hidden crisis beneath our feet. Science (New York, N.Y.), 372(6540), 344–345. https://doi.org/10.1126/science.abh2867
[3] Taucare, M., Viguier, B., Daniele, L., Heuser, G., Arancibia, G., & Leonardi, V. (2020). Connectivity of fractures and groundwater flows analyses into the Western Andean Front by means of a topological approach (Aconcagua Basin, Central Chile). Hydrogeology Journal, 28(7), 24292438. https://doi.org/10.1007/s10040-020-02200-3
[4] Markovich, K., H, Manning, A. H., Condon, L. E., & McIntosh, J. C. (2019). Mountain-block recharge: A review of current understanding. Water Resources Research, 55, 8278–8304. https://doi.org/10.1029/2019WR025676

LID 0438
Evolution processes of geothermal fluids in Rungwe Volcanic Province, Tanzania, interpreted from noble gas geochemistry

Koki Kashiwaya[1]*, Nyora Donald Kobare[1,2], Katsuaki Koike[1]

[1] Kyoto University, Kyoto, Japan
[2] University of Dar es Salaam, Dar es Salaam, Tanzania
* kashiwaya.koki.8a@kyoto-u.ac.jp

Keywords: geothermal fluid, noble gas, isotope

Understanding the circulation regime of water is crucial for achieving sustainable geothermal energy utilization. This presentation reports on the evolution processes experienced by geothermal fluids collected from the Kiejo-Mbaka and Songwe geothermal areas located in Rungwe Volcanic Province, Tanzania, based on the noble gas concentrations and isotopic compositions.

Analyzed samples were collected from hot springs distributed in the Kiejo-Mbaka and Songwe geothermal areas. Hot spring water was introduced into a copper tube using a submersible or peristaltic pump and collected by clamping the tube with metal clamps. The collected samples were analyzed using a quadrupole mass spectrometer and a noble gas isotope ratio mass spectrometer to measure the concentrations of He, Ne, Ar, Kr, and Xe, as well as the isotope ratios $^{3}He/^{4}He$, $^{20}Ne/^{22}Ne$, and $^{40}Ar/^{36}Ar$.

The isotope ratios of He, Ne, and Ar were similar to or higher than those of the atmosphere, suggesting contributions from the atmosphere and additional mantle- and rock-derived noble gases. Although noble gas concentrations varied across locations, they were comparable to those of water equilibrated with the atmosphere at elevated temperatures. ^{85}Kr was detected in bubbling gas in hot springs in these areas, whereas tritium was not detected in the hot spring water at most points [1]. The concentrations and isotope ratios obtained this time imply that water recharged before the 1950s re-equilibrated under subsurface high temperature. The ^{85}Kr in bubbling gas is presumably originating from the degassing of the gas dissolved through this re-equilibration, in addition to the entrainment of atmospheric air during water discharge. These results help interpret the circulation regimes of geothermal fluids in geothermal areas of the Great Rift Valley, such as the study area, and contribute to progress in geothermal energy utilization.

This study was supported by JSPS KAKENHI (Grant No. 23K26602) and JICA KIZUNA program.

Reference:

[1] Kashiwaya et al. (2025) IAH 2025 Abstract Book, 307

LID 0439

New developed isotopic preparative chromatograph for separation and purification enabling precise analysis of various non-traditional isotopes in geological samples

Jianye Gui[1,2]*, Chenling Zhang[1,2], Wei Zou[1,2]

[1] Institute of Hydrogeology and Environmental Geology, Chinese Academy of Geological Sciences (CAGS), Shijiazhuang, Hebei, China
[2] Fujian Provincial Key Laboratory of Water Cycling and Eco-Geological Processes, Key Laboratory of Groundwater Science and Engineering of Nature Resources, Xiamen, China
* Agui_mail@163.com

Keywords: matrix interference, stable isotopes, tracer, isotopic preparative chromatography (IPC), thermal ionization mass spectrometry (TIMS)

Many non-traditional isotopes, such as chlorine, magnesium, calcium, etc., are widely used as groundwater tracers. A new isotopic preparative chromatography (IPC) was developed and a new sample processing protocol of purification and concentration for isotopic analysis is presented to overcome many of the major drawbacks of existing methods. Contemporary sample preparation often requires several laborious off-line procedures in a ultra clean laboratory prior to instrumental determination; additionally, interference ions in real samples are difficult to completely remove, especially when the concentration of those ions is equal to that of the target ions. The new protocol includes the following steps: (i) one-step purification using a newly developed isotopic preparative chromatograph (IPC) with a background suppressed mode to obtain extremely pure components that only have target ions and H_2O; (ii) enrichment of the collected pure solution from the previous step using a newly developed ultra clean concentrator filled with high purity nitrogen; (iii) transforming the enriched target ion into suitable speciation inside the ultra clean concentrator; (iv) finally, sending the enriched solutions to a multi-collector inductively coupled-plasma mass-spectrometer (MC-ICP-MS) or thermal ionization mass spectrometer (TIMS). The present method was validated using certified reference materials and real samples for both chlorine and magnesium; the precision of chlorine ratio value was generally below 0.22‰ and that of Mg was below 0.12‰. This processing protocol provides a potential method for isotope sample preparation and analysis in a small number of geological samples with low concentrations of many other elements or compounds such as nitrate, sulphate, lithium, calcium, strontium, etc.

LID 0440
Development of a groundwater flow estimation method using cooling thermal response test focused on freezing–thawing processes

Shohei Albert Tomita[1]*, Yoshitaka Sakata[1]

[1] Faculty of Geosciences and Civil Engineering, Kanazawa University, Kanazawa, Japan
* albertst0218@gmail.com

Keywords: groundwater velocity, phase change, latent heat effects

Groundwater velocity governs subsurface mass and heat transport, and its accurate estimation is essential in many groundwater-related applications. Conventional thermal response tests (TRTs), which determine effective thermal conductivity under constant heating, have been used to infer groundwater velocity; however, their sensitivity is limited in both low-flow (<0.01 m/d) and high-flow regimes.

This study proposes a Cooling Thermal Response Test (Cooling-TRT), which enhances sensitivity to groundwater flow by inducing freezing and thawing in the subsurface. In this method, a circulating fluid at -5°C is circulated through a borehole heat exchanger for one week, followed by a recovery period. The duration of temperature stagnation near 0°C during thawing, controlled by latent heat effects, depends strongly on groundwater velocity.

Laboratory freezing experiments using saturated silica sand were conducted to examine phase-change behavior, and numerical simulations using FEFLOW with the piFreeze module reproduced the observed temperature evolution.

A field Cooling-TRT was conducted at Hokkaido University, Japan. Distributed temperature sensing using optical fiber sensors was applied under pumping and non-pumping conditions, and vertical groundwater flow velocity within the borehole was measured. Shorter thawing durations at shallower depths corresponded to higher vertical flow velocities.

A two-dimensional model incorporating groundwater flow and phase change was developed. Comparison between simulated and observed thawing durations (−1°C to 0°C) yielded estimated groundwater velocities of approximately 0.095 m/d at 10 m depth, 0.05 m/d at 30 m depth, and nearly 0 m/d at 70 m depth. The velocity–thawing duration relationship showed sufficient sensitivity to detect differences of approximately 0.01 m/d. These findings demonstrate that Cooling-TRT improves sensitivity to groundwater flow compared with conventional TRTs by utilizing freezing-thawing processes.

LID 0441
RRV-based assessment of groundwater extraction sustainability in an over-exploited piedmont plain

Dongmei Han[1,2]*, Guoliang Cao[3]

[1] Key Laboratory of Water Cycle & Related Land Surface Processes, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing, China
[2] College of Resources and Environment, University of Chinese Academy of Sciences, Beijing, China
[3] School of Water Resources and Environment, China University of Geosciences (Beijing), Beijing, China
* handm@igsnrr.ac.cn

Keywords: groundwater sustainability, groundwater dynamic equilibrium, precipitation deficit, RRV analysis

The sustainability of groundwater extraction is often assessed through changes in groundwater storage (GWS), yet the evaluation period covering complete recharge-drought cycles and the relative contributions of precipitation are seldom fully examined. This study focuses on the Beijing Plain, an overexploited piedmont region, to assess the sustainability of groundwater extraction by analyzing long-term variations in multiple regional factors from 1961 to 2023. Using regression analysis and dominance analysis (DA), we explore the relationships between GWS changes, precipitation, and groundwater pumping. Groundwater sustainability is evaluated based on reliability, resilience, and vulnerability (RRV) criteria, along with a sustainability index (SI) derived from GWS changes and precipitation deficits. Our findings show that GWS changes are significantly influenced by the frequency of dry and wet years, with DA revealing that 86% of GWS variation is attributable to precipitation. Notably, GWS loss during dry years accounts for 85% of total depletion, emphasizing the dominant role of droughts. The SI based on GWS changes systematically overestimates the system's sustainability by as much as 34% compared to the SI derived from precipitation deficits. This overestimation is primarily due to the misrepresentation of system reliability, caused by the threshold effects of non-stationary GWS changes. After the implementation of the South-to-North Water Diversion Project (SNWDP), signs of equilibrium in the groundwater system are emerging. However, GWS recovery does not necessarily equate to sustainability, as reflected in the declining SI trend. Even in groundwater systems heavily impacted by human activities and shaped by monsoon climates, assessing sustainability should prioritize the water scarcity situation rather than focusing solely on changes in water reserves. These results highlight the importance of reducing groundwater extraction through dynamically adjusted pumping rates to mitigate the risks of overexploitation in water-stressed aquifers.

LID 0442
Effects of Managed Aquifer Recharge (MAR) with reclaimed water on ambient shallow groundwater

Dongmei Han[1,2]*, Xianfang Song[1,2]

[1] Key Laboratory of Water Cycle & Related Land Surface Processes, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing, China
[2] College of Resources and Environment, University of Chinese Academy of Sciences, Beijing, China
* handm@igsnrr.ac.cn

Keywords: groundwater, reclaimed water, managed aquifer recharge

Managed Aquifer Recharge (MAR) using reclaimed water is an increasingly recognized strategy to address water scarcity. Current studies in this research field have primarily focused on the impacts of MAR on water quantity and quality, risk assessment, and long-term sustainability. This presentation will begin with an overview of key global research trends related to MAR, alongside an examination of relevant water quantity and quality indicators. These include conventional parameters (e.g., Cl^-, NO_3^-), emerging contaminants (such as Endocrine Disrupting Compounds (EDCs) and per- and polyfluoroalkyl substances (PFAS)), and shifts in microbial communities. MAR with reclaimed water offers several benefits, including enhanced groundwater recharge, improved aquifer hydraulic properties, and the dilution of native pollutants. However, potential negative impacts include increased salinity, the accumulation of persistent organic pollutants, and changes in bacterial communities. A case study from Beijing's Chaobai River (Shunyi section) illustrates these dual impacts. In Beijing, reclaimed water usage has exceeded 1.3 billion m^3 in 2024, comprising 31.4% of the total water supply, establishing it as a crucial "second source." From 2008 to 2017, the area impacted by reclaimed water grew from 11.7 km^2 to 26.7 km^2, with the range of chloride concentrations in groundwater rising from 5–75 mg/L to 50–130 mg/L. Additionally, EDCs (up to 7 ng/L) and PFAS (up to 31.3 ng/L in surface water) were detected, with concentrations diminishing downstream. Significant shifts in microbial communities in shallow groundwater were also observed. Finally, this study summarizes the distribution characteristics of typical pollutants found in reclaimed water in China. The findings highlight the critical role of MAR in alleviating water shortages, while underscoring the non-negligible environmental impacts. Effective monitoring and treatment strategies are essential to mitigate environmental risks and ensure the sustainability of water reuse practices. Balancing the benefits and potential hazards is key to achieving long-term success in managed aquifer recharge.

LID 0444
Development of a new pretreatment device and method for hydrogen and oxygen isotope analysis of complex matrix environmental samples

Jianye Gui[1,2]*, Chenling Zhang[1,2], Wei Zou[1,2]

[1] Institute of Hydrogeology and Environmental Geology, Chinese Academy of Geological Sciences (CAGS), Shijiazhuang, Hebei, China
[2] Fujian Provincial Key Laboratory of Water Cycling and Eco-Geological Processes, Key Laboratory of Groundwater Science and Engineering of Nature Resources, Xiamen, China
* Agui_mail@163.com

Keywords: hydrogen and oxygen isotopes, matrix effect, membrane technology, memory effect

The oxygen and hydrogen isotope compositions of water play an important role in various fields as powerful tools for studying water molecular paths in nature. For simple matrix samples, IRMS and IRIS have good test accuracy and precision, but the matrix in the actual environmental samples is complex, especially the organic matter and dissolved salt will have a great impact on the IRIS test. On the basis of assessing the effect of two types of matrix on spectroscopic testing, a set of simple installation, compact structure and convenient water isotope analysis matrix elimination instrument was developed and the complete set of isotope analysis methods was formed.

(1)The effect of different organic matter and different inorganic salts on the oxygen and hydrogen isotope analysis was systematically assessed.

Volatile small molecular organic compounds in the sample will cause serious deviation of the analytical results and cause irreversible damage to the precision optical cavity and other components of the analytical instrument. Among them, the δ^2H deviation caused by different volatile small molecular organic compounds below 5% concentration is between-1.96 and 113.24‰, and the deviation caused to $\delta^{18}O$ is between-0.99 and 66.50‰. The non-volatile macromolecular organic matter and inorganic salts have no obvious deviation impact on the test results of infrared spectroscopy in a short time, but the long-term accumulation will cause hardware damage such as inlet blockage and valve damage.

(2) A new designed pretreatment device of the hydrogen and oxygen isotope was completed and the analytical methods were developed.

With the membrane technology, different adsorption materials as the auxiliary, according to the requirements of isotope analysis technology, a set of isotopic matrix elimination device was designed and the corresponding analysis method was developed. The device mainly includes five parts, namely, initial filter module, membrane treatment module, rear adsorption module, backwashing module and energy supply module. the removal effect of different matrix components was evaluated, the average removal rate of glucose and FA with concentration below 5g/L is more than 99%, the average removal rate of inorganic salt with concentration below 10g/L is above 95%, After combining the adsorption material, the organic matter with concentration of 0.002~5%: the average removal rate of total Petroleum Hydrocarbon is more than 94%. The accuracy and precision of the isotope analysis of the whole analysis method can be controlled within 0.05‰ (for $\delta^{18}O$) and 0.5‰ (for δ^2H).

(3)The performance and effect of the new isotopically analytical method was evaluated.

Comparing the new method with the traditional distillation method, the removal rate of each gradient inorganic salt solution solution ranges from 76.3~93.6%, while the removal rate of the device is between 88.5~98.1%. The analysis error of $\delta^{18}O$ can be controlled between 0.01~0.05‰.

The pretreatment device formed in this study is light in size, easy to carry and easy to operate, and can be used for both indoor and field treatment.

LID 0445
Development of a 3D hydraulic tomography–based parameter heterogeneity estimation framework integrating deep learning and conditional simulation

ChiSan Tsai[1]*

[1] Department of Environment Systems, Graduate School of Frontier Sciences, The University of Tokyo, Japan
* tsaichisan@edu.k.u-tokyo.ac.jp

The heterogeneity of hydraulic parameters (K or Ss) is crucial for contamination remediation and may also vary over time due to the injection of oxidation treatment schedules, which may lead to different degrees of clogging. The Hydraulic Tomography (HT) is a well-developed approach for estimating three-dimensional hydrogeological parameters fields by capturing variations of groundwater head stimulated by pumping/injection events. The core of the HT is the successive linear estimation (SLE), a well-proven geostatistical inverse method in various scale problems. However, the computational efficiency decreases as the number of grid size or head observations increases. This limitation makes it challenging to monitor parameter changes over time, as multiple HT analyses must be conducted. In order to increase the efficiency, we propose a HT-based convolutional neural network (HT-NN) to replace SLE for converting groundwater head variations into hydraulic heterogeneity. Based on the result of first HT using SLE estimation, the domain of training fields can be constrained into a reasonable range by incorporating conditional random field and sampling strategy thus reduce training time. Then the conditional random field will treat as the training data of the network output. Subsequently, we execute the forward simulations for each random field to obtain the groundwater head variations as network input. We conducted a full-scale simulation using a 1m × 2m × 4m sandbox experiment the performance of HT-NN, which also includes Fenton injection to simulate clogging occurred during remediation. The results show that HT-NN successfully converts the groundwater head variations into hydraulic parameters fields. The development of HT-NN can be an efficient tool to depict the subsurface heterogeneity in real-time, and benefiting the strategies of remediation process over time.

LID 0446
Assessment of groundwater quality in compliance with SDG 6.3.2 set targets: Case study of South Africa

Tholoana Mabula[1]*, Lindelani Lalumbe[1]

[1] Department of Water and Sanitation, Pretoria, South Africa
* mabulat@dws.gov.za

Keywords: groundwater chemistry, sustainable development goal 6, compliance

Groundwater can have naturally elevated salinity concentrations, dissolved nutrients and metals. The natural (background) geochemical composition of the groundwater is directly related to the aquifer mineralogy and the rate of dissolution of the aquifer minerals into the groundwater. Because of the high variability in groundwater chemistry, in some cases, groundwater quality may not meet water quality guidelines set out for some relevant environmental values. Assessing groundwater quality using drinking water standards such as SANS 241 (2015) and WHO (2011) maybe misleading. The aim of this study was to assess groundwater compliance to the Sustainable Development Goal (SDG) 6 in South Africa for each of the hydrogeological regions. This will be achieved by comparing 2024/25 data with previous years datasets from the 65 hydrogeological regions. Each of the 65 Hydrogeological Regions (HR) were assigned groundwater quality targets (baseline) for Electrical Conductivity (EC), Nitrate (NO3-), Fluoride (F-) and pH. Groundwater quality data from the past 2021 to 2025 was used to determine compliance to set targets. The methodology applied determined that 80% of all hydrogeological regions with data complied with set groundwater quality targets. In terms of Nitrate (NO3-), seven of the hydrogeological regions (Central pan-belt, eastern highveld, lowveld, northeastern pan-belt, soutpansberg hinterland, swartland, waterberg plateau) groundwater quality data was over the set targets. High concentration levels of NO3-, EC and SO4- in groundwater resulted in 20% of the Hydrogeological regions not complying with set targets. Data shows an increase of Nitrate concentration levels in groundwater, in rural and agricultural communities which calls for the need of localised studies being carried out.

LID 0447
When groundwater models leave the modeller: Evidence, precaution and decision

Alastair Black[1,2]*

[1] Groundwater Science Ltd, Shrewsbury, United Kingdom
[2] Newcastle University, Newcastle, United Kingdom
* a.black@gwscience.co.uk

Keywords: modelling, decision-making, model defensibility

Models do not go to court — but their outputs are increasingly treated as evidence in consequential regulatory, policy and legal decisions. As groundwater models leave the modeller and enter institutional decision frameworks, their role changes. Continuous, uncertain hydrogeological systems are often interpreted through binary thresholds and precautionary rules.

In these settings, recurring patterns emerge. Screening models may be treated as determinative. Guidance-based metrics can harden into de facto compliance limits. Small numerical differences can carry disproportionate institutional weight. Precaution embedded in model design may combine with precautionary decision tests, producing compounded conservatism (“caution squared”).

Drawing on published inquiry material and outreach to experienced groundwater professionals across multiple jurisdictions, this presentation argues that these effects are structural features of decision frameworks rather than failures of modelling practice.

The aim is not to weaken environmental protection, but to strengthen defensible, transparent and proportionate use of groundwater models wherever they inform high-stakes decisions.

LID 0448
Physics informed neural networks for modeling groundwater flow

Marwan Fahs[1]*, François Lehmann[1], Thomas Nagel[2], Mohamad Mahdi Rajabi[3], Anis Younes[2], Hussein Hoteit[4]

[1] ITES, University of Strasbourg, CNRS, ENGEES, Strasbourg, France
[2] Geotechnical Institute, Technische Universität Bergakademie Freiberg, Freiberg, Germany
[3] Faculty of Science, Technology and Medicine, University of Luxembourg, Luxembourg, Luxembourg
[4] Physical Science and Engineering Division, King Abdullah University of Science and Technology (KAUST), Thuwal, Saudi Arabia
* fahs@unistra.fr

Keywords: groundwater flow, physics based models, neural networks

Deep Learning Neural Networks (DLNNs) are gaining significant attention in various applications related to groundwater flow. Physics-Informed Neural Networks (PINNs) help reduce the reliance of DLNNs on large datasets by incorporating physical laws directly into the training process. PINNs therefore represent a promising approach for groundwater flow applications, where data availability is often limited. However, most existing applications of PINNs are restricted to steady-state conditions, confined aquifers, and hypothetical case studies.

This work proposes an appropriate implementation of PINNs for modeling groundwater flow in aquifers. The proposed approach is based on a mixed pressure–velocity formulation of the governing equations, which helps overcome limitations of standard PINNs in modeling flow in heterogeneous aquifers. This formulation is coupled with a discrete-time integration scheme, allowing for improved training efficiency. In addition, a specific weighting strategy is developed to enhance the convergence of the training algorithm.

The proposed implementation is applied to simulate groundwater flow in an unconfined aquifer in France. The performance of the new PINNs without observational data is compared with a finite element solution. Advantages of the new PINNs implementation are also highlighted by comparing its results with purely data-driven models and in case with the boundary conditions are unknown. The results highlight several advantages of the proposed PINN framework and demonstrate that PINNs have significant potential to become a reliable and effective tool for modeling groundwater flow in aquifers.

LID 0449
From local springs to global signals: Why mandatory national spring monitoring is essential for groundwater status assessments

Klaus Hinsby[1*], Inga Retike[2], Francesco La Vigna[3], Anna Ladenberger[4], Jasper Griffioen[5], Anna Kuczyńska[6], Jean-Christophe Maréchal[7], Jaanus Terasmaa[8], Simone Ciadamidaro[9], Maria Rita Minciardi[9], Elena Egidio[10], Manuela Lasagna[10,] Manuel Sapiano[11], Christa Marie Pisani[11], Ana Silva[12], M. Teresa Condesso de Melo[12], Marcin Kiedrzyński[13], Teodóra Szőcs[14], Marco Petitta[15], Laurence Gourcy[16], Philippe Negrel[16], Georgina Arnó[17], Andres Marandi[18], Kirstin Lemon[19], Maria Ondracek[1], Peter van der Keur[1]

[1] Geological Survey of Denmark and Greenland (GEUS), Copenhagen, Denmark
[2] University of Latvia, Faculty of Science and Technology, Riga, Latvia
[3] ISPRA – Geological Survey of Italy, Rome, Italy
[4] Geological Survey of Sweden (SGU), Uppsala, Sweden
[5] TNO Geological Survey of the Netherlands, & Faculty of Geosciences, Utrecht University, Utrecht, The Netherlands
[6] Polish Geological Institute – National Research Institute, Warsaw, Poland
[7] G-EAU, BRGM, Univ Montpellier, France
[8] Institute of Ecology, Tallinn University, Tallinn, Estonia
[9] ENEA – Biodiversity and Ecosystems Laboratory, Saluggia, Italy
[10] Earth Sciences Department, University of Torino, Torino, Italy
[11] The Energy & Water Agency, Qormi, Malta
[12] CERIS/DECN, Instituto Superior Técnico, ULisboa, Portugal
[13] Department of Biogeography, Paleoecology and Nature Conservation, University of Lodz, Poland
[14] Ludovika University of Public Service, Institute for Environmental Sustainability, Budapest, Hungary
[15] Department of Earth Sciences, Sapienza University of Rome, Italy
[16] BRGM – French Geological Survey, Orléans, France
[17] Hydrogeology and Geoenergy Unit, Institut Cartogràfic i Geològic de Catalunya, Barcelona, Spain
[18] Geological Survey of Estonia, Rakvere, Estonia
[19] British Geological Survey/Geological Survey of Northern Ireland, Belfast, United Kingdom
* khi@geus.dk

Keywords: springs, monitoring, global change

Springs are critical interfaces between groundwater (GW) and surface water, sustaining baseflow, regulating water chemistry, and supporting GW-dependent ecosystems. They play a unique role in connecting surface and subsurface ecosystems and in sustaining ecosystem services and water supply. Despite their ecological, socio-economic, and cultural significance, springs are rarely monitored consistently, leaving major gaps in assessing the impacts of geology, climate change, and human pressures on water resources and ecosystems (including groundwater microbiology and stygofauna). The lack of systematic spring monitoring leaves scientists and policymakers without the information needed to observe and forecast changes. Therefore, we propose that internationally standardised monitoring of springs, including discharge, water chemistry, and ecological parameters (including eDNA), should be mandatory under national environmental legislation that protects water resources, ecosystems, and biodiversity. Discharge time series are essential for detecting changes in GW recharge, storage, and flow regimes driven by climate change and abstraction. Monitoring the chemical properties of springs enables early detection of contamination, salinisation, and biogeochemical changes that affect ecosystem services

and water safety and security. Monitoring should include physicochemical parameters, major ions, trace metals, DOC, selected organic and inorganic contaminants, pathogens, and age indicators to infer recharge processes, pollution pathways, and residence times. Ecological monitoring should focus on spring-specific biota and functional indicators, including macrophytes, benthic invertebrates, microbiology, and habitat sustainability. Only integrated hydrological, geochemical, and ecological monitoring provides an effective framework for assessing GW chemical, quantitative, and ecological status, to ensure that changes are detected early enough to enable immediate preventive action.

Twelve of the contributing authors (seven of the contributing institutes) have received national funding for the SentinelSprings project from Fundação para a Ciência e a Tecnologia-I.P. (FCT-Portugal), Agence Nationale de la Recherche (ANR-France), Ministero dell'Università e della Ricerca (MUR-Italy), Narodowe Centrum Badań i Rozwoju (Poland), Innovation Fund Denmark (Denmark), Ministry for the Environment, Energy and Public Cleanliness (MEEC-Malta) and the European Union's Horizon Europe Programme under the 2023 Joint Transnational Call of the European Partnership Water4All (Grant Agreement n°101060874)

LID 0450
Insight from mountain groundwater flows: Springs in deformed and partially-covered karst aquifers in the Roya Valley (Saorge, France)

Benjamin Baud[1,2*], Franciszek Pęski[3,1], Valérie Plagnes[3], Benoît Viguier[1], Tim Bulle[1,2], Sara Lafuerza[4], Diana Chourio Camacho[3], Jamel Benmamar[3], Aurélie Noret[5], Emmanuel Tric[2], Jean-Marc Terpereau[6], Christian Gorini[4]

[1] Université Côte d'Azur, CNRS, OCA, IRD, GEOAZUR, France
[2] Université Côte d'Azur, IMREDD, France
[3] Sorbonne Université, CNRS, EPHE, METIS, Paris, France
[4] Sorbonne Université, CNRS-INSU, Institut des Sciences de la Terre de Paris, ISTeP UMR 719, Paris, France
[5] Université Paris-Saclay, CNRS, GEOPS, Orsay, France
[6] Remontons la Roya, France

Keywords: mountain aquifer, Mediterranean Alps karst, hydrochemistry, water isotopes, structural geology

In mountainous area, surface water from runoff and snowmelt has long been considered sufficient to supply the local needs. While global warming is already driving changes in the surface water availability, groundwater appears to be a more resilient resource, even though it remains poorly studied. This is particularly true in the Mediterranean Alps, where "extreme" precipitation event (Alex Storm in 2020) and drought (2022-2023) are expected to become more frequent. In order to improve knowledge about the functioning of the Mediterranean Alps aquifers, a geological and a hydrogeological characterization are underway in the Roya Valley at Saorge (southern of France, Alpes Maritimes). There, perennial and semi-perennial springs, located between 381 m asl and 742 m asl, flow from the Jurassic karst and overlying colluvium with sometimes Cretaceous marls between both aquifer layers, respectively. Springs supply agricultural activities and drinking water. Most of the springs EC ranges from 193 to 601 µS/cm and are of the Ca-HCO_3 type with calcite over-saturation ($SI_{Calcite}$>0). However, two springs in the valley bottom show higher electrical conductivity (800-1000µS/cm) and are of the Ca-SO_4 type, suggesting that karst groundwater interacts with the underlying Triassic gypsum (SI_{Gypsum} >-1). $\delta^{18}O$ and $\delta^{2}H$ suggest that colluviums and karst springs have a recharge zone located between 560 and 1300 m asl, while Ca-SO_4 karst springs originate from higher elevation around 1700 m asl. This suggests a dual hydrogeological system, with i) small extent aquifers sensitive to short droughts in colluvium locally connected to underlying Jurassic karst by fractures cut-crossing Cretaceous marls and ii) a deformed regional karst system draining water from mountain highs sensitive to long-term decline of snow cover. The overall results encourage to pursue the monitoring of springs over a longer period and on a larger scale to address hydrogeological processes in the Roya valley.

This study is funded by both French Research Agency ANR (Saorge Story) and European Union (Interreg-Alcotra ALPIMED+ ECOTERR). Authors thank Saorge village's inhabitants and municipality for their cooperation.

LID 0452
Hydrogeochemical control by tectonic lithologic contacts in hyperalkaline springs of the Ronda peridotite massif (Málaga, Spain)

Lucía Ojeda[1]*, Pablo Jiménez-Gavilán[1], Antonio Castro-Gámez[1], José Benavente[2], Iñaki Vadillo[1]

[1] Department of Geology, Faculty of Science, University of Málaga, Spain
[2] Department of Geodynamics and Water Research Institute, University of Granada, Spain
* luciaor@uma.es

Keywords: hyperalkaline springs, peridotite

Hyperalkaline springs are characteristic features of serpentinized ultramafic regions and provide valuable insight into deep groundwater circulation and water–rock interaction processes. The Ronda Peridotite Massif (Málaga, southern Spain) hosts the largest known number of hyperalkaline springs in Europe. In this massif, spring occurrence and chemistry are closely linked to tectonic contacts between peridotites and adjacent lithologies, indicating that structural–lithologic interfaces exert a primary control on both fluid pathways and geochemical signatures.

Nine springs were monitored from 2020–2022, including outlets in peridotites and at contacts with limestones, high-grade metamorphic rocks, and flysch units. Waters are highly alkaline (pH 10–12.2) and moderately to highly mineralized (400–1800 µS/cm). The data support a two-stage evolution: (1) deep serpentinization produces Ca–OH fluids with extremely low Mg (<1 mg/L), as Mg is incorporated into secondary serpentine/brucite phases; (2) ascent along fault-controlled pathways leads to lithologic interaction. Springs at metamorphic contacts show higher dissolved Si, while those through schists/flysch are enriched in Na, K, Cl, and Br, increasing mineralization and altering the primary Ca–OH signature. Carbonate-contact springs preserve Ca–OH traits with carbonation, while granular peridotite springs show minimal geochemical overprinting. One spring exhibits higher Mg (up to 19 mg/L), elevated Si and HCO_3^-, and slightly lower pH, suggesting mixing with less-evolved or shallower waters.

Overall, although a common serpentinized fluid underlies the system, final water compositions are mainly shaped by structural compartmentalization and lithologic interactions along tectonic contacts, which control flow paths and geochemical fingerprints.

LID 0453
Development of higher education modules on managed aquifer recharge – a nexus approach

Cornelius Sandhu[1]*, Thomas Grischek[1], Hemant Kumar[2], Gopal Krishan[3]

[1] University of Applied Sciences Dresden (HTW Dresden), Dresden, Germany
[2] Indian Institute of Technology Roorkee, Roorkee, India
[3] National Institute of Hydrology, Roorkee, India
* cornelius.sandhu@htw-dresden.de

Keywords: riverbank filtration, water-food nexus, hydro-economic modelling

Increasing worldwide groundwater extraction and the need to develop new technologies for water treatment is expected to drive the application and development of managed aquifer recharge (MAR) and its elements such as riverbank filtration (RBF) in future. And, the quality and the relevance of post-graduate (PG) studies must be appropriate to meet the consequent demands of research and the industry. This presentation will share our experiences since 2016 on the development and implementation of academic and training measures that are aimed to enhance competence on MAR amongst post-graduates, PhD researchers and professionals from water companies/industry.

The experiences derive from week-long RBF training courses and workshops that were conducted for professionals from water supply companies in India and Egypt. Shorter workshops were conducted there and in the Middle East. Their content included methods to select MAR sites, the design of RBF schemes including well-design, geohydraulic and water quality aspects. This basic structure was expanded into the organization of one- to two-week long MAR summer schools (2021-2026), supported with funds from the German Academic Exchange Service (DAAD). Topics on numerical groundwater flow and transport modelling, hydro-economic modelling, risk-assessment, field and lab investigation methods and a MAR project were added to attract more PG students and researchers.

Positive indicators were the evaluations received from the participants, their diverse academic backgrounds and nationalities, the participation of young and also experienced professionals and that 60 applicants applied per year against only 12 places. Multiplier effects were an expansion of the network and synergies with other projects resulting in more collaborations. An evaluation of the participants' willingness to self-finance their participation, showed that the sustainability of such intensive summer schools is dependent on third-party funding.

LID 0454
GRUVO – An operational machine learning-based platform for groundwater level forecasting in Germany

Stefan Broda[1]*, Patrick Clos[1], Mariana Gomez[1], Roland Harhoff[1], Matthias Heber[1], Martin Krombholz[1], Maria Wetzel[1], Markus Zaepke[1], Bastian Habbel[2], Tanja Liesch[2], Marc Ohmer[2]

[1] Federal Institute for Geosciences and Natural Resources (BGR), Berlin, Germany
[2] Karlsruhe Insitute of Technology (KIT), Karlsruhe, Germany
* stefan.broda@bgr.de

Keywords: groundwater level forecasting, machine learning, national-scale assessment

GRUVO is an operational platform developed at BGR for analysing and forecasting groundwater levels across Germany. It integrates long-term groundwater level monitoring data from the federal state environmental and geological agencies into a harmonised national framework and combines them with observed and projected meteorological data.

The approach follows two steps. Monitoring sites are grouped according to similarity in groundwater level dynamics using Self-Organising Maps (SOM). Clustering is based on diagnostic features describing variability, periodicity, trend components and recession behaviour rather than on raw hydrographs. Within each group, representative reference wells are selected for modelling.

Forecasts at these reference wells are generated using one-dimensional convolutional neural networks (1D-CNNs) driven by gridded climate data. Performance is evaluated using temporally separated training and validation periods. Only wells meeting predefined quality criteria are included in the operational forecast.

GRUVO provides observed and forecast time series together with model diagnostics at the monitoring site level. In parallel, monthly national summaries are derived from the proportion of monitoring sites assigned to defined groundwater level classes relative to 1991–2020. These summaries support simplified communication of groundwater conditions beyond the specialist community.

This contribution will also discuss operational constraints encountered in national-scale implementation and outline ongoing work on regionalisation beyond reference wells using static site descriptors.

LID 0455
An innovative vertical flux sensor for hyporheic exchange monitoring

Goedele Verreydt[1,2]*, Niels Van Putte[1,2], Patrick Meire[2], Maria Grodzka-Łukaszewska[3]

[1] iFLUX, Niel, Belgium
[2] ECOSPHERE, University of Antwerp, Wilrijk, Belgium
[3] WMH, Warsaw University of Technology, Warsaw, Poland
* goedele@iflux.be

Keywords: hyporheic flow, sensor development, wetland ecosystems

Quantifying hyporheic exchange between groundwater and surface water remains challenging due to strong spatial heterogeneity and temporal variability at the sediment–water interface. Conventional methods often provide only indirect or time-averaged estimates and fail to capture short-term fluctuations and flow reversals that control biogeochemical processes and restoration outcomes. An innovative vertical groundwater flux sensor was developed to provide continuous, in situ measurement of exchange dynamics in wetland river systems.

The sensor consists of a vertical probe with a flow channel between two slotted intake zones in hydraulic contact with surrounding sediments. A bidirectional microfluidic thermal mass flow chip detects temperature asymmetry caused by flow across a heated element, allowing determination of flow direction and magnitude. The sensor probe is installed within the streambed, in direct contact with the sediment.

We will explain the sensor technology and present the results of sensor measurements in several wetland ecosystems in Europe. The vertical flux sensor captures rapid changes in hyporheic exchange, driven by diurnal evapotranspiration cycles, seasonal variability and restoration efforts, such as rewetting. In addition, we compare these results with groundwater and surface water level dynamics in the same timeframe.

While the sensor excels in capturing short-term variability in flux, which is not detectable with conventional techniques, further work is required to achieve robust quantitative flux estimates. Therefore, we invite collaboration to improve installation methods and to calibrate the sensor to account for flow field distortion and local sediment properties. These further developments will enable translation of sensor signals into reliable absolute vertical fluxes across diverse field conditions, and will allow authorities and site owners to better monitor and manage their local sites and ecosystems.

LID 0456
Monitoring groundwater ecosystems: Lessons from 20 years of sampling in the Murray–Darling Basin, Australia

Kathryn Korbel[1]*, Grant Hose[1]

[1] School of Natural Sciences, Macquarie University, Sydney, Australia
* kathryn.korbel@mq.edu.au

Groundwater ecosystems occur in almost all aquifers and support diverse microbial and stygofauna communities. Groundwater ecosystems perform critical functions, such as nutrient and carbon cycling, that help maintain clean water and support groundwater-dependent ecosystems such as wetlands, rivers and terrestrial vegetation. Despite their importance, groundwater ecosystems have historically been poorly monitored, prompting the need for robust, long-term monitoring programs to detect change, assess condition, and inform adaptive management.

Our team has undertaken groundwater ecosystem monitoring for around 20 years, generating one of the most comprehensive datasets of its kind. This dataset includes ten sub-catchments of the Murray–Darling Basin, with more than 250 monitoring sites sampled for stygofauna, microbes, water levels and water chemistry. This long-term record captures substantial spatial and temporal variability in groundwater quality, biotic communities, and ecosystem function across contrasting hydrogeological settings. Such variability highlights the importance of sustained monitoring to differentiate natural dynamics from anthropogenic pressures, including abstraction, landuse change and climate variability.

To support consistent assessment and reporting, the NSW government has adopted the Groundwater Health Index (GHI) as a core evaluation framework. The GHI integrates water chemistry, stygofauna and microbial data, and ecosystem-function metrics into a structured method for determining groundwater ecosystem health. This approach enables transparent reporting, improved comparability across regions, and targeted management responses. This presentation outlines new advancements in monitoring methodologies, and preliminary findings from two decades of groundwater ecological data, and highlights management implications for the protection of groundwater ecosystems and their services.

LID 0457
Large-scale groundwater abstraction beneath a freshwater lake for long-term sustainable drinking water supply

Perry G.B. de Louw[1,2*], Geert-Jan Nijsten[1], Ilja America- van den Heuvel[1,3], Bas Knaak[1], Joost Delsman[1]

[1] DELTARES (Groundwater department), Utrecht, The Netherlands
[2] Wageningen University (SLM), Wageningen, The Netherlands
[3] Utrecht University, Utrecht, The Netherlands
* perry.deLouw@deltares.nl

Keywords: sustainable drinking water supply, national groundwater model

Climate change and population growth will increase groundwater demand for drinking water and agriculture and putting more pressure on groundwater reserves. Besides this, current groundwater abstractions already affect groundwater-dependent ecosystems and stream baseflows. Dutch water companies therefore seek sustainable ways to expand their water supply while reducing impacts. MAR-systems are promising but require sufficient high quality recharge water, which is a limitation.

A new potential solution has been posed in the Netherlands which is large-scale extracting groundwater beneath Lake IJssel. This former bay of the North Sea, closed off in 1932, is now a large freshwater lake (1,133 km^2) continuously fed by the River IJssel. The main advantage of using groundwater below the lake is the virtually unlimited freshwater source at the top minimizing effects of abstractions on the shallow system and impacts on groundwater dependent functions. Analysis of available salinity data shows a mix of fresh, brackish, and saline groundwater in the aquifers below the lake due its paleogeographic history. Of 66.000 million m^3 groundwater present below the Ijssel lake, approximately 8-10% is fresh (Cl<0.15 g/L) and 60-70% is brackish (<5.0 g/L Cl), suitable for drinking water production via RO desalination.

The Dutch national variable-density groundwater model was used to explore extraction scenarios (pumping well positions and regimes) and impacts on hydraulic heads, salt loads, salinity distributions, pumped water quality and travel times to pumping wells. Results indicate that a minimum of 150 million m^3 suitable groundwater can be extracted without adverse effects on the shallow water system and its dependent functions. Pumping-induced recharge from the overlying lake freshens the aquifers. An additional win win is achieved by locating wells near low lying polders with saline seepage, reducing salt loads and increasing fresh surface water availability for irrigation.

LID 0458
Socio-hydrogeological approaches for climate-resilient groundwater management in the coastal zone of Southwestern Nigeria

Moshood Tijani[1*], Olutoyin Fashae[2], Sarafat Tijani[3], Jamiu Aladejana[1], Kehinde Thomas[3], Tibor Stigter[4], Yangxiao Zhou[4]

[1] Department of Geology, University of Ibadan, Oyo State, Nigeria
[2] Department of Geography, University of Ibadan, Oyo State, Nigeria
[3] Department of Agric Extension and Rural Development, University of Ibadan, Nigeria
[4] UNESCO IHE Institute of Water Education, Delft, The Netherlands
* tmoshood@gmail.com

Keywords: socio-hydrogeology, coastal aquifers, groundwater, saltwater intrusion, climate change, hydrochemistry, community engagement, southwestern nigeria

There is no doubt that, coastal communities increasingly depend on groundwater to meet rising domestic, agricultural, and industrial water demands under rapid socio-economic development and climate-driven environmental change. In the coastal areas of Southwestern Nigeria, groundwater serves as a primary freshwater resource, yet it is increasingly threatened by quality deterioration, saline intrusion and governance limitations. This study integrates hydrogeological investigations with social and institutional analysis to examine the drivers, patterns, and impacts of groundwater degradation and explores stakeholder-driven pathways to improve long-term coastal groundwater management and water security.

Using a field-based hydrogeophysical (60 VES points) and hydrochemical characterization (80 groundwater samples), spatial assessments of groundwater quality indicators were presented alongside community and stakeholder water-use practices, and perceptions. The study identifies major degradation hotspots and associated key stressors to include coastal flooding, land-use change, poor sanitation and waste disposal practices, and evolving climatic conditions that alter recharge dynamics and increase seawater intrusion vulnerability. Findings also highlighted a dual challenge of declining groundwater quality and constrained adaptive capacity in the coastal communities, emphasising the need to address social equity and governance mechanisms to strengthened groundwater monitoring systems and community-based stewardship to improved sanitation and waste disposal practices.

This study highlights the significance of scientific collaborations to incorporate indigenous knowledge in proffering joint community-driven solutions, while addressing sustainable groundwater and environmental-related problems in coastal communities and offer an adoptable model for strengthening climate change resilience of vulnerable coastal communities in southwestern, Nigeria.

LID 0459
Nitrogen dynamics and natural attenuation in the unsaturated zone: Insights from a high-resolution study in the Arborea NVZ (Italy)

Francesca Lobina[1]*, Stefania Da Pelo[1], Antonio Coppola[1], Riccardo Biddau[1], Andrea Vacca[1], Claudio Arras[1], Maria Chiara Porru[1], Antonio Maria Sessini[1], Salvatore Vacca[1]

[1] Department of Chemical and Geological Sciences, University of Cagliari, Monserrato, Italy
* francesca.lobina@unica.it

Keywords: nitrate, unsaturated zone, nitrates vulnerable zone

The intensification of agricultural and livestock activities has historically led to the surplus application of organic and chemical fertilizers, challenging the sustainability of agroecosystems. Despite regulatory efforts like the EC Nitrate Directive, nitrogen (N) losses remain a critical issue in Nitrates Vulnerable Zones (NVZs). Central to this challenge is the unsaturated zone, a key but often neglected that regulates water movement and the leaching of N-species from the soil to the aquifer.

This study explores nitrogen dynamics and natural attenuation mechanisms within the soil-water-rock continuum to identify strategies for minimizing environmental impacts while sustaining productivity. Research was conducted at a pilot site in the Arborea Plain (Sardinia, Italy), an NVZ characterized by intensive dairy farming. We implemented a high-resolution monitoring system—including TDR probes for volumetric water content and suction cups for pore-water sampling—to track N-transformations through the soil profile.

By integrating chemical analysis with nitrate isotopes, we evaluated the biogeochemical processes and natural attenuation mechanisms occurring during transport through the unsaturated zone. Our findings highlight how seasonality and agricultural practices influence nitrogen dynamics, with deeper soil layers often accumulating higher nitrate concentrations due to complex, overlapping reactions. This research bridges the gap between fundamental process understanding and practical applications, providing essential data to optimize nitrogen management. The results offer a scientific basis for developing targeted mitigation strategies to safeguard groundwater resources while sustaining agricultural productivity.

Acknowledgments: This work was carried out within NPP-SOL — Modelling and Technological Tools to Prevent Surface and Ground-Water Bodies from Agricultural Non-Point Source Pollution under Mediterranean Conditions (PRIMA Call 2022, Section 2). This project is part of the PRIMA programme supported by the European Union. CUP F33C23000150006

LID 0460

Multiple lines of evidence provide a holistic and testable conceptualisation of complex ecosystem-groundwater dynamics at the Doongmabulla Springs Complex, Queensland, Australia

Richard Cresswell[1]*, Anne Gibson[1], Michael Short[1], Sophie Pyrke[1], Emily Bathgate[1], Miles Yeates[2], Penn Lloyd[3], David Stanton[4], Richard Heath[5]

[1] Eco Logical Australia, Newcastle-Canberra-Adelaide, Australia
[2] Essence Environmental, Brisbane, Australia
[3] BAAM Ecology, Brisbane, Australia
[4] WaterMark Ecohydrology, Brisbane, Australia
[5] Tetra Tech Coffey, Melbourne, Australia
* richardc@ecoaus.com.au

Keywords: GDEs, drones, springs, chemistry and isotopes

The Doongmabulla Springs Complex (DSC) in Central Queensland, Australia, comprises over 160 individual vents, ranging from less than 10 cm across supporting individual tussocks of grass to wetlands over 9 hectares with permanent pools of water. These unique springs are home to a variety of plant species (many endemic) that are specially adapted to the varied physical, chemical and hydraulic conditions of the local environment and the groundwater discharge on which they rely.

We have examined these springs across multiple spatial and temporal scales, using remote and field data acquisition techniques, to develop a detailed understanding of the water, soil and floristic characteristics and dynamics at a selection of these springs, documenting species zonation and vegetation dynamics related to seasonal and climatic variability and the local physico-chemical conditions. From these targeted studies we interpolate and extrapolate to other springs in the complex to identify additional studies to fill data gaps. Critically, local drone imagery has augmented regional satellite data to constrain spatial and temporal discharge patterns of springs, whilst inter-seasonal variability in chemistry and isotopes highlight the importance of groundwater for spring health. Notably, run-of-river Radon-222 analysis constrains spatial groundwater discharge patterns.

The DSC conceptualisations must be coherent at all spatial and temporal scales to be used to customise mitigation responses at individual springs and to consider potential changes from climate change and local mining activities. Thus, multi-dimensional conceptualisations inform, and are informed by, a regional numerical groundwater model and link regional observations to local, spring-specific eco-hydrological modelling (described in a companion talk: Gibson, et al. *this abstract book*).

LID 0461
Integrated electrical resistivity and hydrochemical assessments of saltwater intrusion in coastal aquifers of Southwestern Nigeria

Moshood Tijani[1]*, Jamiu Aladejana[1], Abraham R. Adeniyi[1], Tibor Stigter[2], Yangxiao Zhou[2]

[1] Department of Geology, University of Ibadan, Oyo State, Nigeria
[2] UNESCO IHE Institute of Water Education, Delft, The Netherlands
* tmoshood@gmail.com

Keywords: electrical resistivity, hydrochemical assessment, saltwater intrusion, resistivity model, coastal area

The extent of seawater intrusion in coastal areas is influenced by recharge rate, groundwater over-extraction, geology, and climate change. This study assessed the depth and lateral extension of saltwater intrusions in the Coastal Alluvium and Coastal Plain Sands aquifers of parts of southwestern Nigeria using integrated electrical resistivity and hydrochemical approaches. One hundred and thirty-five (135) water samples were tested in situ for electrical conductivity (EC) comprising 126 groundwater and 10 surface water samples) while thirty-nine (39) Vertical Electrical Soundings (VES) were conducted with current electrode spacing (AB/2) ranging from 1 to 300 m, using the Schlumberger configuration.

The resistivity inversions/models were generated and interpreted with WinGLink software, and converted into 2D pseudo-sections and resistivity thematic maps. Results from profiles (A–A' and B–B') reveal resistivity variations from 1 to 200 m depth, while maps at 20 m intervals (1–100 m) show progressive changes in resistivity inland. Low resistivity values (<50 Ωm), corresponding to high EC values (>10,000 µS/cm), consistently indicate saline water intrusion zones (SWIZ) near the coast, particularly around Ugbonla and Ogogoro. However, inland areas display higher resistivity, reflecting freshwater-bearing sands of the Benin Formation.

Further evaluation revealed lateral extent of the intrusion to be about 5km inland, with penetration depths ranging from 20 to 200 m. In addition, ground-truth validation with EC measurements and continuous monitoring with CTD-Diver loggers installed in coastal wells also revealed higher EC values with average of 3,708 µS/cm suggesting active saline intrusions controlled by tidal effects, seasonal recharge, climate-induced sea level rises and groundwater flow direction.

LID 0463
Hydro-mechanical coupling and pore-scale clogging controls on injectivity decline in a geothermal sandstone aquifer

Rita Mwendia Njeru[1,2]*, Matthias Halisch[3], Arne Jacob[4], Andreas Weber[4], János Szanyi[5]

[1] HUNREN EPSS, Sopron, Hungary
[2] HUNREN TKI, Rybach Research Center, Hungary
[3] LIAG Institute for Applied Geophysics, Hannover, Germany
[4] Math2Market GmbH, Kaiserslautern, Germany
[5] University of Szeged, Department of Geology, Szeged, Hungary
* mwenderita@gmail.com

Keywords: hydro-mechanical coupling, injectivity decline, pore-scale clogging, effective stress

Sustained geothermal production in weakly consolidated sandstone aquifers depends on preserving long-term injectivity under coupled hydraulic and mechanical loading. In the Dunántúl Group of the Hungarian Pannonian Basin, reinjection wells frequently exhibit rapid permeability decline, suggesting a combined influence of particle retention and stress-sensitive pore structure.

This study integrates laboratory core-flooding experiments, X-ray µ-CT based pore network characterization, and digital rock simulations to investigate hydro-mechanical controls on injectivity evolution. Experimental results demonstrate progressive permeability reduction dominated by internal filtration and pore throat bridging rather than external filter cake formation. Quantitative pore-scale analysis shows that pore throat radii are comparable to suspended particle fractions, placing the system near the mechanical straining threshold.

Numerical simulations incorporating lithostatic stress and variable injection pressures reveal that increasing effective stress reduces pore throat radii and connectivity, shifting the critical particle-to-throat size ratio toward enhanced retention. In this weakly cemented sandstone, stress-induced throat contraction amplifies particle trapping and promotes deep-seated clogging within the injection zone. Elevated injection pressures may therefore initiate a feedback mechanism in which localized clogging increases pressure gradients, further modifying effective stress and accelerating permeability decline.

Results indicate that particle-induced permeability reduction increases local pressure gradients, modifying effective stress and promoting additional pore throat contraction. This hydro-mechanical feedback mechanism provides a process-based explanation for accelerated injectivity decline and defines the need for operational pressure limits for sustainable reinjection.

LID 0464
Transient time-series analysis to identify anomalous aquifer recharge in the Shenzhen megacity, China

Diego Di Curzio[1]*, Michele Lancia[2], Paolo Fabbri[1], Chunmiao Zheng[2], Stefano Viaroli[3]

[1] Department of Geosciences, University of Padua, Padua, Italy
[2] Eastern Institute for Advanced Studies, Eastern Institute of Technology, Ningbo, China
[3] Department of Earth Sciences, University of Pisa, Pisa, Italy
* diego.dicurzio@unipd.it

Keywords: anthropogenic recharge, time series analysis, urban aquifer

Urban aquifer regimes are often influenced by interactions with the overlying built environment. Pumping and drainage induce drawdowns, whereas leakages from water supply or sewage networks, and irrigation of gardens or small agricultural areas, can produce localized, unconventional recharge. Such sources are frequently associated with contaminant leaking, posing risks to groundwater quality. Shenzhen (China) is a megacity, in which early urbanization created dense low-rise districts with extensive impervious surfaces and subsurface infrastructures. This aquifer is a phreatic system hosted in weathered laterites derived from igneous and metamorphic rocks, locally mixed with fine-grained alluvial deposits.

A monitoring network of 27 disused hand-dug wells and newly drilled piezometers provides daily groundwater level data. In addition, 27 meteorological stations uniformly distributed across the municipality record rainfall. We applied the Sliding-Window Cross-Correlation Function (SW-CCF) to rainfall and groundwater level time series to detect anomalies in recharge dynamics linked to unconventional sources. SW-CCF evaluates the rainfall-groundwater levels relationship within consecutive time windows. This approach allows assessment of temporal variations in rainfall-driven recharge and identification of secondary natural or anthropogenic contributions. Because groundwater records contained missing data due to temporary instrument malfunctions, we applied the machine learning method Multivariate Imputation by Chained Equations to impute reliable missing values.

Results show that rainfall–head correlations peak during the wet season (April-October), with response times of 1–3 days, decreasing where groundwater is shallower. During dry periods, some wells decorrelate from rainfall, likely due to connections with wetlands or streams. Similar anomalies in urbanized areas, unrelated to surface water, suggest local anthropogenic recharge (e.g., sewer leaks, or subirrigation).

LID 0465
Preservation of connate seawater in deep sedimentary aquifers: A case study from The Netherlands

Vincent Post[1]*, Frans Schaars[2], Davíd Brakenhoff[2]

[1] Edinsi Groundwater, Amsterdam, The Netherlands
[2] Artesia Water, Schoonhoven, The Netherlands
* info@edinsi.nl

Keywords: groundwater salinity, sedimentary basins, Tóthian flow systems

Seawater trapped in marine deposits is common in sedimentary basins around the world and their occurrence has been widely discussed in the scientific literature. In this contribution we present the available data about brackish groundwater in the deeper (> 200 m) parts of the sedimentary aquifer system of the Netherlands. Its origin dates back to the Pliocene and Early Pleistocene epochs, when much of the current land surface of the Netherlands was covered by the sea.

Unlike brackish groundwater of Holocene age, these deeper waters have not received a great deal of attention. The factors that play a role in their preservation are therefore largely unknown. For example, it is unclear if their salinity remained high because the deepest aquifer parts were not completely flushed by freshwater, or if their salinity is being sustained by diffusion from underlying aquitards. This question has become pertinent for public water supply now that deeper aquifers are being targeted as a source of drinking water.

To increase our understanding of the ancient brackish groundwater we systematically mapped their occurrence using the available geological, geophysical and hydrochemical data from the national groundwater database of the Netherlands. We used numerical models to simulate Tóthian flow systems in subsiding aquifers over geological timescales (2 Ma).

Our results show that, despite the available time for freshwater flushing, it is conceivable that remnants of seawater have been preserved in the deepest parts of the aquifers. Sediment burial brings the marine strata out of the reach of the most active parts of the topographically-driven flow system. Solute transport then becomes more and more dominated by diffusion rather than by advection. The practical implication is that preservation of seawater remnants in permeable layers poses a greater risk of salinization when groundwater flow gets reactivated by extraction than if they were trapped within low-permeability strata.

LID 0466
Reducing nitrate loads to a Mediterranean aquifer: Effects of crop-rotation strategies and soil nitrogen gas fluxes

Sandra Pool[1], **Joaquin Jimenez-Martinez**[1,2]*

[1] Department of Water Resources and Drinking Water, Eawag, Dübendorf, Switzerland
[2] Department of Civil, Environmental and Geomatic Engineering, ETH Zurich, Zürich, Switzerland
* joaquin.jimenez@eawag.ch

Keywords: nitrate leaching, aquifer contamination, soil nitrogen emissions

Mediterranean agriculture is often characterized by intensively irrigated row-crop systems that exert considerable pressure on local water resources and biogeochemical cycles. The Campo de Cartagena in south-eastern Spain—one of Europe's major vegetable- and fruit-producing regions—is a paradigmatic example, where high productivity supported by up to three crop cycles per year depends on substantial irrigation and nitrogen fertilizer inputs. These practices have long contributed to nutrient enrichment in the nearby coastal lagoon, but they also drive persistent nitrate leaching and deep percolation that threaten the underlying aquifer, a critical freshwater resource in this semi-arid region. In response to ongoing environmental degradation, regional authorities recently limited farmers to two annual crop cycles. However, effective groundwater protection requires a clearer understanding of how crop-rotation choices and the timing of fallow or cover-crop periods influence both aquifer contamination risks and soil-atmosphere nitrogen fluxes. In particular, reducing nitrate leaching may inadvertently shift nitrogen losses toward gaseous pathways (e.g., N_2O), with implications for greenhouse-gas emissions and reactive-nitrogen budgets. In this study, we integrate field measurements with computational modelling to quantify how alternative crop-rotation schemes and fallow/cover-crop strategies affect the full water and nitrogen balance, including (i) deep percolation and nitrate leaching toward the aquifer and (ii) soil nitrogen gas emissions under current climatic conditions. By explicitly linking groundwater contamination pathways with above-soil nitrogen losses, our results provide actionable guidance for designing crop-management practices that simultaneously mitigate aquifer pollution risks and manage soil-derived emissions, supporting more sustainable agriculture in water-limited Mediterranean regions.

LID 0467
Governance pathways for transboundary groundwater cooperation: Lessons from Zambia

Marie-Amélie Pétré[1,2]*, Mkhuzo Chongo[3] , Eric Chibuye Chitambo[3], Jani Rollet[3], Emma Ndhlovu[3], Adamson Sakala[3], Stanley Hantambo[3], Abel Manangi[3], Ngosa Howard Mpamba[3], Oswell Katooka[3]

[1] Geological Survey of Finland (GTK), Espoo, Finland
[2] Now at BRGM (French Geological Survey), Orléans, France
[3] Department of Water Resources Development, Ministry of Water Development and Sanitation, Lusaka, Zambia
* marieamelie.petre@gmail.com

Keywords: governance, transboundary aquifers, international cooperation

Effective international water governance depends on cooperation over both shared river basins and transboundary aquifers. Zambia, situated in a region facing severe water crises and frequent droughts, has recognized transboundary action as essential for resilience. This commitment was reinforced when Zambia became a Party to the UN Water Convention in 2024. This contribution presents the findings of a comprehensive desk study commissioned by the "Water Cooperation and Peace-Finnish Water Way project, aimed at assessing Zambia's shared groundwater resources to foster sustainable cooperative management.

The study identified 13 transboundary aquifers shared between Zambia and its neighbours. While initial inventories have been refined, notably along the Malawi border where nine aquifers were delineated, significant knowledge gaps remain. Most aquifers are currently defined only as two-dimensional shapes with limited understanding of hydrodynamics, water quality, or sustainable yields. A key finding is that eight of the thirteen identified aquifers overlap with Transfrontier Conservation Areas (TFCAs), such as the Kavango Zambezi (KAZA) TFCA, highlighting a critical opportunity to leverage synergies between groundwater management and biodiversity conservation.

Despite existing river basin organizations like ZAMCOM expanding mandates to include groundwater, Zambia currently lacks specific operational agreements for these aquifers. To address these challenges, this study proposes a strategic pathway structured around key priorities: 1) developing a national strategy to systematically screen the border and improve hydrogeological understanding; 2) conducting "hotspot analyses" to prioritize aquifers facing quantity or quality pressures; 3) implementing conjunctive management that integrates surface water, groundwater, and conservation areas; and 4) building trust through joint assessments and harmonized data-sharing frameworks.

LID 0468
Mapping groundwater dependent ecosystems in a mountain setting: An integrated approach

Alessandro Gargini[1]*, Zhila Mahmoudi[1], Stefano Segadelli[2], Marco Cantonati[1]

[1] Alma Mater Studiorum University of Bologna, Bologna, Italy
[2] Emilia-Romagna Region – Geology, Soil and Seismic Risk, Bologna, Italy
* alessandro.gargini@unibo.it

Keywords: groundwater dependent ecosystems, springs, Northern Apennines

The identification of Groundwater Dependent Ecosystems (GDEs) in mountain regions is still limited by the poor recognition of groundwater, by policy an decision makers, as a key driver of biodiversity. In the Apennines, this gap affects management plans, where springs, streams and wetlands are treated as purely surface ecosystems, overlooking the role of the aquifer and neglecting the hydrological vulnerability of the GDE to the land use and climate change of the recharge area. In order to address this issue, an integrated approach for mapping GDEs is proposed based upon five key elements: (i) the spatial distribution of springs, either fully natural or partially uptaken (petrifying springs with tufa formation, recognized as a priority habitat under the EU Habitats Directive, are also included); (ii) aquifer characterization in terms of effective recharge, groundwater storage (stock) and resilience to climate change; (iii) assessment of naturalness, ecological continuity and ecosystem integrity; (iv) quantification of anthropogenic pressures linked to infrastructures, withdrawals and land-use impacts; (v) inclusion of upgradient stream reaches draining main aquifers, recognised as linear GDEs because their summer flow is sustained by groundwater discharge. This activity has resulted in the development of a comprehensive map of springs and strategic aquifers, including also the ”groundwater towers” of the chain, that are considered essential for the protection of biodiversity, habitats, and environmental flows. The resulting framework supports conservation prioritization, sustainable groundwater resource management, and planning decisions in mountain areas increasingly exposed to reduced water availability and climate induced hydrogeological stress. The approach is designed to be replicable and transferable to other mountain settings, offering a robust tool for improving the integration of groundwater processes into ecosystem management.

LID 0470
Temporal evolution of emerging contaminants in groundwater from an area irrigated with reclaimed wastewater

Iñaki Vadillo Pérez[1]*, Marta Inés Llamas Dios[1], Pablo Jiménez Gavilán[1], Lucía Ojeda[1]

[1] Department of Geology, Faculty of Science, University of Málaga, Spain
* Vadillo@uma.es

Keywords: emerging contaminants, reclaimed wastewater, alluvial aquifer

The Axarquía, a semiarid region in the south of the Iberian Peninsula (Spain), is one of the Europe's most important producers of avocado and other subtropical crops. The extreme water crisis of 2019-2024 exposed a long-term structural imbalance between water demand and availability. Piezometric levels of the Vélez alluvial aquifer, in the centre of the Axarquía, dropped dramatically due to excessive groundwater extraction. To alleviate water shortages, tertiary treated wastewater (i.e., reclaimed wastewater; RWW) is currently being used for irrigation. Compared to conventional water resources, RWW contains higher concentrations of chemicals derived from domestic activities, often referred to as emerging contaminants, that may reach the underlying aquifer through return flows.

A plot of avocado farmland overlying the Vélez aquifer, irrigated with a mixture of RWW and reservoir water, was selected for water quality monitoring over a one-year period beginning in July 2025. Samples collected from a piezometer located within the plot, from a well situated upstream of the farmland and from the irrigation water mixture were analysed for general hydrochemistry, metals and organic contaminants (i.e., pesticides, pharmaceuticals and personal care products).

Between July 2025 and September 2026, twenty-nine compounds (fragrances, antibiotics and other pharmaceuticals) were detected in the irrigation water. Nine of these were detected in groundwater from the piezometer from the study plot, some at higher concentrations, suggesting an accumulation process. The use of reclaimed wastewater explains the occurrence of emerging contaminants in groundwater that were not detected upstream of the irrigated area. The absence of certain compounds in groundwater that were present in the irrigation water may be attributed to several processes that may occur simultaneously, including sorption to solid particles in the soil/vadose zone, (bio)degradation and plant uptake.

LID 0471
Advancing knowledge for sustainable groundwater management in Sardinia: An integrated multi-isotopic approach

Stefania Da Pelo[1], Riccardo Biddau[1], **Maria Chiara Porru**[1]*, Francesca Lobina[1], Fabrizio Antonio Piscedda[1], Vittorio Fancello[1], Antonio Maria Sessini[1], Claudio Arras[1], Mara Calia[1]

[1] Department of Chemical and Geological Sciences, University of Cagliari, Monserrato, Italy
* mariachiara.porru@unica.it

Keywords: isotopes, contamination, groundwater management

Sardinia (Italy) represents a complex Mediterranean laboratory characterized by extreme geological heterogeneity. Despite an estimated availability of about1,500 Mm^3 per year,, groundwater is still an underutilized resource, primarily due to a historical reliance on surface reservoirs. However, the escalating impacts of climate change, increasing water scarcity, and diverse anthropogenic pressures now necessitate a strategic shift toward a comprehensive knowledge-based management of these aquifers. Over the last decade, multi-isotopic tracers have been used to complement monitoring by constraining processes --recharge areas, flowpaths, mixing-- and identifying sources of salinity and contamination, thereby reducing conceptual uncertainty in aquifer models. This integrated methodology is effectively demonstrated through three critical case studies across the island. In the Muravera coastal plain, an extensive isotopic suite including Strontium ($^{87}Sr/^{86}Sr$), Boron ($\delta^{11}B$), Sulfate ($\delta^{34}S\text{-}SO_4$, $\delta^{18}O\text{-}SO_4$), Tritium, and Helium was deployed to study seawater intrusion dynamics, successfully identifying flowpaths, and the origin of groundwater. In the Arborea Nitrate Vulnerable Zone (NVZ), the island's primary agricultural district, the application of nitrate isotopes ($\delta^{15}N\text{-}NO_3$, $\delta^{18}O\text{–}NO_3$) coupled with stable water isotopes allowed for the precise fingerprinting of contamination within the Quaternary deposits. Finally, in the Portoscuso industrial district, one of the most polluted areas of Sardinia, characterized by high sulfate concentrations, $\delta^{34}S_{SO4}$ and $\delta^{18}O_{SO4}$ and water isotopes were utilized to discriminate between geogenic sulfate dissolution, legacy mining impacts, and active industrial contributions.

These applications show that geochemical and isotopic analyses add process-based constraints that inform monitoring design and support management choices. They can help value groundwater and, considering quality and availability, guide allocation to appropriate uses (e.g., potable supply versus irrigation). They also support zoning of protection areas, vulnerability assessment, and prioritization of actions, including well protection, nitrate mitigation, and control of industrial discharges.

This study was funded by Agreement POA FSC 2014–2020 - 16.12.2019 among the ex MATTM- DGSTA and River Basin Authority (AdB) of Sardinia - Service for the protection and management of water resources, water services and drought management - Regional Agency of the River basin district of Sardinia, Action 2.3.1 "Interventions to improve the quality of water bodies". CUP F72G16000000001

LID 0472
From hydrogeology to perception: A participatory framework for co-producing water knowledge in a risk-prone mountain territory

Valérie Plagnes[1]*, Remontons La Roya[2], Karine Emsellem[3], Benoit Viguier[4], Sara Lafuerza[5], Isabelle La Jeunesse[3], Diana Chourio Camacho[1], Raquel Bonh Bertholdo[6], Barbara Blin-Barrois[7], Atelier Rural en Roya[8], Christian Gorini[5]

[1] Sorbonne University, CNRS, EPHE, METIS, Paris, France
[2] Association Remontons la Roya, Breil sur Roya, France
[3] Université Côte d'Azur, CNRS, AMU, Avignon Université, ESPACE, France
[4] Université Côte d'Azur, CNRS, OCA, IRD, GEOAZUR, France
[5] Sorbonne Université, CNRS-INSU, Institut des Sciences de la Terre de Paris, ISTeP UMR 719, Paris, France
[6] Aix Marseille Univ, Université Côte d'Azur, Avignon Université, CNRS, ESPACE, UMR 7300, Avignon, France
[7] Association Couleur Forêt, France
[8] Association Atelier Rural en Roya, Breil sur Roya, France
* valerie.plagnes@sorbonne-universite.fr

Keywords: groundwater, society, interdisciplinarity

The research program "Saorge STORY" aims to develop a transversal and participatory approach to understanding water-related issues in the village of Saorge, located in the Roya Valley (Southeastern France), a region exposed to significant natural hazards such as landslides, floods, and droughts. The project is co-constructed by an interdisciplinary research team bringing together geologists, hydrogeologists, geographers, sociologists, and social psychologist from universities, in collaboration with a local residents' collective ("Remontons La Roya") and artists from the valley. Its objective is to produce a comprehensive understanding of the interactions between physical and human dimensions, using water as the main territorial entry point in its diversity (resources, hazards, knowledge, uses, and perceptions). The methodological choice is to apply this approach to a geographically limited area—the village of Saorge in the Roya Valley, in the hinterland of Nice—in order to facilitate an in-depth analysis of the interactions between nature, society, and territory by combining temporal and spatial scales.

The program seeks to analyze the interplay between environmental dynamics (hydrology and geology) and human behaviors (perceptions, land and water uses) within this restricted territory. It adopts a systemic and interdisciplinary framework, involving citizens and artists in the co-production of scientific data and in the co-design of outputs, particularly in science communication. The innovative dimension of the project lies in the continuous integration of scientific, artistic and local knowledge throughout the research process. The results will contribute to a deeper local understanding of society–environment interactions centered on water, facilitating the exercise of citizenship in conscious and appropriate water management. Beyond advancing understanding of water-centered society–environment interactions at the local scale, the project aims to establish a transferable methodological framework for interdisciplinary and participatory research in other risk-prone territories. The presentation will outline the consortium, research design, and the initial phase of co-constructing priority water-related issues.

LID 0473
Aquifer reaction to high-temperature energy storage as a key for a sustainable energy transition

Andrés Velásquez-Parra[1,2]*, Roman Alther[1,3], Reto Britt1, Megan Lee[1,2], Christian Moeck[1], Numa Pfenninger[1], Serina Robinson[1], Kim Schlegel[1], Giulia Zecchin[1], Florian Altermatt[1,3], Michael Berg[1], Matthias Brennwald[1], Rolf Kipfer[1], Mario Schirme[1,4,5], Olga T. Schubert[1,2], Andreas Voegelin[1], Robert Weber[6], Lenny Winkel[1,2], Matthias Sulzer[6], Joaquín Jiménez-Martínez[1,2]

[1] Swiss Federal Institute of Aquatic Science and Technology, Eawag, Dübendorf, Switzerland
[2] ETH Zurich, Zurich, Switzerland
[3] University of Zurich, Zurich, Switzerland
[4] University of Neuchâtel, Neuchâtel, Switzerland
[5] Laval University, Quebec City, Canada
[6] Swiss Federal Laboratories for Materials Science and Technology, Empa, Dübendorf, Switzerland
* andres.velasquez@eawag.ch

Keywords: underground energy storage, groundwater monitoring, energy transition

Underground energy storage is one of the most promising alternatives for achieving a sustainable energy transition. High-Temperature Borehole Thermal Energy Storage (HTBTES) systems use the subsurface as a thermal battery by allowing the storage of excess heat deep in the subsurface during summer, which then remains available for extraction in winter. Depending on the number of boreholes, which act as heat exchangers, and on their depth, expected temperature changes in the subsurface can reach up to 65 °C. However, the effects of such large temperature changes on the aquifer's behaviour remain unanswered, mostly due to the complexity and high cost of performing on-site analyses around operating facilities. In the ARTS project (Aquifer's Reaction to Thermal Storage), we currently investigate the impact of underground energy storage on the underlying aquifer with emphasis on the changes in groundwater chemistry, microbial activity, microbial community composition, and groundwater fauna derived from the cyclic heating and cooling of the subsurface. This is done through an extensive three-year field work campaign consisting of both continuous on-site monitoring and additional periodic sampling and post-analysis at four measurement stations installed in the vicinity of an HT-BTES facility finished recently at the Empa-Eawag campus in Dübendorf, Switzerland. First results after a first mid-temperature heating cycle (38 °C) reflect a very stable aquifer's behaviour with only minor changes in water chemistry and microbiology compared to the undisturbed aquifer condition. A second high-temperature heating cycle reaching up to 65 °C is planned for the summer of 2026. All outputs from this campaign are used for generating a numerical model aimed at simulating the hydro-bio-geochemical processes in the aquifer. It will allow the prediction of the long-term aquifer's behaviour to future operational conditions of the facility, thus contributing to optimizing its operation.

LID 0474
Migration mechanism and health risk warning of polycyclic aromatic hydrocarbons in karst groundwater of industrial cities in China

Li Lu[1,2]*, Shengzhang Zou[1,2], Changsong Zhou[1,2], Jia Wang[1,2], Yeyu Yang[1,2], Rixin Deng[1,2]

[1] Institute of Karst Geology, CAGS/Key Laboratory of Karst Dynamics, MNR & GZAR/International Research Center on Karst under the Auspices of UNESCO, Guilin, Guangxi, China
[2] Pingguo Guangxi, Karst Ecosystem, National Observation and Research Station, Pingguo, Guangxi, China
* 778785216@qq.com

Keywords: polycyclic aromatic hydrocarbons, groundwater, health risks, karst

Liuzhou City, Guangxi Province, is an important industrial city in southern China with a dense population and a high level of industrialization. Due to long-term industrial activities, a large amount of polycyclic aromatic hydrocarbons (PAHs) have been produced in the urban environment of Liuzhou. The karst groundwater, as an important water source for the urban area, has a strong karst development, causing the PAHs to continuously accumulate in the karst groundwater, posing a serious threat to the environment and human health. Therefore, Liuzhou City was selected as the study area to conduct research on the migration mechanism and health risk warning of PAHs in karst groundwater.

The research results show that from the rainy season to the dry season, the concentration of PAHs in the urban area and the proportion of low rings decrease, with the PAHs concentration in the heavy industry area being higher than that in the commercial and residential areas; vertically, a migration path from the atmosphere to soil, karst spring, underground river pipeline has been formed. With the increase in rainfall intensity, the concentration and proportion of PAHs in karst groundwater increase. During the rainfall process, groundwater flow, dissolved organic carbon, and suspended particulate matter are the key factors driving the migration of PAHs in groundwater. Particle size, black carbon, and total organic carbon are the main controlling factors affecting the multiphase distribution and diffusion of PAHs in the water environment. Based on the aspects of pollution sources, migration pathways, migration methods, and influencing factors, the migration mode of PAHs in karst groundwater of industrial cities was constructed.

In response to the shortcomings of the traditional fugacity model, the grid-based multi-media IV-level fugacity model and RAGS health risk model were coupled to conduct health risk warning of PAHs in karst groundwater. With the deterioration of environmental conditions, the carcinogenic health risks for adults and teenagers changed from mild to moderate, while for children, the risk changed from no risk to mild risk. The risk through the intake route was smaller than that through skin contact, and the former changed from no risk to mild risk, while the latter changed from mild risk to moderate risk. The research results can provide effective scientific basis for urban environmental management and public health protection.

LID 0477
Assessing subsurface water pathways in a headwater catchment impacted by extreme flooding using environmental seismology

Laura Rossana Fracica Gonzalez[1,2]*, Christoff Andermann[3], Benoit Abadie[4], John Armitage[4], Niels Hovius[5,6], Michael Dietze[1]

[1] Institute of Geography, RWTH Aachen University, Aachen, Germany
[2] Institute of Geography, University of Göttingen, Göttingen, Germany
[3] Géosciences Rennes, Université de Rennes, CNRS, UMR 6118, Rennes, France
[4] IFPEN, Sciences pour les Sols et Sous-sols, Lyon, France
[5] Helmholtz Center, German Research Center for Geosciences GFZ, Potsdam, Germany
[6] Institute of Geosciences, University of Potsdam, Potsdam, Germany
* laura.fracica-gonzalez@geo.rwth-aachen.de

Keywords: passive seismology, groundwater, critical zone

Extreme hydrological events such as pluvial floods are increasing in magnitude and frequency due to environmental change, yet it remains unclear how extreme events reorganize subsurface flow paths and sediment dynamics, and how subsurface architecture influences flood response. Groundwater levels and critical zone structure may buffer or amplify landscape responses, but conventional hydrological observations rely on spatially sparse point measurements that fail to resolve continuous, catchment-scale subsurface dynamics.

The upper Ahr Valley (Germany), affected by a major flood in 2021, provides a natural laboratory to investigate coupled surface–subsurface processes in a human-influenced headwater system characterized by strong soil moisture variability and rapid discharge fluctuations.

We investigate subsurface hydrological dynamics using passive seismic monitoring based on ambient seismic noise. A network of thirteen seismic stations operates across three headwater sub-catchments developed on intensively folded and fractured Devonian mudstone and carbonate rocks that strongly control groundwater flow pathways. Relative seismic velocity variations (dv/v) are used to infer changes in subsurface water content, groundwater levels, and vadose zone saturation. Seismic data are complemented by six multi-depth soil moisture loggers (down to 40 cm), pressure loggers monitoring creek discharge, and groundwater observations from nearby wells. Monitoring began in May 2024 with staggered sensor deployment, and a five-year flood event was recorded and analyzed.

This integrative approach improves understanding of how subsurface water pathways modulate hydrological and erosional responses in fractured headwater catchments and demonstrates the potential of environmental seismology as a spatially integrative tool for Critical Zone monitoring under changing climatic conditions.

LID 0478
Integrating spectral induced polarization with reactive transport modeling to quantify nitrate remediation capacity of permeable reactive barriers

Deqiang Mao[1]*, Xinmin Ma[2], Shiliang Liu[1], Jian Meng[1]

[1] School of Civil Engineering, Shandong University, Jinan, China
[2] School of Earth Sciences and Engineering, Hohai University, Nanjing, China
* maodeqiang@sdu.edu.cn

Keywords: groundwater remediation, hydrogeophysics, induced polarization

Nitrate contamination in groundwater constitutes a significant threat to human health, with epidemiological studies linking elevated NO_3^- concentrations to increased risks of digestive system cancers. Permeable reactive barriers (PRBs) represent a widely implemented technology for in situ groundwater remediation. Monitoring removal performance of permeable reactive barriers (PRBs) for groundwater nitrate remediation and distinguishing remediation mechanism contributions remains a key challenge.

Based on flow-through column experiments, this study integrated spectral induced polarization (SIP) monitoring with reactive transport modeling to investigate the dynamics of NO_3^- removal by zero-valent iron (ZVI) and activated carbon (AC) mixtures. SIP parameters link material changes to NO_3^- removal performance. The strong correlation between normalized chargeability and cumulative removal capacity of NO_3^- constrained reactive transport model errors, with average relative errors of 12.5% and 21% for predicted NO_3^- breakthrough concentrations. The presence of Ca^{2+} and HCO_3^- in solution promoted the corrosion of ZVI and the total NO_3^--N removal capacity increased from 6.61 to 9.05 mg/g. The remediation enhancement is concentrated primarily in the proximal sections near the contaminant injection point. The reaction term exhibits a substantially increase compared to the adsorption term. Conversely, remediation performance declines in distal sections. This finding highlights the important contribution of regulatory ions to the reaction term and emphasizes the necessity of rational proportioning of remediation materials in different PRB sections for enhanced material utilization efficiency. Transport models calibrated via SIP robustly quantify spatial heterogeneity in adsorption and reaction processes, exhibiting significant potential to guide the design of PRBs.

This study demonstrates the efficacy of integrating SIP monitoring with reactive transport modeling for quantifying the spatiotemporal dynamics of NO_3^- remediation in PRBs. The proposed approach provides a reliable basis for optimizing the proportioning of remediation materials, thereby improving material consumption efficiency and the longevity of PRBs.

LID 0479
Characterizing a multilayer aquifer system with a multiphase pumping test using a shifted reference time approach

Lukas Rolf[1*], Philip Nienhuis[1,2]

[1] Waternet, Amsterdam, The Netherlands
[2] (retired)
* lukas.rolf@waternet.nl

Keywords: pumping test analysis, shifted reference time, recovery-phase analysis, multilayered aquifer system, multi-phase pumping

We analyzed a complex pumping and recovery test in the Amsterdam Water Supply Dunes (The Netherlands) using a novel method based on shifted reference times for determining drawdown. The test involved a 4 km long chain of 50 interconnected production wells pumping from a semi-confined coastal aquifer. Groundwater responses were analyzed using hourly head data from 103 piezometers, supplemented by regular manual measurements. The objective was to estimate local hydraulic parameter values in a multiple leaky aquifer system comprising 4 – 5 aquifers to a depth of over 120 m. The results provide prior information for subsequent calibration of an existing numerical groundwater model.

Several planned and unplanned pumping and recovery phases occurred during the test. Because pumping began before monitoring equipment was fully installed, absolute drawdowns were not available for all piezometers, effectively prohibiting traditional pumping test analysis. To address this, we used a novel approach in which the reference times for calculating drawdown were shifted from the start of pumping to later changes in pumping regimes, after which least squares parameter optimization is based on relative rather than absolute drawdowns. This method can be applied in many other situations where multiple pumping phases have occurred with or without incomplete head time series.

The study demonstrates how multiple pumping periods in a long well row can be used for localized characterization of a heterogeneous multilayer aquifer system, including identification of deeper aquitards. We also investigated the extent to which hydraulic parameters from layers above and below the pumped aquifer can be inferred. We show how we dealt with geological heterogeneity and applied drawdown corrections for partially penetrating wells in the long well row.

LID 0480
Hydrological connectivity during droughts and floods in data-scarce arid transboundary river basins

Syed M.T. Mustafa[1,2]*, Fulvio Franchi[3], Sithabile Tirivarombo[4], Alessia Matano[5], Farisse Chirindja[6], Anne Van Loon[5], Jean-Christophe Comte[2]

[1] Hydrology and Environmental Hydraulics Group, Wageningen University & Research, Wageningen, The Netherlands
[2] School of Geosciences, University of Aberdeen, Aberdeen, United Kingdom
[3] Dipartimento di Scienze della Terra e Geoambientali, Università degli studi di Bari – Aldo Moro, Bari, Italy
[4] Department of Earth and Environmental Science, Botswana International University of Science and Technology (BIUST), Palapye, Botswana
[5] Institute for Environmental Studies, Vrije Universiteit Amsterdam, Amsterdam, The Netherlands
[6] Eduardo Mondlane University, Maputo, Mozambique
* syed.mustafa@wur.nl

Keywords: hydrological connectivity, hydrological extremes, groundwater, improve resilience

Groundwater resources are more resilient than surface water to floods and droughts, but they are under threat of overexploitation and pollution due to anthropogenic and climatic pressures. In this context, achieving sustainable management requires an enhanced understanding of spatio-temporal hydrological connectivity, including groundwater flow dynamics, surface water–groundwater (SW-GW) interactions, and upstream–downstream connectivity within the basin. However, this is particularly challenging in data-scarce transboundary basins (DSTBs).

In this study, we investigated the hydrological connectivity in the Limpopo River Basin (LRB), a DSTB highly vulnerable to floods and droughts. We used a multisector collaborative groundwater modelling approach, in which model conceptualization, parameterization, and evaluation were conducted with input from diverse stakeholders through a series of iterative workshops.

Monitoring data and model results suggest that prolonged floods raised groundwater levels, whereas prolonged droughts depleted them, particularly in the upstream and central regions with low-storage, fractured-bedrock aquifers.

GW-SW connectivity is higher downstream where GW tables are shallower, and interactions increase during floods, especially in the central region. GW-SW interactions show no significant difference between short and long-duration floods and droughts, but changes in groundwater depth are significantly higher during long-duration events. Prolonged floods contribute to higher and longer-lasting baseflow compared to short-duration floods of the same magnitude.

The reduced frequency and severity of floods and droughts on baseflow, compared to recharge, show the groundwater system’s attenuation capacity and its crucial role in enhancing resilience to hydrological extremes.

The study's findings, combined with future research on management scenarios, will help in better managing groundwater resources and improving resilience to hydrological extremes.

LID 0481

The resilience of karst springs to climate change: In-depth analysis of long discharge time series in the Umbria Region (Italy) and potential forecasting

Federica Giaccio[1], Konstantina Katsanou[2], Giuseppe Sappa[1], Francesco Maria De Filippi[3]*

[1] Department of Civil, Environmental and Construction Engineering (DICEA), Sapienza University of Rome, Italy
[2] IHE Delft, Delft, The Netherlands
[3] Department of Wellbeing, Health and Environmental Sustainability (BeSSA), Sapienza University of Rome, Italy
* francescomaria.defilippi@uniroma1.it

Keywords: karst spring discharge, karst modelling, climate change

Climate change and extreme events, such as severe droughts, have a direct impact on global groundwater resources, altering climate patterns and complicating the management of natural resources such as karst springs. In this context, studying available historical series is essential to obtain reliable forecast models of karst spring discharge in relation to the impact of climate change and to enable the development of adaptation and mitigation policies.

This work focuses on the analysis of discharge time series data from some springs in the Umbria Region (Central Italy), made available by the Regional Environmental Protection Agency (ARPA). Examining the Auto-Correlation Function (ACF) and Cross-Correlation Function (CCF) of about 20 years of daily discharge data allowed to better understand some characteristics of these springs, such as storage properties and karst conduit network development within the different feeding aquifers . Thanks to a previous study by De Filippi et al. (2024) the application of a Fully Connected Neural Network (FCNN) model allowed to fill gaps in the historical discharge time series. The present study is enhancing the previous one, in the aim of comparing different analysis and modelling methodologies (based on statistical, physical and artificial intelligence tools) for studying the resilience of karst systems to climate change pressure. Obtained results highlight the importance of having continuous and sufficiently long historical time series, as this is crucial for understanding hydrogeological dynamics in karst and correctly use new tools such as artificial neural network models. This approach may come out particularly useful for proactively addressing current global challenges, enabling not only the filling of gaps in historical data, but also the development of predictive models, with the goal of extending the analysis to future forecasting.

LID 0482

Natural and anthropogenic factors controlling groundwater mineralisation in semi-arid climates: The Zaghouan aquifer system (Tunisia)

Asala Jarraya[1,2]*, Danièle Valdes[2], Rim Trabelsi[1], Benoit Deffontaines[2], Kamel Zouari[1], Valérie Plagnes[2]

[1] National Engineering school of Sfax-LRAE, Sfax, Tunisia
[2] Sorbonne University, CNRS, EPHE, METIS, Paris, France
* asala.jarraya@enis.tn

Keywords: groundwater, overexploitation, salinity, semi-arid

In arid and semi-arid regions, groundwater is the main water resource supporting agriculture, drinking water supply and socio-economic development. In the Zaghouan region (northeastern Tunisia), the structural geological context is complex and the groundwater system comprises two Plio-Quaternary sedimentary aquifers (Sminja and Oued Rmel) and the Jurassic karstic aquifer of Djebel Zaghouan.

Surface water availability is limited and groundwater is extensively exploited throughout the region. Despite government water management, this resource faces hydrological stress resulting from combined effects of overexploitation and insufficient natural recharge. Water quality issues, including salinity exceeding 10 g/L and nitrate concentrations above the WHO limit (50 mg/L), further affect resource sustainability. Our study aims to identify the main sources and processes controlling groundwater mineralization in this area, using structural geology, longterm monitoring of groundwater levels, abstraction volumes and geochemical analyses (major elements, stable isotopes, tritium). Mineralization patterns results from a combination of natural and anthropogenic factors, including geological factors, water-rock interactions, evaporation, cation exchange, vertical groundwater exchanges, and agricultural practices.

Our findings provide new insights into the functioning of aquifer systems in semi-arid areas under combined natural and anthropogenic pressures. They highlight the role of the complex geological structure in controlling water quality and resource availability, offering key information for integrated groundwater management in semi-arid regions.

LID 0483
Surface-groundwater investigations to support ex-ante evaluations of water withdrawals

Vittorio Fancello[1]*, Maria Chiara Porru[1], Fabrizio Antonio Piscedda[1], Claudio Arras[1], Giulio Vignoli[1], Mario Lorrai[2], Paolo Botti[2], Yuri Podmogov[3], John Moilanen[4], Evgeny Karshakov[4], Stefania Da Pelo[1]

[1] University of Cagliari, Cagliari, Italy
[2] Sardinian Hydrographic District Agency, Italy
[3] Geotechnologies, Moscow, Russia
[4] V.A. Trapeznikov Institute of Control Sciences of Russian Academy of Science, Moscow, Russia
* vittorio.fancello@unica.it

Keywords: coastal aquifer management , seawater intrusion , risk-based workflow

Effective groundwater management in coastal alluvial plains requires a robust understanding of surface–groundwater interactions, particularly where seawater intrusion threatens long-term sustainability. This study presents a methodology for the ex-ante assessment of groundwater abstractions consistent with the Water Framework Directive (WFD 2000/60/EC). The Muravera alluvial plain (Sardinia, Italy) serves as a reference site where the conceptual hydrogeological model and groundwater balance were refined through the integration of hydrological, hydrochemical, and hydrogeophysical data. The work was carried out in cooperation with the University of Cagliari, the Sardinian Hydrographic District Agency, and the Regional Environmental Protection Agency of Sardinia. In 2023, within the framework of the PNRR RETURN initiative, an airborne geophysical survey (~1500 line-km) provided spatially dense constraints to support geological interpolation and vulnerability mapping. Extensive field investigations—including piezometric monitoring, geochemical analyses, and river–aquifer exchange assessments—highlight marked spatial variability in the hydraulic response of the phreatic aquifer under prolonged drought conditions. Observed dynamics include seasonal groundwater-level declines and variable hydraulic exchanges along the Flumendosa River, underscoring the inadequacy of static, uniform thresholds for ex-ante abstraction permitting. We therefore propose a tiered, risk-based workflow that combines process-based zoning with adaptive management triggers reflecting local hydrogeological variability. The framework explicitly incorporates uncertainty by retaining alternative conceptual models within scenario-based evaluations. This approach supports WFD implementation through vulnerability zoning and zone-specific admissibility scenarios, offering operational guidance to mitigate seawater intrusion and optimize the integrated management of river releases and groundwater withdrawals.

This study was funded by Agreement POA FSC 2014–2020 - 16.12.2019 among the ex MATTM- DGSTA and River Basin Authority (AdB) of Sardinia - Service for the protection and management of water resources, water services and drought management - Regional Agency of the River basin district of Sardinia, Action 2.3.1 “Interventions to improve the quality of water bodies”.

LID 0486
Reframing groundwater systems sustainability under energy transition and climate pressure: A conceptual framework from Eastern Indonesia

Leonora Waromi[1]*

[1] Independent Researcher, Jakarta, Indonesia
* oladhele85@gmail.com

Keywords: groundwater sustainability, energy transition, climate pressure, land-use change, nature based solution

Groundwater sustainability in Eastern Indonesia is facing increasing pressure from energy-transition-related resource development, land-use change, and climate variability. Conventional sectoral approaches often overlook the systemic interactions that shape groundwater systems. This is especially true in regions with limited data and high socio-ecological sensitivity.

This study presents a conceptual socio-ecological framework for groundwater sustainability that explicitly incorporates Nature-Based Solutions (NBS), such as wetland restoration, ecosystem rehabilitation, and managed aquifer recharge. These mechanisms are intended to enhance groundwater recharge, ecosystem resilience, and socio-economic co-benefits across mining, agro-industrial, and conservation sectors. The framework facilitates the evaluation of NBS impacts through indicator- and parameter-based approaches and is structured to support future predictive or scenario-based modelling by integrating geospatial data and indigenous knowledge as complementary information sources.

This study frames groundwater as an interconnected socio-ecological system. It offers a conceptual contribution by clarifying how NBS can support sustainable water management, green transition, and climate adaptation. The framework also provides a foundation for applied research and collaborative initiatives in ecologically sensitive, data-limited regions. It establishes pathways for future quantitative assessment and predictive analysis.

LID 0487
A conceptual hydrogeological framework for groundwater management under energy transition and climate pressure in Eastern Indonesia

Leonora Waromi[1]*

[1] Independent Researcher, Jakarta, Indonesia
* oladhele85@gmail.com

Keywords: groundwater management, hydrogeological framework, energy transition, climate pressure, land-use change

Eastern Indonesia, particularly Papua and surrounding small islands, faces mounting pressures on groundwater systems from land-use change, resource development, and climate variability. These pressures occur in hydro-ecologically sensitive areas, where groundwater-dependent ecosystems and local communities are particularly vulnerable.

Building on prior research integrating Nature-Based Solutions and AI-driven assessment, this poster presents a conceptual framework adapted to address energy transition and climate pressures.

The framework integrates hydrogeological principles, land-use dynamics, ecosystem resilience, and socio-economic drivers relevant to mining, agro-industrial development, and conservation. Geospatial data and analytical tools support preliminary assessment in data-scarce regions.

Rather than providing predictive results, the framework emphasizes discussion and collaborative exploration of interactions between groundwater recharge, land management, and ecosystem resilience, including the role of Indigenous knowledge. The approach highlights vulnerability pathways, trade-offs between conservation and development, and opportunities for sustainable planning, serving as a foundation for applied research, collaboration, and capacity-building in Eastern Indonesia and similar regions.

LID 0488
Evaluating environmental impacts from abstraction shutdown using the Source Impact Library in UK regional groundwater models

Josh Roberts[1]*

[1] Groundwater Science, Glasgow, United Kingdom
* j.roberts@gwscience.co.uk

In large catchment management strategies, there can be hundreds of different abstraction change options to achieve compliance with environmental flow targets. In England, the future challenge for water resources due to climate change, and the possibility of enhanced environmental protections, has been set out in the Environment Agency's Environmental Destination scenarios. A key first step to build on this early indication of possible future pressures, identified in UK Water Research guidance, is to improve how abstraction impacts are defined in the datasets that are used to calculate the severity of non-compliance with environmental flow targets, and are similarly used to calculate the abstraction reduction needed as a solution. To this end, Groundwater Science have recently engaged with Water Resources East, a regional water resources planning group, to undertake batched abstraction modelling across six large regional groundwater models.

Groundwater Science developed libraries of hundreds of runs for each regional model, in which individual Public Water Supply abstractions were sequentially switched off. A baseline model run, with all PWS wells operating at their maximum rate, enabled quantification of impacts to groundwater heads and stream flows attributable to each abstraction shutdown. The resulting impacts were visualised using Groundwater Science’s Source Impact Library. Users can interactively select abstractions within the GIS project and SIL displays spatial changes in groundwater levels, stream flows, and baseflows relative to the baseline model run, using the rule of superposition. Supporting workflows, including streamflow percentile analysis, FlowSource analysis and zone budget processing, enabled quantification of impacts on sub-catchment water balances and low-flow metrics. These outputs were presented in structured matrix tables and assessed against thresholds such as Environmental Flow Indicators (EFIs), allowing rapid screening of compliance risk.

LID 0489
Groundwater quality assessment in the Middle and Lower Awash Basin (Afar, Ethiopia): An international cooperation experience

Elisabetta Preziosi[1]*, Massimo Spadoni[2], Barbara Casentini[1], Nibret Adela[3], Yirgalem Esuneh[3], Sara Pennellini[1], Silvia Fornasaro[1], Marco Melita[1], Stefano Amalfitano[1], Segni Lemessa Tsegera[4], Massimo Marchesi[5], Eduardo Di Marcantonio[5], Stefano Fazi[1]

[1] National Research Council - Water Research Institute (CNR-IRSA), Montelibretti - Rome, Italy
[2] National Research Council - Institute of Environmental Geology and Geoengineering (CNR-IGAG), Montelibretti - Rome, Italy
[3] Ministry of Water and Energy (MOWE), Addis Ababa, Ethiopia
[4] CIMA Foundation, Italy
[5] Sapienza University of Rome, Department of Earth Sciences, Rome, Italy
* elisabetta.preziosi@cnr.it

In arid and semi-arid regions groundwater represents a critical resource, extensively exploited for drinking water supply, irrigation, livestock farming, and industrial activities. In the Afar region of Ethiopia, including the northernmost sector of the African Rift Valley, the shift from nomadic lifestyles to permanent settlements has increased pressure on groundwater resources, making water quality assessment essential for sustainable management. The area is affected by natural health risk factors, including high geogenic fluoride, highlighting the need for an integrated groundwater management strategy supported by appropriate monitoring and mitigation measures. This study, carried out in coordination with the Ethiopian Ministry of Water and Energy (MOWE), aimed to evaluate groundwater quality along the middle and lower Awash Valley, identifying baseline values of key chemical parameters and the natural and/or anthropogenic processes controlling their spatial evolution. In October 2025, a field campaign was conducted at 12 groundwater sites used for drinking purposes. Physical–chemical parameters, major and minor ions, trace elements, nutrients, stable isotopes and selected microbiological indicators were measured following protocols aligned with the EU Directives. Ethiopian staff from MOWE, Basin Authorities, and regional Water Agencies actively participated in the survey, combining monitoring activities with hands-on technical training. Analyses were performed at the CNR-IRSA laboratories and Sapienza University. Results showed marked spatial variability in groundwater quality along the Awash Valley. Temperature (25–50 °C), electrical conductivity (660–2,000 µS/cm), chlorides (20–250 mg/L), and sodium (80–440 mg/L) increased downstream, while nitrates remained generally at a low level (1–11 mg/L). Fluoride (0.3–9.5 mg/L) and arsenic (1–45 µg/L) exceeded WHO guideline values at several sites, confirming the need for targeted management and mitigation strategies.

Activity implemented within the framework of the EU–AICS funded Integrated Water Resources Management (IWRM) programme for the Awash, Danakil, and Webi Shebele river basins.

LID 0492
Development of a uniform polysulfone–activated carbon sorbent for improved passive flux meter performance

Subeen Kim[1]*, Minjune Yang[2,3]

[1] Division of Earth Environmental System Sciences-Major of Earth & Environmental Sciences, Pukyong National University, Busan, South Korea
[2] Division of Earth and Environmental System Sciences-Major of Environmental Geosciences, Pukyong National University, Busan, South Korea
[3] Wible Inc., Busan, South Korea
* subin_kim@pukyong.ac.kr

Keywords: passive flux meter, groundwater flux, polymer-based sorbet

The Passive Flux Meter (PFM) is a cylindrical device designed to simultaneously measure groundwater flux and contaminant mass flux using sorbent materials preloaded with alcohol tracers. Conventional granular activated carbon (GAC) often exhibits low sphericity and poor size uniformity, potentially introducing heterogeneity in flux measurements. In this study, a uniformly shaped granular sorbent (ASP) was fabricated by blending polysulfone with activated carbon, and its adsorption and flow-dependent behavior were evaluated using isopropanol (IPA) as a representative alcohol tracer. Batch adsorption experiments were conducted over an initial concentration range of 36.49–511.52 mg/L. Equilibrium concentrations decreased to 12.03 – 120.94 mg/L. The adsorption isotherm was reasonably described by a linear model, with a distribution coefficient (K_d) of ~ 20 L/kg, and the maximum observed adsorption capacity within the tested range was ~ 2.6 mg/g. To investigate desorption under advective flow conditions, IPA-preloaded ASP was packed into a one-dimensional column (length 11.8 cm, diameter 1.8 cm, porosity 0.40) and eluted with distilled water at 0.035 mL/min, equivalent to a Darcy flux of ~ 0.20 m/day. Effluent concentrations were monitored for 48 hours (~ 8 pore volumes). Approximately 18% of the initially adsorbed IPA mass was recovered, while 82% remained retained within the sorbent matrix. The residual mass ratio (M_R) decreased linearly with pore volume, enabling estimation of an elution-based retardation factor (R_d). Darcy flux was inversely estimated using the analytical framework of Annable et al. (2005), yielding a flux (~ 0.15 – 0.20 m/day) consistent with the imposed flow rate. The uniformly shaped polysulfone–activated carbon sorbent exhibited stable tracer under flow conditions, demonstrating its suitability for PFM applications. Future work will evaluate ASP-integrated PFMs under three-dimensional flow chamber conditions simulating field-scale aquifers.

This research was supported by Global - Learning & Academic research institution for Master's·PhD students, and Postdocs(LAMP) Program of the National Research Foundation of Korea(NRF) grant.

LID 0493
Groundwater protection in data-scarce regions: Dinokana case study

Awodwa Magingi[1]*, Anders Pytlich[2]

[1] Department of Water and Sanitation, Pretoria, South Africa
[2] Danish Environenmental Protection Agency, Aalborg, Denmark
* awodwamagingi@gmail.com

Keywords: groundwater protection, potential contaminating activities and fixed radius

The need for groundwater protection schemes in South Africa aligns with various legislation which includes National Water Act, National Environmental Act and Spatial Planning and Land Use Management Act by promoting groundwater quality protection and sustainable spatial development. However, there are no implemented legislative guidelines on developing a groundwater protection scheme in South Africa. Water Research Commission developed in collaboration with Danish EPA developed a Guidance document on Protection Zones focusing on development and implementation of groundwater protection schemes to minimize groundwater contamination potential. Dinokana is one of the rural settlements that solely depend on groundwater from a wellfield and two springs.

In protecting the town's only source of water using the guideline; the fixed radius method as one of the groundwater protection zone delineation approaches, has been applied in Dinokana to determine a radius around the boreholes within which certain anthropogenic activities should be banned or controlled through monitoring. This approach is suitable for the study area as it is relatively easy and inexpensive to implement and is based on simple hydrogeological principles. The radius is determined by using the volumetric flow equation which focuses on pumping rate, travel time of contaminants, aquifer effective porosity etc. In Dinokana, the potential contaminating activities include pit latrines, agricultural run-off including cattle feedlots.

Based on the existing data, the calculated fixed radius for each borehole in the wellfield was determined and potential contaminating activities were identified for both the wellfield and the two springs. Recommendations on the protection plans and stipulation of possible roles and responsibilities of the various stakeholders were highlighted and discussed with key stakeholders in this study area as the first step in protecting the main source of water for sustainable use.

LID 0495

^{81}Kr dating of liter-sized groundwater samples enables simple bottle-based field collection

Guo-Min Yang[1*], Jun-Long Deng[2], Xin Feng[2], Jie Wang[1] , Qiao-Song Lin[2], Wei Jiang[1,2], Zheng-Tian Lu[1,2]

[1] Hefei National Laboratory, Hefei, China
[2] University of Science and Technology of China, China
* yanggm@hfnl.cn

Keywords: ^{81}Kr dating, groundwater age, aquifer residence time, noble gases

^{81}Kr (half-life 229 ka) provides a robust chronometer for groundwater in the 30 ka–1 Ma age range and has become increasingly important for quantifying long residence times in regional aquifers. Atom Trap Trace Analysis (ATTA) now enables routine measurement of ^{81}Kr. However, field adoption has remained limited by sampling logistics.

Current protocols require 1–2 µL STP of krypton per analysis, corresponding to extraction of ~2 L of dissolved gases from 20–40 kg of groundwater using membrane-based degassing systems. Although these systems are portable, they are not widely available and add complexity to field campaigns, shipping, and coordination with specialized laboratories.

We have developed an all-optical ATTA instrument that reduces the krypton requirement to 100 nL STP—equivalent to the dissolved gas contained in ~2 kg (≈2 L) of groundwater. This tenfold reduction enables direct collection of groundwater in standard sample bottles, without on-site degassing. Samples can be collected alongside routine hydrochemical sampling and shipped to the laboratory for krypton extraction and analysis.

By removing the need for specialized field equipment, this advance substantially lowers logistical barriers and makes ^{81}Kr dating more accessible for hydrological investigations of old groundwater systems.

LID 0496
Noble gases record last Glacial–Holocene water-table decline in the arid Southeastern Mediterranean

Jakob K. Brinkmann[1], **Roi Ram**[2]*, Kerstin L. Urbach[1], Alan M. Seltzer[3], Itay J. Reznik[2], Wei Jiang[4,5], Li Hao[4], Guo-Min Yang[5], Zheng-Tian Lu[4,5], Werner Aeschbach[1]

[1] Heidelberg University, Heidelberg, Germany
[2] Geological Survey of Israel, Jerusalem, Israel
[3] Woods Hole Oceanographic Institution, MA, USA
[4] University of Science and Technology of China, Hefei, China
[5] Hefei National Laboratory, Hefei, China
* roiram1@gmail.com

Keywords: paleo-hydrology, hydrogeochemistry, old groundwater dating

Noble gases are widely utilized in hydrological research, enabling, among other applications, the estimation of residence times and the reconstruction of recharge temperatures that prevailed at the time and place of groundwater recharge. Recent advancements in stable noble gas (Ar, Kr, Xe) isotope ratio measurements allow, for the first time, the reconstruction of the water-table depth (WTD) during recharge. This reconstruction is based on depth-dependent fractionation in the unsaturated zone (UZ), primarily governed by gravity, under the assumption that the recharging water acquires the isotopic signature at the UZ-groundwater interface, where the ultimate gas exchange takes place.

This innovative method was recently applied in the Karkom Graben, located in the hyperarid Negev Desert (Israel), which hosts a precious freshwater resource (≤300 mg Cl^- L^{-1}). The Karkom aquifer is fed by flash floods in major ephemeral streams draining through the aquifer's permeable clastic rocks. The integration of ^{14}C and ^{81}Kr radioisotope measurements across various aquifer horizons (screens at depths of 100–1000 m) suggests major groundwater recharge toward the late Last Glacial, approximately 10,000–30,000 years ago. Recorded recharge temperatures, calculated based on noble gas concentrations, are 2–4 °C lower than current surface temperatures, consistent with other regional Last Glacial records. Comparison of current (pre-production) and noble-gas based paleo-WTD suggests a 10–20 m decline, indicating higher paleo-recharge rates. Higher levels may also explain the groundwater's observed low dissolved inorganic carbon $\delta^{13}C$ values, as near-surface groundwater availability could have supported more extensive vegetation cover, resulting in enhanced soil air modification. The study's results demonstrate the potential of advanced geochemical and isotope methods as tools for reconstructing paleo-hydrogeological conditions and developing sustainable production management strategies.

LID 0498
Inquiry-based pedagogy and groundwater education

Géraldine Picot-Colbeaux[1]*

[1] BRGM - the French Geological Survey, Orléans, France
* g.picot@brgm.fr

Keywords: education, groundwater, hydrogeological models, training

Groundwater, though crucial for ecosystems and human needs, remains poorly understood due to its invisibility. This vital water resource, is often overlooked in science education. To address this gap, an inquiry-based pedagogical approach using dynamic hydrogeological models has proven effective for learners from kindergarten to university to make groundwater science accessible.

Hands-on learning in the classroom is guided by the researcher, and learners interact collectively and directly with models simulating groundwater flow, recharge, exchange between rivers and groundwater, pumping and pollution. By manipulating colored water, measuring levels, and observing results, they engage in the scientific method: formulating questions, testing hypotheses, and analyzing data. This approach clarifies abstract concepts, develops critical thinking and collaboration skills, linking science to real-world issues.

Given that many teachers, particularly at primary level, have gaps in their knowledge of geoscience teaching, the implementation of these initiatives requires teachers and researchers to be brought together and trained. Dedicated training immerses teachers in the same activities as their learners, helping them guide scientific inquiry in their classrooms. Training focuses on adapting experiments for diverse age groups, managing group work, and collaborating with scientists, ensuring inclusive and effective teaching for all educational levels. Researchers are also trained to communicate complex concepts accessibly, align interventions with educational standards, and collaborate effectively with teachers ensuring an inquiry-based pedagogical approach sustainable, adaptable, and integrated into school curricula.

This inquiry-based pedagogical approach transforms groundwater education, fostering scientific literacy and environmental responsibility across all ages. Learners gain a concrete understanding of groundwater's importance and protection. Learners develop scientific skills and are encouraged to pursue STEM careers, especially girls, through positive role models. It prepares future generations to address sustainable water management challenges, making complex science accessible and actionable for everyone.

LID 0499
Occurrence of contaminants of emerging concern and their metabolites in groundwater below a sewage treatment facility

Alessio Tomei[1*], Brunella Raco[2], Raffaele Battaglini[3], Frederic Huneau[4], Viviana Re[1,2]

[1] Dipartimento di Scienze della Terra, Università di Pisa, Pisa, Italy
[2] Istituto di Geoscienze e Georisorse, CNR, Pisa, Italy
[3] TerreLogiche Ltd, Venturina Terme, Italia
[4] Université de Corse, CNRS UMR 6134 SPE, équipe Hydrogéologie, Corte, France
* alessio.tomei@phd.unipi.it

Keywords: CECs, pollution, groundwater, wastewater, processes

Contaminants of Emerging Concern (CECs) are increasingly used to trace anthropogenic inputs and assess groundwater residence times. Given their incomplete removal during treatment, Wastewater Treatment Plants (WWTPs) act as continuous sources of these compounds to the environment. This study investigates CEC occurrence near a WWTP in Pontedera (Italy), which treats urban and industrial wastewater. Sampling campaigns conducted in November 2024 (wet season) and September 2025 (dry season) analysed surface water (only for the 2024 campaign), wastewater, and groundwater from both shallow and deep aquifers.

Surface water data revealed non-linear patterns that obscured a clear WWTP imprint. For instance, Paracetamol was detected downstream despite its absence upstream or in the effluent at the time of sampling. This discrepancy suggests high temporal variability in discharge composition, indicating that high-frequency monitoring is required to capture these pulses. In shallow groundwater, Acesulfame, Benzotriazole, Valsartan and the metabolite Valsartan Acid were consistently detected across both campaigns, pointing to a persistent chemical signal likely driven by surface runoff infiltration or other unidentified sources.

Deep groundwater exhibited marked seasonal variability: contaminants were below quantification limits in the wet season but detectable in the dry season (September 2025), including Bisphenol A, Bisphenol S, Salicylic acid, and Paracetamol. The detection of Paracetamol—a pseudo-persistent, labile compound—in a confined multilayer aquifer is critical. Since local low-permeability layers prevent rapid vertical infiltration, this finding excludes local leakage as the source, that requires further investigation.

Thus, CECs here serve a dual purpose: they identify pollution and act as hydrogeological tracers, useful to study contaminant transport and their interaction with the aquifer.

LID 0500
Multidisciplinary approaches for characterising infiltration in volcanic sinkholes in the context of recurrent flooding of lowlands in northern Rwanda

Rémi Vigouroux[1]*, Marc Boisson[2], Emery Torbert Mpano[3], Michel-Henri Bourge[3], Davis Bugingo[4], Musana S. Bernard[4]

[1] ARTELIA, Saint-Ouen, France
[2] ANTEA, Lyon, France
[3] S HER, Kigali, Rwanda
[4] Rwanda Water Board (RWB), Kigali, Rwanda
* remi.vigouroux@arteliagroup.com

Keywords: volcanic hydrogeology, infiltration, conceptual modelling

The Mugogo lowland, located in the Volcanoes Region in northwestern Rwanda, is prone to repetitive flood events, contributing to crops and human settlements destruction. The distinctive feature of the hydrological context is the presence of localised infiltration at sinkholes located directly below volcanic formations. These sinkholes are linked to the presence of lava tunnels whose roofs have collapsed but whose voids remain present given the recent nature of the volcanic deposits.

Characterising the infiltration therefore appeared essential in order to propose appropriate solutions. With this in mind, geophysical studies coupled with core sampling were conducted to better understand the nature of the subsoil and thus better understand the mechanisms of infiltration. The infiltration capacities of the various sinkholes were also measured with the help of the local population by diverting the watercourse for the duration of the measurement. Finally, tracing was undertaken to locate the outlets of this infiltration zone and to determine the transit times of the groundwater.

These investigations have led to the proposal of artificial infiltration structures to improve infiltration capacity, but also, and above all, to promote cultivation techniques that retain sediments in catchment basins and thus limit the clogging of natural infiltration.

We would like to thank all participants and stakeholders in the project for their involvement, and particularly the European Union for External Action for its financial support.

LID 0501
Effects of climate change and pond management on bank filtration at Sdier, Germany

Thomas Grischek[1]*, Nele Wotha[1], Philipp Marx[1], Anna Beer[1], Frank Zimmer[2]

[1] University of Applied Sciences Dresden, Dresden, Germany
[2] Fernwasserversorgung Sdier, Sdier, Germany
* thomas.grischek@htw-dresden.de

Keywords: lake bank filtration, infiltration capacity, water supply

The long-distance water supplier FW Sdier is located in northeast Saxony, Germany and abstracts annually about 4 million m3 of groundwater for drinking water supply. Recent climate projections indicate a decline in groundwater recharge for Saxony. Monitoring and modeling studies have been performed to assess the performance and resilience of the abstraction scheme Sdier to climate change effects by simulating different scenarios. It is found that if observed trends in water availability and demand continue, the groundwater levels decline, especially during winter and under limited availability of surrounding surface water bodies.

Surface water infiltration from two fish ponds near to the abstraction wells has been found to contribute a major part to the volume of water abstracted. The fish ponds have no inflow in winter, causing them to dry out. Advantageously, the catchment allows for flexible pumping as it draws on different raw water sources and is therefore capable of withstanding drought periods of several months. But the ponds are becoming increasingly silted up, reed growth is increasing and the maximum water depth is decreasing. Various methods for determining K-values of the bottom sediment and infiltration rates of the larger pond have been applied to determine the proportion of lake bank filtrate and to identify the relevant infiltration areas. The variability of the results and experiences in determining infiltration rates in reed beds are presented and discussed. Dredging the sludge from the ponds is too expensive, so other measures to maintain the infiltration capacity must be examined. However, there is conflicting information in the literature regarding the effect of reed mowing on the infiltration rate and evapotranspiration.

Due to its location, downstream of a reservoir, and favourable hydrogeological conditions, FW Sdier can play a key role within a network of water suppliers to meet future drinking water demand in the region and tackle challenges of climate change. Possible pond management measures are discussed in order to maintain and increase infiltration capacity.

LID 0502
Application of radon measurements to determine groundwater inflows into watercourses in the Lusatian post-mining landscape

Philipp Marx[1], Nyambayar Ganpurev[1], Thomas Grischek[1]*, Carolin Pezenka[2], Wilfried Uhlmann[2]

[1] University of Applied Sciences Dresden, Dresden, Germany
[2] Privates Institut für Wasser und Boden GmbH, Dresden, Germany
* thomas.grischek@htw-dresden.de

Keywords: radon, groundwater inflow, streams, mining region

In the Lusatian mining area, the closure of opencast lignite mines is leading to a rise in groundwater levels and the feeding of watercourses with groundwater containing high concentrations of iron and sulphate. The radon-222 method was used to identify the so-called hotspots of groundwater inflows into the watercourses. Initial experiments were carried out and published by Frei et al. (2020, 2024). However, the application of the method is complicated in the study area, as some watercourses have been relocated and sealed. The equilibrium activities of radon in aquifers are sometimes highly inhomogeneous. The building materials used to reinforce the beds and banks of small streams can also have a significant impact on radon activities in surface water.

A study in 2025 applied the radon-222 mass balance method, coupled with the FINIFLUX model from Frei et al. (2020, 2024), to quantify groundwater inflows in the Kleine Spree and Spree rivers. In the Spree, the detected ^{222}Rn activities ranged from 21 – 809 Bq/m^3, and 0 – 513 Bq/m^3 in the Kleine Spree. Modeling identified four inflow hotspots that matched with prior studies, with the Spreewitzer Rinne remaining the dominant inflow corridor. Sensitivity analysis demonstrated that gas exchange influenced hotspot magnitude, while applied groundwater equilibrium data affected calculated inflow volumes. The radon-FINIFLUX approach deemed effective, with 2025 results highlighting more consistent GW-SW exchange in the Spreewitzer Rinne. Radon measurements could be further used to identify hotspots of GW flow into streams in the mining-affected catchments.

LID 0505
Innovative study to determine remaining drinking water resources using the example of an unconsolidated rock aquifer in the Emmental valley, Switzerland

Rolf Tschumper[1]*, Luca M. Abbuehl[2], Fabien Cochand[3]

[1] Government of the Canton of Bern, Bern, Switzerland
[2] Werner + Partner AG, Burgdorf, Switzerland
[3] CSD AG, Aarau, Switzerland
* rolf.tschumper@be.ch

Keywords: drinking water resource, numerical groundwater model, regional study

In various regions of the Canton of Bern, there are bottlenecks in the supply of drinking water due to conflicts of use and quality problems. The drought that has increasingly occurred in the summer and fall in recent years has also shown that groundwater levels are falling in many places and springs are experiencing a sharp drop in flow.

Both the Canton of Bern as the responsible authority and the affected water suppliers therefore need reliable information on the possibility of increasing the use of existing groundwater wells and developing new ones.

To this end, a procedure was developed for the Emmental region of Switzerland to identify potential drinking water abstraction sites. The procedure was as follows:

1. GIS-based identification of possible, potential areas for the construction of new water catchments, taking into account the groundwater resources and known conflicts of use.

2. analytical and numerical model-based determination of the maximum extraction rate for existing and future drinking water catchments

3. preparation of site assessments for each existing catchment and possible new catchment sites in accordance with the evaluation

4. creation of a regional map of sustainably usable groundwater resources as a basis for the approval of further abstraction sites

Overall, additional potential resources of approx. 100,000 l/min for drinking water extraction were identified as part of this study. Further clarifications, in particular hydrogeological field investigations, will now follow at selected locations in order to determine the effective potential and possible uses.

LID 0506
Diagnosing groundwater storage dynamics through a Budyko-based framework: A comparative analysis of Alpine and Mediterranean catchments

Federico Emanuel Franco[1]*, Warren Meredith[2], Manuela Lasagna [1], Josep Mas-Pla[2,3], Domenico Antonio De Luca[1]

[1] Earth Sciences Department, University of Turin, Turin, Italy
[2] Catalan Institute for Water Research (ICRA), Girona, Spain
[3] Grup de Recerca Geocamb, Dept. Environmental Sciences, Universitat de Girona, Girona, Spain
* federicoemanuel.franco@unito.it

Keywords: groundwater storage dynamics, Budyko framework, catchment water balance

Climate change is altering the timing and partitioning of hydrological fluxes across diverse hydroclimatic environments, with significant implications for groundwater recharge, baseflow sustainability, and seasonal water availability. While catchment-scale water balance approaches are widely used to assess hydrological responses to climatic forcing, the subsurface component remains difficult to quantify directly, particularly at sub-annual timescales. This study introduces a diagnostic framework to investigate groundwater storage dynamics by combining a monthly Budyko-based water budget analysis with normalized runoff metrics and a residual storage parameter, ξ, representing groundwater inflows and outflows across catchment boundaries together with groundwater storage variations, enabling identification of storage accumulation and depletion phases.

The framework is applied to nine catchments in the Western Alps (Piemonte, Italy; four catchments) and NE Catalonia, Spain (five catchments). Analysis of climatic aridity, runoff efficiency, and ξ at the monthly scale reveals distinct seasonal regimes and highlights the role of groundwater storage and interbasin flow. Alpine catchments show structured seasonal storage cycles, with winter accumulation and spring release, whereas Mediterranean catchments display stronger water limitation, frequent summer storage depletion, and more episodic recharge.

Diagnostic graphical representations provide a consistent basis for identifying seasonal hydrological states and storage behaviour across contrasting environments. Analysis of seasonal trajectories in Budyko space and associated storage variations enables detection of transitions between storage accumulation and depletion phases. This approach provides a practical diagnostic tool for assessing groundwater resilience to water balance changes in Alpine and Mediterranean catchments

Funding: Project TREASURE (PCI2024-153494), financed under the 2022 Joint call of the European Partnership 101060874-Water4All. FE Franco benefited from PhD project funds (39th cycle), University of Turin, supported by the Italian Ministry of University and Research (MUR).

LID 0507
Assessing the impacts of climate and land use/land cover change on groundwater recharge and discharge patterns – A case study of the Windhoek Aquifer, Namibia

Hilja Ndakola[1,2]*, John Okedi[1]

[1] University of Cape Town, Cape Town, South Africa
[2] University of Namibia, Ongwediva, Namibia
* ndakolah@gmail.com

Keywords: groundwater recharge and discharge, climate and land use change, semi-arid urban water security

Groundwater resources face growing threats from overuse, contamination, and evolving climate and land use patterns, posing significant risks to water security. Climate change indirectly affects groundwater by altering recharge processes, while land use changes exacerbate these impacts. Despite the recognized effects of climate and land use change on groundwater, their specific influence on recharge and discharge patterns are not yet fully understood, necessitating localized research. This study focuses on Windhoek, Namibia's capital, which partially relies on groundwater and faces increasing water scarcity due to changing precipitation patterns, rising temperatures, and rapid population growth. In February 2024, Windhoek announced critical water shortages, underscoring the urgency of understanding climate and land use interactions for sustainable water management. The study aims to analyze the individual and combined impacts of climate and land use changes on groundwater recharge and discharge patterns. Three key research questions will be addressed: how climate change influences precipitation, temperature, and rainfall-runoff mechanisms; how land use affects land surface temperature and rainfall-runoff mechanisms; and how climate and land use change influence groundwater recharge and discharge independently and in combination. Using a modeling approach, this simulation-based study will provide a comprehensive assessment to inform effective planning and adaptation strategies. The findings will contribute to sustainable water resource management, helping to ensure a resilient and reliable water supply for Windhoek and similar regions facing water scarcity challenges.

LID 0509
Soil water content prediction for precision irrigation in maize using phenology-aware remote sensing

Nxumalo Gift Siphiwe[1]*, Feher Zsolt[1], Radócz László[1], Ramabulana Tondani Sanah[2], János Tamás[1], Attila Nagy[1]

[1] Institute of Water and Environmental Management, Faculty of Agricultural and Food Sciences and Environmental Management, University of Debrecen, Debrecen, Hungary
[2] Institute of Geography and Earth Sciences, Faculty of Sciences, University of Pécs, Pécs, Hungary
* simphiwebounty@gmail.com

Keywords: precision irrigation, SAR, soil water content prediction

Accurate soil water content (SWC) estimation is essential for efficient precision irrigation in maize farming. Conventional synthetic aperture radar (SAR) methods often overlook how crop growth stages affect prediction accuracy, resulting in inconsistent performance throughout the growing season. We developed a phenology-informed approach that combines Sentinel-2 NDVI-based crop development stages with Sentinel-1 SAR data to predict SWC at specific growth phases in maize fields across Hungary's Hajdúság region (2020-2024).

Weekly measurements captured SAR signals (VV, VH polarizations), radar vegetation index (RVI), dual-polarization index (DPI), and vegetation index (NDVI) from four weather stations. Machine learning models—Random Forest and XGBoost—explicitly incorporated phenological stage as a predictor variable. Random Forest delivered the best results (R^2 = 0.78-0.85, RMSE = 2.8-3.6%) with stronger performance than XGBoost, particularly during vegetative and reproductive phases. Early growth stages showed limited accuracy due to weak radar signals.

NDVI, RVI, and VH measurements emerged as the strongest predictive features. The operational framework generated spatially detailed irrigation maps that identify zones requiring variable-rate water application based on predicted soil moisture patterns. This phenology-integrated remote sensing method showcases how accounting for crop development improves irrigation management by capturing the complex interactions between crop physiology, soil conditions, and atmospheric factors.

The research presented in the article was carried out within the framework of the Széchenyi Plan Plus program with the support of the RRF 2.3.1 21 2022 00008 project. This research was also funded by TKP2021-NKTA-32 project. Project no. TKP2021-NKTA-32 has been implemented with the support provided from the National Research, Development and Innovation Fund of Hungary, financed under the TKP2021- NKTA funding scheme.

LID 0510
Hydrogeological analysis of a mountain spring in the Aosta Valley (NW Italy): Insights from harmonic and isotopic Approaches

Martina Gizzi[1]*, Glenda Taddia[1], Fabrizio Bianco[1]

[1] Department of Environment, Land and Infrastructure Engineering (DIATI), Politecnico di Torino, Torino, Italy
* martina.gizzi@polito.it

Keywords: Alpine aquifers, groundwater monitoring, spring recharge

Mountain aquifers are among the most significant sources in northern Italy, playing a crucial role in meeting the population's water demands. However, in recent decades, various hydrogeological issues have emerged across the Italian Alps, including the drying up of springs and the transition of formerly perennial springs into seasonal ones.

The study is conducted in the Aosta Valley, a region characterized by a strong dependence on spring water resources, which account for approximately 80% of the total water supply. Since 2010, the Politecnico di Torino has operated a regional monitoring network, generating longterm hydrological time series. Water probes recording water level, temperature, and electrical conductivity at hourly intervals were installed at the Promise, Entrebin, Gabiet, and Promiod springs, located in distinct mountainous catchments. Complementary meteorological data were supplied by the Centro Funzionale Regionale VDA.

To investigate recharge mechanisms, Fast Fourier Transform (FFT) analysis was applied to hydrograph signals, enabling the identification of relationships among flow rate, temperature, and precipitation. In parallel, stable isotope analyses ($\delta^{18}O$ and $\delta^{2}H$, referenced to V-SMOW2) were performed to characterize recharge sources and groundwater flow paths.

The integration of harmonic and isotopic analyses improved the understanding of spring recharge sources and dynamics. Springs supplying drinking water generally exhibit relatively stable discharge patterns, suggesting well-buffered aquifer systems capable of sustaining baseflow during dry periods. However, significant interannual fluctuations underline the sensitivity of these systems to climate variability.

Overall, the results demonstrate that continuous monitoring, combined with advanced analytical approaches, represents a key tool for assessing groundwater vulnerability and supporting adaptive, sustainable water resource management in Alpine regions under increasing climatic stress.

LID 0511
Assessing shallow groundwater occurrence in Lebowa Granite Suite: Winterveld, North West, South Africa

Rendani Makahane[1]*

[1] University of Pretoria, Pretoria, South Africa
* rmakahane39@gmail.com

Keywords: shallow groundwater, flood risk, wetland

In a peri-urban settlement of Winterveld, North-West, South Africa, an immediate water security crisis has been unfolding. The area's underlying Lebowa Suite Granite geology, overlain by fine sand topsoil, creates a distinct shallow groundwater system where natural seepage wetlands are a defining feature. Historically, these wetlands would have acted as natural sponges, absorbing rainfall and mitigating flood peaks. However, developments such as construction of critical community infrastructures such as schools and homes has directly affected the functionality of these vital hydrological zones. This land-use change has compromised the area's natural drainage capacity. Consequently, during rainfall events, rapid infiltration through the soil meets the shallow water level, causing the wetland to flood. These events regularly disrupt access to education, damaging properties and threatening public health. There is a critical lack of site-specific hydrogeological data to understand this process quantitatively. Without this knowledge, effective mitigation for existing settlements is hindered, and future developments might continue without guidance, therefore continuing the cycle of risk. This research therefore aims to assess the shallow groundwater occurrence Winterveld by generating the foundational hydrogeological evidence using geological and geophysical data, Earth Observation, and Citizen science.

LID 0512
Climate change impacts on groundwater systems in mountain regions: A systematic review of recharge, storage, and cryosphere–groundwater interactions

Federico Emanuel Franco[1]*, Manuela Lasagna[1], Domenico Antonio De Luca[1]

[1] Earth Sciences Department, University of Turin, Turin, Italy
* federicoemanuel.franco@unito.it

Keywords: groundwater recharge, mountain hydrogeology, climate change impacts

Climate change is expected to significantly alter groundwater systems by modifying recharge processes, storage dynamics, and groundwater–surface water interactions. This study presents a systematic review of 109 peer-reviewed articles selected through structured screening, with the aim of synthesizing current knowledge on hydrogeological responses to climate change across different climatic and geological settings.

Results consistently show that groundwater recharge is highly sensitive to shifts in precipitation regimes, evapotranspiration, and seasonality. In cold and mountainous regions, reductions in snowpack and earlier snowmelt timing alter recharge magnitude and timing, often reducing summer groundwater storage and baseflow. Permafrost degradation further modifies infiltration pathways and subsurface storage, in some cases enhancing deep percolation while destabilizing established flow systems. Springs and headwater systems emerge as particularly vulnerable components, as their discharge closely reflects recharge variability and limited storage buffering.

The review also highlights that hydrogeological properties, including aquifer storage capacity, permeability, and flow system scale, strongly control system resilience. Shallow and local flow systems respond rapidly to climatic forcing, whereas deeper and regional systems exhibit delayed and attenuated responses. Seasonal redistribution of recharge, rather than uniform annual changes, is identified as a key mechanism affecting groundwater availability.

In addition to primary hydrological impacts, climate-driven groundwater temperature increases and cryosphere degradation may influence groundwater-dependent ecosystems and slope stability, highlighting broader implications for mountain environments.

These findings emphasize the central role of groundwater in mediating hydrological responses to climate change and underscore the importance of integrating hydrogeological processes into climate impact assessments and water resource management strategies.

LID 0515
Stormwater managed aquifer recharge in pre-alpine catchments

Saulo Vieira[2], Lea Augustin[1], Anne Schultze[1], Jörn Bartels, **Thomas Baumann**[1]*

[1] Technical University of Munich, School of Engineering and Design, Chair of Hydrogeology, Munich, Germany
[2] AQUASOIL Ingenieure & Geologen GmbH, Berlin, Germany
* tbaumann@tum.de

Keywords: managed aquifer recharge, stormwater

Managed aquifer recharge (MAR) is a state-of-the-art strategy to maintain groundwater levels and sustain groundwater-dependent ecosystem services. Increasing rainfall intensity and prolonged drought periods caused by climate change put the availability of river water for MAR at risk. To adapt, MAR has to include stormwater as a source. This requires to infiltrate high volumes of water with high recharge rates, increase buffer and retention capacity and times, and maintain water quality. In the project Smart-SWS we have developed a stormwater-based MAR scheme which consists of an infiltration ditch connected to a stream and a geotechnical barrier set in the aquifer. Water quality issues were addressed with a combination of catchment risk analysis, on-line monitoring backed by extended laboratory analyses and tailored treatment techniques.

The site is located downstream of a flood retention basin (FRB) in the Bavarian alpine foreland. The aquifer is composed of highly conductive quaternary gravel with a thickness of 10 to 20 m in the storage area. The hydrogeological model informed the numerical groundwater model which was used to find the optimal position for the infiltration ditch and the geotechnical groundwater flow barrier. A first real-world proof-of-concept for the design and model was established during the 100-year flooding event in June 2024. The recorded water levels were modeled with an infiltration rate of 1.2 m^3/s along a 670 m relief diversion from the main stream which runs along the planned infiltration ditch. Water quality during the flooding event was better than expected and met the criteria for infiltration. A modeled six months drought situation showed that Smart-SWS will be able to buffer up to 130.000 m^3 of groundwater. Effects on groundwater dependent and surface level ecosystems, and infrastructure were assessed.

LID 0516
Preferential recharge of karst aquifers by winter precipitation

Aurel Perşoiu[1,2,3], Oleg Bogdevici[4]*

[1] Emil Racoviță Institute of Speleology, Romanian Academy, Cluj Napoca, Romania
[2] Stable Isotope Laboratory, Ştefan cel Mare University, Suceava, Romania
[3] Department of Physical and Environmental Geography, School of Geology, Aristotle University of Thessaloniki, Thessaloniki, Greece
[4] Institute of Chemistry, Moldova State University, Chisinau, Republic of Moldova
* oleg.bogdevici@sti.usm.md

Keywords: karst aquifer, recharge, isotopes, snowmelt

Aquifers hosted in karstified rocks (e.g., limestone, dolomite) provide water for ~25 % of the world's population, in several countries being the main source of drinkable water. The high degree of secondary (fissures and fractures) and tertiary (conduits enlarged through dissolution) porosity of these rocks leads to specific recharge and flow patterns of the aquifers, reflected in highly variable values of liquid discharge. Recharge of karst aquifers is done through both point (i.e., sinking rivers) and diffuse inputs, with their contribution being highly variable in both time and space. In this contribution, we assess the timing of aquifer recharge in several karst regions in Romania (SE Europe), using the isotopic composition of water (expressed by $\delta^{18}O$ and $\delta^{2}H$) as an indicator of recharge timing, relative contribution of point and diffuse sources and transfer times from input to output. Our data shows that virtually all types of karst aquifers in Romania are recharged mainly by winter precipitation through diffuse infiltration, the base flow being thus dominated by snowmelt. Episodes of intense rainfall lead to rapid increases of discharge, but these are quickly moving through the highly porous rocks, leading to reduced water storage. In the context of continuous decrease of solid precipitation and subsequent snow cover an increase in highly intense summer rain events, we anticipate a continuous drying-up of the karst aquifers, resulting in intensified water-stress and associated socio-economic troubles.

LID 0517
Collaborative hydrogeology field school: Integrating teaching, research and professional training

Niina Kuosmanen[1*], Kirsti Korkka-Niemi[1,2]

[1] Department of Geosciences and Geography, University of Helsinki, Helsinki, Finland
[2] Geological Survey of Finland, Espoo, Finland
* niina.kuosmanen@helsinki.fi

Keywords: higher education, hydrogeology, field school

Hydrogeology Field School for the master students at the University of Helsinki (UH) has been organized in collaboration with Geological Survey of Finland (GTK) two times, in September 2022 and 2024.

At both times, the location was chosen to coincide with ongoing GTK groundwater research projects. The two-week course began with online lectures attended by students and GTK staff. During the second week, participants carried out practical hydrogeological investigations in mixed groups. The course covered groundwater-sampling methods, field measurements of water levels and quality and determining hydraulic conductivity. Participants also applied methods for quantifying groundwater discharge to surface waters (e.g. infrared imaging, seepage measurements, flow gauging, mini-piezometers). All collected data were analyzed and reported as part of the coursework.

Collaborative organization of the field school allows a broader range of methods to be taught through shared equipment and expertise. This improves both efficiency and quality of fieldwork. GTK experts participated the field school as both instructors and learners, and the course served as in-service training for GTK's field personnel.

A major benefit for students was exposure to real projects and interaction with professionals. The course enabled students and GTK specialists to become familiar with each other's expertise, creating an effective recruitment pathway for students. Four students from the 2022 course have secured permanent positions at GTK, and one student from the 2024 a fixed-term contract—clear evidence of the success of this collaboration.

Our experience shows that collaborative work offers substantial added value: it bridges academic and applied knowledge, deepens participants' understanding of hydrogeological processes and techniques and facilitates networking. This approach supports students' development and simultaneously contributes to progress in hydrogeological research and professional practice.

LID 0518
A framework for integrating models of contaminant transport in vadose zone and groundwater

Adam Szymkiewicz[1]*, Mateusz Pawłowicz[2], Anna Gumuła-Kawęcka[1], Jirka Šimůnek[3]

[1] Gdańsk University of Technology, Gdańsk, Poland
[2] AGH University of Kraków, Kraków, Poland
[3] University of California-Riverside, Riverside, United States
* adams@pg.edu.pl

Keywords: contaminant transport, vadose zone, numerical modeling

The release of contaminants to groundwater typically occurs through the vadose (unsaturated) zone. Integration of contaminant transport models for the vadose zone and groundwater enables more accurate estimation of travel times, peak concentrations, and attenuation, as well as prediction of the effects of land use and climate change. Integrated hydrological models are available that cover contaminant transport in a 3D subsurface domain (vadose zone and groundwater) and the surface water domain. However, such models often require substantial user expertise and computational resources and may lack advanced features found in transport models developed for specific hydrological compartments. Moreover, flow and transport in the vadose zone can often be considered as 1D vertical processes, so the solution of 3D equations is avoided. Such an approach can be particularly advantageous if the pollutant source in the vadose zone has a limited horizontal extent relative to the groundwater domain.

In this contribution, we describe the addition of a contaminant transport model to the HMSE framework for coupling HYDRUS-1D and MODFLOW-2005 (Pawłowicz et al. 2023). HYDRUS-1D has multiple options for equilibrium and non-equilibrium transport modeling. In the groundwater domain, transport is simulated using either MT3D (based on MODFLOW-2005 water-flow simulations) or MODFLOW 6, which integrates flow and transport in a single program. The programs are coupled externally using Python scripts. Contaminant loads at the groundwater table are calculated with HYDRUS-1D and passed as input to the groundwater transport model. The coupled model's capabilities are demonstrated for a range of contaminant-release scenarios.

This work has been partly supported by the EU Horizon project SOILPROM (grant 101156589, soilprom.eu) and by the EU Water4All project AQUIGROW (aquigrow.it), under the grant agreement with the National Centre for Research and Development (Poland) WATER4ALL/I/37/AQUIGROW/2024.

LID 0519
Nature-based aquifer recharge: Experiments and models for public understanding

Judit Mádl-Szőnyi[1]*, Miklós Vincze[2], Ildikó Erhardt[1], Szilvia Simon[1], Brigitta Czauner[1], Márk Szijártó[1,3]

[1] József and Erzsébet Tóth Endowed Hydrogeology Chair, Department of Geology, Institute of Geography and Earth Sciences, Eötvös Loránd University, Budapest, Hungary
[2] von Kármán Laboratory, Department of Materials Physics, Institute of Physics and Astronomy, Eötvös Loránd University, Budapest, Hungary
[3] Department of Geophysics and Space Science, Institute of Geography and Earth Sciences, Eötvös Loránd University, Budapest, Hungary
* judit.szonyi@ttk.elte.hu

Keywords: groundwater flow, nature-based, managed aquifer recharge, public awareness

Hydroclimatic extremes, such as droughts and water surpluses, significantly affect large areas, populations, economies, and production chains worldwide. Addressing these impacts and ensuring water supply for both humans and ecosystems is a major scientific and societal challenge. Groundwater, often overlooked, plays a crucial role in balancing wet and dry periods. Hydrogeologists use Managed Aquifer Recharge (MAR) to store excess water during rainy seasons and reserve it for droughts, making it a vital water retention solution. However, the link between surface and underground water retention is often missing. Locally stored groundwater becomes part of a groundwater flow system. The increased water level altering hydraulic heads and thus intensifying water movement, impacting both underground and surface environments. By understanding the impact of stored water through natural groundwater flow systems, we can better plan with this excess resource.

The NaBa-MAR®, developed by the ELTE Hydrogeology Group and protected by a European trademark, integrates local MAR methods with the natural hydraulic and environmental effects of regional groundwater flow. This innovative approach can mitigate extreme hydrological events on a landscape scale. To ensure its urgent implementation, it is crucial to efficiently disseminate this invention to decision-makers and the public. The presentation showcases a simple physical experiment demonstrating the operation of NaBa-MAR® alongside a surface canal, highlighting its possibilities and limitations. Supported by a numerical model, it discusses the experiment's findings for dissemination.

The research was implemented by the National Multidisciplinary Laboratory for Climate Change (RRF-2.3.1-21-2022-00014) under Hungary's National Recovery and Resilience Plan. Additionally supported by the 2023-1.2.2-HE_PARTNERSÉG-2023-00005, the European Partnership 101060874 — Water4All project, and the ELTE Excellence Fund.

LID 0520
MAR as a sustainable solution? Co-creating groundwater management strategies to improve salinity resilience in deltas

Syed M.T. Mustafa[1*], Kazi Matin Uddin Ahmed[2], Philip S.J. Minderhoud[3], Gualbert Oude Essink[4,5], Sarmin Sultana[2], Md. Abdul Mojid[6] , Wouter M. Kranenburg[5,7], Ruchika Shiva[8], Sara Nowreen[9], Mahbuba Nasreen[10], Art Dewulf[11], Victor Bense[1]

[1] Hydrology and Environmental Hydraulics Group, Wageningen University & Research, Wageningen, The Netherlands
[2] Department of Geology, Faculty of Earth and Environmental Sciences, University of Dhaka, Dhaka, Bangladesh
[3] Soil Geography and Landscape Group, Wageningen University & Research, Wageningen, The Netherlands
[4] Department of Physical Geography, Faculty of Geosciences, Utrecht University, Utrecht, The Netherlands
[5] Deltares, Delft, The Netherlands
[6] Department of Irrigation and Water Management, Bangladesh Agricultural University, Mymensingh, Bangladesh
[7] Department of Hydraulic Engineering, Delft University of Technology, Delft, The Netherlands
[8] IRCWash, The Netherlands
[9] Institute of Water and Flood Management, Bangladesh University of Engineering and Technology, Dhaka, Bangladesh
[10] Institute of Disaster Management and Vulnerability Studies, University of Dhaka, Dhaka, Bangladesh
[11] Public Administration and Policy Group, Wageningen University and Research, Wageningen, The Netherlands
* syed.mustafa@wur.nl

Keywords: Managed Aquifer Recharge (MAR), salinity, deltas, groundwater

Over 70% of large deltas, including the Ganges–Brahmaputra–Meghna (GBM) delta, are under constant threat from groundwater overexploitation, saltwater intrusion, freshwater scarcity, land subsidence, and pollution due to anthropogenic and climatic pressures. In this context, achieving sustainable management requires an enhanced understanding of coastal groundwater systems to develop science-informed strategies that secure freshwater for WASH and food production. While Managed Aquifer Recharge (MAR) has been piloted in the GBM delta, its limited success highlights a need for deeper system insights. This study employs an integrated water system approach to bridge these crucial knowledge gaps and co-create diverse adaptation, mitigation, and management pathways by combining local "Living Lab" evaluations with large-scale, basin-wide hydrogeological assessments.

This multi-scale methodology first involves a systematic analysis of existing MAR initiatives to identify key success factors by learning from previous failures. This is supplemented by site characterization using advanced geophysical methods: Electrical Resistivity Tomography (ERT), TEM2Go, and borehole geophysics. These local insights are then integrated into a novel regional, open-source, and user-friendly modelling framework to analyze the current state of the GBM delta and assess future scenarios related to groundwater availability, salinity, and land subsidence. By utilizing both field measurements and numerical modelling, the study evaluates long-term sustainability to combat water scarcity and deteriorating drinking water quality.

This approach aims to advance from theoretical frameworks to a large-scale integrated systems approach, paving the way for site-specific solutions. Ultimately, this framework enables the identification of optimal MAR siting, ensuring that local technical interventions are scalable, co-created with stakeholders, and resilient to future challenges.

LID 0521
Following microplastics into the subsurface: Experimental insights into sediment retention

Barbara Klun[1]*, Gabriela Kalčikova[1]

[1] Faculty of Chemistry and Chemical Technology, University of Ljubljana, Ljubljana, Slovenia
* barbara.klun@fkkt.uni-lj.si

Keywords: microplastics, sediments, transport

Predictive models of microplastic fate in groundwater and hyporheic environments are limited by insufficient experimental data describing particle transport and retention in porous media. While microplastics are well documented in surface waters, their behaviour after infiltration into sediments—where flow velocities are low and pore-scale heterogeneity controls transport—remains poorly understood. This limits our ability to assess accumulation, residence times, and remobilization potential in subsurface systems.

To generate parameters suitable for groundwater transport modelling, we investigated microplastic migration through three sediments with contrasting grain-size distributions and hydraulic properties. Two polymers with different densities were examined: polyethylene (0.917 ± 0.052 g/mL) and polylactic acid (1.459 ± 0.037 g/mL). Sediment porosity, permeability, dispersivity, and grain-size distribution were characterized prior to transport experiments.

The experiments were conducted in a horizontal glass column (5.5 cm diameter, 60 cm sediment length) under steady-state flow driven by a controlled hydraulic head. Flow rates (0.25–1 mL/s) were selected to represent pore-water velocities typical of riverbeds and shallow groundwater. Microplastics were introduced at the inlet, and migration was monitored over four pore volumes. After each experiment, the column was sectioned to quantify retained particles. Density-specific extraction followed by Nile red staining enabled fluorescence-based identification and reconstruction of spatial retention patterns.

Results show clear density-dependent transport behaviour and strong grain-size control on retention. These findings provide experimentally constrained parameters for porous-media transport models and improve predictions of microplastic accumulation and persistence in groundwater systems.

This work was supported by the Slovenian Research and Innovation Agency (ARIS) through the MR-54975 grant and programme Chemical Engineering (P2-0191).

LID 0522
Hydrogeological modeling for the optimization of an open-loop geothermal system at Politecnico di Torino: The ''Spina della Didattica" case study (Turin, Italy)

Glenda Taddia[1]*, Martina Gizzi[1], Federico Vagnon[1]

[1] Environment, Land, and Infrastructure Department, Diati – Politecnico di Torino, Torino, Italy
* glenda.taddia@polito.it

Keywords: groundwater heat pump, hydrogeological modeling, geothermal system

The "Spina della Didattica" project represents the first phase of a strategic campus redevelopment plan of Politecnico di Torino, located in the former OGR industrial area in Turin (NW Italy). The new four-storey "Manica" building will host lecture halls and interactive learning spaces and will be conditioned through a groundwater-based open-loop geothermal system. In a densely urbanized environment, the sustainable exploitation of shallow aquifers for thermal use requires a rigorous hydrogeological framework and careful plant configuration.

This study presents the integrated methodological approach adopted to define the optimal design of the open-loop system within a complex urban hydrogeological setting. Extensive geognostic investigations were performed, including non-invasive geophysical surveys for underground utility mapping and subsurface characterisation. Exploratory boreholes, continuous coring, stratigraphic and lithotechnical logging have been carried out to explore the details of geological characteristics.

The collected data supported the development of a refined conceptual model of the shallow alluvial aquifer and its interaction with surrounding urban infrastructures. A numerical groundwater flow and heat transport model was implemented to evaluate alternative abstraction–reinjection well configurations, assess hydraulic interference and thermal breakthrough risk, and verify compliance with regulatory constraints.

Results demonstrate how site-specific geognostic investigations combined with hydrogeological modelling are essential to optimise system efficiency, minimise environmental impacts, and ensure sustainable groundwater-energy use in urban environments, supporting resilient and low-carbon campus development.

LID 0524
Numerical modelling of groundwater flow and permafrost evolution over glacial time scales in the context of a deep geological repository for nuclear waste

John Molson[1,2]*, Mahsa Malmir[1,2], René Therrien[1]

[1] Department of Geology & Geological Engineering, Université Laval, Québec City, Canada
[2] Centre for Northern Research, Université Laval, Québec, Canada
* john.molson@ggl.ulaval.ca

Keywords: deep geological repository, permafrost, glacial cycles

Two-dimensional numerical simulations have been conducted for Canada's Nuclear Waste Management Organisation's proposed deep geological repository (DGR) in northwestern Ontario, Canada. The conceptual model includes coupled density-dependent groundwater flow, advective-conductive heat transport with freeze-thaw, and advective-dispersive brine transport within a discretely-fractured porous medium, simulated using the finite element HEATFLOW/SMOKER code (Molson & Frind, 2025). Surface conditions include glacier advance and retreat over 120,000 years, glacial loading, and variable air and ground-ice temperatures derived using the University of Toronto Glacial Systems Model (GSM), which is based on ice-sheet simulations combined with data assimilation and glacial isostatic adjustment (GIA) reconstructions. Geological and cryo-hydrogeological data are based on site-specific investigations, and on representative data collected from permafrost research sites at Umiujaq and Salluit, Nunavik, Quebec, Canada.

Predictive simulations under various scenarios show maximum permafrost depths on the order of 300-400 m, remaining above the proposed 750 m depth of the DGR. While permafrost growth reduces the effective permeability and groundwater flow rates, short transient periods are identified where taliks (unfrozen zones) may form in areas of localised recharge/discharge connected to surface water by high fracture densities. Deep brines remain essentially immobile. Travel times are on the order of millions of years, reflecting extremely low groundwater velocities at the repository depth. The simulations suggest that radioisotope heat generation from the DGR will have limited impact on permafrost depth.

LID 0525
Valley dams as in-channel MAR in Mediterranean intermittent rivers and ephemeral streams: Monitoring recession and recharge in Malta

Julian A. Mamo[1]*, Beppe Agius[2], Christa Pisani[2], Marzio Melis[2], Michael Schembri[2]

[1] Institute of Earth Systems, University of Malta, Msida, Malta
[2] The Energy and Water Agency (EWA), Qormi, Malta
* julian.a.mamo@um.edu.mt

Keywords: in-channel MAR, IRES (intermittent rivers and ephemeral streams), small valley dams, recession analysis, infiltration and recharge, stormwater harvesting, flood attenuation

Small valley dams are widely used in Mediterranean dry valleys to impound storm runoff, reduce flood peaks, and contribute to groundwater recharge by increasing infiltration. In Malta, these in-channel structures occur along temporary watercourses, intermittent rivers and ephemeral streams (IRES), ranging from spring-fed reaches with seasonal baseflow to downstream channels that are ephemeral, flowing only in direct response to rainfall and ceasing soon after events. Yet their hydrological performance is rarely quantified, limiting the evidence base for siting, crest height, and operational releases.

We present a multi-site monitoring programme quantifying ponding-recession behaviour and recession-derived infiltration/recharge rates behind valley dams across contrasting Maltese lithologies and valley settings. High-frequency water-level records (pressure transducers with barometric compensation) are combined with surveyed stage–area/volume relationships, rainfall data and event observations. Recession analysis is used to estimate effective loss rates and to compare controls related to (i) bedrock and valley-fill characteristics, (ii) presence of spring inflows sustaining baseflow, and (iii) upstream imperviousness and abstraction for irrigation.

The dataset supports three applied outcomes for semi-arid catchments: (1) identifying where IRES valley systems act as recharge hotspots and short-term agricultural buffers, (2) providing site-specific parameters to inform dam placement and crest height to balance storage, flood attenuation and recharge and (3) informing operational strategies, including when controlled releases can shift water to downstream reaches with higher infiltration capacity while maintaining flood-risk reduction. The approach provides a transferable, monitoring-based framework to evaluate small in-channel MAR structures in Mediterranean temporary streams.

LID 0526
Stable isotopes in tap water: Insights into urban water supply structure and management in Ljubljana

Klara Žagar[1]*, Polona Vreča[1]

[1] Jožef Stefan Institute, Department of Environmental Sciences, Ljubljana, Slovenia
* klara.zagar@ijs.si

Keywords: urban hydrology, tap water, stable isotopes of hydrogen and oxygen

Urban water supply systems are increasingly exposed to climate variability and growing demand. To manage these systems efficiently, it is important to understand the origin, mixing processes, and sustainability of urban drinking water sources. Stable isotopes of hydrogen and oxygen (δ^2H and δ^{18}O) are powerful tools for tracing water sources, quantifying mixing processes, and detecting shifts driven by climate change, infrastructure operation, and demand patterns. Their application at urban scales enables high-resolution assessment of supply structures and supports adaptive groundwater management. This study examines δ^2H and δ^{18}O in tap water in Ljubljana, Slovenia, where water is supplied from groundwater stored in two aquifers. Between 2019 and 2021, three sampling campaigns were carried out across the city using a citizen science approach. Altogether, 273 tap water samples were collected from 145 different participants. The dataset allowed assessment of spatial differences between water supply areas as well as seasonal variability within the system.

Although the observed variations in δ^2H and δ^{18}O were small, consistent and statistically significant differences were observed between supply areas, reflecting distinct recharge conditions and aquifer characteristics. Seasonal patterns indicate a strong imprint of winter recharge, while comparison with previous investigations suggests sensitivity of the system to interannual climatic variability. Mixing calculations further show that, in some supply areas, tap water is dominated by contributions from deeper groundwater. While these deeper sources provide stability and protection from short-term contamination, their longer residence times and potentially slower recharge highlight the need for careful abstraction management.

The research was conducted in the frame of ARRS programs: (P1-0143) and (PR-09780), and the IAEA: CRP (F33024) and RER-7013. We thank all off the volunteers for their help with sampling.

LID 0529
The Groundwater Project: Global groundwater education

Ineke Kalwij[1]*

[1] The Groundwater Project, Guelph, Canada
* ineke@kalwijwaterdynamics.com

Keywords: groundwater, education, interactive learning

The Groundwater Project, a Canadian NGO (www.gw-project.org), has made it its mission to make groundwater understandable through creating and publishing educational books and related training materials on a comprehensive range of groundwater topics in many languages. The Groundwater Project operates from their own virtual platform globally accessible with publications available for free.

The Groundwater Project is unique in its scope and volunteer framework for creating a comprehensive repository of highly credible synthesized knowledge concerning an entire scientific domain known as groundwater science (hydrogeology), which derives from the broader realms of the geological and environmental sciences.

Since book publication began in 2020, the Groundwater Project has positioned itself as a global leader providing high-quality, groundwater education. Education is provided for children, university students, scientists, practitioners, and members of the public. Groundwater Project books are being used to educate the future generation of hydrogeologists. The Groundwater Project recognizes the importance of making groundwater knowledge accessible to a wide audience, including children. Including water in the early childhood curriculum is essential for promoting environmental awareness and raising children's awareness of potential careers in water-related fields.

In this presentation we share our accomplishments including book publications and our creation of interactive learning modules to facilitate groundwater learning, part of our expanded vision. We will share future endeavours including the development of online certification for online learning modules and our plans for integrating AI tools to support studying based on the books published by the Groundwater Project.

LID 0530
Conventional and unconventional geothermal systems in further development of the geothermal energy sector

Anna Wachowicz-Pyzik[1]*, Elżbieta Hałaj[1], Michał Stefaniuk[1], Marcin Nowak[2], Marcin Kaniewski[3]

[1] AGH University of Krakow, Faculty of Geology, Geophysic and Environmental Protection, Department of Energy Sources, Kraków, Polska
[2] Elektrownia 88 Sp. z o.o., Śrem, Polska
[3] Eavor Technologies Inc., Calgary, Canada
* amwachow@agh.edu.pl

Keywords: geothermal energy, AGS, EGS

The geothermal energy sector is gaining momentum year after year. Its reliability compared to other renewable energy sources, such as solar or wind energy, makes it a stable and dispatchable source used for both heating and electricity production. Conventional geothermal systems are highly dependent on the geological and thermal conditions of the potential location like presence of high-temperature groundwater in abundant quantities, as well as reservoir rocks with high porosity and permeability. Another essential prerequisite for the effective utilization of conventional geothermal energy (particularly for direct-use heating) is the proximity of the geothermal resources to end-users with adequate energy demand. However, favorable geothermal conditions do not always coincide with areas of significant heat consumption.

In recent years, new technologies related to unconventional geothermal energy systems, such as Advanced Geothermal Systems (AGS) or Enhanced Geothermal Systems (EGS), have become more and more important. These systems are far less (or even not) constrained by natural rock porosity, permeability, or the presence of groundwater at suitable temperatures. They enable geothermal energy extraction on a significantly broader scale, including regions where high heat or electricity demand exists but conventional hydrothermal systems are not viable. In addition, the scalability and replicability of certain technologies allow for the application of learning-curve effects, resulting in substantial reductions in energy production costs in the future.

This analysis compares conventional and unconventional geothermal systems according to investments implemented in Europe. It also highlights the advantages and disadvantages of selected technologies and the future prospects for geothermal energy development.

LID 0531
Application of Physics-Informed Neural Networks (PINNs) to seawater intrusion modeling in data limited environments

Maryam Mansouri Bajgiran[1*], François Lehmann[1], Anis Younes[1], Mohammad Mahdi Rajabi[2], Marwan Fahs[1]

[1] Université de Strasbourg, CNRS, ENGEES, Institut Terre et Environnement de Strasbourg, Strasbourg, France
[2] Faculty of Science, Technology and Medicine, University of Luxembourg, Belval, Luxembourg
* mansouribajgiran@unistra.fr

Keywords: seawater intrusion, Physics Informed Neural Networks(PINNs), hybrid approaches

Since their introduction, Physics Informed Neural Networks (PINNs) have marked a significant advancement in scientific machine learning by embedding physical laws directly into the training process of neural networks. PINNs have been applied in various contexts, ranging from purely physics driven to hybrid approaches that incorporate scarce or limited observational data. The latter approach is particularly valuable in environmental and hydrological problems, where measurements are often sparse and incomplete.

In this study, PINNs are applied to model seawater intrusion (SWI), representing one of the first attempts to employ this framework in the context of SWI simulation. The implementation spans the full spectrum of approaches, from purely physics based formulations to hybrid strategies across different physical paradigms. In the hybrid framework, only limited observational data, represented by measurements from wells at different depths within the aquifer, are incorporated during training.

The results highlight the strong potential of PINNs for SWI modeling, particularly within hybrid frameworks under data limited conditions. The study demonstrates that even a small amount of observational data, can yield accurate and stable predictions if they are combined with governing physical laws. To address training difficulties in complex multiphysics settings, transfer learning is employed as a key strategy, where solutions from simpler models are used to initialize more advanced models, improving both convergence speed and predictive performance. Importantly, the study shows that incorporating measurements from only one physical component of a multiphysics system, together with the full set of governing equations, is sufficient to ensure stable training of the entire coupled problem. This property is particularly valuable for practical hydrogeological applications where field data are incomplete.

LID 0534
Multipurpose utilization of the PANNON XL hydrogeological models used for predictive managements in the Hungarian parts of the Pannonian Basin

György Tóth[1*]

[1] Private consulting, Budapest, Hungary
* gyuri14toth@gmail.com

Keywords: modeling large and deep flow system, multipurpose utilization, transboundary management, climate change effects

The Pannonian Basin is a Neogene continental back-arc basin surrounded by the Alpine–Dinaride–Carpathian orogenic belts in Central Europe. The upper part of the Neogene sediment aquifer complex has an upper gravity-driven flow regime overlain an aquitard-aquiclude complex at some regions with overpressured flow regime (Almási and Szanyi, 2024). The PANNON XL conceptual and numerical flow model represents the most comprehensive numerical simulation of the Pannonian Basin's porous sedimentary fill to date, (upper gravity-driven flow system down to ~2,500 m). Water moves from recharge areas (highlands) to discharge areas (lowland river valleys) due to potential differences. The system has geothermal influence: due to the thin lithosphere, the basin has a high heat flow (90–100 mW/m^2) resulting large extent of thermal porous groundwater bodies. Scope and Scale: The model covers the entire Pannonian Basin across national borders, (with 7 neighboring countries), aiming to simulate regional water budget changes, geothermal potential, and the effects of climate change.

PANNON XL Coupled Modeling and Predictive Management

This research emphasizes the integration of the PANNON XL (often referring to expanded regional basin hydrogeological models) with climatological data to create "coupled" predictive tools. These models address the impacts of climate change, drinking water productions and thermal water use for bathing and balneology, but also to some extent in the agricultural sector, geothermal energy, transboundary water managements on extra-large regional gravitational groundwater flow system within Pannonian sedimentary basin. Predictive Management: These tools are used to simulate future scenarios for multipurpose utilization, ensuring that geothermal energy extraction (used for district heating and agriculture), and does not deplete potable water supplies. Groundwater Dependent Ecosystems (GDEs), Ecological Focus: This work aligns with the “Tóthian theory” of regional groundwater flow, which identifies discharge zones as critical areas for GDEs, such as wetlands and salt pans. Risk Assessment: Integrated models now allow for early-spring predictions of the "inundation state" for GDEs like the salt pans in the Pannonian Basin, helping to mitigate threats from drainage and climate-induced drought. Developments in Irrigation. Agricultural Integration: The modeling efforts focus on optimizing irrigation scenarios by identifying areas where groundwater quality is suitable for crops and assessing how extraction affects long-term aquifer stability. Joint Monitoring developments: PANNONIAN XL project aim to harmonize transboundary monitoring to better manage these multipurpose utilizations.

LID 0535
Study of the Heterogeneity of PFAS contamination at a groundwater abstraction site in Nimy within the Chalk Aquifer of the Mons Basin

Fabio Cogliandro[1]*, Anthony Mahieu[1], Guillaume De Schepper[2], Tanguy Robert[2], Pascal Goderniaux[1]

[1] University of Mons – Polytech Mons – Geology and Applied Geology, Mons, Belgium
[2] VIVAQUA – Production Department – Water Resources Management, Brussels, Belgium
* Fabio.COGLIANDRO@umons.ac.be

Keywords: PFAS, groundwater, t-SNE, Modflow

This work investigates PFAS distribution at the Nimy groundwater catchment in the chalk aquifer of the Mons Basin (Belgium). The catchment, covering 80 ha, was commissioned in the mid-20th century and, via abstraction wells, produces 7.3 million m^3/year. Due to PFAS contamination, a hydraulic barrier with pumping at 3,000 m^3/day was implemented in summer 2023 at wells N5 and N10 to limit PFAS migration toward other wells. To characterize contamination and test mitigation measures, a multidisciplinary approach was applied: hydrochemical monitoring, piezometric mapping, multivariate statistical analyses, and numerical modeling of groundwater flow and solute transport.

The study uses years of analyses from nine wells. A piezometric and sampling campaign provided 44 samples collected from numerous piezometers. Samples were analyzed for target PFAS, major ions (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, HCO_3^{-}, SO_4^{2-}, Cl^{-}, F), minor ions, total organic carbon, and hydrochemical parameters (pH, conductivity, redox potential, dissolved oxygen).

Spatio-temporal trends show that short-chain PFAS (e.g., PFHxS, PFBS) predominate in the eastern part of the catchment. Long-chain compounds (PFOS) were also observed in some wells and piezometers, in the northern part of the site. To identify hydrochemical signatures, Principal Component Analysis (PCA) and t-distributed Stochastic Neighbor Embedding (t-SNE) were applied to hydrochemical and PFAS concentration data from the piezometers. The combination of t-SNE/K-means was used to identify five influence zones potentially linked to urban, industrial and agricultural activities, as well as surface water.

The development and calibration by pilot points of a local catchment model, derived from a regional groundwater flow model, enabled simulation of PFAS transport under different pumping and hydraulic-barrier activation scenarios. The simulations highlight the effectiveness of hydraulic-barrier configurations depending on the origin of contamination.

LID 0536
Structural and hydraulic controls on forced convection in Alpine aquifer systems: Insights from two thermal springs in NW Slovenia

Luka Serianz[1], **Nina Rman**[1*]

[1] Geological Survey of Slovenia, Ljubljana, Slovenia
* nina.rman@geo-zs.si

Keywords: forced thermal convection, Julian Alps, carbonate aquifers, regional groundwater flow, thermal water

Alpine carbonate aquifers with high recharge, large elevation gradients and strong lithological heterogeneity provide favourable conditions for forced thermal convection, which can significantly influence groundwater temperature and flow patterns. Advective heat transport is most evident where deep circulation discharges as thermal springs, representing surface expressions of basin-scale flow along hydraulically connected pathways. Yet the mechanisms that regulate such behaviour remain poorly constrained due to structural complexity and limited deep-subsurface observations. A key challenge is to resolve how boundary conditions–particularly heterogeneous permeability–govern such systems, and how these heterogeneities can be represented in conceptual and numerical models through the principle of hydraulic continuity.

This study investigates forced convection in two contrasting thermal systems in the Western Julian Alps (Slovenia): the Bled Toplice spring and the Zatolmin thermal spring. The research combines high-frequency observations at Bled with targeted sampling at both sites, isotopic analyses ($\delta^{18}O$, $\delta^{2}H$, $^{3}H/^{3}He$, ^{14}C), measurements of dissolved noble gases (He, Ne, Ar, Kr, Xe) and thermal-property measurements. Conceptual models are evaluated using coupled groundwater-flow and heat-transport simulations to quantify how permeable faults, stratigraphic barriers and basin geometry interact to control convective behaviour.

Both are recharged from high elevations, yet differ fundamentally in their boundary-condition architecture. At Bled, regional upwelling is shaped by hydraulic confinement beneath thick, low-permeability Oligocene sediments. In contrast, Zatolmin represents a structure-controlled system where deep flow ascends almost exclusively along a major permeable fault zone in Cretaceous limestone. Results improve understanding of deep regional flow in alpine carbonates and highlight the decisive role of permeable structures and hydraulic continuity.

This study was conducted in the frame of the post-doctoral research project “Regional groundwater flow dynamics in alpine carbonate aquifers: mechanisms, boundary conditions and the impact of climate change” (Z1-50031) and the research program Groundwater and Geochemistry (P1-0020), both funded by the Slovenian Research And Innovation Agency (ARIS).

LID 0537
Presence and distribution of contaminants of emerging concern in volcanic aquifers of Valle Central (Costa Rica)

Helga Madrigal-Solís[1], Marta Llamas-Dios[2], Pablo Jiménez-Gavilán[2], Clemens Ruepert[3], Alicia Fonseca-Sánchez[1], Luis Quesada-Hernández[1], Hazel Calderón-Sánchez[1], **Iñaki Vadillo Pérez**[2]*

[1] School of Biological Sciences, National University, Costa Rica
[2] Department of Geology, Faculty of Science, University of Málaga, Spain
[3] Regional Institute for Studies on Toxic Substances (IRET), National University, Costa Rica
* Vadillo@uma.es

Keywords: contaminants of emerging concern, tropical volcanic aquifers, Central Valley, Costa Rica, land-use

The Central Valley of Costa Rica (3,250 km^2) concentrates up to 70% of the country's population (3.5 million inhabitants). The largest urban agglomerations are concentrated in the lower part, occupying 60% of that piece of territory. Wastewater management is primarily conducted via septic tanks, making the aquifers highly vulnerable to contamination from urban activity; agricultural and livestock waste are also an emerging concern in the mid-elevation zones. This land use, combined with the fact that the main source of supply is water resources from four volcanic aquifers, has led to campaigns to identify possible impacts on groundwater quality.

A groundwater monitoring campaign (24 samples) was conducted in November 2022, including general hydrochemical analyses, stable isotopes and the screening of 134 contaminants of emerging concern (CECs). The findings presented elevated nitrate concentrations in urban and agricultural/urban areas, surpassing the Maximum Concentration Levels on several occasions. Similar nitrate contents and spatial patterns in agricultural and urban zones in the shallow Barva aquifer suggest comparable contributions from nitrogen fertilizers and urban wastewaters despite the gradual increase in urban land cover and the reduction of agricultural areas. Despite the inorganic results, 47 compounds of emerging interest have been detected: 2 artificial sweeteners, 9 drugs of abuse, 1 beta-blocker, 13 antibiotics, and 22 other pharmaceutical compounds. Eighteen compounds have been detected at all points in the monitoring network (ethyl sulfate, cotinine, nicotine, cocaine, benzoylecgonine, trimethoprim, sulfanilamide, roxithromycin, clarithromycin, tylosin, carbamazepine, caffeine, gemfibrozil, fenofibrate, pindolol, mefenamic acid, diclofenac, and phenylbutazone). These results support multi-tracer monitoring and wastewater upgrades to protect Central Valley aquifers. Future campaigns should add seasonal sampling and evaluate sanitation measures.

LID 0538
From data to decision: Conceptualising coastal alluvial aquifers for sustainable groundwater abstraction in Namibia

Aqeela Parker[1]*

[1] GEOSS South Africa, Cape Town, South Africa
* aparker@geoss.co.za

Keywords: arid coastal hydrogeology, groundwater resource management, recharge dynamics

Groundwater represents the primary and most reliable water source in Namibia's arid coastal zone, where surface water availability is highly episodic and closely linked to river–aquifer interactions. This study presents a groundwater resource assessment conducted for Namibia's Coastal Business Unit, focusing on the alluvial aquifer systems associated with the Omaruru and Kuiseb River catchments, which are critical to sustaining water supply for the coastal region.

The objective was to develop a robust conceptual understanding of the geology and hydrogeology of both catchments and to quantify aquifer safe yields to support long-term, sustainable water resource management under increasing population and economic pressures. Geological, hydrogeological, and operational datasets, including borehole lithological logs, pumping test data, geophysical investigations, groundwater level records, and historical abstraction volumes, were integrated within Leapfrog software to construct three-dimensional geological and hydrogeological conceptual models. These models defined aquifer geometry, stratigraphic relationships, hydraulic connectivity, and recharge processes driven primarily by episodic river infiltration.

Analytical groundwater assessment techniques were applied to estimate recharge, storage behaviour, and abstraction impacts, with particular emphasis on the dynamic coupling between surface flow events and groundwater replenishment. Safe yields were determined by balancing long-term recharge against abstraction while accounting for climatic variability and aquifer sustainability.

The results provide defensible abstraction limits to guide current and future water supply planning and demonstrate the value of integrated 3D conceptual modelling in complex arid zone groundwater systems. The approach offers a transferable framework for groundwater resource management in other data-limited, river-dependent aquifers across semi-arid and arid regions.

LID 0539
Effects of aquifer scheme choices on calibration reliability

Philip Nienhuis[1]*

[1] retired hydrogeologist, Amsterdam, The Netherlands
* philip.nienhuis@gmail.com

Keywords: calibration, aquifer scheme, multi-aquifer system

In the course of pumping test analysis in a complex multiple leaky aquifer system, insight was required in the robustness of the results with regard to a.o., choices of aquifer scheme and observed heads availability in each aquifer. Literature on systematic exploration of the reliability of parameter estimation in multiple leaky aquifer systems is scarce. Therefore it was decided to investigate this using synthetic pumping tests as follows:

An analytical multi-aquifer groundwater model (MLU) was used to compute drawdowns in a multiaquifer system resembling the aquifer system and pumping under consideration; using these drawdowns hydraulic parameters were re-estimated using various aquifer schemes. Later on, different situations were explored in similar fashion.

The main results are that irrespective of chosen aquifer scheme, the transmissivity and storativity of a pumped aquifer can usually, but not always, be estimated with reasonable reliability; but the reliability of hydraulic parameter estimates of all other layers, especially of aquitards, is very much dependent on the chosen aquifer scheme. In particular, pumping test analysis in a multi-aquifer system using just a leaky single-aquifer scheme while ignoring adjacent (usually deeper) aquifers, leads to possibly significant underestimation of the vertical hydraulic resistance of overlying aquitards. Computed statistical uncertainties of the optimization results yield no clue to this as these are contingent on the input aquifer schemes. Unless one is sure that a pumped or otherwise hydraulically stressed aquifer has an effectively impermeable bottom, it can be advantageous to include at least one leaky aquifer below the pumped aquifer in the calibration procedure, monitored or not.

While these results were obtained using pumping test analysis, they implicitly translate to calibration of numerical models as well.

LID 0540
Considerations for well design and operation of aquifer storage and recovery of fresh water in saline aquifers

Niels Hartog[1,2]*, Gilian Schout[1], Stijn Beernink[1] And Lennart Brokx[1]

[1] KWR Water Research Institute, Nieuwegein, The Netherlands
[2] Utrecht University, Utrecht, The Netherlands
* niels.hartog@kwrwater.nl

Keywords: aquifer storage and recovery, non-uniform well flow, buoyancy

Aquifer storage and recovery systems aim to efficiently recover sufficient of the stored water. When storing fresh water in brackish or saline aquifers, the density difference between the injected and native groundwater is known induce buoyancy flow in the aquifer that negatively impacts recovery efficiencies (RE's). However, pressure differences already occur in the well screen and in this study it is shown, through analytical and numerical analysis, that the density difference can induce non-uniform flow distribution across a well screen that may cause significantly lower recovery efficiencies (e.g. >20% difference in RE) than expected when only considering losses that occur in the storage aquifer. This negative offset can be particularly strong for ASR operation in aquifers with relatively favorable characteristics. Analysis shows that the degree in which non-uniform flow distribution across the well screen occurs depends mainly on the relative density difference and the injection pressure, which in turn is affected by injection and abstraction rates, well screen length and aquifer permeability. In addition to lower recovery efficiencies, non-uniform distribution of flow also results in higher flow velocities at the top of the well and therefore increased clogging risk by exceeding safe flow velocities across the well bore. Overall, this study shows that an assessment of the extent to which non-uniform flow across the well screen occurs for a planned ASR operation should be performed as a part of the ASR design to optimize performance and reduce operational risks.

LID 0541
Benchmarking reactive mass transport in cryo-hydrogeological systems

Kyra Boek[1], John Molson[2]*, Victor Bense[1], Aaron Mohammed[3,4], Ruta Basijokaite[3]

[1] Department of Environmental Sciences, Wageningen University and Research, Wageningen, The Netherlands
[2] Department of Geology & Geological Engineering, Université Laval, Québec City, Canada
[3] Department of Earth and Environmental Sciences, Syracuse University, Syracuse, USA
[4] Department of Civil and Environmental Engineering, Syracuse University, Syracuse, USA
* john.molson@ggl.ulaval.ca

Keywords: cryo-hydrogeological modelling, benchmark, mass transport

Across high-latitude regions underlain by permafrost, coupled thermo-hydro-chemical (THC) processes control groundwater flow, solute release and migration, and freeze-thaw dynamics with direct implications for water resource management and infrastructure stability. Building on the InterFrost benchmarking framework, we present reproducible benchmarks with two test cases (THC2, THC3) designed to evaluate nonlinear THC coupling in cryo-hydrogeological models. The framework, which extends the InterFrost cases to include reactive mass transport, is demonstrated using the SMOKER-BIO numerical code supported by the FlexPDE and SUTRA-SOLICE codes. A sensitivity analysis identifies hydraulic gradient, temperature-dependent reaction rates, dispersivities, freezing-function parameters and spatial and temporal resolution as important controls on the timing and magnitude of solute release. In terms of numerical stability, the Péclet and Courant criteria were found critical, with high hydraulic gradient scenarios requiring millimetre-scale resolution near the frozen source in THC2 to resolve sharp concentration fronts, and small time steps are needed to capture early-time release. Results have shown surprising complexity in process evolution even for such relatively simple cryo-hydrogeological systems. This structured benchmarking approach builds confidence in coupled transport simulations where analytical solutions are unavailable.

LID 0542
ASR well-field optimization: Injection rates, well distancing and recovery efficiency

Gilian Schout[1], Hester Flikweert[1,2], Niels Hartog[1,2]*

[1] KWR Water Research Institute, Nieuwegein, The Netherlands
[2] Utrecht University, Utrecht, The Netherlands
* niels.hartog@kwrwater.nl

Keywords: aquifer storage and recovery, multi-well, well-field optimization

Multi-well Aquifer Storage and Recovery (ASR) systems are increasingly implemented to address seasonal water shortages and enhance freshwater security. The infiltration rate is limited by the maximum permissible hydraulic head rise, to prevent soil fracturing and prevent excessive energy requirements. Although wider well spacing reduces hydraulic interference between wells and increases the infiltration rate per well compared to a single-well system, closer spacing can enhance recovery efficiency by promoting the merging of the injected water volumes. Despite these trade-offs the effect of wellspacing on multi-well ASR system performance remains poorly understood. This study investigates how well spacing affects total infiltration capacity, recovery efficiency, and total recovered volume under varying system and subsurface properties. Results from MODFLOW6 modelling show that fully avoiding hydraulic interference would require unrealistically large well spacings. However, under favorable subsurface conditions, wider spacing maximizes infiltration and enhances overall recovery efficiency. Under unfavorable conditions however, such as high dispersivity, strict water quality requirements, or significant background flow, closer spacing reduces mixing losses and increases the overall recoverable volume. Overall, the findings demonstrate that well spacing is a critical design parameter for multi-well ASR systems that can substantially improve the system performance and cost-effectiveness of ASR well fields.

LID 0543
Groundwater mapping interrupted: Lessons from two contrasting regions in Haiti

James Adamson[1]*, Jonas Bernasconi[2], G. Thomas Lavanchy[3]

[1] Spheros Environmental, Denver, Colorado, United States
[2] CSD Engineers, Geneva, Switzerland
[3] Oklahoma State University, Stillwater, OK, United States
* adamsonjk@gmail.com

Keywords: Haiti, transboundary aquifers, hydrogeologic mapping

A national initiative was launched in Haiti in 2021 to modernize hydrogeological knowledge and mapping, as the country continues to rely on coarse, outdated geological and groundwater data that have seen little meaningful improvement in nearly five decades. The first phase comprised a three-year program focused on two contrasting regions to establish scalable methods and technical outputs for national application.

The southwest zone represents one of the most groundwater-rich settings in the Caribbean, characterized by high-transmissivity carbonate and alluvial systems, strong recharge, and substantial potential for expanded domestic, agricultural, and industrial supply. In contrast, the northeast zone exhibits more limited recharge, less favorable geologic conditions, higher development pressure, and emerging transboundary and political risks. Results identified areas vulnerable to saltwater intrusion, critical recharge zones requiring protection, and the need for transboundary coordination with the Dominican Republic to avoid future resource conflict.

The program included 1:50,000-scale geological mapping, structural interpretation, hydrogeological and hydrochemical investigations, and monitoring of strategic wells and river systems. The work differentiated dozens of aquifer systems, defined aquifer geometry, clarified recharge dynamics, and established a technical foundation to support informed and sustainable groundwater development.

The initiative was terminated abruptly in January 2025, just as regional maps, hydrogeologic frameworks, decision-support tools, and consolidated datasets were nearing completion. In a country where reliable groundwater data remain scarce, the program was intended to close critical knowledge gaps and strengthen decentralized planning. Its interruption underscores the broader risks of disrupting long-term geoscience capacity-building in vulnerable states.

LID 0544
Geophysical and hydrogeological characterization of a karst aquifer in Johannesburg South for groundwater planning

Simon Madileng[1]*, Khuliso Masindi[1], Ndamulelo Mutshafa[1]

[1] University of Witwatersrand, Johannesburg, South Africa
* 2302567@students.wits.ac.za

Groundwater plays a critical role in sustaining water supply in urban and semi-arid regions of South Africa, including Johannesburg South. Increasing reliance on groundwater, driven by the expansion of informal settlements, particularly in areas such as Lenasia, has intensified pressure on local aquifers. The area is underlain by Malmani Subgroup dolomites of the Transvaal Supergroup, forming a structurally complex and heterogeneous karst aquifer system that is highly vulnerable to contamination and land subsidence due to poorly understood subsurface architecture and unregulated abstraction.

This study aims to characterize the geometry and structure of the dolomitic aquifer using an integrated geophysical and hydrogeological approach. Geophysical methods include Electrical Resistivity Tomography (ERT), Electromagnetic (EM) surveys, and gravimetric techniques to identify key subsurface features such as voids, fractures, and groundwater-bearing zones. These results are supplemented with hydrogeological data from borehole lithological logs, water strike depths, yield measurements, and hydraulic testing to estimate transmissivity and storage.

Integration of these datasets will support development of a conceptual model illustrating the spatial variability of the karst system. The model will inform sustainable groundwater abstraction, infrastructure planning, and hazard mitigation, particularly in managing sinkhole risks, and contribute to long-term water resource planning in Johannesburg South’s sensitive dolomitic terrain.

LID 0549
Evaluation of bio-treated manure application impact on groundwater quality using advanced reactive transport models

Alper Elci[1]*, Aleksandra Ukalska-Jaruga[2], Edit Kaszab[3], Lisa Paruch[4], Ana Cristina Rodrigues[5], Lorenzo Proia[6], Marianna Teszarne Nagy[7], Julianna Kobolák[3]

[1] Dokuz Eylül University, Izmir, Türkiye
[2] Institute of Soil Science and Plant Cultivation, Puławy, Poland
[3] Hungarian University of Agriculture and Life Sciences, Gödöllő, Hungary
[4] Norwegian Institute of Bioeconomy Research, Ås, Norway
[5] CISAS, Instituto Politécnico de Viana do Castelo, Viana do Castelo, Portugal
[6] BETA Technological Centre, UVIC-Central Univ. of Catalonia, Vic, Spain
[7] Middle Tisza District Water Directorate, Szolnok, Hungary

Keywords: agriculture, endocrine-disrupting chemicals, unsaturated zone

Managing and reusing agricultural runoff and manure is crucial for efforts to reclaim nutrients and water. In the EU-27 and the UK, over 1.4 billion tons of manure are generated each year, typically processed using separation technologies that split the raw material into liquid and solid parts. This technology enables field application and aligns with the core principles of the circular economy: the composted solid portion serves as a valuable soil fertilizer, enhancing soil structure, aeration, solarization, and organic matter content, whereas the liquid portion can potentially be used for irrigation. However, its use is restricted by several factors, including steroid hormones from the excreta (urine and feces) of farm animals, as well as endocrine-disrupting chemicals (EDCs).

In this study, preliminary results of the multinational BioTreatED project are presented. The project's objectives are to develop and validate biological treatment methods for degrading and detoxifying hormones; to determine the subsurface fate and transport of hormones originating from manure application. Monitoring data from plot experiments are used to setup and calibrate a two-dimensional cross-sectional unsaturated zone flow and transport model (HYDRUS-2D), which simulates the movement and concentration distributions of hormone compounds within the soil profile during irrigation. The lateral boundary conditions are based on local flow conditions, while the upper boundary condition is set according to varying water infiltration rates, which depend on irrigation fluxes and weather conditions. The model accounts for sorption and biochemical reactions in different phases. The subsequent phase will involve a separate model for reactive transport in the saturated zone, using outputs from the unsaturated model to predict groundwater concentrations and velocities of hormones. The transport model will be in the form of a customised module of the multi-species flow and transport model MT3DMS.

The project BioTreatED (Water4All2023-334) has received funding from Nemzeti Kutatási, Fejlesztési és Innovációs Hivatal (Hungary), the Rsearch Council of Norway (Norway), Fundacão para a Ciência e a Tecnologia (Portugal), Agencia Estatal de Investigación (Spain), Narodowe Centrum Nauki (Poland), TÜBITAK - The Scientific and Technological Research Council of Türkiye (Türkiye) and the European Union's Horizon Europe Programme under the 2023 Joint Transnational Call of the European Partnership Water4All (*Grant Agreement n°101060874*).

LID 0551
Hydrochemical and isotopic characterization of geothermal aquifers in the Pannonian Basin – Croatia

Tamara Marković[1]*, Igor Karlović[1], Daria Čupić[2]

[1] Croatian Geological Survey, Zagreb, Croatia
[2] Croatian Waters, Zagreb, Croatia
* tmarkovic@hgi-cgs.hr

Keywords: hydrochemical and isotopic parameters, carbonate and sandy aquifers, origin and interactions

Geothermal aquifers in the Croatian part of the Pannonian Basin System are developed within a tectonically complex sedimentary basin characterized by elevated geothermal gradients, high heat flow, and intensive structural control on groundwater circulation. Such conditions enable the development of low- to high-enthalpy geothermal systems and deep/shallow thermal groundwater flow.

Based on geological and hydrogeological characteristics, two principal reservoir types can be distinguished: basement and basin-fill aquifers. Basement aquifers are occurring in fractured and karstified Palaeozoic/Mesozoic carbonate and fractured crystalline or metamorphic rocks, where secondary porosity generated by tectonic fracturing and karstification represents the dominant control on permeability and fluid flow. These systems enable deep circulation of groundwater and elevated reservoir temperatures.

Basin-fill aquifers occur within Neogene Pannonian sedimentary successions deposited during Miocene extensional tectonics and subsequent lacustrine basin infill. They consist of heterogeneous sequences of sands, sandstones, silts, and marls, characterized predominantly by intergranular porosity and variable hydraulic properties. The spatial distribution, geometry, and hydraulic behaviour of geothermal aquifers are governed by basin architecture, structural heterogeneity, and multiphase tectonic evolution controlling groundwater flow pathways and reservoir conditions.

Each system is characterized by specific hydrochemical signatures that reflect the origin and flow dynamics of groundwater within geothermal aquifers. Therefore, a comprehensive investigation of all available boreholes and thermal springs was performed. Major ion composition, physicochemical parameters, stable water isotopes, noble gases, radon, and radiogenic tracers were analysed to determine similarities and differences between individual aquifer systems.

LID 0552
Overturning “water bankruptcy”: Transforming spontaneous to planned conjunctive management

Shammy Puri[1,2]*

[1] Dept of Geology, University of Warsaw, Poland
[2] Director Centre for Sustainable Solutions with Practical Hydrogeology, United Kingdom
* ShammyPuri@practicalhydrogeology.co.uk

Keywords: water bankruptcy, aquifer depletion, hydrological solvency, peak groundwater

Water bankruptcy has recently been formally defined as a persistent post-crisis state in which human–water systems exceed hydrological carrying capacity, combining insolvency with elements of irreversibility [1]. Unlike episodic “water crises”, bankruptcy reflects structural overspending of renewable flows and erosion of natural capital. A central, yet under-recognised, driver of this condition is the widespread spontaneous use of groundwater to compensate for surface water variability or scarcity.

Over the past half-century, groundwater withdrawals from aquifers have expanded rapidly to sustain irrigation and urban growth. Global modelling indicates that non-renewable groundwater withdrawals are likely to exhibit a peak-and-decline signature in 98% of future climate scenarios, peaking at a median of ~625 km^3 yr^{-1} around mid-century [2]. This peak does not reflect physical exhaustion of global aquifer storage—estimated at ~22.6 million km^3 (in the upper continental crust)—but economic and hydrological limits reached under unmanaged, poorly regulated depletion. Parallel global simulations estimate cumulative aquifer resource depletion of ~7,000 km^3 over 1960–2010, highlighting extensive head declines and altered groundwater–surface water interactions [3].

These findings reveal a systemic accounting error. Surface water and aquifers are commonly governed as separate “buckets”, yet physically form a single, coupled storage system. Spontaneous groundwater abstraction, to offset surface shortages, creates the illusion of supply security while reducing baseflows, shifting capture from rivers to wells, and double-counting interconnected water resources. The result is progressive erosion of strategic aquifer storage—the hydrological equivalent of drawing down bank savings to sustain routine expenditure.

In this keynote I argue that overturning water bankruptcy requires deliberate transformations from spontaneous conjunctive use to ordered conjunctive management. This transformation entails basin-scale water budgeting that integrates storage and flux, monitoring of aquifer depletion and streamflow capture, and, most importantly, institutional realignment linking abstraction rights to coupled surface–groundwater dynamics. Conjunctive management is therefore not a technical optimisation, but the governance framework necessary to restore hydrological solvency as a fundamental recommendation ahead of the 2026 UN Water Conference.

References:

[1] Madani, K. (2026). Water bankruptcy: The formal definition. Water Resources Management, 40, 78. https://doi.org/10.1007/s11269-025-04484-0

[2] Niazi, H., Wild, T. B., Turner, S. W. D., Graham, N. T., Hejazi, M., Msangi, S., Kim, S., Lamontagne, J. R., & Zhao, M. (2024). Global peak water limit of future groundwater withdrawals. Nature Sustainability, 7, 413–422. https://doi.org/10.1038/s41893-024-01306-w

[3] de Graaf, I. E. M., van Beek, R. L. P. H., Gleeson, T., Moosdorf, N., Schmitz, O., Sutanudjaja, E. H., & Bierkens, M. F. P. (2017). A global-scale two-layer transient groundwater model: Development and application to groundwater depletion. Advances in Water Resources, 102, 53–67. https://doi.org/10.1016/j.advwatres.2017.01.011

LID 0553
Eswatini's Water Act reform 2026 – Towards strengthened groundwater governance & conjunctive management

Daniela Benedicto[1]*, Musawenkhosi Mwelase[2], Ian Spellane[3], Enoch Dlamini[4]

[1] Acacia Water bv, Gouda, The Netherlands
[2] Department of Water Affairs of Ministry of Natural Resources and Energy, Mbabane, Eswatini
[3] Castalia, Washington DC, United States
[4] Independent consultant, Mbabane, Eswatini
* daniela.benedicto@acaciawater.com

Keywords: governance, transboundary, IWRM

In Eswatini, groundwater plays an increasingly strategic role in rural water supply, peri-urban development, and drought resilience. Since the implementation of the Water Act (2003), the need for a more comprehensive groundwater governance framework has become evident. The country faces several water provision challenges, including unregulated drilling and the use of solar pumps, which exacerbate risks of aquifer depletion. Groundwater quality is similarly under pressure, particularly in peri-urban areas where inadequate sanitation contributes to contamination risks. In addition, protection of springs and recharge zone remains inconsistently enforced.

A reform of Eswatini's Water Act is currently underway, to strengthen groundwater governance within an IWRM framework and emphasizing the principle of conjunctive management. This process distinguishes between groundwater exploration (e.g., permitting procedures, hydrogeological assessments, yield testing, and allocation for public and private water provision) and groundwater management (e.g., monitoring systems, water quality control, recharge zone safeguarding, and long-term strategic planning).

Transboundary water cooperation is central to this reform. Several initiatives supported by the Southern African Development Community (SADC) ensure that water management aligns with regional efforts for sustainable development. This collaborative approach is essential in sustaining water security amid rising demand and increased climate uncertainty.

By clarifying institutional mandates, strengthening monitoring systems and compliance mechanisms, and formally recognizing protected recharge areas, the revised Water Act advances groundwater stewardship as a shared public resource, moving beyond the concept of private ownership. This project offers lessons for advancing groundwater governance through legal instruments that incorporate stakeholders conultation, regional cooperation, and foster resilience in climate uncertainty.

LID 0554
Ten years of California's Sustainable Groundwater Management Act: Enhanced state and local data collection and integration for climate adaptation

Timothy K. Parker[1]*

[1] Parker Groundwater, Sacramento, California, United States
* tim@pg-tim.com

Keywords: groundwater sustainability, climate adaptation

The California Sustainable Groundwater Management Act (SGMA) of 2014 mandates new groundwater sustainability agency (GSA) formation, groundwater sustainability plan (GSP) preparation and implementation, and quantitative demonstration of sustainability within 20 years based on six sustainability indicators. The GSAs have numerous new authorities but cannot affect water rights. The GSPs must include the groundwater basin hydrogeologic conceptual model, water budget and uncertainties, monitoring program and data gaps. SGMA also requires that the GSP include quantitative sustainable management criteria including minimum thresholds, measurable objectives, and interim (five-year) milestones to demonstrate progress towards six sustainability indicators. The GSP must also contain projects and management actions as needed to achieve sustainability over the 50-year planning horizon, including climate adaptations.

The state has championed and funded informed decision-making through several data collection and dissemination programs, which also includes facilitation and outreach services to support discussions and education of the local communities. These programs comprise collection of groundwater data, remote sensing data on land subsidence and land use-crop type, monitoring well installations, regional groundwater modelling, air-, land-, and water-based geophysics to map aquifers, and online tools to visualize and evaluate state-provided datasets. These online tools are designed to assist in developing refined hydrostratigraphic and texture models through data fusion of borehole lithology, geophysics, geology and hydrogeology datasets. Another state initiative has been to increase recharge during seasonally high precipitation and runoff events through FloodMAR and expedited permitting to help adapt to drying climate. The state also has a Basin Characterization Exchange meeting series and network space for the groundwater community to connect on issues and cross-pollinate.

LID 0555
Advanced recharge analysis to support groundwater management, Westernport Basin, Australia

Ben Hall[1]*, Matthew Hudson[2], Matthew Currell[3]

[1] EarthEon Pty Ltd, Melbourne, Australia
[2] Southern Rural Water, Melbourne, Australia
[3] Griffith University, Brisbane, Australia
* Ben.hall@eartheon.com.au

Keywords: integrated recharge, GDE, saline intrusion, groundwater resources

The Western Port Basin lies adjacent to Melbourne - Australia's most populated city. Groundwater extraction from the basin supports high value horticulture which directly supplies food to the city population. The aquifer system is coastal and low lying and has long been susceptible to the risk of saline groundwater intrusion. The region features Koo Wee Rup ('Black Fish Swimming' in the local Boonwurrung language) and the Ramsar listed West Port Wetlands. Over extraction of groundwater, urban encroachment, and sea level rise all pose risks to the sustainability of the groundwater resource.

Advanced multi-method recharge quantification was completed—combining environmental isotope analysis with chloride mass balance, which utilised interpolated rainfall chloride concentration—to produce spatially resolved, net recharge estimates. This approach reveals the critical influence of shallow geology and land use on recharge variability, providing critical insights for the resource management. The study also leveraged a detailed review of climate and hydrogeological data, to refine the conceptual model and inform future numerical simulations.

The study established the link between environmental and cultural values and groundwater in the region. The risk to these systems was then assessed under multiple scenarios, including climate change, managed aquifer recharge, and increased extraction, using a transparent risk assessment framework that incorporates both likelihood and consequence. Importantly, the study acknowledges the region's Indigenous heritage and the need to protect cultural water values.

The study shows clear steps required to reduce uncertainty and manage groundwater sustainably. And highlights the need to go beyond the technical rigour of a hydrogeological assessment and bring in cultural stewardship in a complex, multi-value catchment.

This study was funded by Southern Rural Water. Project reviews were undertaken by Matthew Hudson and Prof Matthew Currell. Dr Angus Campbell assisted with data compilation.

LID 0557
Generalizing groundwater geochemistry with machine learning: Using new methods on a long-standing arsenic problem

Athena Nghiem[1]*, Logan Goulette[1]

[1] Department of Geoscience, University of Wisconsin-Madison, Madison, Wisconsin, United States
* anghiem@wisc.edu

Keywords: arsenic, machine learning, groundwater

Contamination of naturally-occurring arsenic (As) in groundwater is well-known and widespread. Arsenic release into groundwater is usually associated with microbial reductive dissolution of As-bearing iron (Fe) minerals but is dependent on coupled biogeochemical cycles, geological settings, and hydrologic changes. With the advent of machine learning (ML), studies have focused on predicting total As concentrations in groundwater above or below the World Health Organization guidelines (10 µg/L) with models such as random forest. These models use predictors ranging from geochemical to geological/hydrogeological to hydrological, either at the surface (less accurate) or at depth (more accurate). Despite these predictions of total As concentrations, open questions remain. Recently, the importance of aqueous As speciation has been highlighted: aqueous As species that have an attached sulfide group instead of the typical aqueous As oxyanion poorly sorb onto Fe minerals and lead to faster contamination. However, few measurements of aqueous As speciation are available in groundwater. In general, clear limitations to understanding the overall importance of As speciation are because (i) measurements of aqueous As speciation remain difficult due to the preservation protocols, (ii) thermodynamic models predicting these species remain incomplete, and (iii) machine learning predictions have been non-existent as As speciation is such a small dataset compared to total concentrations. However, here, we explore interpretable ML methods applied to predict As speciation across varied hydrogeological settings in Asia. Specifically, we focus on (i) how to optimize predictions on small datasets, (ii) model validation (e.g., targeted measurements after making predictions) in Vietnam, and (iii) comparison of ML models to thermodynamic models. Finally, we aim to test whether ML models generated apply to other hydrogeologic settings beyond Asia to generalize the importance of As speciation.

LID 0559
Significance and origin of the very large regulating power of the Big Spring Karst Aquifer in Missouri (USA)

Farid Achour[1*], Michel Bakalowicz[2]

[1] GSI Environmental Inc., Irvine, California, United States
[2] Hydrosciences Laboratory, Montpellier, France
* fachour@gsienv.com

Big Spring, located in the Ozarks region of Carter County, Missouri, is one of the largest karst springs in the United States and globally in terms of discharge. The spring has an average flow of approximately 12 m^3/s, corresponding to a mean daily discharge of about 1.1×10^6 m^3, classifying it as a first-magnitude spring. It emerges at the base of a dolomite cliff along the western side of the Current River valley.

Characterization of aquifers typically relies on parameters such as permeability, transmissivity, geometry, and boundary conditions. In karst systems, however, karstification processes produce highly heterogeneous and discontinuous media, both spatially and temporally. Karst aquifers commonly consist of highly transmissive conduit networks embedded within low-permeability rock matrices. In addition, climatic variations and tectonic activity can alter base-level conditions and spring elevations, resulting in multilevel conduit systems.

Daily discharge records from Big Spring collected by the USGS between 1921 and 1996 were analyzed using the method developed by Mangin (1975) and later refined by Bakalowicz (2005). This approach, based solely on aquifer hydrodynamic behavior, was used to characterize infiltration processes (slow, fast, or delayed) and to estimate the dynamic volume, defined as the annually renewable phreatic storage. Four long-term summer recession periods (1944, 1953, 1969, and 1972) were examined.

Recession curve analysis indicates an unusually large dynamic volume, ranging from approximately 5.7×10^8 to 1.1×10^9 m^3, a predominance of slow infiltration, and residence times of 1.5 to 2.5 years. Sorted discharge curves reveal a consistent inflection at about 10 m^3/s, suggesting hydraulic connectivity with an adjacent aquifer, likely alluvial, into which Big Spring discharges below this threshold.

Comparison with other karst springs worldwide indicates that Big Spring is characterized by a deep, extensively karstified phreatic zone developed during earlier karstification phases. The system can be classified as a non-functional karst, exhibiting large storage capacity and complex, partially flooded drainage networks with long residence times. Nevertheless, paleo-conduit systems within the phreatic zone remain partially active.

These results highlight the importance of analytical methods tailored to karst systems, rather than those developed for porous media, to support effective exploitation, management, and protection of karst water resources. Management of the Big Spring system should therefore be based on detailed analysis of aquifer functioning and targeted groundwater monitoring in the vicinity of the spring, an approach applicable to karst springs throughout the continental United States.

LID 0560
Effects of sea-level rise on fresh groundwater resources in coastal dune areas – Case-study in the Netherlands

Gualbert H.P. Oude Essink[1,2]*, Guilherme E.H. Nogueira[2]

[1] Department of Physical Geography, Utrecht University, Utrecht, The Netherlands
[2] Department Groundwater and Water Security, Deltares, Utrecht, The Netherlands
* gualbert.oudeessink@deltares.nl

Keywords: freshwater lenses, sea-level rise, saltwater intrusion, variable-density groundwater modelling

Worldwide, sandy coastal dune systems form a substantial part of the global shoreline. Global assessments show that about one-third of the world's ice-free coastline consists of sandy beaches, many of which host coastal dune systems with freshwater lenses that are crucial for drinking water supply and ecosystem functioning. These lenses are increasingly exposed to saltwater intrusion driven by intensified human water use, land subsidence, sea-level rise and changes in recharge patterns. These processes make them highly relevant as drinking water resources and for safeguarding domestic water availability in coastal regions.

In this study, we quantify the response of these freshwater lenses to the different abovementioned processes, using the Netherlands as a well-monitored and modelled example. We apply a high-resolution 3D variable-density groundwater flow and salt transport model (iMOD-WQ similar to SEAWAT), calibrated against observed hydraulic heads and salinity distributions, to simulate present and future conditions. Scenario simulations include sea-level rise of 0.5 m and 1.0 m by 2100, and an extreme scenario of 3.0 m by 2150, combined with land subsidence, climate-induced changes in recharge, and ongoing groundwater extractions for domestic use.

The simulations resolve key seawater intrusion processes such as lateral saline groundwater intrusion reducing fresh groundwater resources. Results indicate that under moderate sea-level rise scenarios, freshwater lenses remain largely due to sufficient recharge from managed aquifer recharge (MAR) practices. However, absolute freshwater volumes decline gradually, and localized risks of salinization increase near production wells. Under the extreme sea-level rise scenario of 3.0 m by 2150, several low-lying parts of the dune system show pronounced freshwater volume losses and increased vulnerability to saltwater intrusion.

Our results demonstrate that groundwater in coastal dunes can be resilient to sea-level rise when supported by integrated management strategies, but also reveal clear thresholds beyond which freshwater availability rapidly deteriorates. We illustrate that high-resolution modelling can inform sustainable management of coastal aquifers worldwide under a changing climate with increasing human pressures.

LID 0562
California's regional-scale airborne electromagnetic surveys for mapping hydrogeologic features and managed aquifer recharge potential for adaptation to drying climate

Timothy K. Parker[1]*

[1] Parker Groundwater, Sacramento, California, United States
* tim@pg-tim.com

Keywords: airborne electromagnetics, climate adaptation

The California Department of Water Resources has conducted over 25,000 line-kilometers(nearly 16,000 miles) of regional-scale airborne electromagnetic (AEM) surveys of the state's priority groundwater basins to map the aquifer geometry and texture. The results of the AEM surveys are being utilized to support achieving groundwater sustainability through improved subsurface data collection and refined hydrogeologic conceptualization. The SkyTEM312M system is used to conduct the surveys, and the data collection is designed for both early time Low Moment (shallow data) and late time High Moment (deep data) with a typical depth of investigation approximately 305 meters (1,000 feet). The inverted data have revealed a wealth of hydrogeologic structures and features, including mapping areas of brackish and seawater intrusion, fault zones, lacustrine deposits such as the Corcoran Clay, interconnected surface water, and buried alluvial fans.

The AEM datasets are also being utilized to initially identify priority areas for potential managed aquifer recharge (MAR) projects, for example where buried alluvial fans daylight upgradient, and where dominantly coarse fraction deposits are present in the shallow subsurface and continue to depth. Additionally, complimentary shallow-focused land-based towed TEM systems are being utilized for mapping the potential for MAR, and water-based towed TEM systems for interconnected surface water, operating at a high vertical resolution and shallower depth of investigation . This one-of-a-kind scale of geophysical surveys is just starting to be fully utilized by local water agencies in refining groundwater sustainability plans, hydrogeologic conceptual and groundwater flow models, and in planning and siting MAR projects to help to adapt to the overall drying trend California's climate that has occurred over the past 15 to 20 years.

LID 0563
Bayesian priors improve nitrate source attribution in the Barva-Colima volcanic multilayer aquifer system (Costa Rica)

Helga Madrigal-Solís[1], Luis Quesada-Hernández[1], **Iñaki Vadillo Pérez**[2]*, Alicia Fonseca-Sánchez[1], Hazel Calderón-Sánchez[1], Dorian Carballo Ulloa[1], Pablo Jiménez-Gavilán[2]

[1] School of Biological Sciences, National University, Costa Rica
[2] Department of Geology, Faculty of Science, University of Málaga, Spain
* Vadillo@uma.es

Keywords: dual nitrate isotopes, groundwater pollution, MixSIAR

Nitrate in layered volcanic aquifers reflects mixed agricultural and urban inputs, yet source apportionment based on δ15N–NO3− alone carries large uncertainty because endmember overlap can bias Bayesian mixing, particularly under uninformative priors. We test this in the volcanic Barva-Colima multi-aquifer system (Costa Rica), supplying ≥65% of the Greater Metropolitan Area. Nitrate is highest in Barva (max 110.7 mg/L as NO_3^-) and lower but present in Upper and Lower Colima, while forest/grassland recharge shows low background levels (median 1.8 mg/L). The basin includes one-third agriculture and one-third urban cover. Land use includes intensive NH_4^+ fertilization, and septic tanks remain the main wastewater management practice.

We integrated hydrochemistry, land-use context, and dual nitrate isotopes ($\delta^{15}N–NO_3^-$, $\delta^{18}O–NO_3^-$) in MixSIAR and compared alternative model structures and priors. Because uninformative priors assume all sources are equally likely, we tested priors that downweighted SON, consistent with low natural background nitrate in forested recharge (<2 mg/L), a conservatively estimated natural nitrate upper bound of ~12 mg/L under oxic accumulation along flow paths, and literature indicating that nitrate from soil N mineralization typically remains within ~5–10 mg/L as NO_3^-.

To correct unequal sampling density, we report stratified means for the agricultural-urban belt of the Barva-Colima system, weighting Agriculture/Urban (6 sites) and Urban (11 sites) strata equally. Under uninformative priors, the stratified mean was 25.0% fertilizer, 37.8% sewage, 36.7% SON, and 0.5% atmospheric deposition. With SON downweighted, contributions shifted to 34.2% fertilizer, 40.9% sewage, 24.2% SON, and 0.6% atmospheric deposition. Targeted priors reduce a common failure mode in mixed settings, where SON is over-allocated when sources overlap, but posteriors still require validation with independent hydrochemical indicators for management.

LID 0564
Adaptive quantification and subsurface monitoring for advancing resilient agricultural technologies (AQUASMART)

Leunell Chris Buela[1*], Jerome Perez[2], Jastine Mae Galang[1], Grace Maligaya[3], Alea Fate Borlaza[1]

[1] Land Water Resources Engineering Division, Institute of Agricultural and Biosystems Engineering, College of Engineering and Agro-Industrial Technology, University of the Philippines Los Baños, Los Baños, Philippines
[2] National Irrigation Administration Central Office, Quezon City, Philippines
[3] School of Environmental Science and Management, University of the Philippines Los Baños, Los Baños, Philippines
* lmbuela@up.edu.ph

Keywords: groundwater monitoring, numerical modeling, irrigation management, climate variability

Groundwater supplies more than 50% of total water withdrawals in the Philippines and functions as a critical buffer against hydroclimatic variability. However, irrigation abstraction in many agricultural areas remains weakly quantified and insufficiently regulated, contributing to localized aquifer depletion, saltwater intrusion, and declining well productivity. Increasing rainfall variability and prolonged dry periods further intensify stress on shallow alluvial aquifers that sustain food production. This study evaluates an integrated subsurface monitoring and decision-support framework designed to improve irrigation efficiency and maintain groundwater abstraction within sustainable limits. A monitoring network is being established in a tropical agricultural site where groundwater levels and selected quality parameters (electrical conductivity, pH, dissolved oxygen, total suspended solids, salinity and temperature) are continuously measured using solar-powered IoT sensors. Time-series observations are incorporated into a MODFLOW-based groundwater flow model to simulate seasonal dynamics, pumping-induced drawdown, and recharge variability. A random forest algorithm is trained on historical meteorological data to generate short-term rainfall forecasts, which are coupled with soil moisture measurements to inform irrigation scheduling. Preliminary calibration reproduces observed seasonal groundwater fluctuations and localized abstraction responses with satisfactory agreement. Initial scenario analyses indicate that forecast-informed irrigation scheduling can reduce peak abstraction and moderate cumulative drawdown relative to conventional practices. Ongoing analyses focus on full model validation, uncertainty assessment, and evaluation under projected climate variability. The study contributes a transferable methodological framework for strengthening adaptive groundwater management in climate-sensitive agricultural systems.

LID 0565
Geothermal reinjection potential – a parameter to evaluate injection possibilities in siliciclastic aquifers

Ábel Markó[1,2]*, Maren Brehme[3], Judit Mádl-Szőnyi[2]

[1] Supervisory Authority for Regulatory Affairs, Budapest, Hungary
[2] ELTE Eötvös Loránd University, Institute of Geography and Earth Sciences, Department of Geology, József and Erzsébet Tóth Hydrogeology Chair, Budapest, Hungary
[3] ETH Zürich, Department of Earth Sciences, Geothermal Energy and Geofluids, Zürich, Switzerland
* abel.marko@sztfh.hu

Keywords: geothermal, reinjection, potential

In this study, a novel parameter of „geothermal reinjection potential" is introduced and defined as the geological probability of successful reinjection. Since sustainable utilization of thermal water resources requires reinjection, this potential is proposed to be evaluated prior to geothermal developments in siliciclastic aquifers where injectivity issues often hinder geothermal projects.

For the evaluation of this parameter a thematic multi-scale scientific workflow is presented incorporating scale-dependent problem sources, approaches and specific methods. The quantification of the parameter is carried out with a newly developed evaluation scheme.

The methodology was applied to sedimentary subbasins of the Pannonian Basin to demonstrate its effectiveness. In the Zala study area, quasi-hydrostatic conditions within shallow Pannonian siliciclastic aquifers were revealed by the regional hydraulic evaluation. At the reservoir scale, seismic interpretation techniques revealed heterogeneities on the order of 100 meters within the deltaic aquifer formations. RMS amplitude mapping and interpretation of spectral decomposition colour blends was carried out to identify porous sandstone bodies. At the local scale, low risk of carbonate and iron-hydroxide precipitation was predicted using a simplified hydrogeochemical model set-up.

Based on these findings, a reinjection potential map was created reinjection feasibility was for the -700 m to -1200 m interval in the Barlahida seismic block. This integrated methodology—incorporating risk assessment, probability of success quantification, and spatial reinjection potential mapping—supports improved decision-making and enhances the likelihood of successful reinjection in sedimentary geothermal systems.

Research was financed through the KDP-2021 Cooperative Doctoral Programme of the Ministry of Culture and Innovation of Hungary from the source of the National Research, Development and Innovation Fund, grant number: KDP_2021_ELTE_C1789026.

LID 0566
Groundwater resilience to drought: How to define, assess and improve it?

Paolo Colombo[1,2]*, Anna Luisa Hemshorn de Sánchez[2,3,4], Anne F. van Loon[2], Jose Henao Casas[2], Luca Alberti[1]

[1] Department of Civil and Environmental Engineering, Politecnico di Milano, Milan, Italy
[2] Institute for Environmental Studies, Vrije Universiteit Amsterdam, Amsterdam, The Netherlands
[3] Department of Earth Sciences, Vrije Universiteit Amsterdam, Amsterdam, The Netherlands
[4] Department of Soil and Groundwater Systems, Deltares, Utrecht, The Netherlands
* paolo1.colombo@polimi.it

Keywords: resilience, drought, managed aquifer recharge, data-driven modeling, pastas

Groundwater has been described as a resilient resource, buffering hydrological extremes. However, the term resilience is usually understood in different ways, leading to misrepresentation of groundwater. This makes it proner to overconsumption and depletion, two phenomena observed in many areas across the globe.

Here, we define resilience as the ability of a system to return to its initial state after a stress. The resilience to drought periods of groundwater resources was compared against the resilience of surface water (rivers, streams and lakes) in the Po river hydrogeological basin in Northern Italy. We analysed 20 years of data by computing standardized drought indexes based on the Standardized Precipitation Index (SPI) on each hydrological compartment. This comparison showed that groundwater resources requires a longer recovery after dry periods and is therefore less resilient to drought periods compared to surface water. Different responses and recovery dynamics were identified, finding spatial connotation and linkages with human activities. The observed dynamics create a vulnerability to prolonged stresses as multi-year droughts, which could lead to unprecedented impacts.

In addition to the index-based analysis, we tested the use of agricultural managed aquifer recharge to improve groundwater resilience. The Agricultural Managed Aquifer Recharge (AgMAR) system harnesses the extensive surface water irrigation infrastructure and off-season water surpluses available after droughts. To this aim data driven modelling using the pastas python package was used. Once surface water surpluses are available after drought, the measure can provide an additional volume to aquifers. The simulations show that MAR can recover the aquifer faster, thus improving the system resilience.

LID 0567
Irrigation–groundwater interactions as allies in climate change adaptation: results from an AgMAR application

Paolo Colombo[1*], Claudia Medina Montecinos[1], Pietro Mazzon[1], Rachele Eliana Riva[2], Enrico Weber[3], Veronica Piuri[4], Luca Alberti[1]

[1] Department of Civil and Environmental Engineering, Politecnico di Milano, Milan, Italy
[2] Dipartimento di Scienze Agrarie e Ambientali, Università degli Studi di Milano, Milan, Italy
[3] Softwater s.r.l., Milan, Italy
[4] Department of Electronics Information and Bioengineering, Politecnico di Milano, Milan, Italy
* paolo1.colombo@polimi.it

Keywords: managed aquifer recharge, climate change, adaptation

Agricultural Managed Aquifer Recharge (Ag-MAR) utilizes farming practices and landscapes to facilitate the infiltration of surplus water towards groundwater. As climate change increasingly threatens water security, this method emerges as a potential adaptation strategy.

A two-year field experiment was conducted in the outskirts of Milan (Northern Italy), an agriurban landscape where high-density urbanization coexists with intensive farming. Historically, the Po Plain relies on a complex network of canals to divert surface water for summer irrigation. By providing additional water to the aquifer during autumn and winter, periods of high surface water availability, the enhanced groundwater reserves could serve as "insurance" in case of hydrological droughts in the following year. This experiment relied on the synergy between field tests and modeling. During the 2023-2024 and 2024-2025 winters, water was diverted through the existing canal network and onto agricultural fields with the collaboration of local farmers, while monitoring groundwater levels and groundwater-dependent ecosystems. The data was then integrated into a numerical groundwater flow model (MODFLOW) and an agrohydrological model (IdrAgra), simulating the complex interactions between irrigation management and aquifer response under varying climate conditions. We then modeled a distributed network of wells which could then extract the additional volume.

The Ag-MAR measure significantly increased the water volumes available for the following summer, providing a buffer for emergency withdrawals during dry periods and accelerating recovery after drought periods: by using the average summer discharge, this method could have covered the unmet water discharges observed during the 2022 drought along the same canal utilized during the experiments. Ultimately, this research provides a scientific foundation for regional authorities to implement Ag-MAR as a long-term, groundwater-based adaptation strategy.

This research was carried out as a Pilot Action of the MAURICE Interreg project (CE0100184).

LID 0568

Quantitative characterization of non-carcinogenic health risk associated with nitrate exposure in drinking water from the Barva and Colima aquifers (Costa Rica) using Hazard Quotient (HQ) indices

Dorian Carballo-Ulloa[1]*, Helga Madrigal-Solís[1], Alicia Fonseca-Sánchez[1], Luis Quesada-Hernández[1], Hazel Calderón-Sánchez[1]

[1] Environmental Hydrology Program, School of Biological Sciences, National University of Costa Rica, Heredia, Costa Rica

* dorian.carballo.ulloa@est.una.ac.cr

Keywords: nitrates, Barva and Colima aquifers, groundwater, drinking water, health risk assessment, Hazard Quotient, methemoglobinemia, public health, Costa Rica, Python 3

Nitrate contamination in drinking water represents a critical threat to human health and groundwater sustainability in urbanized volcanic regions. The Barva and Colima aquifers constitute the primary drinking water sources for Heredia and Alajuela, Costa Rica, and exhibit high vulnerability due to their high permeability, rapid recharge dynamics, and increasing anthropogenic pressure. Mean nitrate concentrations in supply wells ranged from 6.43 to 21.91 mg/L, with Aurora 2 (21.26 mg/L), Aurora 3 (21.91 mg/L), and Esperanza 2 (19.72 mg/L) exceeding the U.S. EPA drinking water standard of 10 mg/L. Across the regional monitoring network (n = 42), concentrations ranged from 1.41 to 68.72 mg/L, with approximately 62% of sampled sites exceeding the EPA limit and 24% exceeding the Costa Rican alert threshold (25 mg/L), indicating widespread anthropogenic impact and localized contamination hotspots.

Non-carcinogenic health risk was quantitatively assessed using Hazard Quotient (HQ) indices across age groups. Results indicate that infants and children represent the most vulnerable populations due to higher exposure relative to body weight and increased susceptibility to nitrate-related health effects such as methemoglobinemia. Elevated concentrations were spatially associated with urbanized recharge zones, highlighting the influence of wastewater infiltration and land-use intensity on groundwater quality.

Furthermore, spatial analysis of nitrate concentrations and HQ values revealed a consistent pattern of groundwater quality degradation in areas with higher urban density, suggesting progressive anthropogenic pressure on the aquifer system. All risk calculations were automated using Python 3, ensuring reproducibility, traceability, and analytical precision. These findings emphasize the importance of strengthening hydrochemical monitoring programs, improving urban sanitation management, and protecting recharge zones to reduce health risks and ensure long-term drinking water security in the Central Valley of Costa Rica.

LID 0569
Hydrogeophysical characterization of an area close to Cerro Prieto Geothermal Field (Mexico)

Diego Ruiz-Aguilar[1]*, Ewa Glowacka[1], Olga Sarychikhina[1], Luis Alonso Gallardo-Delgado[1], Alejandro González-Ortega[1], Luis Eduardo Ochoa-Tinajero[1], Luis Alejandro Yegres-Herrera[1], Miguel Ángel García-Arthur[1], María Dolores Sánchez-García[1], Mario Alberto Fuentes-Arreazola[2]

[1] Centro de Investigación Científica y de Educación Superior de Ensenada (CICESE), Ensenada, Mexico
[2] Centro Universitario de la Costa, Universidad de Guadalajara. Puerto Vallarta, Mexico
* druiz@cicese.mx

Keywords: transient electromagnetics, subsidence

The Cerro Prieto geothermal Field (CPGF) has been producing electricity from hydrothermal fluid for the last 50 years. CPGF is located in the Mexicali Valley (northern Mexico), in the southern part of San Andreas system, on the border between tectonic plates, characterized by active tectonism, hydrothermal processes, volcanism, and high seismic activity.

Important subsidence effects have been observed in the area, which is related to the activity of the geothermal field. Therefore, CICESE has been monitoring the area through different hydrogeological, geotechnical, and geodesic methods since 1996, and with hydrogeophysical techniques since 2021.

In this work, we present the results obtained by the application of Transient Electromagnetics (TEM). We derived a subsurface resistivity model and correlated it to the main lithological units of the local shallow aquifer. In addition, we show water table variations observed at piezometers located on the study area and correlate important changes with anthropogenic, seismic and meteorological events.

LID 0572
Breathing new life into geophysical data for groundwater modeling

Chin Man W. Mok[1]*, Barbara A. Carrera[1]

[1] GSI Environmental Inc., Emeryville, United States
* cmmok@gsienv.com

Keywords: geophysical, tomography, modeling

Subsurface mapping using geophysical methods provides valuable insights into complex hydrogeological systems. These methods are non-intrusive, relatively cost-effective, and capable of rapidly collecting large volumes of data. A key application of such data is their integration into geologic models that serve as the foundation for groundwater modeling. However, geophysical data are often limited to two-dimensional sections, although three-dimensional geophysical tomography can be performed. In addition, the effectiveness of each method varies depending on local hydrogeological conditions—there is no single “the best” geophysical technique.

In this study, we present an approach for predicting different degrees of rock fracturing/weathering at a fractured rock site in Southern California, using data collected from Towed Time-Domain Electromagnetic (t-TEM), Electrical Resistivity Tomography (ERT), and Seismic Refraction (SR) surveys. Each data set provides some information on fracturing although they do not provide direct measurement of fractures. These geophysical datasets are utilized in a probabilistic context to correlate with borehole log information. We demonstrate a method for propagating the two-dimensional geophysical data into a three-dimensional geologic model within a stochastic framework. The resulting spatial distribution of rock fracture categories is intended for use as prior information in hydraulic tomography, a technique for estimating groundwater parameters from hydraulic head measurements.

LID 0573
Managing integrated water resources under rainfall and demand uncertainty

Chin Man W. Mok[1]*, Nisai Wanakule[1]

[1] GSI Environmental Inc., Emeryville, United States
* cmmok@gsienv.com

Keywords: reliability, uncertainty, integrated

Many water service providers are facing the challenges of increasing water demands and water scarcity, especially under the uncertainty and variability of future demands and hydrologic conditions. Using Northern Tampa Bay region in Florida, USA, as an example, this presentation describes a probabilistic framework to support water supply planning and management decision making. The region water demand is met by several supply sources including over 150 production wells in multiple wellfields, surface water withdrawal, desalination plant, and regional reservoir. The reliability, resiliency, and vulnerability of the water supply system are evaluated using Monte Carlo simulation of future rainfall and water demand, in conjunction with a simulation-optimization approach to manage water supply operations. The hydraulic response of the interacting groundwater and surface water system is simulated by an integrated hydrologic model based on coupling of a HSPF surface water and MODFLOW groundwater model. This presentation also demonstrates the improvement of the historical rainfall estimation through Bayesian integration of rain gauge and Doppler radar rainfall data. The results were used to develop a statistical model that was used to generate Monte Carlo realizations of rainfall time series in 172 subbasins over the water resources planning period. The selected definition of reliability, level of service, resilience, and vulnerability will be discussed.

LID 0574
A probabilistic framework for joint saline and geological model generation with geophysical and petrophysical constraints

Liming Guo[1]*, Thomas Hermans[1], Ellen Van De Vijver[2], David Dudal[3], Wouter Deleersnyder[1,4]

[1] Department of Geology, Ghent University, Ghent, Belgium
[2] Department of Environment, Ghent University, Gent, Belgium
[3] Department of Physics, KU Leuven Campus Kortrijk–Kulak, Kortrijk, Belgium
[4] Department of Earth and Ocean Sciences, University of British Columbia, Vancouver, Canada
* 1012506852@qq.com

Keywords: salinity mapping, hydrogeological modeling, geophysical inversion

Assessment of groundwater salinity traditionally relies on sparse borehole samples, which fail to capture the spatial heterogeneity of coastal aquifers resulting in complex salinity distribution, which leads to significant uncertainties in water quality mapping. This research presents an innovative framework that integrates groundwater modeling, geophysical forward and inverse modelling with geostatistical methods to establish a comprehensive synthetic database for evaluating salinity distributions based on coupled geological and geophysical information.

The workflow begins with the development of a training set using 20 representative lithological models from the Belgian coastal area to run high-resolution salinity transport simulations over multiple year. From these simulations, 100 representative sets of coupled geology-salinity distributions are extracted and translated to bulk conductivity (ECb) using petrophysics. Rather than applying pre-defined petrophysical laws, we introduced prior distributions for the formation factor (F) and surface conductivity (ECs) for lithologies. To account for the practical limitations of geophysical field data, forward modeling and inversions are performed to obtain inverted ECb data, which accurately reflect the resolution limitations of geophysical survey.

This comprehensive database allows for the establishment of robust statistical relationships between inverted resistivity and actual salinity levels, which can be integrated in geostatistical simulations of the mapped area. By bridging the gap between large-scale geophysical soundings and high-resolution hydrogeological properties, the framework provides a probabilistic approach to salinity mapping. The methodology is validated using field measurements. This research offers a transformative tool for hydrogeology, moving beyond sparse sampling to a data-driven approach that significantly improves the reliability of aquifer quality assessments and sustainable water management.

LID 0575
Evaluation of hydrogeochemical processes in former mining areas: The case of the Kirki mine, Evros, NE Greece

Triantafyllia Samara[1]*, Evangelia Zygouri[1], Alexandros Liakopoulos[1], Panagiotis Papazotos[1]

[1] Hellenic Survey of Geology and Mineral Exploration, Acharnae, Greece
* tsamara@eagme.gr

Keywords: water quality, Acid Mine Drainage-AMD, Potentially Toxic Elements-PTEs, tailings, pollution risk, abandoned mine

This study investigates the pollution status of water resources in Kirki's former mining area in Evros, Greece; an area located 22 km from the city of Alexandroupolis. Periodic samplings were conducted to determine geochemical parameters, including physicochemical variables, and major-trace elements. The samples analysed comprised surface water, groundwater, stream sediments, topsoils (0–20 cm), and flotation tailings/tailing dams. Parameters were determined using established analytical methods, such as inductively coupled plasma mass spectrometry (ICP-MS) for PTEs in water samples and portable X-ray fluorescence (pXRF) measurements for solid samples. Data processing and visualisation methods included descriptive, correlation, and multivariate statistics, hydrochemical diagrams (e.g., Piper, Ficklin, etc.), geo-environmental indices, and thematic/spatial distribution. The findings highlight that elevated concentrations of key PTEs (i.e., Zn, Cd, Pb, Cu) were recorded in both water and solid samples. These concentrations could be attributed to the primary source of pollution (i.e., unconfined flotation tailings) and to prevailing geochemical conditions (i.e., pH, Eh, AMD). These S-bearing tailings demonstrate a significant potential for acid generation and enhanced extractability of PTEs; these materials are associated with AMD. The overflow of surface waters and the release of fine-grained tailings from disposal sites, which are subsequently transported over long distances, degrade water quality in the Kirkalon-Erini streams, and associated aquifer systems. The Kirki Mine poses an ongoing pollution risk to water resources, and agricultural soils across the wider catchment. Our approach offers critical insights into the environmental fate of PTEs, aiming to optimise management strategies for the remediation and restoration of a former mining area and to minimise threats to groundwater quality and suitability, as well as to public health in surrounding communities.

LID 0576
Establishing thresholds of potential concern for adaptive management of the Steenbras Wellfield within the Table Mountain Group Aquifer, South Africa

Dale Barrow[1]*, Justine Ewart-Smith[2], Justin Van Blerk[2], Kate Snaddon[2], Johan Van Tol[3]

[1] GEOSS South Africa (Pty) Ltd, Stellenbosch, South Africa
[2] Freshwater Consulting, Plumstead, South Africa
[3] Digital Soils Africa (Pty) Ltd, Bloemfontein, South Africa
* dbarrow@geoss.co.za

Keywords: Table Mountain Group Aquifer (TMGA), hydrogeology, water chemistry, thresholds of potential concern, adaptive management

The Steenbras Wellfield, situated within the Kogelberg Biosphere Reserve, is a strategic water resource for the City of Cape Town. Sustainable abstraction from the fractured Table Mountain Group Aquifer (TMGA) requires an adaptive management framework to protect sensitive groundwater-dependent ecosystems (GDEs). This study established Thresholds of Potential Concern (TPCs) focused on physical drivers, supplemented by chemical and ecological monitoring.

The physical analysis integrated real-time groundwater monitoring with SWAT+ hydrological modelling. Statistical methods assessed to track ecoseep water levels included Z-score normalization, historical percentiles, Rate of Change (RoC) analysis, and a scaled variability approach for data-limited sites. Modelling of the H8_3b wetland catchment demonstrated that these systems are endosaturated, relying on prolonged discharge from the regional aquifer. Drawdown simulations revealed a critical tipping point for disconnection of upland contributions, leading to rapid desaturation.

Dry-season streamflow is predominantly sustained by baseflow. The analysis applied baseflow separation and recession analysis to calculate 7Q2 values (7-day low flow with a 2-year recurrence) for 10 river monitoring locations. Discharge TPCs were set at a 20% reduction of the baseflow component below the 7Q2 value.

Evaluation of piezometer data versus soil moisture probes confirmed that water level monitoring is a reliable proxy for moisture dynamics in the critical top 40 cm. The development of hydrological niche envelopes for 41 plant species and the use of simulations to predict species-specific sensitivity to water table declines provides a deep link between hydrogeology and botany.

While anchored in physical drivers, TPCs are supplemented by chemical (pH, EC, temperature) and ecological variables (vegetation richness, benthic algae, and macroinvertebrate indices) to provide a holistic warning system for wellfield management.

LID 0577
Groundwater characteristics, an observatory approach

Jaber Al-Marri[1]*, Mosab Subeh[1], Yehia Manawi[1], Huda Al-Sulaiti[1]

[1] Qatar Environment & Energy Research Institute (QEERI), Hamad Bin Khalifa University (HBKU), Qatar Foundation, Doha, Qatar

* jbr-91@hotmail.com

This study presents a most recent overview of the status of Qatar groundwater in terms of its physicochemical, heavy metals and radio activity elements. Based on this study, comprehensive sub-studies are being carried out to find out the effect of groundwater with common factors such as soil and vegetables. The outcome of the results are compared with previous results to see the change over time, also to have data base of the results for the groundwater in Qatar.

LID 0578
Geological mapping of unconfined Quaternary fluvial aquifers aided by log-facies correlation and climato-stratigraphic methods

Zoltán Püspöki[1]*, Gábor Markos[1], Tímea Fogarassy-Pummer[1], Julianna Lukács-Mekker[1,2], Yetzabbel G. Flores[2], Zoltán Vári[1], Zsóka Szabó[1], Nóra Edit Gál[1], Éva Kun[1], Andrea Szűcs[1], Eszter Sendula[1], Bálint Szappanos[1], Ellie Nelson[3], Dustin White[3], Kirsty Penkman[3], Richard W. Mcintosh[4], Tamás Fancsik[1]

[1] Supervisory Authority for Regulatory Affairs, Geological Survey, Budapest, Hungary
[2] Institute of Water Resources and Environmental Management, University of Miskolc, Miskolc, Hungary
[3] University of York, Heslington, York, United Kingdom
[4] University of Debrecen, Debrecen, Hungary
* zoltan.puspoki@sztfh.hu

Keywords: Quaternary basin analysis, fluvial deposits, magnetic susceptibility

The several hundred meters thick unconfined Quaternary fluvial successions are among the most extensive and relatively protected groundwater aquifers. Nevertheless, their geological and thus hydrogeological modelling is challenged by the heterogeneous fluvial lithology, lack of fossils, and the limited depth and resolution of near-surface geophysical methods.

The 100–600 m thick Quaternary fluvial succession of the Great Hungarian Plain (Pannonian Basin) forming the basis of local freshwater supply for drinking water and irrigation, has been investigated for several decades at the Unit of Hydrogeology of the SARA. Some internationally relevant outcomes of these investigations include 1) the high resolution Quaternary climato-stratigraphy of the succession, based on magnetic susceptibility measured on cores or logged in wells, 2) the involvement of amino acid geochronology in the interpretation of Quaternary basin development, 3) the recognition of the fluvial response to large scale Pliocene-Quaternary climate changes like the Intensification of Northern Hemisphere Glaciation and the Mid–Pleistocene Transition. These findings are all considered when performing the extended, regional net of wireline log correlations. As a result, local and regional objects like incised valley systems, fluvial fans, and regional unconformities were recognised and mapped, revealing e.g. regionally extensive preferential flow systems and spatial contact between otherwise distinct hydrogeological units.

Since the Pannonian Basin is a representative terrestrial fluvial basin, the applied techniques and recognised phenomena may be relevant in similar regions of the temperate climate zones and can significantly support geological models used in hydrogeological research.

LID 0579
Groundwater quality patterns in a major porous aquifer affected by multiple anthropogenic and climatic pressures in the Northern part of the Great Hungarian Plain

Andrea Szűcs[1*], Nóra Edit Gál[1], Julianna Mekker-Lukács[1,2], Zsóka Szabó[1], Zoltán Vári[1], Zoltán Püspöki[1], Eszter Sendula[1], Éva Kun[1]

[1] Supervisory Authority of Regulatory Affairs, Geological Survey, Budapest, Hungary
[2] Institute of Water Resources and Environmental Management, University of Miskolc, Hungary
* andrea.szucs@sztfh.hu

Keywords: groundwater hydrochemistry, multiple pressures, groundwater flow

Intensive groundwater abstraction for drinking water, as well as agricultural and industrial utilization exerts substantial regional pressure on shallow groundwater resources and contributes to groundwater level decline worldwide. In recent decades, these pressures have been further exacerbated by climate change related stress. The study area is situated in Hungary in the transition zone between the northern hilly region and the Great Hungarian Plain and represents a widely recognised example of an aquifer subjected to multiple stressors. In addition to potential anthropogenic pollution of groundwater, decreasing water table can induce changes in groundwater hydrochemistry in the long term, either resulting in the mobilisation of redox sensitive chemical constituents or the intrusion of groundwater with unfavourable chemical composition, which further deteriorates groundwater quality.

The studied groundwater is generally characterised by $CaNaHCO_3$, $CaHCO_3$ and $CaMgHCO_3$ water types. Hydrochemical data on major chemical constituents, such as chloride, sulphate, as well as minor constituents and parameters indicative of changes in redox conditions and of potential anthropogenic pollution (e.g., nitrate concentration and specific electrical conductivity) are investigated. As chloride concentrations are frequently low in the area, chloride/bromide mass ratios are also investigated. In addition, stable and radioactive isotope data are used to trace the evolution of groundwater flow systems. Preliminary results suggest that both local and regional groundwater flow patterns exert a strong control on geochemical environments, thereby influencing the mobility of redox-sensitive elements and contributing to the observed groundwater chemistry.

LID 0581
Shallow geothermal energy utilization for more sustainable university campus: A case study from ELTE, Budapest

Gergő Glavanov[1]*, Ábel Markó[1,2], Balázs Márton[3], Béla Ádám[3], Judit Mádl-Szőnyi[1]

[1] József and Erzsébet Tóth Endowed Hydrogeology Chair, Department of Geology, Institute of Geography and Earth Sciences, Eötvös Loránd University, Budapest, Hungary
[2] Supervisory Authority for Regulatory Affairs, Budapest, Hungary
[3] HIDRO-GEODRILLING Geothermal Energy Utilization Ltd., Budapest, Hungary
* glavigeri@gmail.com

Keywords: shallow geothermal, borehole heat exchanger, sustainability

Universities worldwide face increasing pressure to reduce carbon emissions, improve energy efficiency, and transition toward sustainable campus infrastructures. Shallow geothermal systems offer a reliable and low-carbon option for heating and cooling large institutional buildings, especially in urban areas where deep geothermal development is restricted. Existing campuses also face spatial limitations and capacity requirements.

This study examines the feasibility of a shallow geothermal borehole heat exchanger (BHE) field to partially replace fossil-fuel-based heating and cooling at a building of Eötvös Loránd University (ELTE) in Budapest, Hungary. Although the area has favourable geothermal conditions, deep geothermal use is prohibited due to the protection of the Budai Thermal Karst system. The assessment therefore focuses on shallow subsurface formations, including artificial fill, gravel terraces, and underlying Oligocene–Eocene clay and marl layers down to at last 130 m.

Geological and thermal property data from the site and literature were used in the Earth Energy Designer (EED) model to evaluate performance under the building's annual demand of 5200 MWh for heating and 1750 MWh for cooling. Results show that available green areas could host 323 BHEs, enabling the system to supply around 50% of heating and 100% of cooling from renewable geothermal energy. Modelling also indicates that a potential nearby (50 m) future BHE system for another building would not significantly affect performance.

These findings demonstrate that shallow geothermal systems can contribute to decarbonizing university campuses even in geologically constrained urban areas.

This work was carried out within the project RRF-2.3.1-21-2022-00014, entitled "Establishment of the Multidisciplinary National Laboratory for Climate Change," under Hungary's Recovery and Resilience Plan, with support from the European Union's Recovery and Resilience Facility.

LID 0586
Conditions of mineral waters formation in Herľany

Daniel Marcin[1]*, František Bottlik[1], Katarína Benková[1], Rudolf Dugovič[1], Peter Čech[2]

[1] State Geological Institute of Dionyz Stur, Division of Hydrogeology and Geothermal Resources, Bratislava, Slovakia
[2] State Geological Institute of Dionyz Stur, Division of Geochemistry and Special Laboratories, Bratislava, Slovakia
* daniel.marcin@geology.sk

Keywords: Neogene rocks, chemical and isotopic water composition, cold water geyser

The discharge area of mineral water in Herľany is located on an uplifted block bounded by the northern and southern Herľany faults, trending NE-SW. This block is further fractured by a system of E-W faults, which facilitate the ascent of deep-circulation mineral water to the surface.

Mineral water sources in the Herľany discharge area capture water through dug wells, with depths ranging from 4 m (KE-3) to 6 m (KE-1, KE-2). Total Dissolved Solids (TDS) of these sources ranges from 2,710 mg.l^{-1} to 2,847 mg.l^{-1}, with a pH of around 6.0, CO_2 content from 1,270 mg.l^{-1} to 1,800 mg.l^{-1}, and water temperatures between 10.1 °C and 12 °C. Chemical type of these sources is Na-Ca-HCO_3-Cl. The only distinct source is KE-9, located in the eastern part of the discharge area near the municipal office. Its parameters are as follows: TDS 987 mg.l^{-1}, pH 6.0, CO_2 content 1,335 mg.l^{-1}, and water temperature 10.3 °C. Chemically, it is a Ca-(Na)-HCO_3-(SO_4-Cl) type. This type of mineral water is characteristic of shallow-circulation mineral waters in neovolcanic rocks. The isotopic composition of the shallow-circulation mineral water reaches values of $\delta^{18}O$ = -9.030 ‰ and $\delta^{2}H$ = -62.681 ‰.

Deeper tapping of mineral water in the discharge area via the 404 m deep "Gejzír" borehole (KE-4), cased to 351 m, confirmed the presence of mineral water with the following parameters: TDS 4,846.75 to 6,631.0 mg.l^{-1}, pH 6.4 to 7.3, water temperature 15 to 23 °C, and CO_2 content 1,300 mg.l^{-1} to 1,621 mg.l^{-1}. Mineral waters captured by the deep borehole exhibit a similar chemical type to the shallow sources (Na-Ca-HCO_3-Cl), but reach higher values of S_1(Cl) from 37.50 eq% to 45.90 eq%, and A_1 from 21.80 eq% to 40.13 eq%. The isotopic composition of the deep-circulation mineral water reaches values of $\delta^{18}O$ = -10.134 ‰ and $\delta^{2}H$ = -71.128 ‰. The mineral waters in Herľany can be classified as polygenic, as multiple mineralization processes contribute to the formation of their final chemical composition.

LID 0588
Investigating the behavior and lateral extent of sand river alluvial aquifers in support of sustainable groundwater development in the Limpopo dryland area of Mozambique

Paulo Sérgio L. Saveca[1,2,3], **Tibor Stigter**[2*], Eelco Lukas[3], Francois Fourie[3]

[1] Instituto Superior Politécnico de Gaza, Divisão de Agricultura, Campus Politécnico de Lionde, Gaza, Mozambique
[2] IHE Delft Institute for Water Education, Department of Water Resources and Ecosystems, Delft, The Netherlands
[3] Institute for Groundwater Studies, University of the Free State, Bloemfontein, South Africa
* t.stigter@un-ihe.org

Keywords: semi-arid areas, sand river, nature-based storage, Limpopo, Mozambique

To investigate the extent and potential of sand river alluvial aquifers (SRAA) to supply water in the semi-arid lower Limpopo area of Mozambique, we applied a field-based assessment employing geoelectrical methods (9 ERT profiles and 17 VES sites), 17 manual drillings, hydrochemical analyses at 66 locations and three pressure sensors installed across the sand river for piezometric measurements over three years. ERT and VES results down to 40 m confirm that sand deposits can reach thicknesses of 10-15 m and can extend far (several km) beyond the current active channel. Away from the margin these sands are typically covered and underlain by clays with brackish water, further confirmed by hand-drilled lithologs and EC measurements. Such sand compartments, typically linked to river migration and paleochannels, can be connected to the main river channel where they can receive and provide additional water through lateral flow. However, further away from the main river channel, these sand compartments appear isolated, which can result in salinisation through vertical leakage from the clay aquitards upon groundwater pumping. Sand river hydrogeochemistry is driven by water-rock interaction, characterized by Ca-HCO3 facies, permanently fresh throughout the year, providing ecosystem services. Water stable isotopes indicate seasonal aquifer recharge: rapidly infiltration river water is isotopically depleted and evaporation rates are low. The rapid water level response is also revealed by the pressure sensors installed in the river bed. Due to their high porosity and permeability, the SRAA systems are ideal nature-based storage systems, with fast recharge during high river flow. Shallow groundwater exploitation using low-cost hand-drilled wells in the sand river, can support climate resilient agriculture. By using the available storage over the dry season, recharge in the following rain season is enhanced and extreme flows can be mitigated.

LID 0589
Treated wastewater reuse for sustainable agriculture using MAR approach. Case study: Kiskunfélegyháza, Hungary

Reham Mohammed[1]*, Szilvia Simon[1], Ildikó Galambos[2], Judit Mádl-Szőnyi[1]

[1] József and Erzsébet Tóth Endowed Hydrogeology Chair, Department of Geology, Institute of Geography and Earth Sciences, Eötvös Loránd University, Budapest, Hungary
[2] Soós Ernő Research and Development Center, University of Pannonia, Nagykanizsa, Hungary
* reham@student.elte.hu

Keywords: Managed Aquifer Recharge, treated wastewater, groundwater recharge, wastewater reuse

In light of global water challenges, including water scarcity and the inefficient management of water resources, it is vital to find effective ways to use resources optimally to ensure their sustainability. Treated wastewater is a highly valuable strategic resource that can be integrated into water management to reduce the depletion of usual sources. As a promising approach to ensuring water availability, it can be used to replenish groundwater levels through Managed Aquifer Recharge (MAR), benefiting agriculture suffering from declining groundwater levels.

It is essential to assess the safety and long-term sustainability of using treated wastewater for groundwater recharge. The Kiskunfélegyháza area provides suitable environment for studying groundwater–surface water interactions, as it contains two canals transporting treated wastewater through agricultural areas. Field analyses recorded high concentrations of total dissolved solids TDS 2807 mg/L and total hardness 451 mg/L in the canal water from wastewater treatment plants. The chemical composition along the canal showed a decrease in all measured parameters, indicating dilution from groundwater discharging in the canals bed. This confirms that the canals still receive groundwater, which may evaporate or flow out of the area suffering from water shortage. These results highlight two problems: (1) canals water quality and (2) the absence of an effective management system to conserve groundwater, shown by the uncontrolled hydraulic interaction between groundwater and canal water.

This research investigates how to modify the hydraulic interaction and keep water in the canals to enhance infiltration and explores the water quality conditions needed to stop groundwater contamination.

The work has been done by the National Multidisciplinary Laboratory for Climate Change (RRF-2.3.1-21-2022-00014) within Hungary's National Recovery and Resilience Plan supported by the Recovery and Resilience Facility of the European Union.

LID 0590
Criteria for selecting the most important karst springs – Output of the MIKAS Project

Zoran Stevanović[1*], John Gunn[2], Neven Kresic[3], Augusto Auler[4], Junbing Pu[5], Peter Malik[6], Avihu Burg[7], Benjamin Tobin[8]

[1] Centre for Karst Hydrogeology, University of Belgrade - Faculty of Mining & Geology, Serbia
[2] School of Geography, Earth and Environmental Science, University of Birmingham, United Kingdom
[3] Independent Consultant and Director, Karst Waters Institute, Warrenton, VA, United States
[4] Instituto do Carste / Carste Ciência e Meio Ambiente, Belo Horizonte, MG, Brazil
[5] School of Geography and Tourism, Chongqing Normal University, China
[6] Geological Survey of Slovakia, Bratislava, Slovakia
[7] Geological Survey of Israel, Jerusalem, Israel
[8] National Cave and Karst Research Institute (NCKRI), NM, United States
[*] zstev_2000@yahoo.co.uk

Keywords: karst spring, criteria, importance

MIKAS (Most Important Karst Aquifer's Springs, https://mikasproject.org/), is a project of the IAH Karst Commission implemented by the authors of this abstract and more than 100 national experts. More than 300 springs were evaluated and classified into two categories (globally and nationally important). The established selection criteria are historic, aesthetic, economic, scientific and ecological. Examples of each criterion are:

Historic. 1. The Bath Hot springs (UK) - developed as a spa in Roman times. 2. Waikoropupu (New Zealand) - high cultural value for indigenous Maori people. 3. Gihon spring (Jerusalem, Israel) - mentioned in the bible and in the Christian tradition.

Aesthetic. 1. Buna spring (Bosnia & Herzegovina) - the largest European spring, flows out from a submerged cave under a high cliff. 2. Ventanas de Tisquizoque (Colombia) – 270m high three-tiered waterfall. 3. Blautopf (Germany) - typical representative of springs characterised by ascending circulation of "blue" water from a deep siphon.

Economic. 1. Kaiserbrunn spring - supplying water to 1.7 million citizens of Vienna since 1873. 2. Jeita - the main source of potable water for Beirut. 3. Peschiera spring - supplies some 60% of Rome's drinking water.

Scientific. 1. Fontaine de Vaucluse (France) - one of the most famous ("vauclusian type") and best explored springs in the world (discharge recorded since 1887). 2. Lez spring - an excellent engineering solution, ensures drinking water to Montpellier, France. 3. João Baio (Brasil) - the only rhythmic (ebb and flow) spring known in South America.

Ecological. 1. Wakulla spring (Florida, USA) – the archaeological site with the longest explored submerged passages, provides abundant freshwater for a complex ecosystem of wild plants and animals. 2. Xe Bang Fai (Laos) - one of the largest springs in the world, vital water source for wildlife, livestock and people. 3. Baotu spring (China) – the source recorded in documents 3,500 years ago, ensures baseflow of downstream river and lake.

The project also considers the threats to which some globally important springs are exposed. Dumanli (Tukiye) – submerged by a reservoir; Ras el Ain (Syria), Ain Zeyna (Libya), Ain Zeidoun (Tunisia) - temporarily drying out due to intensive pumping.

LID 0592
Groundwater flow systems and their influence on microbial methane migration, and accumulation in the Pannonian Basin

Romario Albert Adonya[1]*, Bela Marton[2], Brigitta Czauner[1]

[1] ELTE, Eötvös Loránd University, Institute of Geography and Earth Sciences, Department of Geology, József and Erzsébet Tóth Endowed Hydrogeology Chair, Budapest, Hungary
[2] Vermilion Energy, Budapest, Hungary
* romarioadonya2@gmail.com

Keywords: microbial methane migration, groundwater flow systems, Pannonian Basin

Groundwater flow systems are fundamental to the Pannonian Basin's microbial methane cycle, acting as conduits that connect microbial methane generation zones to discharge areas. Because methane migration occurs in aqueous solution, significant commercial accumulation requires prolonged residence times along extensive lateral flow paths to reach necessary concentration levels. Eventually, these hydraulic systems dictate the dual fate of microbial methane: either as economically viable subsurface reserves or as atmospheric emissions through natural surface seepages.

By integrating hydrogeological and petroleum geological workflows into a custom Python-based environment, this study offers a novel framework for modeling microbial methane dynamics within the Pannonian Basin. The research utilizes an extensive database of over 200,000 solubility points and reverse-engineered data to quantify how fluid dynamics, P-T-S gradients, and aqueous transport influence gas migration and accumulation. The model distinguishes between lateral migration, where dissolved gas accumulates under steady-state conditions, and upward discharge, where flow triggers gas exsolution. This approach identifies critical saturation thresholds and quantifies methane volumes, providing a robust tool for both hydrocarbon exploration and the monitoring of environmental emissions.

Applying the model to the Hajdúszoboszló field identifies regional groundwater flow as the primary driver of methane entrapment, with a mass balance analysis estimating an accumulation of 226 million m^3 over 1 Ma. This confirms the field's commercial viability while simultaneously quantifying a steady environmental impact through a calculated surface flux of 700 m^3/year. These findings underscore the critical influence of hydrogeology on methane distribution; a relationship further explored through ongoing research at the Kunmadaras field to refine the regional understanding of methane dynamics across the Pannonian Basin.

LID 0593
Machine learning spatial downscaling of GRACE terrestrial water storage anomalies: Application to the Bug River Basin

Tatiana Solovey[1]*, Vytautas Samalavičius[2], Justyna Śliwińska-Bronowicz[3], Anna Stradczuk[1]

[1] Polish Geological Institute—National Research Institute, Warsaw, Poland
[2] Institute of Geosciences, Faculty of Chemistry and Geosciences at Vilnius University, Vilnius, Lithuania
[3] Centrum Badań Kosmicznych Polskiej Akademii Nauk (CBK PAN), Warsaw, Poland
* tatiana.solovey@pgi.gov.pl

Keywords: machine learning, GRACE/GRACE-FO, Bug River Basin, spatial downscaling

GRACE and GRACE-FO satellite gravimetry provide unique observations of terrestrial water storage (TWS), but their coarse effective resolution and intermittent temporal gaps limit basin-scale water-resources applications. We present a two-stage, bias-aware machine-learning framework to reconstruct and spatially downscale GRACE TWS anomalies for the transboundary Bug River Basin (Poland–Ukraine–Belarus), a region where in situ monitoring is limited and further disrupted by the 2022 war in Ukraine. First, missing monthly GRACE TWS anomalies (2002–2024) are imputed using a Random Forest model driven only by lagged GRACE values (1–3 months), seasonal timing, and static physiographic attributes to avoid information leakage. Second, the continuous GRACE signal is downscaled from 0.25° to 0.1° using an independent set of hydroclimatic predictors (precipitation, evapotranspiration, river runoff, soil moisture, temperature) with lagged and rolling features, evaluated under strict spatiotemporal holdouts. The key methodological advance is a bias-aware, block-wise mass-conserving correction that reconciles machine-learning downscaled fields with the original GRACE water mass at coarse resolution. After Random Forest downscaling to 0.1°, systematic residual biases between aggregated high-resolution estimates and GRACE observations are quantified monthly and redistributed within spatial blocks using river runoff-based weights. This procedure enforces exact mass closure while preserving physically meaningful sub-grid variability, preventing the accumulation of artificial gains or losses in basin-integrated storage. The resulting high-resolution TWS product retains the integrity of the GRACE signal while enhancing spatial detail, providing a robust and transferable methodology for regional water storage assessment.

This research was funded by National Science Centre, Poland, under the project GRANDE-U (grant number 2023/05/Y/ST10/00234) and by NSF Awards No. 2409395.

LID 0595

Radon and tritium in groundwater of the less permeable sedimentary rocks in Northern part of the Pannonian Basin

Peter Malík[1]*, Natália Bačová[1], Peter Bajtoš[1], Jaromír Švasta[1], Juraj Kotuč[1], Alexandra Vasilenková[1], Natália Bahnová[1]

[1] Division of Hydrogeology and Geothermal Resources, State Geological Institute of Dionyz Stur, Bratislava, Slovakia

* peter.malik@geology.sk

Radon and tritium were (together with other components) sampled from 24 newly drilled hydrogeological boreholes (average depth of 133.3 m, average open casing interval depth 84.2 m), 140 springs, 51 dug wells and 7 surface water sources. Together 248 samples were analysed.

Median value of the ^{222}Rn volume activities from all samples was 5.90 Bq/L, with range of measured values 0.20 – 57.30 Bq/L. Samples taken from hydrogeological wells had slightly lower median values (3.20 Bq/L), while increased values were found for groundwater samples from springs (median 8.90 Bq/L). For groundwater taken from wells, consistently above-average values were found (median 6.30 Bq/L), while for samples from surface streams (8 samples) and from a water reservoir (1 sample), the ^{222}Rn volumetric activities were expectedly lower (median 0.40 Bq/L). The lowest ^{222}Rn values were connected with Neogene volcanic rocks (!), with the median of 4.20 Bq/L, followed by Triassic carbonates of the underlayer (4,50 Bq/L) and Pliocene gravels (6.70 Bq/L). In the Oligocene/Miocene shales groundwater the radon volume activities were slightly higher, while in the sandstones of the Burdigalian Early Miocene the ^{222}Rn volume activities were substantially higher: median 19.50 Bq/L, ranging up to 57.30 Bq/L.

The median tritium volumetric activity for all 248 analysed samples was 3.51 TU (0.415 Bq/L), with a range of measured values from undetectable values (<0.5 TU) to 8.89 TU and a mean of 3.43 TU. In this entire set, 10% samples had a tritium volumetric activity below the detection limit of 0.5 TU and in 58% samples tritium was lower than 2.5 TU.

Samples from boreholes had slightly lower average values than samples from springs and wells (median 1.99 TU), 21% of samples were <0.50 TU and 63% of samples <2.50 TU. Average values were found for groundwater samples from springs – median 3.56 TU, 9% samples <0.50 TU and 26% samples <2.50 TU. Interestingly, groundwater of dug wells, slightly above-average values were found: median 4.57 TU), which did not differ much from 8 samples from surface streams (median 5.08 TU). Tritium in samples taken from dug wells was <0.50 TU in 4% of cases and <2.50 TU in 14% of cases. The highest value of 8.89 TU was in the surface water of an artificial lake.

LID 0598
Changes in groundwater recharge under urban development: An increase in quantity is the rule

Mario Schirmer[1,2,3]*, Morgane Minnig-Pirro[4], Elizabeth Kiflay[1], Dirk Radny[5], Maximilian Ramgraber[6], Jan Willem Foppen[6], Christian Moeck[1,7]

[1] Eawag, Swiss Federal Institute of Aquatic Science and Technology, Dübendorf, Switzerland
[2] Laval University, Quebec, Canada
[3] University of Neuchatel, Neuchatel, Switzerland
[4] GFI Grundwasser - Consulting-Institut, Dresden, Germany
[5] Federal Institute of Hydrology, Koblenz, Germany
[6] Technical University Delft, Delft, The Netherlands
[7] CH-GNet – Swiss Groundwater Network, Dübendorf, Switzerland
* mario.schirmer@eawag.ch

Keywords: urban hydrogeology, groundwater recharge, urban development

Urban groundwater is an important resource for water supply, energy production, flood protection and the integrated management of surface water and groundwater. However, competing interests in its use pose a significant threat to both the quality and quantity of this resource. Urban development affects both groundwater quality and quantity, as water flow systems are strongly modified by infrastructure and human activities. While issues of contamination remain highly relevant, understanding quantitative changes in groundwater systems is equally critical for sustainable urban water management.

A key step in characterising groundwater systems in urban areas is the quantification of groundwater recharge. Although this is a challenge, it is essential for preparing water balances over longer periods of time.

At first glance, this may seem surprising, but the majority of studies show that groundwater recharge increases with urbanisation. This means that this is the rule rather than the exception. We demonstrate this pattern using two detailed case studies and a synthesis of the global literature. In our work, we show that the effect of increasing recharge with urbanisation is mainly due to two factors: the significant reduction in evaporation as a result of the loss of green spaces, and additional water inflows due to pipe losses in the drinking water supply and sewage system.

LID 0603
Multi-isotope tracers for investigating groundwater quality and biogeochemical processes at a landfill site

Andrea Cisternino[1,2]*, Barbara Casentini[2], Stefano Amalfitano[2,3], Marco Melita[2], Elisabetta Preziosi[2]

[1] Sapienza University of Rome, Department of Earth Sciences, Rome, Italy
[2] National Research Council - Water Research Institute (CNR-IRSA), Montelibretti - Rome, Italy
[3] National Biodiversity Future Center (NBFC), Palermo, Italy
* andrea.cisternino@uniroma1.it

Keywords: environmental isotope tracers, hydrobiogeochemistry, dismissed landfill

In fluvio-palustrine deposits, peat-rich layers can promote the reductive dissolution of iron (Fe) and manganese (Mn) (hydr)oxides, leading to the mobilization of Fe, Mn, and associated arsenic. These processes may be further enhanced by anthropogenic inputs, particularly where exogenous organic matter reaches the groundwater system.

This study applies a multi-isotope tracer approach ($\delta^{2}H$, $\delta^{18}O$, $\delta^{13}C$-DIC, $\delta^{37}Cl$, $^{87}Sr/^{86}Sr$, and ^{3}H) to investigate groundwater quality and biogeochemical processes at site of central Italy hosting a dismissed landfill that predates the EU Landfill Directive. A pump-and-treat system is currently active in one disposal basin, while the oldest one has not yet undergone a full reclamation. The site is characterized by a complex stratigraphy consisting of fluvio-palustrine sediments, eolian sands, and volcanic deposits. The shallow aquifer is unconfined and flows toward a nearby stream.

Internal piezometers, external wells, and stream water were sampled during two campaigns (June 2024 and September 2025) and analyzed for major ions, trace elements, isotopic tracers, and unconventional microbiological parameters. Results reveal a variety of groundwater chemical facies within a relatively small area, indicating complex hydrogeochemical evolution, including the coexistence of landfill impact and fossil seawater contribution, as preliminarily supported by $^{87}Sr/^{86}Sr$ data. Between 2024 and 2025, concentrations of Fe and Mn, as well as microbial cell abundance, decreased or remained stable. Tritium concentrations indicate a moderate recent recharge affected by the landfill. Ongoing $\delta^{37}Cl$ and $^{87}Sr/^{86}Sr$ analyses will further constrain the origin of saline groundwater, while methane isotope measurements will help clarify the pathways of carbon reduction processes and assess the relative contributions of microbial methanogenesis versus thermogenic sources.

EcoAmbiente s.r.l. (Itay) is kindly acknowledged for their financial support (Contract 08-07-2024, prot. 236074).

LID 0604
Integrated monitoring reveals hydrochemical shifts in a riverbank filtration system under sustained river impoundment

Krzysztof Janik[1]*, Kinga Ślósarczyk[1], Sławomir Sitek[1]

[1] Institute of Earth Sciences, Faculty of Natural Sciences, University of Silesia in Katowice, Sosnowiec, Poland
* krzysztof.janik@us.edu.pl

Keywords: riverbank filtration, water monitoring, small hydropower plant

Small hydropower plants (SHPs) can alter river stage and groundwater–surface water interactions. However, their implications for riverbank filtration (RBF) systems supplying drinking water remain scarcely investigated, particularly due to the rare occurrence of sites where constant river impoundment coincides with an adjacent well field.

This study shows how long-term, high-resolution river water and groundwater monitoring supports change detection and evidence-based management of RBF systems. The research was conducted at an RBF site in southern Poland, where SHP-induced river impoundment began in the second half of 2024. The analysis integrated continuous hydrodynamic monitoring (water level, temperature, specific conductance), laboratory hydrochemical data and hydrometeorological records from 2020–2025, covering pre- and post-impoundment conditions. Non-parametric and multivariate analyses were applied to distinguish impoundment effects from seasonal variability.

While river water chemistry showed only minor changes, groundwater revealed systematic, spatially differentiated shifts after the impoundment. Wells closer to the river exhibited lower nitrate and sulphate concentrations and higher ammonium, manganese, alkalinity and pH, implying a potential transition towards more reducing conditions. Also, wells further inland showed weaker but still statistically significant changes in water chemistry. Continuous monitoring proved essential for identifying these subtle yet persistent trends and separating them from short-term variability. The results indicate that river impoundment can modify hydrochemical conditions in shallow groundwater even without pronounced changes in river water chemistry. Despite potential benefits such as groundwater quantity, sustained river stage elevation near an RBF site may introduce gradual yet significant shifts in groundwater chemistry, underscoring the need for robust monitoring frameworks to safeguard drinking water resources.

LID 0605

Interaction between surface water-ground water and its ecological effects on the lower reaches of Tarim River Basin affected by ecological water conveyance

Lei Jiang[1]*, Qiang Wang[1], Ziyong Sun[2], Shun Hu[2]

[1] Urumqi Natural Resources Survey, China Geological Survey, Urumqi, China
[2] China University of Geosciences, Wuhan, China
* jianglei1987@126.com

Keywords: interaction between surface water-groundwater, groundwater and ecology, numerical simulation, Tarim River Basin, arid region

Water is a critical factor in sustaining ecosystems in arid regions. In recent decades, escalating global climate warming and intensified human socioeconomic activities have exacerbated water scarcity in arid zones, posing severe threats to China's food security and ecosystem health. Although artificial water allocation can alleviate water-use conflicts between human needs and natural systems, the limited and uncertain availability of water resources undermines the sustainability of ecosystem restoration through external groundwater recharge. Furthermore, optimizing water-use efficiency, rather than merely determining total consumption, is essential for achieving large-scale ecological recovery under constrained water resources. Consequently, balancing water allocation for economic development and ecological preservation has become a central objective in ecological restoration research within China's arid regions.

Against this background, this study focuses on the lower reaches of the Tarim River Basin as the research area. Through systematic field surveys, integration of historical data, and methods including hydrogeochemistry, stable isotope tracing, and groundwater numerical modeling, the transformation dynamics, cycling patterns, and spatiotemporal evolution of surface water-groundwater interactions were analyzed. High-resolution remote sensing data and unmanned aerial vehicle measurements from representative monitoring cross-sections were employed to evaluate the spatiotemporal characteristics of groundwater and vegetation restoration under ecological water conveyance. Fixed-sample plot investigations and observational data analyses revealed dynamic coupling mechanisms between groundwater and vegetation growth, elucidating the controlling principles of vegetation recovery. By simulating different ecological water conveyance scenarios, optimal schemes were explored based on groundwater level variations and water balance dynamics.

LID 0607
Decline of groundwater resources in the Pannonian Basin – The impact of climate change on a vulnerable aquifer system

Balázs Kovács[1]*, János Szanyi[2]

[1] Institute of Water Resources and Environmental Management, University of Miskolc, Miskolc, Hungary
[2] Department of Geology, University of Szeged, Szeged, Hungary
* modflow@gmail.com

Keywords: Pannonian Basin, groundwater level decline, climate resilience

The Pannonian Basin is one of 70 aquifers systems in the world, it is famous for its vast groundwater resources, rich biodiversity, large grasslands with a semi-arid continental climate. Shallow and deep groundwater are considered "natural treasures" in the Pannonian Basin, as they are one of the most important sources of drinking water and renewable energy. There are two vertically stacked major groundwater flow regimes within the Pannonian Basin: an upper “gravity-driven” flow regime, and a lower “over-pressured” flow regime. The upper flow system, which is fed by precipitation, is the main source of water supply.

Over the past decade, there have been numerous signs pointing to a decline in groundwater resources in the Carpathian Basin, particularly in the infiltration areas of the Great Plain (Alföld) region. By examining water budget data, we reveal the driving forces behind this process and forecast changes expected in the near and distant future. Our research indicates that the primary cause is climate change, specifically the increase in evaporation caused by rising temperatures, exacerbated by increasing water use. Given the current approach to water management, we predict that the region's groundwater management will become unsustainable in the future. This will lead to increasing water shortages, which will result in serious difficulties in supplying water to the population and industry, as well as causing ecological problems. In our presentation, we will outline possible solutions which, while not halting the process, will mitigate its harmful effects.

LID 0609
Hydro(geo)chemical modeling as a complementary tool for integrated water resources management

Didier Gastmans[1]*, Carolina S. Quaggio[1], Natália S. Arruda[1], Gustavo R. Leticio[2], Daniel C. G. Pedronette[2]

[1] São Paulo State University (UNESP), Environmental Studies Center (CEA), Rio Claro, Brazil
[2] São Paulo State University (UNESP), Geoscience and Exact Sciences Institute (IGCE), Rio Claro, Brazil
* didier.gastmans@unesp.br

Keywords: isotopic fingerprints, regression models, hydrogeology

Large groundwater qualitative data have been most used for traditional hydro(geo)chemical studies, since their use for water management is often limited to quality purposes. Models based on Artificial Intelligence (AI) techniques represent a novel approach required for the interdisciplinary and multidimensional nature of Complex Water System (CWS). Machine Learning (ML) algorithms can improve traditional model predictions by processing large amounts of data, evaluating nonlinear correlations, quantifying the uncertainty propagation, and describing events at temporal and spatial scales.

Here, we combine more than 200 hydrochemistry and isotopic groundwater samples for understanding the groundwater mixing processes in a complex watershed located in São Paulo state, the Baixo Pardo Grande Basin, that encompass three mains Aquifer Systems: Bauru (BAS), Serra Geral (SGAS) and Guarani (GAS). A multivariate analysis was performed, accompanied by a statistically robust hydro(geo)chemical and hydrogeological conceptual model, to support the use of Machine Learning (ML) algorithms to predict synthetic isotope data and fill data gaps.

Hydrochemically, the mixture processes and the distinguishable depleted isotopic signature of the GAS demonstrate its isolated confined condition. Similar depleted signatures observed in the BAS and SGAS highlight the probable occurrence of groundwater mixing between the three aquifers. This mixture was associated with geomorphological features and intense groundwater exploitation in urban areas. Moreover, the use of synthetic isotope signatures significantly improved groundwater flow path knowledge and processes mapping. Despite the necessary investments in sampling and monitoring, the latter of which is an urgent worldwide demand for sustainable groundwater management, optimizing and calibrating an ML-based model can enhance the agility with which strategic groundwater knowledge is created to support rapid decision-making in CWS.

The authors would like to thank the Coordination of Superior Level Staff Improvement (CAPES) – Grant process 88887.637660/21, the São Paulo Research Foundation (FAPESP) – Grants processes 2022/14.849-7 and 2023/13.079-6, the National Council for Scientific and Technological Development (CNPq) – Research Productivity Grant 304796/2020-4, and the São Paulo State Fund for Water Resources (FEHIDRO), for funding the project 2019-BPG_COB-14, contract 66/2020.

LID 0610
Tracking urban waters in middle size municipality using stable isotopes: A study case in Southern Brazil

Didier Gastmans[1]*, Jheneffer Jacinto[1], Vinicius dos Santos[1], Filipe H. Alem[1], Gabriel F. M. Siqueira[1]

[1] São Paulo State University (UNESP), Environmental Studies Center (CEA), Rio Claro, Brazil
* didier.gastmans@unesp.br

Keywords: groundwater, water isotopes, urban hydrology, recharge

Groundwater supplies about half of Brazil's municipalities, becoming essential to urban water systems. However, population growth has increased demand while climate change have reduced its availability, scenario observed in Araraquara (SP-Brazil), city located in the south-central region of Brazil, with a population about 250,000 inhabitants, which has the Guarani, Bauru and Serra Geral aquifer systems as important sources of water. Supplied by surface and groundwater in a ratio of approximately 40-60%, the city currently faces critical exploitation conditions, with demand exceeding recharge capacity, making it necessary to adopt innovative strategies for monitoring and sustainable management of water resources.

In this context, ISOTRACK project seeks to investigate the effects of urbanization on the local hydrological cycle by assessing spatial and temporal variations in the isotopic ratios of different end-members (groundwater, river and tap water). The data will be integrated to generate meteoric lines, supported by a ten-year rainfall series, and the application of mixing models that allow the identification and quantification of processes such as recharge, contributions from different sources to rivers, as well as the evaluation of the contribution of these sources to the public supply network, supported by basic statistical and geostatistical analyses.

Given this, we seek to understand how urbanization alters the processes of recharge, storage and discharge of surface and groundwater, contributing to the development of local water management strategies based on isotopic tools. The incorporation of traceable spatial and temporal water monitoring tools, from the source to the end user and associated with demographic data, allows supply operators to improve the treatment and estimation of water mixing, in addition to strengthening the planning and conservation of urban water resources in the face of climate change.

This work was carried out with financial support from the Financiadora de Estudos e Projetos (FINEP) – Projeto ISOTRACK. The authors also express their gratitude to the Departamento Autônomo de Água e Esgotos de Araraquara (DAAE) for providing essential technical data and logistical and operational support during the water collection campaigns.

LID 0613
Assessment of water deficient areas considering natural and anthropogenic factors in the Geumgang River Basin, South Korea

Yongje Kim[1]*, Soo-Hyoung Lee[1]

[1] Korea Institute of Geoscience and Mineral Resources (KIGAM), Daejeon, South Korea
* yjkim@kigam.re.kr

Keywords: climate change, drought indices, water scarcity, natural and anthropogenic factors, sustainable water resources management

This study aims to evaluate water deficient areas in the Geumgang River Basin, South Korea by simultaneously considering both drought intensification driven by climate change and vulnerabilities in water supply infrastructure for sustainable water resources management. Natural factors were assessed using five representative drought indices (PDSI, SPI, MSWSI, SGI, and SMI) over the past 10 years, whereas anthropogenic factors were analyzed based on water distribution rate, leakage rate, population without access to water supply facilities, and water source characteristics. Both factors were each classified into four grades to evaluate and score the selection of water deficient areas. The integrated analyses revealed that northern and western regions of the basin, including Sejong, Cheonan, Boryeong, and Asan Cities, exhibited high frequency and severity of drought occurrence. Furthermore, Boeun, Yeongdong, Buyeo, and Yesan Counties were identified as vulnerable areas in terms of water supply due to their low water distribution rates and dependence on unstable water sources such as valley and surface waters. These findings indicate that water scarcity in the Geumgang River Basin results not only from climatic factors but also from deficiencies in water supply systems. Therefore, sustainable water management in the basin requires policy responses that address both climate-induced drought risk and infrastructural weaknesses. In particular, expanding groundwater utilization, improving piped water coverage, and enhancing leakage efficiency are identified as critical measures. The integrated evaluation framework presented in this study contributes to the systematic identification of water-deficient areas and provides essential baseline data for establishing water supply policies under future climate change scenarios.

LID 0614
Comparison between effective infiltration and outflow rate in carbonate aquifers of the Central Apennines

Alessia Di Giovanni[1], Alessandro Lacchini[2], Lucia Mastrorillo[2], Marco Petitta[2], Sergio Rusi[1]*

[1] Department of Science, "G. d'Annunzio" University of Chieti - Pescara, Italy
[2] Depaartment of Earth Sciences, "Sapienza" University of Rome, Italy
* sergio.rusi@unich.it

Keywords: water balance, carbonate aquifer, Central Apennine

In the central Apennines, the boundaries that define carbonate aquifers are predominantly governed by the tectonic relationships between carbonate complexes, permeable due to fracturing and karstification, and terrigenous complexes, mostly turbiditic, marly-clayey-arenaceous, with little or no permeability, and continental-lacustrine silty-clayey complexes, also generally with limited permeability. Not all the above conditions are clearly verified or verifiable, especially due to the complexity of the stratigraphic and tectonic relationships between the hydrogeological complexes with depth.

In this work, a comparison, on an annual/biennial basis, between the estimate of effective infiltration (input), including an estimate of the snow contribution, and the outflow by springs (output), was carried out, in order to verify the extension of about 14 carbonate aquifers identified on a geological and hydrogeological basis for a total outcrop area of 4000 km^2.

The output estimate is affected by approximations due to: - the presence of multi-seasonal water reserves within the aquifers; - intrinsic approximations in the flow measurements of springs and watercourses; - underestimation of outflowing flow rates due to the failure to monitor all springs, especially those with low flow rates, or overestimation of outflowing flow rates due to the re-infiltration of spring water into the aquifer itself.

The input estimate is affected by approximations in the measurements of rainfall and temperatures and in the calculations of the hydrological balance, as well as in the estimate and distribution of the infiltration coefficient.

Regardless of the uncertainties, the obtained results show a significant correspondence for many of the studied aquifers with some exceptions that required appropriate correction.

The study also allowed us to quantify a significant and objective parameter of the "productivity" of the aquifers such as the "unit inflow-outflow rate" expressed in l/s/km^2, which represents the recharge in l/s for each km^2 of aquifer outcrop, feeding spring discharge.

LID 0615
Karstic spring Morské oko in Tornaľa, Southern Slovakia: Recharge area problem

Peter Malík[1]*, Peter Bajtoš[1], Jaromír Švasta[1], Natália Bahnová[1]

[1] State geological institute of Dionyz Stur, Division of hydrogeology and geothermal resources, Bratislava, Slovakia
* peter.malik@geology.sk

The Morské oko karst spring is an unusual concentrated groundwater outlet from a flooded 38 m deep karst abyss near the town of Tornaľa in southern Slovakia. However, this karst phenomenon is located in the middle of Oligocene-Miocene siltstones with extremely low permeability, the thickness of which here reaches more than 100 m. Spring yield according to 21 expedition hydrometric yield measurements is stable 22.01 L/s in average (18.81 – 25.54 L/s with a median of 22.84 L/s). Water temperature at the measurement site ranged from 11.0 to 20.5 °C (however, due to the distance, it may not correspond to the temperature at the spring site), the specific electric conductivity was in the range of 790 – 827 µS/cm (median of 810 and average of 809 µS/cm). Chemical analysis shows a Ca-HCO_3-SO_4 water type (Ca^{2+}: 109 mg/l, Mg^{2+}: 33 mg/l, HCO_3^-: 340 mg/l, SO_4^{2-}: 172 mg/l), the chloride content was low with an increased sodium content (Na^+: 12.1 mg/l, Cl^-: 3.9 mg/l), no nitrates/ammonia ions were detected and the TDS was of 688.2 mg/l. Water chemistry shows close similarity to the karst springs from Triassic carbonates in the broader area around. The volumetric activity of tritium was below the limit of its determination (<0.5 TU), pointing to considerably long period (>50 years) of water retention. In the meantime, the ^{222}Rn volumetric activity was also extremely low (0.40 Bq/L). Previous opinions assumed the origin of the spring water from the karst plateaus area built up by Middle Triassic limestones NE of the spring, but deep drillings revealed the presence of a very thick Neogene pelitic filling of the basin between the plateaus and the spring site. However, recently conducted hydrogeological mapping in the nearby Neogene hills identified the presence of six swallow holes, capturing the entire runoff from the watershed with an area of 14.06 km^2. The average annual effective precipitation of 85 to 88 mm in this area would be able to fully saturate the above-mentioned yield. With the exception of extreme torrential rains, however, the absolute quantitative majority of this transfer should be supposed to occur between December and March, while in the summer months it is only minimal amounts that tend to be swallowed n the highest elevations, leaving the stream beds in the basin dry for most of the year.

LID 0616
Long-term water isotope datasets from Slovenia supporting isotope hydrologeological research

Polona Vreča[1]*, Klara Žagar[1], Jan Gačnik[1], Zoltán Kern[2,3], István Gábor Hatvani[2,3], Nina Rman[4]

[1] Jožef Stefan Institute, Department of Environmental Sciences, Ljubljana, Slovenia
[2] Institute for Geological and Geochemical Research, HUN-REN Research Centre for Astronomy and Earth Sciences, Budapest, Hungary
[3] CSFK, MTA Centre of Excellence, Budapest, Hungary
[4] Geological Survey of Slovenia, Ljubljana, Slovenia
* polona.vreca@ijs.si

Keywords: long-term monitoring, isotopes, Slovenia

Long-term isotope datasets provide essential insights into the functioning of the Earth's climate and hydrological systems. The stable isotopic composition of precipitation reflects integrated atmospheric processes such as moisture source conditions, transport pathways, condensation history, local temperature and precipitation dynamics. Continuous observations over extended periods enable the characterization of seasonal cycles, interannual variability, and long-term shifts in atmospheric circulation patterns. These records are fundamental for identifying emerging trends related to global warming. By linking modern precipitation isotope signals to climatic drivers, long-term datasets offer critical baseline for interpreting paleoclimate proxies derived from archives such as ice cores, speleothems, tree rings, and lake sediments.

In addition, precipitation isotope records contribute directly to hydrological research and water resource management. They enable the tracing of groundwater recharge, assessment of shifts in hydrological processes, and evaluation of changes due to natural and anthropogenic impact. As climate change alters atmospheric dynamics and hydrological extremes, long-term isotope datasets become increasingly valuable for detecting structural changes in regional water cycles and for supporting adaptation strategies.

This research aims to present a short overview of the isotope data sets available in the frame of the SLONIP (Slovenian Network of Isotopes in Precipitation, https://slonip.ijs.si/), their use in different applications and future plans for upgrading the SLONIP platform with new isotope information for the complete water cycle (e.g., precipitation, snow, surface, and groundwater). Upgraded data set will be relevant for several United Nations Sustainable Development Goals (SDGs) because it can directly support sustainable water management, food security, and climate action, particularly if datasets from neighbouring countries are merged.

Activities for this presentation were funded in last decade by the ARIS (Grants P1-0143, P1-0020, N1-0054, N1-0309), EU Partnership Agriculture of Data and IAEA (CRP F33024, F31006, TC RER7013, TC RER7017, TC NC7001).

LID 0617
How to generate power from deep geothermal resources for the growing electricity demand in the future?

Ladislaus Rybach[1], János Szanyi[2,3]*, Shad Abdelmoumen Serroune[4]

[1] ETH Zürich, Zürich, Switzerland
[2] Department of Geology, University of Szeged, Szeged, Hungary
[3] HUN-REN TKI Rybach Research Centre, Sopron, Hungary
[4] Nanogeios Laboratory, Casper, Wyoming United States
* szanyijani.szeged@gmail.com

Keywords: geothermal energy, electricity generation, heat carrier

The basic basis: heat can be converted to electricity. And the key fact: the interior of the Earth is full of heat; Planet Earth can even emit heat to the atmosphere, with 40 million MWth power constantly, without any cooling. This internal heat is sustainable; it is constantly generated by the decay of naturally radioactive elements. The higher the temperature, the better the heat → electricity conversion efficiency. Heat carriers must be submitted to hot depths, heated there and transported back to the surface for conversion.

Heat exchanging fracture surfaces are therefore absolutely essential. Enhanced Geothermal System (EGS) must have many million m^2 surfaces to generate a few MWe. These surfaces are usually established by hydraulic stimulation; the heat carrier is inserted down to get heated by heat extraction. Existing or newly created fracture surfaces are key to heat transfer at depth. Furthermore, closed-loop systems are also being considered nowadays for geothermal electricity generation as a brand-new technology.

In both cases, water remains the baseline heat carrier fluid due to its availability, cost and well-understood thermophysical properties. However, a major emerging theme is the exploration of alternative fluids, particularly supercritical CO_2 and CO_2-water mixtures. Case studies from Utah FORGE and other machine learning and physics-based forecasting work show that the decline in fluid temperature over time is strongly tied to flow rate, injection patterns and reservoir connectivity. In EGS, the working fluid is not merely a heat carrier. It actively controls fracture creation, geochemical evolution, reservoir sustainability, seismic behaviour and, ultimately, project viability. Therefore, fluid engineering is becoming as critical as drilling technology in next-generation geothermal systems.

LID 0618
Eco-hydrogeological assessment of nature-based solutions (nbs) for flood risk reduction in Thailand using isotope fingerprinting technique and SWAT-Modflow simulation

Aksara Putthividhya[1]*, **Sasin Jirasirirak**[2], Somkiat Prajamwong[3]

[1] Chulalongkorn University, Bangkok, Thailand
[2] Chulalongkorn University, Bangkok, Thailand
[3] Chulalongkorn University, Bangkok, Thailand
* dr.aksara.putthividhya@gmail.com

Keywords: NbS, stable isotope, flood risk, groundwater surface water dynamics

There is increasing global interest in employing NbS to help reduce risk to economies and society, including floods, droughts, and water pollution reduction that are likely to become worse under extreme climate. Flood retention system along Yom river and tributaries implemented by Thai government since 2017, consistently serves as a potential NbS to create “room for the rivers” and reduce disaster risks & impacts, however, evidence on the benefits of the approach is still quite limited. This study aims to provide and enhance evidence-based indicators for NbS monitoring and evaluation stemmed from available and reliable dynamic surface water-groundwater interactions through numerical simulation and isotope fingerprinting assessment. Performance-based indicators to evaluate the effectiveness of NbS are systematically developed in 1) hydrology-geology; 2) biodiversity; 3) ecological/environmental; and 4) socio-economic dimensions. SWAT-MODFLOW simulation is employed to demonstrate hydrological interactions between flood retention wetland overflowing river-aquifer based on hydraulics and hydrological principles. Calibrated model can simulate the seasonal river stages and groundwater levels both pre- and post-wetland installation, enhancing the benefits gained from flexible wetland morphology and subbasin-scaled functions as a flood-risk reduction measure. Shifting in local groundwater origin (61% from river water and 39% from rainfall) based on δD and $\delta 18O$ stable isotopic composition analyses suggests the direct enhancement of groundwater recharge from flood water retention scheme. d-excess analyses, beneficial to identify the relative contributions of the wet and dry seasonal sources to the groundwater recharge, indicate that groundwater sources are contributed from ~71.4% wet and ~28.6% dry seasonal sources.

LID 0619
Conceptual uncertainty: The elephant in the room

Saskia Noorduijn[1], Luk Peeters[2], **Okke Batelaan**[3]*

[1] CSIRO, Adelaide, Australia
[2] VITO, Mol, Belgium
[3] National Centre for Groundwater Research and Training, Flinders University, Adelaide, Australia
* okke.batelaan@flinders.edu.au

Keywords: conceptual uncertainty, assumptions, reproducibility

Conceptual uncertainty is widely recognised as a major, if not the largest, source of uncertainty in hydrogeology and groundwater modelling. It is, however, rarely systematically addressed in groundwater studies.

In the pursuit of “accurately” predicting system responses, hydrogeological understanding is simplified into conceptual models that represent our best interpretation of available knowledge, data, and experience for a given project objective. This requires the use of assumptions and simplifications, which are essential for reducing system complexity and extrapolating data into unmonitored areas or predicting unmeasurable quantities. These choices are made to support the project’s objectives by capturing all the pertinent processes relevant to the investigation. Consequently, the process of developing a conceptual model provides insights into the areas of greatest uncertainty. However, this requires that these choices and assumptions be comprehensively documented, which rarely happens, and little guidance is provided on how best to achieve this.

We outline an approach, using water table mapping as an example, to increase transparency and greatly enhance the reproducibility of subsequent investigations. This highlights the role of critical thinking and assumption hunting in assessing the qualitative uncertainty of any conceptual model. By doing so, it is possible to identify, justify, and, if necessary, correct for any biases and assumptions. The benefits of documenting assumptions and simplifications are applicable to a wide range of environmental investigations.

LID 0620
Numerical water balance and groundwater modeling as part of regional MAR feasibility assessment in Dollow, Somalia

Falk Händel[1]*, Michael Bliss Singer[2,3], Edisson Andrés Quichimbo[2,3], Catalin Stefan[1], Fritz Kalwa[1], Jay Matta[4], Lavuun Verstraete[5]

[1] Technische Universität Dresden, Institute of Groundwater Management, Research Group INOWAS, Dresden, Germany
[2] ERIMOS, LTD, United Kingdom
[3] Cardiff University, Cardiff, United Kingdom
[4] UNICEF Wash Innovation Hub, Copenhagen, Denmark
[5] UNICEF Global WASH Practice, Nairobi Centre of Excellence, Kenya
* falk.haendel1@tu-dresden.de

Keywords: water balance modelling, groundwater modelling, data scarcity, humanitarian context

Managed Aquifer Recharge (MAR) is a valuable tool for combating water scarcity, particularly in cases of temporal imbalance. MAR is now widely used not only to support drinking water supply, but also other aspects related to restoration of the balance between water supply and demand. However, thorough investigation and planning are essential for achieving the desired positive impact.

The first step is to assess the water balance of the relevant region, taking into account the time scales over which water scarcity needs to be buffered. This requires a thorough understanding of runoff generation, the resulting streamflow dynamics and their two-way interactions with groundwater systems. Such analysis is particularly important in regions, where local recharge from precipitation is limited, but there may be high contributions from elsewhere in the basin.

Within the R-MAR project, supported by UNICEF, the potential of MAR is being assessed for a section of the alluvial aquifer within the Dawa river catchment in Dollow, Somalia. The aquifer is used for both drinking water and small-scale farming, supporting local communities and internally displaced populations. Current water production is planned to be expanded, which may increase the pressure on existing groundwater resources. The MAR buffering potential is evaluated through an integrated methodological approach, including groundwater balance calculations, surface flow modelling of the Dawa river, and groundwater modelling. In addition, localized modelling is conducted to assess the influence of underlying saline groundwater on newly drilled wells.

The results demonstrate, on the one hand, the necessity of the integrated approach to reliably assess the feasibility and effectiveness of MAR. On the other hand, they also highlight the practical limitations associated with conducting field investigations in regions requiring humanitarian support, where resource constrains restrict data availability and monitoring capacity.

LID 0621
Microplastics in groundwater: Exploring the risk perception of domestic water users in Italy

Barbara Zambelli[1]*, Paul Hynds[2], Viviana Re[1]

[1] Earth Sciences Department, University of Pisa, Via Santa Maria 53, 56126 Pisa, Italy
[2] Sustainability and Health Research Hub, Technological University Dublin, D07 EWV4 Dublin, Ireland
* b.zambelliazevedo@studenti.unipi.it

Keywords: cross-sectional survey, microplastic pollution, KAP (knowledge, attitude, practice)

Groundwater represents a particularly vulnerable yet overlooked environmental compartment for microplastics (MPs) pollution. In Italy, where groundwater constitutes a substantial proportion of national drinking water supplies, protection of these resources is critical for public health security. Despite this reliance, MPs in groundwater remain largely invisible to the public, both literally, given their size, and figuratively, as groundwater (and thus groundwater MPs) presence and movement remains largely misunderstood among the general public. The potential consequences of MP contamination extend beyond ecological impacts, with emerging evidence suggesting risks to human health through ingestion and inhalation, fuelling extensive media coverage. Accordingly, MPs in groundwater represent an emerging and poorly understood threat. This study investigated Italian residents' risk perceptions regarding (i) drinking water quality, (ii) environmental MPs contamination, and (iii) MPs pollution of groundwater, and (iv) how socio-demographic factors and KAP (knowledge, attitude, and practice) influence these perceptions. An online questionnaire was administered across Italy over 80 days, yielding 1,036 valid responses. The survey employed a hierarchical assessment framework, progressing from general drinking water concerns to specific groundwater MPs risks. Results revealed a gradient in levels of concern: participants expressed lowest concern about drinking water quality, followed by MPs groundwater contamination risks towards human health, with substantially higher concern for MPs' broader human health and environmental impacts. “Knowledge” and “attitude” demonstrated significant positive correlations with risk perception, while “practice” showed very weak associations. Findings suggest that age, education, and gender interact with KAP elements to shape risk perception and could be used to inform targeted risk communication strategies.

LID 0622
Hybrid model for enhanced groundwater level estimation

Jun Liu[1]*, Raphael J. M. Schneider [1], Lars Torborg [1], Julian Koch[1]

[1] Department of Hydrology, Geological Survey of Denmark and Greenland, Copenhagen, Denmark
* juliu@geus.dk

Keywords: groundwater level, hybrid machine learning, hydrological modelling, climate change

For water resources assessments as well as to enhance understanding of hydrological extremes, the groundwater level (GWL) is a critical indicator. However, the knowledge basis to understand GWL responses to climate change and anthropogenic pressures is limited. This is due to limited data availability provided by existing monitoring networks, and physically based hydrological models (PBMs) that are computationally demanding when applied over large spatial domains and long temporal periods. Machine learning (ML) provides a promising alternative for GWL estimation, and previous studies have demonstrated its efficiency and predictive capability in terms of accuracy and spatial resolution.

We integrate ML with an existing PBM, the National Hydrological Model of Denmark (DK-model), to develop a hybrid model for multi-scale GWL estimation. The model is first trained to predict PBM residuals using covariates at a spatial resolution of 500 m, consistent with the PBM resolution. Cross-validation results show that the hybrid model reduces PBM prediction errors by approximately 1.5 m. The trained 500 m model is then applied for GWL estimation at enhanced spatial resolution (e.g., 100 m and 10 m), achieving higher accuracy compared to simulations from a 100 m implementation of the DK-model while significantly improving computational efficiency. The hybrid model also demonstrates strong potential at local scales when high-resolution covariates (up to 10 m) are available. Across several local case studies, the hybrid model captures GWL variability at 10 m resolution and provides useful information to elucidate groundwater flooding risk. Moreover, the model is computationally efficient and can be readily applied to PBM based GWL projections under future climate.

This study highlights the potential of integrating ML with PBMs to produce high-resolution, spatially continuous GWL estimates at high accuracy. The proposed methodology is transferable and can be applied to other regions.

LID 0623
Digital twins for groundwater resource management? – A case study of the Patamäki esker aquifer

Anna Autio[1]*, Pekka M. Rossi[1]

[1] Water, Energy and Environmental Engineering, University of Oulu, Finland
* anna.autio@oulu.fi

Digital twins are virtual counterparts of physical systems, maintained through continuous, bidirectional information exchange that enables real-time system assessment and improved forecasting. Although numerous Digital Twins have begun to emerge in surface-water management, the Digital Twin concept remains underexplored in groundwater-resource applications. This is attributed mainly to the slow dynamics governing many large aquifer systems, for which traditional what-if scenario-based modelling is adequate to address many management issues. In Finland, however, groundwater is mainly extracted from small surficial esker and glaciofluvial aquifers that react quickly to changes in weather, abstraction, and contamination. This sensitivity indicates that Digital Twin solutions could offer notable benefits for groundwater abstraction management in the context of the water supply systems. In this study, we assess the potential of a Digital Twin to support groundwater abstraction management in the Patamäki esker aquifer, which supplies drinking water to the mid-sized industrial town of Kokkola. We present the conceptual design of the Digital Twin and the initial results from the groundwater model that forms its foundation, developed using the modular open-source modelling framework MODFLOW 6. This case study provides a first step towards real-time, model-driven groundwater management in Finnish esker aquifers.

The Digital Twin development work is conducted under two interconnected projects: the Digital Waters (https://digitalwaters.fi/) and Safe Water For All (WaterFall, https://turvallistavetta.fi/en/).

LID 0624
Groundwater flooding in urban karst during extreme rainfall: The 2026 Grazalema event (SW Spain)

Fernando Ruiz-Bermudo[1], José Antonio Serrano-Reina[1], Claus Kohfahl[1], Sergio Martos-Rosillo[2], Jorge Jiménez-Sánchez[2], Crisanto Martín-Montañés[2], **Antonio González-Ramón**[2]*, Ana Ruiz-Constán[2], José Manuel Gómez-Fontalva[1], Guadalupe Bru-Cruz[3], Antonio Pedrera[1], Károly Hidas[2]

[1] Instituto Geológico y Minero de España (IGME-CSIC), Seville, Spain
[2] Instituto Geológico y Minero de España (IGME-CSIC), Granada, Spain
[3] Instituto Geológico y Minero de España (IGME-CSIC), Tres Cantos, Spain
* antonio.gonzalez@igme.es

Keywords: karst aquifer, extreme rainfall, water-related risk, inundation, Grazalema, Spain

Extreme precipitation events increasingly expose the vulnerability of urban areas located on karst aquifers. In February 2026, the village of Grazalema (Cádiz, SW Spain) experienced an emergency flooding episode affecting multiple houses after exceptional rainfall (666 mm in 48 h, 1047 mm in 6 days and 2245 mm in 21 consecutive days). The village lies within the recharge sector of the Sierra del Endrinal karst aquifer, where groundwater normally drains through temporary springs such as La Olla estavelle and the Tajos de Grazalema outlets. Some studies have concluded that there must be hidden discharges, but currently it is unknown where they occur. During the event, the piezometric level rose about 300 m in a short period of time, activating all known outlets.

Hydrogeological field surveys and preliminary remote sensing analyses indicate that the flooding was not caused by a regional rise of the water table. Instead, rainfall intensity exceeded the infiltration capacity of the karst system, producing saturation of the epikarst beneath the urban area. Water then flowed laterally as subsurface runoff, preferentially using anthropogenic structures (trenches, drainage networks and foundations) and emerging in topographic low areas of the village. The localized distribution of water emergence and the absence of widespread inundation confirm that the general piezometric level did not reach urban elevation. Concurrently, activation of temporary springs dissipated hydraulic pressure within the aquifer, and all abnormal discharges ceased once rainfall decreased, returning the system to ordinary hydrodynamic conditions.

This episode highlights the vulnerability of urbanized zones in karst terrains to short-duration extreme rainfall, a challenge that is intensifying under emerging hydroclimatic extremes. Understanding rapid recharge dynamics and shallow subsurface flow in urbanized karst is thus essential for risk management and climate-change adaptation.

LID 0627
Evidence for variable sources of Na-Cl in groundwaters of Northern Switzerland

Joshua P. Richards[1]*, Daniela B. Van Den Heuvel[1], Christoph Wanner[1], Florentin Ladner[2], Joël Morgenthaler[3], Johannes Pietsch[3]

[1] Rock-Water Interaction Group - Institute for Geology - University of Bern, Bern, Switzerland
[2] Geotest AG, Basel, Switzerland
[3] Schweizer Salinen AG, Basel, Switzerland
* joshua.richards@unibe.ch

Keywords: upwelling, salinity, Gas Equilibrium Membrane Inlet Mass Spectroscopy

Elevated salinity in the Schinznach Formation aquifer (Upper Muschelkalk aquifer) has been measured in the Muttenz-Pratteln area of Northern Switzerland. This salinity likely originates from deeper formations, and may derive from (1) natural subrosion of the underlying evaporites in the Zeglingen Formation, (2) leakage due to solution mining operations in the area, or (3) the upflow of deeper basement-derived fluids.

Saline water migration in this setting is likely enhanced by coupled processes, including fault-controlled basement upflow, a long history of solution mining, and large-scale groundwater abstraction combined with artificial recharge, promoting mixing with deeper brines. Differentiating and quantifying a basement-derived component is critical for understanding regional flow systems and disentangling natural from anthropogenic drivers of contamination.

While natural tracers such as Br/Cl ratios can confirm halite dissolution in the underlying evaporitic formation, they cannot independently distinguish between shallow subrosion and deeper basement fluids that acquire an evaporitic signature during upward migration through said evaporites, complicating source attribution. Elevated Li and radiogenic ^{4}He concentrations are diagnostic of groundwaters originating from the basement, due to interaction with crystalline rocks and prolonged residence times, and therefore can be used to trace such a contribution.

We combine the collection of trace elements via conventional groundwater sampling methods with in-field dissolved gas quantification, using Gas Equilibrium Membrane Inlet Mass Spectroscopy (GE-MIMS). Targeted measurements of Li, Br, and ^{4}He are used to fingerprint geochemical signatures indicative of a basement component in wells screened within the Upper Muschelkalk aquifer. The integration of these multiple tracers identifies locations where a deep-fluid contribution is probable and supports fault-controlled upflow as a plausible mechanism in the study area.

LID 0628
Assessing the influence of a graben structure on the migration of pollutants from mining and industrial waste facilities

Paul Joël Havemann Lourens[1]*, Josepha Simone Doris Renata Zielke-Olivier[1], Petrus Daniel Vermeulen[1]

[1] Institute for Groundwater Studies – University of the Free State, Bloemfontein, South Africa
* lourenspjh@ufs.ac.za

Keywords: graben, faults, pollution migration, waste facility

Geological structures such as graben structures can influence both direction and rate of groundwater flow and the migration of pollutants. These structures can act as preferred pathways for groundwater flow and pollution migration, or it can as a barrier, depending on the specific characteristics of the structures and associated lithology. The aim of the investigation was to determine the pollution distribution along a graben structure that extends through a mining and industrial facility to determine how the structure influence the migration of pollutants from the associated waste facilities and the identification of potential risks to groundwater resources.

The investigation involved a comprehensive desktop review of existing data supplemented by a geophysical investigation along the graben structure to identify suitable locations for drilling additional boreholes. This was followed by the collection of primary field data through the drilling of boreholes, complemented by a series of aquifer tests, down-the-hole chemical profiling, and isotope analysis. The data was used to develop a conceptual model of the groundwater system, outlining the key processes and interactions within the groundwater system.

The investigation indicated that the faults associated with the graben structure act as conduits for the migration of pollutants from the different waste facilities. The groundwater flow direction within the graben structure is governed by the prevailing groundwater flow system, where pollutants in the western section of the graben flows towards the local rivers valleys in the west, and pollutants located in the eastern section flow towards the local rivers in the east.

In essence, understanding the unique geological and hydrogeological characteristics associated with these structures, allows managers of these waste facilities to implement more robust mitigation and/or pollution control strategies.

LID 0629
Is managed aquifer recharge a nature-based solution? A comparative assessment of MAR methods using NbS criteria

Andrei Del Villar[1], Ádám Tóth[1]*, Niels Hartog[2]

[1] Copernicus Institute of Sustainable Development, Utrecht University, The Netherlands
[2] KWR Water Research Institute, Nieuwegein, The Netherlands
* a.z.toth@uu.nl

Keywords: Managed Aquifer Recharge (MAR), Nature-based Solutions (NbS), water management

Managed Aquifer Recharge (MAR) is increasingly framed as a Nature-based Solution (NbS) in water policy and climate adaptation discourse. However, the designation of MAR as an NbS is often adopted strategically, without systematic evaluation of the extent to which MAR interventions genuinely align with core NbS principles. Given the conceptual ambiguity surrounding NbS, this study critically examines whether and to what degree different MAR methods can substantively be considered nature-based. The research aims to assess the “nature-basedness” of MAR by applying a structured analytical framework grounded in harmonized NbS criteria.

Eight internationally documented MAR schemes representing diverse infiltration methods were evaluated using four core NbS criteria: reliance on natural processes, contribution to societal challenges, provision of multiple environmental, social, and economic benefits, and effectiveness and efficiency in governance and implementation. Results showed that all schemes fundamentally rely on natural subsurface processes and address water-related societal challenges, particularly water security and climate resilience. Effectiveness and economic feasibility were consistently demonstrated. However, variation emerged in multifunctionality. Full alignment across environmental, social, and economic domains was not consistently achieved; however, all cases demonstrated benefits in at least two of the three dimensions. While provisioning and regulating services were common, explicit biodiversity enhancement was documented in only a minority of schemes.

This study demonstrates that MAR can satisfy essential NbS criteria. Yet the diversity observed across methods underscores that nature-basedness is not a binary condition but a matter of degree. Framing interventions strictly as either “nature-based” or not may obscure the hybrid and context-dependent character of many water management solutions. A more flexible and critically reflective application of the NbS concept may therefore enhance, rather than constrain, sustainable innovation.

LID 0632
Groundwater export and import units mediate Pantanal Wetland hydrological fluxes

Bruno Valdambrini[1]*, Alexandra Richey Mclarty[2], André Simões Ballarin[3], Carolina Stager Quaggio[1], Mario Assine[1], Didier Gastmans[1]

[1] São Paulo State University (UNESP), Rio Claro-SP, Brazil
[2] Washington State University (WSU), Pullman-WA, United States
[3] University of São Paulo (USP), São Carlos-SP, Brazil
* bruno.valdambrini@unesp.br

Keywords: intercatchment groundwater flow, GRACE, open water balance

The intensification of weather variability in this century has affected agriculture, industry, and society. Examples include below-normal rainy seasons and heat and cold occurrences decoupled from expected seasonality, with impacts on productivity and daily life. In this context, it is crucial to understand hydrological cycle responses and the capacity of subsurface reservoirs to sustain surface systems under reduced fluvial inputs.

The Pantanal is the largest tropical wetland on Earth, a depressed plain of approximately 195,000 km², integrated into a regional hydrological system in which rivers flow from higher-elevation areas toward the Plain, forming the Upper Paraguay River Basin, with approximately 360,000 km². Despite its ecological relevance, no monitored wells exist within the Plain, which limits direct observation of piezometric levels and the role of groundwater flows. Consequently, a central question remains unresolved: what is the importance of groundwater in sustaining Pantanal surface waters, and is there a functional connection, in terms of subsurface flow, between headwater regions and the Plain?

To address this question, we compartmentalize the basin into Hydrological Response Zones (HRZs) based on the hydrographic network and streamflow monitoring points, defining functionally connected units. For each HRZ, we apply an open water balance: ΔS/Δt (TWSC–GRACE) = P + Q_{in} – ET – Q_{out} – Q_g. In this formulation, Q_g represents lateral groundwater fluxes that does not emerge at the outlet (Q_{out}). The method enables the identification of groundwater-exporting and groundwater-importing HRZs and provides an operational framework for Intercatchment Groundwater Flow (IGF) quantification, with potential application to intra-basin leakage.

Results show that headwater areas control flow persistence in the Pantanal through gradual groundwater release. The Plain responds with a 4–8 month lag, demonstrating regional groundwater–surface water coupling.

Acknowledgements to São Paulo Research Foundation - FAPESP (Grant No. 23/10474-1 and Grant No. 24/03093-4), São Paulo State University – UNESP (Universidade Estadual Paulista) and Washington State University – WSU, for support and hosting.

LID 0633
Separating climate and anthropogenic controls on groundwater-level dynamics using an ARIMAX framework

Mahmoud M. Kazem[1,2]*, Tamás Buday[1]

[1] Department of Geology and Mineralogy, University of Debrecen, Hungary,
[2] Water Research Center, Red Sea University, Sudan
* mahkazem99@mailbox.unideb.hu

Keywords: ARIMAX modeling, groundwater level dynamics, climate–anthropogenic separation

Understanding groundwater level responses to climatic and anthropogenic influences is key to optimal management of alluvial aquifers in data-limited regions. This study surveys groundwater head fluctuations in the Arbaat alluvial aquifer in eastern Sudan in relation to rainfall variability, dam operations, and unreported pumping. Monthly observations from two monitoring wells (W01 and W02) spanning 2001–2025 (n = 299) were analyzed. To highlight time dynamics, heads were converted to first differences.

Rainfall influence was modeled using a distributed-lag exponential memory function (K = 12 months), with response time (τ) determined via AICc grid search. Two intervention variables captured major structural changes: dam construction in 2002 and dam collapse in August 2024. Due to the lack of pumping records, a proxy variable was derived by detecting sustained drawdowns during dry periods through consecutive negative ΔHead values smoothed with a short rolling window.

The final ARIMAX models showed moderate explanatory power (W01: τ = 2 months, R^2 = 0.34, RMSE = 0.26 m/month; W02: τ = 3 months, R^2 = 0.35, RMSE = 0.21 m/month). Results show a rapid rainfall response within 2–3 months, while anthropogenic influences and storage processes remain significant. Residual diagnostics (Durbin–Watson ≈ 2; Ljung–Box p > 0.05 at 12 and 24 lags) confirmed model adequacy. This framework provides a practical method for distinguishing climatic and anthropogenic controls on groundwater dynamics using only rainfall and head data, supporting monitoring and management in arid alluvial systems.

LID 0636
Assessment of groundwater recharge using multi-disciplinary approach, in a data-scarce basin

Adwoba Edjah[1]*, Enoch Sakyi[2], Barbara Stenni[3], Giuliano Dreossi[4], Anthony Ewusi[5], Frederick Sam[6], Ernest Kofi Amankwa Afrifa[1]

[1] Department of Environmental Sciences, University of Cape Coast, Ghana
[2] Department of Statistics and Actuarial Science, University of Ghana, Legon, Ghana
[3] Department of Environmental Sciences, Informatics and Statistics, CA' Foscari University of Venice, Venice, Italy
[4] Institute for the Dynamics of Environmental Processes, National Research Council of Italy, Milan, Italy
[5] Geological Engineering Department, University of Mines and Technology, Tarkwa, Ghana
[6] Department of Physics, University of Cape Coast, Ghana
* aedjah2@yahoo.co.uk

Groundwater recharge is crucial for sustainable water resources management, especially in data-scarce basins. This study investigates groundwater recharge sources and mechanisms in Ghana's Tano River Basin, employing a multi-disciplinary approach that integrates hydrochemical analysis, statistical tools, environmental isotopes, and mixing models. Results show that groundwater recharge primarily occurs from meteoric water (rainwater) and surface water (rivers, streams, and lagoons), with rainwater contributing 60-80% to groundwater recharge. The study identifies Ca^{2+} and SO_4^{2-} as the dominant cation and anion, respectively, and reveals oxidation of sulfide minerals (pyrite) from the underlying geology, anthropogenic sources, and surface water mixing as controlling mechanisms. These findings are agreed by results from Piper diagrams, saturation indices, and bivariate plots. The study's outcomes provide valuable insights for sustainable groundwater management practices in the Tano River Basin, contributing to the achievement of SDG 6 for sustainable water resources management.

LID 0637
Risks of groundwater resources caused by far field great earthquake on Jeju volcanic island, South Korea

Soo-Hyoung Lee[1]*, Yongje Kim[1], Beom-Seok Hyun[2], In-Jong Koh[2]

[1] Korea Institute of Geoscience and Mineral Resources (KIGAM), Daejeon, South Korea
[2] JeJu Research Institute, Jeju-do, South Korea
* rbagio@kigam.re.kr

Keywords: M8.8 Kamchatka earthquake, groundwater resources, volcanic island, seismic waves, groundwater temperature and electrical conductivity

Despite advances, accurate prediction of earthquake events remains challenging with large seismic events continuing to occur worldwide. A magnitude 8.8 earthquake occurred on the Kamchatka Peninsula, Russia at 08:24:52 local time (UTC: 29 July 2025, 23:24:52) on 30 July 2025. Tsunami warnings were issued across the Pacific basin. This study reports groundwater responses in volcanic-rock aquifers on Jeju Island, South Korea due to seismic impacts from the 2025 Kamchatka M8.8 earthquake ~3,400 km away. Variations in groundwater level, temperature, and EC were detected, demonstrating that even distant seismic waves can pose significant risks to groundwater resources in volcanic island aquifer systems. Seismic waves propagated approximately 3,400 km and induced measurable responses in groundwater across Jeju volcanic island, South Korea. Monitoring revealed variations in groundwater level, temperature, and electrical conductivity (EC). Groundwater levels exhibited both oscillatory fluctuations synchronized with seismic waves and sustained rising or falling trends, with similar patterns in temperature and EC. Drawdown at high-elevation area indicates groundwater discharge, whereas shifts in temperature and EC suggest groundwater inflow and mixing. Jeju Island relies entirely on groundwater resources, and thus these hydrological disturbances highlight potential risks to water resources posed by distant seismic events.

LID 0639
Explainable assessment of lithium potential in geothermal reservoirs using AI and decision tree models

Konstantinos Loupos[1]*, Kalliopi Savva[1], Nikolaos Episkopos[1], Efstathios Antoniou[1], Serhat Tonkul[2], Alper Baba[2], Katrin Kieling[3]

[1] INLECOM INNOVATION, Athens, Greece
[2] Izmir Institute of Technology, Izmir, Turkey
[3] GFZ Helmholtz-Zentrum Fur Geoforschung, Germany
* konstantinos.loupos@inlecomsystems.com

Keywords: AI-driven lithium prediction, explainable machine learning (XAI), critical raw materials supply resilience

The accelerating energy and digital transitions dramatically increase the demand for Critical Raw Materials (CRMs) essential to European industry. A largely underexploited opportunity lies in geothermal reservoirs, where circulating fluids naturally accumulate strategic metals and minerals. CRM-GEOTHERMAL advances an integrated approach to co-produce geothermal heat and CRMs, leveraging subsurface resources with minimal additional environmental footprint. By coupling sustainable mineral extraction with clean geothermal energy production, the project aims to reduce land use, lower lifecycle impacts, improve economic viability, and strengthen EU strategic autonomy through domestic CRM supply.

To accelerate the deployment of integrated geothermal-heat and CRM-extraction projects, CRM-GEOTHERMAL has established the first Europe-wide database mapping raw-material occurrence in geothermal fluids across a broad spectrum of Critical Raw Materials. Building on this foundation, INLECOM INNOVATION (Greece) with the support of the Izmir Institute of Technology (Turkey) and the GFZ Helmholtz Centre for Geosciences (Germany), has developed an AI-driven Lithium Prediction Tool designed to identify complex relationships between geochemical signatures and lithium concentrations in geothermal waters. The tool couples geological domain knowledge with state-of-the-art Machine Learning pipelines, with a core focus on producing accurate, reliable and interpretable predictions. A Decision Tree regression model was selected as the optimal approach, markedly improving the precision of lithium concentration estimates across heterogeneous geothermal settings. To ensure full transparency and interpretability, the system incorporates Explainable AI techniques, notably Shapley value analysis, which elucidates the contribution of individual geochemical variables to the model's predictions. This provides operators and researchers with a scientifically grounded, interpretable framework for assessing lithium potential in geothermal resources, supporting faster and more informed project development across Europe.

LID 0640
Hydrogeological characterisation and conceptualisation of groundwater flow in the Quaternary Catchment X11B, Carolina area, Mpumalanga Province of South Africa

Gladness Mohale[1]*, Tebogo Makono[1], Mafeto Malatji[1], Khomotso Sekiba[1], Godfrey Madzivire[1]

[1] Council for Geoscience, Silverton, Pretoria, South Africa
* gmohale@geoscience.org.za

Keywords: acid mine drainage, groundwater flow, legacy mine, passive treatment system

Quaternary Catchment X11B in Mpumalanga Province hosts a vast number of active and legacy coal mines. The widespread occurrence of acid mine drainage (AMD) seepages from the upstream legacy coal mines affects water resource quality and ecosystem health downstream. Flooded underground coal workings and seepages originating from backfilled open cast operations were identified as major AMD pollution sources. In 2012, the discharge of AMD into the freshwater resources resulted in 7-month long water shortages for the people of Carolina. To mitigate these impacts, a pilot passive treatment system is under construction to treat the discharge of mine-impacted groundwater seepages from a legacy mine. However, there is a lack of hydrogeological understanding on the systems that governs the flow, quality and quantity of the decanting acid mine water in the Carolina area. The primary objective of this study is to evaluate the groundwater flow dynamics, particularly in relation to the operation and management of an onsite passive treatment system. Available geological, hydrogeological, hydrochemical and geophysical datasets were used to characterise the aquifer and groundwater flow dynamics in the area. The use of ArcPro, Surfer 10, Strata 5 and Corel draw 5 software's allowed conceptualisation of the hydrogeological system with specific reference to the aquifer structure, water table depth, and main flow direction. The conceptual model indicates that the study area is characterised by an 8 m thick soil layer with some clay pockets, forming a perched water table above the low yielding (<0.5 L/s) weathered aquifer of approximately 20 m thickness. The fractured aquifer is characterised by secondary structures such as faults, joints, and cracks, which have a higher yielding capacity and thickness of <2 L/s and 150 m, respectively. Groundwater level from boreholes in the area ranges between 1.04 to 30 m below ground level (bgl) with an average of 10 m bgl. The hydraulic head distribution indicates that the regional movement of groundwater follows topography, with its flow direction largely mimicking the surface water flows from the south to the north. The findings suggest that the movement of mine polluted groundwater (contaminant plumes) within the shallow aquifer is lateral, primarily influenced by the topography of the impermeable shale layer and the hydraulic gradient.

LID 0644
A validation and comparison study of stable isotope based on mean catchment altitude estimations of springs in the Lebanon Mountains

Paul Koeniger[1]*, Manal Wannous[1], Frank Wagner[1], Sara Vassolo[1]

[1] BGR Federal Insitute for Geosciences and Natural Resources, Hannover, Germany
* paul.koeniger@bgr.de

Keywords: stable isotopes, altitude effect, Lebanon

Stable isotopes of water are known to provide information on mean altitudes of spring recharge areas, which is an important parameter for groundwater resources management especially in karstic environments. Very often, a lack or too short interval of precipitation input data limits the possibility for an appropriate estimation of mean catchment altitudes. In Lebanon, a characterization of precipitation input was possible during two technical cooperation projects; a first project between 2012 to 2014 and a second that is ongoing since 2025. Precipitation samples during the first phase were collected at six stations at varying altitudes (88 amount-weighted monthly samples) and in the snow layer during winter months. A local meteoric water line for the Jeita spring catchment was characterized as $\delta^2H = 6.04 * \delta^{18}O + 8.45$ ($R^2 = 0.92$) for this 2-year observation period. Groundwater samples were continuously collected from six springs (Jeita, Kashkoush, Labbane, Assal, Afqa, and Rouaiss) [1].

During the actual project a precipitation sampler was installed beginning of 2025 (Laqlouq), which was able to collect rain water for 2025. Further seven rainfall sampler have been installed in 2026. Groundwater samples (246 in total) where collected until November 2025 from the springs Khadira (n=40, $\delta^{18}O$=-6.66 ± 0.10 ‰, δ^2H=-31.4 ± 0.6 ‰, d=22 ‰), Mathane (n=28, $\delta^{18}O$=-6.82 ± 0.03 ‰, δ^2H=-33.5 ± 1.5 ‰, d=22 ‰), Madiq (n=41, $\delta^{18}O$=-7.26 ± 0.14 ‰, δ^2H=-35.5 ± 0.5 ‰, d=23 ‰) Ain el Jaouze (n=20, $\delta^{18}O$=-7.31 ± 0.04 ‰, δ^2H=-35.1 ± 0.1 ‰, d=23 ‰), Rouaiss (n=21, $\delta^{18}O$=-8.16 ± 0.20 ‰, δ^2H=-43.0 ± 1.1 ‰, d=22 ‰) and Afqua (n=23, $\delta^{18}O$=-8.19 ± 0.21 ‰, δ^2H=-43.5 ± 1.1 ‰, d=22 ‰). Additional samples were taken from two wells located close to Madiq spring (well #5: n=36, $\delta^{18}O$=-7.29 ± 0.09 ‰, δ^2H=-35.5 ± 0.4 ‰, d=23 ‰ and well #6: n=37, $\delta^{18}O$=-7.28 ± 0.12‰, δ^2H=-35.6 ± 0.5 ‰, d=23 ‰). The sampling campaigns for precipitation and springs is ongoing in 2026. Based on this dataset the altitude effect of two neigbouring watersheds will be compared and discussed. No variation in the isotopic composition of Afqa and Rouiaiss has been observed between 2012-2014 and 2025. This study shows that variability (space and time, snow cover, and rainfall) has direct impacts on mean altitude estimates of spring catchments. A more profound interpretation of spring response to rainfall for additional three local springs in the Lebanon Mountains is possible in comparison to two springs that were also investigated within the first project phase in 2014.

Reference:

[1] Koeniger P., Margane A., Abi-Rizk J., Himmelsbach T. (2016): Stable isotope-based mean catchment altitudes of springs in the Lebanon Mountains. Hydrological Processes 31:3708-3718, DOI: 10.1002/hyp.11291.

LID 0647
Ancient water practices in the arid environment of Cabo de Gata-Níjar Natural Park (SE Spain). An example of resilience in the context of global change

Javier Buera Cuerva[1]*, Matías Mudarra Martínez[1], Bartolomé Andreo Navarro[1]

[1] Department of Ecology and Geology and Center of Hydrogeology of the University of Málaga, Málaga, Spain
* javierbc@uma.es

Keywords: heritage, groundwater, resilience

The Cabo de Gata-Níjar Natural Park -CG-NNP- (380 km2 in Southern Spain) is the driest region in Europe, with rainfall less than 250 mm/year. Runoff water occasionally generated by torrential events results in low infiltration due to the low permeability of the volcanic rock substratum. The aim of this work is to highlight the traditional use of water in CG-NNP, and the related hydraulic heritage, as an example of resilience in the context of global change. To this end, a mapping of cisterns, waterwheels, wells, springs and their associated hydraulic structures has been carried out and analysed.

Cisterns (112 in total) were traditionally used to collect and store pluvial and runoff water, but with no guaranties as it depended of heavy storm period. Downstream, waterwheels (57) built since the 17th century, captured groundwater from detrital deposits of reduced extension. Even low discharge rate (less than 0.5 l/s) of springs (21) was collected and used for irrigation and supply purposes. Water-use practices and the related hydraulic heritage, in addition to the agricultural techniques, have marked the cultural identity of the region. From this perspective, water management played an important role in society and became part of cultural traditions, thereby reinforcing resilience (community-based solution).

The expansion of boreholes (in the mid-20th century) and new resources from a desalination plant since 2001, for supplying water to municipalities and irrigation, led to a paradigm shift in water culture. Soil degradation caused by changes in farming practices has affected groundwater resources and damaged ecosystems that depend on it, impacting biodiversity and long-term environmental balance. Consequently, pressure on water resources in the CG-NNP is not only marked by climate change, but also by due to changes in people's mindsets and the loss of cultural traditions linked to the management of surface water and groundwater.

LID 0648
Enhancing groundwater sustainability in Northern Iraq: Lessons from managed aquifer

Mohammed Ali[1], Reman Hasan[2], **Jay Matta**[3]*

[1] UNICEF Iraq CO, Erbil, Iraq
[2] General Directorate of Water Resources, Erbil, Iraq
[3] UNICEF Wash Innovation Hub, Copenhagen, Denmark
* jaymatta@proton.me

Keywords: managed aquifer recharge, water scarcity Iraq, groundwater mapping, groundwater monitoring, UNICEF

Groundwater plays a critical role in water supply across northern Iraq, yet recharge has declined due to climate variability, reduced rainfall, and increasing abstraction. In response, UNICEF, working with the General Directorate of Water Resources, has supported the implementation of Managed Aquifer Recharge (MAR) pilot projects in Erbil and Duhok governorates to explore practical options for enhancing groundwater recharge under local conditions.

The pilot projects consist of simple surface infiltration structures supported by observation wells equipped with monitoring sensors. Site visits and field verification confirm that construction has been completed to a satisfactory standard and that the systems are functioning as intended. Continuous groundwater level data is now being collected, providing valuable evidence on recharge response and aquifer behaviour in areas where reliable groundwater data has historically been limited.

Alongside physical implementation, the programme has focused on strengthening institutional capacity of government and partners through training government staff and young professionals in groundwater mapping, monitoring, and data analysis. This has improved the ability of institutions to generate, interpret, and use groundwater data to inform planning and management decisions.

Building on lessons from these pilots, work is underway to develop a structured national framework for expanding MAR in Iraq. The focus is on identifying suitable sites, standardising monitoring approaches, and integrating MAR into broader groundwater management practices. The experience from Erbil and Duhok shows that MAR can move beyond isolated pilots when supported by consistent monitoring and strong institutional ownership.

LID 0649
Assessing the feasibility of MAR for climate-resilient water supply in humanitarian contexts: The case of Dollow, Somalia

Catalin Stefan[1*], Fritz Kalwa[1], Falk Händel[1], Jay Matta[2], Mohamud Hussein[3], Lorenz Ewers[4], Agnes Chepkorir[4], Yussuf Abdullahi[4], Khalif Abdirashid[4], Denys Grombacher[5], Matthew Griffiths[5], Michael Singer[6], André Quichimbo[6], Lavuun Verstraete[7]

[1] Technische Universität Dresden, Institute of Groundwater Management, Research Group INOWAS, Dresden, Germany
[2] UNICEF Wash Innovation Hub, Copenhagen, Denmark
[3] UNICEF Country Office, Dollow, Somalia
[4] arche noVa - Initiative für Menschen in Not e.V., Dresden, Germany
[5] Aarhus University, HydroGeophysics Group, Aarhus, Denmark
[6] ERIMOS Ltd., Bristol, United Kingdom
[7] UNICEF Global WASH Practice, Nairobi Centre of Excellence, Kenya
* catalin.stefan@tu-dresden.de

Keywords: managed aquifer recharge (MAR), climate adaptation, humanitarian support, groundwater management

Within UNICEF's Regional Water, Sanitation and Hygiene (R-WASH) programme in Eastern Africa, the R-MAR project aims to assess the feasibility of managed aquifer recharge (MAR) as a climate-resilient water supply solution in water-scarce and crisis-affected settings benefitting over 200,000 forcibly displaced persons including their host community. The area around Dollow in Somalia was selected as a case study due to its acute water supply challenges, driven by highly variable river flows, limited natural groundwater recharge, increasing demand from local communities and internally displaced populations, and growing pressures linked to climate variability.

MAR is being investigated for its potential to enhance the resilience of the local water supply system by storing excess water from Dawa river during periods of availability and making it accessible during drought conditions. The project follows a stepwise, integrated implementation approach. This includes quantitative and qualitative assessments of potential water sources; hydrogeological mapping of the alluvial floodplain; detailed site characterisation and monitoring; and model-based scenario analyses to support the co-design of locally adapted MAR solutions. In parallel, strong emphasis is placed on capacity development, technical training, and stakeholder engagement to ensure local ownership and long-term sustainability.

A key component of the project is the development of an upscaling strategy and a practical guidebook to facilitate replication in similar humanitarian and climate-vulnerable contexts. Expected outcomes include improved understanding of local hydrogeological conditions, identification of feasible MAR interventions, strengthened institutional capacities, and enhanced resilience of water supply systems to climate change and population pressures.

LID 0650
A global assessment of the limits of groundwater use

Marc F.P. Bierkens[1]*, Barry Van Jaarsveld[1], Sioux Fanny Melo Leon[1], Nicole Otoo[1], Gu Oude Essink[2,1], Edwin H. Sutanudjaja[1], Rens L.P.H. Van beek[1], Michelle T.H. Van Vliet, Jarno Verkaik[2], Niko Wanders[1], Daniel Zamrsky[3,1]

[1] Utrecht University, Utrecht, The Netherlands
[2] Deltares, Utrecht, The Netherlands
[3] IHE Delft Institute for Water Education, Delft, The Netherlands
* m.f.p.bierkens@uu.nl

Keywords: depletion, limits, pumping

Until now, research into groundwater depletion and overuse has been mostly limited to quantifying current and future trends in extraction or depletion rates. However, depletion rates per se are insufficient to estimate the critical time horizons at which groundwater reserves will become exhausted, and further, they cannot inform on the negative impacts of groundwater use. This will require insight into the critical depths above which groundwater that still can be physically and economically extracted, and on the relationship between depletion depths and detrimental impacts, such as on groundwater dependent ecosystems.

Here we use the results of a global high-resolution transient groundwater model, extensively compared and corrected with piezometric data, to estimate depth of the water table with respect to physical, economic and ecological critical depths, which together define the limits to groundwater use. Physical critical depths are related to the depth of the stream-groundwater disconnection, the fresh-saline interface and the maximum depth that allows for high-capacity groundwater pumping. Economic critical depths are reached once the costs of pumping persistently exceed the revenues from water use. Ecological critical depths are the minimal water table depths required to support groundwater dependent ecosystems. We assess the current volumes of groundwater stored above these critical depths and use future projections of groundwater levels under various combined climate and socio-economic scenarios to assess when and where critical depths are reached.

LID 0651
Water Resources Expert Group of the Geological Surveys of Europe – role and activities

Laurence Gourcy[1]*, Klaus Hinsby[2], Anna Kuczyńska[3], Georgina Arnó[4]

1 BRGM, Orleans, France
2 GEUS, Geological Survey of Denmark and Greenland, Copenhagen, Denmark
3 Polish Geological Institute – national Research Institute, Warsaw, Poland
4 ICGC (Cartographical and Geological Institute of Catalonia), Barcelona, Spain
* L.gourcy@brgm.fr

Keywords: groundwater, collaboration, interdisciplinarity

Under the umbrella of the EuroGeoSurveys hundreds of experts from all Europe are engaged in expert groups, carrying out research that directly tackles today's diverse societal challenges and helps to build a sustainable future for us all. The Water Resources Expert Group (WREG) provides research-based expertise in groundwater protection and management for decision-making on water resources at national and European levels.

The WREG develops monitoring, modelling methodologies and digital maps to understand, evaluate, and predict the impacts of climate and land use change on groundwater resources, interconnected surface waters, and ecosystems in order to define a climate-robust set of adaptation measures and promote best practices. The WREG also continues to work on synergistic approaches and tools to meet societal and climate change mitigation and adaptation needs.

Many groundwater experts associated with WREG are involved in the EU Common Implementation Strategy Groundwater working group and have contributed to numerous guidance and technical documents related to groundwater. Today the WREG involvement in the 2025-2027 CIS work programme concerned most of the activities, ranging from updating guiding documents, linking WFD to nitrates and drinking water Directives to participation in discussions on groundwater ecology, specific GW watch list and PFAS, microplastics and antimicrobial resistant genes in close collaboration with the CIS Chemical working group.

The WREG is promoting open-access data collection, enhancement and display using the EGDI platform. New initiatives concern a European spring inventory and European Groundwater Monitoring Database (EUGM) within the GSEU project.

Finally, the WREG plays a role in discussions on scientific research needs by participating in the redaction of the EGS Strategic Research and Innovation Agenda which defines directions of the future developments in the area of geological science to meet societal and economic needs.

LID 0652
Water resources monitoring: A key challenge for Lebanon

Marie-Louise Alexandra Vogt[1], Joanna Doummar[2], Sara Ines Vassolo[3], Thomas Schopper[4], Kevin Bonel[1], Joanna Saade[1], **Charbel Hanna**[1]*, Dominique Porteaud[1]

[1] UNICEF, Beirut, Lebanon
[2] American University of Beirut (AUB), Beirut, Lebanon
[3] Bundesanstalt für Geowissenschaften und Rohstoffe (BGR), Beirut, Lebanon
[4] Swiss Development and Cooperation (SDC), Zahlé, Lebanon
* channa@unicef.org

Keywords: water management, water security, climate change impact

Lebanon, unlike many of its neighbours, benefits from a comparatively favourable hydrological balance and a millennia-long legacy of adaptive water management. Yet today, after decades of conflict, institutional erosion and external pressures, the national water supply system struggles to ensure a reliable quantity and quality of service.

A central challenge in the sector is its limited operational control. Due to financial constraints, regional water establishments struggle to accurately measure the volumes delivered, relying instead on indirect estimates from pump size and energy use. This issue is compounded by the absence of user registration and outdated flat-rate tariffs, which don't reflect actual consumption. Without access to volumetric data or cost-reflective pricing, utilities cannot recover operational costs, plan for maintenance or invest in infrastructure renewal. Financial instability has deepened, increasing reliance on external donors and emergency responses rather than fostering long-term management strategies.

Recent reforms led by the Ministry of Energy and Water aim to improve monitoring of abstraction from wells and major springs, detect leaks, develop customer databases and inventory unlicensed wells. While essential, these measures only address part of the broader challenge.

In a country where snowmelt sustains aquifer recharge and karst systems dominate groundwater flow, hydrogeological knowledge is not a luxury but the foundation of water security. Climate change is altering precipitation patterns, reducing snowpack, and increasing variability. Lebanon's water scarcity has historically been episodic rather than structural, fostering a perception of relative abundance. But without systematic monitoring of recharge, storage, abstraction, and quality, decision-makers operate in uncertainty. In this context, monitoring water resources is not an optional refinement of governance; it is a strategic necessity Lebanon can no longer afford to postpone.

LID 0653
Mapping New Zealand coastal shallow groundwater vulnerability to sea-level rise

Amandine Bosserelle[1]*, Leanne Morgan[2], Rogier Westerhoff[3]

[1] The University of Western Australia, School of Earth and Oceans, Perth, Australia
[2] Waterways Centre, School of Earth and Environment, University of Canterbury, Christchurch, New Zealand
[3] Earth Sciences New Zealand, Wairakei Research Centre, Taupo, New Zealand
* amandine.bosserelle@uwa.edu.au

Keywords: groundwater classification, saltwater intrusion, water table rise

A new national-scale assessment classifies New Zealand's near-surface unconfined coastal groundwater systems to predict their vulnerabilities to sea-level rise. Using high-resolution national datasets, the research applies a water table ratio framework to categorize shallow groundwater as either flux-controlled (recharge-limited) or head-controlled (topography-limited). These two classifications represent distinct hydrogeological endmembers with differing responses to sea-level rise.

Flux-controlled systems are primarily susceptible to water table rise and subsequent groundwater flooding. The findings indicate that these systems are the most prevalent by catchment count (64%) and cover the majority of New Zealand's coastline length (60%). Conversely, head-controlled systems are more vulnerable to saltwater intrusion and the exposure of shallow groundwater, which also pose risks to subsurface infrastructure. Although they represent a smaller number of catchments, head-controlled systems dominate in terms of land area (56%) and characterize 71% of low-elevation coastal zones.

This national-scale classification significantly refines earlier, coarser global predictions that estimated 75% of the New Zealand coastline was head-controlled. By providing these location-dependent insights, the research offers a more accurate understanding of coastal shallow groundwater vulnerabilities than previous global models. Ultimately, these findings are essential for informing effective national water management strategies and enhancing resilience against the impacts of climate change on coastal landscapes.

LID 0657
Vulnerability of potential groundwater recharge to future climate change in arid sand-dune aquifers of Western Kazakhstan

Valentina Rakhimova[1]*, Yermek Murtazin[1], Evgeny Sotnikov[1], Timur Rakhimov[1]

[1] Ahmedsafin Institute of Hydrogeology and Environmental Geoscience LLP, Almaty, Kazakhstan
* salybekova_v@mail.ru

Keywords: scenario-based projections, aridity index, water balance, root water stress, sand-dune aquifers

Climate change represents a mounting challenge to the sustainability of groundwater resources, particularly in arid and semi-arid regions. Sand-dune aquifer systems are known to be especially sensitive due to their distinctive hydrogeological structure, high permeability, and strong dependence on climatic recharge processes. In Central Asia, and western part of Kazakhstan in particular, groundwater stored in dune environments represents a critical source of water for ecosystems, agriculture, and human settlements.

The assessment of climate change impacts on groundwater in these systems is a complex undertaking due to subsurface heterogeneity, scale mismatches between climatic drivers and groundwater response, and limited long-term observational data. Projections indicate that changes in precipitation patterns and an escalating frequency of droughts will further complicate assessments and management of groundwater resources.

The present study evaluates the sensitivity of potential groundwater recharge in sand-dune aquifers in western Kazakhstan under projected climate change scenarios. The analysis demonstrates that groundwater responses to rainfall anomalies may differ substantially from surface hydrological responses, emphasising the necessity for groundwater-specific assessment frameworks. The findings underscore the significance of incorporating uncertainty-aware modelling approaches to enhance the representation of recharge variability and future climate impacts. The findings contribute to an enhanced comprehension of groundwater vulnerability in dune environments and support the development of adaptive groundwater management strategies under changing climatic conditions.

LID 0659
Characterizing the Cucco Mt karst aquifer system through hydrogeological monitoring: First results from the Scirca spring (Central Italy)

Costanza Cambi[1], Davide Fronzi[2], Massimiliano Mazzocca[3], Francesco Spinelli[3], Mauro Rossi[4], **Lucio Di Matteo**[1*], Isabella Serena Liso[5], Mario Parise[5], Andrea Vitali[6], Giacomo Schirò[6], Alex Manucci[6], Alberto Tazioli[2], Daniela Valigi[1]

[1] Dipartimento di Fisica e Geologia. Università degli Studi di Perugia, Perugia, Italy
[2] Dipartimento Scienze e Ingegneria della Materia, dell'Ambiente ed Urbanistica (SIMAU), Università Politecnica delle Marche, Ancona, Italy
[3] Gruppo Speleologico CAI Perugia "Sez G. Bellucci", Perugia, Italy
[4] Istituto di Ricerca per la Protezione Idrogeologica, CNR, Perugia, Italy
[5] Dipartimento di Scienze della Terra e Geoambientali, Università degli Studi di Bari Aldo Moro, Bari, Italy
[6] Umbra Acque S.p.A., Perugia, Italy
* lucio.dimatteo@unipg.it

Keywords: karst, spring, Mount Cucco

The Cucco Mt. Massif cave is the deepest and most extensive karst system in the Umbria–Marche Apennines and is hydraulically connected to the Scirca spring, which supplies drinking water to tens of thousands. The cave-spring system was recently equipped with a multi-parametric probe, installed in August 2024, to measure water level, electrical conductivity, and both water and air temperature at the cave's lowest point, 918 m below the surface.

The probe integrates the pre-existing monitoring network of the Cucco Mt. area, which includes monitoring of the Scirca spring discharge, two rain gauges, and one snow-depth sensor.

Hourly data for each parameter measured by the probe were aggregated to the daily scale to assess autocorrelation and cross-correlation with the mean daily discharge of the Scirca spring.

The cross-correlation analyses indicate that the recharge of the aquifer feeding the spring is driven by both rainfall and snowfall. Snow-derived recharge exhibits longer time lags in its correlation with spring discharge compared to rainfall. Snowmelt therefore plays a key role in sustaining spring baseflow, while rainfall produces rapid responses, determining rises in water levels in karst conduits and consequent increases in spring discharge.

By coupling in-cave monitoring with recharge and discharge data, it was possible to assess the roles of rainfall and snowfall in controlling groundwater dynamics.

Artificial tracer tests at the cave bottom and hydrochemical and isotopic monitoring can help improve understanding of the aquifer hydrodynamics.

This is particularly relevant in the Mediterranean context, where the observed decline in snow precipitation is expected to weaken the delayed contribution to spring baseflow and increase the system's vulnerability to prolonged droughts.

LID 0660
A MAR-supported riverbank filtration system – Challenges and opportunities

Tibor Ridavits[1]*, Thomas Riedel[1], Tim aus der Beek[1]

[1] Water Resources Management, IWW Institut für Wasserforschung gGmbH, Mülheim an der Ruhr, Germany
* t.ridavits@iww-online.de

Keywords: riverbank filtration, MAR, ASTR

Riverbank filtration has a long and successful history in Germany and many other parts of the world. However, climate change is increasingly causing extreme and prolonged low-water periods in German rivers. In one of the driest regions of the country, growing population and industrial expansion will further increase water demand and require a reliable long-term supply strategy.

A detailed MODFLOW groundwater flow model was applied to assess the hydraulic impacts of expanding the existing riverbank filtration scheme on groundwater levels in adjacent floodplain and agricultural areas. To mitigate potential negative effects of additional abstraction, particularly declining groundwater levels in climate-sensitive floodplain meadows, the implementation of Managed Aquifer Recharge (MAR) is evaluated. Two MAR options are investigated: (1) infiltration via a natural terrain depression representing a low-impact, nature-based solution, and (2) an Aquifer Storage, Transfer and Recovery (ASTR) type MAR system consisting of an infiltration trench located further inland from the planned abstraction site.

Since the River Rhine is the primary control on groundwater level dynamics in the study area, its water level fluctuations were explicitly considered in the simulations. Infiltration timing and infiltration rates must account for River stage variability to prevent waterlogging and adverse impacts on agricultural land and protected ecosystems.

The results demonstrate that coupling riverbank filtration with MAR can significantly enhance supply security and reduce abstraction-induced groundwater level decline. However, careful consideration of river stage dynamics is essential when selecting infiltration sites, defining operation periods, and determining infiltration rates. The study highlights the importance of integrating river–aquifer interactions into adaptive water supply planning under changing climatic conditions.

LID 0662
Hydrochemical signatures of groundwater salinization in the coastal Jhuoshuei River Alluvial Fan, Taiwan

Chih-Ching Kuo[1]*, Sofia Ya Hsuan Liou[1,2], Tung-Lin Tai[1]

[1] Department of Geosciences, National Taiwan University, Taipei, Taiwan
[2] Science and Technology Research Institute for DE-Carbonization (STRIDE-C), National Taiwan University, Taipei, Taiwan
* d11224003@g.ntu.edu.tw

Keywords: Chelex-100, groundwater salinization, trace metals

Climate change and increasing hydrological variability have intensified pressure on groundwater resources worldwide. In Taiwan, steep topography and seasonally uneven precipitation limit surface water storage, leading to a strong reliance on groundwater. Monitoring data from 2015 to 2019 indicate widespread salinization of shallow groundwater in the coastal area of the southern Jhuoshuei River alluvial fan.

To investigate the hydrochemical characteristics and sources of salinity, eight semiannual sampling campaigns were conducted from 2021 onward, yielding 190 groundwater samples. Major-ion analyses indicate that salinity is significantly higher in shallow aquifers than in deeper groundwater. Conventional hydrochemical indicators confirm mixing with saline water; however, they cannot clearly differentiate between lateral seawater intrusion and anthropogenic inputs from surface activities.

To improve source identification, Chelex-100 ion-exchange chromatography was applied to remove the high-salinity matrix and preconcentrate trace metals. Trace element concentrations provide a useful diagnostic tool because seawater typically contains very low levels of trace metals (ppb to ppt), whereas aquaculture waters commonly exhibit elevated concentrations. Groundwater samples from Taixi show higher trace metal concentrations, particularly Pb, suggesting anthropogenic influence. In contrast, samples from Yiwu and Qiongpu display low trace metal levels consistent with seawater intrusion.

The results demonstrate that integrating trace metal analysis with conventional hydrochemical data improves discrimination of salinization sources and supports a better understanding of salinity processes in coastal aquifer systems.

LID 0663
Effectiveness of surface water retention through canals in terms of groundwater, in the Danube-Tisza Interfluve, Hungary

Szilvia Simon[1]*, Aldeth Garas[1], Márk Szijártó [2,3], András Berecz[4], Adrienn Kovács-Baksi[5], Judit Mádl-Szőnyi[1]

[1] József and Erzsébet Tóth Endowed Hydrogeology Chair, Department of Geology, Institute of Geography and Earth Sciences, ELTE Eötvös Loránd University, Budapest, Hungary
[2] József and Erzsébet Tóth Endowed Hydrogeology Chair, Department of Geophysics and Space Sciences, Institute of Geography and Earth Sciences, ELTE Eötvös Loránd University, Budapest, Hungary
[3] Institute for Geological and Geochemical Research, HUN-REN Research Centre for Astronomy and Earth Sciences, Budapest, Hungary
[4] Ökoszenna Ltd., Kaposvár, Hungary
[5] General Directorate of Water Management, Budapest, Hungary
* szilvia.simon@ttk.elte.hu

Keywords: surface water retention, groundwater, Hungary

Water retention and replenishment solutions are particularly important in areas around the world struggling with water shortages. The Danube-Tisza Interfluve area (DTI) in Hungary is one such region, where climate change and human activities (such as canal construction, overexploitation of groundwater resources, and inappropriate land use) are collectively causing severe groundwater depletion. Natural Water Retention Measures (NWRMs), most of which may be considered Nature-Based Solutions, can be proper solutions in mitigating this process. These techniques focus primarily on surface water retention and are widely used. However, their effect on groundwater and flow systems is rarely studied. The present work aims to evaluate the effectiveness of a canal-based surface water retention solution (NWRM technique) in the municipality of Bátya (DTI) using field observation, data analysis, and numerical simulation. An old, dried-up canal section was flooded with surface water, and an observation network was set up to assess its impact on the environment. Electrical resistivity tomography measurements and sediment analyses were performed to characterize the subsurface geological conditions, and water level and hydrochemical measurements were carried out to investigate the interaction between the canal and the groundwater and the infiltration process. Finally, two-dimensional numerical calculations were performed to assess the long-term effects of the intervention.

The results indicated that infiltration effectiveness is strongly controlled by shallow subsurface geology. Consequently, connectivity between the canal and the groundwater varies along the canal reach. The intervention produced mainly local effects, most notably in adjacent agricultural areas. Flooding additional neighboring canal sections would likely extend the impact to a wider area.

This work was funded by the LIFE LOGOS 4 WATERS project of the European Union and carried out in collaboration with the General Directorate of Water Management (GDWM). The work has been supported by the National Multidisciplinary Laboratory for Climate Change (RRF-2.3.1-21-2022- 00014) project within the framework of Hungary's National Recovery and Resilience Plan supported by the Recovery and Resilience Facility of the European Union, by the János Bolyai Research Scholarship of the Hungarian Academy of Sciences, and by the Papp Simon Foundation, Hungary.

LID 0664
Hydrogeological interventions – The role of the Polish Geological Survey in supporting governmental institutions, local governments and society in field of hydrogeology

Anna Kuczyńska[1]*, Urszula Czarniecka-Januszczyk[1]

[1] Polish Geological Institute – National Research Institute, Warsaw, Poland
* akuc@pgi.gov.pl

Keywords: groundwater, collaboration, local governments

70% of drinking water in Poland comes from groundwater - an invisible resource that must be carefully monitored and protected.

The Polish Geological Survey (PGS), whose functioning in field of water management including groundwaters is regulated by the Water Law Act plays an important role in polish water governance system, providing information needed and used by governmental institutions, EU agencies, local governments, academic and research centres as well as society. Among responsibilities such as collecting, processing and sharing information regarding hydrogeological conditions, resource volumes, chemical and quantitative status of groundwater, maintaining and updating hydrogeological databases, conducting ongoing analyses and assessments of the current hydrogeological situation and it's forecasts, PGS also carries out hydrogeological interventions. These interventions are hydrogeological investigations requested by local governments in areas, where no other entities have responsibilities to take actions. Most often they concern groundwater pollution problems threating public water supplies, mining or post mining areas, where ceasing mining activities or unfinalised recultivation projects cause unforeseen consequences threating lives of local societies. Hydrogeological interventions typically require immediate actions and provide an essential support to local authorities in their decision-making processes. In conclusion, PGS through scientific research, long- term groundwater monitoring, as well as advisory activities supports decision-making processes related to groundwater management on national and local levels. PGS contributes in achieving sustainable water management and environmental protection.

In this oral presentation three such interventions of different genesis and scales will be outlined to show how the hydrogeological expertise gathered within the Polish Geological Survey can help and support society to solve unsolved.

LID 0666

Hydrochemical and isotopic assessment of groundwater recharge mechanisms in semi-arid alluvial aquifers: Integrating environmental tracers with conceptual modeling

Abderrahman El Farchouni[1,2*], Abdessamad Hadri[1], Younes Fakir[3,4], Yassine Ait Brahim[1], Mohammed Hssaisoune[5,6], Lhoussaine Bouchaou[1,5], Mohamed Ouarani[1], Houssne Bouimouass[4], Giulio Castelli[2], Elena Bresci[2], Daniele Penna[2,9], Azzouz Kchikach[7,8]

[1] International Water Research Institute, Mohammed VI Polytechnic University, Morocco
[2] Department of Agriculture, Food, Environment and Forestry (DAGRI), University of Florence, Florence, Italy
[3] Department of Geology, Faculty of Sciences Semlalias, Cadi Ayyad University, Marrakech, Morocco
[4] Center for Remote Sensing Application (CRSA), Mohammed VI Polytechnic University, Ben Guerir, Morocco
[5] Applied Geology and Geo-Environment Laboratory, Faculty of Sciences, Ibn Zohr University, Agadir, Morocco
[6] Faculty of Applied Sciences, Ibn Zohr University, Ait Melloul, Morocco
[7] Geology and Sustainable Mining Institute (GSMI), Mohammed VI Polytechnic University, Morocco
[8] Georessources, Geoenvironment & Civil Engineering, Cadi Ayyad University, Morocco
[9] Oregon State University, Forest Engineering Resources and Management Department, Corvallis OR, United States
* Abderrahman.ELFARCHO@um6p.ma

Keywords: hydrochemistry, stable isotopes, environmental tracers, groundwater recharge, self-organizing maps, conceptual model, semi-arid aquifers

Groundwater recharge in semi-arid alluvial aquifers exhibits regional heterogeneity and is influenced by many processes, including mountain-front recharge (MFR), mountain-block recharge (MBR), and irrigation return flows. Untangling these recharge processes is difficult when depending exclusively on hydraulic-head (piezometric) data. This study enhances the conceptual hydrogeological model of the Central Haouz–High Atlas system (Morocco) by integrating major-ion chemistry and stable isotopes ($\delta^{18}O$, $\delta^{2}H$) from both historical and newly collected groundwater samples. To tackle the elevated dimensionality of the hydrochemical-isotopic dataset, multivariate statistical methods were employed, specifically principal component analysis (PCA) and Kohonen's self-organizing maps (SOMs). The Self-Organizing Map (SOM) was trained on standardized variables and integrated with hierarchical clustering of codebook vectors to objectively define hydrochemical-isotopic facies. The results indicate discrete groupings of groundwater that exhibit differing recharge signatures and mixing mechanisms. Isotopic depletion patterns and bicarbonate-dominated facies imply mountain-derived recharge, while progressive mineralization and particular ion enrichments denote extended residence time and reveal the influence of irrigation on groundwater in agricultural regions. The spatial arrangement of SOM clusters facilitates the reconstruction of groundwater flow trajectories from the High Atlas recharge areas to the middle plain and offers quantitative insights into the relative contributions of MFR and MBR. This study integrates environmental tracers with unsupervised machine learning to diminish conceptual uncertainty and illustrates the enhanced use of data-driven clustering for improving groundwater recharge models in semi-arid mountainous alluvial systems. The suggested framework provides a transportable method for enhancing groundwater conceptualization in data-intensive and climate-affected aquifers.

LID 0667
Hydrogeological typologies of the aquifer systems underlying Lagos State, Nigeria

Laura Holliday[1]*, Kirsty Upton[1], Alan Macdonald[1], Adrian Healy[2], Jean-Christophe Comte[3], Olowaseun Olabode[3], Akinade Olatunji[4], Moshood Tijani[4], James Akanmu[5], Ezechiel Longe[5], Nurudeen Oshinlaja[2], Mark Cuthbert[2], Jamiu Aladejana[4], Kehinde Kolawole[5], O Alo[5], Akomeno Oteri[6]

[1] British Geological Survey, Lyell Centre, United Kingdom
[2] Cardiff University, Cardiff, United Kingdom
[3] The University of Aberdeen, Aberdeen, United Kingdom
[4] University of Ibadan, Ibadan, Nigeria
[5] The University of Lagos, Lagos, Nigeria
[6] Independent Hydrogeologist, Lagos, Nigeria
* lholl@bgs.ac.uk

Keywords: monitoring, typologies, governance

Lagos, Nigeria is one of the world's fastest growing megacities, home to over 15 million people and growing by 3.5% annually. With inadequate provision of piped water supply, most residents rely on groundwater, largely through privately installed boreholes. Effective management of this strategically important resource is constrained by limited, fragmented or outdated data. Across Lagos State, we addressed this challenge by consolidating pre-existing open access data and literature to develop new hydrogeological typologies, combining these with new groundwater-level and water-quality data across 44 sites to develop an updated understanding of groundwater pressures.

The monitoring evidence provides a recalibration of previous assumptions of widespread groundwater depletion and contamination. While pressures remain, the integrated dataset shows a more nuanced picture, with localised rather than widespread issues and partial recovery of groundwater levels in some areas following historical depletion. This highlights the essential role of even modest but well-designed monitoring networks in revealing system behaviour and supporting more accurate assessments of groundwater status.

From this work, clear priorities emerge for improving groundwater security in Lagos:

- The need for a sustained "big conversation on groundwater" involving regulators, planners and water users to align understanding of risks, expectations and responsibilities.
- Countries require robust, strategic monitoring networks capable of establishing reliable baselines to inform regulation, licensing and long-term management.
- Improvements in groundwater practice, policy and management frameworks are critical to ensure evidence is used effectively and consistently in decision-making.

The Lagos experience shows even with limited resources, integrating available data with structured monitoring can generate actionable insights and support more resilient groundwater governance across rapidly urbanising settings.

LID 0668

Advancing integrated continental-scale hydrologic simulation and forecasting through democratized data and ML-accelerated modeling

Reed Maxwell[1]*, Leonard Sandoval[2], Yueling Ma[3], Amelia Peeples[1], Marie Joe Sawma[1], George Artavanis[1], Amy Defnet[1], Andrew Bennett[2], Laura Condon[2]

[1] Princeton University, Princeton, NJ, United States
[2] University of Arizona, Tucson, AZ, United States
[3] F-Z Jülich, Jülich, DE
* reedmaxwell@princeton.edu

Today, water and resource managers face a significant challenge managing systems that are rapidly evolving in a warming climate, where historical observations are no longer a reliable guide. Capturing interactions from bedrock to treetops is important for understanding water stresses and represents a critical gap in our current models. Simulations with integrated hydrology models (that solve the 3D Richards' equation and 2D shallow water equations in a globally implicit manner) provide robust results out to continental scales, yet are computationally expensive. Groundwater-surface water interactions are tightly coupled and can have a large impact on watershed dynamics, yet are challenging for all models to accurately resolve.

We have developed a hybrid physics-based, machine learning digital twin over the entire continental US (CONUS). This proof-of-concept forecast system runs operationally, providing all hydrologic states and fluxes from bedrock to the top of the canopy at hourly timesteps and greater than 1 km resolution. Automated comparison to observations is enabled through the HydroData platform, supporting continuous evaluation and model improvement. This talk will highlight the technical challenges of combining integrated hydrologic modeling with machine learning in a national forecast system, including physics-based approaches that improve solver performance by more than an order of magnitude for continental-scale simulations. Machine learning emulators embedded within integrated hydrology models can also drastically reduce computational burden and provide 30 m spatial resolution for groundwater and surface water. We advance a vision that deploys these models and openly available forcing and parameter datasets to understand future water challenges from local to continental scales.

LID 0669
Quantifying vegetation transpiration from groundwater in Mediterranean forests: An isotope-informed model integration

Simone Gelsinari[1,2,3]*, Andrea Alessandri[2], Daniele Penna[1]

[1] DAGRI, Universita' di Firenze, Firenze, Italy
[2] CNR - ISAC, Bologna, Italy
[3] SAgE, The University of Western Australia, Perth, Australia
* simone.gelsinari@unifi.it

Keywords: groundwater evapotranspiration, Earth System Models, stable isotopes

In the Mediterranean basin, sustainable water management is challenged by frequent and prolonged droughts. A critical component of the aquifer balance is the abstraction of shallow groundwater by phreatophytic vegetation. When soil moisture depletes, these ecosystems have the potential to shift source of water in order to sustain transpiration. Hence, this evapotranspiration from groundwater (ETg) acts as a direct sink term, significantly altering net recharge and surface-atmosphere fluxes.

We aim at quantifying ETg estimates in Mediterranean aquifers, investigating two Italian coastal forests over shallow water tables (Pines in San Rossore and Oaks in Castel Porziano), where evapotranspiration (ET) decouples from soil moisture during dry periods. To partition ET sources and isolate ETg, we integrate Eddy Covariance fluxes with stable environmental isotope analysis $\delta^{18}O$, $\delta^{2}H$ of xylem, soil water, and groundwater.

This multi-tracer dataset improves critical zone conceptualization. Crucially, these ecohydrological observations serve a dual modeling purpose: they provide dynamic top-boundary conditions for regional groundwater management models, and help parameterizing the bottom boundary conditions of Earth System Models (ESM). Accurately representing ETg as a bottom boundary flux significantly reduces uncertainties in simulating groundwater-climate feedback mechanisms under changing global climates.

LID 0670
Spatio-temporal changes of river-aquifer interactions in North-Central Bangladesh

José Zolezzi-López[1*], Edinsson Muñoz-Vega[1], Mohammad Shamsudduha[2], Stephan Schulz[1]

[1] Institute of Applied Geosciences – Technical University Darmstadt, Darmstadt, Germany
[2] Department of Risk and Disaster Reduction – University College London, London, United Kingdom
* zolezzi@geo.tu-darmstadt.de

Keywords: Bangladesh, river-aquifer interaction, MODFLOW6

Bangladesh, one of the most densely populated countries, relies primarily on its irrigated agriculture, which has doubled the used land in the last 30 years. This rapid expansion has relied heavily on shallow groundwater abstraction, which, with increasing domestic and industrial abstraction, has led to declining groundwater levels, altering the river-aquifer exchange in the Bengal Delta. Previous studies have estimated the total recharge changes due to increased abstraction through freshwater capture, however, have not quantified the change in the focused recharge from river leakage. To address this, we developed a numerical groundwater flow model to assess the impact of increasing abstraction over the past four decades in the river leakage in North-central Bangladesh.

The 3D numerical model was implemented in MODFLOW-6 and was set up using Flopy, covering an area of 27670 km2 from the Meghalaya foothills to the confluence of Meghna and Ganges rivers. It considers 11 layers (~370 m total thickness) based on a regional borehole-derived geological model reflecting the multilayer aquifer system described in the literature. Main river networks within the domain, diffuse recharge, and abstraction for different purposes were considered as boundary conditions. River-aquifer exchanges were simulated using the RIV package, driven by long-term monthly stage data. Hydraulic properties including hydraulic conductivities, anisotropies, storage, along with riverbed conductance were calibrated using PEST++, based on long-term groundwater levels and drawdowns between 1980 and 2018.

The preliminary results show that increased groundwater abstraction for irrigation has reversed the direction of flow in several rivers compared to the pre-irrigation condition, changing the system from gaining to losing regime. The magnitude of these changes is highly uncertain due to the system heterogeneity, riverbeds conductance, channels morphology, and other factors, especially during the monsoon.

LID 0671
Predictive modeling of climate-driven radon mobilization in groundwater in Igbesa, Ogun State, Nigeria

Michael Oluwasegun Dada[1]*, Morohunfoluwa Adeola Olaoye[1]

[1] Department of Physics, Lagos State University, Lagos State, Nigeria
* dadamichaeloluwasegun@gmail.com

Keywords: radon-222, groundwater mobilization, climate projections, predictive modeling, radiological risk assessment, Nigeria

Radon-222 (^{222}Rn) in groundwater represents a major radiological health risk, especially in areas where there is high dependency on untreated water sources and where there are concerns regarding climate change. This study aims to expand on empirical data regarding the levels of radon in water samples from Igbesa, Ogun State, Nigeria, which were collected in May 2025 and comprise 20 water samples. Baseline levels were established using LR-115 solid-state nuclear track detectors and were found to range from 5.7 ± 1.3 Bq L^{-1} to 39.7 ± 8.3 Bq L^{-1} with a mean value of 13.535 ± 2.505 Bq L^{-1}, which exceeded national guidelines in Nigeria at 11.1 Bq L^{-1} but was still below the 100 Bq L^{-1} threshold recommended by the World Health Organization. By using short-term data from the Nigerian Meteorological Agency (NiMet) for 2026 and long-term data from the Intergovernmental Panel on Climate Change (IPCC) under their Shared Socioeconomic Pathway SSP2-4.5, a scenario-based model was developed to forecast levels of radon in water. This model took into consideration projected increases in precipitation levels (5-15%) and temperature (1.5-2.5°C) by mid-century, which would cause a 10% increase in the levels of radon in water, escalating mean levels by 10% to 14.9-16.2 Bq L^{-1}. This would result in a corresponding increase in annual effective doses (AED) from 0.0347 ± 0.0064 mSv y^{-1} to 0.0416-0.0486 mSv y^{-1} and a corresponding increase in excess lifetime cancer risks (ELCR) from 0.1214 ± 0.0224 × 10^{-3} to 0.1457-0.1700 × 10^{-3}, which are amplified in industrial areas due to variability in climatic conditions and thus advocating for the integration of radon levels in water into national strategies regarding climate change in Nigeria.

LID 0672

Increasing groundwater dependence under population growth and hydro-climatic variability: Implications for surface-water transfer solutions in the Bubu River Catchment, Tanzania

January Mlomo[1]*, Festo R. Silungwe[1], Japhet J. Kashaigili[2]

[1] Department of Civil and Water Resources Engineering, Sokoine University of Agriculture, Morogoro, Tanzania
[2] Department of Forest Resources Assessment and Management, Sokoine University of Agriculture, Morogoro, Tanzania
* january.mlomo@camartec.go.tz

Keywords: groundwater dependence, surface-water transfer, climate variability, water supply, Tanzania

Dodoma, the rapidly growing capital city of Tanzania, relies predominantly on groundwater for urban water supply due to limited perennial surface-water sources in its semi-arid environment. Increasing abstraction, population growth, and hydro-climatic variability are intensifying pressure on aquifers, raising concerns over the long-term sustainability of groundwater-dependent supply. To reduce this reliance, the Government of Tanzania plans the Farkwa Dam in the Bubu River Catchment to transfer more than 100,000 m^3/day of surface water to Dodoma. This study evaluates the hydro-climatic reliability and supply potential of the Bubu catchment to inform the viability of this surface-water transfer strategy under current and future conditions.

Hydro-meteorological records (1971–2024) and projected climate data (2025–2070; RCP8.5) were analysed using ensemble machine-learning streamflow modelling and a GIS-based water-balance framework integrating rainfall–runoff processes, evapotranspiration, and sectoral demand. Results show a strongly seasonal unimodal flow regime with prolonged dry-season low flows (<5 m^3/s) and episodic floods (>150 m^3/s), limiting dependable yield without storage. Water demand within the basin is projected to increase substantially, led by agriculture (~36%) and domestic use (~14%), creating a potential near-term deficit of ~341 million m^3 and heightened downstream vulnerability.

Despite substantial annual rainfall, effective water availability is constrained by high evaporative losses, variable runoff, and limited storage, conditions that currently reinforce Dodoma's dependence on groundwater. However, simulations indicate that regulated storage through the proposed Farkwa Dam could stabilise seasonal supply and enable sustained surface-water transfers to the city. The findings support conjunctive surface- and groundwater management, in which strategic reservoir development reduces urban groundwater stress while enhancing regional water security under climate variability in semi-arid Tanzania.

LID 0673

Contribution of electric tomography, chemical and isotopic tools to the understanding of the resilience and salinization of wetlands along the Northern coast of the Cape-Verde Peninsula: The case of the Retba Lake

Mansour Gueye[1]*, Fatou Diop Ngom[1], Aguibou Ba[1], Moctar Diaw[1]

[1] Université Cheikh Anta Diop, Faculté des Sciences et Techniques, Département de Géologie, Dakar, Senegal
* mansour5.gueye@ucad.edu.sn

Keywords: tomography, isotope, Lake Retba, coastal aquifer, hydrosystem, salinization, resilience

Wetlands, protected by the Ramsar Convention, play a major role in biodiversity and the economy. The drought that began in the Sahel at the end of the 1960s led to the drying up of many bodies of water and the lowering of groundwater tables. On the northern coast of the Cape Verde Peninsula, Lake Retba is one of the few depressions that has retained its water body, despite a significant reduction in surface area and marked salinization. This saline ecosystem holds considerable socio-economic importance due to salt exploitation and its integration into the development dynamics of Senegal through the Emerging Senegal Plan.

This study analyzes the interactions between the lake, the coastal dune, the ponds, and the ocean in order to understand the mechanisms of its resilience. Investigations using electrical resistivity tomography (ERT), supplemented by chemical and isotopic analyses, reveal a superposition of fresh and saline waters in the dune, with a predominance of saline water near the former channel. Geochemical data confirm a contact between the marine salt wedge and the lake, showing that fresh and brackish waters rest on salty waters that then feed the highly saline waters of the lake.

Thus, the lake is fed by the sea, via the salt wedge and ponds corresponding to its outcrop, as well as by the freshwater lens in the dune and the groundwater table. These contributions explain the lake's resilience to drought, while also being the source of its salinization and salt deposits. The preservation of the ponds located to the north is essential for the sustainable survival of the lake.

LID 0674
Creating large AI training datasets for hydrogeologic generative deep-learning models

Luk Peeters[1]*, Guillaume Rongier[2]

[1] VITO Digital Water & Soils, Mol, Belgium
[2] Department of Geoscience & Engineering, Delft University of Technology, Delft, The Netherlands
* luk.peeters@vito.be

Keywords: artificial intelligence, geological models, uncertainty quantification

AI tools capable of generating text, images, and scripts are now widely used, but their underlying models rely on extremely large training datasets. In contrast, subsurface characterization often suffers from sparse observations, making purely data-driven 3D modelling approaches inadequate as they struggle to incorporate geological process understanding. Generative AI offers a pathway to embed such process knowledge, but suitable training datasets remain limited.

In this study, we generate a large synthetic 3D dataset of alluvial deposits using a process-based landscape evolution model. These simulations provide geologically consistent training data for a deep-learning generative algorithm capable of producing ensembles of 3D subsurface models. We then test the trained model for inversion, generating 3D realisations that honour borehole and seismic information while remaining consistent with geological processes.

The CHILD landscape evolution model was used to simulate 20,200 realisations of fluvial deposition over 10,000s of years, varying parameters controlling meander migration, aggradation, incision, and overbank deposition. Resulting fine- and coarse-grained sediment distributions were gridded to form the training dataset. A Generative Adversarial Network (GAN) was trained on these data and successfully reproduced key characteristics of the deposits, including non-stationarity, stratigraphic architecture, and superposition. These outcomes indicate that GAN can learn underlying geological process relationships.

We then applied the GAN in an inversion setting to generate subsurface models conditioned on borehole and seismic constraints. While promising, the inversion required substantial fine-tuning to ensure geologically plausible outcomes. The study demonstrates significant potential for AI-based generative modelling to enhance subsurface characterization and uncertainty quantification, while highlighting the need for large, process-consistent training datasets.

LID 0675
Geological characterization with stochastic modeling for a managed aquifer recharge site

Marta García-Gámez[1]*, Carlos Duque[1]

[1] Faculty of Science Department of Geodynamics, University of Granada, Granada, Spain
* martagarcia@ugr.es

Keywords: managed aquifer recharge, stochastic modeling, alluvial aquifer

The accurate geological characterization of managed aquifer recharge (MAR) systems allows to identify preferred flow paths and assess chemical reactions and interactions during recharge. Traditional approaches to subsurface modeling are frequently limited by complex parameterization, and difficulties in conditioning observed data. This study aims to address these challenges by integrating high-resolution borehole data with stochastic modeling techniques to characterize a MAR experimental site.

A total of 20 boreholes were drilled across a 20 m^2 plot. After visual inspection 160 sedimentological samples were collected whenever lithological changes were observed and analyzed by dry-sieving granulometry. Based on textural changes, 5 distinct hydrofacies were differentiated, revealing laterally and vertically heterogeneous layering, with finer-grained lenses embedded within coarser deposits that control flow connectivity. Hydraulic conductivity was estimated for each facies using 15 empirical approaches and found to be consistent with field-based slug test measurements, supporting the reliability of the hydrofacies-based hydraulic parametrization.

Modeling was performed using multiple-point statistics conditioned directly to the borehole dataset. The resulting model reproduces fine-scale heterogeneities and abrupt lithological transitions that are characteristic of alluvial aquifers yet poorly represented by deterministic models. These findings suggest that stochastic approaches offer a valuable alternative to rule-based geological modeling, particularly in highly heterogeneous alluvial settings.

This study demonstrates that conditioning stochastic geostatistical simulations to high-resolution borehole data yields geologically realistic models. The enhanced representation of sedimentary heterogeneity provides a robust framework for subsequent flow and transport modeling in MAR systems.

LID 0676
Continental to global scale modelling to advance the inclusion of groundwater processes

Sarah Collins[1], Alberto Martinez de La Torre[4], Johanna Scheidegger[2], Douglas Clark[3], Sonja Folwell[3], Vasileios Christelis[2], Tom Gribbin[2], Tom Gribbin [1], Alan MacDonald[1], **Andrew Hughes**[2]*

[1] BGS Edinburgh, United Kingdom
[2] BGS Keyworth, United Kingdom
[3] UKCEH Wallingford, United Kingdom
[4] Spanish Meteorological Service, Spain
* aghug@bgs.ac.uk

To close the terrestrial water balance, land surface models require a groundwater modelling component. The Joint UK Land Environment Simulator (JULES), a community model jointly supported by UKCEH and UK Met Office, is no exception. Various attempts have been made to add saturated groundwater flow to JULES. Recent work on the UK's NERC-funded Hydro-JULES programme has enabled the inclusion of groundwater, creating the JULES Dynamic Groundwater or JULES_DGW model. Using LEAFHYDRO as a basis a single layer saturated groundwater model, using both exponential variation of hydraulic conductivity with depth and the product of saturated thickness and hydraulic conductivity, has been added alongside the inclusion of river–aquifer interaction and abstractions.

The implementation has been tested using the River Kennet catchment of the Cretaceous-aged chalk in south-east England, applied at a continental scale to Africa, and is now being extended globally. The African configuration was developed using the conceptual understanding provided by the Africa groundwater atlas and the model has been parameterised and initial runs undertaken. These have produced promising results that demonstrate that evaporation is modified by the inclusion of saturated groundwater flow. The work has been extended to a global configuration, and we describe the approach used for identifying different groundwater flow regimes and the associated parameterisation.

LID 0677
Hydrogeological characterisation of an integrated managed aquifer recharge system in Southern Poland using electrical resistivity tomography

Sławomir Sitek[1]*, Marta Kondracka[1], Krzysztof Janik[1]

[1] Institute of Earth Sciences, Faculty of Natural Sciences, University of Silesia in Katowice, Sosnowiec, Poland
* slawomir.s.sitek@us.edu.pl

Keywords: electrical resistivity tomography, near-surface geophysics, managed aquifer recharge, aquifer characterisation, infiltration ditches, riverbank filtration

Groundwater is the primary source of drinking water in many European countries, making the sustainable use and protection of this resource a strategic priority. However, climate change, intensive abstraction, and contamination of aquifers are increasingly negatively affecting them. Managed Aquifer Recharge (MAR) can enhance groundwater quantity and quality, but its effective implementation requires a detailed understanding of the site's hydrogeological characterisation. This study assessed the geological framework and hydrogeological conditions of the Świerczków well field in Tarnów, southern Poland, using Electrical Resistivity Tomography (ERT). Eight ERT profiles (54–315 m in length) were acquired, allowing the determination of subsurface structures at depths of 10–24 m. The data, jointly interpreted with borehole logs and groundwater monitoring results, enabled the delineation of three principal zones differing in their geophysical and hydrogeological properties: an unsaturated zone (40–200 Ωm and 200–650 Ωm), a high-resistivity aquifer (up to 1500 Ωm), and a Miocene aquitard (4–200 Ωm). Spatial electrical resistivity variations reflect differences in lithology and groundwater electrical conductivity, supporting identification of zones influenced by MAR recharge and areas receiving inflow of more mineralised native groundwater from the industrial zone. ERT results contributed to optimising the location of new observation wells and improving the conceptual and numerical groundwater flow model of the site. This research indicates that ERT is a reliable method supporting MAR system management.

LID 0678
Tritium as an indicator of legacy groundwater pollution to Mediterranean ecosystems

Emilie Garel[1]*, Sébastien Santoni[1], Thomas Leydier[1], Pierre-Alain Guisiano[1], Frédéric Huneau[1]

[1] Université de Corse, UMR CNRS 6134 SPE, Equipe Hydrogéologie, Corte, France
* garel_e@univ-corse.fr

Keywords: isotope hydrology, groundwater-dependent ecosystem, environmental trajectory, nitrate

Groundwater-dependent ecosystems (GDEs) can remain impacted by pollution even after land-use practices improved. In many cases, this persistence is not linked to ongoing contamination but to the long residence time of groundwater connected to the ecosystems. Understanding this time lag is essential for realistic groundwater management.

Tritium (^{3}H) is a tracer of modern recharge and can be used as a semi-quantitative indicator of groundwater residence time. In this study, more than ten years of regional tritium monitoring in precipitation were used to define the present-day recharge signal. Groundwater samples collected in several Mediterranean GDEs were then compared to this reference.

In some sites, low tritium values indicate that groundwater feeding the ecosystems is dominated by older flow paths with limited recent recharge. This suggests that the water currently discharging into the ecosystems infiltrated years or decades ago. In such conditions, nitrate concentrations observed today reflect past land-use practices rather than present pressures. The ecosystems therefore receive legacy contamination transported through old groundwater flow lines.

These results show that groundwater vulnerability must be interpreted in relation to residence time. The delay between land-use change and ecosystem response is controlled by subsurface flow dynamics. Tritium monitoring provides a simple and robust tool to identify these hydrogeological time lags and to avoid misinterpretation of pollution trends. Integrating tritium into long-term monitoring programs can support more realistic and adaptive management of Mediterranean groundwater-dependent ecosystems.

LID 0679
From monitoring to management: Why groundwater data alone may not prevent ‘water bankruptcy’

Shammy Puri[1,2]*

[1] Department of Hydrogeology, University of Warsaw, Poland
[2] Centre for Sustainable Solutions with Practical Hydrogeology, United Kingdom
* ShammyPuri@practicalhydrogeology.co.uk

Keywords: groundwater monitoring, conjunctive management, water bankruptcy, adaptive governance, evidence-based decision-making

Over the past three decades groundwater monitoring has expanded significantly in technical sophistication and global coverage. Recent global assessments confirm widespread and accelerating aquifer depletion, and in many regions peak groundwater withdrawal seems already to have been reached. The quantitative and qualitative status of major aquifers is therefore not unknown. Yet depletion persists and governance responses remain slow and limited.

This paper examines the break in the assumed causal chain between monitoring and action. It argues that groundwater monitoring remains largely one-dimensional: aquifer conditions are tracked in isolation rather than embedded within conjunctive water management systems. Hydrographs & water chemistry document decline, but rarely function as operational triggers for policy adjustment.

In many jurisdictions, monitoring generates information without predefined management thresholds, institutional accountability or links to surface water allocation. In some regions it just leads to knee-jerk reactions – such ‘no more drilling’! As a result, spontaneous conjunctive use—where groundwater informally compensates for surface water variability—continues unchecked. Monitoring describes the symptoms of structural overdraft but does not address its systemic drivers. This will not help in making transformations from spontaneous to planned governance.

Drawing on five decades of professional engagement, this contribution proposes a governance perspective in which monitoring becomes a feedback mechanism for transformation to planned conjunctive management. Groundwater indicators must be integrated with surface water operations, demand dynamics and clear response triggers.

Without such integration, monitoring risks becoming a precise record of progressive, and emotive, ‘water bankruptcy’. Reframing monitoring as part of an adaptive conjunctive management cycle may be essential to reconnect data with effective action.

LID 0680

Spatial distribution of the isotope hydrological characteristics (δ^2H, $\delta^{18}O$, d_{exc}) of groundwater in Hungary in the 2020s - contribution to the National Atlas of Isotope Hydrology project

István Gábor Hatvani[1]*, István Fórizs[1], Zoltán Kern[1], György Czuppon[1], Bence Reitmeyer[1], Dániel Erdélyi[1], Adrienne Clement[2], József Deák[3], Patrik Nyolcas[4], Mátyás Gede[4]

[1] Institute for Geological and Geochemical Research, HUN-REN Research Centre for Astronomy and Earth Sciences, Budapest, Hungary
[2] Budapest University of Technology and Economics, Budapest, Hungary
[3] GWIS (Ground Water Isotope Studies) Ltd., Veszprém, Hungary
[4] Institute of Cartography and Geoinformatics, ELTE Eötvös Loránd University, Budapest, Hungary
* hatvaniig@gmail.com

Keywords: isotope database, groundwater, Hungary

The first systematic sampling campaign across Hungary was conducted, with the support of several government bureaus, between 2023 and 2026 collecting groundwater samples 2 to 4 times a year at approximately 260 locations. Stable hydrogen and oxygen isotope composition of the samples were measured using a LGR Liquid Water Isotope Analyzer at Institute for Geological and Geochemical Research. The isotope hydrological data along with the related geographical and hydrogeological metadata were compiled into a database. In regions of the country not covered by systematic monitoring, the gaps were partly filled with data produced in the projects with ad hoc sampling. The groundwater isotope hydrology database currently contains 616 δ^2H – $\delta^{18}O$ data pairs from 259 locations. The water samples represent a depth range from 1 to 440 m, but shallow groundwater (depth < 20 m) is highly overrepresented (n > 200). The ranges characterizing the isotopic compositions span -107.2 to -43.8‰ for δ^2H and -14.6 to -4.5‰ for $\delta^{18}O$. The secondary isotopic parameter (d_{exc}) ranges from -13.7 to 13.8‰. The database provides reference data not only for future but also to retrospective comparisons regarding either the mean values or the seasonality of groundwater in the early 2020s across Hungary. Data can support paleoclimate studies, since water bodies with most negative δ values were infiltrated during the Last Glacial Maximum.

The data can be useful not only in Hungary but also for cross-boundary water bodies. The database is completed with a viewer and explorer website with a map-based interface that helps visualize and analyze the underlying data both in spatial and temporal dimensions. The latest version of the database is available at https://hdl.handle.net/21.15109/CONCORDA/XRLKLY

The research presented herein was supported by the National Research, Development and Innovation Office (OTKA project grant number SNN 143868).

LID 0681
Exploring the promise of InSAR ground deformation in regional groundwater simulation

Katherine H. Markovich[1]*, Eric O. Lindsey[1], Carly Salazar[1], Jeremy T. White[2], Joseph Hughes[2]

[1] Dept. of Earth & Planetary Sciences, University of New Mexico, United States
[2] INTERA Incorporated, United States
* kmarkovich@unm.edu

Groundwater systems are famously under-constrained by observations, and the distribution of these observations are highly non-uniform across the globe. Over the past two decades, the promise of remote sensing and geophysical data for filling in spatial and temporal gaps in groundwater monitoring has grown. Yet progress towards that promise has largely remained in the realm of academic research and routine assimilation into applied groundwater modeling remains rare. While slow adoption and limited knowledge transfer play a role, we argue that the primary barrier is insufficient characterization and methodological approaches for coping with the complex noise structures and uncertainties in these datasets for predictive modeling applications.

InSAR-derived ground deformation illustrates this gap. Since 2014, the European Space Agency's Sentinel-1 satellites have provided weekly, near-global geodetic imagery which can be processed to detect millimeter-scale ground deformation at high spatial resolution. These measurements capture subsidence from compaction of aquifer sediments due to pumping and elastic rebound from recharge. Hence, InSAR data holds promise for informing and constraining elusive parameters such as pumping rates, storage properties, and recharge. However, InSAR ground deformation measurements contain complex, correlated noise attributable to atmospheric and ionospheric structures, topography, and vegetation, making assimilation into groundwater models non-trivial.

We present a proof-of-concept exploration of the promise of InSAR data in regional groundwater simulation. Using a synthetic "truth" model and empirically derived noise from a non-deforming region, we quantify the value of InSAR data in improving forecast accuracy and reducing bias/uncertainty in model water budget components relative to traditional calibration targets under noise representations ranging from a simple homoscedastic assumption to fully spatiotemporally correlated structures.

LID 0682
Fiber optic distributed temperature sensing deployment scenarios for high-resolution hydrogeologic characterization and monitoring

Carlos Maldaner[1,2]*, Jonathan Kennel[1], Jonathan Munn[1,3], Beth Parker[1]

[1] Morwick G360 Groundwater Research Institute, University of Guelph, Guelph, Canada
[2] Silixa Inc, Calgary, Canada
[3] City of Guelph, Guelph, Canada
* cmaldane@uoguelph.ca

Keywords: Distributed Temperature Sensing, groundwater flow, monitoring well seal integrity

Fiber-optic distributed sensing enables the collection of temperature data at very high spatial and temporal resolution. This capability opens new opportunities in hydrogeology, where traditional point-sensor measurements provide limited spatial coverage. Because the optical fiber itself acts as the sensor—with no electronics or moving parts—a fiber-optic cable can remain functional indefinitely. When copper conductors are incorporated into a hybrid cable, heat can be applied along its length to intentionally disturb the ambient temperature field. This approach, known as active Distributed Temperature Sensing (A-DTS), allows estimation of the thermal properties of the surrounding materials. During the first minutes of heating, the temperature response is dominated by the cable's own construction materials; afterward, the response reflects the properties of the adjacent formation, which depend on how the cable is deployed. This work focuses on fiber-optic cable installation in monitoring wells, typically vertical wells, but also includes a unique deployment in a horizontal well installed by directional drilling. The simplest installation involves lowering a cable into an open borehole, where both ambient and heated temperature profiles can provide insight into conditions within the water column. Vertical flow can be detected, although the temperature signal is often dominated by the largest flow zones, masking smaller ones. To avoid vertical flow and ensure consistent thermal coupling between the cable and the borehole wall, impermeable and flexible liners can be installed. By temporarily sealing the well, natural groundwater flow in the aquifer is re-established, allowing hydraulically active zones or fractures to be identified from active DTS data. Flow magnitudes can then be estimated through numerical modeling. However, open-hole installations are only feasible in competent bedrock. In unconsolidated formations, fiber-optic cables are typically attached to steel or PVC casing, and the annulus between the casing and borehole wall is permanently cemented. In these cases, the distance between the cable and the formation, as well as the presence of cement, can dampen the thermal response to groundwater flow and reduce sensitivity. In multilevel monitoring systems, the cable is positioned as close as possible to the borehole wall by securing it to the ends of centralizer fins. Active DTS measurements in these installations provide valuable information about the top and bottom of screened intervals, the thickness of monitoring zones, and the long-term integrity of bentonite seals. Data from three multilevel boreholes in a dolostone aquifer in Guelph, Ontario, show clear thermal contrasts between backfill materials. One interval exhibits a thermal anomaly consistent with a bentonite bridge, matching field-noted backfilling difficulties.

LID 0683

Machine learning diagnosis of baseflow index discrepancy between digital filters and hydrochemical tracers across South Korea

Hyun-Ji Kang[1]*, Seoin Choi[1], Min Seo Bae[1], Soonjae Lee[1], Seong-Taek Yun[1]

[1] Department of Earth and Environmental Sciences, Korea University, Seoul, Republic of Korea
* bisuraa@korea.ac.kr

Keywords: baseflow index, machine learning, hydrochemical tracer, recession analysis, SHAP, groundwater storage dam

Accurate baseflow index (BFI) estimation is fundamental to groundwater resource management, including storage dam siting and drought resilience planning. Digital filters (e.g., Eckhardt) rely solely on discharge data with fixed coefficients that may inadequately capture local hydrogeological heterogeneity. Machine learning (ML) can diagnose such limitations by integrating heterogeneous national-scale datasets.

Five national databases were compiled for 86 South Korean watersheds (55 after quality control): streamflow, surface water electrical conductivity (EC; 683 stations), groundwater EC (~1.6 million daily records from 1,157 wells), GIS layers, and climate indices — yielding 67 features including dual-scale TPI classification. Chemical BFI (cBFI) was derived via EC two-component mixing. XGBoost with SHAP identified discrepancy drivers; recession analysis constrained filter parameters; seasonal decomposition characterized temporal dynamics.

Four principal findings are identified: (1) Filter BFI (mean 0.66) systematically and substantially exceeds cBFI (0.19), with cBFI correlating significantly with 19 watershed attributes versus 7 for filter BFI, (2) Recession calibration indicates BFI_{max} should be ~0.29 rather than the default 0.80; the Collischonn–Fan (2013) method reduces RMSE from 0.48 to 0.26, (3) Discrepancy peaks in summer–autumn (0.50–0.54) versus winter (0.33), reflecting the prevalence of monsoon-driven recharge dynamics, and (4) XGBoost with permutation feature selection (LOO R^2 = 0.38) significantly outperforms linear models (Lasso R^2 = 0.13), with SHAP identifying EC separation, TPI composition, and urban land cover as principal predictors, confirming nonlinear hydrogeological controls on cBFI.

Extrapolation to 850 sub-basins yields a national cBFI map (mean = 0.28), providing a spatially continuous baseflow estimate independent of filter assumptions. Ongoing work integrates cBFI predictions with aquifer vulnerability indices for groundwater dam site prioritization.

This work was supported by the Management Technology for Groundwater Dams in Water Supply Vulnerable Areas Program of the Korea Environmental Industry & Technology Institute (KEITI), funded by the Ministry of Climate, Energy and Environment (MoCEE) (RS-2025-01842970).

LID 0684
Groundwater-level prediction in a limestone aquifer with a subsurface dam using tree-based ensemble learning

Shun Inoue[1]*, Mariko Suzuki[1], Kazuya Inoue [1]

[1] Graduate School of Agricultural Science, Kobe University, Kobe, Japan
* 259a006a@stu.kobe-u.ac.jp

Keywords: groundwater level, subsurface dam, machine learning

The southwestern islands of Japan are underlain by highly heterogeneous limestone aquifers forming karst hydrogeological systems with rapid hydraulic responses and limited natural storage. To secure irrigation water in these vulnerable environments, subsurface dams have been widely constructed to intercept groundwater flow using impermeable cutoff walls, thereby enhancing aquifer storage. Although these systems have improved agricultural productivity, groundwater levels within subsurface dam reservoirs cannot be directly observed throughout the domain, and physically based models capable of capturing their nonlinear dynamics remain limited. Increasing climate variability has intensified drought frequency and magnitude, leading to rapid groundwater-level declines and highlighting the need for reliable predictive tools.

This study develops a machine learning–based framework for one-month-ahead groundwater-level prediction to support adaptive and cost-effective groundwater management. Twenty-four observational variables, including meteorological factors, water quality parameters, pumping volume, and antecedent groundwater level, were used to construct training and testing datasets. Two decision tree–based ensemble algorithms, Extremely Randomized Trees (ERT) and eXtreme Gradient Boosting (XGBoost), were applied. Model performance was evaluated using multiple feature-selection strategies.

The results indicate that antecedent groundwater level, precipitation, potential evapotranspiration, and pumping volume consistently emerged as dominant predictors, underscoring the central role of aquifer storage. Additional meteorological and hydrochemical variables further improved prediction accuracy. XGBoost outperformed ERT, yielding lower prediction errors. The proposed framework successfully predicted groundwater levels one month ahead, demonstrating strong potential for drought risk mitigation and groundwater management in karst-based subsurface dam systems.

LID 0685
Constraining gamma transit time distributions in a volcanic island aquifer by combining seasonal $\delta^{18}O$ attenuation with multi-tracer ages

Hyun-Ji Kang[1]*, Suhyung Moon[2], Soohyun Moon[2], Hyun Ju Yoo[2], Kyounggu Kang[2], Seong-Taek Yun[1]

[1] Department of Earth and Environmental Sciences, Korea University, Seoul, Republic of Korea
[2] Jeju Special Self-Governing Province Development Corporation, Jeju, Republic of Korea
* bisuraa@korea.ac.kr

Keywords: stable water isotope, mean residence time, transit time distribution, dual porosity, CFCs, volcanic aquifer

Characterizing both young and old groundwater components is essential for vulnerability assessment in volcanic aquifers, where fractures and lava tubes coexist with porous basaltic matrix. In Kang et al. (2025), we investigated the Jeju volcanic island aquifer (South Korea) through monthly monitoring of 10 wells during 2016–2019, using CFC-11, CFC-12, CFC-113 and ^{3}H. Dispersion model (DM) fitting yielded mean residence times (MRTs) of 24.7–41.7 years, confirming multi-decadal groundwater dominated by slow matrix flow. Noble gas recharge temperatures (7.5–18.1 °C) and $\delta^{18}O$ altitude effects constrained recharge to 1095–1533 m a.s.l. on the mid-to-upper volcanic flanks. However, the multi-tracer approach primarily resolves the old water component, leaving the young fraction and full transit time distribution (TTD) shape poorly constrained.

To address this, we extend the analysis by applying the seasonal $\delta^{18}O$ amplitude attenuation method. Sinusoidal fitting to precipitation $\delta^{18}O$ from seven stations yields an annual amplitude of 1.17‰. The ratio of groundwater to precipitation amplitudes gives the young water fraction (F_{yw}), representing water younger than approximately 2.3 months. Across the 10 wells, F_{yw} ranges from 0.5% to 6.9% (median 2.0%), revealing a small but persistent young component despite multi-decadal mean ages.

By jointly constraining the gamma TTD with F_{yw} (young tail) and DM-MRT (bulk age) as independent inputs, we solve for the shape parameter α (0.43–0.93; median 0.69). All $\alpha < 1$, independently confirming dual-porosity flow inferred from the original tracer study. Age partitioning shows 3–17% of groundwater younger than 1 year and 13–34% younger than 5 years, quantifying contamination vulnerability that MRT alone cannot resolve. The weak F_{yw} –MRT correlation ($\rho = -0.22$) evidences partial decoupling of preferential and matrix flow in this heterogeneous volcanic system.

This study was financially supported by the 2024 research project (Title: Study on the interpretation of groundwater age and recharge characteristics of Jeju Samdasoo) funded by the Jeju Special Self- Governing Province Development Corporation.

LID 0689
Hydraulic testing and instrumentation strategies under extreme deep underground conditions

Bartosz Kaczynski[1]*

[1] Valenza Engineering, Melbourne, Australia
* bartosz@valenza-engineering.com

Hydraulic testing and pore pressure monitoring at depths approaching 1.7 km increasingly push beyond the practical limits of conventional hydrogeological instrumentation. This paper presents field experience from subhorizontal boreholes intersecting thermally elevated, hypersaline groundwater under very high differential pressures. Standard packer testing systems, drill stem testing (DST) approaches and permanent instrumentation such as vibrating wire piezometers were assessed where corrosion, mechanical damage risk, drilling instability and operational constraints significantly affect reliability.

Results indicate that equipment survivability, sealing performance and pressure control often govern data quality more strongly than formation properties themselves. Elevated temperature and brine density influence pressure recovery behaviour, fluid compressibility assumptions and interpretation confidence. Permanent installations near active underground development were frequently impractical, requiring modified testing sequences and acceptance of incomplete datasets.

To address these constraints, alternative monitoring concepts not typically applied in mining hydrogeology were conceptualised and evaluated, including retrievable liner-based systems and staged temporary monitoring installations. These options were assessed from both technical feasibility and cost-benefit perspectives, considering infrastructure longevity, operational risk and data value.

The study shows that deep groundwater characterisation increasingly demands adaptive testing design, cross-disciplinary interpretation and pragmatic monitoring strategies rather than reliance on standard shallow groundwater methodologies.

LID 0691
Evolution of hydrogeological conceptual models through feasibility stages and their influence on mining project outcomes

Bartosz Kaczynski[1]*

[1] Valenza Engineering, Melbourne, Australia
* bartosz@valenza-engineering.com

Hydrogeological conceptual models are frequently treated as static reporting requirements; however, in practice they evolve significantly as mining projects advance through scoping, prefeasibility and feasibility stages. This paper examines how progressive refinement of conceptual understanding — particularly of pore pressure distribution and hydraulic connectivity — can directly influence engineering design, risk allocation and overall project viability.

A case study is presented in which successive interpretation of hydraulic testing data, structural controls and groundwater behaviour resulted in substantial updates to the site conceptual model. Pore pressure, as one of the few hydrogeological parameters that can be actively managed through depressurisation and drainage strategies, proved central to design optimisation. Improved conceptualisation altered assumptions regarding ground support requirements, inflow management, development sequencing and operational risk.

The implications extended beyond geotechnical stability to broader water management components, including site water balance forecasts, sedimentation pond sizing, drainage infrastructure layout, water treatment capacity and tailings facility design. Parallel examples from established open pit operations demonstrate similar outcomes, where refinement of hydrogeological parameters has maximised resource access and supported production rates during favourable commodity cycles.

The study demonstrates that rigorous, iterative conceptualisation is a critical engineering control that materially affects both technical feasibility and economic performance.

LID 0692
Comparison and validation of groundwater sampling methods used in the groundwater chemical status assessment in Poland

Michał Wyszomierski[1]*, Anna Rojek[1]

[1] Polish Geological Institute - National Research Institute, Warsaw, Poland
* michal.wyszomierski@pgi.gov.pl

Keywords: groundwater monitoring, groundwater sampling methods, groundwater status and quality assessment

Field research and groundwater sampling are the core of every groundwater monitoring focused on the groundwater quality and chemical status assessing. Improper groundwater sampling, mistakes in adapting the sampling method to a specific purpose lead to incorrect results and generate significant errors.

The main purpose and goal of the research is quality and quantity evaluation of groundwater sampling techniques. The key task is to determine the impact of the applied groundwater sampling methods on the results variability and to assess the reliability and representativeness of groundwater field tests.

Comparison and validation included conservative methods, requiring purge pumping before sampling (submersible impeller pump and suction pump), modern methods as “low-flow” sampling and discrete sampling techniques (discrete passive bailer).

The range of physicochemical parameters analyzed in the test corresponds to the scope of monitoring the chemical status of groundwater in Poland, enabling common use of techniques listed above.

For statistical evaluation of the results SAS/Stat statistical software was used. Multivariate statistical analysis was based on generalised linear models (GLM models). The extended statistical analysis used Tukey's Post-Hoc HSD test (honest significant difference test). This made it possible to identify significant differences between methods and determine the impact of the sampling technique used on the variability of chemical test results. The test results showed that the techniques tested differed from each other in terms of quantity, while maintaining a similar level of quality.

The identified differences may affect the interpretation of monitoring results during groundwater chemical status assessing.

Identified quantitative differences can be interpreted as technical "BIAS" of the method. These errors can be corrected using the empirical transformation formulas proposed by the authors, developed on the Passing-Bablok robust regression model.

LID 0693
Understanding groundwater salinization dynamics in an alluvial coastal aquifer in eastern India

Bharat Moharana[1,2]*, Atulya Kumar Mohanty[1,2], Devender Kumar[1, 2], B. Kiran Kumar[1]

[1] CSIR- National Geophysical Research Institute, Uppal Road, Hyderabad, India
[2] Academy of Scientific and Innovative Research (AcSIR), Ghaziabad, India
* bharatmoharana80@gmail.com

Keywords: sand dunes, groundwater-seawater interaction, stable isotope, salinization

Over-extraction, Saline water mixing, and the escalating effects of climate change are putting coastal aquifer under increasing stress, which leads to salinization. Higher salinity not only degrades quality of water but also affects agriculture, which relies on freshwater resources. Hence, it is necessary to understand the salinization dynamics for better management practice. An integrated approach combining hydrogeology, hydrochemistry and $\delta^{2}H$ and $\delta^{18}O$ was conducted for this study in a coastal aquifer of Odisha, eastern India. The study found that wide variation in TDS (45 to 5278 mg/l), with Na^{+} and Cl^{-} being the major cation and anion, respectively in the groundwater. The samples having higher salinity showed elevated concentrations of Bromide (Br-) and Strontium (Sr^{2+}) along with ionic ratios (Na^{+}/Cl^{-}, Br^{-}/Cl^{-}), HFE diagram and correlation (Cl^{-} with Br^{-}, Li^{+}, B, Sr) resemble the mixing of saline water with coastal aquifer. The saline zone is mostly restricted along the tidal inlets, suggesting lateral and/or vertical intrusion of saline water. Further, the enriched $\delta^{2}H$ and $\delta^{18}O$ values in these samples support the mixing mechanism. The samples plotted against the Local Meteoric Water Line (LMWL) suggested a few samples were influenced by evaporation process before reaches water table, as it is potted below and to the right side of the LMWL, which is further supported by the D-excess value. An important observation found that the presence of sand dunes preserves the freshwater near coast because of high recharge potential and has not yet been salinized which is further protected by clay layer from below. However there is a chance of lateral intrusion from the tidal river if not managed well, as the low-lying region in the inland region has been affected by this process. The insights from this study are crucial for developing suitable strategies for the deployment of efficient monitoring and mitigating strategies for sustainable management of groundwater.

LID 0694
Concentration–Discharge hysteresis to characterise recharge at karst springs: The Unica springs case study

Blaž Kogovšek[1,2]*, Igor Jemcov[3], Nataša Ravbar[1,2], Cyril Mayaud[1,2], Matej Blatnik[1,2], Sara Skok[1,2], Janez Mulec[1,2], Metka Petrič[1,2]

[1] ZRC SAZU, Karst Research Institute, Postojna, Slovenia
[2] UNESCO Chair on Karst Education, University of Nova Gorica, Vipava, Slovenia
[3] University of Belgrade, Faculty of Mining and Geology, Belgrade, Serbia
* blaz.kogovsek@zrc-sazu.si

Keywords: karst aquifer, spring dynamics, water quality, hydrogeology

Karst aquifers are recharged by diffuse infiltration via soil and rock (autogenic recharge) and by concentrated inflow via swallow holes and sinking streams (allogenic recharge). Shifts in recharge origin can cause rapid changes in the physicochemical and microbiological characteristics of the water. To analyse these phenomena, we use concentration–discharge hysteresis analysis to define and compare the recharge behaviour of two karst water sources. The research was conducted in a binary karst aquifer within the catchment of the Unica and Malenščica springs (south-western Slovenia), an area with complex hydrodynamics shaped by both autogenic and allogenic recharge. The site benefits from extensive prior hydrogeological knowledge and a long-standing, dense monitoring network. Long-term records of temperature, specific conductance, and discharge at springs, water-active caves, and sinking streams were supplemented by event-based sampling for chemical and microbiological parameters. We used descriptive statistics to compare individual monitoring sites and identify hydraulic connections. We examined selected storm events under contrasting hydrological conditions in greater detail. Specific conductance–discharge hysteresis at the springs was evaluated alongside those from sinking streams and underground channels to characterise the mixing of groundwater derived from different recharge pathways. For selected storm events, we analysed hysteresis plots between discharge and water quality parameters (specific conductance, temperature, turbidity, $[Ca^{2+}/Mg^{2+}]$ ratio, chloride, and bacteria). The results show clear contrasts between the two springs in recharge dynamics, water transfer through the system, and chemical and microbiological characteristics. These differences constrain the spatial and temporal patterns of autogenic and allogenic recharge feeding each spring – information that is critical for designing effective protection strategies for these karst water resources.

The work was financially supported by the project "Coupled application of single-storm events and tracer analyses to characterise the flow and transport features of a karst aquifer" (Z2-50091) and the programme "Karst Research" (P6−0119), both funded by the Slovenian Research Agency.

LID 0695
Accounting for uncertainty in managed aquifer recharge potential mapping

Luk J.M. Peeters[1*], Dennis Gonzalez[2], Joseph Ha Guillaume [3,4]

[1] VITO Digital Water & Soils, Mol, Belgium
[2] CSIRO Environment, Adelaide, Australia
[3] Australian National University, Fenner School of Environment and Society, Canberra, Australia
[4] Australian National University, Institute for Water Futures, Canberra, Australia
* luk.peeters@vito.be

Keywords: managed aquifer recharge, uncertainty quantification

Scaling managed aquifer recharge (MAR) for agricultural resilience under a changing climate requires reliable estimates of storage potential. To support risk-based decision-making by industry and government, this study develops a stochastic spatial multi-criteria framework to quantify MAR potential in unconfined and confined aquifers across the Murray–Darling Basin (Australia).

The framework propagates uncertainty by varying threshold values for all suitability criteria, avoiding the subjectivity of weight-based approaches. For unconfined aquifers, stochastic criteria included aquifer presence, topographic slope, aquifer thickness, soil hydraulic conductivity, long-term groundwater level decline, and salinity. For confined aquifers, criteria comprised aquifer presence, effective thickness, overburden depth, hydraulic conductivity, groundwater level decline, and salinity. At each confidence level, feasible recharge or injection rates were estimated using spatially resolved aquifer properties.

Results highlight several high-potential regions, including the Lower Namoi Alluvium, where unconfined recharge rates of 5–20 ML/ha are achievable with high confidence. Confined aquifers also show strong potential, with feasible injection rates of 2.5–20 ML/d at high confidence and up to 80 ML/d at lower confidence thresholds. Groundwater-level trends and salinity consistently emerged as the most influential criteria controlling spatial uncertainty.

Across all unconfined resource units, total storage potential is approximately 10,000 GL, with ~65 % located within 5 km of major rivers. Confined aquifers exhibit extensive areas suitable for injection-based MAR across a wide range of rates.

This basin-scale, uncertainty-explicit assessment provides a robust platform for prioritizing local feasibility studies, identifying where high recharge potential aligns with groundwater stress and high-value agricultural production, supporting strategic MAR deployment to enhance water security.

LID 0697
Groundwater and soil contamination from gas stations in Jakarta Groundwater Basin: Hydrogeological risk, socioeconomic impacts, and strategic pollution control measures

Fikri Noor Azy[1]*, Dwi Nowo Martono[1], Haruki Agustina[1]

[1] School of Environmental Science, University of Indonesia, Central Jakarta, Indonesia
* fikrinoorazy@gmail.com

Keywords: groundwater pollution, hydrocarbon contamination, gas station leaks, benzene, MTBE, risk assessment, pollution control, SWOT analysis, Jakarta Groundwater Basin

Leaking underground storage tanks (LUSTs) at gas stations present a serious environmental risk, particularly in urbanized areas with high groundwater dependency. This study investigates hydrocarbon contamination from six gas stations in the Jakarta Groundwater Basin (Cekungan Air Tanah Jakarta), assessing pollutant dispersion, hydrogeological vulnerability, socioeconomic impacts, and the effectiveness of pollution control measures. Groundwater samples from affected sites revealed benzene concentrations ranging from 42 to 22,600 µg/L, while MTBE levels reached 117,000 µg/L, far exceeding the WHO limits. Soil analysis confirmed Total Petroleum Hydrocarbon (TPH) levels of up to 40,000 mg/kg, surpassing regulatory limits. The diameters of Benzene plumes extended between 40–122 meters, while MTBE plumes reached 44–72 meters, with migration patterns influenced by local hydrogeology and groundwater extraction. A quantitative SWOT analysis places Jakarta's pollution control efforts within the "Progressive" quadrant, indicating strong regulatory potential but requiring enhanced implementation. Strategic mitigation measures include improving leak detection technology, integrating Environmental Site Assessment (ESA) into Indonesian regulatory frameworks, and implementing targeted remedial action plan approaches. Additionally, most affected residents prefer receiving a reliable alternative water supply over financial compensation. Based on the economic analysis of alternative water supply options for affected residents during the clean-up process highlights that piped water supply (PDAM) is the most cost-effective mitigation measure, averaging Rp 84,444 per person per month, compared to Rp 336,111 per person per month for tanker-supplied water. These findings emphasize the urgency of proactive contamination prevention, regulatory reinforcement, and integrated remediation strategies to safeguard Jakarta's groundwater resources.

LID 0698
Development of a novel modelling framework to simulate global element fluxes at land-ocean interfaces

Stephan L. Seibert[1]*, Kayziel Martinez[2], Rena Meyer[1], Nils Moosdorf[2], Johannes Ritter[1], Janek Greskowiak[1]

[1] Institute for Biology and Environmental Sciences, Carl von Ossietzky Universität Oldenburg, Oldenburg, Germany
[2] Leibniz Centre for Tropical Marine Research (ZMT), Bremen, Germany
* stephan.seibert@uol.de

Keywords: coastal hydrogeology, submarine groundwater discharge, subterranean estuaries

Groundwater discharging into coastal environments is an important pathway for fluxes of dissolved species. Consequently, it has been shown that submarine groundwater discharge is an essential driver sustaining coastal ecosystems. The biogeochemical processes that occur prior to groundwater discharge within the so-called Subterranean Estuaries (STEs) are highly complex, involving various chemical reactions coupled to variable-density groundwater flow and salt transport.

The non-linear behaviour of the biogeochemistry in concert with the strong hydrodynamics encountered at coasts, including waves, tides and storm surges, call for the application of reactive transport modelling. Ultimately, a comprehensive process understanding of the STE biogeochemistry based on robust reactive modelling frameworks, taking into account relevant environmental parameters and biogeochemical processes, will enable global quantifications of element fluxes via submarine groundwater discharge. Such model-based insights are urgently needed for sustainable coastal management and to predict how climate change will impact coastal ecosystems in the future. Yet, the high numerical burden for global reactive modelling frameworks remains a major obstacle.

We aim to fill this gap by combining field-informed reactive transport modelling with surrogate modelling, e.g., machine learning, within the project DynaDeep (The Dynamic Deep Subsurface of High-Energy Beaches). The results of our work at this stage present the conceptual modelling framework, covering the assemblage of a global database, identification of main environmental parameters governing the STE biogeochemistry, as well as the development of surrogate modelling approaches. Future work will focus on testing and validating the conceptual modelling framework for simulating global STE element fluxes, along with rigorous uncertainty estimations.

LID 0699
Hydrogeological characterization of flow system feeding the Lake Hévíz by the application of natural tracers

Saeed Bidar Kahnamuei[1]*, Katalin Hegedűs-Csondor[1], Ákos Horváth[2], Dénes Szieberth[3], György Czuppon[4], Márta Vargha[5], Bálint Izsák[5,6], Anita Erőss[1]

1 ELTE Eötvös Loránd University, Institute of Geography and Earth Sciences, Department of Geology, József and Erzsébet Tóth Endowed Hydrogeology Chair, Budapest, Hungary
2 ELTE Eötvös Loránd University, Institute of Atomic Physics and Astronomy, Department of Atomic Physics, Budapest, Hungary
3 Budapest University of Technology and Economics, Department of Inorganic and Analytical Chemistry, Budapest, Hungary
4 HUN-REN Research Center for Astronomy and Earth Sciences, Institute for Geological and Geochemical Research, Budapest Hungary
5 National Center for Public Health and Pharmacy, Department of Public Health Laboratories and Methodology, Budapest, Hungary
6 Faculty of Health Sciences, Department of Public Health Sciences, Semmelweis University, Budapest, Hungary
* saeedbdr@student.elte.hu

Keywords: thermal lake, hydrogeochemical characteristics, mixing fluids, radionuclides, stable isotopes, ICP-MS, NucFilm, alpha spectrometry

Lake Hévíz, known as one of the largest thermal lakes in the world, is located in the western part of Hungary, in the discharge zone of the Transdanubian Range karst system. Several springs, located within a cave in the lakebed, discharge waters at varying temperatures and generate the lake's sulfuric therapeutic water. These springs play a significant role in the formation of the cave and the lake's unique ecosystem as well. In this study we conducted a comprehensive geochemical analysis of water samples from the lake's drainage basin, including springs, observation wells, thermal and drinking water wells. ICP-MS and ion chromatography were used for hydrochemical analysis to measure major ion concentrations and define water facies. In general, a similar dissolved solid content was detectable in the water samples, while substitution of Ca^{2+} (as the dominant cation) with Mg^{2+} occurred in the cation facies of some thermal wells and one of the cave samples, alongside disparate temperature regimes with notable variations in redox conditions. In addition, alpha spectrometry on selectively adsorbing NucFilm discs, as an innovative approach was applied to measure uranium and radium isotopes. Radon was measured by the liquid scintillation technique. Low radium, uranium, and radon levels were detected in the thermal wells with the highest temperature, while the highest radionuclide concentrations occurred inside the cave related to mixing of different fluids. The stable isotope (δ^2H and $\delta^{18}O$) composition of the samples suggests meteoric origin with different subsurface residence times. The integrated groundwater geochemistry framework for Lake Hévíz revealed that the lake receives water via various flow paths. Particularly, this approach offered a novel perspective by using radionuclides as natural tracers when conventional hydrochemical data were not fully sufficient to identify complex rock-water interaction processes.

LID 0700
Crossing nitrate isotopes and contaminants of emerging concerns to investigate pollution processes to N'Djamena urban groundwater resources

Sougoudji Mahamat Ahmat[1,2], **Frédéric Huneau**[1]*, Abdallah Mahamat Nour[2], Wassef Ben Nasr[1], Emilie Garel[1]

[1] Université de Corse, UMR CNRS 6134 SPE, Equipe Hydrogéologie, Corte, France
[2] Université de N'Djaména, Laboratoire d'Hydro-Géosciences et Réservoirs (LHGR), Département de Géologie, N'Djaména, Chad
* huneau_f@univ-corse.fr

Keywords: urban groundwater, nitrate isotopes, contaminants of emerging concerns, Chad

As in many rapidly expanding African capitals, groundwater in N'Djamena faces growing anthropogenic pressure from rapid urbanization, uncontrolled spatial expansion, and sustained population growth. These processes place increasing stress on aquifers and lead to progressive groundwater quality degradation, threatening the long-term security of this essential resource. Meeting this challenge requires an integrated understanding of groundwater system functioning, including recharge sources and mechanisms, residence times, and mixing between shallow aquifers and deeper borehole-captured units. Assessing groundwater quality and identifying pollution fingerprints under urban pressure are equally critical. In this framework, contaminants of emerging concern (CECs) combined with isotopic tracers provide a robust monitoring approach. Emerging organic compounds—such as pharmaceuticals, personal care products, and artificial sweeteners—act as sensitive indicators of domestic wastewater inputs. Stable and radioactive isotopes ($\delta^{18}O$, $\delta^{2}H$, ^{3}H, $\delta^{15}N$) help characterize recharge dynamics, groundwater age, and nitrogen pollution sources. Nitrogen isotopes are particularly effective for tracing nitrate origins and distinguishing anthropogenic from natural inputs. Despite their relevance, emerging contaminants have not previously been investigated in groundwater or surface waters in N'Djamena, Chad. This study therefore applies an innovative multi-tracer strategy integrating hydrochemical parameters and the screening of 126 emerging organic compounds to identify groundwater degradation processes. Sampling was carried out in October 2024 at 35 sites, including river water, shallow wells, and deep boreholes. Results show clear evidence of domestic pollution affecting shallow groundwater. However, some deeper aquifers remain relatively preserved, likely due to local hydrogeological conditions that restrict vertical contaminant transfer. Overall, this integrative approach provides new insights into groundwater vulnerability and resilience in urban Sahelian settings and supports sustainable groundwater management in N'Djamena.

LID 0701
Combined time-series analysis, satellite data and machine learning techniques in water balance assessment for the Kis-Balaton Water Protection System

Márk Szijártó[1,2,3]*, Adél Petneházy[1,2,3], István Fórizs[2,3], György Czuppon[2,3], Fruzsina Kapolcsi[4], Zsófia Látrányi-Lovász[4], Adrienne Clement[5], Bruno Batki[6], István Gábor Hatvani[2,3]

[1] Department of Geophysics and Space Science, Department of Geology, József & Erzsébet Tóth Endowed Hydrogeology Chair, ELTE Eötvös Loránd University, Budapest, Hungary
[2] Institute for Geological and Geochemical Research, HUN-REN Research Centre for Astronomy and Earth Sciences, Budapest, Hungary
[3] CSFK, MTA Centre of Excellence, Budapest, Hungary
[4] West-Transdanubian Water Directorate, Szombathely, Hungary
[5] Department of Sanitary and Environmental Engineering, Budapest University of Technology and Economics, Budapest, Hungary
[6] Freelancer
* mark.szijarto@ttk.elte.hu

Keywords: time-series analysis, machine learning, satellite data, water protection system

The Kis-Balaton Water Protection System (KBWPS) is a complex, semi-constructed wetland consisting of multiple habitats (functional units) that play a significant role in protecting the water quality of Lake Balaton, the largest shallow freshwater lake in Central Europe. Previously, it was noted that the water balance of the KBWPS can only be determined with high uncertainty. For instance, estimating evaporation and subsurface water input is one of the most crucial factors in water balance calculations.

To quantify and predict the system's hydrological behaviour, a Long Short-Term Memory (LSTM) model was developed to estimate daily outflow at a single-point-shaped civil engineering structure connecting the KBWPS to Lake Balaton. The model was trained using meteorological variables and observed daily discharge time series, allowing the network to capture temporal dependencies and delayed system responses. A comprehensive statistical analysis was carried out to identify relationships among the parameters and reduce measurement errors and the need for manual correction. In addition, isotope time series provide insights into water residence times and mixing processes (including subsurface water contribution), which are essential for understanding the water quality protection function of the system.

In parallel, NDVI-based satellite estimates were applied to characterise evapotranspiration dynamics. In addition, Sentinel-2 satellite data were used to refine the spatial structure of vegetation, which directly influenced the transpiration. The development of a vegetation delineation methodology based on NDVI classification improves the accuracy of water balance component determination by separating water surfaces from vegetation-covered areas.

This project was supported by the János Bolyai Research Scholarship of the Hungarian Academy of Sciences. The research was supported by the National Multidisciplinary Laboratory for Climate Change, RRF-2.3.1–21-2022–00014 project.

LID 0703
The influence of climate change on the groundwater vulnerability index of the hydrogeological map of Poland 1:50,000

Magdalena Nidental[1]*, Małgorzata Woźnicka[1], Krzysztof Jóźwiak[1]

[1] Polish Geological Institute – National Research Institute, Warsaw, Poland
* magdalena.nidental@pgi.gov.pl

Keywords: groundwater, vulnerability, climate change

The Hydrogeological Map of Poland 1:50,000 (HMP) includes information layers regarding the First Aquifer (FA) like conditions of occurrence, hydrogeological properties, groundwater vulnerability to pollution and groundwater quality. The study of groundwater vulnerability to pollution index was carried out in the years 2006-2013 and has not yet covered the entire territory of Poland. The assessment of the FA's groundwater vulnerability was created using modified methodology applied in Groundwater Vulnerability Map 1:500,000. Shown on the collective HMP groundwater vulnerability index presents an approximate time needed for pollution to be transferred to the FA, based on the mean residence time (MRT), which is an average amount of time that a particle spends in a particular flow system. The modified methodology based on an assessment of the geological and hydrogeological environment of the FA also includes conditions of the land surface like terrain slopes, land development and types of soil.

The observed changes in the natural environment caused by climate change (drought, floods, extension of the growing season) and the resulting changes related to land development and agriculture make it clear that there is a need to change the applied methodology, which would include the above-mentioned aspects of the changes. The coefficients that should be modified are recharging infiltration (consideration of the amount and intensity of precipitation in the prognosis used until 2050) and land development – urbanization and agriculture (consideration of biologically active areas and growing season).

The proposed changes to the methodology may significantly affect the time needed for pollution to be transferred to the FA. This will be most noticeable in areas where the FA occurs at shallow depths and there is no geological isolation (influence on the thickness of the saturation zone).

LID 0705
From conceptual to large-scale integrated hydrological modelling

Okke Batelaan[1]*, Daniel Partington[1], Saskia Noorduijn[2], Huade Guan[1]

[1] National Centre for Groundwater Research and Training, Flinders University, Adelaide, Australia
[2] CSIRO, Adelaide, Australia
* okke.batelaan@flinders.edu.au

Keywords: conceptual, large-scale, Australia

There is a growing realisation in the scientific community that groundwater-related processes need to be better integrated into large-scale climate and earth system modelling. Incorporating groundwater into these models enables the emergence of fluxes and feedback mechanisms between components of the earth system. Although the importance of groundwater in large-scale models is place- and time-dependent, these feedbacks are hypothesised to be critical drivers of terrestrial water storage anomalies and latent heat fluxes. Translating the physical understanding of local and basin-scale groundwater flow processes into earth system models presents challenges, but it will also depend on the modelling purpose, e.g., water resource management, climate projection, or system understanding. In hydrogeology, we are accustomed to expressing our understanding of a groundwater system, before we start modelling, in a conceptual model. However, it is also becoming increasingly obvious that conceptual uncertainty is one of the larger and least addressed parts of the known-unknowns we deal with.

In this contribution, we aim to provide a structured methodology that ensures greater model transparency and reproducibility by assessing and documenting the hydrogeological conditions and groundwater processes, along with the associated assumptions and simplifications. This approach systematically generates one or more conceptualisations that can be rigorously tested in large-scale integrated hydrological modelling exercises. We will also argue why, for the hydrogeological community, large-scale (groundwater) integrated hydrological modelling will advance our field of science and support local-to-regional-scale groundwater management. Finally, by adapting and refining established continental-scale frameworks to the unique hydrogeological context of Australia, we present the first steps towards large-scale (groundwater) integrated hydrological modelling for Australia.

LID 0706

Application of nitrate and water stable isotopes to evaluate nitrate dynamics and surface-groundwater interaction in the Lower Lobau Floodplain Aquifer (Danube River Basin)

Monis Nolitha Gcakasi[1]*, Clemens Karwautz[2], Naomi S. Wells[3], Grit Rasch[2], Christian Griebler[2], Christine Stumpp[1]

[1] Institute of Soil Physics and Rural Water Management, Department of Landscape, Water and Infrastructure, BOKU University, Vienna, Austria
[2] Department of Functional and Evolutionary Ecology, University of Vienna, Vienna, Austria
[3] Department of Soil & Physical Sciences, Agriculture and Life Sciences, Lincoln University, Lincoln, New Zealand
* monis.gcakasi@boku.ac.at

Keywords: nitrate, groundwater, isotopes

The Lower Lobau floodplain aquifer, part of the Lobau Wetland east of Vienna, Austria, provides important ecosystem services, including the removal of excess nitrate (NO_3^-) and support of microbial transformations such as denitrification. However, limited knowledge exists regarding the sources of NO_3^-, its long-term biogeochemical dynamics, and the role of surface water-groundwater interactions in regulating NO_3^- cycling within this aquifer. This study applies NO_3^- and water (H_2O) stable isotopes to address these knowledge gaps. Groundwater and surface-water end-member sampling was conducted from October 2023 to November 2024. Field measurements included pH, electrical conductivity (EC), dissolved oxygen (O_2), and temperature. Laboratory analyses comprised dissolved inorganic carbon (DIC), major cations and anions, and stable isotopes of water (δ^2H-H_2O and $\delta^{18}O$-H_2O) and nitrate ($\delta^{15}N$-NO_3^- and $\delta^{18}O$-NO_3^-). Additional hydrochemical and water isotope data from 2020-2025 were incorporated to enable assessment of long-term dynamics. pH (7.62-8.08) and EC (513-614 µS cm^{-1}) showed no significant temporal fluctuations. All samples were classified as calcium-magnesium-bicarbonate type waters, with Ca^{2+} and Mg^{2+} as the dominant cations and HCO_3^- as the dominant anion. On average, NO_3^- concentrations were lowest during summer (June-August: 0.13±0.2 mg L^{-1}) and highest during winter (December-February: 0.81±0.8 mg L^{-1}), exhibiting seasonal trends corresponding to O_2 dynamics. The $\delta^{15}N$-NO_3^- and $\delta^{18}O$-NO_3^- values indicate that NO_3^- is mainly sourced from soil nitrogen, while the δ^2H-H_2O and $\delta^{18}O$-H_2O values demonstrate clear seasonal variability and confirm hydraulic interaction between the aquifer and nearby surface waters. Overall, this study highlights the role of surface-groundwater interaction in controlling biogeochemical transformations within the Lower Lobau.

LID 0707
Comparative analysis of different methods for delineating three-dimensional groundwater flow systems

Zhi-Yuan Zhang[1]*, Xiao-Wei Jiang[1], Han-Yu Yin[1], Xu-Sheng Wang[1], Jun-Zhi Wang[2], Li Wan[1]

[1] China University of Geosciences, Beijing, China
[2] Yellow River Engineering Consulting Co., Ltd., Zhengzhou, China
* zhiyuan.zhang@cugb.edu.cn

Keywords: groundwater flow systems, Python codes, 3D basins

Identifying groundwater flow systems is a fundamental step in applying the theory of hierarchically nested flow systems. However, delineating such systems in complex three-dimensional (3D) basins remains a substantial challenge. In recent years, our research group has developed several approaches for 3D flow system delineation, including the residence time distribution (RTD) method—based on dimensionless residence times of dividing streamlines; the stagnation/pseudo-stagnation line method—based on abrupt changes in the direction of dividing streamlines; and the connective indices method—based on the topological relation between recharge and discharge zones. Despite these developments, a direct comparison of the three methods has not yet been carried out. In this study, we implement the RTD and connective indices methods using open-source Python code for the first time. By applying these three methods to several classic Tóthian-type basins, we evaluate and compare their performance in delineating flow systems and discuss their respective applicability and limitations. This study elucidates the methodological disparities in delineating groundwater flow systems, thereby facilitating the broader application of groundwater flow system theory.

LID 0708
Assessing climate change impacts on mountain karst spring discharge using hydrological modelling and climate projections

Nataša Ravbar[1,2]*, Herve Jourde[3], Matej Blatnik[1,2], Cyril Mayaud[1,2], Blaž Kogovšek[1,2], Metka Petrič[1,2]

[1] ZRC SAZU, Karst Research Institute, Postojna, Slovenia
[2] UNESCO Chair on Karst Education, University of Nova Gorica, Vipava, Slovenia
[3] HydroSciences Montpellier, Université de Montpellier, Montpellier, France
* natasa.ravbar@zrc-sazu.si

Keywords: karst water source, KarstMod, climate change, hydrological changes, Alps

Understanding climate change impacts on hydrological processes in mountainous karst regions is essential for reliable water resource management. This study examines Zelenci Spring in northwestern Slovenia, which has a flow of up to 6 m^3/s, and is one of the main sources of the Sava River, a major tributary of the Danube. Long-term meteorological and hydrological data were analysed and the KarstMod model was used to simulate the response of the karst spring to projected climate variability. Precipitation, air temperature, and evapotranspiration data from Rateče meteorological station, along with discharge data from Kranjska Gora gauging station for the period 1981–2023 were used. In addition, hydrological modelling used climate projections from an ensemble of six global and regional climate models under the RCP 4.5 and 8.5 scenarios for the periods 2011–2040, 2041–2070, and 2071–2100, relative to the 1981–2010 reference period. Preliminary results of model validation against observed discharge for 2011–2023 showed good agreement at the annual scale, with an overall difference of 6%, although modelled discharge was slightly underestimated. The largest underestimations occurred in late spring and summer, while overestimations were observed in winter and autumn. Due to significant uncertainties in climate projections, climate-driven simulations projected higher discharge than measured values, with increases ranging from 0.84 to 1.8 m^3/s. Differences between scenarios were relatively small. Seasonal projections consistently showed the highest discharge in autumn and spring, with lower values in winter and summer. Trend analysis revealed very weak to weak and mostly non-significant trends, with limited statistical significance and strong model dependence. These results indicate that while overall annual discharge may remain relatively stable, seasonal redistribution of flow is likely, with potential implications for water availability under future climate conditions.

The work was financially supported by the Slovenian Research Agency through the programme Karst Research (P6−0119) and the Slovenian Environment Agency (Grant number 2571-24-700010).

LID 0709
Integrated hydro-climatic assessment of groundwater storage variability using recharge models and GRACE data

Dhara Kakwani[1]*, Padmaja Sudhakar[1,2]

[1] Department of Environmental Studies, Faculty of Science, The Maharaja Sayajirao University of Baroda, Vadodara, India
[2] Department of Chemistry, Faculty of Science, The Maharaja Sayajirao University of Baroda, Vadodara, India
* dharakakwani@gmail.com

Keywords: groundwater recharge, GWSA, GRACE, Mann–Kendall test, Sen's slope, semiarid basin, correlation analysis

Understanding groundwater sustainability in semi-arid regions requires integrated evaluation of recharge dynamics and groundwater storage variability. The present study assesses the relationship between rainfall, multiple recharge estimation methods, and Groundwater Storage Anomaly (GWSA) derived from GRACE satellite data for a semi-arid watershed in western India. The Heran watershed, a part of the lower Narmada basin, is a unique bedrock watershed dominated by several structural controls and is an agrarian watershed. Annual groundwater recharge was estimated using four empirical approaches, including Water Balance (WB), Krishna Rao (KR), Modified Empirical (ME), and Chaturvedi methods. Trend detection was performed using the non-parametric Mann–Kendall test with Sen's slope estimator, while Pearson correlation analysis was applied to examine associations between recharge estimates and annualized GWSA changes.

Results indicate that annual rainfall exhibits no significant monotonic trend ($Z = 0.158$, $p = 0.874$) with a marginal Sen's slope of +1.63 mm/year, suggesting interannual variability rather than systematic climatic change. Similarly, groundwater storage anomalies show no statistically significant trend ($p > 0.05$), indicating relative long-term stability. Correlation analysis reveals weak and negative relationships between recharge estimates and annual GWSA change ($r \approx -0.15$; $p > 0.46$), as well as between rainfall and GWSA ($r = -0.146$; $p = 0.506$). The non-significant correlations suggest that groundwater storage variability is not directly controlled by annual recharge alone.

The findings imply that factors such as groundwater abstraction, irrigation demand, delayed aquifer response, and basin-scale GRACE smoothing effects may play a dominant role in governing groundwater storage dynamics. This study highlights the complexity of hydroclimatic interactions in semi-arid aquifer systems and underscores the need for integrating satellite observations with ground-based hydrological assessments for sustainable groundwater management.

LID 0710
Coupling pumping-test interpretation and natural tracers to characterize compartmentalization in a mineral water fractured aquifer

Davia Orticoni[1]*, Romain Chesnaux[2], , Sébastien Santoni[1], Emilie Garel[1], Frédéric Huneau[1]

[1] Université de Corse, UMR CNRS 6134 SPE, Equipe Hydrogéologie, Corte, France
[2] Research Group R2Eau, Centre d'études sur les ressources minérales, Université du Québec à Chicoutimi, Chicoutimi, Québec Canada
* daviaorticoni123@gmail.com

Keywords: fractured rock aquifer, pumping-test, tracer coupling, Zilia mineral water

Understanding the functioning of exploited aquifers is essential for sustainable groundwater management, particularly for natural mineral waters where long-term physico-chemical stability depends on flow dynamics and recharge pathways. Pumping-test interpretations based on classical analytical solutions (e.g., Theis) are widely used but may be limited in heterogeneous systems such as fractured basement aquifers overlain by colluvial deposits, where double-porosity processes and compartmentalized flow can occur.

This study investigates an exploited heterogeneous basement aquifer system to test the hypothesis that apparent hydraulic responses may conceal multiple groundwater contributions. We examine whether standard analytical approaches adequately describe such systems, how flow geometry (flow dimension n) evolves during pumping, and whether pumping mobilizes distinct groundwater compartments within the fractured bedrock–colluvial continuum.

Two constant-rate pumping tests conducted in March and September 2025 were analysed using logarithmic drawdown derivatives to identify flow regimes and estimate n. Hydraulic interpretation was coupled with natural tracers, including stable isotopes (δ^2H, $\delta^{18}O$), tritium and dissolved radon (^{222}Rn), monitored throughout the tests.

Both tests show comparable hydraulic behaviour, with an initial linear flow regime ($n \approx 1$) followed by radial conditions ($n \approx 2$), suggesting a progressive hydraulic homogenization. Tracer responses, however, differ. In March, isotopic and tritium variations indicate alternating contributions from at least two groundwater compartments, likely involving fractured bedrock and colluvial storage. In September, a single, younger signature associated with lower radon activities dominates, suggesting either mobilisation of one main compartment or stronger mixing and dilution by recent recharge.

These results demonstrate that hydraulic homogenization may mask dynamic variations in groundwater sources. The coupled hydraulic–tracer approach shows strong potential to characterize internal connectivity and refine conceptual models, although interpretations remain influenced by observation scale and non-uniqueness of conceptual scenarios.

LID 0711
Water mixing processes and eco-hydrogeological dynamics in Mediterranean temporary lagoons

Thomas Leydier[1]*, Marie Astruc[1], Emilie Garel[1], Marie Garrido[2], Sébastien Santoni[1], Sandy Ton-Thât[3], Ileana Quiquerez[3], Laetitia Hugot[3], Frédéric Huneau[1], Vanina Pasqualini[1]

[1] Université de Corse, UMR CNRS 6134 SPE, Equipe Hydrogéologie, Corte, France
[2] Service Biodiversité Terrestre, Office de l'Environnement de la Corse, Corte, France
[3] Conservatoire Botanique National de Corse, Office de l'Environnement de la Corse, Corte, France
* leydier_t@univ-corse.fr

Keywords: groundwater-dependent ecosystems, Mediterranean temporary lagoons, eco-hydrology

Coastal wetlands provide key ecosystem services, including biodiversity support, regulation of the water cycle, shoreline protection and preservation of socio-economic and cultural heritage. Among them, Mediterranean temporary lagoons are particularly sensitive ecosystems, whose seasonal hydrological dynamics regulate catchment fluxes while sustaining highly specialized biological communities. However, this strong seasonal variability also makes these systems especially vulnerable to increasing anthropogenic pressures and climate change, which are amplified in Mediterranean contexts.

This study aims to characterize the eco-hydrogeological functioning of Mediterranean temporary lagoons by focusing on water mixing processes and hydrological connectivity between multiple water sources, including groundwater. Five temporary lagoons located in Corsica were monitored, covering a wide range of climatic, geomorphological, geological and anthropogenic settings. Hydrological monitoring combined with physicochemical and isotopic tracers was used to identify the relative contributions of seawater, precipitation, surface runoff, rivers and groundwater to lagoon water balance and seasonal dynamics.

These hydrological and hydrogeological investigations were coupled with an ecological monitoring of phytoplankton and macrophyte communities, which were used as integrative indicators of hydrological regimes, salinity gradients and water residence time. Pollutant sources and fluxes were also investigated to better constrain the functional space of these coastal hydroecosystems. By linking water mixing processes with biological indicators, this study highlights the role of hydrological interactions in shaping the structure and functioning of Mediterranean temporary lagoons, and provides insights to support their conservation under global change pressures.

LID 0713
Multi-tracer isotope approach for groundwater–surface water interactions in a Mediterranean complex aquifer exploited for natural mineral water

Davia Orticoni[1]*, Sébastien Santoni[1], Emilie Garel[1], Thomas Leydier [1], Frédéric Huneau[1]

[1] Université de Corse, UMR CNRS 6134 SPE, Equipe Hydrogéologie, Corte, France
* daviaorticoni123@gmail.com

Keywords: groundwater–surface water interactions, environmental tracers, natural mineral water

Mediterranean hydrosystems are strongly influenced by seasonal hydroclimatic variability, which controls groundwater recharge and groundwater–surface water interactions. Understanding these processes is essential in aquifers exploited for natural mineral water, where both quantitative sustainability and physico-chemical stability must be preserved.

This study investigates the seasonal functioning of a Mediterranean double-porosity hydrosystem and proposes a conceptual model of groundwater–surface water interactions together with an assessment of the vulnerability of the exploited resource. A catchment-scale hydrogeochemical and isotopic monitoring network was deployed, including 14 sites (boreholes, springs and rivers) sampled every two weeks over two hydrological cycles since May 2024. In situ parameters were combined with dissolved radon (^{222}Rn), stable water isotopes ($\delta^{18}O$, $\delta^{2}H$), major ions, silica and rainfall monitoring.

Groundwater from the exploited FZ2 borehole shows a remarkably stable isotopic signature throughout the year ($\delta^{18}O$ from −8.7 to −8.5‰), whereas river waters display a wider range (−8.6 to −7.0‰) with summer enrichment. Radon concentrations are systematically higher downstream of the aquifer than upstream and increase markedly during low-flow periods, highlighting active groundwater discharge zones. These combined tracers indicate a gaining-stream system sustained by persistent groundwater inputs, intensifying downstream and remaining dominant throughout the year, with no seasonal flow reversal.

These findings indicate limited qualitative vulnerability of the exploited resource, reflecting buffered recharge and long residence times, and confirm the key role of groundwater discharge in sustaining summer baseflow, supporting catchment-scale sustainable management under increasing climatic pressure.

LID 0714
Exploring the potential of Nature-based Solutions for Mediterranean coastal groundwater-dependent wetlands through a participatory Living-Lab approach

Thomas Leydier[1]*, Marie Astruc[1], Emilie Garel[1], Sébastien Santoni[1], Frédéric Huneau[1], Vanina Pasqualini[1]

[1] Université de Corse, UMR CNRS 6134 SPE, Equipe Hydrogéologie, Corte, France
* leydier_t@univ-corse.fr

Keywords: Nature-based Solutions, Living-Lab approach, Mediterranean coastal wetlands, groundwater connectivity

Mediterranean coastal wetlands provide multiple essential ecosystem services, including shoreline protection, nursery habitats, and cultural heritage. These systems are increasingly exposed to climatic and anthropogenic pressures, such as urbanization, pollution, erosion, flooding, droughts, and sea-level rise. In this context, Nature-based Solutions (NbS) are considered as promising tools to support sustainable management and restoration.

This study explores the potential of NbS for Mediterranean groundwater-connected coastal wetlands in Corsica and their integration into local management strategies. The work is structured around three key axes: (i) establishing an overview of NbS implemented locally through literature review and stakeholder surveys, (ii) improving understanding of the eco-hydrogeological functioning of complex Mediterranean coastal wetlands, and (iii) supporting stakeholders in decision-making through co-construction, including a participatory workshop to discuss applicability and adaptation of NbS to local contexts.

The interventions considered include hydrological and hydrogeological reconnection, management of invasive species, and protection or restoration of sandy and salt-marsh ecosystems. Through co-construction with stakeholders and integration of scientific knowledge, this approach examines how NbS could contribute to adaptive and inclusive water management in groundwater-connected coastal wetlands.

The study is part of the PEPR SoluBioD research program and the MedCoast Living Lab, fostering the integration of scientific research and co-construction with local actors.

LID 0715
Influence of hydraulic conductivity distributions on solute transport in a karstic limestone aquifer

Kanako Fujieda[1]*, Hokuto Okabe[1], Shun Inoue[1], Kazuya Inoue[1]

[1] Graduate School of Agricultural Science, Kobe University, Kobe, Japan
* 253a009a@stu.kobe-u.ac.jp

Keywords: solute transport, macro-dispersion, karstic limestone aquifer, random walk particle tracking, hydraulic conductivity distribution

Karst aquifers are characterized by pronounced hydraulic heterogeneity and preferential flow pathways, which strongly govern solute transport behavior. To quantitatively evaluate transport characteristics in a karst setting, single-well dilution tests using NaCl tracer were conducted at 20 observation wells to identify the spatial heterogeneity of hydraulic conductivity. Based on the estimated degree of heterogeneity, a hydraulic conductivity field was constructed through block kriging. To examine how the representation of heterogeneity influences solute transport, laboratory experiments were performed in a two-dimensional sandbox model (200 cm × 80 cm × 3 cm) reflecting the kriged conductivity distribution. In addition to the kriging-based heterogeneous field, a stratified conductivity structure representing sedimentary layering was also considered for comparison.

Solute transport processes were simultaneously simulated using a random walk particle tracking to numerically reproduce the experimental results and to analyze transport characteristics from the perspective of macro-dispersion. The results revealed that temporal evolution of dispersion differed markedly between the stratified and spatially heterogeneous fields. At the experimental scale, the stratified configuration produced larger longitudinal dispersion than the kriging-based heterogeneous distribution. These findings indicate that fast flow components and localized preferential transport pathways, which are intrinsic to karst systems, play a fundamental role in controlling solute migration. Furthermore, even when derived from the same degree of hydraulic heterogeneity identified by single-well dilution tests, different methods for expanding point-scale information into spatial distributions lead to different estimations of solute transport behavior. The study highlights the critical importance of appropriately representing subsurface heterogeneity when evaluating solute transport in karst aquifers.

LID 0716
Integrated hydrogeophysics and hydrogeological modelling to support managed aquifer recharge and climate-resilient groundwater supply

Ankita Prayag[1]*, Peter Dahlqvist[2], Jan-Erik Rosberg[1], Tina Martin[1]

[1] Engineering Geology, Lund University, Sweden
[2] Geological survey of Sweden, SGU, Sweden
* ankita.prayag@tg.lth.se

Keywords: managed aquifer recharge, groundwater, hydrogeophysics, SkyTEM

Managed Aquifer Recharge (MAR) is a key climate adaptation strategy to enhance groundwater storage and secure drinking water supply under increasing climate variability. The Vomb Water Works in southern Sweden operates a large MAR system comprising 54 infiltration ponds constructed in highly permeable glaciofluvial deposits within the Vomb Trough aquifer system. Surface water from Lake Vomb infiltrates through the ponds and is recovered via abstraction wells after subsurface residence, providing natural filtration and improving water quality. At the site scale, a pilot infiltration pond was equipped with continuous hydrogeophysical monitoring, including electrical resistivity tomography (ERT), groundwater level, soil moisture, and temperature sensors. Time-lapse measurements collected before and after infiltration enabled mapping of subsurface saturation changes, infiltration pathways, and groundwater mounding. The results improve understanding of recharge dynamics and provide insight into processes affecting infiltration efficiency and aquifer storage. Wetland areas within the Vomb Trough were investigated, revealing organic surface layers overlying sandy aquifer materials and demonstrating strong seasonal groundwater–wetland interactions. To place site-scale observations in a regional context, airborne SkyTEM transient electromagnetic data were used to characterize aquifer geometry and resistivity structure across the entire Vomb Trough. Integration of SkyTEM-data with geological and hydrogeological data will enable the development of a regional conceptual and numerical hydrogeological model, improving delineation of groundwater resources and recharge zones. This multi-scale approach, combining MAR- and wetland monitoring with regional airborne geophysics, provides critical insight into groundwater recharge, storage, and system connectivity. The results will support optimization of MAR operations and optimal rewetting location, and will provide a scientific basis for sustainable groundwater management and climate-resilient drinking water supply in southern Sweden.

LID 0717
“GrounDwater sAlinizaTion and pollution AsseSsmEnt Tool” (DATASET) index, a holistic vulnerability assessment framework specifically designed for coastal aquifers

Efthymia Zavridou[1*], Gianluigi Busico[2], Yassine Ez-Zaouy[2], Beata Jaworska-Szulc[4], Dawid Potrykas[4], Nebojsa Jovanovic[3], Ricardo Hirata[5], Konstantinos Chalikakis[1], Micòl Mastrocicco[2]

[1] UMR1114 EMMAH (AU-INRAE), Avignon Université, Avignon, France
[2] Department of Environmental, Biological and Pharmaceutical Sciences and Technologies (DiSTABiF), Campania University “Luigi Vanvitelli”, Caserta, Italy
[3] Department of Earth Science, University of the Western Cape, Bellville, South Africa
[4] Faculty of Civil and Environmental Engineering, Gdańsk University of Technology, Gdańsk, Poland
[5] CEPAS|USP Groundwater Research Center, Institute of Geoscience, University of Sao Paulo, Brazil
* efthymia.zavridou@alumni.univ-avignon.fr

Keywords: groundwater vulnerability, coastal salinization, agricultural pollution

Coastal areas host strategic resources that support economic development and societal well-being. However, salinization processes driven by both natural and anthropogenic factors constitute one of the most critical and widespread environmental threats in coastal regions worldwide. Groundwater contamination in these areas can occur through multiple pathways: nitrate is widely recognized as a major indicator of agricultural and anthropogenic pressure, while groundwater salinization, primarily associated with chloride concentrations, is increasingly observed across many coastal plains due to climate variability and groundwater overexploitation. These challenges highlight the need to develop standardized and user-friendly frameworks capable of identifying areas that require targeted and site-specific management strategies. To address this goal, we propose the “GrounDwater sAlinizaTion and pollution AsseSsmEnt Tool” (DATASET) index, a holistic vulnerability assessment framework specifically designed for coastal aquifers. The DATASET index aims to provide an efficient and adaptable tool for groundwater protection offering significant flexibility by enabling the assessment of vulnerability related to either salinization due to saltwater intrusion or agricultural contamination through the selective activation of relevant parameters. The resulting framework is designed to be site-specific, avoiding fixed parameter classification ranges while ensuring comparability through a standardized vulnerability ranking scale. The framework incorporates key hydrogeological and environmental factors (i.e. morphology, recharge, and more), calibrated using chloride and nitrate concentrations as dependent variables across fifteen coastal study areas worldwide. Application results demonstrate strong agreement with previously published vulnerability assessments, while significantly reducing data requirements and improving operational applicability.

LID 0718
Understanding the role of compartmentalization in stream response to major precipitation events in central European upland catchments: The Ahr valley, Germany

Benoit Abadie[1]*, John Armitage[1], Christoff Andermann[2], Michael Dietze[3], Laura Rossana Fracica Gonzalez[3], Niels Hovius[4]

[1] IFPEN, Rueil-Malmaison, France
[2] Géosciences Rennes, Université de Rennes, CNRS, UMR 6118, Rennes, France
[3] Institute of Geography, RWTH Aachen University, Aachen, Germany
[4] Helmholtz Center, German Research Center for Geosciences GFZ, Potsdam, Germany
* benoit.abadie@ifpen.fr

Keywords: compartmentalization, groundwater modeling, erosion

Major flood events are an increasing risk in many parts of the world. Recent destructive flooding in central European upland catchments, such as the 2021 Eifel floods, highlight the importance of improving our understanding of the mechanisms behind erosion response to precipitation events in upland catchments. The HILANDER project that started in spring 2024 has two major goals: 1. Put in place an observatory in the Ahr catchment (Germany) to characterize water flow paths through the subsurface. 2. Incorporate subsurface flow in sediment transport models, improving prediction of erosion.

The Ahr valley is characterized by gently sloped hilltops and a steep, incised river valley. Stream gauges were installed in three subcatchments in the upper Ahr valley. Water has been sampled in summer and winter from springs, streams and boreholes within the subcatchments. Samples were analyzed for major ions, stable isotopes and CFC concentrations. Flow through a compartmentalized sub surface is modelled using a two-dimensional model approach that accounts for partially saturated flow.

Annual springs are found throughout all sub-catchments. Many seasonal springs were also found during winter. CFC analysis shows transit times through the different compartments of the subsurface ranging from fast (years) to slow (decades). Recession analyses of the three tributaries point towards a compartmentalization of the subsurface with streamflow dominated by a fast-flowing shallow layer in the early recession and a slow-flowing deep layer in the later recession. Hydrogeochemical analysis shows a large streamflow component from shallower pathways. Finally, there is very little evidence of overland flow within the landscape.

Combined, these results suggest that the majority of precipitation, even during heavy rain events, reaches the stream through subsurface pathways, implying that erosion is dominated by bank collapse within upland gullys and not wash load from open fields.

LID 0719
Integrated spatial database for transboundary groundwater resilience assessment

Marlen Hunt[1,2]*, Argo Jõeleht[1], Magdaleena Männik[1,2], Raul Paat[1], GRANDE-U team

[1] Department of Geology, University of Tartu, Tartu, Estonia
[2] Department of Hydrogeology and Environmental Geology, Geological Survey of Estonia, Tartu, Estonia
* marlen.hunt@egt.ee

Keywords: groundwater monitoring, spatial database, GRACE-FO, transboundary aquifers, data integration

GRANDE-U (Groundwater Resilience Assessment through iNtegrated Data Exploration for Ukraine) is an international research initiative advancing fine-scale assessment of groundwater storage, flows, and resilience in transboundary regions. Groundwater is a critical drinking water source globally, yet its quantitative and qualitative status remains difficult to assess where monitoring networks are sparse and data are fragmented. The project integrates machine learning models with satellite observations and in situ measurements to improve water balance parameterization and support evidence-based decision-making under uncertainty.

The study areas include several transboundary aquifers and river basins: Poland–Ukraine, Lithuania–Latvia, Latvia–Estonia, and US-Mexico. Across these regions, heterogeneous data structures, uneven monitoring densities, and differing hydrogeological descriptions complicate joint assessment and coordinated management.

To address these challenges, the project has developed a consolidated spatial database that integrates satellite data (including GRACE-FO terrestrial water storage), in situ groundwater level observations, meteorological variables (precipitation, evapotranspiration, temperature), topography, and geological data. Building on earlier transboundary databases, the system expands thematic coverage, harmonizes datasets across countries. The resulting information system provides comprehensive access to spatial data on water balance components for transboundary aquifers.

By integrating multi-source datasets into a unified framework, the database supports groundwater modeling, visualization, and reporting. It improves access to science-based information for collective action and sustainable aquifer management. The system enables coordinated, data-driven assessment of aquifer status and resilience across transboundary regions.

The study has been funded by the National Science Foundation (NSF) under the project NSF 23-135 and the Estonian Research Council, “EAGER: IMPRESS-U: Groundwater Resilience Assessment through iNtegrated Data Exploration for Ukraine (GRANDE-U)”

LID 0720
Groundwater in international cooperation at IGME-CSIC

Jose Luis Garcia-Arostegui[1]*, Africa De La Hera[1], Luis Javier Lamban[1], Jorge Jodar[1], Sergio Martos[1], Juan Fornes[1]

[1] IGME-CSIC, Spain
* j.arostegui@igme.es

Keywords: cooperation, development, groundwater

The IGME-CSIC has extensive experience in activities related to international development cooperation in Latin America and the Caribbean. In this regard, it has collaborated with the AECID (Spanish Agency for International Development Cooperation) in hydrogeological training activities, teaching various courses aimed at professionals involved in public groundwater management at the AECID's International Training Centres in Latin America and the Caribbean. This collaboration began in 2001. Over the last ten years (2016-2025), the IGME-CSIC and the AECID have jointly developed 22 activities in the field of groundwater, with the participation of 27 collaborating entities, both national and international, involving more than a thousand experts from 15 Iberoamerican countries.

Alongside this training activity, the IGME-CSIC has also developed specific projects in Latin America with the AECID related to the reduction of pollution in groundwater for human consumption (Bolivia) and the sustainable development of the Guatemala City Valley aquifer.

In addition to its activities in Latin America, IGME-CSIC has participated in several UNESCO-funded projects in North Africa and the Middle East related to hydrogeological knowledge, groundwater management and its relationship with wetlands in the Mediterranean countries of this region. Similarly, the AECID's Masar Al'an Programme, part of the Regional Cooperation Programme with the Arab world in which the IGME is participating, seeks to exchange knowledge and strengthen capacities in water resource management, with a special focus on groundwater and its sustainable governance.

LID 0721
Exploring climatic drivers of groundwater level changes in the Po Plain (Italy)

Laura Landi[1]*, Giovanni Liguori[1], Maria Elena Cavallini[8], Luca Alberti[2], Filippo Battaglini[3], Elena Egidio[4], Manuela Lasagna[4], Marco Marcaccio[5], Pietro Mazzon[2], Rudy Rossetto[6], Cesare Vasini[3], Chiara Zanotti[7], Maria Filippini[1]

[1] Department of Biological, Geological and Environmental Earth Sciences, Alma Mater Studiorum – University of Bologna, Italy
[2] Environmental and Civil Engineering Department, Politecnico di Milano, Italy
[3] Autorità di Bacino Distrettuale del Fiume Po, Parma, Italy
[4] Earth Sciences Department, University of Turin, Italy
[5] Arpae Emilia-Romagna, Technical Direction, Bologna, Italy
[6] Institute of Crop Science, Scuola Superiore Sant'Anna, Pisa, Italy
[7] Department of Earth and Environmental Sciences, University of Milano-Bicocca, Italy
[8] Province of Ferrara - Territorial and Urban Planning Service, Italy
* laura.landi11@unibo.it

Keywords: climatic drivers, groundwater level, Po Plain

The Po Plain in northern Italy hosts ~40% of the national population and generates ~50% of Italy's GDP, making it one of the country's most strategic regions. Groundwater represents a fundamental resource for agricultural, domestic, and industrial uses in this region, making the impacts of climate change and natural climate variability particularly critical. Over recent decades, drier winters, more frequent and prolonged droughts, and reduced snow cover have been observed, with inevitable repercussions on groundwater storage. Recent literature has identified trends in groundwater levels across the Po Plain and associated them with changing climatic conditions as well as anthropogenic stressors (e.g. irrigation); here, we extend these findings by examining how multiple climatic drivers affect groundwater level fluctuations, highlighting their varying impacts across different sectors of the plain and aquifer depths. Using piezometric data from the MIDASPO project—comprising several hundred time series collected at multiple depths across the Po Plain over the 2010–2025 period—we decompose groundwater fluctuations into trend, interannual, and seasonal components, which are subsequently correlated with multiple climatic variables (e.g., precipitation, temperature, evapotranspiration) to identify the most relevant climatic stressors and underlying processes. Our analysis reveals spatially distinct piezometric responses that reflect the combined effects of climatic and anthropogenic pressures (e.g., irrigation and withdrawals), highlighting the system's complexity and vulnerability. By characterizing groundwater variability during a decade marked by severe droughts, this study provides the process-based understanding needed to interpret climate projections in terms of groundwater impacts and to guide management priorities.

This work was funded by "Fondo per lo Sviluppo e la Coesione (FSC) 2014-2020 - Piano Operativo Ambiente - Interventi per la Tutela del Territorio e delle Acque - Sviluppo di modellistica idrogeologica e delle conoscenze di supporto al piano del bilancio delle acque sotterranee (Modello idrogeologico delle Acque Sotterranee del distretto idrografico del fiume Po – MidAS-Po)".

LID 0722
Educating for the green transition: Embedding GreenComp in groundwater education

Ádám Tóth[1]*, Silvia Gallagher[2]

[1] Copernicus Institute of Sustainable Development, Utrecht University, The Netherlands
[2] Trinity College Dublin, Ireland
* a.z.toth@uu.nl

Keywords: education, competences, sustainability

Groundwater plays a pivotal role in the green transition through its contribution to drinking water supply, geothermal energy, climate adaptation, and the sustainable extraction of critical mineral resources. As subsurface systems become increasingly central to energy, resource, and water security strategies, hydrogeology education must evolve to reflect these expanding societal expectations and responsibilities, and address broader sustainability competencies in its design and delivery.

This contribution explores how the European Commission's GreenComp sustainability competences framework can be integrated into hydrogeology and groundwater education across undergraduate, graduate, and lifelong-learning contexts, serving as a common language for sustainability education. While technical expertise remains essential, future professionals must also be equipped to navigate ethical dilemmas, systemic thinking, futures thinking, and stakeholder perspectives linked to sustainable subsurface use.

To support this shift, we developed an AI-supported dialogic design assistant that helps educators and course developers reflect on and translate GreenComp competences into hydrogeology-specific learning outcomes and teaching activities. Rather than prescribing content, it stimulates critical reflection on how sustainability competences can be embedded within existing curricula and professional training.

By aligning groundwater education with sustainability competences, this approach supports the preparation of professionals capable of balancing resource use with long-term environmental stewardship, thereby strengthening the contribution of hydrogeology education to a just and sustainable green transition.

LID 0723
Characterization of unsaturated-saturated flow fronts in heterogeneous porous media

Patricio Hernández-Parra[1]*, Vanessa A. Godoy[1], Rafael Magnabosco[1], Pedro Assunção[2], J. Jaime Gómez-Hernández[1]

[1] Universitat Politècnica de València (UPV), Instituto de Ingenieria del Agua y Medio Ambiente (IIAMA), Grupo de Hidrogeología, Valencia, Spain
[2] Universidade Federal de Minas Gerais (UFMG), Instituto de Geociências, Laboratório de Estudos Hidrogeológicos (LEHID), Belo Horizonte, Brazil
* paherpa1@doctor.upv.es

Keywords: capillarity, Monte Carlo simulation, numerical modeling

The dynamics of unsaturated-saturated flow fronts in porous media control key processes such as groundwater recharge, contaminant transport, and the response of unconfined aquifers to hydrological stresses. While natural formations exhibit multi-scale heterogeneity, most modeling efforts either neglect the unsaturated zone or assume simplified homogeneous conductivity fields, failing to capture the complex interactions between capillary forces and gravity-driven drainage. This study systematically characterizes and directly compares flow fronts in heterogeneous media using two numerical approaches with fundamentally different physical assumptions: OpenGeoSys (OGS), which solves the Richards equation and accounts for capillary effects across the entire moisture spectrum, and MODFLOW-NWT, which approximates free-surface flow and neglects capillarity. A finite volume of water is instantaneously released within a closed domain, and its subsequent redistribution is analyzed under different heterogeneity scenarios. Ensembles of Gaussian and non-Gaussian hydraulic conductivity fields are generated using geostatistical techniques (multi-Gaussian simulation and sedimentary-like facies realizations), covering multiple log-conductivity variances. For each scenario, a set of Monte Carlo realizations are simulated to construct probability maps of saturation fronts from both models. The comparison quantifies the influence of capillary forces on front propagation and assesses how different heterogeneity patterns amplify or reduce discrepancies between the two modeling approaches, as well as the uncertainty in the position and shape of the fronts. The resulting probabilistic characterization provides insights into the reliability of simplified free-surface models in heterogeneous aquifers. This work highlights the importance of incorporating both capillary effects and geological heterogeneity in the characterization of hydrogeological systems.

LID 0724

What groundwater processes matter? Developing appropriate groundwater typologies for earth system models

Alan MacDonald[1*], Tom Gribbin[2], Sarah Collins[1], Donald John MacAllaster[1], Johanna Scheidegger[2], Kirsty Upton[1], and Andrew Hughes[2]

[1] British Geological Survey, Lyell Centre, Edinburgh, United Kingdom
[2] British Geological Survey, Keyworth, Nottingham, United Kingdom
* amm@bgs.ac.uk

Groundwater dynamics are complex. Improved investigation techniques and increased temporal monitoring are helping uncover the wide spectrum of groundwater behaviour, particularly when stressed by human activity and floods or droughts. Processes at the interface with other parts of the hydrological cycle are some of the most complex, with groundwater recharge and discharge processes exhibiting nonlinear behaviour - exacerbated with climate or anthropogenic stress. Alongside increased hydrogeological understanding, some groundwater models have become more sophisticated, enabling some of these processes to be more accurately represented in catchment and aquifer models.

This increased understanding of groundwater poses interesting problems: (1) which of these processes are important when including groundwater in global earth system models, where many coupled processes are included and computational effort high? (2) do we have sufficient information to parameterise relevant processes globally? and (3) what datasets or approaches are most useful to validate such models? In this talk we will give examples of a typology approach we are developing as part of the NERC TerraFIRMA project to expand the coupled processes enabled within UKESM (the UK Earth System Model). The work builds on several decades of work with partners developing hydrogeological typologies for groundwater management in the UK, Africa and South Asia. We also discuss the choices made to include or exclude different processes when working at global scales.

LID 0725
Pressure increase behaviour within injection wells: A numerical study in stochastically heterogeneous reservoirs

Bence Nagy[1*], Ábel Markó[2,3], Attila Galsa[1,4], Bence Molnár[1,5]

[1] Department of Geophysics and Space Science, Institute of Geography and Earth Sciences, ELTE Eötvös Loránd University, Budapest, Hungary
[2] ELTE Eötvös Loránd University, Institute of Geography and Earth Sciences, Department of Geology, József and Erzsébet Tóth Hydrogeology Chair, Budapest, Hungary
[3] Supervisory Authority for Regulatory Affairs, Budapest, Hungary
[4] Institute of Earth Physics and Space Science, HUN-REN, Sopron, Hungary
[5] MS Energy Solutions Ltd., Eger, Hungary
* nagybencefazek@gmail.com

Keywords: geothermal reinjection, heterogeneity, numerical modelling

Reinjection projects encounter many practical problems, and as such there has been extensive research regarding unsuccessful injection wells, attributing many of the issues to local scale biological-mechanical-chemical problems (e.g. pore-scale clogging). However, these don't always fully explain the pressure increase in the well. As such, we propose that regional scale heterogeneity of siliciclastic reservoirs can be an equally important risk, affecting the effective reservoir volume and the connectivity between permeable zones, greatly reducing reinjection efficiency.

To investigate the issue, we generated stochastic permeability distributions using Sequential Gaussian (SGS) and Sequential Indicator (SIS) algorithms. The effect of 5 different correlation lengths (i.e. the scale of the heterogeneity) and 3 different variances were tested. 2D transient flow modelling was carried out using COMSOL Multiphysics, quantifying the effect of the heterogeneity on hydraulic head increase in the well. The propagation of the pressure front was also monitored to assess the transient effects of reinjection.

Model results show a pressure increase of up to several bars over the typical lifetime of the injection well, strongly dependent on the correlation length of the heterogeneity. Anomalous pressure increase is observed when the pressure front reaches lower permeability areas, indicating that areas more distant from the well also play a part in the well head, and therefore influence the reinjection efficiency. Additionally, the onset time of the pressure increase is typically much longer than an average pumping test. Insufficient preliminary data or disregarding the macroscale hydrogeological variations can lead to overestimations of the injection well capacity. Therefore understanding the influence of aquifer heterogeneity on reinjection efficiency, and relying on detailed preliminary studies can contribute to proper reinjection well positioning and to more successful projects.

LID 0727
Nature-based solutions for nitrate impacts in a Mediterranean coastal aquifer–lagoon system

Vanessa A. Godoy[1]*, Rafael Magnabosco[1], J. Jaime Gómez-Hernández [1], Patricio, Hernández-Parra, Eduardo Cassiraga[1], Javier Rodrigo-Illari[1], Carmen Hernández-Crespo[1], Miguel Martín Monerris [1]

[1] Universitat Politècnica de València, Research Institute of Water and Environmental Engineering, Valencia, Spain
* vaalde1@iiama.upv.es

Keywords: coastal aquifers, hydrological modelling, nitrate pollution

Mediterranean coastal lagoons are strongly influenced by groundwater discharge from intensively cultivated coastal aquifers. In the Albufera Natural Park (eastern Spain), persistent eutrophication is sustained not only by legacy wastewater inputs but also by nitrate-rich groundwater emerging through springs and drainage channels hydraulically connected to a contaminated coastal aquifer. This study evaluates the role of Nature-Based Solutions (NbS), particularly constructed wetlands, as interception buffers designed to mitigate the transfer of groundwater-derived nitrogen loads into the protected lagoon ecosystem. Rather than explicitly simulating subsurface flow, the approach quantifies groundwater-related inflows, seasonal water availability, and their contribution to nutrient pressures at system scale. An integrated modelling framework combining basin-scale hydrological simulation with a data-informed nitrogen removal model is applied across three hydrologically distinct zones of the park, where groundwater contributions are particularly relevant in two of them. The analysis considers irrigation, non-irrigation and winter flooding periods to explore how seasonal hydrodynamics influence interception capacity and wetland performance. Results suggest that NbS effectiveness is influenced by discharge timing and flow variability. Periods outside peak irrigation generally provide higher potential for nitrate interception, while ecological winter water demands may reduce the volumes available for treatment. Sensitivity analyses indicate the relevance of hydraulic retention time for robust wetland design under variable hydrological conditions. Overall, the findings illustrate how NbS can function as adaptive transition buffers between nutrient-enriched inflows and sensitive lagoon ecosystems, supporting long-term water-quality improvement in Mediterranean protected areas.

LID 0728
Hydrological analysis of long-term cave drip hydrographs for quantifying vadose zone heterogeneity in a karst aquifer

Metka Petrič[1,2]*, Janja Kogovšek[1], Blaž Kogovšek[1,2]

[1] ZRC SAZU, Karst Research Institute, Postojna, Slovenia
[2] UNESCO Chair on Karst Education, University of Nova Gorica, Vipava, Slovenia
* metka.petric@zrc-sazu.si

Keywords: karst, cave drip hydrograph, effective precipitation, hydrological analysis, Postojnska Jama, Slovenia

Cave drip discharge offers a direct, high-resolution insight into water movement and storage in the vadose zone of karst aquifers. This study analyses a 10-year record of cave drip hydrographs from three monitoring sites in the Postojnska Jama cave system, Slovenia. Meteorological variables were measured above the cave and used to estimate effective precipitation, enabling a paired analysis of recharge function and drip discharge response. A series of hydrological analyses was applied to the time-series data from each drip, and the results were compared. Hydrograph separation quantified base flow and fast flow components, and recession analysis inferred flow and storage properties. These aspects were also examined using correlation and spectral analysis, which further enabled the linking of discharges with effective precipitation. The outflow volumes of individual drips during hydrological years were compared with the amounts of effective precipitation over the same periods. All three drips display distinct response patterns, demonstrating strong spatial variability over short distances within the karst vadose zone. Hydrograph separation indicates that the proportional contribution of base flow differs markedly among sites. Recession behaviour and autocorrelation further highlight differences in storage release and flow organisation. Cross-correlation and cross-spectral results show that effective precipitation drives identifiable discharge signals, yet the strength and timing of this relationship vary for each drip. Over multi-year timescales, discharge is strongly influenced by previously stored water, while the timing and magnitude of intense precipitation events also clearly affect short-term variability. The combined methodological approach provides a useful tool for quantifying the heterogeneity of flow and storage characteristics within the vadose zone of karst aquifers.

The work was financially supported by the Slovenian Research Agency through the programme Karst Research (P6−0119).

LID 0731
The regulatory effect of paleogeomorphological reconstruction on groundwater distribution in fault basins

Luo Penghui[1]*, **Lyu Lei**[1]

[1] School of Logistics and Management Engineering, Yunnan University of Finance and Economics, Kunming, China
* 153188779@qq.com

Keywords: fault basin, paleogeomorphological reconstruction, groundwater distribution, regulation, sequence stratigraphy

The paleogeomorphic features of rift basins significantly influence groundwater accumulation and distribution, but the quantitative control mechanism between the two remains unclear. This paper takes the Middle Permian Maokou Formation in the Sichuan Basin as the research target area, integrating multi-source data from over 1070 wells, 7.19×10^4 km^2 seismic data, and 20 measured profiles. Seven sequence boundaries were identified using sequence stratigraphy.

The paleogeomorphic evolution process was reconstructed using paleotopographic impressions and residual thickness methods. The response relationship between paleogeomorphism, sedimentary facies, and aquifer systems was established through sedimentary facies analysis. The study reveals that the Maokou Formation developed four phases of slope break zones. Among them, the slope break zones of phases I to III migrated a distance of 120 km from north to south, with the migration rate accelerating from 12.5 mm/a to 32 mm/a. This drove the paleogeomorphism to evolve from a north-dipping gentle slope (slope <0.5°) into a platform basin tectonic pattern, forming a geomorphic unit of "two depressions and one uplift". The porosity of linear aquifers in the slope break zone ranges from 8% to 12%, while that in karst highlands reaches 12% to 18%, and confined aquifer systems are developed in the depression area. The quantitative prediction accuracy based on the geomorphology-groundwater correlation model reaches 85%, providing new technical support for groundwater resource assessment in rift basins.

This work was supported by the National Natural Science Foundation of China Project (NSFC) [Grant Numbers 42362036].

LID 0733
Thermal springs as indicators of structurally controlled groundwater flow and deep geothermal potential in the Buda Thermal Karst

Tamara Tóthi[1,2,3]*, Lajos Ádám Csicsek[4], Gábor Héja[5], Judit Mádl-Szőnyi[3], Márk Szijártó[3]

[1] HUN-REN Institute of Earth Physics and Space Science, Sopron, Hungary
[2] University of Twente, Faculty of Geo-Information Science and Earth Observation, GAIA Department, Enschede, The Netherlands
[3] Eötvös Loránd University, Institute of Geography and Earth Sciences, József and Erzsébet Tóth Endowed Hydrogeology Chair, Budapest, Hungary
[4] Universidad de Granada, Departamento de Geodinámica, Granada, Spain
[5] Supervisory Authority of Regulatory Affairs, Budapest, Hungary
* tothi.tamara@ttk.elte.hu

Keywords: geothermal energy, hydrogeological simulation, thermal springs

The Buda Thermal Karst, located in Budapest, the capital of Hungary, extends west of the Danube as a partially confined – partially unconfined karst, while east of the river it occurs in a fully confined setting. It is characterised by three geographically and geologically separated discharge areas along the Danube, containing lukewarm, lukewarm–warm, and warm springs, respectively. This research aims to understand the geological separation and differences in physical parameters (temperature and chemical properties) of these discharge areas and their significance for geothermal exploration under the hydraulically confined Pest side.

Based on a newly developed geological interpretation of the area, three east-west trending cross-sections were used in the simulations, refined with hydrostratigraphic and structural details. These sections served as the basis for numerical simulations, providing higher accuracy in evaluating groundwater flow and thermal patterns.

The primary objectives of the modelling were:

1. To evaluate how 2D numerical simulations complement hydraulic data processing and previous assessments of spring behaviour.
2. To assess the role of structural elements in the spatial distribution of springs and confined karst areas.
3. To identify which spring groups are connected to specific recharge areas and detect potential hydraulic separations or interconnections within the system.

The results suggest that the interplay of structural blocks, hydrostratigraphy, recharge and discharge patterns, and geothermal conditions shapes the regional flow system, which can be inferred from the temperature patterns of the thermal springs. This study provides an improved framework for assessing geothermal potential in complex karst systems.

This research was carried out within the framework of the project RRF-2.3.1-21-2022-00014 of the Climate Change Multidisciplinary National Laboratory.

Supported by the EKÖP-24 University Excellence Scholarship Program of the Ministry for Culture and Innovation from the Source of the National Research, Development and Innovation Fund. Contract number: ELTE/15380/1(2024)

LID 0735
Co-designing an optimized groundwater monitoring network for the Shire Transboundary River Basin

Steve Kumwenda[1*], Girma Ebrahim[2], Omar Sirage[3], Gift Wanangwa[4], Yamikani Zingani[4], João Fortunato[5], Claudio Pacacheque[6], Jonathan Lautze[7]

[1] IWMI G4DR Project, Blantyre, Malawi
[2] International Water Management Institute (IWMI), Addis Ababa, Ethiopia
[3] IWMI G4DR Project, Maputo, Mozambique
[4] Ministry of Agriculture, Irrigation and Water Development, Lilongwe, Malawi
[5] Mozambique DNGRH, Maputo, Mozambique
[6] Mozambique ARA-Centro, Tete, Mozambique
[7] International Water Management Institute (IWMI), Pretoria, South Africa
* smkumwenda@yahoo.co.uk

Keywords: groundwater-monitoring, transboundary aquifer, hydrogeology, GIS-MCDA

The Shire River basin, shared between Malawi and Mozambique, is an important groundwater resource that is increasingly exposed to climate variability, population growth with an ever increasing water demand. However, the basin does not have a harmonized and technically sustainable groundwater monitoring network. The objective was to co-design a harmonized groundwater monitoring network for the Shire River Basin with prioritization to a transboundary productive alluvial aquifer.

Over 85 sites including observation wells, production boreholes, and potential contamination sites were evaluated through a hydrocensus to ascertain existing borehole infrastructural integrity, aquifer properties, telemetric data transmission suitability, and physical accessibility to these sites. Hydrogeological expertise approach using GIS-based Multi-Criteria Decision Analysis integrating seven thematic layers (geology, rainfall, lineament density, land use/land cover, soil, slope, and drainage density) was applied, with weighting derived from the Analytic Hierarchy Process. A geo-statistical approach using the semivariogram model of groundwater levels was also applied to determine spatial correlation length, optimal well spacing, and overall network density.

The optimally designed basin-wide monitoring network proposes 66 groundwater-monitoring sites across Malawi and Mozambique. For the strategically important lower Shire basin alluvial aquifer, 4 sites in each country will be drilled for construction of observation boreholes with installation of data loggers. The co-designed monitoring network is to be integrated with the harmonised data-sharing protocol through a transboundary cooperation between Malawi and Mozambique and these initiatives are poised to strengthen understanding of recharge, storage dynamics, and abstraction impacts on groundwater, thus supporting joint management, climate resilience planning, and long-term sustainability of the shared Shire River Basin aquifer system.

This study was conducted under the Groundwater for Advancing Resilience in Africa (G4DR) Project, funded by the Global Environment Facility (GEF), implemented by the Food and Agriculture Organization (FAO) and executed by the International Water Management Institute (IWMI).

LID 0737
Developing a standardised diagnostic and physical audit manual for handpumps and boreholes serving rural groundwater water supply systems

Steve Kumwenda[1*], Donald John Macallister[2], Kerstin Danert[3,4], Jack Brickell[3,4]

[1] BASEflow, Malawi
[2] British Geological Survey, United Kingdom
[3] Ask for Water Ltd, United Kingdom
[4] Rural Water Supply Network, Switzerland
* smkumwenda@yahoo.co.uk

Keywords: borehole diagnostics, handpump performance, groundwater infrastructure, rural water supply

Approximately one in five rural water services in sub-Saharan Africa rely on handpump-equipped boreholes, yet high rates of non-functionality and underperformance persist. In Malawi and similar Sub Saharan African contexts, premature borehole failure raises concerns regarding construction quality, hydrogeological suitability, and regulatory oversight. Weak documentation systems and limited post-construction inspections further constrain evidence-based accountability and corrective action.

To address these gaps, a structured diagnostic and physical audit framework has been developed to systematically investigate infrastructure, environmental, and hydrogeological causes of borehole failure. The methodology synthesizes established borehole inspection procedures and research from BASEflow's borehole forensics work, the British Geological Survey Hidden Crisis research methodology and the Rural Water Supply Network (RWSN) Stop the Rot initiative. A coherent step-by-step manual was developed and refined through a series of consultative webinars and expert technical reviews to enhance methodological rigour, clarity, and practical applicability.

The result is a Handpump and Borehole Diagnostic Manual structured around twelve methodological steps to guide troubleshooting, inspection, and reporting. It provides clear rationale, required equipment, and templates for data collection and reporting. The manual includes procedures for site assessment, civil works inspection, handpump component evaluation, pumping test analysis, and water quality testing. This manual provides a robust scientific basis for understanding handpump and borehole failure, enabling evaluation of installation quality, drilling and construction practices, and aquifer-related factors. Integrating this approach into post-construction monitoring and rehabilitation programmes can strengthen accountability, improve professional standards, and enhance the long-term sustainability of rural groundwater supplies.

LID 0738
hydrogeological site characterization of pyroclastic soils: Case studies from Campania (South Italy)

Serena De Luise[1], Giuseppe Vitiello[2], Giovanni Forte[1]*, Marianna Pirone[1]

[1] Department of Civil, Building and Environmental Engineering (DICEA), University of Naples Federico II, Naples, Italy,
[2] Department of Structures for Engineering and Architecture (DIST), University of Naples Federico II, Naples, Italy
* giovanni.forte@unina.it

Keywords: permeability, hydrogeological setting, pyroclastic soils

Rainfall-induced flow-like landslides represent a major hazard in the Campania region (southern Italy), where steep slopes are commonly mantled by pyroclastic deposits derived from Somma-Vesuvius and the Phlegraean Fields. These phenomena are typically triggered by intense and prolonged rainfall events that modify subsurface flow regimes, promote pore water pressure increases, and reduce the shear strength.

This study presents the hydrogeological characterization of a representative slope located in the municipality of Salerno, on the SE of the Lattari Mts. The slope consists of a pyroclastic cover overlying highly fractured dolomitic bedrock, a stratigraphic setting that exerts strong control on vertical infiltration, lateral subsurface flow, and groundwater storage.

A multi-scale experimental program was implemented to quantify the hydraulic properties of both the superficial deposits and the bedrock. In situ investigations included Lefranc permeability tests carried out in boreholes to estimate hydraulic conductivity within the t pyroclastic cover and the fractured dolostone. Double-ring infiltrometer tests were performed at the ground surface to evaluate infiltration rates and near-surface saturated hydraulic conductivity under controlled hydraulic gradients.

Laboratory analyses on undisturbed samples provided further constraints on grain-size distribution, porosity, bulk density, water retention behavior, and saturated and unsaturated hydraulic conductivity

The integrated results reveal a pronounced hydrogeological contrast between the highly permeable pyroclastic cover and the underlying fractured dolomitic bedrock. This contrast governs subsurface flow pathways, favors perched water table formation, and controls pressure transmission mechanisms, representing a key preparatory factor in rainfall-triggered flow-like landslides.

LID 0739

Integrating environmental isotopes and contaminants of emerging concern to unravel hydrogeological processes in Mediterranean coastal lagoons: A Case study of Étang de l'Or (Occitanie, France)

Hatice Turan[1]*, Thomas Leydier[1], Emilie Garel[1], Stéphane Ghiotti[2], Vanina Pasqualini[1], Frédéric Huneau[1]

[1] Université de Corse, UMR CNRS 6134 SPE, Equipe Hydrogéologie, Corte, France
[2] Université de Montpellier Paul Valery, UMR CNRS 5281 Art-Dev, Montpellier, France
* turan_h@univ-corse.fr

Keywords: hydrogeological connectivity, anthropogenic legacy contamination, groundwater–surface water interaction

Mediterranean coastal lagoons are exposed to intense anthropogenic and climate-driven pressures and are therefore among the most vulnerable transitional ecosystems. Increasingly, they are impacted by Contaminants of Emerging Concern (CECs), including pesticides, pharmaceuticals, lifestyle-related compounds, industrial chemicals, and their transformation products. Even at trace concentrations, these substances can significantly degrade water quality and ecosystem functioning. Assessing lagoon contamination thus requires a comprehensive evaluation of all hydraulically connected waters including rivers, agricultural drains, canals, and especially groundwater, within highly interconnected hydrogeological systems. However, the relative contributions of these sources remain poorly constrained.

This study integrates CECs as tracers with multiple environmental stable isotopes ($\delta^{18}O$, $\delta^{2}H$, $\delta^{3}H$, $\delta^{11}B$ and $\delta^{15}N\text{-}NO_3^-$) to elucidate hydrogeological processes and contaminant origins. The approach was applied to the Étang de l'Or lagoon on the Languedoc coast of southern France, a system subjected to substantial anthropogenic pressure and marked environmental change over the past five decades.

Stable isotopes reveal a complex interaction between surface water and groundwater, showing that the lagoon receives significant allochthonous inputs, including waters influenced by the Rhône River. Groundwater retains a chemical legacy of historical land use, evidenced by the presence of several banned pesticides and their transformation products. Surface waters show comparatively lower agricultural influence but are more strongly affected by pharmaceuticals and lifestyle-related compounds linked to domestic wastewater. The lagoon functions both as a dilution zone and as an accumulation point for CECs derived from surface water and groundwater. These findings call for ecosystem protection frameworks that explicitly account for full hydrogeological connectivity and multi-scale water interactions.

LID 0742
Hyperalkaline springs as indicators of the natural hydrogen potential in Inner Dinaric ophiolites

Nebojša Atanacković[1]*, Vladimir Živanović[1], Sava Magazinović[1], Sunčica Gardijan[1], Veselin Dragišić[1]

[1] University of Belgrade – Faculty of Mining and Geology, Belgrade, Serbia
* nebojsa.atanackovic@rgf.bg.ac.rs

Keywords: white hydrogen, geological hydrogen, serpentinization, Zlatibor, Serbia

Hyperalkaline springs emerging from ultramafic rocks are a globally rare natural phenomenon that provides insight into low-temperature (<100 °C) serpentinization and associated generation of secondary minerals, hydrogen, methane, and highly alkaline waters. On the Balkan Peninsula, such springs occur in Jurassic ophiolites of the Vardar and Dinaride Hellenide belts. About twenty such springs are currently identified in Serbia, predominantly within the Inner Dinaride Ophiolite Belt and especially on Zlatibor Mountain. As interest in natural H_2 as an energy resource increases, these ultramafic regions are being evaluated as potential hydrogen-producing systems. However, estimates of their global importance remain highly uncertain due to the scarcity of flux data.

The study improves understanding of multiphase hyperalkaline spring systems and proposes a method to classify terrain by potential for serpentinization-related natural hydrogen generation. Diverse datasets on hydrochemistry, gas composition, hydrogeological and structural settings are integrated into a schematic model describing the formation, evolution, and dynamics of the investigated springs, then transferred into a GIS database to enable spatial interpretation. A multicriteria semi-quantitative assessment method is proposed, in which controlling factors are parametrized and weighted on a spatial scale to derive a natural hydrogen potential index.

The springs are characterized by low mineralization (TDS < 500 mg/l), hyperalkaline pH between 10 and 12, Ca-OH water type, and maximum temperatures of 21 °C. Three springs on Zlatibor Mt. show visible hydrogen emissions. The geological and hydrogeological features of these zones are key factors in spatial assessment. The resulting map outlines generally NE trending sectors of the peridotite massif as most prospective. These sectors follow similarly oriented tectonic structures and are proposed as priority targets for future natural hydrogen exploration.

LID 0743

Contaminants of emerging concern as tools to unravel hydrogeological dynamics and contaminant pathways in contrasting Mediterranean lagoons: Étang de Biguglia (Corsica, France) and Étang de l'Or (Occitanie, France)

Hatice Turan[1]*, Frédéric Huneau[1], Emilie Garel[1], Thomas Leydier[1], Vanina Pasqualini[1]

[1] Université de Corse, UMR CNRS 6134 SPE, Equipe Hydrogéologie, Corte, France

* turan_h@univ-corse.fr

Keywords: lagoon hydrology, multi-tracers, legacy pollutants

The Étang de Biguglia (Corsica, France) and the Étang de l'Or (Occitanie, France) are coastal lagoons exhibiting typical island versus mainland characteristics and subjected to varying anthropogenic and climate pressures. Land use, agriculture, urbanization, and hydrological connectivity strongly influence their water quality and ecosystem functioning. Both lagoons are increasingly exposed to Contaminants of Emerging Concern (CECs) including pesticides, pharmaceuticals, life-related and industrial compounds. Understanding their hydrogeological and contamination dynamics requires integrated assessment of all hydraulically connected waters.

By comparing Biguglia and Étang de l'Or, we aim to disentangle the relative contributions of surface water and groundwater in relation to hydrological functioning, evaluate the legacy of past land use and contamination, and identify key differences in the accumulation and transport of CECs.

The Étang de l'Or is subject to more severe anthropogenic pressures, while the Étang de Biguglia is affected to a relatively moderate extent. In the Étang de Biguglia, the propagation of pollutants is facilitated by artificial drainage networks. In contrast, in the Étang de l'Or, anthropogenic impacts are somewhat mitigated by allochthonous inputs via the Rhône. CECs were detected at higher concentrations in the Étang de l'Or compared to the Étang de Biguglia. The functioning and water quality of the lagoon are strongly influenced by the entire watershed, particularly groundwater, which, due to its longer residence time, reflects the historical legacy of agricultural and sanitation practices. This study highlights differences in anthropogenic impacts between the two lagoons, calling for targeted and sustainable management strategies.

LID 0745
Collaborative groundwater monitoring for action in diverse but connected environments: From tropical water towers through sand rivers to the coast

Tibor Y. Stigter[1]*, Michel Frem[1], Benson Lombo[2], Tilahun Azagegn[3], Paulo Saveca[4], Marmar Badr[5], Daniel Olago[6], Jamiu Aladejana[7], Elisabeth Lictevout[8]

[1] IHE Delft Institute for Water Education, Delft, The Netherlands
[2] Independent water resources expert, Wundanyi, Kenya
[3] Addis Ababa University, Addis Ababa, Ethiopia
[4] Instituto Superior Politécnico de Gaza, Chokwe, Mozambique
[5] Heliopolis University, Cairo, Egypt
[6] University of Nairobi, Nairobi, Kenya
[7] University of Ibadan, Ibadan, Nigeria
[8] IGRAC, Delft, The Netherlands
* t.stigter@un-ihe.org

Keywords: groundwater monitoring, tropical water towers, sand rivers, coastal environments

Here we provide an overview of ongoing initiatives in collaborative groundwater monitoring and data collection in very diverse but connected environments in African contexts. In two tropical water towers in Kenya (Taita Hills, metamorphic rock) and Ethiopia (Wondo Genet, volcanic rock) with over 1000 mm/year of rainfall and playing a crucial role in regulating freshwater resources, groundwater is monitored through springs, streams and rainfall, both in terms of quantity and chemistry, to assess highland-lowland relations and the links to land use. Results show, for example, a strong control of geological faults and fractures in subsurface flow and baseflow, as well as a diminished water retention capacity in the Kenyan study area linked to the expansion of settlements and agriculture. These results feed into recommendations for sustainable land and water management. Beyond these water towers, where the climate becomes semi-arid, groundwater is available in and below the riverbed of so-called sand rivers, which originate from deposition of eroded material. Abundant in both Kenya and Ethiopia, currently sand river monitoring sites are being set up there, and have already been implemented in the Limpopo River in Mozambique. Here (partly automated) data collection on water level and salinity in the river and underlying aquifer reveals the importance of the sand deposits as natured based storage in otherwise harsh hydrogeological environments, and the high potential of sand rivers for smallholder irrigation, provided that the river flows annually to provide a recharge source. Finally, a project in Kenya, Nigeria and Egypt is implementing both automated and community-led monitoring of well water levels and salinity in coastal environments, to promote sustainable and equitable groundwater development. Monitoring data are feeding into numerical groundwater flow and saltwater intrusion models that are used to run scenarios of abstractions under a changing climate.

We would like to acknowledge EU DeSIRA (https://www.helsinki.fi/en/projects/climatesmart-agropastoral-ecosystem-transformation-east-africa) and IHE WDPP (https://www.unihe.org/what-we-do/water-and-development-partnership-programme) for funding the projects.

LID 0747
Hydrogeological education – Optional knowledge or a higher necessity?

Małgorzata Woźnicka[1]*, Agnieszka Kowalczyk[1], Agnieszka Felter[1]

[1] Polish Geological Institute – National Research Institute, Warsaw, Poland
* malgorzata.woznicka@pgi.gov.pl

Keywords: hydrogeological education, social awareness, level of knowledge

In contemporary society, faced with increasing pressure resulting from economic development, there is a growing need for education that encompasses environmental aspects of human functioning in a broader dimension. Groundwater, as a resource of key importance, is becoming one of the main elements requiring intensified educational activities.

During the development of the guidelines for a nationwide educational project on sustainable groundwater management, a survey study was conducted among primary and secondary school students in 2025. The aim of the study was to assess the level of knowledge of children and young people about hydrogeology, including the use, threats, and protection of groundwater. The survey also provided information on the sources from which students derive their knowledge of hydrogeology and the extent of their interest in learning more about this subject. A total of 164 students participated in the survey. The majority were primary school students (64%), among whom children up to 12 years of age predominated (41%). Secondary school students aged 18 and over accounted for less than 6% of respondents.

The most difficult questions for both age groups were those concerning the very concept of groundwater—most of the answers were incorrect or indicated a lack of knowledge on the subject. Similar difficulties were encountered with questions concerning the health risks associated with the use of uncontrolled wells, which 49% of respondents answered incorrectly. At the same time, most students pointed to the need to protect groundwater, although they were unable to name specific measures.

Based on the research conducted, the knowledge school students about groundwater should be assessed as highly incomplete. The gaps in knowledge mainly concern basic concepts in the field of hydrogeology and the principles of safe use of groundwater. The main reason for this is the lack of hydrogeology topics in the core curriculum of both primary and secondary schools.

LID 0748
The process of establishing protected areas of the strategic groundwater resources - Major Groundwater Basins

Agnieszka Piasecka[1]*, Dorota Węglarz[1], Małgorzata Woźnicka[1]

[1] Polish Geological Institute – National Research Institute, Warsaw, Poland
* agnieszka.piasecka@pgi.gov.pl

Keywords: Major Groundwater Basins (MGWBs), groundwater protection, strategic groundwater resources

The Major Groundwater Basins in Poland are geological structures of regional extent which are abundant in good quality groundwater. They constitute, or may constitute in the future strategic groundwater resources for use in supplying the population and key economic sectors requiring high-quality water. They require special protection regarding the chemical and quantitative status of groundwater and control over resource management, with priority given to collective water supply for consumption and meeting essential economic needs. Therefore, in hydrogeological documentation of MGWBs Protection Areas (PAs) are designated determined primarily on hydrogeological conditions, with adjustments to identifiable terrain boundaries. The concept of providing legal protection to strategic water resources is crucial for Poland, as it fulfils the provisions of Directive 2006/118/EC on the protection of groundwater against pollution and deterioration.

There are 163 MGWBs within the entire territory of Poland. In the long national research programme 160 MGWBs were documented and 3 MGWBs remain to be initially identified. As a result of documentation work, for 137 of MGWBs the PAs were delineated. The hydrogeological documentation of MGWBs developed by 2016 constitutes the basis for PAs establishment, but despite such a large amount of work, only 5 MGWBs are legally protected so far. There are a few main reasons for this situation. One of them was significant change in the regulations governing the establishment of PAs, that lengthened the procedures. The change in the authority responsible for the establishing the PAs was also relevant. Besides that, the main barrier to establish PAs is the potential costs associated with compensation for land use restrictions within the protected area. The lack of a normalized methodology for cost-benefit analysis leads to discrepancies in the estimation of the economic balance of protection measures, thus delaying their implementation.

LID 0749
Hybrid modelling of urbanized karst aquifer under intensive pumping in Brazil

Pedro Assunção[1,2], Vanessa A. Godoy[2]*, Rafael Magnabosco[2], Patricio Hernández-Parra[2], Camila Schuch[1], Rafael Magno[1], Allan Matos[1], Flávia Braga[1], Rodrigo De Paula[1], Paulo Galvão[1], J. Jaime Gómez-Hernández[2]

[1] Universidade Federal de Minas Gerais (UFMG), Programa de Pós-graduação em Geologia, Instituto de Geociências, Laboratório de Estudos Hidrogeológicos (LEHID), Belo Horizonte, Brazil
[2] Universitat Politècnica de València (UPV), Instituto de Ingenieria del Agua y Medio Ambiente (IIAMA), Grupo de Hidrogeología, Valéncia, Spain
* vaalde1@iiama.upv.es

Keywords: equivalent porous medium, discrete karst network, Sete Lagoas

Karst aquifers consist of conduit networks formed by the dissolution of fractures in soluble rocks, creating highly heterogeneous and anisotropic flow systems. Groundwater flow is complex, with turbulent flow occurring in conduits and laminar flow in the surrounding rock matrix. Distributed models are commonly used to simulate these systems. The Equivalent Porous Medium (EPM) approach simplified flow as occurring in porous media, but it may not adequately represent conduit-dominated flow. The Hybrid Model (HM) combines the EPM framework with a three-dimensional discrete model to explicitly represent karst conduits, requiring network discretization. Tools such as pyKasso are used to simulate conduit geometry. In northern Sete Lagoas, the karst aquifer is hydraulically connected to an aquitard and a porous aquifer, forming a complex system that has been heavily exploited for urban and industrial water supply, leading to groundwater overexploitation and declining water levels. This study applied a hybrid model to simulate groundwater flow to assess the influence of urban-industrial pumping on the Sete Lagoas karst aquifer. Conduit networks were generated using pyKasso, the geological framework was developed in Leapfrog Geo, and flow simulations were performed with FEFLOW. The results indicate that conduits strongly influence hydraulic heads and promote rapid hydraulic connectivity between aquifer units, while industrial pumping plays a major role in groundwater level decline. Overall, the hybrid model provides a more realistic representation of the system, particularly considering the sensitivity of karst aquifers to heterogeneity and anthropogenic stresses such as intensive pumping. However, the workflow as it requires the integration of multiple software tools and demands significant development time and calibration effort to achieve a reliable final model.

LID 0750
Muography: An effective geophysical tool for detecting fracture systems and cavities

László Balázs[1]*, Gergely Surányi[1], Gergő Hamar[1], Dezső Varga[1]

[1] HUN-REN Wigner Research Center for Physics, Budapest, Hungary
* balazs.laszlo@wigner.hu

Keywords: muography, fault detection, cavity detection

Detecting cavities, fractured zones, and faults and reconstructing them accurately often poses a serious challenge for various surface geophysical methods, and the task can be further complicated by complex surface conditions. The novel muography method, which is based on the detection of high-energy muons arriving at the surface as part of cosmic showers, can often be an effective tool in this area, providing high-resolution, relatively sharp-contoured, X-ray-like images of geological objects.

High-energy muons are short-lived particles which, due to their relatively high mass and energy, travel in a straight trajectory with almost no deviation through rock formations up to several hundred meters thick. Muon intensity decreases as a function of the density distribution of the object.

Although the interaction with the rock material is different, for the reasons mentioned above, the imaging results are very similar to those obtained with X-rays, allowing for the non-destructive examination of geological objects with a much larger scale, and in the case of multiple measurement points in proper arrangement, the 3D tomographic reconstruction of density distribution. The presentation will show the results of tomographic reconstruction based on field measurements performed with high-sensitivity and high-resolution detectors developed at Wigner Research Centre for Physics (Budapest), demonstrating what spatial resolution can be achieved at different scales, proving that muography can also be a useful tool for detecting geological structures that are important in terms of subsurface flows.

LID 0751
Contribution of research groundwater monitoring in solving transboundary problems – Experiences from Poland

Dorota Palak-Mazur[1]*, Anna Kuczyńska[1], Karol Zawistowski[1]

[1] Polish Geological Institute – National Research Institute, Warsaw, Poland
* dpal@pgi.gov.pl

Keywords: groundwater monitoring, collaboration, transboundary problems

Areas subjected to strong anthropogenic pressure, particularly related to mining activities, pose a significant challenge for the assessment and protection of groundwater resources. Long-term mine dewatering, morphological changes, and alterations in the water balance lead to lowering the water table, modifications of flow systems, and potential hydrochemical changes. Under such conditions, conducting an independent, long-term research monitoring is crucial, forming the basis for rational water management. The Polish Geological Institute – National Research Institute (PIG–PIB), carrying out the tasks of the national geological service in the field of groundwater monitoring, presents experiences in implementing research monitoring.

The research monitoring system includes measurements of groundwater levels, hydrogeochemical investigations, analysis of long-term trends, and regional flow modeling. The results obtained are essential components in assessing the quantitative and qualitative status of groundwater as well as directly supports the process of developing and updating water management plans.

As an example, the monitoring conducted in the vicinity of the Turów Mine in southwestern Poland is given. Long-term data allowed for determining the extent and dynamics of the depression cone as well as assessing transboundary impacts that caused an international conflict considered at an EU level. Expert analyses based on monitoring data and hydrogeological modeling provided substantial support in the process of resolving disputes regarding the impact of mining on the territory of the Czech Republic. Poland's experience indicates that research monitoring of groundwater in heavily anthropogenically transformed areas is not only a tool for assessing environmental pressures but also a strategic instrument supporting international dialogue, decision-making processes, and sustainable management of water resources in conditions of conflicting interests.

LID 0752
Looking at the micro level to address macro nitrate contamination problems in the Bauru Aquifer System (Brazil)

Lívia Freitas[1]*, Daphne Pino[1], Ricardo Hirata[1]

[1] Universidade de São Paulo, São Paulo, Brazil
* livia.almeidafr@usp.br

Keywords: nitrate contamination, X-ray computed microtomography, synchrotron light

Nitrate contamination is one of the most persistent and challenging forms of groundwater pollution worldwide. This problem affects virtually all aquifers in the state of São Paulo (Brazil), including the Bauru Aquifer System (BAS), the main water supply source for cities in the central-western region of the state. Despite over two decades of research, no clear consensus exists on the mechanisms controlling nitrogen species in groundwater, particularly at the pore scale.

This study investigates the hydrobiogeochemical controls on nitrogen transformations at this scale, initially focusing on characterizing the porous medium of BAS using rocks collected in a contaminated urban area of Bauru (São Paulo, Brazil). Complementary methods were applied, ranging from traditional techniques such as grain-size analysis and petrographic thin sections to advanced synchrotron-based X-ray computed microtomography (µCT). The µCT measurements were conducted at the Brazilian Synchrotron Light Laboratory, where 3D images of 26 samples were acquired, and 17 injection experiments were performed. These experiments enable 4D analyses of fluid behavior in the porous medium over time at high spatial resolution. Image reconstruction and segmentation are being adapted to mineralogy and porosity type, and the datasets are under analysis.

Results allowed discrimination of three lithological formations within BAS, revealing two more permeable units and a basal unit expected to behave as an aquitard. This structural characterization will be correlated with microbiological analyses, including genetic sequencing, and hydrogeochemical data from soils and groundwater to identify microenvironments controlling nitrogen behavior in contaminated aquifers. Overall, this study contributes to a more integrated physical, geochemical, and microbiological understanding, supporting improved mitigation of nitrate contamination in urban aquifers.

The authors would like to thank FAPESP (processes 2020/15434-0, 2024/16743-7, 2025/06742-6) for funding this research. We also acknowledge LNLS/CNPEM (proposal 20241618) for beamline infrastructure.

LID 0753
Groundwater retention variability as a measure of aquifer system vulnerability to climate change

Agnieszka Kowalczyk[1]*, Małgorzata Woźnicka[1]

[1] Polish Geological Institute – National Research Institute, Warsaw, Poland
* akow@pgi.gov.pl

Keywords: retained groundwater, variable resources, groundwater vulnerability

Climate change vulnerability refers to the manner and degree to which a system or exposed element, including groundwater, responds to a hazard. It is governed by factors determining the extent of exposure to climate-related threats (sensitivity) and the resources available to mitigate impacts (adaptive capacity).

Groundwater, as the most stable component of the hydrological cycle, demonstrates considerably greater resilience to short-term climatic variability than surface waters. Nevertheless, the detection of long-term trends necessitates extended observation periods and the inclusion of a wider range of factors influencing dynamics of groundwater resources. The variability of groundwater retention, expressed as fluctuations in dynamic resources, represents one of the key indicators for assessing vulnerability to climate change.

Variable groundwater resources are defined as the portion of static or dynamic resources occurring between the long-term minimum and maximum groundwater table levels. Based on groundwater table measurements conducted from 1985 to 2024 at points within the national observation and research network, an indicator of changes in groundwater retention was derived. The selected sites, representing unconfined aquifers, were located across three hydrogeological regions of Poland: upland, lowland, and lakeland. Cluster analysis revealed a high degree of intra-group synchronicity in groundwater table fluctuations in the lakeland and upland regions. Minimum retention indicator values were detected in 1992 in the lowland region, in 2004–2006 across all regions, and in 2020 in the upland region.

An analysis of groundwater retention variability over the last decade (2014–2025) was performed in the context of the entire observation period (1984–2025). The results indicate a general trend of peak retention periods shifting from later to earlier months within the hydrological year, with a similar temporal shift observed for periods of minimum retention.

LID 0754
Hydraulic absement analysis of pumping tests

Stephen David Thomas[1]*, Jamie Bates[1]

[1] OGI Groundwater Specialists Ltd, City of Durham, United Kingdom
* stephen.thomas@ogi.co.uk

Keywords: hydraulic absement, pumping test analysis, groundwater modelling

Hydraulic absement is a measure of sustained change in hydraulic head from an initial steady-state head level. During pumping tests, hydraulic absement at an observation point is the time integral of measured head change, with units of length · time (m·s). Plotting hydraulic absement versus time produces typically smoother response curves than conventional head-time plots. This is particularly the case when the changes in measured hydraulic head over time, whether water table or potentiometric surface, have significant measurement scatter.

Theoretical simulations to match the field data points can be generated by time integration of established analytical solutions, such as those by Theis (1935), or Hantush (1964).

Alternatively, time integration can be applied to finite element solutions, as has been demonstrated in this development.

This method can improve accuracy when back-calculating aquifer parameters such as: transmissivity, storativity, and leakage coefficient, particularly when head change versus time data are scattered and would often otherwise be considered unusable for analysis.

Case studies are presented to demonstrate the effectiveness of the technique to back calculated aquifer parameters for low permeability ground conditions, or where the observation points are at large distances from the pumping wells.

LID 0755
Stormwater attenuation and enhanced infiltration systems to mitigate flooding

Stephen David Thomas[1]*, Louise V. Griffin[1], Açelya Ballı[1],

[1] OGI Groundwater Specialists Ltd, City of Durham, United Kingdom
* stephen.thomas@ogi.co.uk

Keywords: stormwater attenuation, enhanced infiltration, modelling

A school located in Cumbria, UK, experiences recurrent surface water flooding during periods of intense rainfall. Runoff from surrounding agricultural land flows down the gradient, resulting in flooding of the school grounds. This floodwater subsequently enters a nearby combined sewer system, which conveys flow to a wastewater detention tank located close to a normally high-quality river. During intense rainfall, the additional stormwater inflow imposes substantial hydraulic stress on the detention tank, reducing its capacity to attenuate wastewater and increasing the risk of sewage overflow to the river.

To assess mitigation strategies for surface floodwater entering the detention tank, numerical simulations were undertaken using the Storm Water Management Model (SWMM) under multiple scenarios. This included variations in the location, size, and number of stormwater attenuation and enhanced infiltration systems, designed to intercept and attenuate runoff, and then enhance infiltration, so mitigating the stormwater to the combined sewer network. The implementation of a Stormwater Attenuation and Enhanced Infiltration System (SAEIS) is designed for a 6-hour, 50 mm rainfall event over a 4-ha catchment corresponding to a total rainfall volume of approximately 2,000 m^3, and represents a 1-in-50-year return period event for the location.

Based on the site-specific hydrogeological, topographical, and meteorological conditions, simulation results indicate that a single SAEIS with dimensions of 2m×165m×1.2m deep can intercept approximately 38% of the generated runoff, whilst the implementation of two SAEIS increases the surface water interception to approximately 75% of the total overland runoff towards the school. The system design demonstrates a significant reduction of peak runoff entering the combined sewer network under the designed storm conditions, thereby alleviating pressure on the wastewater detention tank and improving flood resilience at the site.

LID 0757
CSIA for assessing chlorinated solvents bioremediation: A user's perspective on the state of practice

Erica Oldani[1]*, Luca Alberti[1], Massimo Marchesi[2], Sergio Gil Villalba[3]

[1] Department of Civil and Environmental Engineering, Politecnico di Milano, Milano, Italy
[2] Department of Earth Sciences, Sapienza University of Rome, Rome, Italy
[3] Isotope Tracer Technologies Europe S.r.l., Origgio (Varese), Italy
* erica.oldani@polimi.it

Keywords: Compound-Specific Isotope Analysis (CSIA), in situ bioremediation, groundwater monitoring

In situ groundwater remediation through biological-based solutions has proven effective in harnessing natural degradative processes to restore contaminated aquifers, offering sustainable and cost-competitive solutions to legacy industrial pollution. However, it requires direct evidence of contaminant degradation, which concentration data alone cannot provide. Compound-Specific Isotope Analysis (CSIA) is a well established tool for demonstrating in situ biodegradation, particularly for chlorinated hydrocarbons (CHC). Despite its recognised potential, CSIA is not yet routinely integrated into standard site management protocols in Europe, largely due to limited familiarity among practitioners and the perceived complexity of isotope data interpretation.

This contribution discusses: (i) the practical benefits of integrating multi-isotopic tools ($\delta^{13}C$- and $\delta^{37}Cl$-CSIA) with site conceptual models, hydrogeochemical data, and microbiological indicators to support evidence-based remediation decisions; and (ii) an application-oriented approach to bridge academic research and industrial practice in the use of CSIA for groundwater remediation.

A case of extensive operational-scale application of CSIA is presented from a CHC-contaminated aquifer beneath a former industrial site. Isotopic, hydrochemical, and biomolecular data were systematically collected to assess ENA performance across different areas of the site, from pilot testing to post-operation monitoring. CSIA results showed in situ reductive dechlorination and contaminant rebound, consistent with concentration trends, favorable redox conditions, and increased abundance of organohalide-respiring bacteria and reductive dehalogenase genes.

Overall, the study highlights the value of integrated monitoring programs and the importance of structured guidelines, and stronger regulatory recognition to facilitate the transition of CSIA from research to an operational decision-support tool for managing legacy groundwater contamination.

LID 0758

Isotope tracers to assess groundwater connectivity in small Mediterranean coastal lagoons: Hydrological insights and methodological recommendations

Sebastien Santoni[1*], Alexis Guerin[1], Emilie Garel[1], Maria Emilia Zabala[2], Ioannis Matiatos[3], Isadora Aumond Kuhn[4], Prasanta Sanyal[5], Lucia Otega[6], Frederic Huneau[1]

[1] Université de Corse, CNRS UMR 6134 SPE, Campus Grimaldi, Corte, France
[2] Institute of Large Plains Hydrology "Dr. Eduardo J. Usunoff", Azul, Buenos Aires, Argentina
[3] Institute of Marine Biological Resources and Inland Waters, Hellenic Centre for Marine Research, Anavissos Attikis, Greece
[4] Geological Survey of Brazil, Rua Banco Província, Porto Alegre, Brazil
[5] Department of Earth Sciences, IISER Kolkata, Mohanpur Campus, India
[6] Isotope Hydrology Section, Division of Physical and Chemical Sciences, Department of Nuclear Sciences and Applications, International Atomic Energy Agency, Vienna International Centre, Vienna, Austria
[*] santoni_s@univ-corse.fr

Keywords: groundwater-dependent ecosystem, EC mapping, Radon-222, Oxygen-18, Deuterium, D-excess, mixing processes, evaporation

Small Mediterranean coastal lagoons are transitional groundwater-dependent ecosystems located at the land–sea interface and subjected to strong hydroclimatic seasonality. While groundwater inputs are known to sustain these systems, their spatial and seasonal dynamics remain poorly investigated. We hypothesize that groundwater contributions are spatially heterogeneous and seasonally modulated by hydroclimatic and recharge conditions. The objectives of this research are: (i) to detect groundwater inputs and identify the main hydrological processes governing lagoon water balance in time and space; and (ii) to formulate operational recommendations for isotope-based assessment of coastal lagoon connectivity.

Two small coastal lagoons of Eastern Corsica (Terrenzana and Stagnolu) were sampled monthly from high to low-flow periods. An innovative drone-based high-density electrical conductivity (EC) mapping approach (~500 measurements per lagoon per campaign) was combined with Radon-222 and stable isotopes (Oxygen-18, Deuterium, d-excess) point measurements. The results suggest strong spatial-temporal contrasts, with focused groundwater discharge controlled by geological constraints and gaining streams during high-flow, whereas seasonal evaporation and seawater intrusion dominate during low-flow conditions. Field experience demonstrates that Radon-222 signals may be controlled by factors such as distance from discharge zones and advective dilution, radon degassing and decay, and vertical stratification. Failure to account for these factors may result in misinterpretation of isotope tracer signals in coastal lagoon studies.

Accordingly, we propose methodological recommendations including explicit characterization of hydrological end-members, integration of EC mapping with isotope tracers, preliminary temperature–salinity profiling to identify stratification, and depth-resolved sampling strategies. This integrated framework can improve the robustness, comparability, and transferability of groundwater–lagoon connectivity assessments and supports evidence-based conservation of small Mediterranean coastal systems.

LID 0760
Long-term monitoring of water and carbon dynamics in a groundwater-dependent Mediterranean peatland

Sebastien Santoni[1]*, Emilie Garel[1], Thomas Leydier[1], Frederic Huneau[1]

[1] Université de Corse, CNRS UMR 6134 SPE, Campus Grimaldi, Corte, France
* santoni_s@univ-corse.fr

Keywords: groundwater-dependent ecosystem, monitoring, water-carbon interactions

Mediterranean peatlands are climate-sensitive Groundwater-Dependent Ecosystems located at the warm and dry bioclimatic margin of peatland distribution. Consequently, they offer early indications of peatland responses to increasing hydroclimatic stress. However, long-term process-based data remain scarce, limiting robust assessments of their vulnerability and resilience in such a context.

The low-elevation, Ramsar-listed Moltifau Mediterranean peatland (Corsica, France) represents a strategic site exposed to strong hydroclimatic variability and ongoing global change. A monitoring strategy is built on this site upon previous studies that established the conceptual hydrogeological model and quantified its carbon stock, providing the hydrogeological and biogeochemical baseline for long-term investigations. We hypothesize that water table fluctuations and hydroclimatic forcing govern DOC production and mobilization through coupled biogeochemical and hydrogeological processes, thereby controlling carbon fluxes at the peatland outlet. The objective is to characterize the coupled water–carbon cycles and identify dominant controls on carbon export under contrasting hydrological conditions.

Since late 2025, an integrated monitoring system has been deployed. Two piezometers located upstream and downstream are equipped with CTD probes recording water level, temperature and electrical conductivity at 30-min intervals. Downstream instrumentation includes a barometric sensor and an EXO2 multiparameter probe measuring turbidity and fluorescent dissolved organic matter (FDOM). A precipitation collector enables rainfall quantification and isotope analyses. Bi-monthly to quarterly sampling campaigns complement continuous monitoring through analyses of TC, TOC/DOC, TN and 3D fluorescence EEM characterization. TOC measurements calibrate continuous FDOM signals. Stable isotopes ($\delta^{18}O$, $\delta^{2}H$) and radon (^{222}Rn) constrain water sources and mixing processes between groundwater and surface water supplying the peatland under varying hydrological and climatic conditions.

Aligned with the scientific objectives of the French SNO-Tourbières network, this long-term observatory contributes to harmonized national monitoring and provides a reference framework for assessing peatland responses to climate change.

LID 0761
A national groundwater well dataset to advance water security in Brazil

José Gescilam Uchôa[1], Paulo Tarso S. Oliveira[1,2]*,André S. Ballarin[1,2], Didier Gastmans[3], Jamil A. A. Anache[1], Bridget R. Scanlon[4], Clyvihk R. Camacho[5], Valmor J. Freddo Filho[5], Edson C. Wendland[1], **Lívia Freitas**[6]*

[1] Department of Hydraulics and Sanitation, São Carlos School of Engineering, University of São Paulo, São Carlos, SP, Brazil
[2] Faculty of Engineering, Architecture and Urbanism, and Geography, Federal University of Mato Grosso do Sul, Campo Grande, MS, Brazil
[3] Environmental Studies Center, São Paulo State University, Bela Vista, Rio Claro, SP, Brazil
[4] Bureau of Economic Geology, Jackson School of Geosciences, University of Texas at Austin, Austin, TX, United States
[5] Geological Survey of Brazil, Rio de Janeiro, Brazil
[6] Groundwater Research Center, University of São Paulo, São Paulo, SP, Brazil
* livia.almeidafr@usp.br

Keywords: groundwater-surface water interactions, groundwater management, integrated water management

Groundwater is essential for sustaining water supply, ecosystem integrity, and climate resilience, representing the largest accessible freshwater reserve. Yet, fragmented monitoring networks and inconsistent data standards have limited the ability to assess groundwater dynamics and their interactions with surface waters at national scales. To address this challenge, we compiled and harmonized a comprehensive national groundwater well dataset for Brazil (GWD Brazil) in partnership with the Geological Survey of Brazil.

The resulting database consolidates 371,438 well records dating from 1900 to 2024, including approximately 351,000 unique wells after quality control procedures. Around 450 wells provide continuous daily groundwater-level observations between 2010 and 2024. The dataset was developed through a structured workflow including data acquisition, harmonization, consistency screening, cross-validation, and export. A transparent flagging system was implemented for numerical variables to identify potential inconsistencies while preserving original records, enabling users to tailor data to specific analytical needs.

The database is openly available in tabular and geospatial formats, containing key attributes such as geographic coordinates, well depth, construction details, and usage type. Beyond inventory purposes, this resource enables national- to basin-scale investigations of groundwater recharge dynamics, seawater intrusion vulnerability, land subsidence risk, groundwater-dependent ecosystems, vegetation drought resilience, streamflow depletion, and integrated water resource planning. By providing a harmonized groundwater well dataset, this initiative provides a foundational tool for strengthening hydrogeological research, advancing evidence-based management, and enhancing long-term water security under increasing climatic and anthropogenic pressures.

LID 0762
Groundwater pumpage-induced streamflow capture in the continental United States

Joseph Hughes[1]*, Jeremy White[2], Wesley Zell[3], Mohamed, Hayek[4], Katherine Markovich[5]

[1] INTERA Incorporated, Chicago, United States
[2] INTERA Incorporated, Fort Collins, United States
[3] U.S. Geological Survey, Reston, United States
[4] INTERA Incorporated, Wettingen, Switzerland
[5] University of New Mexico, Albuquerque, United States
* jdhughes99@gmail.com

Keywords: MODFLOW, streamflow capture, adjoint-state, CONUS

Streamflow capture is defined as a dimensionless fraction of change in flow to surface water features of interest divided by the withdrawal rate that causes the change in flow. Perturbation methods, which inject or extract a small quantity of water into each model cell, are typically used to develop capture fractions. Perturbation methods are computationally intensive and require one run for each model cell and one base run. The adjoint-sensitivity method is an efficient alternative to perturbation methods and only require one adjoint solution and a base model run to calculate capture fractions.

The MF6-Adj Python package was used to calculate capture fractions for the continental United States (CONUS). The MF6-Adj Python package uses the MODFLOW application programming interface (API) to save coefficient matrix terms that are used to calculate the adjoint state for one or more performance measures while MODFLOW is running. The advantage of using the MODFLOW API to calculate the adjoint state is that it is non-intrusive and will continue to work with future versions of MODFLOW.

CONUS capture fractions were calculated using 75 separate groundwater models based on HUC4 river basins in the United States. The models, which were originally calibrated to steady-state conditions, were converted to transient models using geologic-based storage values and run for 1-, 5-, 10-, and 25-years. Solving the adjoint state took about 3 hours for 125,163,546 active model cells. East of the Mississippi River, median capture fractions increase from 0.4 after 1-year to 0.9 after 25-years. West of the Mississippi River, median capture fractions increase from 0.04 after 1-year to 0.6 after 25-years. Differences in simulated capture fractions west of the Mississippi River are a result of increased depth to water, increased reliance on groundwater storage, and limitations of the current model conceptualization.

LID 0763
Hydrogeologist at the Spanish-policy interface

Carolina Guardiola-Albert[1]*, Almudena De La Losa Román[1]

[1] Department of Water and Global Change, Mining and Geological Institute of Spain (IGME-CSIC), Spanish National Research Council (CSIC), Spain
* c.guardiola@igme.es

Keywords: hydrogeology, water management, IGME-CSIC

Within the Mining and Geological Institute of Spain (IGME-CSIC), the Department of Water and Global Change develops applied hydrogeological work in close collaboration with River Basin Authorities and regional administrations, bridging scientific research and water management practice.

Long-term institutional agreements with major River Basin Authorities (including the Guadalquivir, Guadiana, Júcar, Miño-Sil, among others) enable the implementation of groundwater monitoring strategies, hydrochemical assessment, aquifer characterization, and numerical modeling to support planning under the EU Water Framework Directive and Groundwater Directive. These collaborations contribute to quantitative and qualitative status assessment, risk analysis, and the design of adaptive management measures in stressed aquifer systems.

At regional scale, cooperation with provincial administrations (such as the Provincial Council of Granada and Jaén) strengthens local-scale groundwater assessment, drought preparedness, and sustainable abstraction strategies.

More recently, nationwide coordination through the Spanish Directorate-General for Water under the National Groundwater Action Plan (PAAS by its Spanish acronym) has expanded technical support to all Spanish river basin districts, reinforcing harmonized hydrogeological methodologies across demarcations.

Through these institutional partnerships, hydrogeologists operate at the science–policy interface, providing independent technical expertise, integrating monitoring networks and advanced modeling tools, and ensuring that groundwater knowledge is effectively embedded into decision-making processes. This experience illustrates the broader role of hydrogeologists within geological surveys and equivalent national scientific bodies in advancing science, governance transparency, environmental protection, and long-term water security.

LID 0764
Operational hydrogeology in extreme events: Contributions from the Disaster and Emergency Advisory Group of the Geological and Mining Institute of Spain (IGME-CSIC)

Carolina Guardiola-Albert[1]*, **Almudena De La Losa Román**[1]

[1] Department of Water and Global Change, Mining and Geological Institute of Spain (IGME-CSIC), Spanish National Research Council (CSIC), Spain

* c.guardiola@igme.es

Keywords: emergency response, extreme events, IGME-CSIC

In recent years, Spain has faced a succession of natural disasters, prompting a shift in the role of geosciences in public safety. A major institutional response was the creation of the Disaster and Emergency Advisory Group (GADE) in 2024. As a rapid-response unit of the Spanish National Research Council (CSIC), GADE brings together multidisciplinary specialists, including hydrogeologists from the Mining and Geological Institute of Spain (IGME), to provide real-time scientific advice during extreme events.

Within this framework, IGME-CSIC hydrogeologists have contributed to the assessment of recent emergency situations in Spain. During and after the 2021 Tajogaite volcano eruption in La Palma, IGME-CSIC evaluated volcanic impacts on groundwater quality and dynamics, focusing on hydrochemical changes and dissolved gases. The results supported drinking water risk assessment and resource management. During the 2024 Valencia DANA, investigations examined flood-induced contaminant mobilization and its effects on groundwater hydrochemistry. Extreme rainfall enhanced pollutant infiltration and remobilized legacy contaminants, producing measurable quality changes. Following the 2025 wildfires in Las Médulas (León) and Pico del Lobo (Guadalajara), the loss of vegetation cover modified infiltration dynamics and sediment transport processes, enhancing erosion and facilitating the infiltration of ash-related contaminants into groundwater. In early 2026, extreme rainfall in karst environments in the mountain areas of Cádiz and Málaga, highlighted the dual role of carbonate aquifers as acting generally as buffers, but locally as amplifiers of flood processes in discharge zones.

These case studies demonstrate the essential role of hydrogeologists in on-site emergency response and the need to integrate high -resolution monitoring, numerical modeling, and interdisciplinary collaboration into operational risk management under accelerating climate variability and compound geohazards.

LID 0767
Integrating aquifers, watersheds, and participatory governance

Suraya Modaelli[1]*, Emilio Prandi[1]

[1] Agencia de Águas do Estado de São Paulo, Marília, Brazil
* suraya.modaelli@gmail.com

Keywords: participatory approaches; knowledge co-production; groundwater policy

Advancing socio-hydrogeology implies integrating knowledge about groundwater into social systems and decision-making in participatory bodies, such as River Basin Committees and the Water Resources Council. In Brazil, this movement aligns with the principles of Law No. 9.433, which proposes a decentralized and integrated management of water resources, but which historically prioritized surface water bodies.

The growing dependence on aquifers for urban water supply, production, and water security has driven their incorporation into River Basin Plans. In this context, technical chambers and universities have been acting as bridges between science and management, promoting studies, the use of hydrogeological data, monitoring, and the protection of recharge areas.

However, integration faces significant challenges. The management units are distinct: while surface waters are organized by river basins, aquifers follow geological boundaries that extend beyond these boundaries. In addition, there are gaps in information and social perception regarding the connection between surface and groundwater.

Experiences such as the Technical Chamber for Groundwater Integration (CTIAS) of the Paranapanema River Basin Committee illustrate concrete advances in bringing science, management, and social participation closer together. Initiatives such as the expansion of piezometric monitoring, training, and communication actions make the strategic role of groundwater visible and strengthen its inclusion in decision-making.

In this sense, socio-hydrogeology establishes itself as a way to integrate technical knowledge, governance, and social engagement. Recognizing the interdependence between aquifers and rivers—even those governed by distinct territorial boundaries—is fundamental for a more systemic management, capable of responding to the complexity of the hydrological cycle and promoting long-term water security.

LID 0769
Mapping potential groundwater recharge in the mountainous and hyperarid Atacama Desert (Northern Chile)

Javiera Alcayaga[1], Benjamín Carriel[1], Linda Daniele[1], **Matías Taucare**[1]*

[1] Departamento de Geología, Facultad de Ciencias Físicas y Matemáticas, Universidad de Chile, Santiago, Chile
* matias.taucare@gmail.com

In hyperarid mountain environments, evaporation far exceeds precipitation, constraining natural groundwater recharge while groundwater remains the principal freshwater source. In the Salar de Atacama basin at 2,300 m a.s.l., where evaporation and precipitation are 1,800 mm/year and <30 mm/year, respectively, recharge is not fully understood. Current models suggest groundwater originates in the eastern highlands (>4,000 m a.s.l.) and recharges along the eastern margin of the salt flat. However, the southwestern edge of the Salar de Atacama is bordered by a mountain chain of fractured rocks whose role in the hydrogeological system remains unknown, even though they reach elevations >3,000 m a.s.l. Using a multicriteria GIS workflow in QGIS, we map potential recharge zones. A Recharge Potential Index (0-100) is computed in the raster calculator from weighted layers representing: (i) geomorphology (flat/convex/concave) derived from a digital elevation model using the geomorphons tool, (ii) lithology grouped as unconsolidated deposits versus rocks in a binary mask, and (iii) a fracture connectivity proxy in the rocks domain. Concave landforms, mainly valleys, exhibit the highest potential indices (RPI > 55), consistent with focused infiltration, whereas convex and flat landforms exhibit low potential. Hard rock domains display intermediate potential (35 < RPI < 55), with the highest values occurring where NW-SE-trending structures are more connected, suggesting they serve as preferential conduits rather than as primary infiltration zones. Overall, geomorphology exerts first-order control on recharge potential along the southern margin of the Salar de Atacama, while fracture connectivity likely governs groundwater flow paths. The resulting maps provide a screening-level basis for prioritising field verification and for assessing the importance of episodic recharge during rare extreme precipitation events.

LID 0770
Development of an integrated hydrological model for large-scale SW-GW dynamics with automated multi-objective calibration

Rafael Magnabosco[1], **Diego Meléndez-Saldaña**[1]*, Vanessa A. Godoy[1], Patricio Hernández-Parra[1], Pedro Assunção[2], J. Jaime Gómez-Hernández[1], Félix Francés[1]

[1] Research Institute of Water and Environmental Engineering (IIAMA), Universitat Politècnica de València, Valencia, Spain
[2] Universidade Federal de Minas Gerais (UFMG), Instituto de Geociências, Laboratório de Estudos Hidrogeológicos (LEHID), Belo Horizonte, Brazil
* damelsal@upv.edu.es

Keywords: SW-GW coupling, TETIS–MODFLOW, NSGA-II

Integrated surface-groundwater (SW-GW) models are needed to represent interactions among soils, rivers, lakes and aquifers, especially in stressed Mediterranean wetlands such as the Albufera Natural Park (Spain). Despite its ecological and socio-economic relevance, no integrated hydrological model has yet been applied to this area. We present an ongoing, fully distributed integrated hydrological model in which the inexpensive raster-based TETIS component provides cell-by-cell surface and near-surface fluxes (runoff, subsurface flow, infiltration and percolation), which are exchanged with MODFLOW 6 packages (GWF, SFR, LAK) governing SW-GW interactions. The system runs primarily at daily steps to capture groundwater-soil feedbacks, but monthly stress periods for faster screening and simplified modules are also optional.

Novelty lies in the automation and calibration pipeline: a FloPy-based workflow automatically builds the model from standard GIS rasters and shapefiles, while the MODFLOW API allows interactive control and state-dependent updates during runtime, enabling tight coupling. An evolutionary algorithm (e.g., NSGA-II) can be used in an automatic multi-objective calibration through flexible settings to adjust key parameters, such as i) streambed conductance and Manning's coefficient per reach or larger segments of the river, ii) hydraulic conductivity for each unit, in addtion to (iii) TETIS global correction factors for refining conceptual thematic maps.

The model is under active development, and some TETIS/MODFLOW packages are being progressively tested and incorporated. However, simulations using synthetic data demonstrate fast model generation, stable coupling, and water balance consistency results, setting the basis for application in the Albufera wetland, as well as for embedding additional modules (e.g., AquaTool) within the integrated model to align simulations with user-specific management objectives.

This research is part of the PRE2022-101977 grant, funded by MCIN/AEI/10.13039/501100011033 and by the FSE+.

LID 0772

How can radiocarbon data assimilation improve estimates of sustainable abstraction volumes in confined aquifer systems? A case study from the Aquitaine Basin

Carlos Felipe Marin-Rivera[1*], Alexandre Pryet[1], Nicole Fernandez[2], Marc Saltel[3], Olivier Atteia[1], Michel Franceschi[1], Julio Goncalves [4], Bruno Hamelin[4], Pierre Deschamp[4], Christelle Marlin[5], Adrien Claveau[5]

[1] Univ. Bordeaux, CNRS, Bordeaux INP, EPOC, UMR 5805, France
[2] ETH Zürich, Department of Earth and Planetary Sciences, Switzerland
[3] BRGM French Geological Survey, Pessac, France
[4] Aix Marseille Univ., CNRS, IRD, INRA, Coll France, CEREGE, Aix-en-Provence, France
[5] Geosciences Paris-Saclay, UMR 8148, University of Paris-Saclay, CNRS, France
* cmarinriver@bordeaux-inp.fr

Keywords: confined aquifers, parameter estimation, radiocarbon, inverse modelling

Sustainable groundwater abstraction volumes can be estimated using long-term numerical simulations that account for the adverse impacts of pumping. Within large sedimentary basins, the hydrodynamic response of confined aquifers is strongly controlled by leakage through aquitards. However, the hydraulic properties of confining units are often poorly constrained in basin-scale models, challenging sustainable yield estimations.

Radioactive tracers are widely used to estimate groundwater residence times. Because leakage influences both hydrodynamics and residence times in confined aquifers, tracer data can provide information on vertical exchange processes that may not be identifiable through hydraulic head calibration alone. Yet, their use to constrain flow hydrodynamics in multi-layer systems with state-of-the-art inverse modelling approaches remains limited.

We developed a 2D cross-sectional flow and reactive transport model of the Eocene-Oligocene aquifer system in the Aquitaine Basin, Southwest France. Parameter estimation was implemented through an inverse modelling approach that assimilates hydraulic heads and ^{14}C activity. This study evaluates the potential of incorporating radiocarbon data to improve the estimation of hydraulic parameters in confining units, thereby advancing the robustness of model-based sustainable yield estimations in confined aquifer systems and supporting improved groundwater resource management under changing conditions.

LID 0776
Multi-site assessment of open-access global data for coastal groundwater vulnerability mapping

Yassine Ez-zaouy[1]*, Dawid Potrykus[2], Efthymia Zavridou[3], Stefania Stevenazzi[4], Micòl Mastrocicco[1], Gianluigi Busico[1]

[1] Department of Environmental, Biological and Pharmaceutical Sciences and Technologies (DiSTABiF), Campania University "Luigi Vanvitelli", Caserta, Italy
[2] Państwowy Instytut Geologiczny, Oddział Geologii Morza, Gdańsk, Poland
[3] UMR1114 EMMAH (AU-INRAE), Avignon Université, Avignon, France
[4] Università degli studi di Milano, Milan, Italy
* yassin.zawi@gmail.com

Keywords: open-access data, groundwater vulnerability, coastal area

Assessing groundwater vulnerability to agricultural pollution is crucial for sustainable management, particularly in highly stressed coastal environments. This study provides the first systematic evaluation of open-access global datasets for groundwater vulnerability assessment across multiple coastal regions worldwide. Several global databases were compiled and examined to evaluate their suitability for environmental applications.

The DRASTIC index was applied to eleven coastal areas representing diverse climatic settings. Results show that six sites display vulnerability patterns consistent with previously published local-scale studies, supporting the reliability of global datasets in specific contexts. Using the normalized median DRASTIC index, the investigated sites were classified into five vulnerability categories: very low, low, medium, high, and very high.

Sensitivity analysis revealed that depth to water, recharge, aquifer media, and vadose zone impact are the most influential parameters controlling groundwater vulnerability in most study areas. In contrast, hydraulic conductivity exhibited a significantly lower effective weight than its theoretical weight, raising concerns about its representativeness when derived from global databases.

Overall, this study highlights the strengths, limitations, and uncertainties associated with open-access global datasets and provides practical recommendations for improving future groundwater vulnerability assessments at regional to global scales.

LID 0777
Numerical characterization of fracture permeability for groundwater flow modeling in a tin mine using GEOFRAC

Lei Lyu[1]*, Chunxue Liu[1], Penghui Luo[1], Gang Cheng[2]

[1] Yunnan University of Finance and Economics, Kunming, China
[2] Kunming University of Science and Technology, Kunming, China
* leilyu@ynufe.edu.cn

Keywords: discrete fracture network, geostatistics, permeability tensor, groundwater flow, fault distribution

Numerous geological studies and mining operations have proven that fractures significantly control groundwater flow, mineralization, and ore distribution in metallic deposits. Current approaches for simulating groundwater flow in fractured media often rely on calculating equivalent permeability tensors from discrete fracture networks (DFN). Therefore, constructing a DFN in mining areas is essential for preventing water inrush accidents, resource exploration, and ensuring underground mining safety.

This study constructed a two-dimensional DFN using the GEOstatistical FRACture simulation method (GEOFRAC), a geostatistical approach that conditions fracture directions (strike/dip) and locations based on sample data. The northern part of the Gejiu tin district in Southwest China was selected as the study area, utilizing 3,724 outcrop fractures sampled on the ground of Gaosong Mountain. The study area covers a 17 km × 9 km rectangle encompassing the Gaosong mining area, which is located in an alpine hilly region. Key DFN parameters include density, direction, and connectivity conditions of the discs representing fracture planes. The simulated fractures were validated by comparing their directions with sample data.

Based on the constructed fracture network, the permeability tensor was calculated for each modeling grid. The GEOFRAC method was validated by the consistency between simulated fracture orientations and outcrop data, as well as the positional agreement of continuous fractures with actual faults. The calculated permeability field aligns well with major fractures and faults in the study area.

This study demonstrates that GEOFRAC is an effective tool for generating rational DFNs that capture fracture controls on groundwater flow paths, contributing to mine water inrush prevention. Future work should reduce directional sampling bias, incorporate fracture widths for more realistic modeling, and integrate both surface and underground fracture networks to enable comprehensive groundwater flow simulation in this tin mining area.

This work was supported by the National Natural Science Foundation of China Project (NSFC) [Grant Numbers 42362036 and 42062020].

LID 0778
Implementation of a groundwater monitoring network to support decision-making for the issuance of water use permits in the Paranapanema river basin, Brazil

Emilio Prandi[1]*, Suraya Modaelli[2]

[1] Paranapanema River Basin Committee, Brazil
[2] São Paulo State Water Agency, Marília/SP, Brazil
* ecprandi@gmail.com

Keywords: integrated management, piezometric monitoring, Paranapanema River Committee

The Brazilian Geological Survey (SGB) operates a groundwater monitoring network. This network is called the Integrated Groundwater Network (Rede Integrada de monitoramento de águas subterrâneas - Rimas). To improve the understanding of aquifer behavior in the Paranapanema Basin, the SGB, together with the Paranapanema River Hydrographic Basin Committee and the National Water and Basic Sanitation Agency (ANA), carried out a project to drill new piezometric wells in the Basin. The project was divided into two stages, one of intelligence and the other of works. In the first stage of the project, the intelligence stage, a survey was carried out that considered the hydrogeology, the density of the wells, and assessed the degrees of interference of the aquifers in the base flow of the hydrographic basins. The choice of drilling locations prioritized areas where the variation in groundwater levels was as natural as possible, not suffering interference from human actions.

This work served to identify the ideal monitoring "windows" for the installation of complementary piezometric wells. In the second stage, the piezometric wells were drilled. These wells were located in the sedimentary aquifers called the Bauru Aquifer and the Guarani Aquifer. The choice of these aquifers is related to the fact that they are aquifers with high permeability, and the relationship between sedimentary aquifers with high permeability and surface waters is intimate and dynamic, being fundamental for the survival of rivers, especially during periods of drought. In the Paranapanema River Basin, this interaction occurs mainly through the phenomenon known as baseflow.

Nine wells were drilled, with depths varying between 30 and 40 meters, with drilling diameters of nine and seven-eighths of an inch and four-inch casing. Selected sands were installed between the borehole and the casing to act as pre-filters.

Of these wells, those that are already in operation are measured daily. Some of them have automatic measurement systems with the data being sent directly to the RIMAS network. They already indicate the natural variation in water levels in the aquifers, which is an important indication of water availability in the base flows of the rivers.

LID 0779

Marine electromagnetic constraints on the geometry and preservation of offshore freshened groundwater and submarine permafrost

Anna Eliana Pastoressa[1*], E. Mark Everett[2], Aaron Micallef[3], K. Charles Paull[4], Johann Voigtlander[3], Jong Kuk Hong[5], J. Mathieu Duchesne[4]

[1] Marine Geology and Seafloor Surveying, Department of Geosciences, University of Malta, Msida, Malta
[2] Department of Geology and Geophysics, Texas A&M University, College Station, TX, United States
[3] Monterey Bay Aquarium Research Institute, Moss Landing, CA, United States
[4] Geological Survey of Canada, Quebec, QC, Canada
[5] Division of Earth Sciences, Korea Polar Research Institute, Incheon, South Korea
* eliana.pastoressa@um.edu.mt

Offshore freshened groundwater and relict permafrost represent two end-members of low-salinity pore-fluid systems preserved beneath continental shelves following postglacial sea-level rise. Both systems exert strong controls on fluid flow, salinity structure, and, in Arctic settings, methane stability. However, their geometry, continuity, and physical state remain poorly constrained due to limited direct sampling.

This study presents marine electromagnetic surveys from two contrasting environments: a temperate margin (Monterey Bay, California) and Arctic shelf (Canadian Beaufort Sea). In both regions, subsurface electrical resistivity structure is used to resolve salinity- and temperature-controlled contrasts associated with offshore freshened groundwater and ice-bonded or partially thawed permafrost.

In Monterey Bay, laterally coherent resistive anomalies beneath the seafloor are interpreted as freshened groundwater bodies embedded within saline marine sediments. In the Beaufort Sea, high-resistivity layers are evaluated in the context of relict permafrost distribution and degradation following marine transgression. Sensitivity analyses quantify the influence of source-receiver geometry, water depth, and sediment conductivity on depth of investigation and resolution limits in each setting.

Our results demonstrate how marine electromagnetic methods can distinguish between salinity-driven and temperature-driven resistivity contrasts and provide quantitative constraints on the geometry and preservation state of offshore hydrogeological systems across contrasting climatic regimes.

This research is conducted within the framework of the Marie Skłodowska-Curie Action project MARPERWISE: Submarine permafrost and seafloor geomorphic change in the Canadian Beaufort Sea, funded by the European Union’s Horizon Europe research and innovation programme.

LID 0780
Groundwater–glacier connectivity and meltwater recharge in an Antarctic periglacial system revealed by radon and isotopes

Ana Ferreira[1*], Ricardo Passos[1], Stela Cota[1], Caio Macedo[1], Júlia Severo[1], Alexandre Muselli[2], Larissa Demarco[2] , Cristina Nakayama[3], Sheila Furquim[3], Juliana Freitas[3]

[1] Centro de Desenvolvimento da Tecnologia Nuclear (CDTN), Belo Horizonte, Brazil
[2] Instituto de Pesquisas Tecnológicas (IPT), São Paulo, Brazil
[3] Universidade Federal de São Paulo (UNIFESP), São Paulo, Brazil
* anaclara.ferreira@cdtn.br

Keywords: Antarctica, tracer, radon

Antarctica contains the largest freshwater reserve on the planet and plays a fundamental role in regulating the global climate. However, the dynamics of groundwater in Antarctic periglacial environments remain poorly quantified in the context of ongoing climate change. Rising temperatures accelerate glacier retreat and active layer thaw, altering recharge processes and interactions between groundwater and surface water. In this context, the application of environmental tracers integrated with isotopic techniques constitutes a robust approach to identify the origin and dynamics of meltwater-related flows in rapidly changing polar environments.

This study uses radon (^{222}Rn) as a natural tracer, integrated with isotopic analyses (^{3}H, $\delta^{2}H$ / $\delta^{18}O$, ^{15}N, ^{13}C) and hydrochemical analyses (cations, anions, and alkalinity), to investigate the origin, flow paths, and processes controlling hydrological interactions in the Keller Peninsula, King George Island, Antarctica, with the aim of supporting conceptual and predictive models under climate change scenarios. Sampling was conducted in monitoring wells, glacial meltwater, lakes, streams, precipitation, and seawater in the surroundings of the Comandante Ferraz Antarctic Station, which currently relies on adjacent lakes for its freshwater supply.

Preliminary tritium results indicate that recharge is dominated by seasonal thaw of the active layer, while elevated radon concentrations reveal subsurface hydrological connectivity between glaciers and shallow surface water bodies. These observations confirm the importance of glacier-derived groundwater in sustaining local water resources. In the context of accelerated glacial retreat, understanding this contribution is essential for the sustainable management of the water resources that supply the Brazilian Antarctic Station. Furthermore, this integrated tracer-based methodology is transferable and can be applied to investigate aquifer systems in other Antarctic coastal environments.

LID 0782
Assessing a sub-river talik aquifer in continuous permafrost: Implications for potential water-supplies in Arctic regions

Nicolas Benoit[1]*, John Molson[2], Florence Parent[2], Daniel Paradis[3], Richard Martel[3], Richard Fortier[2], Jean-Michel Lemieux[2], Karine Bédard[1]

[1] Geological Survey of Canada, Natural Resources Canada, Québec, Canada
[2] Department of Geology & Geological Engineering, Université Laval, Québec, Canada
[3] Institut National de la recherche scientifique, Eau Terre et Environnement, Québec, Canada
* Nicolas.Benoit@NRCan-RNCan.gc.ca

Keywords: sub-river talik aquifer, continuous permafrost, numerical modelling

As Arctic communities adapt to climate change and increasing water demands, sub-river taliks have significant potential for providing resilient local water supplies. Recent field investigations along the Kuuguluk River in Salluit (Nunavik, Canada) have confirmed the presence of a sub-river talik embedded within continuous permafrost. This unfrozen zone already offers a valuable groundwater resource for the community, yet its hydrogeological properties and its long-term sustainability under pumping remain uncertain. To better evaluate its aquifer potential, seven piezometers were installed on three small alluvial islands along the river. Drilling operations provided detailed stratigraphic information, while the instrumentation allowed continuous monitoring of hydraulic heads and temperature profiles, complemented by hydraulic testing within the underlying Quaternary sediments.

Preliminary observations show that talik thickness ranges from approximately 3 m to more than 5 m, and that hydraulic heads exhibit seasonal fluctuations between 1 and 1.73 m. Estimated horizontal hydraulic conductivities (Kh) span four orders of magnitude (10^{-7} to 10^{-3} m/s), with higher Kh in shallow alluvial units and lower Kh within deeper glaciomarine and till deposits, in agreement with the stratigraphic sequence. Together, these measurements constitute the first integrated hydrostratigraphic and thermo-hydraulic dataset describing this sub-river talik. To further assess its groundwater resource potential, numerical simulations were conducted using the coupled groundwater flow and heat transport model HEATFLOW-SMOKER, including freeze-thaw and latent heat. The cryo-hydrogeologic modelling framework aims to reproduce talik dynamics and explore its response to various groundwater extraction scenarios. Early results suggest that horizontal wells may provide an effective pumping strategy for this narrow potential aquifer, while minimizing thermal disturbance to the surrounding permafrost.

LID 0783

Seawater intrusion and groundwater quality in an intensively exploited coastal limestone aquifer in the island of Cebu, Philippines

Kathrina Marie Borgonia[1,2]*, Alice Legrain[2], Maria Nenita Jumao-As[3], Pascal Goderniaux[2], Marcelino Palanas[3], Julius Anthony Daclan[2], Melvin Raymund Dangin[3], Clofer Suson[1,4], Janice Jamora[1], Ricardo Fornis[1], Rosana Ferolin[1]

[1] University of San Carlos, School of Engineering, Cebu City, Philippines
[2] University of Mons, Polytech Mons, Geology and Applied Geology, Mons, Belgium
[3] University of San Carlos Water Resources Center Foundation, Inc., Cebu City, Philippines
[4] Université catholique de Louvain, Louvain-la-Nueve, Belgium
* kmmborgonia@usc.edu.ph

Keywords: seawater intrusion, coastal limestone aquifer, hydrogeochemical analysis, PFAS

Groundwater remains an important source of potable water in the Philippines. Intensified anthropogenic activities associated with urbanization, however, has affected the quality and quantity of the already stressed coastal groundwater resource. Although Cebu's coastal area possesses a productive limestone aquifer, its geometry, hydraulic properties, exhaustive exploitation and presence of highly urbanized land use make it vulnerable to saltwater intrusion and the spread of subsurface pollution. Additionally, the potential presence of emerging contaminants, including PFAS compounds, poses a problem since there is no existing legislation on its monitoring and regulation in the Philippines.

This study aims to assess the quality of groundwater in Danao City, Cebu, Philippines, identify and determine the potential sources of contamination, and explore on per- and polyfluoroalkyl substances in the area since not much is known about its presence.

The investigation commenced with the establishment of a monitoring network consisting of 80 various types of wells, handpumps, and springs spread throughout the coastal barangays of Danao City. From this network, 30 water samples underwent hydrochemical analyses. Groundwater levels and conductivity were monitored in 11 locations within the network to see the influence of tidal signals and the interaction between the aquifer and river.

Initial results reveal greater conductivity levels for wells located close to the coastline, with some piezometric signals appearing to be affected by tides. Some perched rivers probably influence the groundwater quality. Moreover, some PFAS compounds were identified throughout the studied area. The findings of this study can be used by planning agencies as a basis in making policies for the protection and sustainable management of its aquifer.

LID 0784
Urbanization and overexploitation impacts in a complex aquifer in semiarid region in Northeastern Brazil

Didier Gastmans[1]*, José Guilherme Filgueiras[2], Nicolas Q. Bernardo[1], Natália S. Arruda[1], Jhennefer V.G. Jacinto[1], Mariana F. Duarte[1], Zulene Almada[2], Felipe H. Além[1]

[1] São Paulo State University (UNESP), Environmental Studies Center (CEA), Rio Claro, Brazil
[2] Company of Water Resources Management (COGERH), Fortaleza, Brazil
* didier.gastmans@unesp.br

Keywords: Cariri region, stable isotopes, nitrate

Groundwater in arid and semi-arid regions sometimes represents the only available water source for drinking and irrigation. Despite its importance for these regions, management challenges involving groundwater vulnerability to pollution, impacts of urbanization on groundwater and overexploitation requires urgent actions. This is the scenario in the Cariri region, located in the Brazilian Semiarid region where aquifers encompassed in the units of the Araripe Sedimentary Basin (ASB) are responsible by water supply for the population and the growing agricultural economy based.

Combining groundwater flow, hydrochemical, stable isotope and 14C data from wells located in the Cariri valley here we present an evaluation about the impacts on groundwater quality and flow specially in the CRAJUBAR (Crato-Juazeiro do Norte-Barbalha) a conurbated region, that encompasses about half million inhabitants.

Groundwater flow is controlled by the Araripe plateau, about 900 masl, south of the Cariri Valley, and by the rivers network in the eastern portion of the area. In the CRAJUBAR region the flow is impacted by the high concentration of wells, and a flow inversion is observed. Related to this drainage capture by the groundwater pumping high level of nitrate (>45 $mg.L^{-1}$ NO_3) are observed, associated with more enriched $\delta^{18}O$ isotopic signatures. Apparent 14C groundwater residence times corroborates this flow and contamination model. Along the Araripe plateau groundwater has high 14C content (about 100 pCm) decreasing towards the north in the CRAJUBAR region, expect in the high nitrate zone, where groundwater is modern. In the eastern region, 14C decreases toward the rivers, indicating a discharge zones.

Our results indicate the urgent need of controls in overexploitation and sanitary measures in the CRAJUBAR region, as well as integrated water management policies in the eastern portion, due to the connection of ground and surface water.

LID 0785

Assessment of groundwater circulation and recharge paleotemperature using multiple isotopic and noble gases in a Brazilian semiarid aquifer

Didier Gastmans[1*], Natália S. Arruda[1], José Guilherme Filgueira[2], Hannah Eckertt[3], Bertram G. Reventlow[3], Edith Engelhardt[3], Jürgen Sültenfuß[4], Werner Aeschbach[3], Zulene Almada[2]

[1] São Paulo State University (UNESP), Environmental Studies Center, Brazil
[2] Company of Water Resources Management (COGERH), Fortaleza, Brazil
[3] Heidelberg University, Institute of Environmental Physics Heidelberg, Germany
[4] Bremen University, Institute of Environmental Physics, Germany
* didier.gastmans@unesp.br

Keywords: paleotemperature, isotopic tracers, excess air

The Potiguar Basin, a passive margin sedimentary basin formed during the breakup of Africa and South America, is located in the Brazilian semiarid region, encompassing onshore oil reservoirs and two main aquifers: the karst Jandaíra and the porous Açu Aquifer, the latter responsible for supplying water to the population and for fruit production irrigation. Açu aquifer has not been properly studied regarding groundwater flow, isotopic, and hydrochemical groundwater evolution, the main purpose of this project. From the outcrop area, groundwater flows preferentially in the SW to NE direction influenced by the geological and structural framework of the basin. Three hydrochemical groups were identified in the study area, enabling the distinction between recharge zones and confined zones at greater depths, in accordance with the groundwater flow. Groundwater isotopic signatures values were found to be more depleted than those of actual precipitation (<-3.5‰ for $\delta^{18}O$ and -10‰ for $\delta^{2}H$ in groundwater, and up to -2.0‰ for $\delta^{18}O$ and close to 0 ‰ for $\delta^{2}H$ in precipitation), as the age tracer C-14 indicates that young groundwater (close to 100 pMC) is present in the outcrop area and that very old groundwater is found about 45 km far from recharge areas, at the deepest zones of the basin, where the C-14 concentration was near the detection limit of the method (0.3 pMC). Colder climate conditions during recharge can be inferred based on the noble gas concentrations, suggesting temperatures up to 8°C below the modern mean annual temperature, in agreement with previously paleoclimate temperature studies in the region. The high excess air values from older deep waters indicate a larger fluctuation of the water table level. Although further sampling and more precise data analysis are needed, these initial findings highlight the complexity of groundwater flow in the Açu Aquifer, and the importance of effective groundwater management to ensure the sustainability of the resource.

LID 0788
Hierarchical groundwater flow systems and their interactions with the river–lake system in dry closed basins

Yong Xiao[1]*

1 Faculty of Geosciences and Engineering, Southwest Jiaotong University, Chengdu, China
* xiaoyong@swjtu.edu.cn

Keyword: hierarchical groundwater flow systems, surface water-groundwater interaction, water exchange flux, arid basin

The interaction between surface water and groundwater is crucial for the management of water resources and the preservation of ecosystems within arid basins, but knowledge on their interaction regimes at the watershed scale remains relatively limited. The present research synthesizes a range of multi-proxy data to elucidate the interaction dynamics and patterns between surface water and groundwater within a representative dry closed basin on Tibetan Plateau. Water in the basin originates primarily from the glacier/snow melt water and precipitation in the mountainous regions, and would experience multiple but spatially heterogeneous interactions between river and aquifers from the mountain pass to the tail salt lakes after entering the basin. Water interaction in the piedmont alluvial plain is dominated by the pattern of river seepage into aquifers with a water flux of 25.82 m^3/s, which drives the development of hierarchical groundwater flow systems in the basin. The interaction pattern converts to groundwater discharge of the local groundwater flow system at the front of alluvial fan plain, which forms the principal spring-fed rivers and the predominant overflow zone in the basin with the groundwater discharge flux of 3.22 m^3/s. Most of these discharged groundwaters would infiltrate back into the aquifers in the middle-upper part of the loess plain with the river water leakage flux of 2.89 m^3/s. River water and phreatic groundwater present a gradual enrichment of hydrochemcial components and water stable isotopes along the flow path due to the intense evaporation in the loess plain. The multiple water interactions between surface water and groundwater lead to the anomalous distribution of fresh water in the middle-lower stream area, which is related to the intermediate groundwater flow system and the local variable groundwater flow system. Water interaction in the lowest salt-marsh plain is in the pattern of regional groundwater flow system discharge into the tail salt lakes under natural condition, but evolves to only discharge into the artificial brine extraction canals rather than the tail salt lakes after decades of brine exploitation. Our findings provide a conceptual understanding of the interaction regimes between surface water and groundwater in dry closed basins at watershed scale.

LID 0792

Karst aquifer dynamics: A multi-tracer approach combining ^{3}H, ^{222}RN, ^{18}O, AND ^{2}H with lumped-parameter modelling in Sete Lagoas, Minas Gerais, Brazil

Lucas D. Cunha De Paula[1]*, Fernanda C. Camargo[1], Carlos A. C. Filho[1], Eliana A. N. Knupp[1], Carolina S. Lamounier[1], Ana C. Mariante[1], João H. M. Viana[2], Ricardo G. Passos[1]

[1] Centro de Desenvolvimento da Tecnologia Nuclear (CDTN), Belo Horizonte, Brazil
[2] EMBRAPA Milho e Sorgo, Sete Lagoas, Brazil
* lucas2daniel@gmail.com

Keywords: karst aquifers, environmental tracers, lumped-parameter modelling

Evaluating groundwater vulnerability in complex karst systems is challenging due to their highly variable structures. This study investigates the flow dynamics of the Sete Lagoas karst-granular aquifer at EMBRAPA Experimental Farm, Brazil. We combined time-series tritium (^{3}H) data, Radon (^{222}Rn) monitoring, and water stable isotopes ($\delta^{18}O$, $\delta^{2}H$) analysis with lumped-parameter modelling (TracerLPM; USGS, JURGENS, 2012). Samples were collected during dry seasons. The historical tritium input function was reconstructed for 1953–2015 from a literature compilation. Missing data were estimated using regional data from the GNIP-CDTN Station till 2025. Exponential and Dispersion flow models were tested, focusing on the physical meaning behind mathematical limitations. Three distinct flow dynamics were identified: 1) Deep groundwater: deep wells showed pre-modern water (75–95 years old) with tritium below detection limits and high radon (up to 12,600 Bq/m^3), indicating slow, protected deep flow with low contamination vulnerability. 2) Karst shortcuts: suggested by a monitoring well in karst limestone that displayed fluctuating tritium and high radon (over 26,000 Bq/m^3). Simple models failed to capture this, suggesting a dual system where old water mixes with recharged water through fractures. 3) Surface water: one lake acts as an evaporation-dominated recharge zone, while another functions as a groundwater discharge area, evidenced by high radon and the absence of evaporation signatures in the water isotopes. Combining lumped-parameter modelling with geochemical data successfully differentiates vulnerable karst flows from protected deep groundwater, providing clear evidence for sustainable water management. Results will be refined with additional data and integrated with numerical flow models (MODFLOW) to support vulnerability assessment.

LID 0793
Advancing global aquifer mapping for earth system modeling, satellite interpretation, and groundwater sustainability assessments

Bridget R. Scanlon[1*], Alan M. Macdonald[2], Chunmiao Zheng[3], José Gescilam S. M. Uchôa[4]

[1] Bureau of Economic Geology, Jackson School of Geosciences, University of Texas at Austin, Austin, Texas, United States
[2] British Geological Survey, Edinburgh, United Kingdom
[3] Global Engagement and Engineering, Eastern Institute of Technology, Ningbo, China
[4] Dept. of Hydraulics and Sanitary Engineering, São Carlos School of Engineering, University of São Paulo, Brazil
* bridget.scanlon@beg.utexas.edu

Keywords: global aquifers, mapping, satellite interpretation

Global groundwater assessments increasingly rely on spatially explicit aquifer frameworks. The recent release of the Transboundary Aquifers of the World Map (2021) by International Groundwater Resources Assessment Centre documents more than 460 transboundary aquifers worldwide, representing a major step toward coordinated international groundwater governance. This effort builds upon decades of work under the World-wide Hydrogeological Mapping and Assessment Programme (WHYMAP), which provides global-scale hydrogeological maps depicting major groundwater provinces, recharge conditions, and large aquifer systems.

Despite these advances, existing global products focus primarily on transboundary systems or broad hydrogeological units. There remains a critical need to expand mapping efforts to include nationally bounded aquifers and sub-basin scale systems that are heavily exploited but not transboundary. Such expanded datasets are essential for integrating groundwater into global hydrologic and land surface models, which increasingly represent groundwater storage, recharge, and surface–groundwater interactions explicitly.

Updated, high-resolution aquifer boundaries would substantially improve interpretation of satellite observations, including Terrestrial Water Storage trends from GRACE satellites and ground deformation from InSAR. Attribution of storage changes and land subsidence to specific aquifers would greatly benefit from accurate delineation of aquifer geometry and confinement status (confined versus unconfined).

Water scarcity and sustainability assessments would also benefit from enhanced characterization of aquifer thickness, depth, storage coefficients, and economically recoverable groundwater volumes. Incorporating information on groundwater depletion status could further inform evaluations of subsidence risk and the potential for Managed Aquifer Recharge (MAR). Linking hydrogeologic characteristics with indicators of vulnerability and adaptive capacity would strengthen global assessments of groundwater resilience under climate and demand stress.

The proposed mapping effort would build on the established frameworks of IGRAC's transboundary aquifer inventory and WHYMAP's global hydrogeologic base maps to develop a more comprehensive, multi-scale global aquifer database. Such an integrated product would support Earth system modeling, satellite data analysis, water scarcity diagnostics, and groundwater management planning, providing a more complete and policy-relevant representation of global groundwater resources.

LID 0796
Geoelectrical and isotopic constraints on seawater intrusion: A case study from Ras Sudr, Western Central Sinai

Ali Mohamed[1,2]*, Tamás Buday[1]

[1] Department of Mineralogy and Geology, University of Debrecen, Debrecen, Hungary
[2] Department of Geology, Ain Shams University, Cairo, Egypt
* alimohamed@mailbox.unideb.hu

Keywords: Wadi Sudr, seawater intrusion, stable isotopes, hydrogeophysics, hydrochemistry

Investigating seawater intrusion (SWI) in Ras Sudr is critical for safeguarding the Quaternary aquifer against pressures from tourism and land reclamation. This study represents the first integrated application of geophysical, physicochemical, and stable isotope techniques in this Gulf of Suez coastal region to characterize groundwater sustainability. Hydrogeochemical parameters (pH, EC, TDS, major ions) and stable isotopes ($\delta^{18}O$, $\delta^{2}H$) were analyzed across 22 monitoring wells and integrated with subsurface imaging via three 2D Electrical Resistivity Tomography (ERT) profiles and 17 Transient Electromagnetic (TEM) soundings.

Geophysical inversion delineated the seawater wedge geometry and identified three geoelectric units: 1) surficial unsaturated alluvial deposits (20–660 Ω·m, 10–25 m thick); 2) brackish water-saturated sand and silt (20–50 Ω·m, 10–30 m thick); and 3) a saline groundwater layer (0.5–8 Ω·m). Eastern wells (510 km from coast) show minimal salinization and 40 m depths, while coastward samples exhibit shallow (6 m) water tables and Na–Cl dominance.

Isotopic analysis reveals that despite water table fluctuations after precipitation, the aquifer is hosted by non-renewable paleo-water. Depleted freshwater end-member signatures ($\delta^{18}O \approx -5.6‰$) relative to modern rain (−4.0‰) indicate ancient recharge under cooler paleoclimatic conditions. Most samples align along a distinct Seawater Mixing Line (SWML) from eastern paleo-water toward the Red Sea end-member. The $\delta^{18}O$-Cl relationship shows vertical scatter at constant salinity (2,000–10,000 mg/L TDS), confirming secondary evaporative enrichment in shallow coastal zones. These findings demonstrate negligible modern recharge relative to aquifer storage, with pressure responses likely reflecting preferential flow or lateral inflow rather than mass recharge. Current extraction rates directly induce seawater encroachment into this fossil system, necessitating immediate sustainable management to prevent irreversible aquifer degradation.

LID 0799
Integrated geophysical characterization of aquifer depressurization and karstic subsidence induced by open-pit mining in Southern Peru

Edgard Gonzales[1]*

[1] National University of San Agustin of Arequipa, Arequipa, Peru
* hgonzalesz@unsa.edu.pe

Keywords: TEM, ERT, karst hydrogeology, mine dewatering, sinkholes

Open-pit mining in the high-Andean hydrogeological systems of southern Peru triggers significant aquifer drainage and geomechanical instability. In the Antapaccay region (Cusco), the recent disappearance of springs and the emergence of sinkholes near the Cañipia River required a quantitative validation of their link to mining dewatering. This research implemented an integrated geophysical approach, executing 21 Transient Electromagnetic (TEM) soundings using the ABEM WalkTEM system and two 630-meter Electrical Resistivity Tomography (ERT) profiles.

Data processing included 1D smooth inversions and a petrophysical analysis based on Archie's Law to differentiate saturated alluvial deposits (20–80 Ω ·m) from fractured karstic limestones (80–400 Ω ·m). The results identified a continuous aquifer structure with thicknesses ranging from 15.6 to 198.9 meters. Spatial modeling revealed a systematic water table drawdown forming a cone of depression with a hydraulic gradient of $i \approx 0.02$ oriented toward the North Pit. ERT sections ruled out regional tectonic faults, confirming that groundwater migration is governed by the intrinsic karstification of the Ferrobamba Formation.

The study concludes that sinkhole formation is a mechanical response to the loss of hydrostatic pressure (Ph), which increases effective stress (Pe) and triggers the collapse of pre-existing cavities. The implementation of Managed Aquifer Recharge (MAR) and InSAR monitoring is recommended to mitigate further hydrogeological destabilization.

LID 0802
From assessment to strategy: Advancing water quality in Lebanon

Joanna Doummar[1]*, May Massoud[2], Zeinab Al Ashkar[1]

[1] American University of Beirut, Department of Earth Sciences, Beirut, Lebanon
[2] American University of Beirut, Department of Environmental Health, Beirut, Lebanon
* jd31@aub.edu.lb

Keywords: water quality, strategy, analysis

This project presents a comprehensive water quality situational Analysis at a country scale for preparation of an evidence-based national water quality strategy grounded in both secondary and primary data. The study integrates historical datasets, new field investigations, stakeholder consultations, legislative review, and gap analysis to inform strategic planning and implementation.

The secondary data assessment covers peer-reviewed publications spanning the past 50 years, compiling 4,427 water samples from springs, wells, rivers, reservoirs, and wastewater systems across Lebanon. Analyses include physico-chemical parameters (major cations and anions, electrical conductivity, TDS, nutrients, BOD_5, COD), bacteriological indicators (*E. coli*), heavy metals (e.g., Pb, Cd, Ni, Cr, Zn, Fe, Mn), and selected micropollutants and isotopes. Hydrochemical patterns indicate dominant Ca–HCO_3 facies in karstic aquifers highly prone to contamination, with deviations linked to saltwater intrusion in coastal zones and nutrient enrichment in agricultural areas.

Primary data collection includes two national sampling campaigns covering all of Lebanon. More than 208 samples were collected for conventional analyses and 50 selective pharmaceuticals were collected from 60 springs, 84 wells, 16 wastewater facilities, including source-to-tap assessments. The second campaign expands coverage to major river basins and key supply systems during contrasting hydrological conditions.

An in-depth analysis of the dataset will enable a clearer understanding of contamination patterns in relation to major recharge zones and their intrinsic vulnerability. Advanced statistical analyses will identify correlations among key water quality parameters, particularly those measured in situ, allowing for improved interpretation of pollution sources and pathways. In coordination with the ministry of water and energy, the findings will inform the development of the national strategy, which prioritizes the protection of upstream water sources, enhancement of treatment performance, strengthening of automated monitoring systems, and compliance with national standards through a phased implementation and monitoring framework.

LID 0803
Groundwater-precipitation isotopic relationship at several sites in Romania

Virgil Drăguşin[1]*, Mihai Caminschi[1], Huan Fang Dang[1,2], Vasile Ersek[3], István Gábor Hatvani[4], Zoltán Kern[4], Boglárka-Mercedesz Kis[5], Ionuţ Cornel Mirea[1], Marius Vlaicu[1]

[1] Emil Racoviţă Institute of Speleology, Romanian Academy, Bucharest, Romania
[2] Faculty of Geology and Geophysics, University of Bucharest, Bucharest, Romania
[3] Department of Geography and Environmental Sciences, Northumbria University, NE1 8ST Newcastle-upon-Tyne, United Kingdom
[4] Institute for Geological and Geochemical Research, HUN-REN Research Centre for Astronomy and Earth Sciences, Budapest, Hungary
[5] Babeş-Bolyai University, Department of Geology, Cluj-Napoca, Romania
* virgil.dragusin@iser.ro

Keywords: groundwater, precipitation, Romania

We present stable isotope data from different types of groundwaters in Romania, such as karst, thermal, or mineral waters from volcanic regions. Our aim is to explore their relationship with precipitation isotopic values in order to better understand their recharge regime and possible influences from climate change, especially modification in recharge seasonality.

In south-western Romania, isotopic values from the thermal aquifer at Băile Herculane are compared with long-term values of karst waters from its recharge area. A limited sampling campaign during 2023 revealed that thermal waters from eight sources had virtually identical isotopic values with those from its recharge area, in the nearby Isverna karst system. The water lines of the two sources are also relatively similar, with equations close to $\delta^{2}H=5\times\delta^{18}O-22$, whereas the local meteoric water line had a slope of > 7 and an intercept of ~3.

In south-eastern Romania, the meso-thermal sulfidic aquifer from Mangalia has lower values (by ~2‰ for $\delta^{18}O$, and ~10‰ for $\delta^{2}H$, respectively) compared to other ground waters in the region, implying different recharge dynamics.

Mineral waters from volcanic sources in central Romania are generally of meteoric origin. The average $\delta^{18}O$ range between -12 and +8.5 ‰, (V-SMOW) whereas the $\delta^{2}H$ values range between -87 and -12 ‰ (V-SMOW) exhibit shifts from the local meteoric water lines due to geochemical interactions and diagenetic processes.

This work is part of the project *Climate forcings of the thermal aquifer at Băile Herculane: a stable isotope perspective,* and supported by the Academia Europea: From Knowledge to Action Initiative (Project 8) and the joint project of the Hungarian Academy of Sciences and the Romanian Academy (No. NKM2025-20 /2025). We would like to thank Pål Tore Mørkved (University of Bergen, Norway), for analysing some of the samples presented here.

LID 0804
Probabilistic seepage modeling in earthen dams: Quantifying uncertainty for risk-aware safety assessments

Dheeraj Sonkar[1]*, Brijesh Kumar Yadav[1]

[1] Indian Institute of Technology Roorkee, Haridwar, Uttarakhand, India
* Dheeraj_s@hy.iitr.ac.in

Keywords: seepage modelling, uncertainty analysis, earthen dam, decision support, risk assessment

Earthen dams play a crucial role in water management, yet their safety evaluations often face significant challenges. Internal erosion driven by seepage and high pore pressures are primary contributors to dam failures. To effectively assess internal flow dynamics and predict structural vulnerabilities, probabilistic seepage models are essential. However, like many subsurface flow models, they operate under inherent uncertainties due to limited knowledge of material properties and internal geometries. Traditional deterministic approaches frequently fall short in capturing the impact of these unknowns on vital safety predictions. In alignment with contemporary decision-support frameworks, this study shifts the importance from deterministic seepage predictions to a thorough quantification of uncertainty. We assess subsurface flow dynamics within an earthen dam utilizing COMSOL Multiphysics software. By systematically varying key uncertain properties within convincing ranges, we quantify how imprecise knowledge of the dam's internal zones affects safety-critical predictions. The resulting probability distributions indicate that a correlated subset of parameters primarily drives uncertainty, significantly influencing the predicted phreatic surface and exit gradients. Despite these uncertainties, our model produces robust prediction intervals for seepage flux and pore pressure that align well with values found in existing literature. Ultimately, this probabilistic approach transforms seepage modeling into an effective decision-support tool. By clearly communicating parameter ranges, likelihoods, and predictive bounds, it empowers stakeholders to evaluate trade-offs and develop adequate, risk-aware strategies for dam safety and monitoring, even in the presence of imperfect physical parameters.

LID 0805
Regional-scale numerical modeling of groundwater flow and contaminant migration associated with resource recovery facility in San Pablo City, Philippines

Leunell Chris Buela[1]*, Maurice Duka[1], Nervy Santiago[2], Jovelyn Alcantara[2]

[1] Land Water Resources Engineering Division, Institute of Agricultural and Biosystems Engineering, College of Engineering and Agro-Industrial Technology, University of the Philippines Los Baños, Los Baños, Philippines
[2] Alterna Verde Corporation, San Pablo City, Philippines
* lmbuela@up.edu.ph

Keywords: groundwater flow modeling, capture zone analysis, contamination risk assessment

Groundwater sustains the domestic water supply of San Pablo City, Laguna, within a complex hydrogeologic setting influenced by topography and surface water bodies. To safeguard the city's primary water source, a comprehensive assessment of potential contamination risk is essential in an area where a resource recovery facility is operational. This study develops a regional-scale groundwater flow model coupled with particle tracking analysis to assess groundwater flow dynamics, delineate well capture zones, and evaluate potential contaminant migration pathways in San Pablo City sanitary landfill and resource recovery facility with resource recovery carbon capture waste to energy project. The hydrogeology of the region is defined through a four-layer hydrostratigraphic system derived from Vertical Electrical Sounding (VES) surveys. A steady-state MODFLOW model is constructed using a 100 m resolution domain. Boundary conditions are assigned using spatially distributed recharge based on land cover and long-term precipitation patterns, observed static water levels, constant-head lake boundaries, and abstraction rates from nine production wells. Model calibration yields strong spatial agreement ($R^2 = 0.88$) between observed and simulated hydraulic heads. Baseline simulations indicate predominantly topography-driven flow from upland recharge areas toward streams and lakes. Results reveal regionally variable flow toward the wells as a result of localized drawdown. Well protection zones are delineated for 50-year and extended simulation periods, identifying Well 1 (W1) as the dominant hydraulic sink. Forward particle tracking from the resource recovery facility indicates limited short-term risk to the city's production wells; however, extended simulations suggest potential long-term migration toward W1, while the remaining wells, springs, and surface water bodies exhibit low contamination risk. Contamination vulnerability is spatially localized and strongly governed by regional flow patterns and pumping stress. The study provides a scientific basis for groundwater protection planning and targeted monitoring to safeguard the city's groundwater resources.

LID 0806
Cave drip water reflects karst hydrology and precipitation dynamics

György Czuppon[1]*, Mihály Braun[2], Yuefeng Liu [3], Lóránt Biró[4], József Stieber[5], Márta Czuppon-Lázár[6], Zsófia László-Kovács[1]

[1] Geological and Geochemical Research, HUN-REN Research Centre for Astronomy and Earth Sciences, Budapest, Hungary
[2] Institute for Nuclear Research (ATOMKI), HUN-REN, Debrecen, Hungary
[3] School of Resources and Environment, Yili Normal University, Yining, China
[4] Budapest University of Economics and Business, Budapest, Hungary
[5] Stieber Environmental Ltd, Budapest, Hungary
[6] Doctoral School of Environmental Sciences, Eötvös University, Budapest, Hungary
* czuppon.gyorgy@csfk.org

Keywords: drip water, precipitation, stable isotopes

The cave drip water refers to the water which drips from cave ceilings and play key role in speleothem formation. It serves useful and essential information for the factors which controls the carbonate formation during growth of speleothems including its petrographic texture and geochemical composition. Nevertheless, it provides also valuable knowledge about how the cave and karst function hydrologically. The water that drips from the cave ultimately originates from precipitation that has infiltrated the soil and rock above the cave. This water dissolves minerals along the way and eventually reaches the cave chamber, where it falls to the cave surface inducing precipitation of carbonates. Therefore, the chemical and stable isotope composition and intensity of drip water can provide insight into the processes that occur from precipitation to dripping.

Within the framework of cave monitoring in Hungary several cave drip sites in Csodabogyós Cave (Keszthely Mt., NW Hungary), Baradla- and Béke caves (Aggtelek Karst, NE Hungary) and Pálvölgy- and Szemlőhegy caves (Buda Mt, Central Hungary) have been studied. These sites have been used to evaluate flow paths and the structure of the aquifer, with a particular focus on the residence and response times and the main infiltration periods. The stable isotope compositions of the drip waters in all cases (except one) show systematically lower values than those found in amount-weighted annual precipitation suggesting that the source of the infiltrating water dominantly derives from winter precipitation. Moreover, the relative contribution of winter precipitation can vary even within same cave system reflecting also the local morphology of the karst above the cave. In addition, the drip intensity along with the chemical and isotopic composition is used to estimate the response and transit time as well as to determine how the groundwater recharge varies over time and among caves.

The research was supported by the Ministry for Innovation and Technology, the National Research, Development and Innovation Office (project No. FK 138626).

LID 0807
Multivariate analysis of spring waters in the Aggtelek karst (NE Hungary): Controlling factors of hydrochemistry and hydrochemical grouping

Márta Czuppon-Lázár[1], József Kovács[1], Péter Dobosy[2], Lóránt Biró[3], József Stieber[4], Péter Gruber[5], **György Czuppon**[6]*

[1] Eötvös University, Doctoral School of Environmental Sciences, Budapest, Hungary
[2] Institute of Aquatic Ecology, Centre for Ecological Research, HUN-REN, Budapest, Hungary
[3] Budapest University of Economics and Business, Budapest, Hungary
[4] Stieber Environmental Ltd., Budapest Hungary
[5] Directorate of Aggtelek National Park, Jósvafő, Hungary
[6] Insitute for Geological and Geochemical Research, RCAES, HUN-REN, Budapest, Hungary
* czuppon.gyorgy@csfk.org

Keywords: spring waters, CCDA, stable isotopes, anions, cations

A detailed investigation of springs in the Aggtelek karst (NE Hungary) was carried out to improve understanding of karst hydrodynamics, assess the influence of climatic conditions, and classify the springs into distinct groups. For this purpose, a monitoring network was established in 2020, comprising 24–26 wells and springs distributed across the entire study area. The springs were monitored on a monthly basis to measure in situ physico-chemical parameters (temperature, pH, electrical conductivity) and to collect water samples for laboratory-based chemical and stable isotope analyses. During major hydrological events, sampling frequency was increased to capture short-term variations. The resulting dataset was evaluated using combined cluster and discriminant analysis (CCDA) to determine the optimal number of groups, identify their structure, and assess their internal homogeneity. This approach provided new insights into the hydrogeological characteristics of the area.

The analysis identified seven optimal groups of springs. The results indicate that geological and geochemical properties of the host rocks are the primary controls on group membership. Springs belonging to the same group generally share similar aquifer characteristics, including lithology and stratigraphic formation. In addition to group identification, homogeneity tests were performed to evaluate relationships within each group. Three groups proved to be clearly homogeneous. Time-series analysis of geochemical data revealed distinct temporal responses to meteorological conditions. Some springs showed rapid reactions (within 1–2 days) to major precipitation events, indicating quick recharge pathways, while others exhibited stable behavior with little or no variation in chemical and isotopic composition throughout the study period. The stable isotope composition of the spring waters further suggests that the main recharge period occurs during the winter half-year.

The research was supported by Doctoral Student Scholarship Program of the Co-operative Doctoral Program of the Ministry of Innovation and Technology Financed from the National Research, Development and Innovation Fund (KDP-2021 - C1794892 to Márta Czuppon-Lázár). In addition, we are also thankful for the support and permission to the Aggtelek National Park Directorate.

LID 0808
An integrated karst groundwater monitoring solution to support local water management from springs and wells intended for urban water supply

Juan Antonio Barberá Fornell[1*], J. Fernández-Ortega[1], A. Romero[1], B. Andreo[1], L. Llopis-Torres[2], C. Martín[2], A.J. Chaves[2], M. Díaz[2]

[1] Department of Geology and CEHIUMA, Ada Byron research building, University of Málaga, Málaga, Spain
[2] ITIS Software, Ada Byron research building, University of Málaga, Málaga, Spain
* jabarbera@uma.es

Keywords: karst groundwater, monitoring station, advanced data analysis, aquifer status indicators, local management

Karst waters comprise a valuable resource of excellent quality for urban use, therefore a significant worldwide population depends directly or indirectly on it. In numerous rural areas of Malaga province (southern Spain), karst groundwater is very often limited and the unique water resource available for drinking water supply, which is increasingly endangered by aquifer overexploitation and agricultural practices. In four rural settlements, where groundwater is captured or pumped from small karst aquifers, integrated open-sourced groundwater monitoring stations are installed in spring and wells to aid local water management and technicians improving update knowledge about aquifer status and operational procedures. A hydrogeological monitoring set-up consisting of set of commercial sensors plugged in to a programmable logic controller, ad-hoc designed and optimised, is able to gather on-line parametric readings, temporarily store it and send it to a cloud server for a posterior advanced data analysis in a user-friendly digital platform. Easy-to-measure sensors (groundwater discharge/level, electrical conductivity, water temperature, dissolved oxygen and turbidity) are combined with a nitrate optical probe for applying soft computing to capture behavioural patterns and statistical relationships within the acquired database and, consequently, predict temporal trends of nitrate concentrations. The set-up of the karst groundwater monitoring stations and the first version of the visualization platform are presented and the strategies for nitrate soft-sensor development are discussed, as well as other technical challenges. The scientific knowledge about aquifer functioning and characterisation, together with the technical management of the digital solution implemented for a real-time groundwater monitoring, will be transferred to local water managers and operators, resulting in advanced decision support and early warning systems to overcome uncontrolled aquifer exploitation and potential groundwater pollution risks.

LID 0810
Challenges and impacts of legal regulations on the result of the assessment of the chemical and quantitative status of groundwater in Poland

Anna Rojek[1]*, Dorota Palak-Mazur[1], Anna Kuczyńska[1]

[1] Polish Geological Institute - National Research Institute (PGI-NRI), Warsaw, Poland
* anna.rojek@pgi.gov.pl

Keywords: groundwater status and quality assessment, groundwater bodies, groundwater chemical status legal regulations

Groundwater status assessment is a legal requirement of Water Framework Directive. In Poland, methodology for the status assessment was developed in 2012 (and updated in 2020) and in general follows recommendations of the CIS Guidance Documents no.18 [1]. It consists of five groundwater quality tests and four quantity tests.

Experience from preparing groundwater bodies status assessment reports shows that results require critical expert analysis. Supportive input datasets are often less comprehensive and robust than required. Data gaps concern monitoring coverage and analytical scope, as well as incomplete recognition of groundwater-dependent ecosystems and related environmental objectives. Knowledge of ecosystems directly dependent on groundwater remains fragmented, hampering reliable assessment of groundwater impacts on their condition.

Additional uncertainty stems from limited and methodologically inconsistent information on environmental flow requirements and undisturbed/ecological flow of surface waters hydraulically connected with groundwater. Insufficiently defined reference conditions for surface waters make it difficult to fully assess groundwater–surface water interactions and their role in achieving good status.

Maintaining low flexibility of assessment tests despite imperfect data is crucial to preserve their systematic and repeatable character. Reconciling methodological rigor with data limitations remains a key challenge.

Another issue concerns threshold values (TVs) for good chemical status. Currently, 54 physicochemical indicator TVs are established in Poland. A 2019 case study by the Polish Geological Institute – NRI proposed three variants of TV revision based on natural background levels. Simulations showed that each variant would noticeably change chemical status assessment results, highlighting the strong impact of legal regulations on final classification outcomes.

Reference:

[1] Technical Report – 2009 – 026: CIS Guidance Document no.18: Guidance on Groundwater Status and Trend Assessment

LID 0811
An integrative approach focusing on MAR to increase the climate resilience of the water supply in the European city of Görlitz-Zgorzelec on the German-Polish border

Zhao Chen[1*], Bernd Bauer[3], Diana Burghardt[1], Stephan Beil[1], Saman Moghimi Benhangi[1], Thomas Fichtner[1], Paul Franke[3], Adam Helik[6], Jörg Heinze[5], Krzysztof Janik[2], Franziska Lauer[1], Kai Meiselbach[1,3], Agnieszka Patrzałek[4], Sławomir Sitek[2], Kinga Ślósarczyk[2]

[1] Dresden University of Technology, Germany
[2] University of Silesia in Katowice, Poland
[3] Stadtwerke Görlitz AG, Germany
[4] Przedsiębiorstwo Wodociągów i Kanalizacji “NYSA” Sp. z o.o. in Zgorzelec, Poland
[5] City Görlitz, Germany
[6] City Zgorzelec, Poland
* zhao.chen@tu-dresden.de

Keywords: transboundary aquifer, climate resilient water supply, integrative approach

The European city of Görlitz-Zgorzelec relies on natural groundwater resources, riverbank filtration from the Neisse River, and artificial groundwater recharge via infiltration ponds for its water supply. The shallow, unconfined aquifer used for the water supply extends across the German-Polish border and consists of Quaternary glacial-fluvial sediments. Current research indicates an unfavorable trend in changing regional climate conditions, which are having a negative effect on local water resources. Extreme hydrological events, such as prolonged droughts and flooding, pose significant challenges to the management and protection of local groundwater resources. The CRossWATER project, funded by the EU Interreg Poland-Saxony program from 2025 to 2027, aims to increase the climate resilience of the Görlitz-Zgorzelec water supply. The project consortium consists of two university research institutes (Dresden University of Technology as the lead partner and Silesian University in Katowice), the Görlitz and Zgorzelec administrative authorities, and the local water suppliers Stadtwerke Görlitz AG and PWiK “NYSA” Sp. z o.o. in Zgorzelec. To achieve the project's objective, a integrative approach comprising four technical work packages (WPs) has been planned, focusing strongly on existing MAR activities at German and Polish water supply sites. WP1 will establish a joint monitoring network, WP2 will develop a GIS-based system for efficiently exchanging data and information, as well as a numerical groundwater flow model representing the transboundary groundwater system, WP3 will assess the risk posed by changing climatic conditions to the water supply and develop concepts for appropriate adaptation measures, and WP4 will develop guidelines for implementing project results in water management practices. This presentation will focus on the project's main challenges and preliminary results stemming from investigation, monitoring, and modeling work.

LID 0814
Understanding the spatio-temporal dependence of global water withdrawals for drinking water supply on karst aquifers

Zhao Chen[1]*, Saman Moghimi Benhangi[1], Carlos Felipe Marin Rivera[2], Maria Alejandra Vela Castillo[1]

[1] Institute of Groundwater Management, Dresden University of Technology, Germany
[2] UMR 5805 EPOC, Bordeaux INP, University of Bordeaux, France
* zhao.chen@tu-dresden.de

Keywords: global water withdrawals, karst aquifer, uncertainty analysis

Utilizing karst aquifers for water supply is crucial due to their significance in regions facing water scarcity, as well as their unique hydrogeological properties. However, it is challenging to estimate global karst groundwater utilization due to limited data and uncertainties. This study aims to improve previous global-scale estimations by conducting a comprehensive analysis of existing datasets with explicit uncertainty consideration. Global datasets such as the World Karst Aquifer Map (Chen et al., 2017) and the gridded water withdrawal dataset (Huang et al., 2018) were involved. A stochastic approach using Monte Carlo simulations of sigmoid function parameters was developed to integrate the global potential karst groundwater recharge estimation by the large scale VarKarst-R model (Hartmann et al., 2015), generating the spatially and temporally varying Karst Potential Dependency Index, and constraining regional karst water availability. The proposed approach was first tested in Europe and then applied to other continents. In this study, global estimation of karst water utilization revealed an average proportion of approximately 10% of total domestic withdrawals for the period 1992-2010, with notable regional variability. Spatial distribution analysis revealed regional disparities and identified "hotspots" of variability influenced by geological, climatic, or human factors. This study emphasizes the importance of data quality and reliability when interpreting global estimates, and further investigation into specific regions revealed insights into reliance on karst aquifers and variability in water proportions.

LID 0817
Hidrogeodía: Scalable international model for groundwater public outreach

Almudena De La Losa Román[1]*, Carolina Guardiola-Albert[1], Concepción Pla Bru[2]

[1] Department of Water and Global Change, Mining and Geological Institute of Spain (IGME-CSIC), Spanish National Research Council (CSIC), Spain
[2] Department of Civil Engineering, University of Alicante, Alicante, Spain
* a.delalosa@igme.es

Keywords: Hidrogeodía, dissemination, AIH-GE

Hidrogeodía is an annual public outreach initiative held around World Water Day (22 March) that aims to connect hydrogeology with society. Organized by the Spanish Chapter of the International Association of Hydrogeologists (AIH-GE), in collaboration with universities, scientific institutions, and public research organizations, the event promotes free, open-access guided routes designed to raise awareness of the importance of groundwater for sustainable development, ecosystem protection, climate resilience, and human well-being.

The initiative is based on guided field trips or thematic itineraries that translate complex hydrogeological concepts into accessible language. Through direct interaction in real-world settings, participants gain insight into groundwater processes and their links to issues of public concern, including water scarcity, environmental degradation, and climate change impacts. Hidrogeodía helps communities understand how groundwater dynamics influence floods, land subsidence, contamination following extreme rainfall, coastal salinization, and other natural hazards, and how inadequate groundwater management can amplify such risks.

Hidrogeodía serves as an effective bridge between science and society, bringing students, families, and citizens closer to hydrogeological practice and strengthening trust in scientific expertise. Since its launch in 2017, participation has grown steadily, expanding beyond Spain to include Andorra, Portugal, several Latin American countries (Brazil, Mexico, Ecuador, Peru, Colombia, among others), and African nations such as Botswana and South Africa.

This sustained growth demonstrates a strong societal interest in understanding groundwater systems and highlights the strategic value of structured scientific outreach. Hidrogeodía represents a scalable model for enhancing groundwater literacy, fostering responsible water management, and reinforcing the social relevance of hydrogeology in addressing contemporary environmental challenges.

LID 0818
Permafrost-controlled submarine groundwater discharge and sea ice processes amplify radium signals in the Arctic Ocean

Xinyan Lu[1]*, Xiaogang Chen[1], Ling Li[1]

[1] Westlake University, Hangzhou, China
* luxinyan@westlake.edu.cn

Rapid thaw of Arctic coastal permafrost is expected to enhance submarine groundwater discharge (SGD), potentially increasing the delivery of radium isotopes from land to the Arctic Ocean. Short-lived radium isotopes are widely used to trace coastal inputs and ocean mixing, yet their behavior in ice-covered environments remains poorly understood. Here we synthesize published observations of radium isotopes across the Arctic Ocean and show that summer surface waters exhibit anomalously high activities of ^{224}Ra compared with other ocean basins. A coupled sea ice–ocean radium mass balance model developed in this study further indicates that ^{228}Ra can accumulate within long-lived permafrost sediments, resulting in progressively higher activities in older permafrost reservoirs. As coastal permafrost thaws, submarine groundwater discharge therefore releases increasingly enriched ^{228}Ra to the coastal ocean, providing a sustained source for in situ production of ^{224}Ra. Laboratory experiments provide mechanistic evidence that radium can be transferred from sediment surfaces to the ice interface through α-recoil during freezing, where it becomes trapped within the ice matrix. Subsequent radioactive decay within the ice generates additional ^{224}Ra, which is released to surface waters during seasonal melt. Model simulations reproduce the magnitude of observed summer ^{224}Ra activities and indicate strong cross-seasonal coupling between winter ice storage and summer tracer enrichment. Satellite records of sea ice seasonality from 1989-2024 further suggest that ongoing changes in Arctic ice conditions enhance this amplification effect. These results reveal a previously unrecognized linkage between permafrost evolution, submarine groundwater discharge, sea ice processes, and Arctic Ocean radium dynamics. As Arctic warming accelerates permafrost degradation and alters sea ice seasonality, radium isotopes may provide a sensitive tracer for monitoring changing land–ocean connectivity and the evolving influence of groundwater inputs to the Arctic Ocean.

LID 0819

Spatial interpretation of GALDIT vulnerability drivers using explainable AI in a coastal aquifer : A case study in Tongyeong, South Korea

Linn Kim[1*], Taeyong Kim[2], Sungtaek Lim[3], Minjune Yang[4,5]

[1] Department of Eco-friendly Energy Technology, Pukyong National University, Busan, South Korea
[2] Division of Earth Environmental System Sciences-Major of Earth & Environmental Sciences, Pukyong National University, Busan, South Korea
[3] Gyeongnam Regional Headquarters, Korea Rural Community Corporation, Changwon, South Korea
[4] Division of Earth and Environmental System Sciences-Major of Environmental Geosciences, Pukyong National University, Busan, South Korea
[5] Wible Inc., Busan, South Korea
* linn_kim@pukyong.ac.kr

Keywords: GALDIT, seawater intrusion, explainable AI

The original GALDIT index assesses seawater intrusion vulnerability using six hydrogeological parameters with predefined weights. However, these weights are applied uniformly regardless of location and do not account for site-specific hydrogeological conditions. This study applies SHapley Additive exPlanations (SHAP) and Local Interpretable Model-agnostic Explanations (LIME) to an XGBoost model (R^2 = 0.774) trained on 117 coastal wells in Tongyeong, South Korea. The standard GALDIT parameters, pumping volume (P), and seawater abstraction (SA) served as inputs, with electrical conductivity (EC) as the target. Scores were normalized to the W15 scale for comparison with the original weights. SHAP ranked distance from shore (D = 5.20), hydraulic conductivity (A = 3.37), and seawater intrusion impact (I = 2.67) as the top three factors. LIME identified I (6.21), A (2.82), and SA (2.54) as most influential. Groundwater level (L, original weight = 4) showed low importance (SHAP = 0.85, LIME = 1.28), while aquifer type (G) and thickness (T) scored near-zero in both methods. The high ranking of I may be attributed to its chemical association with EC. Both variables appear to capture overlapping aspects of the intrusion process. The low scores of G and T likely reflect limited geological diversity (two aquifer types) and reliance on interpolation from sparse measurements (T measured at 8 wells). SHAP ranked D first globally, whereas LIME ranked I first at individual wells, suggesting complementary perspectives: global variance partitioning versus local sensitivity. LIME spatial analysis showed dominant factors shifting from I near the coast to A inland. The results show that data-driven importance differs from the original weights and varies spatially. Identifying which factors dominate at each location may help target management efforts, supporting more effective coastal groundwater protection.

LID 0820
Biogeochemical processes in a complex aquifer system: Implications for defining natural geochemical background levels

Andrea Cisternino[1,2]*, Barbara Casentini[2], Stefano Amalfitano[2,3], Marco Melita[2], Philippe Renard[4], Francesca Castorina[1,5], Elisabetta Preziosi[2]

[1] Sapienza University of Rome, Department of Earth Sciences, Rome, Italy
[2] National Research Council – Water Research Institute (CNR-IRSA), Montelibretti - Rome, Italy
[3] National Biodiversity Future Center (NBFC), Palermo, Italy
[4] The Centre for Hydrogeology and Geothermics, University of Neuchâtel, Neuchâtel, Switzerland
[5] CNR-IGAG, Institute of Environmental Geology and Geoengineering – National Research Council, c/o Sapienza University of Rome, Department of Earth Sciences, Rome, Italy
* andrea.cisternino@uniroma1.it

Keywords: environmental isotopes, ProUCL, SGeMS

In geologically complex aquifers, distinguishing natural background from contamination remains a major challenge. Integrating stable isotopes (δ^2H, $\delta^{18}O$, $\delta^{13}C$-DIC, and $^{87}Sr/^{86}Sr$), with geochemistry and microbiology allows to identify recharge sources, water-rock interaction, and biogeochemical processes, supporting the definition of Natural geochemical Background Levels (NBL).

The Sacco river basin (central Italy) features peat-rich alluvial and lacustrine deposits, volcanic products, and travertine of Pleistocene-Holocene age, hosting a water-table aquifer, hydraulically separated from a deeper Meso-Cenozoic limestone aquifer by a Miocene sandy-marly flysch sequence.

More than 90 groundwater samples were collected between November 2024 and December 2025. Groundwaters are mostly calcium-bicarbonate with a slight tendency toward alkaline-earth facies. Reducing conditions were mainly found in alluvial deposits, while an oxidizing environment dominated in volcanic rocks. High values of arsenic, iron, and manganese were observed under reducing conditions, while less negative $\delta^{13}C$-DIC values suggested interaction with deep CO_2 at specific sites. Preliminary statistical analyses revealed a good correlation between microbial respiration and Ca^{2+}, HCO_3^-, and $\delta^{13}C$-DIC, highlighting the role of biologically mediated carbonate dissolution and carbon cycling processes.

Volatile organic compounds, nitrate and ammonium were used as markers of anthropic impact. After a preliminary separation of reducing and oxidizing facies, unimpacted samples were lithologically grouped using field observations, geological maps and $^{87}Sr/^{86}Sr$ results for the definition of lithology-specific NBLs for a dataset comprising at least 10 samples. The ProUCL 5.2.0 software package and the SGeMS geostatistic software were then used respectively to calculate the NBLs and compute probability maps of exceedance, modeled as a function of the biogeochemical and hydrogeological parameters of the study area.

This project is funded by Accordo interistituzionale per la definizione dei Valori di Fondo di acque e suoli della Valle del Sacco. Convenzione tra Regione Lazio – Direzione Ciclo dei Rifiuti, CNR-IRSA e Arpa Lazio (Prot. Reg. 0083524 U. 4/12/2023).

LID 0822

Using nitrate isotopes and ancillary catchment information on nitrate sources to perform a coupled estimation of source apportionment and denitrification losses in drinking water aquifers

Julien Farlin[1]*

[1] Luxembourg water agency, Esch-sur-Alzette, Luxembourg
* julien.farlin@eau.etat.lu

Keywords: nitrate contamination, denitrification, mixing model

The isotopes of the nitrate molecule have been used for decades to study nitrate sources and processes affecting ground water and surface water nitrate concentrations. As different sources can contribute to total nitrate load in receiving water bodies, isotope-based mixing calculations can yield estimates of each source's contribution. It is however notably difficult to define the isotopic composition of these ideal pure sources, also because denitrification processes can further modify their initial values. Up to now, it was assumed that either mixing ratios or denitrification losses could be estimated using isotopes, but not both at the same time. We show here how a quantitative source apportionment can indeed be made from nitrogen 15 measurements, taking both denitrification and mixing between cropland nitrate and woodland nitrate into account, by constraining the values of the initial sources using simple regression analysis based on the recharge area's cropland to woodland ratio. Such estimates can then guide decisions on best management practices in water protection zones.

LID 0823
Groundwater for water security in the agro-pastoral LMIC setting of northern Côte d'Ivoire

Paul Evans[1]*, Pauline Jurczak[1], Ernest Kouassi[2]

[1] Hydroconseil, Avignon, France
[2] University Félix Boigny, Abidjan, Côte d'Ivoire
* evans@hydroconseil.com

Keywords: groundwater management, transhumance, agro-pastoral

In many low- and middle-income countries, groundwater underpins water security and climate-resilient livelihoods. In the semi-arid regions of Tchologo and Bounkani (northern Côte d'Ivoire), domestic supply and pastoral mobility depend almost entirely on discontinuous alterite and fractured crystalline aquifers characterised by inherently low productivity. These hydrogeological constraints intersect with transhumance, cross-border migration, seasonal shifts in demand, and limited institutional capacity.

This study integrates hydrogeological assessment with demographic and governance analysis to inform regional groundwater planning. A total of 627 water points were surveyed and combined with records from 900 historical boreholes to develop a GIS-based multi-criteria regional assessment. Seasonal groundwater dynamics, infrastructure performance and management functionality were analysed alongside stakeholder interviews to capture institutional and livelihood dimensions.

Results show widespread low-yield aquifers (mean ≈2 m^3/h) and seasonal variations in groundwater levels of up to 10 m. Villages rely on multiple water points (often >10), yet dry-season functionality declines markedly. Observed failure rates are 27%, reflecting hydrogeological limits compounded by inadequate siting, weak maintenance systems and fragile financing mechanisms.

The findings demonstrate that groundwater resilience in LMIC settings is not solely a function of aquifer potential but of systemic integration across hydrogeological, infrastructural and governance domains. The study has informed regional planning by identifying priority intervention zones and recommending monitoring systems to strengthen adaptive management. It highlights how robust groundwater science, embedded within interdisciplinary analysis, can shape practice and enhance water security under climatic and socio-political stress.

LID 0824
Groundwater depletion following the destruction of the Kakhovka Dam (Ukraine): Hydrogeological consequences and emerging risks

Tatiana Koshliakova[1*], Kateryna Boiko[2], Patrick Flamm[3], Stefan Kroll[3], Christiane Fröhlich[4], Christian Zeeden[5], Matthias Vinnepand[6]

[1] M.P. Semenenko Institute of Geochemistry, Mineralogy and Ore Formation of the NAS of Ukraine, Kyiv, Ukraine
[2] State Institution “The Institute of Environmental Geochemistry of National Academy of Sciences of Ukraine”, Kyiv, Ukraine
[3] Peace Research Institute Frankfurt, Frankfurt, Germany
[4] German Institute for Global and Area Studies, Hamburg, Germany
[5] LIAG-Institut für Angewandte Geophysik, Hannover, Germany
[6] Albert-Ludwigs-Universität Freiburg, Freiburg, Germany
* tatianakoshliakova@gmail.com

Keywords: groundwater depletion, groundwater sustainability, dam destruction

The destruction of the Kakhovka Dam in June 2023 represents a major anthropogenic perturbation of the regional hydrological system in southern Ukraine. The former reservoir played a critical role in maintaining elevated groundwater levels and supporting large-scale irrigation systems in an area characterized by limited natural groundwater recharge and high evapotranspiration. Following the loss of surface water storage, groundwater levels are expected to return to their natural equilibrium, estimated to be approximately 8 m lower than under reservoir conditions, while groundwater abstraction has increased significantly to compensate for the loss of irrigation and industrial water supply.

This study, conducted within a collaborative project involving German research institutions and Ukrainian research partners, investigates the hydrogeological consequences of the dam destruction, focusing on groundwater level dynamics, resource sustainability, and environmental risks. Increased groundwater abstraction for agriculture and critical infrastructure is expected to accelerate groundwater depletion and modify regional groundwater flow systems. Potential long-term impacts include declining groundwater tables, reduced groundwater discharge to dependent ecosystems, and increased risk of seawater intrusion in coastal aquifers near the Black Sea.

The research integrates hydrogeological analysis, regional water balance assessment, and evaluation of anthropogenic pressures on groundwater resources in a conflict-affected environment. Preliminary findings indicate a shift from surface water dependency toward increased reliance on groundwater, raising concerns about the long-term sustainability of regional groundwater systems.

This study highlights the critical role of groundwater as an emergency water resource following large-scale hydrological disturbances and emphasizes the need for sustainable groundwater management strategies in post-reservoir and conflict-affected regions.

LID 0825
Observed groundwater storage increases in response to extreme rainfall in the Central Sahel: Opportunities for socio-economic development

Boukari Issoufou Ousmane[1], Maman Sani Abdou Babaye[2], Rabilou Abdou Mahaman[1], **Guillaume Favreau**[3]*, Baba Musami Sheriff[4], Ibrahim Baba Goni[4], Richard Graham Taylor[5], Yahaya Nazoumou[1]

[1] Département de Géologie, Faculté des Sciences et Techniques, Université Abdou Moumouni, Niamey, Niger
[2] Département de Géologie, Faculté des Sciences et Techniques, Université Dan Dicko Dan Koulodo, Maradi, Niger
[3] Université Grenoble Alpes, Institut de Recherche pour le Développement (IRD), CNRS, Grenoble INP, IGE, France
[4] Department of Geology, University of Maiduguri, Nigeria
[5] Department of Geography, University College London, London, United Kingdom
* guillaume.favreau@ird.fr

Keywords: River Goulbi Maradi, Sahel, extreme rainfall events, groundwater levels

Over the last decade, the Central Sahel has experienced extreme heavy daily and seasonal rainfall, consistent with the amplification of precipitation extremes under climate change.

In the transboundary river Goulbi Maradi basin of Niger and Nigeria, high-frequency monitoring of groundwater levels in the shallow alluvial aquifer and the underlying Continental Hamadien aquifer, together with river stage and rainfall, reveal pronounced rises in response to extreme rainfall events and associated flood discharges. Further, a multi-annual rising trend in piezometric levels following the cessation of the multi-decadal (1970s-1990s) Sahelian Drought is aligned to a regional increase of the total terrestrial water storage indicated by satellite gravimetry (GRACE and GRACE-FO).

These hydrological dynamics offer substantial and vital opportunities for local socio-economic development that include increased climate-resilient access to drinking water, large-scale livestock economy and water for irrigation. This contribution highlights the importance of integrating new hydrogeological dynamics into sustainable water resource management strategies in order to transform the constraints of climate change into development opportunities in the Sahel.

LID 0826
Where rivers depend on groundwater: Mapping baseflow dynamics across São Paulo State, Brazil

Fernando Schuh Rörig[1], **Carolina Fernanda Dos Santos**[1], Ricardo Hirata[1]*, Alexandra, Suhogusoff[1]

[1] Groundwater Research Center, Institute of Geosciences, University of São Paulo, Brazil
* rhirata@usp.br

Keywords: baseflow, hydrogeology, water availability

During droughts, perennial rivers rely on an invisible contribution: groundwater discharge. Rising abstraction and climatic pressures can reduce this support through aquifer-storage depletion and flow capture, without an immediate impact on conventional low-flow metrics such as $Q_{7,10}$ or Q_{90}. Thus, basins with similar low-flow magnitudes may differ in vulnerability, depending on aquifer type, stream-aquifer connectivity, and pumping intensity and location. Using data from 139 stream gauging stations in São Paulo State (Brazil) with daily discharge records (1990-2010), we examine how aquifer characteristics control baseflow and how basin geometry, groundwater abstractions, and land use/land cover (LULC) modulate it. We adopt three hypotheses: (i) basins over sedimentary aquifers (e.g., Guarani) show higher baseflow fraction and stronger support of dry-season flows than fractured-aquifer basins, reflecting differences in subsurface storage and response times; (ii) baseflow declines or becomes more variable with higher pumping and LULC change linked to reduced effective recharge and higher water use; and (iii) in sedimentary basins, observed surface discharge may underestimate total basin water availability if part of regional groundwater flow occurs along deeper flow paths not discharging to the river at that measurement section. Baseflow was estimated with recursive digital filters and was related to basin attributes, LULC, and abstraction metrics (extracted volumes and distance to drainage) using econometric models (OLS and Fixed Effects). We evaluated the effects of abstraction intensity and LULC change on baseflow variability, accounting for differences across aquifer systems, and estimated the degree to which water availability inferred from surface-flow measurements may be underestimated in sedimentary basins. By integrating hydrogeology, LULC, and abstractions over time, we provide indicators that support integrated surface and groundwater management.

We acknowledge the SACRE Project and the São Paulo State Research Foundation (2020/15434-0, 2022/15693-0, and 2024/04168-8).

LID 0829
New stage groundwater recharge strategy optimization to control land subsidence in Shanghai

Jianxiu Wang[1*], Hanmei Wang[2], Yu Zhu[1], Jianzhong Wu[2], Xinlei Huang[2] Huboqiang Li[1]

[1] Tongji University, Shanghai, China
[2] Shanghai Institute of Natural Resources Survey and Utilization, Shanghai, China
* wang_jianxiu@163.com

Keywords: new stage, groundwater recharge, strategy optimization, land subsidence

Shanghai belongs to a coastal megacity which is famous for both its development in economy and land subsidence history. The hydrogeological conditions of Shanghai is charactered by multi-aquifer and multi aquitard (MAMA) system. In its 20th century industry development in exhausting groundwater caused exploitation in deep aquifers of the MAMA system which induced serious land subsidence. In order to control the developing land subsidence, groundwater exploration is controlled and deep aquifer recharge is performed to compensate the drawdown cone. After that, the land subsidence is slowed down and the deep groundwater level is increasing. Until now, the evolution of land subsidence has entered a new stage. The current recharge volume of groundwater has exceeded the pumped volume. Most of the current groundwater exploitation is contributed by the dewatering of deep excavation. The deep confined water level of the MAMA system continues to increase and large area deep layer rebound is observed. How to optimized the traditional deep recharge become urgent.

Under above background, the deep confined groundwater exploration history is reviewed, together with the evolution history of land subsidence in Shanghai. The new stage land subsidence characteristics is also summarized. The bigdata of land subsidence and potential contributing factors are collected. Random forest AI tools are introduced to identify the contribution of shallow dewatering and deep pumping, together with the deep recharge. The contribution of traditional deep confined water to land subsidence is evaluated and identified. Based on the conclusions, the tradition deep recharge strategy is optimized based on the evaluation. The traditional recharge is adjusted to hot point and the recharge volume is decreased. The shallow dewatering is compensated by shallow recharging. A prediction system for the influence of deep foundation pit is established to predict the potential drawdown in the 3H (H is excavation depth) location. A new optimized recharge strategy with Shanghai experience considering both shallow dewatering and deep recharging is established to adapt to new stage land subsidence evolution.

LID 0830
Application of global open-source data for groundwater vulnerability assessment in the Polish coastal area

Dawid Potrykus[1,2]*, Beata Jaworska-Szulc[2], Adam Szymkiewicz[2], Yassine Ez-Zaouy[3], Gianluigi Busico[3]

[1] Polish Geological Institute—National Research Institute, Gdańsk, Poland
[2] Gdansk University of Technology, Gdańsk, Poland
[3] University of Campania “Luigi Vanvitelli”, Caserta, Italy
* dawpotry@pg.edu.pl

Keywords: open-source data, groundwater vulnerability, DRASTIC, Polish coast

In many regions worldwide, the availability of local, high-resolution environmental spatial data required for groundwater vulnerability assessment is significantly limited. Consequently, there is a growing need to explore alternative data sourced from global databases. This study focuses on the application of easily accessible, open-source global databases to evaluate intrinsic groundwater vulnerability to contamination using the DRASTIC method. The analyzed region is the Polish coastal area (southern Baltic coast), characterized by a complex multi-aquifer system formed in Quaternary fluvioglacial deposits (sand and gravel) separated by moraine tills.

The DRASTIC method for estimating groundwater vulnerability to contamination includes seven parameters: depth to water table (D), net recharge (R), aquifer media (A), soil media (S), topography (T), impact of the vadose zone (I), and hydraulic conductivity of the aquifer (C). Open-access databases, including the Global Water Table Depth (WTD), the new Global Lithological Map (GLiM), Global Hydrogeology Maps (GLHYMPS), and an Edited Digital Elevation Model (EDEM), were processed within a GIS environment to derive the necessary parameters and generate a groundwater vulnerability map. Furthermore, a comparative analysis was conducted between global datasets and local data derived from previous research.

Based on the obtained results, it was determined that the GIS-based global open-data framework is scalable and adaptable. A satisfactory level of agreement was achieved when comparing the generated groundwater vulnerability maps derived from global versus local data. Additionally, the continuously improving availability of global data facilitates further vulnerability scenario analyses, allowing for the integration of both climate change projections and anthropogenic stress factors.

This study was funded by National Centre for Research and Development, Poland within the Water4All (JTC Call 2022) partnership as a part of project DATASET (WATER4ALL/I/38/DATASET/2024).

LID 0831
Identification and mapping of the groundwater recharge potential zone in Bayandelger Soum

Demchig Oyun[1]*, Enkhbold Bolorchimeg[2]

[1] Mongolian University of Science and Technology, Mongolia
[2] Buir nuur-Menegiin tal River Basin, Mongolia
* oyund@must.edu.mn

Keywords: groundwater recharge zone, remote sensing and GIS, multi influencing factor, analytical hierarchy process, inverse distance weighting

In recent years, the growing the urban development, industrial expansion, and mining activities have significantly increased the demand for groundwater resources and highlighted their critical importance. Consequently, ensuring sustainable water security requires the ~~timely~~ implementation of effective groundwater resource management strategies that address issues such as depletion, recharge variability, and regional water balance. In this context, delineating and assessing potential groundwater recharge zones has become essential, particularly in regions where urbanization, infrastructure development, and mining activity apply to hydrological impacts.

This study delineates potential groundwater recharge zones within Bayandelger Soum, Sukhbaatar Province, Mongolia, by integrating geospatial data, Geographic Information Systems (GIS), remote sensing techniques, multi-criteria decision analysis (MCDA), and the Analytic Hierarchy Process (AHP). The adopted methodology was validated through groundwater inventory data and supplementary hydrogeological investigations conducted within the study area.

Within the MCDA–AHP framework, thematic layers such as precipitation, geology, lineament density, slope, drainage density, land use, vegetation cover, and soil characteristics were developed using satellite imagery, geological and hydrogeological datasets. These layers were assigned weighted ranks according to their relative influence on groundwater recharge and subsequently integrated through a weighted overlay analysis in the ArcGIS to make potential groundwater recharge zone map.

The results identified three classes of groundwater recharge potential: low (40.08%), moderate (51.12%), and high (8.8%). The outcomes of this study provide valuable baseline information for sustainable groundwater management and regional water resource planning in arid and semi-arid environments of Mongolia.

LID 0834
Hydrochemical clustering and machine learning mapping for urban groundwater suitability and risk assessment in Belgrade

Sunčica Gardijan[1], **Vladimir Živanović**[1]*, Nebojša Atanacković[1], Saša Stojadinović[1]

[1] University of Belgrade – Faculty of Mining and Geology, Belgrade, Serbia
* vladimir.zivanovic@rgf.bg.ac.rs

Keywords: urban groundwater; hydrochemistry; urbanisation; springs and dug wells; machine learning

Urban springs and dug wells are widespread in many cities and represent potentially valuable supplementary groundwater resources. However, their hydrochemical reliability is highly sensitive to land use, infrastructure, and shallow redox processes. This study investigates the hydrochemical status and urbanisation impacts on shallow groundwater quality across the City of Belgrade (Serbia) by integrating hydrochemical characterisation, clustering, and machine-learning modelling, based on approximately 700 springs and dug wells.

Variability in electrical conductivity and major-ion composition is used to distinguish groundwater types and geogenic background. In contrast, NO_3^-, Cl^-, SO_4^{2-}, NH_4^+, and redox-sensitive Fe and Mn are used to distinguish anthropogenic influence and water suitability. Cluster analysis of urbanisation and hydrogeological descriptors (e.g., land-use intensity, road and population density, runoff potential) reveals distinct spatial patterns and gradients in groundwater quality across urban and suburban environments.

Random Forest outlines key hydrochemical indicators and suitability outcomes to predictors derived from geology, soils, hydrogeology, land use, and DEM-based terrain metrics, using spatial cross-validation to ensure robust performance. Cluster-defined groundwater conditions are incorporated to evaluate differences in controlling factors across urbanisation patterns, while partial dependence analysis is used to interpret non-linear relationships and threshold behaviour. Suitability and probability-based risk maps are generated by comparing predicted concentrations against drinking-water guideline thresholds and propagating prediction uncertainty, thereby identifying areas with elevated risk of water-quality deterioration and zones with consistently favourable hydrochemical conditions. The results provide a spatially explicit basis for targeted monitoring and sustainable, risk-informed use of urban springs and dug wells.

This work was partially supported by the Ministry of Science, Technological Development, and Innovation of the Republic of Serbia (agreements 451-03-34/2026-03/ 200126 and 451-03-33/2026-03/ 200126).

LID 0835
Tracing anthropogenic contamination in a shallow coastal aquifer using an integrated multi-tracer approach (Lomé, Togo)

Piriziwè Palakimwé Bodjona[1,2], Frédéric Huneau[1], Masamaéya D.-T. Gnazou[2], **Emilie Garel**[1]*

[1] Université de Corse, CNRS UMR 6134 SPE, Equipe Hydrogéologie, BP 52, 20250 Corte, France
[2] Université de Lomé, Département de Géologie, Laboratoire d'Hydrologie Appliquée et Environnement (LHAE), 01 BP 1515, Lomé, Togo
* garel_e@univ-corse.fr

Keywords: anthropogenic impact, coastal aquifer, groundwater management, nitrate isotopes, emerging organic contaminants

Rapid and poorly controlled urbanization in West African coastal cities exerts increasing pressure on shallow groundwater systems. In Lomé, the capital of Togo (≈2.2 million inhabitants) the unconfined Continental Terminal (CT) aquifer provides nearly 60% of the drinking water supply. Due to its shallow depth and hydrogeological configuration, the CT aquifer is particularly vulnerable to anthropogenic contamination. Understanding its functioning and recharge dynamics is therefore essential for sustainable groundwater management.

To identify contamination sources and transfer pathways, a multi-tracer approach was carried out, combining hydrochemistry, stable isotopes (δ^2H, $\delta^{18}O$, $\delta^{15}N–NO_3^-$, $\delta^{18}O–NO_3^-$), tritium (^3H), emerging organic contaminants (EOCs), and land-use analysis. This integrated framework allows characterization of recharge processes, groundwater age structure, and pollutant transport mechanisms.

Across the urban area, 55 groundwater samples were collected. Nitrate concentrations rise to 416 mg/L, with 62% of samples exceeding the WHO drinking water limit. $\delta^{15}N–NO_3^-$ values (7.3–30.5‰) indicate dominant inputs from domestic wastewater and septic systems, while isotopic enrichment trends suggest denitrification under locally reducing conditions.

Stable water isotopes highlight heterogeneous recharge patterns, including direct infiltration, lateral flow contributions, and river–aquifer interactions. Tritium contents (0.07–2.05 TU) indicate predominantly mixed and recent waters but reveal limited effective renewal in highly urbanized sectors. Among 126 analysed compounds, 33 EOCs were detected, confirming rapid contaminant transfer from surface sources to groundwater.

Overall, the CT aquifer represents a highly polluted shallow system that requires monitoring and management strategies due to its limited attenuation capacity and increasing vulnerability under urban expansion.

LID 0836
Integrating machine learning approaches for groundwater vulnerability assessment in the Lombardy Plain area (Italy)

Stefania Stevenazzi[1]*, Marco Masetti[1], Alessandro Sorichetta[1]

[1] Università degli Studi di Milano, Dipartimento di Scienze della Terra „A. Desio", Milan, Italy
* stefania.stevenazzi@unimi.it

Keywords: groundwater protection, nitrate, ensemble methods

Groundwater is a strategic resource for guaranteeing safe and clean freshwater for human consumption and the preservation of natural ecosystems. Aquifers worldwide are increasingly threatened by pollution from urbanization, industrial development, agricultural activities and mining.

The most efficient tool for supporting land use planning, while protecting groundwater from contamination, is represented by groundwater vulnerability assessment. Recently, the use of artificial intelligence – and machine learning – techniques, individually or in combination with other statistical techniques and/or numerical models, has become increasingly widespread in this field.

Here, we evaluate the efficiency, robustness and reliability of selected machine learning techniques for the identification of natural and anthropogenic factors affecting groundwater quality and vulnerability. These techniques are evaluated, individually and in combination (i.e., ensemble), to obtain a scientifically reliable product (i.e., a vulnerability map) representing a useful tool for the protection and proper management of groundwater resources. Model optimization and validation (e.g., AUROC, statistical metrics) are assessed for evaluating the comparative performance of the selected techniques. Moreover, the final products are also compared with an already validated groundwater vulnerability assessment developed through the spatial statistical method Weights of Evidence (WofE). We selected the shallow aquifer of the Lombardy Plain, which is a nitrate-vulnerable area, as case study. The Lombardy Plain case study is of particular interest because of its long history of groundwater monitoring (quality and quantity), availability of hydrogeological data and combined presence of various anthropogenic sources of contamination.

This study is carried out in the context of the project „Valutazione della vulnerabilità degli acquiferi all'inquinamento mediante l'utilizzo di tecniche di machine learning", funded by the Piano di Sostegno alla Ricerca (PSR Linea 8 - Early Career Development) by the Università degli Studi di Milano.

LID 0839
EuroGeoSurveys: Bridging geoscience and policy for groundwater and subsurface integrated spatial planning in a changing world

Klaus Hinsby[1*], Laurence Gourcy[2], Georgina Arnó[3], Peter van der Keur[1], Stefan Broda[4], Julie Lions[2], Rob van der Krogt[5], Bob Hoogendoorn[5], Renata Barros[6], Patrick Wall[6], Julie Hollis[6]

[1] GEUS, Geological Survey of Denmark and Greenland, Copenhagen, Denmark
[2] BRGM, French Geological Survey, Orléans, France
[3] ICGC, Hydrogeology and Geoenergy Unit, Institut Cartogràfic i Geològic de Catalunya, Barcelona, Spain
[5] BGR, Federal Institute for Geosciences and Natural Resources, Berlin, Germany
[6] TNO, Geological Survey of the Netherlands, Utrecht, The Netherlands
[7] EuroGeoSurveys, Brussels, Belgium
* khi@geus.dk

Keywords: Science-Policy Interface (SPI), research agenda (SRIA), Sustainable Development Goals (SDGs), inter- and transdisciplinarity, spatial planning

Hydrogeologists in EuroGeoSurveys (EGS), together with geoscience colleagues across its 11 expert groups, generate policy-relevant geoscience information for Europe. A key achievement is the European Geological Data Infrastructure, EGDI, which offers FAIR [1] access to groundwater and other geoscience data via an interactive map viewer and free-text search. This facilitates open access to harmonised data, reports and scientific publications that support the sustainable management of Europe's subsurface and natural resources[2]. EGDI contributes to the EGS vision of establishing a permanent Geological Service for Europe (GSE) to support the implementation of European policies.

Within EGS, hydrogeologists in the Water Resources Expert Group (WREG) play a central role in strengthening the understanding of groundwater within the European science–policy landscape. Supporting the vision of a GSE, WREG contributes to the development of the Strategic Research and Innovation Agendas (SRIAs) of EGS and the European Partnership *Water4All – Water Security for the Planet*. These activities aim to raise the profile of groundwater and hydrogeology within European Framework Programmes, with an emphasis on assessing the chemical and quantitative status of groundwater to protect water safety, water security, and ecosystems, including groundwater ecosystems.

Here we present key WREG activities at the Science–Policy Interface, focusing on policy-relevant inputs to the SRIAs of EGS and Water4All, in the context of the European Water Resilience Strategy. We highlight how research data, scientific advice and inter- and transdisciplinary cooperation support the implementation of European water policies and the UN Sustainable Development Goals, particularly SDG 6. Finally, we outline WREG's engagement with the international groundwater community through contributions to IAH Networks and Commissions, including the IAH *Groundwater Resources UNECE Classification and Management Network (GRUCMN)*.

Part of the work discussed in this abstract has been completed within the framework of the GSEU – Geological Service for Europe project, funded by the European Commission under the Horizon Europe framework programme (grant agreement 101075609).

References:

[1] Wilkinson, M., Dumontier, M., & Aalbersberg, I. (2016). The FAIR Guiding Principles for scientific data management and stewardship. Sci. Data 3 (2016). Scientific Data, 3, 1–9. 10.1038/sdata.2016.18

[2] Hinsby, K., Négrel, P., de Oliveira, D., et al. (2024). Mapping and understanding Earth: Open access to digital geoscience data and knowledge supports societal needs and UN sustainable development goals. International Journal of Applied Earth Observation and Geoinformation, 130. https://doi.org/10.1016/j.jag.2024.103835

LID 0840
Transboundary aquifer systems in Libya: A comprehensive review of hydrogeology, management, and cooperation frameworks

Belkasem Alkaryani[1]*

[1] Omar Al-mukhtar University, Albayidha, Libya
* belkasem.alkaryani@omu.edu.ly

Keywords: transboundary aquifers, Libya, Nubian Sandstone Aquifer System (NSAS), North Western Sahara Aquifer System (NWSAS), Great Man-Made River Project (GMMRP)

Libya's water security is critically dependent on two major transboundary aquifer systems: the Nubian Sandstone Aquifer System (NSAS) and the North Western Sahara Aquifer System (NWSAS). These fossil aquifer systems represent the world's largest non-renewable groundwater resources, shared with neighboring countries including Egypt, Sudan, Chad, Tunisia, and Algeria. This comprehensive review synthesizes current knowledge on the hydrogeological characteristics, management challenges, and transboundary cooperation frameworks governing these aquifers. The NSAS covers approximately 2.2 million km^2 with an estimated freshwater storage of 500 trillion m^3, while the NWSAS extends over 1 million km^2 across North Africa. Libya's exploitation of these resources, particularly through the Great Man-Made River Project (GMMRP), has transformed water availability for domestic, agricultural, and industrial uses. However, significant challenges persist including unsustainable extraction rates, land subsidence, water quality degradation, inadequate monitoring systems, and limited transboundary cooperation mechanisms. This review examines the hydrogeological setting, current utilization patterns, environmental impacts, institutional frameworks, and prospects for sustainable management and international cooperation.

LID 0842
Hydrogeochemical mixing and deep fluid contributions in a Precambrian shield graben: A multi-isotope and noble gas approach

Julien Walter[1]*, Dominique Ngombé[1], Romain Chesnaux[1], John Molson[2]

[1] University of Quebec at Chicoutimi, QC, Saguenay, Canada
[2] Laval University, Québec, QC, Canada
* Julien_walter@uqac.ca

Keywords: paleohydrogeology, Precambrian shield, groundwater mixing

This study investigates the relative contribution of old groundwaters to the present-day hydrogeological system within a graben geological setting. The Saguenay Graben, located within the Canadian Precambrian Shield, was used to explore the imprint of long-term hydrogeochemical processes on shallow groundwater. Brackish waters were sampled from fractured crystalline bedrock and analyzed using a comprehensive multi-tracer approach. The methodology integrates major, minor, and trace element geochemistry with stable and radiogenic isotopes ($\delta^{11}B$, $\delta^{7}Li$, $\delta^{37}Cl$, $\delta^{81}Br$, $^{87}Sr/^{86}Sr$, ^{14}C) and noble gases (He, Ne, Ar). The study reveal three distinct sources of salinity at shallow depth: (1) Holocene marine water associated with the regional Laflamme postglacial sea; (2) Paleozoic marine brine derived from evaporation of local Ordovician seawater; and (3) Precambrian Shield brine, hundreds of millions of years old, associated with crystalline basement rocks and containing 1–5% mantle-derived helium, which suggests the upward migration of deep Precambrian brines through faults associated with the Saguenay Graben. The study also provides the first evidence in this region for the preservation of Wisconsinan glacial waters (~8,225 to 25,500 years BP) at depth. Elevated $\delta^{81}Br$, $\delta^{11}B$, and $\delta^{7}Li$ values in the Paleozoic and Precambrian brines indicate that their chemical evolution was significantly modified by cryo-concentration processes during the last glaciation. This research highlights the temporal overlap and diversity of hydrogeochemical processes shaping the regional groundwater system. It demonstrates hydraulic connectivity between shallow aquifers and the deep crystalline basement, likely controlled by crustal-scale faults bordering the Saguenay Graben. These findings contribute to a better understanding of groundwater origin and deep–shallow fluid interactions, providing fundamental knowledge for effective water resource management in complex groundwater flow systems.

LID 0843
Groundwater monitoring, seasonal dynamics and sustainable operation of the Dunas Aquifer System on the Western coast of Ceará, Brazil

Zulene Almada Teixeira[1]*, José Guilherme Filgueira[1], Ana Lúcia Maia De Souza[1], Davi Martins Pereira[1], Fracisco Alves Veras Júnior[1], Didier Gastmans[2]

[1] Water Resources Management Company of Ceará, Fortaleza, Brazil
[2] São Paulo State University, Center for Environmental Studies, Rio Claro, Brazil
* zulene.almada@cogerh.com.br

Keywords: coastal sedimentary aquifer, groundwater monitoring, sustainable groundwater management

Quantitative monitoring in coastal sedimentary aquifers is essential for the sustainable management of groundwater resources, as it allows understanding the natural dynamics of these systems and distinguishing natural seasonal variations from potential operational effects. In the Taíba region, on the western coast of Ceará, systematic monitoring of static water levels, combined with historical precipitation records, has enabled the identification of effective recharge and the assessment of hydrogeological behavior over the past decade.

The monitored area, strategically acquired by the Water Resources Management Company from the State of Ceará, is located in a coastal environment dominated by sandy sediments of the Dunas Aquifer System, underlain by units of the Barreiras Group. This is an unconfined aquifer, highly porous and permeable, with direct recharge and rapid response to rainfall seasonality, typical characteristics of coastal sedimentary systems. The preservation of approximately 95 hectares ensures the protection of recharge areas, reinforcing the environmental sustainability of groundwater exploitation.

Monitoring data collected between 2016 and 2025 from dozens of wells and piezometers, together with rainfall time series, show a well-defined seasonal signature, with groundwater level rises during the rainy season and drawdown during the dry period.

Operation of the well field is consistent with the aquifer's natural behavior. Interference tests and comparisons between production wells and community wells indicate the absence of significant impacts, even under prolonged pumping, demonstrating that the observed fluctuations are predominantly driven by climatic factors. Continuous monitoring therefore confirms that system operation remains within the expected range of natural variability, providing a fundamental technical basis for integrated and preventive management of coastal sedimentary aquifers.

LID 0844
Hydrochemical assessment of a natural uranium anomaly in a fractured crystalline aquifer, Santa Quitéria, Northeastern Brazil

Zulene Almada Teixeira[1]*, José Guilherme Filgueira[1], Ana Lúcia Maia De Souza[1], Davi Martins Pereira[1], Fracisco Alves Veras Júnior[1], Didier Gastmans[2]

[1] Water Resources Management Company of Ceará, Fortaleza, Brazil
[2] São Paulo State University, Center for Environmental Studies, Rio Claro, Brazil
* zulene.almada@cogerh.com.br

Keywords: hydrochemistry, uranium anomaly, fractured crystalline aquifer

A uranium anomaly identified in well at the school Jocundo da Costa Parente, Santa Quitéria, Brazil, with concentrations exceeding the Maximum Permissible Value (MPV) for drinking water, prompted detailed hydrogeochemical investigations. This occurrence led to the expansion of the analyses to other wells in the region, evaluating their spatial distribution and distinguishing possible anthropogenic causes from natural factors.

The study area lies within the Ceará Central Domain of the Borborema Province is characterized by Paleoproterozoic metasedimentary rocks of the Itataia Group, associated with gneisses, migmatites, and calc-silicate lenses. Uranium mineralization shows strong structural control and is related to hydrothermal/metasomatic processes of the Transamazonian Cycle, during which uranium- and phosphorus-enriched fluids precipitated colophanite discontinuously. This geological framework results in a fractured aquifer within a crystalline environment marked by high anisotropy.

Within this context, the Water Resources Management Company from the State of Ceará registered wells across Santa Quitéria, Itatira, and Canindé, collecting 38 samples for inorganic analyses. Results indicate nine wells with uranium above the MPV, along with localized anomalies of aluminum, iron, and manganese. The discontinuity of these occurrences reinforces their localized and endogenous nature.

Regional studies by Nuclear Industries of Brazil show that the main uranium concentration is restricted to the Itataia area, distinct from the Trapiá area. Consistently, aerogammaspectrometric data from the Geological Survey of Brazil reveal strong anomalies confined to the deposit area, while Trapiá shows no significant response.

The integrated hydrochemical, geological, and geophysical evidence demonstrates that the uranium anomaly at Trapiá is natural and restricted, controlled by specific lithological and structural conditions, and not related to past mineral prospecting activities.

LID 0845
Transformation of Gazipur from agricultural hub to industrial-urban hotspot and consequential adverse impacts on underlying groundwater

Kazi Ahmed[1]*, Aziz Hasan[1], Ashraful Islam[1], Mahfuzur Khan[1], Nubahush Chowdhury[1], Pavel Khan[1], Saleh Sifat[1], Saifur Rahman [2], Syed Hakim[3], Faria Badhon[3], Mohammad Alam[3], Peter Maes[3], Vijoy Matta[4]

[1] University of Dhaka, Dhaka, Bangladesh
[2] Department of Public Health Engineering, Dhaka, Bangladesh
[3] UNICEF WASH, Dhaka, Bangladesh
[4] UNICEF Consultant, Zurich, Switzerland
* kmahmed@du.ac.bd

Keywords: industrialization, groundwater, impacts

Gazipur is Bangladesh's fastest-growing urban and industrial hub where thousands of industries have been established over the past three decades. Rapid industrialization and urban expansion have triggered a profound shift from a traditionally agricultural-dominant landscape to a critical industrial-urban hotspot. The industrial-urban growth has resulted into exponential increase in groundwater abstraction, causing significant depletion of water tables.

We present here results of an assessment of land use change, industrial expansion, and consequential adverse impacts on groundwater conditions in Gazipur. The 2004 and 2024 LULC maps reveal a striking transformation of the landcover where built-up areas have expanded and croplands and vegetation cover have decreased. Eight major industrial clusters have been delineated which provided the basis for water sampling and piezometer installations. Three clusters having three piezometers at each and two clusters with two piezometers were installed to monitor GWL and WQ.

Water quality survey of March 2025 revealed that most river water samples in Gazipur exceeded standards for BOD, COD, and mercury indicating industrial and municipal discharges as the primary source of contamination. Groundwater quality, however, remains generally excellent across all depth zones, with minimal vertical variation and no clear evidence of surface contamination. Model simulations indicate that in 2025, the upper aquifer exhibits severe water level depletion exceeding 80 meters, while the lower aquifer shows moderate decline of about 55 meters. Model projections for 2030 indicate further deepening and radial expansion of the cone of depression.

Our findings indicate that Gazipur groundwater system is under increasing stress from rapid urbanization, industrial expansion, and declining recharge potential. A comprehensive 4M-model (mapping, monitoring, modeling, mandating) is proposed for sustainable groundwater management of the hotspot.

LID 0846
Modern characterization of fractured dolostone aquifers for safe low-temperature geothermal deployment

Ferdinando Manna[1]*, Ken M. Walton[1], Jonathan D. Munn[1], Beth L. Parker[1]

[1] Morwick G360 Groundwater Research Institute, University of Guelph, Ontario, Canada
* fmanna@uoguelph.ca

Keywords: geothermal, fractured rock, monitoring

Low-temperature geothermal is gaining popularity as society transitions to carbon-neutral energy systems. However, risks associated with these systems have been reported, including cross-connections between shallow and deeper formations, thermal plumes that can alter geochemistry, and groundwater flow disruption. In fractured rock, these risks are often amplified by limited knowledge of the exact location of aquitards, preferential flow zones, and prediction of heat transport and attenuation that hinder regulatory acceptance and system designs. Hence, there is value in using advanced characterization and monitoring approaches specifically tailored for fractured rocks to inform groundwater flow and transport models, geothermal system design and monitoring to identify potential impacts and mitigate risks.

In Guelph, Ontario, the dolostone aquifer, representing the primary local freshwater source, was characterized using high-resolution geological and geophysical tools, including fibre optic Active Distributed Temperature Sensing. Ambient flow was found to occur in discrete intervals associated with fractures and dissolution features. Thermal conductivity profiles showed enhanced heat transfer in zones of active flow, with variability at depth and between fractures, indicating variable flow rates. These data were used to inform a discrete fracture matrix numerical flow and transport model simulating an open-loop geothermal system proposed at the University of Guelph. Simulations indicate that the thermal plume remains local to the injection interval due to effects of heat convection-conduction interaction, analogous to solute matrix diffusion that constrains plume migration.

We propose a fractured rock field characterization framework that leverages methodological advances to inform the design of monitoring systems capable of early detection of hydraulic and geochemical changes, thereby supporting safe geothermal deployment in multi-use fractured bedrock aquifers.

LID 0847
Opportunities and challenges of restoring the depleted Dupi Tila Aquifer of Dhaka Megacity, Bangladesh

Kazi Ahmed[1*], Mahfuzur Khan[1], Muhammad Hasan[1], Goutam Mridha[2], Mohammed Alam[2], Sumit Saha[2], Fokrul Islam[3], Toufiqur Rahman[3], Sumaiya Islam[3], Brando Angeles[4], Minhajur Khan[5], Mohammad Rashedunnabi[5], Ali Chavosian[6]

[1] University of Dhaka, Dhaka, Bangladesh
[2] Institute of Water Modeling, Dhaka, Bangladesh
[3] Dhaka WASA, Dhaka, Bangladesh
[4] ADB, Manila, Philippines
[5] ADB, Dhaka, Bangladesh
[6] Pacific Consultants Co Ltd, Tokyo, Japan
* kmahmed@du.ac.bd

Keywords: urbanization, depletion, restoration

Dhaka, with a history of more than 400 years, is one of the fastest growing megacities of the world with a population of about 20 million. Rapid urbanization brought in significant changes in land use and land cover. Water bodies and low-lying areas disappeared fast replaced by built up areas with number of adverse impacts on the city hydrologic cycle such as increase in surface runoff, water logging/urban flooding, decrease in infiltration, and deterioration of water qualities. DWASA currently serve the city dwellers by supplying 2075 MLD groundwater pumped through high capacity deep tube wells. Also there is substantial private abstractions from the same Plio-Pleistocene Dupi Tila Aquifer (DTA) resulting into a huge cone of depression.

The reckless extraction of groundwater is leading to continued depletion of groundwater levels over the last few decades and a large part of the DTA has been dewatered and supplying more groundwater for meeting demand is becoming challenging. Also, there are proven and perceived adverse impacts which need to be addresses by restoring the depleted aquifer. To address these challenges effectively, a structured approach to groundwater management is essential and implementation of a Managed Aquifer Recharge (MAR) Master Plan, which focuses on replenishing depleted aquifers while ensuring long-term water security, can be one of the best options.

The opportunities for MAR applications include substantial amount of rainfall, existence of inland surface water bodies, surrounding rivers and treated waste water alongside presence of a large number of abandoned wells. Challenges include poor quality of surface water, seasonal variability of water sources and cultural issues regarding use of treated wastewater. Although there is no specific law/guideline for MAR in the country, but there is scope for safe implementation of the management option taking advantage of existing policies and strategies.

LID 0851
Machine learning-enhanced 3D seismic characterization in Upper Pannonian thermal water reservoirs, case study of Polgár 3D (Hungary)

Erika Buday-Bódi[1]*, Kyrillos Samir Ghattas[2], Tamás Buday[2]

[1] Department of Water Science and Environmental Informatics, Institute of Water and Environmental Management, Faculty of Agricultural and Food Sciences and Environmental Management, University of Debrecen, Debrecen, Hungary
[2] Department of Mineralogy and Geology, Institute of Earth Sciences, Faculty of Natural Sciences and Technology, University of Debrecen, Debrecen, Hungary
* bodi.erika@agr.unideb.hu

Keywords: 3D seismic data, machine learning, Upper Pannonian

The basic conditions for geothermal energy utilization based on water extraction are the presence of sufficient quantity, quality and temperature of groundwater in the reservoirs, as well as reservoir parameters that promote water flow (porosity, permeability, reservoir geometry). Although thermal water is widely available in Hungary, the above conditions can vary significantly even within a small distance due to differences in reservoir formation, which can be effectively detected in areas with high drilling density or by using 3D seismic technology.

The aim of our research is to determine the properties of sandy sediments deposited on the shores of the former Lake Pannon in our research area in the northern part of Trans Tisza Region, in the Polgár 3D seismic survey area. The data analysis was performed in the OpendTect software environment, which offers a number of machine learning methods for the efficient analysis of large amounts of data. In accordance with the methods used to calculate the potential of reservoirs, we mapped the tectonic elements using reflection surfaces and based on the seismic pattern, the Upper Pannonian reservoirs, including the prospective sand bodies. The vertical position of the basement significantly influenced the extent of sediment accumulation and the progression of the shoreline. Nearly 100 fault units formed mainly post-sedimentary are identified in the NE-SW direction in the area, which indicates that the sand bodies in this zone are fragmented, which has a negative impact on water recharge. The results obtained show good agreement with the stratigraphic data obtained from deep wells in the area, but extend them in terms of space and data-type aspects. In addition to providing information related to water extraction, the methods also aid in the reconstruction of developmental history.

LID 0852
Beyond technical rationality: A socio-hydrogeological framework for groundwater decision-making in agro-exporting economies

Lucas D. Cunha De Paula[1]*, Admardo B. Gomes Junior[2], Ricardo G. Passos[1]

[1] Centro de Desenvolvimento da Tecnologia Nuclear (CDTN), Belo Horizonte, Brazil
[2] Centro Federal de Educação Tecnológica de Minas Gerais, (CEFET-MG), Belo Horizonte, Brazil
* lucas2daniel@gmail.com

Keywords: socio-hydrogeology, decision-making human-water systems

Groundwater governance in agro-exporting economies remains largely shaped by a technoscientific rationality that frames aquifer management as a problem of optimal resource allocation, obscuring the political, historical, and territorial dimensions of human-water systems. This theoretical essay proposes a critical socio-hydrogeological framework that bridges groundwater science, social theory, and decision-making analysis through an interdisciplinary approach integrating epistemology, political economy, environmental history, and territorial studies. We argue that effective and equitable groundwater decision-making requires three analytical shifts. First, an epistemological reorientation: drawing on the distinction between scientific and technoscientific reasoning, we question how hydrogeological knowledge has often been mobilized to legitimize extraction and, at times, to normalize contamination, rather than to challenge the structural conditions that produce them. Second, a political-territorial reading, using Brazil as a reference: virtual water flows, estimated at over 119 billion m^3/year in net exports, reveal an invisible water metabolism embedded within global commodity chains. Interpreted through the concepts of "accumulation by dispossession" and "used territory," these flows expose how local decisions regarding aquifers are structurally subordinated to transnational economic logics. Third, a historical perspective on contamination governance: pollution, since the industrial era, has not been a byproduct of negligence but the result of deliberate legal and scientific arrangements that displace risks onto vulnerable populations. Together, these three dimensions challenge the post-Dublin technocratic consensus and advocate for a socio-hydrogeology committed to knowledge coproduction, environmental justice, and the recognition of groundwater as a territorial commons. Both the epistemological critique and the evidence presented suggest that linking hydrogeological science with social systems requires not only methodological innovation but also a fundamental repositioning of knowledge in relation to power.

LID 0854
Groundwater temperature monitoring in Wrocław (Poland) - Changes over two decades (2004–2024) due to climate and urban infrastructure impacts

Monika Hajnrych[1]*, Jan Blachowski[1], Magdalena Worsa-Kozak[2]

[1] Wrocław University of Science and Technology, Faculty of Geoengineering, Mining and Geology, Department of Geodesy and Geoinformatics, Wrocław, Poland
[2] Wrocław University of Science and Technology, Faculty of Geoengineering, Mining and Geology, Department of Mining, Wrocław, Poland
* monika.hajnrych@pwr.edu.pl

Keywords: SubUHI, hydrogeology, groundwater temperature GWT, spatio-temporal patterns, climate change

Climate change and rapid urban development contribute to rising groundwater temperatures, fostering the formation of the subsurface urban heat island (SubUHI) and the groundwater urban heat island (GUHI) phenomena. This study presents the results of comparative analysis carried out in the city Wrocław (Poland) between two measurement campaigns conducted in 2004–2005 and 2022–2024. The primary objective was to evaluate thermal changes in groundwater in relation to air temperature using statistical and spatial analysis methods. The dataset was processed using descriptive statistics, ordinary kriging interpolation, map algebra techniques, and Pearson correlation analysis. Additionally, spatial and statistical analyses were performed to assess the influence of district heating infrastructure on groundwater temperature patterns.

The findings reveal a pronounced increase in groundwater temperatures, particularly during the winter season, when the mean temperature rise ranged from 2 to 4°C compared to the first measurement period. The most significant changes were identified in shallow Quaternary aquifers, which exhibited a strong correlation with air temperature ($r \approx 0.8$). Spatial analyses indicated that the greatest groundwater temperature increases occurred in the city center and densely built-up areas, confirming the intensification of the GUHI effect. Furthermore, a reduction in the seasonal amplitude of groundwater temperature fluctuations and a localized decline in the groundwater table were observed. These results highlight the growing influence of urbanization and climate change on subsurface thermal regimes and emphasize the need to consider groundwater temperature dynamics in urban planning and groundwater management.

LID 0857
Landscape evolution and hydrogeologic change

Grant Ferguson[1]*, Jennifer C. McIntosh[2]

[1] University of Saskatchewan, Saskatoon, Canada
[2] University of Arizona, Tucson, United States
* grant.ferguson@usask.ca

Keywords: fossil groundwater, geologic change, landscape evolution

Much of the Earth's groundwater is fossil, with residence times of thousands to millions of years or older. Interest on fossil groundwater systems has often focused on the effects of past climates on recharge, while the effects of geologic change over time have received comparatively less attention. Here, we provide an overview of how landscape evolution can result in notable influences on groundwater fluxes and residence times in groundwater systems. Geological processes can both strengthen and weaken connections between deep groundwater systems and the rest of the hydrologic cycle, which can result in substantial changes geochemical fluxes. Changes in the geological framework of groundwater flow systems may also have important implications for anthropogenic activities in the deep subsurface, including storage of nuclear waste and carbon sequestration.

LID 0859
Assessing groundwater pumping energy consumption through spatially distributed numerical groundwater flow modelling

Tolossa Dabi Dinagde[1]*, Rudy Rossetto[1]

[1] Institute of Crop Science - Scuola Superiore Sant'Anna di Pisa, Italy
* tolossa.dinagde@santannapisa.it

Keywords: energy consumption, groundwater pumping, water management, climate change, greenhouse gases, WEFE NEXUS

Groundwater is a crucial resource in areas with limited surface water. However, groundwater pumping accounts for a considerable share of total energy use, especially when pumping from a deep aquifer. As a considerable part of energy comes from fossil fuels, effective management of energy consumption is therefore necessary to reduce greenhouse gases (GHGs) emissions and mitigate climate change.

We developed a QGIS3 Plugin that supports a standardized, easy-to-use workflow for storing, visualizing, and analyzing energy-consumption data associated with groundwater pumping. The plugin calculates groundwater pumping energy consumption at each well for each stress period of the transient MODFLOW-2005 simulation using the mechanical pumping equation, given as $E = \frac{\rho g Q H}{3.6 \cdot 10^{-6} \eta tot}$ where, E is the daily energy consumption (kWh/day), ρ is the density of water (Kg/m^3), g is gravitational acceleration (m/s^2), Q is the discharge rate (m^3/day), H is the lift height, the difference between the top elevation and the pump depth, $\frac{1}{3.6 \cdot 10^{-6}}$ is the conversion factor from Joules per day to kilowatt per day, and ηtot is the motor and pump efficiency.

We evaluated the energy consumption for irrigation groundwater pumping using the calibrated MINDCORNIA groundwater flow numerical model (using the FREEWAT-Q3 graphical user interface and the MODFLOW-2005 code). The study area is characterized by groundwater serving as the sole source of water for irrigation, industry, and domestic use. Energy consumption information is essential for estimating energy costs and GHGs emissions. This tool may provide information on how much additional energy is required if drawdown increases, how energy consumption increases if abstraction increases, and how energy can be saved if management strategies such as Managed aquifer recharge are applied. These informations are essential for integrated climate adaptation and planning agricultural policies in the light of the adoption of the Water Energy Food Environment (WEFE) NEXUS framework for sustainable development.

This research is funded within the PhD Programme in Agrobiosciences (39th cycle) Scuola Superiore Sant'Anna di Pisa, Italy.

LID 0860
Drought propagation and groundwater storage dynamics in Southern Angola

Pedro Lombe[1,2]*, Elsa Carvalho[1,2], Paulo Rosa-Santos[1,2]

[1] Department of Civil Engineering and Georesources, Faculty of Engineering of the University of Porto (FEUP), Porto, Portugal
[2] Interdisciplinary Centre of Marine and Environmental Research of the University of Porto (CIIMAR), Matosinhos, Portugal
* up201407072@edu.fe.up.pt

Keywords: ground water, drought, GRACE, Southern Angola

Southern Angola has experienced recurrent droughts of increasing frequency and intensity over recent decades, placing growing pressure on water resources in a region where surface water is highly vulnerable to precipitation variability. Understanding how meteorological drought propagates into groundwater systems is therefore essential for sustainable water management.

This study investigates the relationship between drought conditions and groundwater storage dynamics across the provinces of Huíla, Namibe, and Cunene using GRACE-derived groundwater storage anomalies (ΔGWS) and the Standardized Precipitation Index (SPI) for the period 2003–2023. Trend detection was performed using the Mann–Kendall test and Sen's slope estimator to evaluate long-term behavior and temporal shifts in system response.

Groundwater storage exhibited distinct temporal phases, with an initial recharge-dominated period followed by increasing variability and decline under intensified drought conditions. Although aggregated long-term trends suggest relative groundwater stability, sub-period analysis reveals growing groundwater stress in the last decade. The relationship between SPI and ΔGWS indicates that severe and consecutive drought events increasingly constrain groundwater storage, particularly in Huíla and Cunene, while Namibe shows a comparatively buffered response.

These findings demonstrate that groundwater systems in southern Angola are progressively responding to sustained drought intensification, highlighting the need to strengthen monitoring frameworks and integrate groundwater management into regional drought adaptation strategies.

1. Introduction

Groundwater has a crucial role in ensuring both agricultural and domestic water supply in sub-Saharan Africa, particularly in regions facing severe water scarcity. This importance is increasingly recognized, with a growing emphasis on groundwater use for irrigation to enhance food security [1]. In Angola, the situation is no different. The country faces a high prevalence of waterborne diseases due to limited access to safe and clean water for human consumption [2]. Indeed, water scarcity in semiarid regions such as southern Angola is exacerbated by declining river flows and aquifer recharge rates, leaving less than 20% of communities with access to safe water [3].

Efforts to mitigate water scarcity in Angola date back to the 1960s, when programs involving geoelectrical prospecting and drilling were implemented [4]. However, despite groundwater's buffering capacity during droughts and its contribution to rural water supply in southern Africa [5], Angola's groundwater management remains insufficiently developed. Southern Angola faces recurrent and prolonged droughts, affecting millions of people and causing significant socioeconomic challenges. For

instance, an estimated 7.9 million people—about 30.8% of Angola's population—are exposed to drought, with 1.9 million affected annually [6].

Communities in southern Angola rely heavily on shallow, hand-dug wells (*cacimbas*) and rainwater collection systems (*chimpacas*) for drinking water. These sources are highly vulnerable to drying out and contamination, especially during droughts. Contaminated water from chimpacas, shared with animals, poses significant public health risks (Serrat-Capdevila et al., 2022). Climate change further compounds these challenges, with southern Angola experiencing the worst droughts in 40 years, severely impacting food security and water access [7]. Drought-related economic losses in southern provinces exceed $749 million, with agriculture, livestock, and fisheries being the most affected sectors (Serrat-Capdevila et al., 2019).

Groundwater offers potential as a sustainable adaptation strategy for drought management in Angola, yet its development is hindered by insufficient data, limited public information, and a lack of systematic groundwater monitoring. Current drilling efforts are often unsuccessful due to inadequate hydrogeological studies, leading to high costs and failure rates [8]. Hydrological observations in Angola are scarce, leaving water allocation and resource management highly uncertain [9]. The problem is not solely due to low rainfall but also stems from a lack of appropriate policies, resources, and strategies to capture, store, and utilize water efficiently during critical months [10].

The Gravity Recovery and Climate Experiment (GRACE) satellite presents a promising solution for addressing Angola's groundwater information gaps. GRACE data enable cost-effective assessments of groundwater storage changes, offering valuable insights into terrestrial water storage [11]. Globally, GRACE data have been widely applied for groundwater drought monitoring, improving simulations of groundwater storage variations and aiding resource management (Li et al., 2019). Studies in regions such as Argentina, China, and the Ganga River Basin highlight GRACE's effectiveness in monitoring groundwater dynamics and its potential for guiding drought mitigation strategies [12, 13].

This study utilizes GRACE and GRACE-FO data to analyze groundwater resources in southern Angola, emphasizing their role as a critical adaptation strategy for managing drought. With drought intensity and frequency increasing in the region, and limited access to reliable groundwater information, this article offers a unique exploration of how groundwater resources can support sustainable water management in one of Angola's most vulnerable regions. To the authors knowledge, it is the first to directly address the intersection of groundwater and drought in Angola, providing insights into make use of these resources for resilience in the face of escalating climate challenges.

2. Groundwater and drought dynamics

To better understand the long-term interaction between drought conditions and groundwater availability, monthly ΔGWS and SPI data were aggregated into annual averages, and their temporal trends were analysed (Figure 1). Trend detection was carried out using the non-parametric Mann–Kendall test, while Sen's slope estimator was applied to quantify the magnitude of change. This methodological approach allows for a clearer assessment of how meteorological drought patterns influence medium-term groundwater availability in southern Angola.

Overall, groundwater storage displayed an increasing tendency across the three provinces throughout most of the study period. Between 2003 and 2007, ΔGWS values were predominantly negative, indicating groundwater deficits. From 2007 onwards, storage conditions gradually improved, reaching peak levels around 2012, particularly in Huíla and Cunene. Although a decline in ΔGWS was observed after this peak, values generally remained positive, suggesting that groundwater storage, while reduced, did not immediately return to deficit conditions.

In contrast, drought conditions intensified over time. While the SPI exhibited only a weak downward tendency between 2003 and 2015, a pronounced decline became evident from 2016 onwards, with values falling below −2 in several years. This shift reflects a substantial increase in drought severity during the latter part of the study period, particularly in the most recent years.

3. Conclusions

Drought in southern Angola has intensified over recent decades, and the analysis demonstrates a clear linkage between increasing drought severity and groundwater storage dynamics. While groundwater exhibited a recharge-dominated phase during the early part of the record, recent years show growing sensitivity to sustained drought conditions. The apparent long-term stability of groundwater storage masks a shift toward declining trends in the last decade, particularly in Huila and Cunene.

These findings indicate that consecutive and severe drought events are progressively constraining groundwater recharge and altering subsurface storage behavior. The spatial variability observed among provinces suggests that groundwater response is influenced not only by climatic forcing but also by local hydrogeological characteristics and potential anthropogenic pressures, including water abstraction and demographic demand.

Overall, the results confirm that groundwater systems in southern Angola are increasingly vulnerable to prolonged meteorological stress, and their buffering capacity may be diminishing under persistent drought intensification. Understanding the combined influence of climatic and anthropogenic drivers is essential for anticipating future groundwater availability under a changing climate.

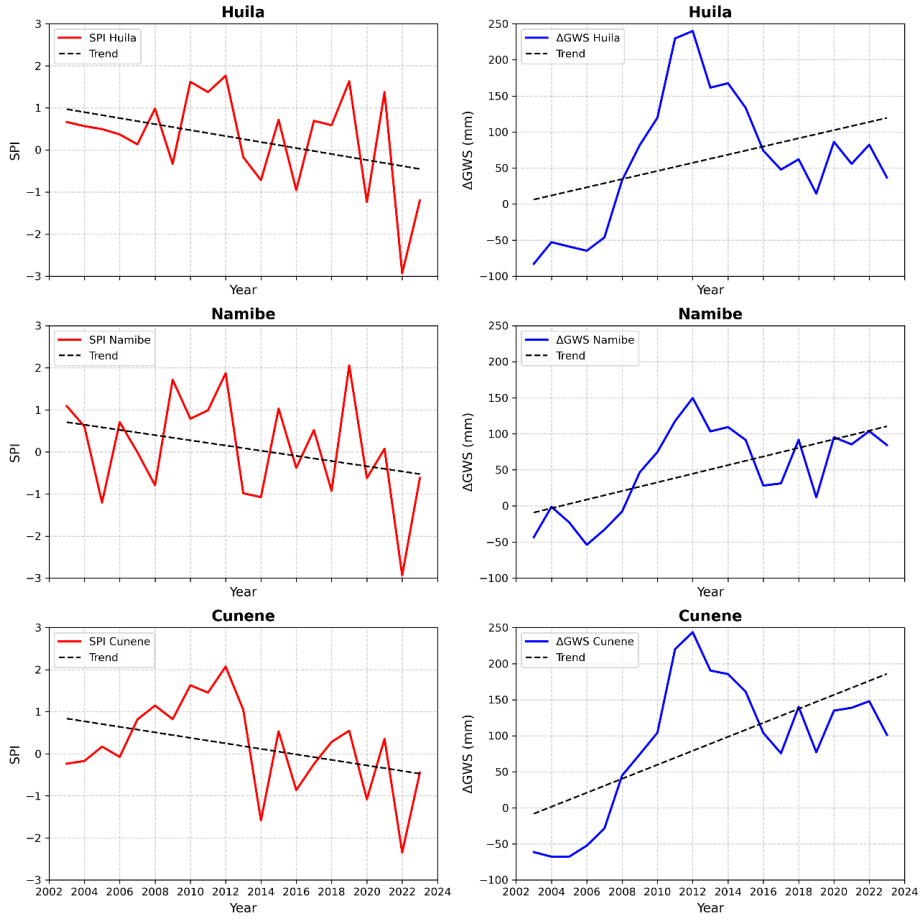


Figure 2. *Temporal evolution of groundwater storage anomalies (ΔGWS) and meteorological drought conditions (SPI) in southern Angola (2003–2023).*

References:

[1] de Bont, C., & Börjeson, L. (2024). Policy Over Practice: A Review of Groundwater Governance Research in Sub-Saharan Africa. International Journal of the Commons, 18(1), 82–93. https://doi.org/10.5334/ijc.1313

[2] Paca, J. M., Santos, F. M., Pires, J. C. M., Leitão, A. A., & Boaventura, R. A. R. (2019). Quality assessment of water intended for human consumption from Kwanza, Dande and Bengo rivers (Angola). Environmental Pollution, 254. https://doi.org/10.1016/j.envpol.2019.113037

[3] Blanes, R. L., Cardoso, C. V., Bahu, H. A., & Fortuna, Cláudio. (2022). Drought in Angola. Situation Report 2020-2021. Causes, Responses and Solutions. Research Report.

[4] Ramalho, E. C., Francés, A., & Santos, F. M. (2022). Interpretação hidrogeológica da modelação 3D das sondagens eléctricas verticais (SEV) da década de 1960 na bacia do Cunene, Angola. 107.

[5] Farr, J. L., Gumiremhete, R., Davies, J., & Robins, N. S. (2005). Groundwater dependence and grought Within the Southern African Development Community.

[6] Mateus, N. P. A. (2022). Assessment of the impacts of natural disasters related to drought in Angola. http://www.ict.unesp.br/biblioteca/normalizacao

[7] Correia, C. D. N., Amraoui, M., & Santos, J. A. (2024). Analysis of the Impacts of Climate Change on Agriculture in Angola: Systematic Literature Review. In Agronomy (Vol. 14, Number 4). Multidisciplinary Digital Publishing Institute (MDPI). https://doi.org/10.3390/agronomy14040783

[8] Marcus. (2023). Making Water Security and Drought Resilience in the South of Angola Happen Synthesis Report. www.worldbank.org

[9] Almeida, M., Pombo, S., Rebelo, R., & Coelho, P. (2021). The probability distribution of daily streamflow in perennial rivers of Angola. Journal of Hydrology, 603. https://doi.org/10.1016/j.jhydrol.2021.126869

[10] Bonga, J. Y. H. (2016). Tecnologias para a mitigação dos efeitos da seca na Bacia Hidrográfica do Rio Caculuvar em Angola.

[11] Singh, V. K., Pandey, H. K., & Singh, S. K. (2023). Groundwater storage change estimation using GRACE data and Google Earth Engine: A basin scale study. Physics and Chemistry of the Earth, 129. https://doi.org/10.1016/j.pce.2022.103297

[12] Aon, S., Nandi, S., Sen, S., & Biswas, S. (2024). GRACE based groundwater drought evaluation of Ganga Basin and analysis of drought propagation using wavelet based quantitative approach. Science of the Total Environment, 951. https://doi.org/10.1016/j.scitotenv.2024.175666

[13] Zheng, W., Ge, W., Shi, S., Chen, H., Wang, F., Askari, K., Song, C., Shi, P., Ge, W., Shi, S., Chen, H., Wang, F., Zheng, W., Wang, F., Chu, J., & Wang, F. (2024). Increasing vulnerability of vegetation to Meteorological and Groundwater drought: A Case study in Argentina. Journal of Hydrology: Regional Studies, 55. https://doi.org/10.1016/j.ejrh.2024.101931

LID 0861
A combined Pastas and MODFLOW approach for characterizing groundwater recharge and MAR potential on Öland

Nikolas Benavides Höglund[1]*, Peter Dahlqvist[2], Raoul Collenteur[3]

[1] Department of Earth and Environmental Science, Lund University, Lund, Sweden
[2] Geological Survey of Sweden, Lund, Sweden
[3] Collenteur Hydroconsult, Spiez, Switzerland
* nikolas.benavides_hoglund@mgeo.lu.se

Keywords: recharge, MAR, groundwater modeling

Öland is the third-largest island in the Baltic Sea and one of Sweden's most popular tourist destinations. The island has only 30 000 permanent residents but hosts around 300 000 seasonal residents and tourists each summer. This creates a strong pressure on local water resources, as private well owners, municipal supplies, and agriculture must compete for limited freshwater. The island is among the sunniest and driest regions in Sweden, with sparse, thin soil cover that restricts both the spatial extent and volume of groundwater. Proximity to the coast and shale rich in organic carbon and heavy metals further complicate water quality. These constraints have led the island's authorities to impose preventive irrigation bans for private households in the past years.

Historically, freshwater has been trucked across the Öland Bridge from the mainland at times of high demand, serving as a temporary but unsustainable solution. Recent interventions include the construction of two desalination plants, but desalinated Baltic Sea water costs roughly three times more than fresh groundwater, and even combined, these solutions remain insufficient. Hence, there is a need to take action to increase precipitation recovery or enhance groundwater recharge through Managed Aquifer Recharge (MAR) solutions.

In this study, we use lumped-parameter groundwater modeling to characterize groundwater recharge over time at monitoring wells managed by the Geological Survey of Sweden (SGU). The study spans the period 2020–2026, corresponding to SGU's installation of transducers within the national survey network on the island. We then extend this characterization using MODFLOW and PEST++ to analyze recharge across both space and time, history matching against recharge estimates while accounting for land use variability. Finally, we map the thickness of the unsaturated zone across the island, which is a critical step in identifying candidate locations for future MAR interventions.

LID 0862
Data-driven optimization of groundwater potential zones in the Hamissana Shear Zone, Sudan: A comparative study of AHP and genetic algorithm approaches

Mohammed Noor Hassan[1,2]*, Abdalla Elsheikh[2], Khalid A. Elsayed Zeinelabdein[2], Basheer Easia[1], Mahmoud M. Kazem[3], Tamás Buday[1]

[1] Department of Mineralogy and Geology, University of Debrecen, Debrecen, Hungary
[2] Faculty of Petroleum and Minerals, Al Neelain University, Khartoum, Sudan
[3] Water Research Center, Red Sea University, Port Sudan, Sudan
* noorm.noorm@gmail.com

Keywords: groundwater potential mapping, genetic algorithm optimization, fractured basement aquifer

Exploration of groundwater in basement terrains is difficult because of structural complexity, limited primary permeability, and rainfall effects. This study maps groundwater potential zones (GWPZs) in Wadi Orshap, within the south Hamisana Shear Zone, northeastern Sudan. An integrated workflow combined geophysical surveys, borehole lithologic data, remote sensing, and GIS parameters. Nine layers were prepared: slope, curvature, wetness index, geology, fracture density, transmissivity, transverse resistance, total depth, and saturation depth. All layers were standardized and aligned to the same CRS, resolution, and extent.

Two approaches were compared: Analytic Hierarchy Process (AHP) and a Genetic Algorithm (GA). AHP assigned expert weights, whereas GA optimized weights through fitness evaluation using borehole productivity data. Performance was evaluated using confusion-matrix metrics from productive versus low/dry wells.

GA outperformed AHP, achieving 79% accuracy, 78% precision, and 88% recall, compared with 57% accuracy, 71% precision, and 56% recall for AHP. Higher recall indicates improved detection of productive wells within high-potential zones. Optimized weights identify transverse resistance and geology as the most influential controls on groundwater occurrence.

These results show evolutionary optimization offers an objective alternative to traditional multi-criteria decision-making in basement terrains, improving prediction reliability and supporting groundwater exploration in arid, fracture-controlled aquifer systems.

LID 0865
Lithostratigraphy as an important factor in the characteristics of geothermal reservoirs of the Great Hungarian Plain

Endre Dömötör Mucsi[1]*, Erika Bódi-Buday[2], Tamás BUDAY[1]

[1] Department of Mineralogy and Geology, Institute of Earth Sciences, Faculty of Natural Sciences and Technology, University of Debrecen, Debrecen, Hungary
[2] Department of Water Science and Environmental Informatics, Institute of Water and Environmental Management, Faculty of Agricultural and Food Sciences and Environmental Management, University of Debrecen, Debrecen, Hungary
* mucsidomotor@gmail.com

Keywords: Upper Pannonian, thermal water production, thermal reservoir

A significant portion of Hungary's geothermal reservoirs were formed during the accumulation in the Pannonian Lake, as the primarily sandy deposits (known as the Újfalu Formation) that settled in the deltas along the shoreline are now found at sufficient depths across most of the Great Hungarian Plain to reach temperatures of 30 °C, which is the lower temperature limit for thermal water in Hungary. Moreover, these sand bodies are extensive, thus ensuring sufficient recharge during thermal water extraction. Nevertheless, unfavorable changes occur over time in many thermal wells, the lithological causes of which we seek to explore in our current research.

During the analysis of thermal water reservoirs, we examined the penetrated and screened lithological units, geophysical well logs, and seismic data, as well as water chemistry analyses and production data for 70 thermal wells in the Middle Tiszántúl area, between Polgár, Debrecen, and Cserkeszőlő.

Based on the results obtained, a decline in production parameters can be expected in wells that produce from many depth levels, even from different formations, which was a common practice in early wells in order to increase water yield. This is because the shallower sand bodies typically belong to the fluvial-lacustrine Zagyva Formation, in which their extent is typically smaller and anisotropic. In many cases, reservoirs with different hydraulic heads were filtered in, allowing for interlayer seepage, while the yield at the well-head decreases. In such cases, the temperature and dissolved substance content of the produced water may vary according to the current pressure conditions, which also limits its usability. In addition, variability may also occur in the Újfalu Formation, primarily at the edges of the deltas and in tectonically active areas, which cause less favorable reservoir properties. Understanding these lithological differences can increase the predictability of thermal water production.

LID 0867
Determining optimal sampling frequency using transducers within groundwater monitoring wells

Farid Achour[1]*

[1] GSI Environmental Inc., Irvine, California, United States
* fachour@gsienv.com

On a daily basis, millions of groundwater levels are recorded by transducers installed in monitoring wells by consultants and government agencies dealing with environmental and water resources issues across the United States. The time step or sampling frequency used is often an arbitrary selection based solely on the storage capacity of the transducers, rather than being based on scientifically sound rationale that takes into account the specific dynamics of the aquifer under investigation.

Not optimizing the sampling frequency will result in collecting unnecessary data that will create noise in the signal that will, in the time domain, mask useful information about the aquifer.

Typically, the analytical focus is on water level fluctuation over time. Such a focus deals only with long term trends, or at best a signature of a nearby pumping well. The information that can be extracted from the time domain is only a small part of a much larger picture: this is due to the limitations of tools that analyze data in the time domain. The full range of information can be extracted by switching the frequency domain.

ENVIRON has developed a method to determine the optimal sampling frequency, by analyzing a preliminary dataset composed by water level data, recorded over a short time period and analyzed using a Fast Fourier Transform algorithm (FFT). While the correlogram will indicate how important the storage capacities of the aquifer are, the spectral density function will help determine the optimal sampling frequency.

By combining the results of the spectral density function and the fundamentals of the Nyquist-Shannon theorem, it is possible to determine the optimal sampling frequency, which corresponds to the cut-off frequency, directly identified on the spectral density function graphic.

To be rigorous with our reasoning, we calculate the percent error induced by the selected sampling frequency in reproducing the observed phenomenon (i.e. groundwater fluctuations). We also use a statistical hypothesis testing as an important value judgment to check the reliability of the results.

LID 0868
Variability in submarine groundwater discharge estimates: A comparative review from the Campo de Cartagena–Mar Menor system (Spain)

Jonathan Van Hanja[1], Paul Baudron[2]*, Christian Leduc[2], Elisa Ferrari[3], Virginia Robles Arena[4], José-Luis García-Aróstegui[4]

[1] École de Technologie Supérieure, Montréal, Canada
[2] Institut de Recherche pour le Développement, Montpellier, France
[3] Ferrari Groundwater Consulting, Roma, Italy
[4] Spanish Geological Survey, Murcia, Spain
* paul.baudron@ird.fr

Keywords: submarine groundwater discharge, coastal aquifers, conceptual modelling

Submarine groundwater discharge (SGD) is widely recognized as a relevant pathway linking coastal aquifers and marine environments. However, reported SGD magnitudes often differ substantially between studies, even within the same hydrogeological system. Understanding the origin of this variability is essential for meaningful comparison and interpretation.

This contribution presents a comparative review of seventeen published SGD estimates for the Campo de Cartagena–Mar Menor coastal system (SE Spain). Reported values range from less than 10 to more than 80 $hm^3 \cdot yr^{-1}$. Rather than proposing a new estimate, we examine how differences in methodological approach and system representation contribute to this dispersion.

The comparison considers tracer-based methods, water-balance approaches, and numerical modelling studies. Particular attention is given to differences in spatial domain definition, boundary conditions, representation of groundwater–surface water exchanges, recharge assumptions, pumping reconstruction, and treatment of vertical fluxes. Temporal averaging periods and calibration strategies are also examined.

The analysis shows that much of the variability among published SGD values can be related to methodological structure and conceptual framing, rather than solely to data uncertainty. When methodological differences are explicitly considered, the reported range of estimates reflects alternative representations of the same system rather than contradictory results.

This study highlights the importance of transparent methodological documentation and clearly defined system boundaries when comparing SGD estimates in coastal aquifers.

LID 0869
How to measure groundwater levels with a smartphone?

Dirk Diederen[1], **Fritz Kalwa**[2,3]*

[1] Groundwater Global Foundation, Nijmegen, The Netherlands
[2] TU Dresden, Institute of Groundwater Management, Research Group INOWAS, Dresden, Germany
[3] TU Freiberg, Chair for Hydrogeology and Hydrochemistry, Freiberg, Germany
* fritz.kalwa@tu-dresden.de

Keywords: groundwater monitoring, digitalization, data scarcity

Effective groundwater monitoring is essential for informed decision-making and sustainable water management. Traditional groundwater monitoring methods often require a certain form of technical expertise and specific equipment, which is not always at hand. This limits the accessibility, especially in resource-constrained regions. To address these challenges, we present an innovative approach to groundwater monitoring that leverages acoustic measurements with the convenience and widespread availability of smartphones.

The app emits a selection of acoustic signals, which are recorded and processed to determine the water level with an accuracy of few centimeters. Type and setup of the assessed well affect suitability and accuracy of the approach, whilst the principle appears to be robust over a series of different phone types. The measurement results are stored in a database and assigned to previously defined locations, which can be accessed by other users in the same project.

This smartphone-based application paves the way for a simpler data collection with reduced costs, and enhances accessibility for a broader range of users, including local communities, researchers, and policymakers.

LID 0870
River and groundwater monitoring for MAR feasibility assessment in Dollow, Somalia

Fritz Kalwa[1]*, Falk Händel[1], Mohamud Hussein[2], Lorenz Ewers[3], Agnes Chepkorir[3], Yussuf Abdullahi[3], Khalif Abdirashid[3], Catalin Stefan[1], Jay Matta[4], Lavuun Verstraete[5]

[1] Technische Universität Dresden, Institute of Groundwater Management, Research Group INOWAS, Dresden, Germany
[2] UNICEF Country Office, Dollow, Somalia
[3] arche noVa - Initiative für Menschen in Not e.V., Dresden, Germany
[4] UNICEF Wash Innovation Hub, Copenhagen, Denmark
[5] UNICEF Global WASH Practice, Nairobi Centre of Excellence, Kenya
* fritz.kalwa@tu-dresden.de

Keywords: groundwater monitoring, data scarcity, humanitarian context

The use of groundwater as a drinking water source in the humanitarian context is often as crucial for a cost-effective and secure solution in Water, Sanitation and Hygienics (WASH) programs as it is challenging. In addition to technical aspects with regard to drilling, equipping, operating and maintaining wells in an adequate form, the sustainability of groundwater abstraction is of rising importance. Long-term groundwater usability can be jeopardized by overuse and hence, a significant decline in groundwater levels or by saline intrusion.

Managed Aquifer Recharge (MAR) has proofed to address these and other issues in various contexts all over the world. The humanitarian context, however, may offer specific challenges with regard to data availability, which makes it more difficult to assess site suitability, conceptualize appropriate designs and quantify potential impact.

In the scope of the R-MAR project, we assess the sustainability of groundwater abstraction from and resilience of the alluvial aquifer of the Dawa River in Dollow (Somalia) and to what degree MAR can support these. In order to evaluate seasonal and long-term effects on groundwater flow and quality as well as its interaction with the river, a monitoring system was put in place. The data is used for calibration of a groundwater model, while the monitoring system has to deliver robust data at low cost and needs to be operated and maintained in cooperation with the local communities.

LID 0871
An integrated framework for groundwater potential mapping and spatiotemporal trend assessment in the Erbil Regional Groundwater Basin, North of Iraq

Sarkhel Hawre Mohammed[1,2,3]*, Diary A. Mohammed Al-Manmi[4], Viktoria Mikita[1,2], Péter Szűcs[1,2]

[1] Institute of Water Resources and Environmental Management, University of Miskolc, Miskolc, Hungary
[2] National Laboratory for Water Science and Water Security, University of Miskolc, Institute of Water Resources and Environmental Management, Miskolc
[3] Department of Earth Sciences and Petroleum, College of Science, University of Sulaimani, Sulaimani, Iraq
[4] Technical College of Engineering, Sulaimani Polytechnic University, Iraq
* sarkhel.geo@gmail.com

Keywords: Erbil Regional Basin, groundwater potential mapping, groundwater level trend, non-parametric trend test, ITA

The Erbil Regional Basin, a vital water source in the semi-arid Kurdistan Region of Iraq, faces severe pressure from rapid urbanization, agricultural expansion, and climate variability. This study addresses the urgent need for a robust spatial and temporal understanding of groundwater dynamics to prevent further aquifer depletion.

A hybrid approach was employed, combining multi-criteria decision analysis (MCDA) using Analytical Hierarchy Process (AHP) and Frequency Ratio (FR) to delineate Groundwater Potential Zones (GWPZ). Key thematic layers, including geology, Soil, slope, land use, drainage density, and rainfall, lineament density, distance to river, topography, topographic witness index (TWI) were assigned. Furthermore, long-term groundwater level trends (2004–2024) were analyzed using non-parametric trend tests including Mann Kendall, modified Mann Kendall and Sen's Slope estimator coupled with innovative trend test analysis to quantify the rate of decline across the Erbil regional basin. Additionally, relation between rainfall and recharge to uncover hidden spatial patterns, climate forcing and storage was evaluated through Cumulative Rainfall Departure (CRD) and Wavelet Coherence Analysis. Finally, a Vector Autoregression (VAR) model was implemented for multivariate forecasting.

The GWPZ mapping identified critical recharge zones primarily within the Quaternary deposits and Upper Bakhtiary formations. The result of AHP and FR revealed a difference in delineating recharge areas. However, ITA, MK and MMK results indicate a significant downward trend in groundwater levels across the Erbil Regional groundwater basin. Furthermore, wavelet coherence analysis reveals a strong correlation between rainfall events and aquifer response, while the VAR model's impulse response function quantifies the duration of recovery periods following drought stress.

In conclusion by integrating gap between spatial potential mapping and advanced time-series forecasting, this framework provides a high-resolution and robust interpretation for sustainable groundwater resources management. The results emphasize that potential mapping alone is insufficient without accounting for spatial distribution of groundwater level trend, especially in the case of the eliminating depth related factors in groundwater potential mapping researches.

LID 0872
Informing groundwater flow systems from an aquitard perspective

Beth L. Parker[1]*

[1] Morwick G360 Groundwater Research Institute, College of Engineering, University of Guelph, Guelph, Ontario, Canada
* bparker@uoguelph.ca

Keywords: aquitards, fractured rock aquifers, multi-level monitoring

Knowledge of groundwater flow systems is fundamental to the sustainable and safe use of freshwater resources. Within these systems, aquitards play a critical role in controlling flow behaviour and protecting aquifers, yet they have historically received far less attention than aquifers themselves. Hydrogeologic investigations have traditionally emphasized aquifer characterization and monitoring, often assuming that aquitards are thick, laterally extensive, low-permeability units that can be reliably inferred from lithostratigraphy. However, high-resolution characterization in sedimentary basins, including sedimentary rock environments, has revealed that aquitards are frequently thin, discontinuous, and difficult to predict based solely on stratigraphic information.

Over the past three decades, major advances in subsurface investigation techniques have transformed our understanding of aquitard occurrence, thickness, and hydraulic behaviour. These innovations include drilling core holes that produce high-quality continuous rock core for detailed logging and sampling, as well as the development of sophisticated downhole hydro-geophysical characterization tools. Techniques such as fiber-optic distributed sensing and temporary deployment of pressure-sensor strings behind flexible, impermeable liners allow hydrogeologists to measure formation pressures and flow with unprecedented resolution. These methods also support improved multiport well construction and monitoring designs that minimize borehole hydraulic cross-connection, thereby preserving natural flow system integrity and enhancing data quality.

Modern bedrock characterization approaches have significantly refined hydrogeologic conceptual site models, enabling more timely and defensible decisions about physical and contaminant threats to groundwater resources. Applications span urban, peri-urban, and remote settings, addressing both shallow and deep groundwater challenges. At the plume scale, high-resolution data improve assessments of contaminant transport and fate, supporting scientifically robust evaluations of environmental impacts, future risks, and remediation strategies. For example, core holes and sentry multiport monitoring wells installed in a dolostone bedrock water-supply aquifer provide a stronger basis for evaluating long-term risks to municipal groundwater systems. Similarly, baseline groundwater quality investigations in the Liard Basin of the Northwest Territories help anticipate potential impacts from conventional and unconventional oil and gas development.

A renewed focus on aquitards, combined with expanded use of 3D monitoring infrastructure, strengthens flow-system thinking across spatial and temporal scales. This integrated approach provides a more reliable foundation for decision-making across the energy, environment, and water sectors, ultimately supporting the sustainable management and protection of groundwater resources.

LID 0873
Evaluation of thermal energy potential from snow-melting wells in Japan

Yoshitaka Sakata[1]*, Aoi Baba[1], Shotaro Tadokoro[1], Shohei Albert Tomita[1]

[1] Faculty of Geosciences and Civil Engineering, Kanazawa University, Kanazawa, Japan
* y-sakata@se.kanazawa-u.ac.jp

This regional study presents an evaluation of thermal energy potential by extracting groundwater from snow-melting wells in Japan. There are thousands to ten-thousands wells available for snow melt in each city located in the Hokuriku area along the coast of Japan Sea due to a large amount of groundwater resources, heavy snow fall, and moderately cold temperatures in winter.

Considering decreasing trends in snow fall under the climate change, this study proposes to use the groundwater resources for various thermal uses such as heating/cooling buildings. First, this study shows current situation for use of snow-melting wells such as their spatial distributions, depths and discharges. Next, thermal energy potential from the wells and thermal demands for heating and cooling buildings in each city of the region are calculated and analyzed statistically. Finally, this study discusses the feasibility of groundwater thermal energy utilization in the Hokuriku areas and regional contribution to CO2 mitigation by using the numerous wells installed in the region of highly groundwater resources.

LID 0875
Altitude-controlled recharge and groundwater flow patterns in a semi-arid Andean alluvial aquifer

Virgilio Martinez[1,2]*, Andres Gonzales[2], Alfredo Mendoza[1], Jan-Erik Rosberg[1], Gerhard Barmen[1]

[1] Division of Engineering Geology, Lund University, Lund, Sweden
[2] Laboratorio de Hidraulica, Universidad Mayor de San Simon, Cochabamba, Bolivia
* virgilio.martinez@tg.lth.se

Keywords: groundwater flow patterns, semi-arid alluvial aquifer, data-scarce mountainous basins

Groundwater stored in semi-arid mountainous alluvial systems plays an important role in sustaining water supply for rapidly growing urban and agricultural regions. However, groundwater flow patterns and recharge processes in these environments remain poorly studied due to heterogeneous alluvial stratigraphy, strong elevation gradients, and limited subsurface data. These challenges are particularly significant in inter-Andean basins, where hydrogeological conceptualization often relies on sparse information.

This study investigates groundwater flow patterns in an alluvial aquifer of the Central Bolivian Andes using an integrated hydrochemical, isotopic ($\delta^{18}O$ and $\delta^{2}H$), and multivariate statistical approach. Isotopic signatures indicate recharge primarily controlled by high-altitude precipitation, with focused infiltration in proximal alluvial fan sectors. Hydrochemical facies evolution and cluster analysis reveal coherent spatial groupings consistent with local and regional flow paths, suggesting hydraulic connectivity despite stratigraphic heterogeneity. Progressive mineralization and water-rock interaction along downgradient zones further support the interpretation of altitude-controlled regional groundwater flow within the aquifer system.

In addition, unexpected waterlogging event caused by excess upstream hydroelectric discharge provided independent evidence of aquifer connectivity and permeability contrasts. The system's response under altered hydraulic conditions was consistent with the inferred flow framework, providing independent hydrodynamic support for the conceptual model.

By integrating isotopic, hydrochemical, statistical, and hydrodynamic evidence, this research develops a conceptual model of groundwater flow in a data-scarce semi-arid mountainous basin. The proposed framework improves understanding of inter-Andean alluvial systems and provides transferable insights for sustainable groundwater management in comparable hydrogeological settings worldwide.

LID 0876
Complex or simple—getting the best of both worlds in groundwater modelling for mine dewatering

Luis Suescun[1]*, Mauro Sanchez[1], Robin Dufour[1], Pablo Saez[1], Edith Ore[1]

[1] DHI Group, Lima, Peru
[2] Antamina, Lima, Peru
* lcsc@dhigroup.com

Keywords: mine dewatering, groundwater modeling, FEFLOW

In open-pit mining, pore pressure management and site water balance control are critical for slope stability, operational safety, and environmental performance. Mining hydrogeological systems are often highly complex and non-linear due to multi-scale heterogeneity, fault and/or karst connectivity, and transient operational forcing that changes with the mining sequence. This combination increases calibration non-uniqueness and can reduce predictive reliability when models are difficult to operate or too expensive to run. For this reason, computational performance becomes a methodological requirement: if not managed, high-resolution models can limit uncertainty analysis, option screening, and timely decisions. We apply a multi-scale workflow that combines a 3D reference model with consistent proxy/sub-models, supported by parallel execution and cloud resources, to accelerate simulations and enable ensemble-based assessment.

The workflow is demonstrated for a large copper project in South America. A regional 3D FEFLOW model was built with unstructured discretization and local refinement in pit areas of hydrogeotechnical control. Calibration was performed in steady-state and transient modes using an Iterative Ensemble Smoother (IES), estimating depth-dependent hydraulic properties from conceptual-model priors. The calibrated ensemble was used to propagate uncertainty to pore pressure predictions along representative sections and to inflows into the pit, under operational scenarios, depressurization alternatives, and closure conditions. Results from the complex reference model and the proxies were compared using predictive envelopes and performance metrics, showing consistent pressures and inflows. The reference model provides higher spatial precision, while proxies reproduce dominant responses at much lower computational cost, supporting stability analyses, monitoring prioritization, and preliminary drainage optimization under uncertainty.

LID 0877
How management options change data worth: Monitoring design for adaptive post-mining strategies

Luis Suescun[1,2]*, Peter Cook[1], Daniel Partington [1], Saeed Torkzaban[3], Ilka Wallis[1]

[1] Flinders University, Adelaide, Australia
[2] DHI Group, Lima, Peru
[3] Rio Tinto, Perth, Australia
* lcsc@dhigroup.com

Keywords: mine closure, data worth, monitoring network design, FEFLOW

Post-closure groundwater recovery in open pit mines can last for decades and may require adaptive interventions (e.g., staged backfill, engineered recharge or injection) to meet environmental and water-management targets. Monitoring is essential to reduce uncertainty in recovery forecasts, but budgets and access constraints rarely allow dense, long-term networks. Previous phases of this work used a transient finite-element model to quantify forecast uncertainty with first-order second-moment (FOSM) analysis and to rank the single most valuable observation wells using data-worth metrics. Here we extend the real-site workflow to (i) evaluate combinations of observation locations (next-best wells beyond the top choice) and (ii) test how data worth changes under alternative post-mining management strategies.

A calibrated 3D FEFLOW model represents dewatering, closure and recovery, including backfilling and optional recharge/injection controls. Hydraulic properties are parameterised with pilot points and informed by historical pumping and piezometric records. FOSM sensitivities are propagated to decision-critical forecasts (pit and receptor heads), and data worth is computed for individual wells and for ranked multi-well sets under different sampling frequencies. Results show that optimal monitoring sets are scenario-dependent: passive recovery favours wells constraining regional recharge and far-field gradients, while active recharge/injection shifts value to near-field wells controlling storage and local connectivity. A small “core” set remains informative across scenarios, and adding a few targeted wells provides large marginal uncertainty reduction. The approach supports cost-effective, adaptive monitoring plans that remain defensible under changing closure strategies.

LID 0880
Unravelling hydrogeochemical controls on groundwater quality and potability in Central Ganga alluvial plain

Radha Dixit[1], Shive Prakash Rai[1]*, Abhinav Patel[2], Rajesh Singh[2], Nijesh P[3], Abhinesh Kumar Singh[1], Raju Rai[1], Surykant Singh[1], Dev Sen Gupta[1], Shailesh Kumar Yadav[1]

[1] Department of Geology, Institute of Science, Banaras Hindu University, Varanasi, Uttar Pradesh, India
[2] Environmental Hydrology Division, National Institute of Hydrology, Roorkee, Uttarakhand, India
[3] National Centre for Earth Science Studies, Ministry of Earth Sciences, Govt. of India, Thiruvananthapuram, Kerala, India
* sprai1966roorkee@gmail.com

Keywords: hydrochemistry, shallow aquifer, mineral dissolution, Central Ganga Plain

India faces immense pressure on its water resources due to being the world's largest user of groundwater, with agriculture consuming nearly 90% of the approximately 245 km^3 abstracted annually. This stress is amplified by rapid urbanization; by 2050, 66% of the global population is projected to live in urban areas, placing significant strain on local groundwater supplies for domestic, industrial, and agricultural needs.

The Central Ganga Plain, a densely populated region with a multitier aquifer system, provides a crucial case study. This research focuses on the urban region of Varanasi, to analyze the spatial and vertical variability of groundwater quality and the geochemical processes that influence it. In December 2024, 98 groundwater samples were collected from a 1.5 x 1.5 km^2 grid. The samples underwent major ion analysis, and in-situ measurements of pH, EC, and temperature were recorded to characterize the water quality. Hydrochemical analysis revealed that silicate weathering and mineral dissolution are the primary drivers of groundwater chemistry. Strong correlations among key ions like Na^+, Ca^{2+}, Mg^{2+}, and HCO_3^- confirmed the significant influence of silicate and carbonate mineral interactions. The dominant hydrochemical facies-including Ca-HCO_3, Mg-HCO_3, and Ca-Na-HCO_3 types originate from the dissolution of calcite and dolomite. The presence of Ca-Na-HCO_3 types points to longer groundwater residence times. The elevated Na^+ levels, where Na^+ exceeds Cl^-, suggest contributions from silicate minerals like orthoclase, transported from the Peninsular region. The study also found that fluoride enrichment is restricted to shallow aquifers, likely from the dissolution of F-bearing minerals like mica and amphibole. Elevated nitrate (NO_3^-) concentrations indicate localized anthropogenic pollution from domestic waste. The dense urban population (~2400 persons/km^2) and thick clay capping restrict vertical infiltration, leading to localized recharge through areas where the clay layers are discontinuous.

This study underscores how a combination of natural geochemical processes, aquifer heterogeneity, and localized anthropogenic inputs shape the groundwater chemistry in urban areas. The findings offer valuable insights into how aquifers behave under rapid urbanization and can inform strategies for sustainable groundwater management and pollution mitigation in similar hydrogeological environments.

LID 0882
Integrated urban groundwater modelling for sustainable subsurface planning: Tei Area, Bucharest case study

Irina Moraru[1]*, Traian Ghibuş[1], Constantin Radu Gogu[1]

[1] Technical University of Civil Engineering, Bucharest, Romania
* irina.serpescu@utcb.ro

Keywords: groundwater modelling, subsurface infrastructure, sewer network, risk

Urban expansion increasingly extends into the subsurface, where complex interactions between groundwater and underground infrastructure influence both environmental stability and construction safety. Despite this, urban planning commonly overlooks hydrogeological processes, even though groundwater-related problems are a major source of project delays, rising costs, and long-term infrastructure damage. This paper emphasizes the need to integrate groundwater balance analysis into urban management by investigating the hydraulic interaction between aquifer systems and anthropogenic structures.

Lessons from European cities such as London, Barcelona, and Bucharest illustrate how barrier effects, drainage systems, and changes in pumping regimes can significantly alter groundwater levels and impact underground works. Building on this context, a detailed hydrogeological study was carried out in the Tei district of Bucharest, focusing on the shallow aquifer hydraulically connected to Circului Lake. A detailed 3D geological model was intersected with major infrastructure elements (sewerage network, metro tunnels, foundations) to develop a steady-state groundwater flow model using MODFLOW. Results indicate that groundwater recharge in the study area is largely controlled by anthropogenic sources, particularly losses from the water distribution network. Between 2006 and 2014, substantial reductions in these losses led to a decline in groundwater levels and a corresponding decrease in Circului Lake water levels. Scenario simulations show that a complete elimination of distribution losses could lower the shallow aquifer by up to 1.8 m, enhance wastewater exfiltration from sewer pipes, and increase the risk of subsidence and ecological degradation.

The study demonstrates that improving infrastructure efficiency may unintentionally disrupt the established urban groundwater equilibrium. Systematic monitoring and integrated hydrogeological modeling are therefore essential tools for sustainable urban planning, risk mitigation, and the resilient management of subsurface environments.

This research is supported through the HORIZON-CL6-2023-CLIMATE-01-2, AWARD research project “Alternative Water Resources and Deliberation process to renew Water Supply Strategic Planning” Grant agreement ID: 101136987.

LID 0883
Optimized geometric selection algorithms for large 3D datasets in groundwater modelling

Steven Abdelshahid[1]*

[1] Valenza Engineering, Melbourne, Australia
* Steven@valenza-engineering.com

Keywords: groundwater modelling, spatial selection algorithms, custom scripting, 3D point cloud filtering, mesh processing, mining

Data preparation remains one of the most time-intensive components of groundwater modelling workflows. Typical inputs include geological structures, faults, open-pit geometries, and mine infrastructure. Although many specialized Python libraries exist for hydrogeological modelling, mesh manipulation, and geospatial processing, they often suffer from limited documentation, inconsistent format support, and sparse usage examples. These gaps create inefficiencies when implementing advanced selection or filtering algorithms within large datasets.

Custom scripting helps overcome these limitations by allowing practitioners to tailor workflows to project-specific data inputs. This study examines the development of custom scripting frameworks designed to improve, or entirely replace the selection mechanisms available in groundwater modelling software. By constructing modular selection algorithms based on geometric criteria, tolerance thresholds, and optimized filtering strategies, users gain greater control over their data selection processes and can automate tasks that would otherwise rely on manual, time-consuming default methods.

The study presents a specific algorithm that provides an optimized computational pipeline for filtering massive 3D point clouds against complex open-pit mine meshes. The final output is serialized into both raw CSV format and a compressed XML file directly importable into groundwater modelling software. By integrating Axis-Aligned Bounding Box (AABB) pre-filtering with a dual-stage Ray-Casting and Winding Number evaluation, the workflow achieves high-speed spatial selection while maintaining a low memory footprint through iterative stream-processing (chunking). This approach also enables efficient automation across large numbers of files.

LID 0884
Steenkampskraal Rare Earths Mine: Baseline hydrogeological monitoring and stakeholder engagement

Julian E. Conrad[1]*

[1] GEOSS South Africa (Pty) Ltd, Stellenbosch, South Africa
* jconrad@geoss.co.za

Keywords: mining hydrogeology, groundwater monitoring, stakeholder engagement

The Steenkampskraal Monazite Mine contains 15 rare earth elements (REE), including those used to make electric motors and many other applications. After an initial period of mining activity, the mine was placed in "care and maintenance" for a while. However, the plan is to bring the mine back into operation as new markets have opened up. Located in South Africa, the deposit is a monazite ore body rich in REEs and thorium. The orebody is widely considered one of the highest-grade rare-earth resources in the world. A 3-stage development plan is in place, and the mine is fully licensed and compliant. The Department of Water and Sanitation has issued a Water Use Licence which satisfies the water requirements for the entire operation. Production boreholes have been drilled to provide sufficient water for the mine's requirements, and monitoring boreholes have been drilled to ensure compliance with water-use and mining conditions.

The production boreholes are carefully monitored for water levels, volumes abstracted and groundwater chemistry. In addition, the 17 monitoring boreholes have water levels measured and then sampled for macro- and trace-element chemistry and radionuclide content (uranium, thorium and radium). Monitoring commenced in 2019, and a robust baseline of data is being developed. The area is characterised by low rainfall (119 mm/a), deep groundwater levels (~50 mbgl), and saline groundwater (TDS ~3,000 mg/L). This baseline monitoring has revealed a fascinating set of highly variable data, reflecting the geological complexity of the area [1] and sampling methodologies. This baseline data set has enabled the development of a Groundwater Monitoring Programme (GWMP) and a Threshold Exceedance Response Plan (TERP), with associated levels of action dependent on exceedance levels.

A critical component of the groundwater compliance monitoring has been the holding of 6-monthly stakeholder engagement meetings. The stakeholder meetings comprise government authorities, conservation organisations, the local municipality and farming associations. These engagements are critical for the distribution and sharing of accurate, scientific data on the deposit in light of the anticipated recommencement of mining activities.

This paper and presentation highlight a fascinating geological deposit, key findings from groundwater monitoring, and the critical role of stakeholder engagement.

Reference:

[1] Basson I.J., Muntingh J.A., Jellicoe B.C., and Anthonissen C.J., (2016). Structural interpretation of the Steenkampskraal monazite deposit, Western Cape, South Africa, Journal of African Earth Sciences, Volume 121. Pages 301-315.

LID 0885
Revealing Rome's hidden waters: Innovation and urban hydrogeology in CARG Thematic Sheet No. 374

Francesco La Vigna[1]*, Rossella Maria Gafà[1], Mauro Roma[1], Isidoro Bonfà[2], Lucio Martarelli[1], Gennaro Maria Monti[1], Claudio Papiccio[2], Angelantonio Silvi[1], Valerio Vitale[1], Silvana Falcetti[1], Roberta Carta[1], Stefania Gaudino[1], Daniela Paganelli[1], Chiara Fiori[1], Raffaele Proietti[1], Maria Paola Campolunghi[1]

[1] ISPRA – Geological Survey of Italy, Rome, Italy
[2] Roma Capitale, Rome, Italy
* francesco.lavigna@isprambiente.it

Keywords: CARG project, hydrogeological mapping, urban groundwater, anthropogenic deposits, Rome

The CARG Project is the national geological cartography program of Italy at 1:50,000 scale. Within this framework, hydrogeological sheets remain limited, despite their strategic relevance for groundwater protection and urban resilience. Sheet No. 374 – Rome, currently developed in-house by ISPRA, aims to update and strengthen the hydrogeological framework of the capital city, building upon the Hydrogeological Map of Rome (2015) and integrating new geological, monitoring and historical datasets.

A key innovation concerns the upgrading of Rome's groundwater monitoring network through the installation of 50 automated probes measuring groundwater level and temperature, with 10 stations also recording electrical conductivity. Real-time acquisition and online dissemination of hourly data represent a significant advancement beyond the minimum CARG requirements, enabling a dynamic representation of groundwater behaviour in a highly complex urban setting.

In parallel, specific investigations focus on the interaction between anthropogenic fill deposits and the historical spring system that once characterized the city. Centuries of urbanization have deeply modified natural drainage pathways; therefore, assessing the interference between artificial deposits and former spring areas is essential to better understand recharge processes, groundwater emergence and possible impacts on infrastructure.

As a pilot experience, the Rome hydrogeological sheet proposes an innovative methodological model for future CARG thematic sheets, combining high-resolution monitoring, historical reconstruction and urban hydrogeology to support evidence-based groundwater management at national scale.

LID 0886
Multiscale groundwater drought dynamics in a shallow lowland aquifer system

Ewa Krogulec[1]*, Katarzyna Sawicka[1], Sebastian Zabłocki[1]

[1] University of Warsaw, Faculty of Geology, Warsaw, Poland
* ewa.krogulec@uw.edu.pl

Keywords: groundwater drought, resilience, SGI, drought propagation, shallow aquifer

Groundwater drought represents a delayed and cumulative response of aquifer systems to climatic stress, yet its multiscale dynamics and spatial variability remain insufficiently understood, particularly in shallow lowland environments. This study investigates groundwater drought propagation and resilience in a shallow post-glacial aquifer system of Kampinos National Park (central Poland), based on long-term monitoring data from 56 piezometers covering 1999–2025.

Monthly groundwater levels were used to calculate the Standardized Groundwater Index (SGI) at 3-, 6- and 12-month aggregation scales to distinguish short-term variability from long-term storage depletion. Drought episodes were identified using a threshold of SGI < −1. A set of complementary metrics describing frequency, duration, severity, resistance, recovery capacity and drought propagation was applied to quantify aquifer response. Hierarchical clustering based on long-term (SGI-12) metrics enabled identification of spatially coherent response types.

Results demonstrate strong scale dependency of groundwater drought characteristics. Short-term deficits were frequent and transient, whereas long-term drought was characterized by fewer but substantially longer and more severe episodes, reflecting pronounced system memory and cumulative storage depletion. Only 40–60% of short-term drought events propagated to the annual scale, with a typical lag of 4–5 months, indicating selective transmission of climatic signals through the vadose zone.

Two contrasting resilience patterns were identified. Dune areas exhibit higher resistance to drought initiation but low recovery capacity, leading to prolonged depletion once drought develops. Wetland areas respond more dynamically, with shorter drought duration and faster recovery. These findings demonstrate that local hydrogeological conditions control long-term vulnerability more strongly than uniform climatic forcing.

The study highlights the importance of multiscale groundwater drought assessment for climate adaptation and groundwater management in protected lowland aquifer systems.

LID 0887
Hydrogeological conditions and recharge potential of a shallow alluvial aquifer in the Lower Mekong Basin (Lao PDR)

Ewa Krogulec[1]*, Tomasz Krogulec[1]

[1] University of Warsaw, Faculty of Geology, Warsaw, Poland
* ewa.krogulec@uw.edu.pl

Keywords: shallow groundwater, recharge, alluvial aquifer, monsoon climate, Lower Mekong Basin

Shallow groundwater plays a critical role in rural water supply and supplementary irrigation in Lao PDR. However, hydrogeological knowledge in the Lower Mekong Basin remains largely based on regional-scale interpretations, while detailed local investigations and systematic monitoring data are scarce. This limits reliable assessment of recharge processes and agricultural use potential of shallow aquifers.

This study presents hydrogeological investigations carried out within a small research polygon located in the Vientiane Basin (Xanakharm District), situated in the hydrological influence zone of the Mekong River. Although spatially limited, the site represents typical alluvial floodplain conditions and provides field-based quantitative information rarely available for this region.

The research combined lithological profiling, granulometric analyses and estimation of hydraulic conductivity, electrical resistivity tomography (ERT), groundwater level observations, and physico-chemical analyses of groundwater and surface water. Results confirm a heterogeneous Quaternary aquifer composed of sands and gravels interbedded with clay layers, forming a locally multilayered system. Seasonal groundwater fluctuations demonstrate strong monsoon-driven recharge and hydraulic interaction with the river system.

Estimated hydraulic parameters indicate moderate to high infiltration capacity in sandy zones and measurable storage potential sufficient to support small-scale dry-season irrigation, provided abstraction remains controlled. At the same time, the shallow system shows vulnerability to bacteriological contamination and potential alterations in river regime related to planned hydropower development.

The study highlights the importance of detailed local-scale investigations as a basis for quantitative groundwater assessment and sustainable agricultural water management in monsoon-dominated environments.

LID 0888
Hydrochemical clustering and machine learning mapping for urban groundwater suitability and risk assessment in Belgrade

Sunčica Gardijan[1], **Vladimir Živanović**[1]*, Nebojša Atanacković[1], Saša Stojadinović[1]

[1] University of Belgrade – Faculty of Mining and Geology, Belgrade, Serbia
* vladimir.zivanovic@rgf.bg.ac.rs

Keywords: urban groundwater, hydrochemistry, urbanisation, springs and dug wells, machine learning

Urban springs and dug wells are widespread in many cities and represent potentially valuable supplementary groundwater resources. However, their hydrochemical reliability is highly sensitive to land use, infrastructure, and shallow redox processes. This study investigates the hydrochemical status and urbanisation impacts on shallow groundwater quality across the City of Belgrade (Serbia) by integrating hydrochemical characterisation, clustering, and machine-learning modelling, based on approximately 700 springs and dug wells.

Variability in electrical conductivity and major-ion composition is used to distinguish groundwater types and geogenic background. In contrast, NO_3^-, Cl^-, SO_4^{2-}, NH_4^+, and redox-sensitive Fe and Mn are used to distinguish anthropogenic influence and water suitability. Cluster analysis of urbanisation and hydrogeological descriptors (e.g., land-use intensity, road and population density, runoff potential) reveals distinct spatial patterns and gradients in groundwater quality across urban and suburban environments.

Random Forest outlines key hydrochemical indicators and suitability outcomes to predictors derived from geology, soils, hydrogeology, land use, and DEM-based terrain metrics, using spatial cross-validation to ensure robust performance. Cluster-defined groundwater conditions are incorporated to evaluate differences in controlling factors across urbanisation patterns, while partial dependence analysis is used to interpret non-linear relationships and threshold behaviour. Suitability and probability-based risk maps are generated by comparing predicted concentrations against drinking-water guideline thresholds and propagating prediction uncertainty, thereby identifying areas with elevated risk of water-quality deterioration and zones with consistently favourable hydrochemical conditions. The results provide a spatially explicit basis for targeted monitoring and sustainable, risk-informed use of urban springs and dug wells.

LID 0889
CII500K: A new harmonized national framework of Italy's groundwater systems at 1:500,000 scale

Francesco La Vigna[1]*, Corrado A. S. Camera[2], Giovanni P. Beretta[2], Rossella Maria Gafà[1], Mauro Roma[1], Andrea Citrini[2], Lucio Martarelli[1], Gennaro Maria Monti[1], Angelantonio Silvi[1], Valerio Vitale[1], Chiara Fiori[1], Marco Masetti[2], Fabio Pascarella[1], Raffaele Proietti[1], Stefano Lo Faro[1], Maria Pia Congi[1], Marco Gerardi[1], Stefano Tersigni[3], Tiziana Baldoni[3], Simona Ramberti[3], Giuliana Barbato[4], Paola Mercogliano[4]

[1] ISPRA – Geological Survey of Italy, Rome, Italy
[2] Dipartimento di Scienze della Terra "Ardito Desio", Università degli Studi di Milano, Italy
[3] ISTAT, Italian National Institute of Statistics, Rome, Italy
[4] CMCC Foundation - Euro-Mediterranean Center on Climate Change, Italy
* francesco.lavigna@isprambiente.it

Keywords: Hydrogeological Map of Italy, groundwater systems, national cartography, GIS, water management

The new Hydrogeological Map of Italy at 1:500,000 scale (CII500K) provides a comprehensive and harmonized national overview of groundwater systems across the country. The map is organized into four sheets, accompanied by explanatory notes and thematic tables, and is complemented by an online version offering an updated and integrated representation of Italy's hydrogeological framework.

The CII500K synthesizes groundwater distribution, recharge conditions and main uses at national scale. It builds upon the most recent regional hydrogeological studies and data integration processes, adopting a unified methodology for the identification of hydrogeological complexes, relative permeability classes and aquifer productivity. This harmonized approach ensures consistency across regional boundaries and enhances the comparability of groundwater information.

The map was developed through extensive GIS-based processing and supported by a WebGIS platform designed to promote participatory collaboration among technicians and researchers from different institutions. Key thematic layers include perennial freshwater springs, thermal and coastal springs, piezometric contour maps and major groundwater flowpaths, offering a multi-layered interpretation of groundwater dynamics.

As a strategic cartographic product, the CII500K represents a reference framework for sustainable groundwater management and supports climate adaptation strategies in alignment with European water policies. By integrating updated datasets within a standardized national structure, it provides an essential tool for decision-makers, planners and water managers operating at regional and national scales.

LID 0890
Hydrogeoethics and inclusion in projects with traditional communities: The case of the Baía Formosa Quilombo, Armação dos Búzios – Brazil

Dandara Rodrigues[1]*

[1] Department of Geology, Federal University of Rio de Janeiro, Rio de Janeiro, Brazil
* dandarasr@gmail.com

Keywords: hydrogeoethics, hydrogeology, Quilombola agriculture

Social communities such as the Quilombo Baía Formosa (small rural communities in Brazil with an African culture heritage), in the municipality of Armação dos Búzios, Rio de Janeiro State, Brazil, have been suffering, among other difficulties, from the chronic lack of resources for their well-being and social and economic development. Thus, a water supply that allows for subsistence farming is essential for the community's progress. This work addresses the application of geological and hydrogeological knowledge in the search for water autonomy in vulnerable communities, in an approach that takes into account the principles of Hydrogeoethics. This is a new transdisciplinary scientific discipline whose central concept is to apply concepts from human sciences, arts and culture, in situations where water, and groundwater in particular, plays a relevant role. The main objective of the dissertation is, in this context, to implement self-sufficient technologies for water collection, supporting family farming and cultural tourism. The study area, marked by natural beauty and rich cultural history, faces water vulnerability. Two springs were identified, with water of medium low salinity and neutral pH, but insufficient for the entire Quilombola area. The methodology included geological mapping of surface and underground water resources, socioeconomic assessment and water demand assessment, with a view to installing a groundwater collection system whose energy supply for pumping is provided by solar panels. The studies identified viable flows in local water bodies, using accessible methods, such as floatation, to estimate flow. In the underground collection, a well was evaluated, with results indicating limited water potential. Based on the analyses, a new well was located and drilled in the Zebina community, and the collection was registered with INEA, and its operation began. Another collection point is being located in the Original community. The project reinforces the importance of applying Hydrogeoethics, especially for marginalized communities. Despite financial challenges, the results indicate the possibility of water autonomy and improved quality of life, highlighting the historical and environmental relevance of the quilombo, as a model for future similar initiatives.

LID 0892
Calcium and multi-isotope constraints on cation exchange in groundwater

Tianming Huang[1,2]*, Yin Long[1,2,3], Zhenbin Li [1,2,4]

[1] State Key Laboratory of Lithospheric and Environmental Coevolution, Institute of Geology and Geophysics, Chinese Academy of Sciences, Beijing, China
[2] College of Earth and Planetary Sciences, University of Chinese Academy of Sciences, Beijing, China
[3] PetroChina Shenzhen New Energy Research Institute Co., Ltd., Shenzhen, China
[4] China Electric Power Planning and Engineering Institute, Beijing, China
* tmhuang@mail.iggcas.ac.cn

Keywords: calcium isotope fractionation, cation exchange, water-rock interaction

Cation exchange is one of the most important processes in water-rock interaction in the presence of clay minerals, with common Ca/Mg-Na exchange system. There is a lack of systematic verification of Ca isotopes for tracing cation exchange in natural environments, due to complex influencing factors, such as dissolution-precipitation of Ca-minerals and sorption-desorption processes. In this study, Ca isotope fractionation factors during sorption were measured in the laboratory and then used in two field study (a loess tableland and a site for hydraulic fracturing) to trace Ca-related cation exchange. The results show that light Ca isotope (^{40}Ca) is preferentially adsorbed onto clay minerals, and montmorillonite exhibits the greatest fractionation extent, followed by illite and kaolinite. There is a general trend that the lower the initial Ca2+ concentration, the smaller the particle size, and the stronger the fractionation of Ca isotopes. Results from multiple tracers (^{44}Ca, $^{87}Sr/^{86}Sr$, ^{13}C, ^{15}N, ^{3}H, ^{14}C, and water chemistry) in the loess tableland have shown that groundwater Ca^{2+} and Mg^{2+} were derived mainly from the dissolution of loess carbonates, and that Na+ was derived from cation exchange beyond atmospheric input. The decrease in Ca^{2+} concentration and increase in Na^{+} concentration were mainly due to cation exchange, leading to an increase in $\delta^{44/40}Ca$. The changes in Ca^{2+} concentration and $\delta^{44/40}Ca$ conformed to the Rayleigh model. The other case study showed that high-resolution flowback water following hydraulic fracturing of a shale gas reservoir offers unique material for exploring the mechanism of Ca isotope changes. The Ca isotopic fractionation factor during adsorption was measured using authentic field samples ($10^{3}ln\alpha$ of 0.28), and then applied to simulate changes in the Ca isotopic composition of flowback water. The results showed that an increase in $\delta^{44/40}Ca$ and a decrease in Ca^{2+} concentration in the flowback water beyond mixing were primarily controlled by adsorption and/or cation exchange, rather than by carbonate dissolution or precipitation. The batch equilibrium fractionation model can simulate isotopic composition trends more accurately than the Rayleigh model. This study systematically validates Ca isotopes as a robust tracer of cation exchange in natural systems, bridging laboratory-measured fractionation factors with field observations to accurately decipher the evolution of water chemistry.

LID 0894
Hydrogeologists in geological surveys as strategic actors in groundwater governance and climate resilience: The Serbian experience

Katarina Atanasković Samolov[1]*, Tanja Petrović Pantić[1], Milan Tomić[1], Marina Magazinović[1]

[1] Geological Survey of Serbia, Belgrade, Serbia
* katarina.samolov@gzs.gov.rs

Keywords: hydrogeologists, geological surveys, socio-economic and environmental benefits

Geological Surveys represent national authorities in geoscientific knowledge, and hydrogeologists within these institutions play a strategic role in groundwater governance, environmental protection, and climate adaptation. Through systematic data collection, mapping, and modelling, they provide the scientific foundation for evidence-based policymaking and long-term resource management.

The Department of Hydrogeology of the Geological Survey of Serbia (GZS) is responsible for regional hydrogeological investigations, preparation of Basic Hydrogeological Maps at a 1:100,000 scale, and implementation of studies of national importance. These activities serve as the basis for spatial planning, drinking water protection, and sustainable groundwater allocation.

A current national study, “Impact of Climate Factors and Surface Waters on the Quantity and Quality of Groundwater in Vojvodina”, demonstrates this strategic role and delivers forecasts of groundwater level and quality dynamics under different climate scenarios. The data collected during research, conceptual hydrogeological models, and machine learning approaches are used for participation in the Geological Service for Europe (GSEU) project co-funded by Horizon Europe.

At the same time, geothermal assessments conducted by the GZS highlight the contribution of hydrogeologists to the energy transition. Evaluation and sustainable development of low-enthalpy geothermal resources are carried out while ensuring groundwater protection and environmental safety.

The Serbian experience illustrates that strengthening hydrogeological capacity within Geological Surveys enhances institutional resilience, supports cross-sectoral cooperation, and generates clear socio-economic and environmental benefits. Closer integration of Geological Surveys, Water and Environmental Agencies, and IAH is essential to reinforce the visibility and impact of hydrogeologists at national and European levels.

LID 0895
Assessing organo-mineral interactions using a stable isotope hydrology approach

Travis Meador[1]*, Astolfo Valero[2], Daniel Petrash[2]

[1] Biology Centre of the Czech Academy of Sciences, České Budějovice, Czech Republic
[2] Department of Environmental Geochemistry and Biogeochemistry, Czech Geological Survey, Prague, Czech Republic
[3] University of South Bohemia, Faculty of Science, České Budějovice, Czech Republic
* travis.meador@bc.cas.cz

Keywords: mineral-associated organic matter, porewaters, stable isotopes

The accumulation of mineral-organic frameworks can influence the reactivity and enhance the sequestration of carbon and thus energy, particularly in subsurface environments, where shallow surface and groundwater serve as the medium for the formation of mineral-associated organic matter (MAOM). However MAOM cycling and turnover time remain highly uncertain. Well-established global trends in isotope hydrology offer a lens to interpret MAOM accumulation patterns, but it remains unclear how the isotopic composition of this fluid is chemically imprinted into the resulting organic-mineral aggregates. To address this gap, we conducted sorption experiments by resuspending goethite or montmorillonite particles in isotopically depleted or enriched waters containing an organic compound representative of distinct chemical classes (cyclodextrin, menaquinone, tannic acid, EDTA, or pond-isolated natural organic matter). Following equilibration for 72 h at pH 7 and 25°C, the isotope compositions ($\delta^{2}H$ and $\delta^{18}O$) of the resulting mineral aggregates and supernatants were analysed using UniPrep-IRMS, while the formation of MAOM was confirmed by X-ray diffraction and Raman and energy dispersive spectroscopy. MAOM consistently exhibited lower $\delta^{2}H$ and $\delta^{18}O$ values than pure organics and supernatants. Increasing the organic-to-mineral ratio slightly affected the $\delta^{2}H$ and $\delta^{18}O$ signals of montmorillonite but had negligible effects in goethite. These results highlight that the isotope values of MAOM represent composite signals governed by the specific polarity and structure of the involved organic molecules and the sorption capacities of the mineral aggregates. This study establishes that $^{2/1}H$ and $^{18/16}O$ ratios in mineral-organic frameworks may effectively trace the source water involved in its formation, and that these signals can be applied to assess organic-mineral interactions in the environment.

This project was supported by Czech Science Foundation Grant 24-12587S; stable isotope measurements were additionally supported by MEYS CZ grant LM2015075 Projects of Large Infrastructure for Research, Development and Innovations as well as the European Regional Development Fund-Project: research of key soil-water ecosystem interactions at the SoWa Research Infrastructure (No. CZ.02.1.01/0.0/0.0/16_013/0001782).

LID 0897
Planning of MAR (Managed Aquifer Recharge) without political aspects

Jenő Lábdy[1]*

[1] International Department, General Directorate of Water Management, Budapest, Hungary
* labdy.jeno@ovf.hu

Hungarian water management has undergone significant changes in the past few years. The main reasons for this are the consecutive drought years and the resulting social expectation for a quick solution to the problems caused by water shortages. Experts also emphasize that the flood risk has not decreased due to the increasingly frequent occurrence of water shortages. However, it is characteristic that water management still does not work in an integrated manner, typically focusing on only one problem at a time, the lack of water. Moreover, drought management focuses primarily on the problems of agriculture, ignoring the fact that crop production is not only a victim of water shortages, but also one of the root causes of surface and groundwater shortages.

Groundwater is one of the most important water sources not only in Hungary, but also throughout the world. One reason for this is that it is easily and cheaply accessible in many places. Its use is difficult to control, most often only by indirect methods. Restrictions and regulations on its use provoke loud protests, especially among farmers.

One of the main technical tasks of water management in the current situation is to implement the natural recharge of groundwater, or artificial water replenishment. However, water retention and infiltration also raise significant water quality and quantity problems. On the one hand, the quality of the water to be controlled and the chemical and mechanical parameters of the receiving soil must be continuously measured. On the other hand, the excess water volume that can be used to recharge groundwater must be determined at the watershed level. We must be careful not to endanger the water quantity status of our surface watercourses with the well-sounding “water into the landscape” program. A solution to this could be the dynamic determination and forecasting of water resources.

LID 0898
RECHARGE: Opportunities and limits of NWRMs to promote groundwater recharge: toward a transdisciplinary co-constructed research-action

Danièle Valdes[1]*, Corinne Le Gal La Salle[2], Camille Nourayand[1], Théo Maura[1], Thierry Berthe[3], Julie Leloup[4], Béatrice Gisclard[5], Somar Khaska[2], Yvan Caballero[6], Noémie Neverre[6], Laurent Moulin[7], Thomas Thiebault[1], Fabrice Alliot[1], Mila Gallais[1]

[1] UMR METIS, Sorbonne Université/EPHE/CNRS, Paris, France
[2] UPR CHROME, Nîmes Univertsité, Nîmes, France
[3] UMR M2C, Université Rouen-Normandie, Rouen, France
[4] UPR iEES, Sorbonne Université, Paris, France
[5] UPR PROJEKT, Nîmes Univertsité, Nîmes, France
[6] UMR G-EAU, BRGM, Montpellier, France
[7] R&D, Eau de Paris, Paris, France
* daniele.valdes_lao@sorbonne-universite.fr

Keywords: recharge, water resources, adaptation, perception, chemical and pathogenic microbial contaminants, natural water retention measures, socio-hydro-ecosystems, co-construction, stakeholders, sustainability

In the context of global changes, with increasing drought, heavy rainfall events and growing population, pressure on fresh water resources increases. Hence, exploring ways of enhancing groundwater recharge is crucial to maintain sustainable resources. Natural Water Retention Measures (NWRMs) associated with non-conventional water resources (urban stormwater, rural runoff, treated wastewater) provide a range of promising solutions to improve groundwater recharge. Nevertheless scientific questions and societal hurdles to the implementation of NWRMs remain including the evaluation of their impact in quantity and quality on the groundwater resource, economical cost and ecosystemic value, up to societal perception and acceptability of such systems. In that context there is an urgent need for more investigation on the opportunities and limits of NWRMs for increasing groundwater recharge.

The RECHARGE project aims to investigate the NWRMs to enhance groundwater recharge through a truly interdisciplinary, or even transdisciplinary, approach including an innovative approach of social design. The project aims to investigate co-constructed strategies to improve the recharge for water resilience based on an interdisciplinary approach.

4 scientific questions are addressed: 1) What is the ability of NWRMs to improve recharge? 2) What is the ability of the receiving environment to remove chemical and microbial contaminants? 3) What are societal locks and drivers? 4) What are the appropriate indicators to monitor them?

One of the study sites is Agon-Coutainville. Treated effluent from the WWTP, discharged into reed beds, infiltrates and then flows in the sand aquifer to the sea (800 m). Piezometers (existing and to be installed within the project) located along the flow transect provide information on the water table and sediments (aquifer sands). First results about the fate of chemical and microbial contaminants along the flow will be presented.

LID 0900
Evaluation of the impact of agricultural practices on groundwater levels, mineralization and salt accumulation in the Republic of Karakalpakstan, Uzbekistan

Ilia Dorofeev[1], Catalin Stefan[1]*, Javlonbek Ishchanov[2], Mukhamadkhan Khamidov[2], Shamshodbek Akmalov[3]

[1] Technische Universität Dresden, Institute of Groundwater Management, Research Group INOWAS, Dresden, Germany
[2] Tashkent Institute of Irrigation and Agricultural Mechanization Engineers - National Research University, Tashkent, Uzbekistan
[3] Institute of Agriculture and Agrotechnologies of Karakalpakstan, Nukus, Uzbekistan
* catalin.stefan@tu-dresden.de

Keywords: reactive transport modeling, groundwater mineralization, soil salinization, water scarcity, drainage, land management, Karakalpakstan

Republic of Karakalpakstan faces two interconnected problems: soil salinization and water scarcity, both reducing agricultural productivity and carrying significant socio-economic consequences for this agriculture-dependent region. Shallow groundwater plays a dual role – driving secondary soil salinization while also offering a potential alternative water source if its mineralization is kept low. Assessing the impact of agricultural practices, drainage system parameters, and land management approaches on groundwater quality through reactive transport modeling can serve as a decision-support tool for addressing both problems.

A one-dimensional reactive transport model was developed using sequential coupling of PHREEQC and Python. PHREEQC handles reactive transport calculations, while Python computes groundwater hydrodynamics and salt accumulation in soils. The model calculates solute concentrations along the flow path and groundwater level dynamics, accounting for the seasonal agricultural cycle and variable boundary conditions. Post-processing yields specific groundwater level values. By coupling a series of interconnected 1D flow paths, the model resolution is extended to 1.5D; post-processing further enhances it to quasi-2.5D. The conceptual model was built using data provided by project partners. A series of scenarios was designed to explore the relationship between agricultural practices, drainage system parameters, land management approaches, and groundwater quality.

The analysed scenarios varied in drainage system parameters, soil leaching and irrigational practices, and land use patterns. In all cases, groundwater mineralization responded to changes in the scenario parameters. Deteriorating drainage conditions led to higher mineralization, while modified leaching practices showed potential for reducing the impact on groundwater quality. Based on these results, practical recommendations can be formulated for adapting reclamation practices to water scarcity.

LID 0901
Seasonal freeze-thaw controls on groundwater flow and solute transport in an Arctic permafrost hillslope

Andrew Frampton[1]*, Alexandra Hamm[1], Erik Schytt Mannerfelt[2], Aaron A. Mohammed[3], Scott L. Painter[4], Ethan T. Coon[4]

[1] Dept. Physical Geography and Bolin Centre for Climate Research, Stockholm University, Stockholm, Sweden
[2] Department of Geosciences, University of Oslo, Oslo, Norway
[3] Department of Earth and Environmental Sciences, Syracuse University, New York, United States
[4] Climate Change Science Institute and Environmental Sciences Division, Oak Ridge National Laboratory, Oak Ridge, Tennessee, United States
* andrew.frampton@natgeo.su.se

Keywords: permafrost-hydrogeological modelling, permafrost active layer dynamics, coupled processes

Groundwater flow in permafrost hillslopes is governed by seasonal freeze-thaw dynamics that control subsurface connectivity and solute transport within the shallow, seasonally thawed, active layer. As climate warming alters thaw depth and timing, understanding how groundwater flow paths and transport processes respond is critical for predicting solute export from permafrost catchments.

We investigate groundwater flow and solute transport in a high-Arctic hillslope in Endalen Valley, Svalbard, underlain by continuous permafrost. A physics based thermal-hydrological model is used to simulate subsurface flow and tracer plume migration under present day conditions as well as selected climate warming scenarios. Tracer breakthrough curves are analysed for sources released at different depths in the active layer and below the permafrost table.

Results show strong depth-dependent differences in transport behaviour. Solutes released near the ground surface move slowly through predominantly unsaturated conditions within the active layer, producing long residence times. In contrast, solutes originating near the permafrost table undergo rapid lateral transport during thaw periods, when saturated conditions and laterally connected flow paths develop above the permafrost boundary.

Mobilisation of solutes from newly thawed permafrost is also highly sensitive to the rate and mode of warming. Gradual warming leads to limited annual mobilisation dominated by vertical percolation and cryosuction, whereas abrupt thaw during anomalously warm years promotes rapid lateral transport comparable to that within the active layer. Rapid transport under highly saturated conditions also limits in situ solute transformation prior to export.

These results demonstrate how seasonal groundwater flow regimes control solute transport in permafrost hillslopes and highlight the sensitivity of subsurface transport pathways to climate-driven thaw dynamics.

LID 0902
Enhancing urban flood resilience through nature-based solutions in data-scarce environments

Ronald Mugabi Maseruka[1], **Syed Mustafa**[2*], Dragan Milosevic[2,3], Allan John Komakech[1], Isa Kabenge[1], Martine Van Der Ploeg[2]

[1] Water and Irrigation Section, Makerere University, Kampala, Uganda
[2] Hydrology and Environmental Hydraulics Section, Wageningen University & Research, Wageningen, The Netherlands
[3] Meteorology and Air Quality Section, Wageningen University & Research, Wageningen, The Netherlands
* syed.mustafa@wur.nl

Keywords: Sub-Saharan Africa, nature-based solutions, managed aquifer recharge, flood resilience

Many rapidly growing cities in Sub-Saharan Africa face frequent and severe flooding due to unplanned urban expansion, inadequate drainage systems, and changing climate patterns. Conventional gray infrastructure has often proven inadequate, leading to significant economic losses, public health challenges, and ecosystem degradation. Nature-Based Solutions (NbS), such as green infrastructure and groundwater recharge, offer promising alternatives, yet their potential remains largely unexplored in these data-scarce urban environments. This study aims to investigate how integrating surface-focused Nature-Based Urban Infrastructure (NbUI)—such as rain gardens, wetlands, and rainwater harvesting—with Managed Aquifer Recharge (MAR) as the subsurface technique can reduce urban flood risks while enhancing groundwater sustainability and improving water quality. The study adopts an integrated field-based and model-driven approach to assess the flood mitigation potential of combined NbS and their co-benefits. Field data, remote sensing, geophysical surveys, participatory mapping, and hydrological modelling are used to achieve the objectives of this study. Using Kampala as a case study, the research first examines the city's aquifer system to determine its potential to support recharge. It then identifies suitable NbUI interventions across the urban landscape and assesses their performance under current and future climate and urbanisation scenarios using an integrated modelling framework. Finally, the study evaluates the co-benefits of combining MAR and NbUI in urban settings. Integrating these approaches generates practical insights into how cities with limited data can implement combined nature-based strategies for effective flood management.

LID 0904
Cele River – Keriya River Basin alluvial – proluvial fan depression zone groundwater reservoir formation conditions and regulation & storage potential study

Qiang Wang[1,2]*

[1] Urumqi Natural Resources Survey, China Geological Survey, China
[2] Xinjiang Engineering and Technology Research Center for Utilization of Saline Water Resources, China
* 1498691460@qq.com

Keywords: groundwater reservoir, artificial recharge, reservoir formation conditions, numerical simulation, alluvial-proluvial fan depression zone

In the arid to semi-arid regions of northwest China, groundwater is the life source that sustains the ecosystem. The continuous decline in water table has already had a serious impact on the local ecological environment, leading to varying degrees of vegetation degradation in oasis-desert transition zones and the ongoing encroachment of deserts into artificial oases. To effectively address these issues, increasing the volume of groundwater with adjustable storage capacity is crucial to achieve a sustainable development and utilization of groundwater resources. Research is urgently needed to explore the feasibility of groundwater reservoirs developed in alluvial fan depressions of large sedimentary basins.

This study focuses on the Tarim Basin in the Cele River-Keriya River basin. Through comprehensive data collection, literature review, and field surveys, the study firstly analyzes and evaluates the current status of water resources and their development in the research area. It then identifies the boundary conditions, storage space conditions, water source conditions, water quality conditions, infiltration conditions, and water intake conditions for constructing groundwater reservoirs in the alluvial fan depressions of the Cele River-Keriya River basin. Finally, by developing a numerical simulation model of the groundwater in the reservoir area, different storage schemes are simulated and compared. The main findings and conclusions are as follows:

1. The geological and hydrogeological conditions of the research area were analyzed, and the water resources and available water supply were calculated. The water consumption levels and the current status of water resources development were evaluated. The results indicate that the per capita comprehensive water consumption in Cele County and Yutian County is slightly lower than that of Hotan Prefecture and the entire Xinjiang region, showing a certain potential for further development and utilization of surface water resources in Yutian County.

2. The natural conditions in the north and south sides as well as the west side of the groundwater reservoir are controlled by uplift structures, while the east side is controlled by a large sinistral strike-slip fault, forming a natural barrier for water storage. The Quaternary aquifer in the area has a wide distribution and thickness, providing good storage space. The surplus water from the Keriya River and floodwater from the reservoir are the main sources for replenishing the groundwater reservoir, with abundant water quantity and good water quality. The main aquifer in the reservoir area is the late Pleistocene gravel layer, with strong infiltration capacity.

3. A numerical groundwater model was constructed using the GMS software to simulate three different artificial recharge scenarios. The results show that implementing scenario three (recharge volume of 1.5 billion m3/year) leads to the most significant rise in groundwater levels, with a maximum rise of 10 meters. Increasing the recharge volume rapidly boosts the groundwater resources, but corresponding extraction

plans are necessary to maintain a relatively stable groundwater level, reduce the risk of submergence, and ensure the safe operation of the groundwater reservoir.

LID 0905
Beyond infrastructure: Structuring social engagement for sustainable MAR in fragile contexts (Dollow, Somalia)

Lorenz Ewers[1]*, Jay Matta[2],Agnes Chepkorir[1], Catalin Stephan[3], Lavuun Verstraete[4]

[1] arche nova e.V., Dresden, Germany
[2] UNICEF Wash Innovation Hub, Copenhagen, Denmark
[3] Technische Universität Dresden, Institute of Groundwater Management, Research Group INOWAS, Dresden, Germany
[4] UNICEF Global WASH Practice, Nairobi Centre of Excellence, Kenya
* lorenz.ewers@arche-nova.org

Keywords: managed aquifer recharge (MAR), community, resilience, WASH, RANAS

In Dollow, Somalia, water supply is under increasing pressure due to erratic rainfall, rising demand and depleted protected groundwater sources. The R-MAR project, involving TUTechnical University Dresden, arche nova, Aarhus University, ERIMOS, UNICEF, proposes managed aquifer recharge (MAR) as a potential solution to buffer drought periods and stabilise supply. However, experience in fragile contexts shows that even well-designed infrastructure can fail when roles, incentives and trust are unclear. We therefore treat social engagement as part of the technical design, not a parallel activity.

We employ a six-step engagement process grounded in the RANAS behaviour-change framework (Risks, Attitudes, Norms, Abilities, Self-regulation). This process involves: (1) stakeholder mapping and introductory meetings; (2) trust-building and joint problem framing; (3) behavioural diagnosis using short surveys and facilitated discussions; (4) co-designing locally workable rules and tools for recharge and protection; (5) practical capacity building through field demonstrations and targeted communication; and (6) community-led monitoring with feedback mechanisms.

Local governance is provided through Water Resilience Committees with representation from farmers, pastoralists, internally displaced persons, women and youth, as well as local authorities. Activities are scheduled around livelihood calendars (planting/harvest periods, market days, pastoral mobility) to reduce opportunity costs. Observations from initial implementation phase suggest that co-design enhances clarity of responsibilities and increases willingness to contribute to routine operation and maintenance, which is critical for long-term MAR success.

This presentation shares the engagement design, field methods and practical lessons for integrating behavioural science into MAR planning in humanitarian WASH settings.

LID 0906

Nationwide machine-learning prediction of arsenic, fluoride, and their joint occurrence in Mexican groundwater: Implications for drinking-water exposure and risk management

Juan A. Torres-Martínez[1], Joel Podgorski[1], Michael Berg[1], Dugin Kaown[1], Frank J. Loge[1], Abrahan Mora[1], **Jürgen Mahlknecht**[1]*

[1] Instituto Tecnologico y de Estudios Superiores de Monterrey, Monterrey, Mexico

* jurgen@tec.mx

Elevated concentrations of arsenic (As) and fluoride (F^-) in groundwater represent major public health concerns, particularly in arid and semi-arid regions where both contaminants often occur simultaneously. We compiled a harmonized national database for Mexico including 3,403 As and 2,084 F^- measurements, of which 44% and 24%, respectively, exceed the World Health Organization guideline values (10 µg/L for As; 1.5 mg/L for F^-). Using 69 environmental predictors encompassing climatic conditions, hydrogeological characteristics, and anthropogenic pressures, we developed and compared three machine-learning classifiers: Random Forest (RF), Extreme Gradient Boosting (XGBoost), and Artificial Neural Networks (ANN). Among them, XGBoost achieved the highest predictive performance (test balanced accuracy/AUC: As 0.82/0.90; F^- 0.83/0.94; co-occurrence 0.83/0.92). The final model produced 1-km resolution probability maps for individual exceedance and joint exceedance of As and F^-—representing, to our knowledge, the first national-scale co-occurrence assessment for Mexico. Risk mapping identifies potentially affected areas covering 15.1% (As), 13.5% (F^-), and 8.9% (joint exceedance) of the national territory, with pronounced hotspots in north-central Mexico. Population overlay analysis indicates that approximately 10.37 million people (8.2% of the population) may be exposed to elevated As, 9.65 million (7.7%) to elevated F^-, and 7.19 million (5.7%) to concurrent exposure. These spatially explicit products provide a quantitative framework to guide targeted monitoring, well management strategies (including well switching), point-of-use treatment deployment, and risk communication in communities facing the highest burden of groundwater contamination.

LID 0908
Urban growth and groundwater recharge decline in Monterrey

Danael Aceves-Padilla[1], Danael Aceves-Padilla[1], Rogelio Ledesma-Ruiz[1], Laura Rodriguez[2], Daisy K. Nunez-Flores[1], Margarito M. Vazquez Del Carmen[1], Rosario Sanchez[2,3]*, Jurgen Mahlknecht[1]

[1] Escuela de Ingenieria y Ciencias, Tecnologico de Monterrey, Monterrey Mexico
[2] Water Management and Hydrological Sciences Program, Texas A&M University, College Station, United States
[3] Texas Water Resources Institute, Texas A&M University, College Station, United States
* rosario@tamu.edu

Keywords: groundwater recharge, remote sensing, analytic hierarchy process, land-use change, urbanization, sustainable water management, Monterrey Metropolitan Area, Lower Rio Grande basin

The Monterrey Metropolitan Area (MMA), a major urban–industrial center in northeastern Mexico, faces growing hydrogeological stress driven by rapid land transformation, recurrent droughts, and limited surface-water availability. Since 2024, additional pressures associated with binational allocations under the 1944 U.S.–Mexico Water Treaty have intensified regional water competition. Understanding how groundwater recharge conditions have evolved spatially is therefore critical.

This study evaluates changes in groundwater recharge potential between 1990 and 2022 using a multi-criteria framework that integrates Remote Sensing, Geographic Information Systems, and the Analytic Hierarchy Process. Eight hydro-environmental factors—geology, structural lineaments, geomorphology, slope, precipitation, drainage density, vegetation cover (NDVI), and soil type—were weighted to generate a Groundwater Potential Index and delineate recharge suitability classes.

Results indicate substantial spatial redistribution of recharge capacity over three decades. Areas classified as very low potential expanded by more than 1000 km^2, while very high potential zones declined markedly. In total, over 1100 km^2 shifted toward lower recharge capacity, largely linked to urban growth and land-use change. These findings emphasize the need to incorporate hydrogeological criteria into land-use planning and to strengthen long-term protection of recharge areas to reduce groundwater depletion in the MMA.

LID 0909
Integrated transboundary aquifer management in the Sahara–Sahel: lessons from ITTAS and SMAS

Mohamedou Baba Sy[1]*, Abdel Kader Dodo[1], Apolline Bambara[1], Soumaya Mouhli[1]

[1] Sahara and Sahel Observatory, Tunis, Tunisia
* lamine.babasy@oss.org.tn

Keywords: groundwater, management, cooperation

The joint experience of the Sahara and Sahel Observatory (OSS) through the Iullemeden Taoudeni/Tanezrouft Aquifer Systems (ITTAS) and the Senegal–Mauritanian Aquifer System (SMAS) directly addresses the challenge of transforming largely spontaneous and fragmented conjunctive groundwater use into an ordered, cooperative, and investment-ready system.

Across the Sahara–Sahel, groundwater abstraction has often evolved in an uncoordinated manner, driven by urgent development and climate adaptation needs. ITTAS and SMAS demonstrate how such “lost opportunities” can be turned around through structured regional mechanisms that combine hydrogeological science, institutional anchoring, and political dialogue.

ITTAS advances this transition by harmonizing data, developing shared conceptual models, and promoting joint planning frameworks across major transboundary aquifers. By aligning scientific assessment with governance structures, it transforms dispersed knowledge into coordinated management tools that support collective decision-making.

Complementing this, SMAS operationalizes monitoring and data exchange through interoperable platforms and harmonized indicators, strengthening transparency, trust, and evidence-based policymaking. By linking monitoring systems with climate resilience strategies and investment planning, SMAS moves groundwater governance from reactive abstraction toward proactive, ordered conjunctive management.

Together, these initiatives illustrate how technical innovation and sustained political commitment can convert fragmented groundwater exploitation into a coherent regional governance architecture—enhancing climate resilience, reducing security risks, and creating enabling conditions for sustainable, cooperative aquifer management at scale.

LID 0911
Groundwater pollution risk assessment based on GIS and game theory combination weighting: A case study of the oasis area in the Hotan River Basin

Wenwen Shi[1,2]*, Jinlong Zhou[3], Pengwei Zhang[1,2], Qiang Wang[1,2], Jinyu Liu[1,2]

[1] Urumqi Natural Resources Survey, China Geological Survey, Urumqi, China
[2] Xinjiang Engineering and Technology Research Center for Utilization of Saline Water Resources, Urumqi, China
[3] College of Water Conservancy and Civil Engineering, Xinjiang Agricultural University, Urumqi, China
* 1542094922@qq.com

Keywords: groundwater, game theory, pollution risk, vulnerability, pollution load, functional value

Groundwater pollution risk assessment constitutes a critical foundation for regional groundwater contamination control and environmental management. Taking the oasis area of the Hotan River Basin as a case study, this study developed a comprehensive evaluation framework integrating three components: groundwater vulnerability assessment using the DRSTIW model, groundwater pollution load assessment based on contamination source investigation and land use types (differentiating point and non-point sources), and groundwater function value assessment considering natural, economic, and ecological values. The game theory combination weighting method was employed to determine the integrated weights, and groundwater pollution risk zoning maps were generated using weighted overlay analysis in ArcGIS. The results indicate that the overall groundwater pollution risk in the study area is at a moderate level, exhibiting a spatial pattern characterized by a gradual decrease from the oasis core to the desert transition zone. High and relatively high-risk areas account for 32.32% of the total study area and are primarily distributed in the central oasis regions of Hotan City, Hotan County, and Moyu County. These areas are characterized by multiple driving factors, including strong aquifer water yield, high permeability of vadose zone materials, weak groundwater runoff conditions, large recharge modulus, and concentrated pollution sources. Combined with the high natural and economic values of groundwater in these areas, the synergistic effects of high vulnerability, high pollution load, and high functional value result in significantly elevated local groundwater pollution risks. This study provides scientific support for optimizing groundwater monitoring networks and implementing pollution prevention measures in the region.

LID 0912
Pan-EU assessment of aquifer vulnerability to pollution using the DRASTIC framework

Bouchra Haddad[1]*, Efthymia Zavridou[1], Yassine Ez-Zaouy[2], Eleni-Anna Nanou[1], Konstantinos Chalikakis[1]

[1] UMR1114 EMMAH (AU-INRAE), Avignon Université, Avignon, France
[2] Department of Environmental, Biological and Pharmaceutical Sciences and Technologies (DiSTABiF), Campania University “Luigi Vanvitelli”, Caserta, Italy
* bouchra.haddad-akni@univ-avignon.fr

Keywords: groundwater, vulnerability assessment, DRASTIC, Pan-EU scale

Continental-scale groundwater vulnerability assessments are increasingly required to support transboundary aquifer management and harmonized risk screening across Europe. However, methodological inconsistencies and heterogeneous input datasets have historically limited comparability among national-scale applications. This study presents a harmonized implementation of the DRASTIC: A Standardized System for Evaluating Ground Water Pollution Potential Using Hydrogeologic Settings methodology across Europe at 1 km spatial resolution.

The seven DRASTIC parameters (D, R, A, S, T, I, C) were derived from open global datasets, including hydrogeological lithology compilations, Global Patterns of Groundwater data, Copernicus DEM topography, SoilGrids texture products, recharge estimates from a high-resolution gridded multivariate climate dataset, and a global aquifer hydraulic conductivity dataset. All inputs were standardized within the ETRS89-LAEA coordinate framework and harmonized to ensure spatial consistency. Rating and weighting followed the original formulation of Lynn Aller et al. (1987).

Results show that high intrinsic vulnerability is concentrated in major sedimentary basins and shallow Quaternary alluvial systems. Nonetheless, limitations arise from the global hydraulic conductivity dataset and from scale-induced smoothing of local hydrogeological heterogeneity. Karstified carbonate provinces also remain a challenge for the application of the DRASTIC vulnerability assessment.

The study confirms that a harmonized DRASTIC approach provides a robust first-order intrinsic vulnerability framework at the European scale and offers a reproducible baseline for future scenario analysis under climate-driven recharge variability.

LID 0913
Analysis of streamflow data in a groundwater-dominated karst catchment demonstrates early signals of streamflow capture

Riley Nicholson[1,2]*, Matthew Currell[1], Dioni Cendon[3], Elisabetta Carrara[1], Christopher Ndehedehe[1]

[1] Australian Rivers Institute, Griffith University, Nathan, Australia
[2] Australian Government Bureau of Meteorology, Melbourne, Australia
[3] Australian Nuclear Science and Technology Organisation, Lucas Heights, Australia
* riley.nicholson@griffithuni.edu.au

Keywords: streamflow capture, surface water-groundwater, baseflow analysis

Groundwater discharge from the Cambrian Limestone Aquifer is critical to the dry season flows of the culturally and ecologically, significant Roper River (Northern Territory, Australia). However, groundwater extraction near major springs has increased dramatically over the last decade, with current volumes approaching one-third of the dry season flow. This extraction is expected to grow, with the current extraction rate representing approximately 6% of the basin wide allocation limit of 248,000 ML/year. Informed by a karst-specific conceptual model of groundwater-surface water interaction; the analysis of baseflow recession and flow-duration curves, show clear indications of streamflow capture at both the high and low flow ends of the streamflow hydrograph. These analyses utilise climatic reference periods to control for the influence of climate variability, the veracity of which is confirmed by multi-parameter regression modelling. These findings are further supported by recent remote sensing studies, groundwater level data, and align with the current system conceptual model. Interpreted alongside environmental tracer data and groundwater modelling studies of the system, these early signals of streamflow capture demonstrate the need for urgent intervention to protect these MIKAS-listed springs and the Roper River. Further studies will seek to integrate findings with geochemical and environmental isotope data to explore potential implications for the climatic resilience of the Roper River.

LID 0915
Enabling kilometer-scale global groundwater modeling with performance-portable ParFlow

Muhammad Fahad[1]*, Stefan Kollet[1], Zbigniew Piotrowski[2], Jörg Benke[1], Daniel Caviedes-Voullième[1], Jaro Hokkanen[3], Georgios Artavanis[4], Reed Maxwell[4], Steve Smith[5]

[1] Forschungszentrum Jülich GmbH, Jülich, Germany
[2] European Centre for Medium-Range Weather Forecasts, Bonn, Germany
[3] Independent Researcher, Porvoo, Finland
[4] Princeton University, Princeton NJ, United States
[5] Lawrence Livermore National Laboratory, Livermore CA, United States
* m.fahad@fz-juelich.de

Keywords: groundwater-surface water interactions, integrated hydrologic modeling, earth system modeling, global water modeling, High Performance Computing (HPC), performance portability

Water is essential for food security, economic stability, ecosystem resilience, and public health. Understanding and predicting water-cycle dynamics across scales is therefore central to hydroclimate science and global sustainability challenges. Despite its importance, groundwater-surface water interactions remain underrepresented in many Earth system models, largely due to the complexity of subsurface processes and the computational and software demands of resolving them at high spatial resolution.

Physically based integrated hydrologic models provide a pathway to explicitly represent these interactions over large domains. ParFlow is an open-source framework that models variably saturated subsurface flow coupled with surface hydrology and land-atmosphere processes. Such tightly coupled, multi-scale simulations require substantial compute resources, particularly as hydrologic modeling moves toward kilometer-scale continental and global domains relevant for Earth system applications.

At the same time, modern supercomputing platforms increasingly rely on heterogeneous architectures combining CPUs with GPUs. Efficiently leveraging these systems while maintaining sustainable, portable software is a central challenge for large-scale environmental modeling. Performance portability, the ability to efficiently run on diverse hardware without extensive code specialization, has thus become critical.

Here, we present recent developments enabling scalable, performance-portable Global Water Modeling with ParFlow. These leverage a flexible portability layer integrating a GPU backend based on Kokkos for cross-platform parallel execution and Umpire for architecture-aware memory management. Complementing the existing CUDA implementation, this backend enables efficient execution across diverse HPC architectures while maintaining a unified code base, supporting high-resolution simulations of groundwater processes and advancing the objectives of the GEWEX Global Groundwater Network.

The authors gratefully acknowledge the Earth System Modelling Project (ESM) for funding this work by providing computing time on the ESM partition of the supercomputer JUWELS at the Jülich Supercomputing Centre (JSC).This project has received funding from the European High Performance Computing Joint Undertaking under grant agreement n°101144014. Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the EuroHPC JU. Neither the European Union nor the granting authority can be held responsible for them. We acknowledge the EuroHPC Joint Undertaking for awarding this project access to the EuroHPC supercomputer LUMI, hosted by CSC (Finland) and the LUMI consortium through a EuroHPC Extreme Scale Access Call.

LID 0918
Modeling a moving target: A chemical conceptual model for groundwater plumes under changing pumping conditions

Lily Yu[1]*

[1] University of Illinois Urbana-Champaign, Champaign, United States
* lilyyu2024@arizona.edu

At a former pesticide manufacturing facility in Brazil, groundwater and contaminant models must account for frequent changes in nearby pumping, including increased withdrawals from multiple aquifers at different depths to meet demands from a growing population. Since start-up of the industrial complex in the 1970s, new municipal and industrial supply wells have been added in multiple waves, including major wellfield expansions in the 1980s-1990s, around 2004, and again from 2017 through 2024. These evolving pumping stresses can shift hydraulic gradients, flow directions, and groundwater velocities. As a result, models set up for current conditions may misrepresent earlier plume movement and may require repeated recalibration each time new wells are installed.

This poster presents how a Chemical Conceptual Model (CCM) improves modeling under these changing conditions by focusing on time-stable information: production history, primary source areas, release mechanisms, and the chemistry of site ‘mixtures of interest’ that occur mainly as non-aqueous phase products (NAPPs). In this approach, mixtures are sampled and analyzed, then used to build simple one-dimensional diagrams that reflect vertical transport, phase changes and likely transformations over time. To test whether these predictions are realistic, accelerated column experiments are run to mimic key natural attenuation processes under representative layering, while compressing field timescales into manageable laboratory timeframes.

The CCM provides a consistent foundation for complex, variable-rich modeling. This improves confidence in plume interpretation, supports updates to flow and transport models as pumping changes, and can speed remediation decisions by focusing sampling on the zones where contaminants are most likely to accumulate and persist.

LID 0919
Risk-based geothermal planning in the Milan urban area using surrogate modeling

Alberto Previati[1]*, Valerio Silvestri[1], Paolo Frattini[1], Riccardo Castellanza[1], Giovanni Crosta[1]

[1] Dept. Earth and Environmental Sciences, University of Milan-Bicocca, Milan, Italy
* alberto.previati@unimib.it

Keywords: groundwater temperatures, shallow geothermal energy, urban groundwater management

Urbanization, climate change, and the rapid deployment of shallow geothermal systems are increasingly altering the thermal regime of aquifers. Groundwater heat pumps (GWHPs) provide an efficient solution for urban heating and cooling; however, their widespread adoption raises concerns regarding thermal interference and sustainability of densely exploited aquifers. Moreover, their potential depends both on the expected groundwater temperature and on the allowable alteration imposed by neighboring installations and regulatory constraints.

This study presents a novel framework for risk-based geothermal resource management in Milan, Italy, jointly addressing GWHP thermal plume development and groundwater temperature analysis. The method relies on a neural network surrogate model trained on 3D FEM heat-transport simulations. The training dataset spans a wide range of hydrogeological conditions and GWHP operational scenarios, including variable injection rates and combined heating-cooling operations. The surrogate model replicates the thermal plumes of numerical simulations with high accuracy, achieving a mean absolute percentage error of 5% in predicting the extent of the ±1 °C thermal perturbation.

The surrogate model was embedded within a Monte Carlo framework to account for uncertainty in hydrogeological parameters and system operation, enabling probabilistic mapping of the thermal perturbation from the existing GWHP installations. Finally, the approach was extended to resource planning by estimating the groundwater thermal potential for new installations limiting the temperature perturbation at existing wells. The proposed framework bridges the gap between fast analytical and computationally intensive numerical models, providing a scalable and robust decision-support tool for the sustainable management of shallow geothermal energy in urban aquifers.

LID 0920
Isotope hydrological proof of the special properties of the Hungarian mineral waters

István Fórizs[1]*, József Deák[2], György Czuppon[1]

[1] Institute for Geological and Geochemical Research, HUN-REN CSFK Budapest, Hungary
[2] GWIS Ltd, Veszprém, Hungary
* forizs@geokemia.hu

Keywords: bottled mineral waters, $\delta^{18}O$ and $\delta^{2}H$ stable isotopes, tritium, ^{14}C

$\delta^{18}O$ and $\delta^{2}H$ ratio of 60 bottled mineral and medical water samples have been analysed in the Institute for Geological and Geochemical Research, HUN-REN CSFK, Budapest. Using those mineral waters for which isotopic data were available for the raw water (taken from the well), we found that the δ values of the bottled waters exceeded those of the raw water data by +0,3 ‰ in $\delta^{18}O$ and +1,2 ‰ in $\delta^{2}H$, indicating a small degree of isotope enrichment. This divergence does not disturb the evaluation of bottled water data as the natural variations are substantially higher. The study is based on the relationship between the monthly average $\delta^{2}H$ and $\delta^{18}O$ values of precipitation (and the groundwater infiltrating from it) and the monthly mean air temperature.

Stable isotope data ($\delta^{18}O$ and $\delta^{2}H$) lower than of the Holocene groundwater (in Hungary $\delta^{2}H$ = <-65‰ and $\delta^{18}O$ = <-9.2‰), prove that significant part of the Hungarian mineral waters has infiltrated in a climate colder than today (Ice Age). Available ^{14}C groundwater ages (>10 ka) along with hydrogeological features prove the Ice Age origin of these mineral waters.

Bottled waters with extremely low $\delta^{2}H$ = <-100‰ and $\delta^{18}O$ = <-14‰ can be considered as waters infiltrated during the last Glacial peak period (26.5 to 19 ka ago), indicating their very special attribute („Hungaricum”).

The great divergence in the stable isotope ratios of Hungarian bottled waters provides an opportunity to verify their authenticity and prevent adulteration, which is mainly a risk for the most popular bottled waters.

Hungarian bottled waters are protected against the anthropogenic pollutions containing non detectable (<0.5 TU = <0.06 Bq/L) tritium, in accordance with the Ministerial Decree of 21/2001.

LID 0921
Mapping the groundwater thermal regime in the Milan urban aquifer

Valerio Silvestri[1]*, Alberto Previati[1], Giovanni Crosta[1]

[1] Dept. Earth and Environmental Sciences, University of Milan-Bicocca, Milan, Italy
* valerio.silvestri@unimib.it

Keywords: thermal regime, probabilistic analysis, mitigate surface worming

The increase in global temperatures associated with climate change, together with the progressive expansion of urbanized areas, is contributing in many metropolis worldwide to a significant urban heat island effect, that is also reflected underground leading to sub-surface urban heat islands (SUHIs). Therefore, the thermal regime of shallow aquifers can be altered, affecting groundwater quality and long-term sustainability as a geothermal resource. Hence, the continuous monitoring of groundwater temperature and level is essential to better understand these processes and to support strategies aimed at mitigating subsurface warming.

In the city of Milan, groundwater variables have been systematically monitored over the past decade, providing a valuable long-term dataset for investigating the evolution of the subsurface thermal regime. By performing statistical analysis on time-series data (auto- and cross-correlation, PCA analysis, wavelet analysis) such as groundwater data (water depth, oscillations, temperature) and meteorological variables (air temperature and precipitation), the interactions between atmospheric conditions, hydrological processes, and urbanization in controlling groundwater temperature dynamics have been analysed.

Beyond the comprehension of the underground thermal regime, this study aims to develop groundwater temperature maps to support management strategies and geothermal resource planning. Several spatialization techniques were compared for the generation of groundwater temperature maps and their associated uncertainty. The produced maps can contribute to the assessment of groundwater thermal potential and to the spatial planning of groundwater heat pump (GWHP) systems, by supporting the sustainable development and management of shallow geothermal resources.

LID 0923
Localized urban recharge and return flows shape groundwater dynamics in the Patiño Aquifer, Asunción, Paraguay

María Leticia Montiel[1,2], Ricardo Sánchez-Murillo[3], Max Pasten[4], Melanie Vital[5], Juan Camacho-Puerto[3], **Lucia Ortega**[5], Claudia Avalos[4,2]*

[1] Comisión Nacional de Energía Atómica, Universidad Nacional de Asunción, San Lorenzo, Paraguay
[2] Facultad de Ciencias Químicas, Universidad Nacional de Asunción, San Lorenzo, Paraguay
[3] Department of Earth and Environmental Sciences, University of Texas at Arlington, Arlington, TX, United States
[4] Centro Multidisciplinario de Investigaciones Tecnológicas, Universidad Nacional de Asunción, San Lorenzo, Paraguay
[5] Isotope Hydrology Section, Division of Physical and Chemical Sciences, Department of Nuclear Sciences and Applications, International Atomic Energy Agency, Vienna International Centre, Vienna, Austria
* cavalos@rec.una.py

Keywords: stable isotopes (δ^2H, $\delta^{18}O$), urban groundwater recharge, Patiño Aquifer

The Patiño Aquifer is one of the main sources of groundwater for the metropolitan region of Asunción, Paraguay, supplying water for domestic, industrial, and agricultural uses. Increasing demand and concerns about groundwater sustainability highlight the need for a better understanding of recharge processes and groundwater flow dynamics within this aquifer system. In this study (2019-2025), stable water isotopes (δ^2H and $\delta^{18}O$) and dissolved radon (^{222}Rn) were used to investigate a) the hydrological connectivity between precipitation, surface waters, and groundwater as well as b) the flow dynamics within the aquifer.

Precipitation isotopes revealed a clear sinusoidal seasonality mainly controlled by the South American Low-Level Jet (SLLJ) (HYSPLIT clusters: 54-66% with $\delta^{18}O$ as low as -13.78‰) and the South Atlantic Subtropical High (SASH) (HYSPLIT clusters: 6-32% with $\delta^{18}O$ as high as +4.17‰). The local meteoric water line in Asunción, Paraguay (2019-2025, N=73) was defined as $\delta^2H = (8.00\pm0.24) \cdot \delta^{18}O + (12.10\pm1.41$; r2=0.98; p-value<0.001). The arithmetic (precipitation-weighted) δ^2H, $\delta^{18}O$, and d-excess values corresponded to -20.86 (-25.98), -4.12 (-4.88‰), and -12.09 (-13.06‰), respectively. Lake Ypacaraí, Paraguay River, urban streams, and wells (mainly located near the urban center) exhibited the highest (lowest) $\delta^{18}O$ (d-excess) values, indicating secondary evaporation and the potential influence of return flows in the northern portion of the aquifer. LC-excess values exhibited a similar spatial trend, with northern urban wells ranging from -3.3‰ to -7.5‰, and higher values in the middle and southeastern areas (0.4‰ to 3.1‰). $\delta^{18}O$ and d-excess in the middle and southeastern portion of the aquifer were closer to the mean annual precipitation weighted values, suggesting direct recharge with minimal kinetic fractionation.

^{222}Rn values aligned with $\delta^{18}O$, d-excess, and LC-excess observations, with an increasing trend (up to 18.4 Bq/L) towards the southeastern portion of the aquifer. Relatively low ^{222}Rn (<1.0 Bq/L) was reported in the Paraguay River, urban streams, and Lake Ypacaraí. The spatial variability in ^{222}Rn activities indicates heterogeneity in water-rock interactions and groundwater residence times across the aquifer, suggesting the presence of relatively younger waters in the northern sector and progressively older groundwater along the flow path toward the southeast. Our tracer results provide new insight into urban recharge processes and groundwater flow pathways within this heavily utilized aquifer system, highlighting localized recharge during heavy rainfall events and emphasizing the potential influence of urban return flows on groundwater quality.

LID 0924
Hydrogeology of the Gioia Tauro Coastal Plain (Southern Italy): Integrating baseline knowledge and numerical modeling for groundwater management under global change

Giuseppe Cianflone[1], Rosanna De Rosa[1], Giovanni Vespasiano[1], Rocco Dominici [1], Carmine Apollaro[1], Shubham Tiwari[2], Maurizio Polemio[3]*

[1] University of Calabria, Department of Biology, Ecology and Earth Sciences, Rende (CS), Italy
[2] University of California Davis, Department of Land Air and Water Resources, UC Davis, United States
[3] CNR-IRPI, National Research Council – Research Institute for hydrogeological Protection (CNR-IRPI), Bari, Italy
* maurizio.polemio@cnr.it

Keywords: hydrostratigraphic framework, numerical modeling, global climate change

The research combines hydrostratigraphic reconstruction, physicochemical and isotopic analyses, and variable-density groundwater modeling to evaluate aquifer structure, dynamics, and vulnerability under anthropogenic and climatic pressures in an intensively cultivated coastal area in southern Italy.

Subsurface data from boreholes and geophysical surveys enabled reconstruction of a complex aquifer system: (i) a deep aquifer hosted in Late Miocene deposits, (ii) an aquitard of Pliocene clayey–silty sediments, and (iii) a shallow aquifer formed by Late Pleistocene–Holocene marine and alluvial deposits. Structural geology strongly influences the geometry of the aquitard and the thickness of the shallow aquifer. Long-term monitoring indicates a major groundwater decline since the 1970s (up to −35 m), mainly driven by irrigation demand, particularly for kiwi cultivation.

Hydrogeochemical and isotopic analyses show that both aquifers are dominated by Ca–HCO_3 waters, with localized Na–HCO_3, Na–Cl, and Ca–SO_4 facies. In the deep aquifer, prolonged water–rock interaction and cation exchange generate Na–HCO_3 waters, while mixing with connate brines and deep thermal fluids produces isolated high-salinity Na–Cl waters. The shallow aquifer generally contains fresh groundwater with local anthropogenic contamination.

A variable-density groundwater model developed with SEAWAT simulated past conditions (1950–2000) and future scenarios to 2100. The model provides a first estimate of deep thermal groundwater flow, validated through heat and salinity effects. Results indicate that thermal groundwater upflow contributes about 4.35% of total inflow, increasing salinity and temperature in fault-controlled zones. Climate projections indicate a 21% reduction in effective rainfall by 2100, leading to declining hydraulic heads, increased salinity in the shallow aquifer, and higher subsidence risk. These findings highlight the combined influence of structural controls, climate change, and intensive land use on coastal groundwater systems.

LID 0925
Coastal aquifers at the crossroads: Groundwater dynamics, human dependence, and lessons from India for global coastal sustainability

Palak Singh[1], Kaustub Sinha[2]*

[1] Institute for Community Development, Shiprapath, Jaipur, India
[2] University of Rajasthan, Jaipur, Rajasthan, India
* kaustubsinha@gmail.com

Keywords: coastal aquifer, groundwater management, policy framework

The growing imbalance between recharge and extraction has intensified processes such as seawater intrusion, salinization, and degradation of groundwater quality in the coastal aquifers. Understanding the dynamic interaction between coastal aquifer systems and dependent communities is therefore essential for sustainable groundwater management. India, with a coastline of more than 7,500 km and a large population dependent on groundwater for drinking water, agriculture, and livelihoods, provides an important natural laboratory to examine coastal aquifer dynamics. This study synthesizes hydrogeological evidence from selected Alluvial to hard rock coastal aquifer of India to examine groundwater flow systems, recharge mechanisms, aquifer vulnerability, and the evolving freshwater–seawater interface. The analysis integrates hydrogeological observations, groundwater quality indicators, abstraction trends, and socio-economic dependence to highlight how human pressures alter aquifer equilibrium and accelerate saline ingress. The findings demonstrate that coastal aquifer sustainability depends not only on hydrogeological parameters such as aquifer geometry, permeability, and recharge rates, but also on governance structures, water-use practices, and community awareness. Over-exploitation, poorly regulated extraction, and unplanned coastal development significantly modify natural groundwater dynamics. Conversely, integrated management approaches—including managed aquifer recharge, demand regulation, protection of recharge zones, and community-based groundwater stewardship—can help restore aquifer resilience. The Indian experience offers valuable lessons for many coastal regions of the world facing similar hydro-environmental pressures. Strengthening the interface between hydrogeological science, policy frameworks, and community participation is essential to safeguard coastal groundwater systems and ensure long-term water security in the context of global environmental change.

LID 0926
From algorithms to aquifers: Assessing impact of AI data centres on groundwater sustainability

Kaustub Sinha[1]*, Vikas Kumar[1]

[1] Chhatrapatishivaji Maharaj University, Navi Mumbai, Maharshtra, India
* kaustubsinha@gmail.com

Keywords: AI technologies, aquifer, data centres, aquifer sustainability

The rapid expansion of artificial intelligence (AI) technologies, including large language models such as Chat GPT, has led to an unprecedented growth of hyper scale data centres worldwide. While the environmental implications of AI are often discussed in terms of energy consumption and carbon emissions, the associated impacts on water resources—particularly on Aquifer—remain relatively underexplored. Data centres require significant quantities of water for cooling systems, thermal regulation, and electricity generation, creating a direct link between digital infrastructure and regional water resources particularly Aquifer extraction

This study examines the emerging nexus between AI-driven computing infrastructure and Aquifer sustainability. It analyses how the increasing deployment of AI data centres contributes to water demand and assesses the potential implications for Aquifer systems in water-stressed regions. The research integrates hydrogeological perspectives with digital infrastructure analysis, drawing on available water-use data, Aquifer stress indicators, and case studies from major data centre hubs.

The findings highlight that the rapid proliferation of AI infrastructure may intensify local groundwater withdrawals, potentially exacerbating aquifer stress in already vulnerable regions. The paper emphasizes the need for incorporating groundwater sustainability considerations into the planning and operation of AI data centres. It also explores technological and policy pathways—such as alternative cooling technologies, water recycling, and sustainable siting strategies—to mitigate the hidden hydrological footprint of the AI revolution.

LID 0928
Nature-based Solutions for enhancing groundwater recharge on the volcanic island of Madeira: A case study insights

Susana Prada[1,5]*, Sérgio Lopes[2], Nuno Gouveia[1], Celso Figueira[3], Nelia Sousa[4], Yasmin Chllouf[1], Eduardo Leite[1]

[1] Universidade da Madeira, Funchal, Portugal
[2] Laboratório Regional de Engenharia Civil, Funchal, Portugal
[3] Instituto das Florestas e Conservação da Natureza, Funchal, Portugal
[4] Águas e Resíduos da Madeira, Funchal, Portugal
[5] IVAR, Ponta Delgada, Portugal
* slprada@staff.uma.pt

Keywords: Madeira Island, basaltic, volcanic aquifers, recharge, NbS

Nature-based Solutions (NbS) are increasingly recognized for their role in the sustainable management of water resources, especially in rugged volcanic islands where groundwater is the main source of water supply.

Madeira Island is located in the North Atlantic Ocean, corresponding to a shield volcano of Mio-Holocene age (>7 Ma), deeply dissected by erosion. With a surface area of 741 km^2 and a total population of approximately 255,000 inhabitants, is visited annually by about 3,000,000 tourists, possessing a high population density of approximately 344 inhabitants/km^2, with about 45% of the population concentrated in the city of Funchal.

Genesis project aims to increase the resilience of the main groundwater intake infrastructure for supplying water to the population of Funchal, the main city on the island of Madeira, in the face of climate change, by reinforcing the infiltration of the Tornos Tunnel - the largest groundwater intake on the island of Madeira (350 l/s).

The intervention will consist of the creation and monitoring of an infiltration basin, located at 1500 m altitude, at the headwater of a river basin in the municipality of Funchal, an area with favorable geological, geomorphological and hydrogeological conditions,

This pilot intervention aims to contribute to increasing water infiltration in strategic areas of the island and, consequently, increasing aquifer recharge, constituting an appropriate adaptation measure to the decrease in groundwater resources on the island of Madeira.

LID 0929
Monitoring-based validation of GALDIT seawater intrusion vulnerability mapping: The Muravera coastal aquifer (SE Sardinia)

Fabrizio Antonio Piscedda[1]*, Claudio Arras[1], Maria Chiara Porru[1], Riccardo Biddau[1], Francesca Lobina[1], Vittorio Fancello[1], Stefania Da Pelo[1]

[1] Department of Chemical and Geological Science, University of Cagliari, Monserrato, Italy
* fabrizioa.piscedda@unica.it

Keywords: groundwater vulnerability, coastal aquifer, saltwater intrusion, GALDIT, Muravera aquifer

Index–overlay methods such as GALDIT are widely used to screen coastal aquifers for seawater intrusion vulnerability, but they are rarely benchmarked against long monitoring records. We apply GALDIT to the Muravera coastal aquifer (SE Sardinia) and validate the vulnerability classes using multiyear hydrochemical and hydraulic observations.

GALDIT factors (G, A, L, D, I, T) were implemented in QGIS on a 25×25 m grid. The October 2024 survey was selected as a worst-case snapshot for the phreatic domain. Distance (D) was computed to a saline boundary including both the open coastline and the connected coastal lagoons (“foxi”); L derives from the October 2024 piezometric surface; A and T from the hydrogeological model [1]; I from the October 2024 conductivity field. The weighted index was classified into five classes.

Validation uses the 2017–2024 groundwater dataset: a seawater-influence index (SWI) is computed from major ions and chloride-based seawater fraction and compared across GALDIT classes. SWI increases with GALDIT class (Spearman ρ=0.64 for samples), with class-5 areas showing the highest seawater influence. Age-dating [2] indicates that the most saline waters can be centuries old; therefore, GALDIT is interpreted as susceptibility to seawater-influenced salinisation and potential mobilisation of inherited salinity under present stresses. Consistently, in high-vulnerability sectors SWI tends to increase during low piezometric heads, and continuous piezo–conductivity records at a class5 site show a delayed conductivity rise following drawdown. Overall, the monitoring-based workflow supports GALDIT as a practical screening tool to prioritise intrusion-prone sectors in Muravera and analogous low-gradient coastal plains.

We acknowledge financial support under the National Recovery and Resilience Plan (NRRP), Mission 4 Component 2 Investment 1.5 - Call for tender No.3277 published on December 30, 2021 by the Italian Ministry of University and Research (MUR) funded by the European Union – NextGenerationEU. Project Code ECS0000038 – Project Title eINS Ecosystem of Innovation for Next Generation Sardinia – CUP F53C22000430001- Grant Assignment Decree No. 1056 adopted on June 23, 2022 by the Italian Ministry of Ministry of University and Research (MUR). Historical data supporting this study was funded by Agreement POA FSC 2014–2020 - 16.12.2019 among the ex MATTM- DGSTA and River Basin Authority (AdB) of Sardinia - Service for the protection and management of water resources, water services and drought management - Regional Agency of the River basin district of Sardinia, Action 2.3.1 “Interventions to improve the quality of water bodies”. Authors are grateful to ENAS for providing monitoring data.

References:

[1] Porru, M.C., Davids, T., Arras, C., Oude Essink, G.H.P., Piscedda, F.A., Da Pelo, S. – Sustainable groundwater management in coastal areas: modeling saltwater intrusion dynamics in Muravera, Italy. Hydrogeology Journal — manuscript under major revision.

[2] Porru, M. C., Manning, A., Arras, C., Piscedda, F. A., Lobina, F., Biddau, R., & Da Pelo, S. (2023). Groundwater age tracer challenges: A case study from the Muravera plain, Italy. SGI, Potenza, Italy. (Oral abstract).

LID 0930
The role of hydrogeologists in the development of critical mineral deposits: The Jadar Project in Serbia case study

Vladimir Živanović[1]*, Nebojša Atanacković[1], Sava Magazinović[1], Veselin Dragišić[1]

[1] University of Belgrade – Faculty of Mining and Geology, Belgrade, Serbia
* vladimir.zivanovic@rgf.bg.ac.rs

Keywords: hydrogeological investigation, critical raw materials, lithium, green mining, environmental impact assessment

The growing demand for critical minerals essential for the global energy transition has renewed focus on “green mining” and its sustainability. In this context, hydrogeologists play a crucial role in assessing and mitigating the environmental impacts of large-scale mining projects such as the Jadar Project in western Serbia. This paper explores the systemic role of hydrogeological research in the planning and development of mineral deposits, emphasising its importance for integrated environmental impact assessment and sustainable water resource management.

In the Jadar area, hydrogeological investigations were conducted on a comprehensive scale, providing a robust basis for understanding groundwater systems and their relationship to proposed mining operations. The research included nearly 1000 packer hydraulic tests (injection, slug, and pumping), an extensive monitoring network of 177 wells and piezometers, and long-term monitoring of groundwater levels and quality. Additional studies involved pumping tests on production wells and advanced numerical modelling to analyse inflow, dewatering, and impacts on surface waters and shallow groundwaters. Hydrodynamic and contaminant transport simulations supported the assessment of migration pathways and the development of protective measures for surrounding aquifers. These comprehensive investigations serve as the foundation for mitigation planning and compliance with environmental and water management standards.

The Jadar case study demonstrates how hydrogeological expertise contributes to both environmental protection and responsible mine design within the green transition framework. Rather than representing a conflict between mining and environmental preservation, hydrogeological science should support balanced decision-making that aligns resource development with groundwater conservation.

This work was partially supported by the Ministry of Science, Technological Development, and Innovation of the Republic of Serbia (agreements 451-03-34/2026-03/ 200126 and 451-03-33/2026-03/ 200126).

LID 0931
Analysis of the average drawdown effect of periodic water extraction using analytical and numerical methods

Tamás Buday[1]*, Kyrillos Samir Ghattas[1], Erika Bódi-Buday[2]

[1] Department of Mineralogy and Geology, Institute of Earth Sciences, Faculty of Natural Sciences and Technology, University of Debrecen, Debrecen, Hungary
[2] Department of Water Science and Environmental Informatics, Institute of Water and Environmental Management, Faculty of Agricultural and Food Sciences and Environmental Management, University of Debrecen, Debrecen, Hungary
* buday.tamas@science.unideb.hu

Keywords: periodic water production, Theis well function, MODFLOW

During the production of groundwater, water extraction may be periodic, for example, only in working hours during the day, or irrigation water demand may only occur during the driest periods. This type of water extraction causes significant water level fluctuations over shorter periods, the nature of which depends not only on the characteristics of production, but also on the properties of the aquifer, the hydraulic properties of the entire aquifer sequence, and the distance from the well. Water permit processes may require the determination of the maximum water yield and the permanent water level decline based on the daily water withdrawal in order to assess the impact on the environment, but this may significantly overestimate the actual (transient) impact.

The aim of our research is to examine the effect of transient phenomena using analytical and numerical modeling. During analytical modeling, we use Theis well function interpolation to calculate how the daily amplitude decreases with distance from the well in the produced layer, and at what distance the transient depression caused by periodic and constant yield production can be considered identical. For three sediment types and four production schedules, we determined the hourly values of water level decline for 10 years at seven different distances, then the daily averages, minimums, and maximums. Using numerical modeling, we calculated the effect of water extraction from deeper layers, examining the impact of uncertainties on the values obtained. In all cases, the permanent models significantly overestimate the actual impact. The results can be used in water management planning, specifying the distance beyond which it is sufficient to use the model containing the daily average production, depending on the parameters.

LID 0934
A study of baseflow separation using end-member mixing analysis during consecutive events

Sunghyen Cho[1]*, Tea Seung Kim[1], Woo Jin Shin[2], Ghwang-Sik Lee[2]

[1] National Instrumentation Center for Environmental Management (NICEM), Seoul National University, Seoul, South Korea
[2] Korea Basic Science Institute (KBSI), 162 Yeongudanji-ro, Ochang-eup, Cheongwon-gu, Cheongju-si, Chungcheongbuk-do, South Korea
* sunghc@snu.ac.kr

Keywords: baseflow, environmental tracer, end-member mixing analysis, mass-balance, trial-and-error

This study examines the temporal dynamics of streamflow components during two consecutive rainfall events separated by a two-day interval. End-Member Mixing Analysis (EMMA) was used to quantify the influence of antecedent rainfall and to identify the relative contributions of runoff sources. Environmental tracers, including stable isotopes ($\delta^{18}O$, δD) and dissolved silica (Si), were applied to distinguish water origins and subsurface flow pathways.

Hydrograph separation was conducted using both three-component (Event 1, Event 2, and baseflow) and four-component (including soil water) mixing models. Because direct measurements were unavailable, the maximum silica concentration of the soil-water end-member was estimated using a mass-balance–based trial-and-error approach.

The four-component model produced a more physically realistic representation of streamflow composition. While the three-component model attributed more than 50% of discharge to baseflow, the four-component model identified soil water as the dominant contributor. Event 1, which was 4.5 times larger than Event 2, exerted a sustained influence on streamflow during and after the second rainfall event. These results indicate that streamflow during successive rainfall events is governed primarily by pre-event water (baseflow and soil water) rather than direct event water. The dominant soil-water contribution reflects hydraulic contrasts between rapid soil flow pathways and slower groundwater flow.

LID 0936
Wardrobe-type karst and bed-type karst: Structural, geomorphological, and hydrogeological general characteristics

Juan José Durán Valsero[1]*, Sergio Raúl Durán Laforet[2], Raquel Morales García[1], Pedro Agustín Robledo Ardila[3], Eulogio Pardo Igúzquiza[4]

[1] Instituto Geológico y Minero de España (IGME-CSIC), Madrid, Spain
[2] Amphos 21, Madrid, Spain
[3] Instituto Geológico y Minero de España (IGME-CSIC), Palma de Mallorca, Spain
[4] Instituto de Geociencias (IGEO-CSIC), Madrid, Spain
* jj.duran@igme.es

Keywords: aquifer classification, carbonate aquifers, karst

When analyzing the planet's major karst aquifers, two clearly distinct patterns emerge, primarily based on their 3D geometry: wardrobe-type aquifers and bed-type aquifers. The former are characterized by a morphology where the vertical component predominates over one or both planar dimensions, while in the latter, the two-dimensional component predominates over the vertical. Both types share a number of general characteristics from tectonic, geomorphological, and hydrogeological perspectives, which are described below. Wardrobe-type aquifers are typically composed of relatively old carbonate rocks, sedimentary or metamorphic, influenced by significant orogenic processes, whose tectonic structure is controlled by folding and fracturing. Morphologically, they exhibit mountainous relief, sometimes reaching significant altitudes above sea level. Typical exokarstic geomorphology includes poljes, doline fields and karren, often structurally controlled. The most representative endokarstic features are vertical caves, in the upper reaches. In the middle and lower areas, subhorizontal cave networks may develop, sometimes linked to active springs. From a hydrogeological perspective, the unsaturated zone is very large, potentially reaching hundreds of meters or even exceeding one thousand meters in depth. Typical examples of this type of aquifer are those found in the large circum-Mediterranean alpine karst massifs, such as Picos de Europa, Pyrenees, Alps, or Caucasus. Bed-type aquifers are typically located on geologically recent carbonate platforms with moderate to minimal deformation, gentle folding, and limited fracturing. Morphologically, plateau or plain-like reliefs are common, with shallow, closed depressions of varying sizes and frequent sinkholes (cenotes, for example). Endokarst is usually composed of subhorizontal cavities, which may form extensive networks with epiaquatic or subaquatic development. Hydrogeologically, the water table is relatively close to the topographic surface, with a small unsaturated zone, typically less than 100 meters deep. Notable examples include the karst of the Yucatán Peninsula and the Edwards Aquifer in Texas, USA.

LID 0937
Unsustainable transition to groundwater use as a response to a systemic shock: Case study of Pench Irrigation Project, Maharashtra, India

Amruta Pradhan[1,2]*, Veena Srinivasan[3], Swanand Khanapurkar[4]

[1] Ashoka Trust for Research in Ecology and the Environment, Bengaluru, India
[2] Manipal Academy of Higher Education, Manipal, India
[3] Water, Environment, Land and Livelihoods (WELL) Labs, Bengaluru, India
[4] Centre for Sustainable Development, Gokhale Institute of Politics and Economics, Pune, India
* amruta.pradhan@atree.org

Keywords: unsustainable groundwater use, surface-groundwater interaction, dams, India

India is the third-largest dam-building country in the world, with over five thousand large dams. Despite this, more than 60% of India's irrigation happens through groundwater. Use of groundwater in conjunction with the canal water in the commands of major and medium dams is increasing new.

We however present a case study of the Pench Irrigation Project (PIP) of Nagpur District, a part of the Pench Project Complex (PPC), an interstate project between Maharashtra and Madhya Pradesh (MP) on Pench River where the farming system in the command area has tipped towards unsustainable groundwater use as a response to a systemic shock.

In 2017-19 the PIP command experienced a severe water crisis owing to newly unfolding inter-state dynamics. The yield of the project suffered a major setback when MP built a dam upstream of PPC to utilise its allocated share of Pench River water that was routinely used by Maharashtra. During this scarcity period, water supply to the city of Nagpur was prioritised for drinking water purposes. The brunt of the crisis was borne almost exclusively by the irrigation sector for two years.

We wanted to understand the nature and underlying causes of the crisis.

The crisis acted as a shock to the command area, triggering a rapid transition to bore wells at the middle and head of the command which traditionally has had a higher dependence on canal water.

The Water Resources Department of Maharashtra is reluctant to acknowledge the surface-groundwater dynamics and focuses excessively on making provisions for more surface water since the water availability of PIP has become highly vulnerable to rainfall post the construction of the upstream dam.

LID 0938
Stochastic modelling of karst conduit networks informed by geological and hydrodynamic constraints

Attila Kovács[1]*

[1] University of Miskolc, Institute of Environmental Management, Miskolc-Egyetemváros, Hungary
* attila.geo.kovacs@gmail.com

Keywords: karst hydrogeology, conduit network, hydrograph analysis

Stochastic modelling of karst systems now enables the generation of ensembles of realistic conduit networks that incorporate geological structure, hydrological observations, and surface karst features. These methods quantify uncertainty in conduit geometry and allow it to be carried into flow and transport simulations. Existing approaches—such as fast-marching models, rule-based growth, probability-map ensembles, modular simulators, and deep generative graph tools—typically rely on known cave segments, even though these represent only a small portion of the active network. Hydrogeological evidence shows that most flow follows conduits developed along conjugate fracture sets, while mapped conduit segments reflect only the most enlarged pathways. In unconfined aquifers, effective drainage requires spatially coherent conduit patterns, emphasizing the importance of structural density.

The method presented here introduces two innovations: a maze-like network concept instead of a branching hierarchy, and hydrodynamic conditioning based on conduit spacing inferred from hydrograph behaviour. This geometric constraint is essential for reproducing transient hydraulic responses. The workflow includes identifying conductive features, analysing directional families with distribution functions, and estimating spacing from hydrograph data. Conduits aligned with dominant structural directions are fitted using Monte Carlo sampling and least-squares optimization, followed by stochastic generation of cross-conduits using spacing and orientation statistics.

This structural-statistical framework integrates geological realism with hydrodynamic plausibility. It proceeds through three stages: extraction of structural patterns, statistical characterization of orientations and spacings, and stochastic generation of conduit networks conditioned by both geological and hydraulic constraints. It offers a robust basis for simulating realistic conduit architectures in structurally complex karst aquifers.

LID 0939
Co-production of geothermal energy and critical raw materials (CRM)

Tamás Madarász[1]*, János Szanyi[2], Anna Seres[1], Éva Hartai[1], Péter Szűcs[1]

[1] University of Miskolc, Faculty of Earth and Environmental Sciences and Engineering, Miskolc, Hungary
[2] University of Szeged, Department of Mineralogy and Geochemistry, Szeged, Hungary
* tamas.madarasz@uni-miskolc.hu

Keywords: geothermal brines, critical raw materials, co-production

The co-production of critical raw materials (CRMs) and geothermal energy has recently emerged as an innovative concept that can simultaneously support the energy transition and secure access to strategic minerals in Europe. Geothermal fluids circulating in deep reservoirs often contain dissolved elements such as lithium, strontium and rare earth elements, which originate from long-term water–rock interaction at elevated temperatures. When these fluids are produced for geothermal heat or electricity generation, they may also represent a potential source of critical raw materials.

The concept of integrated geothermal energy and metal recovery has been explored in several European Horizon research projects, including CHPM2030, REFLECT and CRM-Geothermal, which demonstrated the scientific feasibility of extracting valuable metals from geothermal brines while utilizing the thermal energy of the same fluids. These initiatives highlighted the importance of combining geothermal reservoir exploitation with innovative extraction technologies and advanced data integration approaches.

One of the outcomes of these projects is the European Fluid Atlas, a pan-European database compiling information on geothermal wells, reservoir properties and the chemical composition of geothermal fluids. Such harmonized datasets provide an important basis for identifying geothermal systems enriched in critical elements and for supporting future exploration and technology development. The most recent project is focusing into the potential resources of the Pannonian basin.

By integrating geothermal energy production with the recovery of dissolved metals, this approach can increase the overall efficiency and economic value of geothermal operations while significantly reducing the environmental footprint compared with conventional mining. As research and technology continue to advance, geothermal-CRM co-production may become an important component of sustainable resource utilization in Europe.

LID 0941
Transboundary aquifer monitoring: Pioneering a critical tool for conjunctive management of shared water

Jonathan Lautze[1*], Girma Ebrahim[2], Moctar Dembele[3]

[1] International Water Management Institute (IWMI), Pretoria, South Africa
[2] IWMI, Addis Ababa, Ethiopia
[3] IWMI, Accra, Ghana
[*] j.lautze@cgiar.org

Keywords: transboundary, aquifer, monitoring, Africa

While the importance of conjunctive management of transboundary waters has gained increasing recognition, practical implementation is not extensive. One major barrier to effective implementation is integrated surface and groundwater data to inform design of management approaches. In shared waters, core parameters on surface water (such as flow volumes) are often collected separately by countries and exchanged; this has improved coordination of surface water management but allowed issues to linger e.g. time-lags on exchanged data, lack of harmonization, data gaps. On groundwater, there is relatively less data collected and it is generally not exchanged. Further, joint monitoring of shared aquifers – collaborative design and installation of a monitoring network in a way that optimally characterizes shared aquifer dynamics – is virtually nonexistent.

The Global Environmental Facility (GEF) financed Groundwater for aDvancing Resilience in Africa (G4DR) project aims to enhance water security and resilience by unlocking the potential of groundwater in Africa. As part of this project, activities on transboundary groundwater monitoring are being undertaken in two basins: the Shire (Malawi, Mozambique) and Mono (Benin, Togo). This presentation will outline the pioneering approaches utilized in these two basins, which have followed stepwise processes centered on: i) collaborative workplan formulation, ii) hydrocensus implementation, iii) monitoring network co-design, iv) collaborative identification of sites for data logger installation, v) joint platform & data sharing protocol development, and vi) data generation and analysis. Key complementary efforts are also undertaken on community engagement in monitoring sites.

While critical risks have been flagged around sustainability, both due to vandalism and seemingly trivial tasks like adding data to sim cards, in addition to limited funds for maintenance post-project, these experiences provide initial examples of a potentially powerful tool to realize conjunctive management of shared waters.

LID 0943

Natural radioactivity in drinking water: Application of environmental tracers and regional groundwater flow analysis in Northwestern Hungary

Reyana Dawn Urbiztondo Garcia[1*], Katalin Hegedűs-Csondor[1], Petra Baják[1,2], Viktor Jobbágy[3], Bálint Izsák[4,5] Ákos Horváth[6], György Czuppon[7], Viktória Kohuth-Ötvös[8], Márta Vargha[4], Mikael Hult[9], Anita Erőss[1]

1 ELTE Eötvös Loránd University, Institute of Geography and Earth Sciences, Department of Geology, József and Erzsébet Tóth Endowed Hydrogeology Chair, Budapest, Hungary
2 Università degli Studi di Milano, Department of Earth Sciences “Ardito Desio” (DiSTAD), 20133 Milan, Italy
3 Social Organization for Radioecological Cleanliness, Veszprém, Hungary
4 Public Health Directorate, National Public Health Institute, Budapest, Hungary
5 Faculty of Health Sciences, Department of Public Health Sciences, Semmelweis University, Budapest, Hungary
6 Eötvös Loránd University, Institute of Physics and Astronomy, Department of Atomic Physics, Budapest, Hungary
7 Institute for Geological and Geochemical Research, Research Centre for Astronomy and Earth Sciences, HUN-REN, Hungary
8 Sopron Waterworks Ltd., Sopron, Hungary
9 European Commission, Joint Research Centre (JRC), Geel, Belgium
* garciareyanadawn@gmail.com

Keywords: drinking water, uranium, flow systems

Groundwater accounts for 92% of drinking water supply in Hungary, making natural radioactivity in aquifers a major concern for drinking water quality. This study investigates the causes of gross alpha activity exceeding the EU parametric value of 0.1 Bq/L in northwestern Hungary using a regional groundwater flow system approach. Geochemical sampling of springs, drinking water wells and thermal wells was carried out in 2021 and 2024. In-situ physicochemical parameters such as pH, redox potential, temperature and electrical conductivity were measured in the field. Laboratory analyses determined concentrations of major ions, trace elements, oxygen and hydrogen stable isotopes ($\delta^{18}O$, $\delta^{2}H$) to characterize recharge sources and groundwater flow dynamics, and activity concentrations of total uranium (^{234}U + ^{238}U), ^{226}Ra, and ^{222}Rn. Pressure–elevation profiles were used to characterize local and regional groundwater flow conditions. In drinking water samples, total uranium activity reached up to 540 mBq/L, which can be linked to the local geogenic sources in the metamorphic outcrops of the Sopron Mountains and adjacent Pannonian sediments. Radionuclide-specific measurements indicated that elevated gross alpha activity in several drinking water wells is primarily due to dissolved uranium under oxidizing conditions in local flow systems and recharge areas. Activity concentrations of ^{226}Ra and ^{222}Rn were generally low, with one sample showing 301 mBq/L of ^{226}Ra and 219 Bq/L of ^{222}Rn. The presence of radium may be attributed to regional flow systems, whereas the high radon activity cannot be explained solely by in-situ decay of radium and warrants further investigation. The results demonstrate that the integration of hydrochemistry, environmental isotopes, and groundwater-flow-system analysis is a powerful tool for understanding the causes of natural radioactivity in groundwater-derived drinking water.

This work has been implemented by the National Multidisciplinary Laboratory for Climate Change (RRF-2.3.1-21-2022-00014) project within the framework of Hungary's National Recovery and Resilience Plan supported by the Recovery and Resilience Facility of the European Union. Furthermore, some radioactivity measurements were supported by the open-access scheme of the European Commission’s Joint Research Centre (JRC) (Research Infrastructure Access Agreement No. 36227-1).

LID 0944
Students' knowledge and attitudes towards groundwater and Nature-Based Managed Aquifer Recharge – Effects of a short educational intervention

Attila Varga[1*], Iván Zsolt Berze[2,1], Álmos Levente Szőcs[3,1], Brigitta Czauner[4], **Ildikó Erhardt**[4], Ádám Zoltán Tóth[5], Judit Mádl-Szőnyi[4]

[1] ELTE Eötvös Loránd University, Institute of People-Environment Transaction, Budapest, Hungary
[2] ELTE Eötvös Loránd University, Doctoral School of Psychology, Budapest, Hungary
[3] ELTE Eötvös Loránd University, Doctoral School of Education, Budapest, Hungary
[4] ELTE József and Erzsébet Tóth Endowed Hydrogeology Chair, Department of Geology, Institute of Geography and Earth Sciences, Eötvös Loránd University, Budapest, Hungary
[5] Utrecht University, Copernicus Institute of Sustainable Development, Utrecht, The Netherlands
* varga.attila@ppk.elte.hu

Keywords: managed aquifer recharge, students' perception, evidence-based educational development

Groundwater constitutes 98% of mobilisable freshwater resources, yet it remains largely invisible in education, leading to persistent misconceptions among students. To address this gap, the ClimEx-PE project developed a short educational intervention combining inquiry-based and direct instructional elements. The 90-minute program includes interactive group activities, a 3-minute educational film, and a structured presentation introducing groundwater flow systems and Nature-Based Managed Aquifer Recharge (NaBa-MAR®).

The intervention aimed to promote a dynamic understanding of groundwater flow by conceptualising recharge, subsurface transport, and discharge as hydraulically connected processes operating at the landscape scale. This modern approach contrasts with static or compartmentalised aquifer models that are still common in education.

A pre-test–post-test design was implemented with 174 secondary school and university students in Hungary to assess the impact of the intervention on students' knowledge, their support for adaptation to extreme hydrological events, and their attitudes towards NaBa-MAR®. According to the repeated measures analysis results, the levels of all three constructs were significantly higher after the educational intervention. The effect was greatest on knowledge while support and attitudes also increased significantly.

The study provides empirical evidence for the effectiveness of a short educational intervention related to groundwater and NaBa-MAR®. The results corroborate previous findings in environmental and sustainability education, showing that knowledge is the component of groundwater-related awareness most readily influenced. Even a short, easy-to-implement intervention was able to improve participants' attitudes and support. Though only short-term effects were yet measured, these findings provide an evidence base for refining the ClimEx-PE learning materials and for their potential wider application in European educational contexts.

The research was financed by Project no. 2023-1.2.2-HE_PARTNERSÉG-2023-00005, implemented with the support of the Ministry of Culture and Innovation of Hungary from the National Research, Development and Innovation Fund, financed under the 2023-1.2.2-HE_PARTNERSÉG funding scheme. The project received funding from multiple national funding agencies within the frame of the collaborative international consortium ClimEx-PE financed under the 2022 Joint call of the European Partnership 101060874 — Water4All.

LID 0946
Predictive modeling of groundwater levels using machine learning: Case study of the Berrechid aquifer (Morocco)

Naïma El Assaoui[1]*, Sylvius Rodrigue Nitiema[1], Assia El Kabouss[1], Hiba Anaiber[1], Oumaima Ouahine[1], Omar Chafki[2], Rachida Lyazidi[3]

[1] Laboratory LG2E, Department of Geology, Faculty of Sciences, Mohammed V University in Rabat, Morocco
[2] Bouregreg and Chaouia Hydraulic Basin Agency (ABHBC), Benslimane, Morocco
[3] Direction of Water Research and Planning (DRPE), Rabat, Morocco
* nelassaoui@gmail.com

Keywords: hydrogeology, machine learning, remote sensing, Morocco

The Berrechid aquifer, a vital water resource for the Chaouia plain in Morocco, faces unprecedented pressure due to intensive agricultural exploitation and recurrent drought cycles. Traditional piezometric monitoring often lacks the spatiotemporal density required for real-time management. This study proposes an integrated approach using Machine Learning to enhance groundwater level prediction. A hybrid dataset was constructed by integrating 15 years of monthly piezometric records with satellite-derived variables. We utilized Sentinel-2 and Landsat 8/9 to extract vegetation indices (NDVI) and Land Surface Temperature (LST) as proxies for agricultural water demand. Climate stressors were accounted for using standardized precipitation anomalies from GPM (Global Precipitation Measurement). A Random Forest (RF) regressor was implemented to model the non-linear relationship between surface stressors and water table drawdown.

The RF model demonstrated high predictive accuracy ($R^2 > 0.85$), identifying LST and agricultural seasonality as the primary drivers of aquifer depletion. Spatial mapping reveals critical cones of depression in the central Berrechid plain, where the gap between recharge and extraction is most pronounced.

The results highlight the effectiveness of integrating satellite-derived proxies into traditional hydrogeological frameworks. This study provides a scalable methodological flowchart for groundwater monitoring in semi-arid regions. The findings offer a decision-support tool for the Association of Hydrogeologists and local water authorities to implement sustainable management strategies in the Berrechid basin.

LID 0947

The dynamic link between economic development and freshwater withdrawal: A global decomposition for country income groups and economic sectors

Joseph Igbinedion[1]*, Ferenc Gyuris[2]

[1] ELTE Eötvös Loránd University, Doctoral School of Environmental Science, Institute of Geography and Earth Sciences, Department of Social and Economic Geography, Budapest, Hungary
[2] ELTE Eötvös Loránd University, Institute of Geography and Earth Sciences, Department of Social and Economic Geography, Budapest, Hungary
* joigbinedion@student.elte.hu

Keywords: Annual Freshwater Withdrawal (AFW), sectoral water, per capita AFW, per capita GDP, population, Environmental Kuznets Curve

The recent global trajectories of freshwater demand shaped by agriculture, industry, and the domestic sector, have influenced water-stress patterns in complex ways. In this study, we analyze global total and per capita annual freshwater withdrawals by country income groups and sectors, and conduct comprehensive cross-sectional analyses to examine the relationship between economic development (GDP per capita) and per capita AFW in 4 different country income groups, in 3 different sectors (agricultural, industrial, domestic), and in all 12 combinations of the two factors. The results reveal that these 3x4 groups do not follow identical trajectories but rather distinct ones, highlighting the need for diverse and combination-specific analytical frameworks and policy measures rather than generalized solutions. In academic terms, our findings will also confirm the relevance of the Environmental Kuznets Curve (EKC), a popular yet contested concept in the study of the relationship between economic development and environmental stress, from certain perspectives. However, we will present that EKC is not a uniform, deterministic concept with universal relevance, but rather a potentially valuable conceptual aid that requires careful, context-specific application to better reveal and understand dynamically changing patterns in the relationship between economic development and freshwater withdrawal. As the results will show, especially low-income countries' share of global freshwater withdrawal may multiply in the future, particularly in the agricultural sector, which means measures focused in geographical and sectoral terms are required to avoid a rapid increase in global AFW.

LID 0951
Impacts of sluice regulation on nitrogen fate in riparian groundwater-surface water systems

Baoling Li[1]*

[1] College of Geographical Sciences, Faculty of Geographical Science and Engineering, Henan University, Zhengzhou, China
* libaoling15@mails.ucas.ac.cn

Keywords: groundwater-surface water, nitrogen isotopes, nitrate fate

Sluice regulation alters hydrological connectivity and biogeochemical processes in riparian groundwater-surface water (GW-SW) systems, yet its integrated impacts on nitrate fate remain poorly understood, especially in regulated rivers. This study focuses on the nitrogen-polluted Shaying River, a typical sluice-controlled watercourse in China, and combines two years monitoring to elucidate how sluice operations shape GW-SW interactions and nitrate dynamics in riparian zones. We characterized GW-SW exchange qualitatively and quantitatively using hydrological, hydrochemical, isotopic ($\delta^{18}O$, δD, ^{222}Rn, $\delta^{15}N\text{-}NO_3^-$, $\delta^{18}O\text{-}NO_3^-$) and microbial community data, and quantified nitrate sources and transformations via nitrate functional gene analysis and the MixSIAR Bayesian mixing model. Results showed that sluice regulation drives seasonal GW-SW interaction patterns: flood-season sluice opening lowers river levels, triggering riparian groundwater discharge to the river, while sluice closure elevates river levels, enhancing river water infiltration into riparian aquifers. These hydrological shifts directly control nitrate fate: manure and sewage were identified as the dominant nitrate sources (66.20–91.20%) in both river and riparian groundwater, with sluice operations mediating nitrate transport, mixing, and removal. Nitrate stored in river water is diluted or removed by mixing with groundwater and rainwater during flood seasons, and nitrate removal efficiency increases with longer residence time of infiltrated river water in riparian aquifers. We further developed a conceptual model illustrating the complex interplay between sluice regulation, hydrological connectivity, and biogeochemical processes governing nitrogen dynamics. This work advances the mechanistic understanding of nitrogen fate in sluice-controlled riparian systems, providing critical scientific support for sustainable water resource management and nitrogen pollution mitigation in regulated river basins globally.

LID 0952
Integrated water balance modeling – Sustainable and climate-adapted water management in the Borken water catchment area

Philipp Huttner[1]*, Zoltan Trabak[2], Maximilian Winderl[1], Zdenek Hosek[3]

[1] DHI WASY GmbH, Munich, Germany
[2] DHI Hungary Kft., Budapest, Hungary
[3] DHI a.s., Prague, Czech Republic
* phhu@dhigroup.com

Keywords: groundwater, agriculture, sustainability

The Borken region in northern Germany faces growing water challenges due to climate change and increasing water demand. Prolonged summer droughts and extreme storm events are becoming more frequent, raising concerns about water scarcity and flood risks. These changes impact stakeholders such as farmers, drinking water suppliers, and industries, who are concerned about reductions in water use permits. Addressing these challenges requires a holistic water management strategy. Therefore, an integrated water balance model was developed to support regional planning, with plans to evolve it into an operational system for real-time monitoring and management.

The hydrological model is based on MIKE SHE, enabling high-resolution temporal and spatial simulations and integrating all components of the hydrological cycle. It includes a three-dimensional groundwater flow module, providing insights into subsurface hydrodynamics. The unsaturated zone is modeled with high precision, accounting for soil properties, moisture, and evapotranspiration, which is essential for predicting impacts of climate and land-use changes on groundwater recharge.

Overland flow processes are included to simulate surface runoff during storm events, and the model is coupled with a 1D river model based on MIKE+, ensuring exchange between aquifer and surface water. Anthropogenic factors such as groundwater extractions, irrigation, drainage systems, and hydraulic structures are also incorporated.

Unlike conventional models focusing mainly on groundwater or surface water, this integrated approach simulates all hydrological processes in detail. The model is calibrated against groundwater levels and river discharge. It enables accurate simulation of groundwater levels, discharge peaks, and a closed water balance, improving predictive quality.

The model is already used to assess retention measures, supporting stakeholders in decision-making and climate adaptation.

LID 0954
High resolution modelling of groundwater recharge with MIKE SHE

Philipp Huttner[1]*, Zoltan Trabak[2], Maximilian Winderl[1]

[1] DHI WASY GmbH, Munich, Germany
[2] DHI Hungary Kft., Budapest, Hungary
* phhu@dhigroup.com

Keywords: groundwater, recharge, sustainability

Due to climate change, available water resources are decreasing in many regions of the world. To provide spatially and temporally differentiated assessments of water availability, both the requirements and the data basis for future water rights allocation must be adapted. The current approach for determining groundwater recharge relies on soil water balance models or rainfall–runoff models at the national or federal state level. These models are based on a soil storage approach and separate runoff into direct runoff, interflow, and baseflow.

Most of the soil water balance models currently applied in Europe neglect temporally varying groundwater levels as well as changing dynamics and variability caused by climate change. They are typically calibrated only against discharge data of main rivers. Groundwater monitoring data, local flow conditions, and groundwater–surface water interactions are not considered in the calibration.

In the context of climate change, these approaches are no longer sufficient to provide reliable estimates of groundwater availability. New methods have repeatedly been called for that can represent the influence of long-term declining or changing groundwater levels.

One of the most reliable modern methods for determining groundwater recharge is the use of integrated water balance models such as MIKE SHE. These models represent all processes of the hydrological cycle within a single framework and calculate them based on physical laws. In contrast to conventional approaches, the exchange between the unsaturated and saturated zones—and thus the groundwater response to recharge—is explicitly included in both simulation and calibration.

LID 0956
Toward transboundary groundwater cooperation: Developing a groundwater strategy for the Cubango-Okavango River Basin (CORB)

Lizanne Smit[1], **Dale Barrow**[1]*, Simon Johnson[2], Joanne Crimes[2], Derek Weston[2]

[1] GEOSS South Africa, Stellenbosch, South Africa
[2] Pegasys, Cape Town, South Africa
* dbarrow@geoss.co.za

Keywords: Transboundary aquifers, groundwater governance, conjunctive water use, Cubango-Okavango River Basin, groundwater strategy, SADC-GMI, OKACOM, groundwater–surface water interactions

Conjunctive use of water resources often develops as a pragmatic response to supply constraints, particularly in transboundary basins. In the Permanent Okavango River Basin Water Commission (OKACOM), significant progress has already been made in fostering cooperative water resource management through established basin-wide institutional frameworks. Historically, these efforts have largely focused on surface water systems, with comparatively limited integration of groundwater into basin-scale planning and decision-making.

At the same time, groundwater use across the basin is increasing, often in a decentralised manner. This presents both a challenge and an opportunity: while spontaneous conjunctive use can enhance water security, its benefits are not fully realised without structured integration into existing governance frameworks.

Importantly, OKACOM's strategic direction already recognises the need for a more inclusive and integrated approach. The groundwater strategy proposes a number of key interventions, including basin-wide hydro-census studies, targeted groundwater knowledge dissemination, contamination awareness campaigns, and the deliberate inclusion of local communities and marginalised groups. While these initiatives are not yet fully implemented and will require substantial funding and institutional support, they provide a clear and structured pathway towards strengthening both the technical and social dimensions of water resource management.

This contribution therefore explores how these proposed interventions can support the progressive incorporation of groundwater into conjunctive management approaches. Emphasis is placed on aligning monitoring systems, integrating surface and groundwater data, and enabling cooperative, socially inclusive decision-making across member states. In this context, technical integration is intrinsically linked to improved stakeholder engagement and capacity development. By building on these proposals, existing 'lost opportunities' can be transformed into coordinated, basin-wide water security strategies.

LID 0958
Incremental drawdown-based interpretation of pumping tests: Implications for spatio-temporal variability and parameter uncertainty

Ion Pasarica[1]*

[1] Romanian Hydrogeologists Association, Bucharest, Romania
* ipasarica@yahoo.com

This study presents a drawdown-based incremental framework for the interpretation of pumping tests, formulated as a state-space extension of the classical Theis solution. By inverting the conventional relationship s=f(r,t)s = f(r,t)s=f(r,t) into t=f(s)t = f(s)t=f(s), the proposed approach enables the analysis of aquifer response as a sequence of hydraulic states defined by constant drawdown increments.

Within this framework, transmissivity and hydraulic diffusivity are estimated as dynamic, scale-dependent parameters that evolve during the expansion of the cone of depression. This formulation reveals a structured spatio-temporal variability of hydraulic properties, which is typically represented as parameter uncertainty in conventional groundwater modelling.

Application to a reference dataset highlights systematic variations in transmissivity and diffusivity with drawdown, indicating heterogeneous and anisotropic conditions. The ratio Δt/t, used as the primary diagnostic parameter, provides increased sensitivity to flow regime transitions and is shown to be consistent with the Bourdet logarithmic derivative.

The results suggest that the proposed method offers an alternative perspective for parameter estimation, in which apparent uncertainty is reinterpreted as a physically meaningful expression of spatial variability and scale-dependent aquifer behavior. This approach may contribute to improved conceptualization and calibration of groundwater flow models under heterogeneous conditions.

LID 0959
Remote sensing-based modelling of lake-groundwater interactions in a data-scarce tropical floodplain system

Thijs De Klein[1*], Victor Bense[1], Syed Mustafa[1], Albrecht Weerts[1,2]

[1] Wageningen University, Wageningen, The Netherlands
[2] Deltares, Delft, The Netherlands
* thijs.deklein@wur.nl

Keywords: coupled surface-groundwater modelling, remote sensing, MODFLOW-6, lake-floodplain systems, data-scarce regions

Changing climate and land use patterns can have a devastating impact on water availability and ecosystems connected to tropical lake-floodplain system. As lake-floodplain systems are often both surface- and groundwater dependent, a coupled surface-groundwater model is usually applied to quantify the hydrological effect of these changes. The setup, calibration and validation of such models in data-scarce regions is challenging as it requires sufficient knowledge of a region's hydrology, which is often unavailable for tropical lake-floodplain systems.

In this study, we develop a coupled groundwater-surface water model for Lake Urema, which is located in Gorongosa National Park in Mozambique. A MODFLOW-6 model is developed to simulate groundwater fluxes and the interaction between the lake and shallow groundwater. For recharge and tributary inflow into the lake, a one-way coupling to the wflow_sbm model is applied. Historical lake extent data based on Remote Sensing imagery is combined with topographical data to construct a lake volume timeseries, which is used for model calibration and validation.

Initial results show that the one-way coupled model performs reasonably well against Remote Sensing-based lake volumes for the period 2015-2024 (Nash-Sutcliffe Efficiency = 0.51, R^2 = 0.54). The seasonal variability is well captured with lake volume peaking 1-2 months after the peak in precipitation, mimicking the buffering effect of the lake-floodplain system. The modelled interaction between the lake and shallow groundwater shows a net influx during the dry season, confirming the hypothesis that the lake is groundwater-fed during that season. Although further calibration of model parameters to measured discharges and improvement of the modelled interaction between the lake-floodplain system and shallow groundwater is still necessary, this study shows the potential of applying a coupled wflow-MODFLOW model calibrated to Remote Sensing data in similar data-scarce regions.

LID 0962
Fault-controlled recharge zones and geophysical methodologies for groundwater sustainability in Ethiopia's Rift Valley

Biruk Eremacho[1]*, Yontan Garkebo[2]

[1] Addis Ababa University, Addis Ababa, Ethiopia
[2] Adama Science and Technology University, Adama, Ethiopia
* birukwolde57@gmail.com

Groundwater sustainability in Ethiopia's Rift Valley is governed by fault-controlled recharge processes and complex subsurface heterogeneity. To address these challenges, this study employed an integrated geophysical methodology combining resistivity imaging, seismic refraction, and gravity surveys with hydrogeological modeling. The methodology enabled precise delineation of aquifer geometry, identification of fault-related recharge pathways, and assessment of aquifer vulnerability. Results from case studies in central and northern Ethiopia demonstrate that major fault systems act as preferential recharge conduits, enhancing infiltration and aquifer connectivity. Resistivity imaging revealed zones of high permeability along fault lines, seismic surveys confirmed fractured basement structures, and gravity data constrained aquifer thickness and geometry. Hydrogeological modeling validated these findings, showing improved recharge estimates and reduced uncertainty in groundwater–surface water interactions. By presenting reproducible methodologies and clear results, this research situates Ethiopia's Rift Valley as a model for understanding fault–aquifer dynamics in tectonically active regions. The outcomes contribute to evidence-based strategies for water security, climate resilience, and sustainable resource governance across Africa.

LID 0963
On understanding the role of uncertainty behind 3D geological structural models towards better groundwater modelling predictions

Carlos Andres Rivera Villarreyes[1]*

[1] DHI, Am Studio 26, Berlin, Germany
* cvi@dhigroup.com

Keywords: uncertainty quantification, FEFLOW, groundwater modelling

Significant work has been carried out in the last decade to quantify the uncertainty of the model predictions in the groundwater field. The uncertainty quantification is typically focused on parameter variability. However, today's industry practice still assumes a strong link between the groundwater model and one single 3D geological structural model. The fundamental reason of such limitation is that the current modelling technology does not allow us to iterate programmatically between a 3D geological model and 3D groundwater numerical model, or vice-versa without passing a tedious workflow of reconstructing both models entirely. Some attends have been done to overcome this limitation; however, the studies are purely based on simple geometries (box-like domains) and cannot be applicable to complex 3D geological settings.

The current study presents on-going research, which facilitates the bridge between 3D structural geology and 3D groundwater modelling. Common 3D geological tools (open-source and/or commercial) are based on implicit modelling techniques such as radial basis functions, co-kriging, etc. DHI has been working extensively in the last years to close the gap between implicit modelling, 3D meshing and parametrization. The goal is to have all together within one single workflow from geological boreholes up to an entire 3D groundwater model. The implicit modelling is based on typical geological information such as boreholes, stratigraphical stack and/or fault constraints. Results of the implication are the 3D geological contacts within the user-defined domain. Geological contacts are passed forward to FEFLOW's meshing algorithm to create a finite-element mesh acknowledging the geological constraints. The workflow is scriptable through Python and allows the user to combine existing open-source packages for uncertainty quantification such as PEST++. In this work, the new methodology is presented and tested against typical groundwater applications.

LID 0964
Understanding the feasibility of Aquifer Thermal Energy Storage using numerical simulations

Carlos Andres Rivera Villarreyes[1]*

[1] DHI, Am Studio 26, Berlin, Germany
* cvi@dhigroup.com

Keywords: Geothermal modelling, ATES, energy storage

The challenge of promoting the application of renewable energy is the seasonal mismatch between the thermal energy supply and demand. To resolve this issue, the technology of thermal energy storage (TES) has been introduced to balance the mismatch, to achieve the efficient usage of renewable energy, and to realize waste heat/cold recovery. The selection of an appropriate storage method depends on several factors such as storage capacity, storage duration, and supply and demand temperature. Underground Thermal Energy Storage (UTES) is a sensible TES method, characterized by high storage efficiencies and high storage capacities and is therefore the preferred choice for long-term TES. UTES can be further subdivided into open-loop or closed-loop systems. In open-loop systems, also referred to as Aquifer Thermal Energy Storage (ATES), sensible heat and cold is temporarily stored in the subsurface through injection and withdrawal of groundwater.

In the present study, we focus on the understanding of performance and efficient of the ATES system via numerical simulations. The finite-element simulator FEFLOW is used to model the subsurface flow and heat transport conditions. The typical operations of ATES system usually contain two stages: a summer stage and a winter stage. Multiple scenarios combined with operation cycles (injection, storage, abstraction) were tested with FEFLOW to evaluate the efficiency and the subsurface thermal impact of the ATES system. Here, we present our most recent simulation results.

LID 0965
Implications of blue-green infrastructure for enhancing groundwater quantity and quality in urban areas: Benefits and constraints

Majid Taie Semiromi[1]*, Traugott Scheytt[2], Eva Paton[1]

[1] Institute of Ecology, Technical University of Berlin, Berlin, Germany
[2] Institute of Geology, Technische Universität Bergakademie Freiberg, Freiberg, Germany
* m.taie.semiromi@tu-berlin.de

Keywords: blue-green infrastructure, groundwater recharge, urban hydrology, water quality, climate adaptation

Urbanization alters natural hydrological processes by increasing impervious surfaces, reducing infiltration, and degrading groundwater quality. Blue-Green Infrastructure (BGI) has emerged as a promising nature-based solution to restore hydrological functions in urban systems. This study synthesizes global evidence on the effectiveness of BGI in enhancing groundwater quantity and quality, with a focus on underlying hydrological mechanisms and context-specific constraints.

BGI elements such as green roofs, permeable pavements, bioswales, and urban wetlands promote infiltration and reduce surface runoff, thereby increasing groundwater recharge. Reported recharge enhancements vary widely (5–30% of annual precipitation), depending on soil properties, design characteristics, and climatic conditions. Additionally, BGI systems facilitate pollutant attenuation through filtration, adsorption, and biogeochemical processes, leading to reductions in nutrient loads (e.g., 20–70% for nitrogen species) and suspended solids.

However, the effectiveness of BGI is constrained by site-specific factors, including soil permeability, groundwater depth, contamination risks, and maintenance requirements. In densely urbanized areas, limited space and potential for pollutant mobilization (e.g., heavy metals, hydrocarbons) may offset recharge benefits. Climate variability influences system performance, particularly under extreme rainfall events and prolonged droughts and conflicting interests (evaporation as means of cooling) may further constrain the application.

This review highlights the dual role of BGI in enhancing groundwater sustainability and urban climate resilience, while emphasizing the need for integrated design approaches that consider hydrogeological conditions, pollutant pathways, and long-term system performance. Future research should focus on coupling physically based models with field observations to quantify trade-offs and optimize BGI implementation at multiple spatial scales.

LID 0967
Integrated groundwater flow and reactive transport modelling for climate change adaptation: Results from the NINFA project

Marco Petitta[1]*, Sathish Sadhasivam[1], Mariachiara Caschetto[2] Valeria Lorenzi[1], Annarita Basso[1]

[1] Earth Sciences Department, Sapienza University of Rome, Rome, Italy
[2] Department of Civil and Environmental Engineering, Politecnico di Milano, Milano, Italy
* marco.petitta@uniroma1.it

Keywords: groundwater modelling, nitrate contamination, climate change, EU funded project

The European project NINFA, funded under Horizon Europe, aims to develop integrated strategies for preventing and mitigating groundwater pollution, with particular focus on diffuse nitrate contamination and salinity. The project combines advanced monitoring, real-time sensing systems, chemical and bioanalytical analyses, treatment technologies, and numerical modelling, integrating all results into a Decision Support System to support sustainable groundwater management.

Within this framework, the present contribution focuses on the results derived from groundwater flow and transport modelling activities, which represent a key tool for understanding contaminant dynamics and supporting future management strategies. These models were implemented in two representative case studies: CS1, located in the Achterhoek region (The Netherlands), and CS2, in the Campo de Cartagena aquifer system (Spain). In CS1, characterized by intensive agriculture and strong groundwater–surface water interactions, the model simulates nitrate transport under drought conditions and reduced nitrogen loading scenarios, highlighting the role of recharge variability and agricultural pressure on groundwater quality. In CS2, a semi-arid Mediterranean system hydraulically connected to the Mar Menor lagoon, modelling focuses on nitrate persistence, salinization processes, and nutrient fluxes toward the coastal lagoon, emphasizing the long-term effects of intensive irrigation and fertilizer application.

The calibrated models allow the identification of the main hydrogeological and biogeochemical processes controlling contaminant transport and attenuation, supporting the evaluation of future scenarios under different climatic and management conditions. These modelling tools represent effective predictive instruments for assessing groundwater vulnerability, planning mitigation strategies, and supporting adaptive water management policies in the context of current and future climate change.

LID 0969
“WELLth Kraków! © – Where security flows from nature”

Nikola Rystwej[1]*, Emilia Ząbek[1], Kajetan Góra[1], Bernard Szlęk[1]

[1] AGH University of Krakow, Faculty of Geology, Geophysics and Environmental Protection, Kraków, Poland
* nrystwej@student.agh.edu.pl

Keywords: groundwater, urban water security, emergency water supply, hydrogeology, water quality assessment, GIS, mobile application, urban resilience, environmental monitoring, Kraków

The scientific project “WELLth Kraków! © - Where security flows from nature” responds to the growing need to strengthen the resilience and security of residents in large European cities, particularly in the context of armed conflicts, hybrid threats, and cyberattacks on critical infrastructure. During military incidents, crises, or even planned power outages, many urban water supply systems may cease to operate, while emergency water deliveries by tanker trucks are often insufficient to meet the needs of large populations.

WELLth Kraków! is a pioneering, freely accessible mobile application designed for the residents of Kraków. Using GPS technology, the application identifies the nearest available groundwater intake point and provides users with clear information about water quality and usability. The system introduces a transparent seven-class classification of water suitability, allowing residents to quickly understand whether the water can be used for drinking, household purposes, or emergency supply.

Groundwater in Kraków occurs within two main hydrodynamic and hydrochemical zones. The upper zone of active groundwater exchange is associated primarily with Quaternary deposits as well as shallow Cretaceous and Jurassic formations. The pilot phase of the WELLth project, conducted in the Krowodrza district of Kraków, documented 23 wells, with 10 of them containing Quaternary groundwater. These waters are slightly alkaline Ca-HCO_3 type waters with an average mineralization of approximately 900 mg/L. Their potential use may be locally limited by elevated concentrations of certain elements, most commonly iron (up to 5.16 mg/L) and manganese (0.91 mg/L), as well as selenium (0.02 mg/L) and zinc (1.5 mg/L).

By integrating applied hydrogeology, environmental monitoring, and modern digital technologies, the WELLth project creates a unique bridge between scientific research and practical urban safety solutions. The initiative demonstrates how groundwater resources, often overlooked in modern cities, can become a strategic element of urban resilience, environmental awareness, and crisis preparedness in 21st-century Europe.

LID 0970
ENSO-driven global teleconnections of terrestrial water storage anomalies

Jiawen Yang[1]*, Yun Pan[1], Chong Zhang[1], Yuchi Wang[1]

[1] College of Resources Environment and Tourism, Capital Normal University, Beijing, China
* yangjwonline@163.com

Keywords: terrestrial water storage, teleconnections, ENSO

Although global climate change has intensified fluctuations in the terrestrial water cycle, a systematic quantitative understanding of the organization and propagation mechanisms of cross-regional hydrological anomalies at the global scale remains lacking. Using reconstructed GRACE terrestrial water storage (TWS) anomaly data from 1980 to 2019, this study constructs a global directed and weighted complex network of TWS changes that accounts for time-lag effects. The results indicate that anomalies in global TWS—particularly in large-scale groundwater and soil moisture storage regions—are not merely local responses, but rather propagate globally through a complex, time-lagged teleconnection network. We identified eight significant TWS teleconnection propagation pathways, four of which transmit hydrological anomaly signals across oceans to Southern Africa, revealing its critical role as a “super sink” for global water cycle anomalies. Lead-lag regression analysis further confirms that this spatial teleconnection network pattern is predominantly driven by the El Niño-Southern Oscillation (ENSO). By modulating tropical sea surface temperature anomalies and global atmospheric circulation, ENSO progressively triggers precipitation and recharge anomalies in both source and sink regions over a lag period of several months. This study breaks beyond the traditional local hydrological response paradigm, revealing the spatial connectivity structure and dynamic mechanisms of TWS fluctuations at the global scale. It provides a novel dynamical perspective for the coordinated management of cross-regional water resources and the understanding of global water cycle mechanisms under climate change.

LID 0972
Potentially toxic elements in groundwater of Southern Honduras and its potential relevance for chronic kidney disease

Isabel Margarida Antunes[1]*, Teresa Valente[1], Fátima Patrícia Gomes[1], Tania María Peña Paz[2], Josseline Faviola Núñez[2], Marcio Chirinos[2], Marta López[3], Luis Montenegro[4], Acacia Naves[4]

[1] ICT | University of Minho, School of Sciences, Braga, Portugal
[2] National Autonomous University of Honduras, Honduran Institute of Earth Sciences (IHCIT), Faculty of Sciences, Tegucigalpa, Honduras
[3] University of Santiago de Compostela, Faculty of Veterinary Medicine, iTERRA Research Institute, Lugo, Spain
[4] University of A Coruña, CICA Research Centre, A Coruña, Spain
* imantunes@dct.uminho.pt

Keywords: groundwater contamination, cadmium exposure, one health

Chronic Kidney Disease (CKDu) of non-traditional origin is a major public health problem in several regions of Central America, particularly along the Pacific corridor. In southern Honduras, especially in the departments of Valle and Choluteca, health authorities have documented a high prevalence of CKDu, placing increasing pressure on dialysis services. Although the disease has a multifactorial etiology, chronic exposure to environmental contaminants, namely Potentially Toxic Elements (PTE) in drinking water, has been identified as a plausible contributing factor in groundwater dependent rural communities.

The CADMIO project investigates the occurrence, distribution, sources and mobility of PTE in groundwater systems of southern Honduras, with particular focus on cadmium, while also explores their potential transfer along the trophic chain. The study adopts an integrated approach combining hydrogeology, environmental geochemistry and biomonitoring, framed within a One Health perspective and developed in close collaboration with Honduran academic institutions, health authorities and local communities.

Fieldwork conducted in February 2026 included groundwater and surface water sampling from drinking water sources, headwater areas and agricultural zones in two communities with high incidence of CKDu, and one control community. Complementary sampling of soils, rocks, crops and livestock products was performed to evaluate potential sources of contamination and pathways of transfer to the trophic chain. Water physic-chemical parameters were determined in situ, while PTE analyses are currently in progress using atomic absorption spectroscopy and inductively coupled plasma mass spectrometry.

The integrated dataset generated by the project will allow the evaluation of hydrogeochemical controls on PTE mobilisation, including lithology, redox conditions, agricultural practices and aquifer dynamics under prolonged drought conditions. CADMIO will provide the first systematic evidence base to support groundwater protection, water resources management and public health decision making in vulnerable areas of southern Honduras.

This project has been funded by the 2025 Research for Development call of the Xunta de Galicia (PR815A/2025/26) and complements ongoing initiatives in southern Honduras promoted by the NASMAR Mancomunidad, CODDEFFAGOLF and Enxeñería Sen Fronteiras Galicia. The principal investigator also acknowledges support from the Xunta de Galicia through the GRC Consolidation Project (ED431C 2025/55). The authors thank the Honduran Ministry of Health, UNAH, INHGEOMIN, CESCCO, the CDM laboratories of Nacaome and the Research Support Services of the University of A Coruña for their institutional and technical support. Special thanks are extended to local communities and all Honduran participants whose collaboration and commitment made this work possible.

LID 0975
Real-time groundwater monitoring and early warning systems for municipal decision-making in Estonia and Latvia

Magdaleena Männik[1]*, Liina Hints[1], Inga Retike[1], Jānis Bikše[1], Mārcis Tirums[1], Dace Zandersone[1], Enn Karro[1]

[1] University of Tartu, Tartu, Estonia
* magdaleena.mannik@ut.ee

Climate change is increasing the frequency and intensity of extreme events such as droughts and floods, while pollution continues to place additional pressure on groundwater resources across Europe. In Estonia and Latvia, groundwater is a critical resource, sustaining ecosystems and providing the main source of drinking water. Despite this, groundwater management is often reactive, as existing monitoring systems rely on delayed data collection and manual analysis. As a result, municipalities frequently respond to problems only after they have escalated.

The HydroScope project (Interreg Estonia–Latvia) addresses this gap by developing a real-time groundwater monitoring and early warning system in two pilot municipalities: Saaremaa (Estonia) and Dienvidkurzeme (Latvia). The project introduces telemetry-based monitoring wells and digital spring systems, enabling continuous observation of groundwater quantity and quality.

Real-time data are processed using automated methods, including machine learning approaches for pattern detection and short-term forecasting. The results are integrated into user-oriented early warning platforms that provide clear visualisations, indicators, and recommendations to support timely decision-making by municipalities and other stakeholders. The project demonstrates how groundwater monitoring can evolve from periodic reporting into a practical tool for proactive and evidence-based water management.

The ‘HydroScope’ project is a first step toward establishing a real-time groundwater monitoring paradigm in Estonia and Latvia, and toward making that real-time data directly usable for local decision-making, thus supporting sustainable and proactive groundwater management practices.

The project HydroScope (EE-LV00250) is funded by the European Union through the European Regional Development Fund (ERDF) within the Interreg VI-A Estonia–Latvia Programme 2021–2027.

LID 0976
Occurrence and preliminary patterns of PFAS in groundwater of Latvia based on national monitoring data

Jānis Bikše[1]*, Inga Retike[1]

[1] Universiy of Latvia, Faculty of Science and Technology, Riga, Latvia
* janis.bikse@lu.lv

Keywords: PFAS, groundwater monitoring, vulnerability

Per- and polyfluoroalkyl substances (PFAS) are persistent contaminants of growing concern because of their mobility, resistance to degradation, and potential risks to human health and ecosystems. Groundwater may be especially vulnerable where recharge areas are influenced by urban land use, industry, waste sites, or surface water interactions. National-scale evidence remains limited in many parts of Northern and Eastern Europe.

This study presents a screening of PFAS occurrence in Latvian groundwater using national monitoring data from 2021 to 2025. The dataset includes measurements from 45 wells and springs, covering 337 sampling events and 17 PFAS compounds. PFAS were detected above reporting limits in 245 samples (5.4%), while 36 of the 45 monitored sites had at least one detection.

Preliminary results show spatially uneven occurrence, with higher detection frequencies and more diverse PFAS mixtures mainly at sites within or near urban areas. PFOA and PFBA were the most frequently detected compounds and were often the only PFAS present at individual sites. In contrast, several wells and springs contained more complex mixtures, with up to ten compounds detected, indicating multiple sources or more efficient transport pathways. Summed PFAS concentrations also varied markedly among locations.

These initial findings suggest that both anthropogenic pressures and hydrogeological factors influence PFAS occurrence in Latvian groundwater. Further analyses will assess links with land use intensity, well depth, aquifer type, and connectivity to surface waters. The study provides a first overview of PFAS in Latvian groundwater and supports future risk-based monitoring in the Baltic region.

The study is supported by the project “AQUAPFAS – Assessing Quality and Understanding PFAS in Water Systems (00185/2025)”, funded by the SI Baltic Sea Neighbourhood Programme 2025.

LID 0978
Developing Australia's national geological framework for a 3D groundwater systems atlas

Caleb Bishop[1]*, Nadege Rollet[1], Catherine Norton[2], Carey Hannaford[3], John Vizy[1], Penny Kilgour[1], Steven Lewis[1]

[1] Geoscience Australia, Canberra, Australia
[2] Catherine Norton, Adelaide, Australia
[3] MGPalaeo, Adelaide, Australia
* caleb.bishop@ga.gov.au

Keywords: chronostratigraphy, hydrostratigraphy, sedimentary basin, national-scale groundwater systems, 3D model

Geoscience Australia has developed a preliminary national-scale 3D geological model to enhance understanding of Australia’s groundwater systems. Driven by Geoscience Australia’s Resourcing Australia’s Prosperity initiative, this chronostratigraphic model integrates key geological and groundwater datasets to depict the distribution, depth, thickness, and characteristics of aquifers and aquitards within layered geological formations through time, improving understanding of groundwater connectivity both within stratigraphy and with surface features such as springs and groundwater-dependent ecosystems.

Geoscience Australia has adopted a chronostratigraphic framework that anchors 3D stratigraphic surfaces to geologic time rather than lithology, standardising stratigraphic nomenclature and aligning geoscientific and hydrological datasets to enable nationally consistent data integration through multi-agency collaboration. The model integrates national data from 53 sources and over 171,000 drillholes, along with legacy and new geophysical data, including airborne electromagnetic and seismic interpretations. It includes depth surfaces for eight geological time slices, extending from the surface to the crystalline basement. These typically correlate to the base of geological Eras and some geological Periods, however ongoing refinement has produced several higher resolution chronostratigraphic surfaces within basins that may be correlated across adjacent basins, improving model resolution.

Geoscience Australia’s national chronostratigraphic model lays the groundwork for the development of a 3D groundwater systems atlas, fostering a collective understanding that provides new insights into geological basin architecture, aquifer connectivity, and groundwater flow. Collaborative national hydrogeological integration between government agencies, academia, industry and the community will support decision-making on water use, environmental policies, and resource development for Australia’s long-term water sustainability.

LID 0979
Understanding the impact of groundwater abstraction in urban city Karachi Pakistan

Yasmin Raza[1]*

[1] Geological Survey of Pakistan, Pakistan
* yasminraza27@gmail.com

Pakistan accounts for over 9% of global groundwater withdrawals, making it the world's third largest user. However, with minimal or no replenishment of aquifers, groundwater reserves are depleting at an alarming rate, posing a significant threat to the sustainability of this vital resource.

Similarly, in urban centers such as Karachi, the water supply remains insufficient to meet the city's growing demand, leading to an increasing dependence on groundwater for domestic and industrial purposes. This reliance has resulted in a rapid decline in the water table. The city's water demand ranges from 820 to 1200 million gallons per day (MGD), while the available supply is approximately 650 MGD, resulting in a daily shortfall of over 400 million gallons. Consequently, Karachi faces a severe water crisis, compelling residents to resort to alternative means such as digging wells and boreholes, purchasing bottled water, or acquiring potable water from private vendors and tankers. The proliferation of illegal hydrants, with an estimated 40,000 to 50,000 daily deliveries, has turned water supply into a lucrative commercial enterprise.

Despite the presence of the Water Act and Water Policy, both industries and individuals in Karachi continue to extract millions of gallons of groundwater daily, making regulatory enforcement a significant challenge. This study examines the factors driving excessive groundwater withdrawals and their long-term consequences. Furthermore, it underscores the necessity of implementing stringent regulations and a robust water accountability framework to control groundwater abstraction, ensuring that withdrawals do not exceed the natural recharge rate, thereby promoting the sustainability of this critical resource.

LID 0980
Coupled ocean–groundwater numerical modeling for understanding coastal aquifer dynamics under variable marine forcing

Albert Folch[1,2]*, Jiangyue Jin[1,2,3], Daniel Fernandez-García[1,2], Manuel Espino[3]

[1] Groundwater Hydrology Group, Universitat Politècnica de Catalunya (UPC), Barcelona, Spain
[2] Associated Unit: Hydrogeology Group (UPC-CSIC), Spain
[3] Laboratori d'Enginyeria Marítima (LIM), Universitat Politècnca de Catalunya, Barcelona, Spain
* albert.folch.s@upc.edu

Keywords: coastal aquifers, groundwater–ocean interaction, coupled numerical models

Coastal aquifers are highly dynamic systems where interactions between groundwater and the ocean control key processes such as seawater intrusion (SWI) and submarine groundwater discharge (SGD). Accurate representation of these processes is essential for sustainable coastal water management, particularly under increasing environmental and anthropogenic pressures. This study presents a coupled numerical modeling framework integrating the hydrodynamic model TELEMAC-3D with the groundwater flow model MODFLOW 6 to investigate groundwater–ocean interactions under variable marine conditions.

The coupled approach incorporates two-way feedback mechanisms between oceanic and groundwater systems through dynamic boundary conditions accounting for salinity, temperature, tides, and wave-induced processes. Model coupling was implemented using Python-based interfaces, enabling synchronized simulation of coastal hydrodynamics and subsurface flow. The framework was applied to analyze the contrasting behavior of confined and unconfined coastal aquifers under identical geometric conditions but subjected to varying ocean forcings.

Results indicate that aquifer confinement strongly controls system sensitivity and exchange dynamics. Confined aquifers exhibit greater response to density-driven processes associated with seawater salinity variations, whereas unconfined systems are more affected by surface-driven forcings such as tidal oscillations, thermal gradients, and wave activity. The simulations further reveal that SGD-induced freshening of nearshore waters generates a feedback mechanism capable of moderating subsequent seawater intrusion, highlighting the importance of fully coupled simulations for realistic assessment of coastal groundwater systems.

The proposed modeling framework improves the representation of water and salt exchange processes at the land–sea interface and provides a robust tool for evaluating coastal aquifer vulnerability and submarine groundwater discharge under changing marine and climatic conditions.

LID 0982
Integrated short- and long-term hydrogeochemical monitoring to investigate geochemical processes in a waste landfill area

Daniela Ducci[1]*, **Stefania Stevenazzi**[2], Elena Del Gaudio[1], Claudio Persico[3], Ciro D'Aniso[3]

[1] Università degli Studi di Napoli Federico II, Naples, Italy
[2] Università degli Studi di Milano, Milan, Italy
[3] S.A.P.NA. S.p.A., Naples, Italy
* daniela@unina.it

Keywords: chemical and isotopic analyses, trend analysis, Italy

In this study, we investigated the processes leading to anomalously high values of some metalloids and minor elements (As, F, Fe, Mn) in groundwater in a porous/fractured pyroclastic aquifer at a closed municipal solid waste landfill site. The goal of the study is to distinguish between natural enrichments and anthropogenic pressures. This study takes the advantages of the synergy between scientists, landfill operators and local authorities. The long-term monitoring activity on groundwater quality conducted by the landfill operators was complemented by a short in-depth groundwater monitoring of physical-chemical parameters, inorganic compounds, water stable isotopes, carbon isotopes and tritium.

Long-term monitoring shows a general stability or a decrease in the concentration of the elements of concern, despite peculiar fluctuations of Fe and Mn concentrations. The presence of As and F in groundwater is natural and associated with adsorption-desorption processes or with the rise of hydrothermal fluids from a nearby active volcanic area. Instead, the presence or absence of Fe and Mn can be attributed to local redox conditions that favor or inhibit the mobilization of these elements. These conditions may be related to the combined effect of natural phenomena and interference related to the presence of the landfill. In fact, the landfill body may act as a barrier between the saturated zone and the atmosphere, favoring anoxic/abiotic conditions and creating a more reducing chemical environment below and downgradient of the landfill. Possibly due to the occurrence of oxidizing conditions, no other wells downgradient the landfill show physical-chemical anomalies.

Short in-depth and long-term monitoring activity effectively supported the comprehension of the geochemical processes occurring in the aquifer in presence of a municipal landfill. The outcomes of this study will help decision makers in planning and managing present and future activities at the landfill aimed at reducing the impact on groundwater resources.

LID 0984
Modelling groundwater flow system into surface water in the upper uMgeni Catchment

Thakhani Rambuda[1]*, Seifu Kebede-gurmessa[1]

[1] North West University, Potchefstroom, South Africa
* 39662942@mynwu.ac.za

Keywords: groundwater-surface water interaction, regional groundwater flow, MODFLOW 6

Understanding groundwater-surface interactions is important for sustainable water resources management, particularly in fractured-rock aquifer systems where flow processes are complex and poorly constrained. In south Africa, limited knowledge of deep and regional groundwater flow systems restricts their integration into water management strategies. This study investigates groundwater flow dynamics and discharge processes in the upper uMgeni catchment, Kwazulu-Natal, a key water supply region dominated by karro fractured -rock aquifers.

conceptual hydrogeological model is developed to represent recharge, flow and discharge processes, emphasizing regional groundwater contributions to rivers, wetlands, and groundwater-dependent ecosystems. This framework will be implemented using a numerical groundwater flow model (MODFLOW via Flopy), applying a two dimensional approach justified by dominant lateral flow conditions and data limitations.

Model calibration and sensitivity analysis will be conducted to evaluate system behaviour and reduce uncertainty. Scenario analysis will be performed to assess the impacts of groundwater abstraction on surface water connectivity. This study aims to quantify regional groundwater discharge and improve understanding of multi-scale flow systems in fractured-rock environments, contributing to improved groundwater representation in catchment-scale water resources management in South Africa.

LID 0985
Geo-Log's activities in thermal water wells in Hungary and the Carpathian Basin

Áron Szlukovinyi[1]*, Jónás Révész[1], Gábor Szongoth[1], Sándor Hegedűs[1]

[1] Geo-Log Ltd., Budapest, Hungary
* szlukovinyi.aron@geo-log.hu

Keywords: borehole geophysics, well investigation, thermal water exploration, temperature logging

Geo-Log Ltd. Has been actively involved in the investigation of thermal water wells in Hungary and the surrounding countries since 1990. Over the past 35 years, the company has carried out borehole geophysical and well investigation measurements in 500 thermal water well deeper than 1000 m in Hungary and neighboring countries, including Romania, Ukraine, Slovenia, and Slovakia. The deepest measurements were performed in a 3200 m deep well, while the highest recorded temperature reached 150 °C.

This presentation reviews the result of several interesting borehole and well investigations, including measurements, interpretation, and documentation, as well as the joint evaluation of approximately 20 wells drilled in the Great Hungarian Plain, each about 2000 m deep and with temperatures of around 100 °C. Special emphasis is placed on the importance of temperature logging, which made it possible to derive substantially more geological hydrogeological, and production-geophysical information than is usually obtained from temperature measurements carried out in both shut-in and producing wells.

LID 0986
Geo-Log Ltd.: 35 years of borehole geophysics, well logging, and geological exploration

Lénárd Pál[1]*, Gábor Szongoth[1]

[1] Geo-Log Ltd., Budapest, Hungary
* pal.lenard@geo-log.hu

Keywords: borehole geophysics, well logging, geothermal exploration, geological investigation

Geo-Log Ltd. was founded in 1990 by geophysicists from the Eötvös Loránd Geophysical Institute (ELGI) and became fully independent in 1998. A defining milestone in the company's history was its participation in the geological investigation of the National Radioactive Waste Repository at Bátaapáti for low- and intermediate-level radioactive waste, an ongoing project that significantly strengthened the company both professionally and financially.

During the 2000s and 2010s, Geo-Log continuously expanded its equipment base and expertise, becoming a leading company in Hungary and the Central and Eastern European region in borehole geophysics, well logging, water exploration, geothermal investigations, and geological exploration. The company has participated in major domestic and international projects, including BAF, Paks 2, Visaginas (Lithuania), and Krško (Slovenia), as well as numerous thermal-water exploration and well investigation projects in Hungary and neighboring countries. Since 2010, it has also been the Southeast European partner of Coca-Cola HBC in the investigation of mineral water wells.

Geo-Log applies a wide range of measurement methods from 10 to 3300 m depth, with operational limits of up to 125°C and 350 bar. Over the past 35 years, it has performed approximately 16,500 measurements in around 10 countries at about 10,600 sites. This presentation highlights the company's history, selected projects, applied methods, and interpretation approaches.

LID 0987
Sustainable integration of low-temperature geothermal waters and energy with RES and thermal energy storage in Poland's regions

Elżbieta Hałaj[1]*, Anna Sowiżdżał[1], Dominika Dawiec[1], Anna Chmielowska[1], Marek Hajto[1], Wojciech Luboń[1], Grzegorz Pełka[1], Bartłomiej Ciapała[1], Maciej Szymanek[1]

[1] AGH University of Kraków, Kraków, Poland
* ehalaj@agh.edu.pl

Poland possesses significant low- to moderate-temperature geothermal resources, primarily located within the Polish Lowlands. While these reservoirs offer massive potential for decarbonizing the heating sector, their low-temperature nature requires innovative, integrated approaches to maximize efficiency and guarantee long-term reservoir sustainability. This study explores the synergistic integration of Poland's geothermal waters with renewable energy sources (RES) and advanced thermal energy storage (TES) technologies.

To overcome seasonal demand fluctuations and temperature limitations, we evaluate the deployment of Aquifer Thermal Energy Storage (ATES) and Borehole Thermal Energy Storage (BTES) systems. These technologies allow for the balanced management of thermal resources by storing surplus heat during low-demand periods. Furthermore, the utilization of shallow geothermal energy is enhanced through energy geostructures, such as energy piles, which integrate thermal activation directly into urban infrastructure.

Central to this integrated framework is the coupling of geothermal systems with complementary RES. High-efficiency heat pumps are utilized to elevate low geothermal temperatures to required district heating levels. Additionally, photovoltaic (PV) installations supply the necessary electricity to drive these heat pumps, while solar thermal collectors provide high-temperature peak shaving and assist in recharging the ATES/BTES fields during summer.

By combining geothermal water exploitation with hybrid RES configurations and subsurface storage, Poland can transition from traditional, isolated geothermal plants to resilient, low-emission heating networks. This approach ensures the sustainable use of mineralized thermal waters while mitigating over-exploitation risks, offering a scalable blueprint for Central Europe's energy transition.

This publication was funded by the subsidy granted to the AGH University of Krakow by the Ministry of Science and Higher Education. Research project supported by program „Excellence initiative – research university" for the AGH University of Krakow.

LID 0988
Hydrological memory and baseflow dynamics in a tropical catchment from long-term hydrological modeling

Carolina Fernanda Dos Santos[1]*, Ricardo Hirata[1], Lina Maria Osorio Olivos[1], Arisvaldo Vieira Méllo Júnior[1], Alexandra Suhogusoff[1]

[1] Groundwater Research Center (CEPAS|USP), Institute of Geosciences, University of São Paulo, Brazil
* carolina.fernanda.santos@alumni.usp.br

Keywords: groundwater recharge, storage, river-aquifer interaction

The maintenance of river streamflow during dry periods in tropical catchments strongly depends on the interactions among aquifer recharge, groundwater storage, and baseflow. However, water planning strategies frequently prioritize immediate hydrological responses to precipitation, without adequately accounting for groundwater storage processes and the temporal lags inherent to subsurface dynamics. This study investigates the temporal dynamics between precipitation, recharge, and baseflow in the Alto Batalha catchment (São Paulo State, Brazil) using the RUBEM hydrological numerical model for the 2000-2024 period. Hydrological time series, seasonal patterns, the relative contribution of baseflow to streamflow, and lagged temporal correlations between recharge, baseflow, and river discharge were evaluated. Temporal correlation analyses revealed a rapid response between recharge and baseflow, with the maximum correlation occurring after 1 month ($r = 0.89$), suggesting relatively high hydrological connectivity and efficient recharge transfer to the aquifer system. In contrast, streamflow exhibited persistent correlation with baseflow for up to 4-5 months, indicating sustained groundwater contribution and delayed subsurface water release, with the progressive attenuation of the hydrological signal reflecting the role of groundwater storage in maintaining streamflow during dry periods. The results reveal a combined behavior of rapid recharge response and prolonged hydrological memory, highlighting the importance of groundwater contribution for climate-resilient water planning strategies in tropical monsoonal catchments. We acknowledge the SACRE Project and the São Paulo State Research Foundation (2020/15434-0 and 2024/04168-8).

LID 0989
Seasonal patterns of emerging organic contaminants in groundwater: Tracing anthropogenic impacts

Lufuno Ligavha-Mbelengwa[1]*, Modreck Gomo[2], Godfrey Madzivire[1]

[1] Council for Geoscience, Silverton, Pretoria, South Africa
[2] University of the Free State, Bloemfontein, South Africa
* lligavhambelengwa@geoscience.org.za

Keywords: climatic conditions, emerging organic contaminants, groundwater, seasonal variation, water quality

The widespread occurrence of emerging organic contaminants (EOCs) such as pharmaceuticals, pesticides, hormones, industrial and lifestyle compounds in the environment has become an increasing concern for water quality and ecosystem health. This is because these compounds continue to enter and persist in the aquatic systems, particularly groundwater. While considerable global progress has been made in the study of EOCs in various aquatic environments, recent studies emphasise that groundwater remains less characterised compared to other environments, like surface water resources. This study aimed to assess the seasonal patterns of EOC concentrations in groundwater within an area characterised by various land use activities. The study was conducted in the Eastern Basin of the Witwatersrand Goldfields. The groundwater samples were collected from 12 monitoring boreholes and were analysed for different EOCs using a hybrid triple quadrupole ion trap mass spectrometer with a Shimadzu high performance liquid chromatography. The findings showed distinct seasonal trends in the EOC concentrations as evidenced by high average concentrations during the spring season which were associated with the first rainfall flush. During this period, water that is concentrated with anthropogenic contaminants was transported through runoff. More evidence of seasonal variations was provided from the lowest EOC concentrations that were measured during the winter season after prolonged rainfall periods which led to dilution of water resources. The observed patterns demonstrate the influence of groundwater quality by anthropogenic activities and climatic conditions. These seasonal patterns provide early warnings of anthropogenic pressure on aquifers. This research highlights the need for and importance of integrating EOC tracers into long-term monitoring programmes to gain insights into the effects of climate variability to groundwater quality. Furthermore, this approach supports targeted pollution prevention and better aquifer management.

LID 0990
Trifluoroacetic acid: A small molecule with the potential to cause big groundwater challenges

Tim Besien[1]*

[1] Independent Hydrogeologist, Tewkesbury, United Kingdom
* tbesien@iah.org

Keywords: trifluoroacetic acid, groundwater contamination, PFAS, environmental policy

Trifluoroacetic acid (TFA) is a small synthetic organofluorine compound with properties that raise increasing concern for groundwater systems worldwide. This paper reviews the current literature on TFA occurrence in water, examining evidence of contamination and assessing the extent of its presence in groundwater environments across different regions.

The analysis highlights the persistence and mobility of TFA, which together suggest a strong potential for widespread distribution and long-term accumulation in aquifers. These characteristics indicate that groundwater may increasingly act as an environmental sink for TFA, with implications for water quality and resource management over time. In addition, the paper considers emerging evidence for source apportionment of TFA in groundwater, including the relative contributions from atmospheric deposition, degradation of precursor compounds, and direct anthropogenic inputs. Understanding these pathways is critical for identifying dominant sources and informing effective mitigation strategies.

The paper further explores the technical and practical challenges associated with monitoring, assessing and mitigating TFA contamination, including limitations in current analytical approaches and treatment options. It then considers emerging policy responses, reflecting on how regulatory frameworks are beginning to address this compound within the broader context of persistent fluorinated substances.

Finally, the paper outlines key knowledge gaps and proposes priority areas for research and policy development, aimed at improving understanding of TFA behaviour in groundwater and supporting effective management strategies.

LID 0991

Hydrochemical evolution characteristics and genesis of groundwater under long-term infiltration (2007–2018) of reclaimed water in downstream of Chaobai River region

Binghua Li[1,2]*, Qiwen Xia[1,2], Fandong Zheng[1,2], Junxiong Huang[1,2]

[1] Beijing Water Science and Technology Institute, Beijing, China
[2] Beijing Key Laboratory of Groundwater Monitoring, Early Warning, and Safety Controlling, Beijing, China
* libinghua75@163.com

Keywords: reclaimed water, groundwater, infiltration, hydrochemical evolution

The reuse of reclaimed water (RW) for river ecological restoration has inevitably brought some potential risks for groundwater. However, little is known about the effects of reclaimed water on the hydrochemical evolution of groundwater. Herein, 11-years monitoring data (2007–2018) of reclaimed water and groundwater were adopted to analyze the characteristics and genesis of groundwater hydrochemical evolution. The results showed that the hydrochemical components in groundwater totally performed a significant increase in Na^+, Cl^-, and K^+ and decrease in Ca^{2+}, Mg^{2+}, and HCO_3^- concentration. Meanwhile, a significant hydrochemical evolution difference were observed in different regions. In Jian region, the hydrochemical type in groundwater shifted from HCO_3–Ca.Mg to HCO_3.Cl–Na.Ca. However the hydrochemical evolution in the Chaobai River region showed the type beginning from HCO_3–Ca.Mg to HCO_3.Cl–Na.Mg and finally deviating reclaimed water type of Cl·HCO_3.SO_4–Na. PHREEQC simulation indicated that the differences of hydrochemical evolution were mediated synergically by sediment thickness and geochemical processes. These findings advance the understanding of reclaimed water effect on groundwater and also guide future prediction of evolution trends.

LID 0992
Evolution of groundwater resources of Wallonia in a changing climate

Julien Hutzemakers[1]*, Philippe Orban[1], Xavier Fettweis[2], Catherine Sohier[3], Aurore Degre[3], Pascal Goderniaux[4], Serge Brouyere[1]

[1] ULiège Hydrogeology & Environmental Geology, Liège, Belgium
[2] ULiège Climatologie et Topoclimatologie, Liège, Belgium
[3] ULiège Gembloux Agro-Bio Tech, Liège, Belgium
[4] Université de Mons, Géologie fondamentale et appliquée, Mons, Belgium
* julien.hutzemakers@doct.uliege.be

Keywords: groundwater flow model, regional-scale, climate change

Climate change is expected to significantly alter the global water cycle, with direct consequences for groundwater systems. Anticipating these impacts requires robust modelling tools capable of translating future climate conditions into groundwater responses. In this study, a comprehensive set of climatic projections—combining two greenhouse gas emission scenarios (SSP3-7.0 and SSP5-8.5), three global earth system models (MIROC6, CMCC, MPI) downscaled to 5km with a regional climate model (MARv3.14), and a soil model (EPICgrid)—is integrated into regional-scale numerical groundwater flow models representing the major aquifer systems of Wallonia (southern Belgium). These models simulate future changes in groundwater levels and quantify shifts in groundwater fluxes between aquifer recharge, groundwater abstraction, river discharge, and cross transfers between aquifers. To assess these evolutions, spatial maps of piezometric variations relative to historical conditions are produced, alongside indicators describing the magnitude and direction of flux changes.

Results indicate limited and uncertain changes over the coming decades, with no clear trend across scenarios. By the end of the century, however, projections tend to converge on greater groundwater recharge driven by an increase in winter precipitation, leading to higher groundwater levels and enhanced river discharge. These projections reflect climate-driven changes only, assuming constant abstraction rates, land-use and soil health. It thus represent a baseline of system response in the absence of adaptation. The resulting analyses provide an improved understanding of how groundwater resources may evolve under future climate conditions, highlighting potential impacts on water availability, ecosystems, and socio-economic activities. This integrated modelling framework supports informed decision making for sustainable groundwater management in a changing climate.

LID 0993
Bringing groundwater to the water table: IAH Canada's committee for groundwater advocacy

Cynthia Mcclain[1*], Audrey Marie Hill[1,2], Keelan Kells[1,3], Mike Wei[1,4], Cathy Ryan[1,5], Reginald Somera[1]

[1] Department of Earth and Atmospheric Sciences, University of Alberta, Edmonton, Canada
[2] Department of Civil and Resource Engineering and Centre for Water Resources Studies, Dalhousie University, Halifax, Canada
[3] Department of Earth and Environmental Sciences, University of Ottawa, Ottawa, Canada
[4] School of Earth and Ocean Sciences, University of Victoria, Victoria, Canada
[5] Department of Earth, Energy, and Environment, University of Calgary, Calgary, Canada
* cnmcclain@gmail.com

Keywords: groundwater advocacy, policy, Canada

Groundwater is the largest source of liquid freshwater in Canada, providing drinking water to a third of all Canadians, with more than half of all First Nations and up to 80% of rural communities relying on it. Despite shallow groundwater alone comprising 75% of Canada's freshwater, the subject as a whole is often overlooked in federal freshwater policy and communications, resulting in little to no share in freshwater programs, funding, and education. To address this gap, the International Association of Hydrogeologists Canada (IAH Canada) established the Committee for Groundwater Advocacy (CGA) in 2023. An early milestone was a brief submitted to the House of Commons Standing Committee on Environment and Sustainable Development urging integration of groundwater into federal freshwater policy.

In 2025, IAH Canada, with support from the Gordon Foundation on "Strengthening Groundwater Advocacy and Policy Engagement in Canada," doubled CGA's capacity and formalized four working groups: Advocacy and Engagement, Communications and Public Outreach, Events and Professional Development, and Policy Review.

In 2026, CGA has translated these foundations into measurable policy impact. The CGA delivered recommendations on integrating groundwater into the *Canada Water Act* to the Canada Water Agency, prompting interest in groundwater-inclusive definitions of transboundary waters and follow-up engagement. CGA also submitted recommendations to Canada's Federal Sustainable Development Strategy to embed groundwater across multiple goals and SDG targets (e.g., 6.1.1, 6.3.2). Internationally, CGA raised its profile by co-moderating the UN Water "Groundwater Matters" webinar and IAH Budapest plenary.

Looking ahead, CGA is preparing for a Day on the Hill in fall 2026 in addition to increased engagements with Members of Parliament to strengthen federal relationships and elevate groundwater in national dialogue. Forthcoming work includes op-eds, expanded francophone communications, and partnerships with ally organizations. This presentation outlines CGA's roadmap to embed groundwater meaningfully in Canadian freshwater governance.

LID 0994
Impact of different replenishment and exploitation schemes on groundwater environment in typical water conservation areas

Peng Dou[1]*, Binghua Li[1], Xia Wu[1]

[1] Beijing Water Science Technology Institute, Beijing, China
* doupengdoupeng@163.com

Keywords: groundwater ecological replenishment, water conservation area, groundwater flow field, surface water-groundwater interaction, Yongding River Basin

Ecological surface water replenishment is a key measure for surface water-groundwater collaborative restoration and groundwater over-exploitation mitigation in arid and semi-arid regions, critical for maintaining river ecosystem health and sustainable groundwater utilization. This study systematically evaluates the impacts of different replenishment-exploitation schemes on the groundwater environment in the Yongding River typical water conservation area, North China, based on the ecological replenishment project of the river's typical representative area. Field monitoring and numerical simulation methods were combined to construct a professional groundwater simulation model for typical ecological conservation areas, revealing the coupled hydrodynamics-water quality response law under ecological replenishment, and simulating the long-term evolution of the groundwater flow field under multiple regulation schemes. Principal Findings: (1) The groundwater flow field shows significant spatial heterogeneity, with an upstream high-velocity zone and a significantly increased proportion of downstream slow-flow zone, and the flow velocity presents a regular gradient change with replenishment discharge; (2) The regional groundwater level shows a continuous upward trend throughout the simulation period under all schemes, with the water level rise amplitude significantly higher in wet years than in dry years, and the peak water level reaching the maximum value in wet years; (3) Some typical monitoring points have the largest groundwater level rise amplitudes, with the increase in wet years far exceeding that in dry years, and the rise amplitudes are significantly higher than those of other monitoring points; (4) Typical cross-sections Ⅰ and Ⅱ show an overall consistent upward trend in water level, with an obvious spatial gradient that the groundwater level increases significantly with the proximity to the river channel. The research results provide scientific support for the optimization of ecological replenishment schemes and the collaborative management of surface water and groundwater in the basin.

LID 0995
Isotopic assessment of groundwater–wetland interactions under changing hydrological conditions

Lucia Ortega[1*], Maria Emilia Zabala[2], Sebastien Santoni[3], Ioannis Matiatos[4], Isadora Kuhn[5], Prasanta Sanya[6], Germain Esquivel-Hernández[7], Jared Van Rooyen[8], Frederic Huneau[3], Jodie Miller[1]

[1] Isotope Hydrology Section, Division of Physical and Chemical Sciences, Department of Nuclear Sciences and Applications, International Atomic Energy Agency, Vienna, Austria
[2] Institute of Large Plains Hydrology "Dr. Eduardo J. Usunoff", Azul, Buenos Aires, Argentina
[3] Université de Corse, CNRS UMR 6134 SPE, Campus Grimaldi, BP52, 20250 Corte, France
[4] Institute of Marine Biological Resources and Inland Waters, Hellenic Centre for Marine Research, Anavissos Attikis, Greece
[5] Geological Survey of Brazil, Rua Banco Província, Porto Alegre, Brazil
[6] Department of Earth Sciences, IISER Kolkata, Mohanpur Campus, India
[7] Stable Isotope Research Group, ChemistryDepartment, Universidad Nacional Costa Rica, Heredia, Costa Rica
[8] Water Resources and Drinking Water, Eawag, Swiss Federal Institute of Aquatic Science and Technology, Dübendorf, Switzerland
* l.ortega@iaea.org

Keywords: isotopes, groundwater–wetland interaction, multitracer approach

Many wetlands depend directly on groundwater inflows to sustain their hydrological regime and ecological functioning, yet increasing pressures from climate variability, land-use change, and groundwater abstraction are altering these interactions in ways that conventional monitoring methods alone cannot resolve. The objectives of this study are: (i) to assess how groundwater-dependent wetlands respond to variations in rainfall regimes and climatic forcing, and whether these responses are rapid or delayed; (ii) to evaluate which isotopic and hydrochemical tracers are most sensitive to changes in groundwater–wetland connectivity, and under which environmental conditions they are most effective; and (iii) to derive practical, transferable guidance for isotope-based wetland monitoring and management.

Within the IAEA Coordinated Research Project F33027, twelve Member States applied a harmonised multitracer framework, combining stable water isotopes ($\delta^{18}O$, $\delta^{2}H$, d-excess), radon-222, and tritium, alongside hydrochemical parameters, across contrasting hydroclimatic and geological settings, including arid, temperate, tropical, volcanic, and coastal environments. Seasonal sampling under contrasting hydrological conditions revealed that groundwater contributions are spatially heterogeneous and temporally variable. Radon-222 identified active discharge zones where stable isotope contrasts were masked by evaporation or salinity. Deuterium-excess and $\delta^{18}O$–$\delta^{2}H$ relationships captured the interplay of evaporation and recharge seasonality, while tritium distinguished modern from older groundwater sustaining wetlands during dry periods.

A consistent finding across all sites is that no single tracer is sufficient: multitracer integration, guided by a site-specific conceptual model, is essential to disentangle evaporation, mixing, recharge and discharge processes. These results support the development of operational recommendations for isotope-based assessment of groundwater-dependent wetlands under changing hydrological conditions.

LID 0996
Tracing hidden hydrological reorganization in glacier-related hazard systems: An isotope-hydrology framework

Melanie Vital[1], Edison Jara[1], Janie Masse Dufresne[2], Johannes Cullman[3], Maria Shahgedanova[4], Vassily Kapitsa[5], Vitalii Zaginaev[6], Subodh Dhakal[7], **Lucia Ortega**[1]*, Yuliya Vystavna[1]

[1] Isotope Hydrology Section, Division of Physical and Chemical Sciences, Department of Nuclear Sciences and Applications, International Atomic Energy Agency, Vienna International Centre, Vienna, Austria
[2] École de technologie supérieure 1100, Montréal, Canada
[3] Federal Institute of Hydrology (Bundesanstalt für Gewässerkunde), Koblenz Germany
[4] School of Archaeology, Geography and Environmental Science (SAGES) Walker Institute for Climate System Research, University of Reading, United Kingdom
[5] Central Asian Regional Glaciological Centre, Almaty, Kazakhstan
[6] Mountain Societies Research Institute, University of Central Asia, Bishkek, Kyrgyzstan
[7] Tribhuvan University Ghantaghar Kathmandu, Kathmandu, Nepal
* m.vital@iaea.org

Keywords: isotope hydrology, cryosphere hazards, hydrological reorganization, environmental tracers, high-mountain hydrology

Widespread glacier retreat, permafrost degradation, and rapid glacial lake expansion are reshaping high-mountain environments into increasingly dynamic and unstable landscapes. These changes are not limited to glacier mass loss; they involve broader reorganization of hydrological and geomorphological systems, with direct implications for water resources management, groundwater recharge, aquifer storage, and natural hazards.

Current glacier-related hazard assessment has advanced considerably through remote sensing, digital elevation models, geomorphological mapping, field surveys, and hydrodynamic modelling. These approaches are essential for identifying hazardous lakes, unstable slopes, dam conditions, flood pathways, and exposed communities or infrastructure. However, they remain largely surface-oriented and may not fully capture subsurface hydrological processes that condition hazard development.

In glacierized basins, critical changes can occur below the surface or within mixed ice–debris systems. Stable water isotopes, particularly $\delta^{2}H$ and $\delta^{18}O$, together with complementary tracers such as ^{222}Rn, ^{3}H, major ions, electrical conductivity, and selected geochemical indicators, can help distinguish processes that may influence lake level, dam stability, aquifer connectivity, sediment mobilization, and downstream flood response before visible geomorphic changes are detected.

The proposed framework links isotope and hydrochemical information to five operational steps. It does not position isotope hydrology as a stand-alone tool for predicting the timing of glacier-related hazards and their impact on groundwater storage. Rather, it frames isotopes as a diagnostic layer that can identify when a cryosphere-impacted system has shifted from expected seasonal behaviour toward an internally reorganized and potentially more sensitive state. This approach can complement existing hazard assessment methods and support more integrated monitoring strategies in rapidly deglaciating mountain regions.

LID 0998
Using time-lapse gravimetry to quantify subsurface hydrogeological heterogeneity

Nazanin Mohammadi[1]*, Hugo Delottier[1], Landon J.S Halloran[1]

[1] Centre for Hydrogeology and Geothermics, University of Neuchâtel, Switzerland
* nazanin.mohammadi@unine.ch

Keywords: time-lapse gravimetry, geophysics, hydrogeodesy, hydrogeophysical inversion, hydraulic heterogeneity, uncertainty quantification

Subsurface heterogeneity fundamentally controls hydrogeological processes, such as groundwater recharge under climate variability, groundwater flow pathways, and surface-subsurface water exchanges. Reliable prediction of their spatiotemporal dynamics therefore requires knowledge of subsurface hydraulic properties and their spatial variability. As distributed, direct measurements are generally not feasible, estimation of hydraulic property spatial fields can be carried out through the assimilation of passive observation data into numerical groundwater models. Here, we leverage time-lapse gravimetry, a geophysical and geodetic technique that measures the change in gravity at the surface caused by changes in groundwater storage and provides spatially integrated observations to resolve subsurface heterogeneity. Extracting hydrogeological information from this data requires its assimilation within a coupled inversion framework. Here, we use GravCHAW, a recently developed software framework for assimilating time-lapse gravity data into groundwater models. Using a realistic synthetic aquifer system, we demonstrate the potential of time-lapse gravimetry for imaging subsurface hydraulic heterogeneity and reducing uncertainty in groundwater model predictions.

LID 1000
Characterizing hydrogeological properties of aquifers with InSAR-based land subsidence observations and a coupled modeling approach

Yueting Li[1,5], **Alper Elci**[2]*, Claudia Meisina[3], Elif Aysu Batkan[2], Ali Hakan Ören[4], Claudia Zoccarato[5], Pietro Teatini[5]

[1] Department of Hydrosciences, Nanjing University, Nanjing, China
[2] Department of Environmental Engineering, Dokuz Eylül University, Izmir, Türkiye
[3] Department of Earth and Environmental Sciences, University of Pavia, Pavia, Italy
[4] Department of Civil Engineering, Dokuz Eylül University, Izmir, Türkiye
[5] Department of Civil, Environmental and Architectural Engineering, University of Padova, Padova, Italy
* alperelci@gmail.com

Keywords: remote sensing, groundwater flow modeling, geomechanical modeling

Predicting how aquifer systems will react to anthropogenic and natural stressors and safeguarding sustainable groundwater management depend on accurate characterization of critical hydrogeological parameters, particularly hydraulic conductivity (K) and specific storage (S_s). However, in basins, where piezometric records, pumping test data, and production well information are scarce, such characterization is still very difficult. In this study, we suggest an iterative modeling approach that uses a nested inversion scheme to couple a 3-D geomechanical (GM) model with a 3-D groundwater flow (GW) model. To obtain an initial estimate of the heterogeneous K distribution given a homogeneous S_s, the workflow starts with calibrating the GW model against piezometric records. Interferometric Synthetic Aperture Radar (InSAR) measurements are then combined with the resulting hydraulic head changes to estimate pointwise S_s values, which are then interpolated across the basin scale. The GM model is used to validate this S_s field, which is then fed back into the GW model for the subsequent K calibration iteration. Until the relative change in the estimated parameters drops below a predetermined threshold, this iterative cycle is repeated. We apply this method to an alluvial aquifer in the Gediz River Basin in western Türkiye, where excessive irrigation use of groundwater is causing significant land subsidence. The estimated K and S_s distributions enable the reconstruction of both hydraulic head evolution and land subsidence patterns with a consistent modeling setup, and our results show significant variation in the aquifer's hydrogeological properties.

This study is funded by the PRIMA foundation of the European Union's Horizon 2020 framework program under grant agreement No: 1924, project RESERVOIR.

LID 1001
Influence of submarine groundwater discharge on porewater chemistry and its relevance to coastal enhanced weathering

Soumya Kanta Nayak[1*], Murugan Ramasamy[1], Cátia M. Ehlert Von Ahn[1], Janardhana Raju Nandimandalam[2], Nils Moosdorf[1,3]

[1] Leibniz Centre for Tropical Marine Research (ZMT), Bremen, Germany
[2] School of Environmental Sciences, Jawaharlal Nehru University (JNU), New Delhi, India
[3] Institute of Geosciences, Kiel University, Kiel, Germany
* soumya.kanta.nayak@leibniz-zmt.de

Keywords: subterranean estuary, coastal enhanced weathering, submarine groundwater discharge, porewater

Subterranean estuaries (STEs) are dynamic mixing zones where fresh groundwater and saline seawater interact within coastal sediments, generating complex hydrogeochemical conditions and influencing submarine groundwater discharge (SGD). Understanding the spatial variability of these mixing processes is important for evaluating intertidal environments as potential sites for coastal enhanced weathering (CEW), where mineral dissolution and associated CO_2 drawdown depend strongly on porewater circulation and fluid-mineral interactions. This study investigates meter-scale porewater salinity variability at two contrasting coastal systems: Marine Drive Beach along the tropical Odisha coast, India, and Spiekeroog Island, a temperate high-energy barrier island in Germany. Multiple shore-perpendicular porewater sampling grids were used to assess spatial variability in intertidal mixing processes. Both sites exhibited irregular salinity distributions, localized freshening zones, and patchy mixing structures over short spatial scales, indicating spatially confined groundwater discharge pathways and heterogeneous porewater circulation. These patterns reflect the combined influence of sediment architecture, permeability contrasts, tidal pumping, wave-driven infiltration, varying groundwater-seawater mixing proportions and local morphological shifts. The observed hydrogeological heterogeneity likely influences porewater residence times, mixing intensity, and fluid-mineral interactions thereby regulating subseafloor reactivity and weathering conditions. Such dynamic environments are particularly relevant for CEW, where mineral dissolution efficiency may depend strongly on tidal flushing, porewater renewal, salinity fluctuations, temperature variability and repeated seawater-mineral interaction. Resolving heterogeneous porewater circulation and mixing processes is therefore critical for understanding and evaluating CEW performance and associated CO_2 sequestration potential in coastal environments.

LID 1002
Machine learning–based classification of *E. coli* and total coliforms for sanitary risk assessment in karst springs

Anna Pölz[1,3], Alfred Paul Blaschke[1,3], Katalin Demeter[2,3], Margaret Stevenson[1,3], Andreas Farnleitner[2,3], **Julia Derx**[1,3]*

[1] Institute of Hydraulic Engineering and Water Resources Management, TU Wien, Vienna, Austria
[2] Institute of Chemical, Environmental and Bioscience Engineering, Research Group Microbiology and Molecular Diagnostics, TU Wien, Vienna, Austria
[3] Interuniversity Cooperation Centre Water and Health, Vienna, Austria
* julia.derx@tuwien.ac.at

Keywords: karst springs, microbial contamination, machine learning

Reliable and timely assessment of microbiological contamination in alpine karst springs used for drinking water abstraction remains a major challenge, due to rapid hydrological responses and high temporal variability in *E. coli* and total coliform concentrations. Conventional monitoring schemes yield only delayed information on sanitary risk. This study investigates whether machine-learning classification models can convert high-frequency hydrological, meteorological, and physicochemical data into early-warning sanitary risk categories for karst systems. We used 10 years of twice-weekly microbial measurements from three Austrian karst springs (LKAS2, PK3, PK4), combined with 4-hourly environmental records (discharge, precipitation, air and water temperature, electrical conductivity, turbidity, UV254).

Microbial concentrations were classified into low, medium, and high sanitary risk, and five ML classifiers (Random Forest, XGBoost, logistic regression, LSTM, Transformer) were evaluated under three input configurations: Static (instantaneous predictors), Hydro (time-series windows), and Hydro-Coli (including most recent microbial values). Nested cross-validation with RF and XGB yielded the best performance, with Static configurations generally outperforming time-series–based setups, indicating that the instantaneous system state best captures contamination dynamics in these highly dynamic karst aquifers. Accuracies ranged from 0.78 to 0.83 and AUCs for low and high risk classes reached ≥0.90 at LKAS2 and PK3, while PK4 showed lower performance due to a smaller dataset. Results highlight that static ML models can provide useful risk screening for water resource management, yet current performance remains insufficient for a fully reliable early-warning system.

LID 1003
A coupled SWAP–MODFLOW framework for evaluating Ag-MAR strategies in rice-growing areas

Giulio Gilardi[1], Daniele Pedretti[2], Michael Valtorta[3], Petra Baják[2]*, Lorenzo Sangalli[2], Marco Masetti[2], Darya Tkachenko[1], Alessandro Sorichetta[2], Arianna Facchi[1]

[1] Università degli Studi di Milano (UNIMI), Department of Agricultural and Environmental Sciences – Production, Landscape, Agroenergy (DiSAA), Milan, Italy
[2] Università degli Studi di Milano (UNIMI), Department of Earth Sciences 'Ardito Desio' (DiSTAD), Milan, Italy
[3] Stantec Ltd., Milan, Italy
* petra.bajak@unimi.it

Keywords: Ag-MAR, irrigation scenarios, sustainable water management, agro-hydrological model, groundwater flow model

Rice-growing regions require irrigation strategies that satisfy crop water demand while sustaining groundwater recharge and improving resilience to water scarcity. Agricultural Managed Aquifer Recharge (Ag-MAR), which involves intentionally flooding agricultural land in winter to enhance groundwater replenishment, has recently emerged as a promising approach. However, quantifying the hydrological benefits of Ag-MAR remains challenging due to the strong nonlinear interactions between irrigation and subsurface processes.

This study presents an integrated agro-hydrological and groundwater modeling framework developed to evaluate Ag-MAR strategies in the 1,250 km^2 Lomellina area in northern Italy, located within Europe's largest rice-growing district. The framework couples QGIS-SWAP-Paddy (a GIS-integrated, semi-distributed version of the SWAP model (https://www.swap.alterra.nl/) to simulate irrigation and groundwater recharge, with MODFLOW-6 to simulate groundwater flow. QGIS-SWAP-Paddy simulates transient net percolation rates from agricultural fields and irrigation canals, considering land use, soil variability, groundwater depth, agro-meteorological conditions and irrigation management. MODFLOW-6 uses these percolation rates as recharge rates to reproduce seasonal and interannual groundwater dynamics across the area.

As recharge rates and groundwater levels are strongly interdependent, feedback between the two models is considered to improve estimation of both percolation rates and the groundwater balance. Calibration and validation against irrigation discharge data and observed groundwater levels (2018–2020) allowed a successful simulation of the irrigation water needs and groundwater seasonal fluctuations.

The modeling framework proved to be a powerful tool for forecasting the impact of irrigation management strategies, such as Ag-MAR (e.g. winter flooding of rice paddies) or 'water-saving' strategies (e.g. Alternate Wetting and Drying), on the entire water resource system in lowland irrigated rice areas.

This study was conducted within the framework of two projects: (1) the PROMEDRICE project (PRIMA-Section2–2022), funded for the Italian partners by the Italian Ministry of University and Research (MUR), and (2) the project "Applicazione di metodi di statistica spaziale per la valutazione della vulnerabilità e disponibilità della risorsa idrica sotterranea in diversi contesti idrogeologici", funded by the "Piano di Sostegno alla Ricerca (PSR Linea 4)" of the University of Milan.

LID 1004
PFAS and pesticides in Dutch groundwater under sandy soils

Nienke Kamstra[1]*, Tano Kivits[1]

[1] TNO Geological survey of The Netherlands, Utrecht, The Netherlands
* nienke.kamstra@tno.nl

Keywords: groundwater quality, PFAS and pesticides, age dating

The occurrence of pesticides and emerging contaminants such as PFAS in groundwater systems is a concern due to their possible adverse health effects and their persistence in the environment. Therefore, monitoring and analyzing these contaminants is important for understanding their behavior in the subsurface and groundwater.

For the provinces of Noord Brabant and Limburg (The Netherlands), recharge years were determined in earlier research using the $^{3}H/^{3}He$ method. In this study, the most recent measuring round, with particular attention to PFAS, pesticides, and other contaminants, is analyzed using the method published by [1]. The method allows contaminants to be related to their redox status, land use, and recharge year. Therefore, this approach enables an interpretation of the mobility and persistence of these substances in the groundwater. The results are presented in colour-coded tables, which facilitates an overview of the patterns in the occurrence of the measured contaminants.

The results indicate a high frequency of PFAS in groundwater with relatively young recharge years. In addition, the results also show that certain pesticides and PFAS stay in the groundwater for a long period of time, highlighting potential concerns for groundwater quality.

Reference:

[1] Broers, H. P., Kivits, T., Sültenfuß, J., Ten Harkel, M., & van Vliet, M. (2024). Mobility and persistence of pesticides and emerging contaminants in age-dated and redox-classified groundwater under a range of land use types. Science of The Total Environment, 954, 176344.

LID 1005
Assessing baseflow and groundwater-level declines in the Requena-Utiel aquifer system using TETIS-derived recharge

Diego Meléndez-Saldaña[1]*, Félix Francés[1], Eduardo Cassiraga[2], J. Jaime Gómez-Hernández[2]

[1] Research Group of Hydrological and Environmental Modelling (GIMHA), Universitat Politècnica de València, Valencia, Spain
[2] Research Group of Hydrogeology (GH), Research Institute of Water and Environmental Engineering (IIAMA), Universitat Politècnica de València, Valencia, Spain
* damelsal@upv.edu.es

Keywords: groundwater overexploitation, baseflow decline, TETIS

The Requena-Utiel region has historically been characterized by rainfed viticultural production. Since the 1980s, however, groundwater exploitation has progressively increased, intensifying after 2000 with the expansion of modern irrigation systems and currently exceeding thousand registered wells. Concurrently, significant declines have been observed both in the discharge of the Magro River in dry periods and in the piezometric levels of the Cretaceous aquifer.

Although these declines are commonly attributed to groundwater overexploitation, their assessment requires a groundwater flow model capable of reproducing both piezometric evolution and baseflow dynamics. Previous modeling studies in the area have been hindered by limited geological and piezometric information, as well as uncertainties in pumping rates and extraction depths. In this study, recharge estimated with the distributed hydrological model TETIS was incorporated into a MODFLOW model together with pilot-point parameterization and PEST-based calibration.

The results indicate that the decline in piezometric levels within the Cretaceous aquifer is primarily associated with groundwater overexploitation, which may also contribute to the observed changes in baseflow dynamics through a reduction in hydrological buffering capacity within the shallow groundwater system. These findings are consistent with the presence of a marl-clay formation that likely restricts the hydraulic connection between the deep and shallow aquifers, suggesting partially differentiated responses between groundwater depletion and baseflow dynamics.

LID 1006
Methodology for assessing groundwater balance in Quaternary groundwater bodies in the Czech Republic

Ondřej Nol[1,2]*, Martin Zrzavecký[3], Vratislav Žabka[1], Jiří Burda[1]

[1] Czech Geological Survey, Prague, Czech Republic
[2] Faculty of Science, Charles University, Prague, Czech Republic
[3] Czech Hydrometeorological Institute, Prague, Czech Republic
* ondrej.nol@geology.cz

Keywords: groundwater balance, groundwater level, groundwater body

In the Czech Republic, the annual water management balance of groundwater quantity in groundwater bodies (GWBs) is assessed as the ratio of total groundwater abstractions to natural resources estimated from baseflow (BF) separated from total runoff by the Czech Hydrometeorological Institute. This approach is generally suitable for shallow groundwater systems without significant interaction with surface water but is less applicable to Quaternary GWBs, where groundwater balance assessment is complicated by multiple recharge and discharge pathways. Groundwater resources in Quaternary GWBs vary over time depending on recharge conditions and abstraction rates. Recharge may originate from precipitation, inflow from adjacent slopes and underlying GWBs, or infiltration from surface streams, while groundwater may also drain to underlying aquifers. Due to these complexities, annual BF evaluation is not performed for Quaternary GWBs.

In contrast, groundwater levels (GWLs) reflect the cumulative effects of recharge processes and groundwater exploitation. Therefore, GWLs are evaluated together with BF development in inflow and underlying GWBs, changes in surface water levels, and groundwater abstractions (GA). An important aspect is the analysis of GWL fluctuations at individual wells and between wells according to their hydrogeological setting and dominant fluctuation regime. The objective is to distinguish the effects of natural recharge and groundwater abstraction on GWL dynamics and to use these relationships for groundwater balance assessment in Quaternary GWBs.

The proposed assessment is based on comparing GWL and GA development during historical drought periods and during 2015–2020, when the lowest GWLs were recorded. Dry periods provide the best conditions for identifying the influence of abstraction on groundwater levels, while elevated abstraction rates during droughts verify the availability of groundwater resources for use. By comparing GA trends with GWL fluctuations, the impact of groundwater abstraction on groundwater balance was estimated.

Many Quaternary GWBs contain hydraulically separated wellfield areas or are divided by major watercourses. Therefore, several GWBs were subdivided into smaller assessment units that were evaluated separately.

LID 1007
Hydrodynamic controls on nearshore groundwater discharge: Implications for hydrogeochemical fluxes

Murugan Ramasamy[1]*, Nils Moosdorf[1,2]

[1] Leibniz Centre for Tropical Marine Research (ZMT), Bremen, Germany
[2] Institute of Geosciences, Kiel University, Kiel, Germany
* murugan.ramasamy@leibniz-zmt.de

Keywords: land-ocean flux, tidal forcing, groundwater–seawater interaction

Coastal fresh groundwater discharge is an important land-to-sea pathway, but its nearshore spatial organization remains poorly constrained. In particular, the combined influence of tidal forcing and coastal aquifer properties on the location, magnitude, and offshore extent of fresh groundwater discharge is not well understood. Because fresh groundwater discharge also transports dissolved constituents, these spatial patterns have important implications for coastal hydrogeochemical fluxes. To address this gap, we applied an idealized density-dependent groundwater flow model to examine how tidal amplitude and hydraulic conductivity control fresh groundwater discharge across contrasting coastal aquifer settings. Simulations show that fresh groundwater discharge is strongly concentrated near the shoreline and decreases rapidly offshore, indicating that discharge is confined to a narrow nearshore transition corridor. The magnitude and decay structure of discharge vary substantially with hydraulic conductivity, with the strongest and most spatially extended fluxes occurring under high-permeability conditions. Tidal forcing further redistributes nearshore flow and modifies the offshore decay pattern, demonstrating that marine forcing actively reorganizes groundwater discharge rather than acting only as a boundary fluctuation. These results suggest that shallow coastal aquifers operate as narrow transition zones where fresh groundwater discharge and associated dissolved matter fluxes become spatially concentrated before discharge to coastal waters.

LID 1008
Factors influencing organisational purchasing practices in the handpump supply chain and their implications for quality assurance

Mahilet Berihun[1]*, Katherine Pond[1], Donya Hajializadeh[1] , Donald John Macallister[2], Kerstin Danert[3]

[1] University of Surrey, Surrey, United Kingdom
[2] British Geological Survey, The Lyell Centre, Edinburgh, United Kingdom
[3] AskForWater Ltd, Edinburgh, United Kingdom
* m.berihun@surrey.ac.uk

Keywords: handpumps, quality assurance, rural water supply

Handpumps have played a pivotal role in providing safe and reliable drinking water to rural communities around the world. Despite this, concerns surrounding the reliability of services provided by handpumps continue to persist, especially in sub-saharan Africa. Whilst various attempts have been made to tackle the issue of reliability, less attention has been paid to how organisations in the handpump supply chain approach quality assurance.

This poster draws on qualitative research conducted with 26 participants from 19 organisations working in sub-saharan Africa to examine factors influencing organisational purchasing practices in the handpump supply chain and the implications these factors have for quality assurance. Data was generated through in-depth interviews with staff from drilling contractors, NGOs installing or maintaining handpumps and retailers.

Findings revealed that organisations are making purchasing decisions under a wide range of contextual influences which restrict options available for buyers. Contextual constraints, such as security issues and access to foreign exchange, prevent organisations from accessing desired suppliers and products, including corrosion resistant materials. Participants also linked funding restrictions to the creation of an environment which enables supplier opportunism, consequently leading to the purchase of cheap sub-standard parts.

We also found that there were diverging views on both buyer-supplier relationships and reliability of external quality assurance practices such as certifications. As such, some organisations are relying on their own experience to navigate an unregulated market with cheap sub-standard imports and in-country fabrications.

These findings emphasise the need for all explorations and interventions into improving quality assurance practices to account for broader contextual factors in which organisations operate.

LID 1009
Numerical modelling of typical geothermal reservoirs of the Pannonian Basin – Handling challenges and uncertainties in early exploration

Koppány Földvári[1]*, Péter Tóth[2], Márk Lakos[2], István Vass[1], Adrienn Mártonné Szekszárdi[1]

[1] MOL Upstream Zrt., Budapest, Hungary
[2] Rock Flow Dynamics, Budapest, Hungary
* jfoldvari@mol.hu

Keywords: geothermal reservoir model, static model, uncertainty, dynamic simulation

Both the geothermal and petroleum industries often exploit the same reservoirs. However, they typically focus on different aspects and properties of the subsurface. In most cases geothermal exploration in a certain area relies on data acquired during former petroleum exploration activities. Nonetheless, due to the differences in investigation objectives and priorities, the dataset often lacks crucial information required for a detailed geothermal reservoir assessment.

Seismic and well-log data offer invaluable information for geothermal subsurface characterization allowing reservoir evaluation with a certain degree of confidence. Additional data that are important for geothermal assessment are often poorly defined or completely unavailable; hence can only be acquired during later stages of exploration (extended well test information, rock specific heat capacity etc.). To mitigate risks imposed by information quality and availability, and to support decision making; uncertainties have to be handled with preliminary modelling based on the available data.

In this study we present a couple of practical examples highlighting how the data gaps and modelling challenges can be addressed, particularly with respect to the expected numerical ranges and spatial distributions of some critical reservoir parameters, such as porosity and permeability. We further demonstrate how uncertainties can be characterized and incorporated into static modelling and dynamic simulation workflows using RFD's tNavigator® software. By performing several iterations and realizations ensembles of models may also be carried out for geothermal reservoirs.

LID 1011
Electromagnetic Odyssey: An educative video game to learn how to set up geophysical soundings for groundwater exploration

Diego Ruiz-Aguilar[1]*, Katya Álvarez-Molina[2], Luis Romero-Ramos[3], Guillermo Sánchez Basoco[3], Alejandro Méndez González[3]

[1] Departamento de Geofísica Aplicada, Ensenada, Mexico
[2] Unidad Académica Tepic, CICESE, Tepic, Nayarit, Mexico
[3] Centro Multimedia, Centro Nacional de las Artes, Ciudad de México, Mexico
* druiz@cicese.mx

Keywords: serious video games, hydrogeophysics

In the education of Hydrogeophysics, innovative learning tools are essential to bridge the gap between theory and practical field experience. Fieldwork is critical for reinforcing classroom knowledge and fostering peer interactions. However, it faces financial costs, physical accessibility, and logistical challenges, which can deter student participation and create equity concerns.

To address these issues, adaptable educational models and digitalization are crucial. Integrating Information and Communication Technologies (ICT) has significantly enhanced learning processes, with alternatives like recorded fieldwork videos, high-resolution imagery, and virtual outcrop models gaining prominence, particularly during the COVID-19 pandemic. Through thoughtful design, video games offer educational potential by enhancing motivation and engagement.

In this regard, we introduce Electromagnetic Odyssey, an immersive learning tool to overcome traditional field trips' financial and logistical constraints. This video game considers the application of Electromagnetic methods for groundwater exploration. Electromagnetic Odyssey aims to promote equitable access to quality education and motivate students through well-designed, technology-enhanced activities, aligning with educational principles emphasizing motivation's importance in learning. The video game has been successfully used by students of geosciences from different universities of Mexico and other countries of Latin America.

LID 1013
Systematic nitrate monitoring in a volcanic fractured aquifer in Southern Brazil: Sources, pathways, and water security implications

Camila Müller[1]*, Gustavo Athayde[1]

[1] Hydrogeological Research Laboratory - UFPR, Curitiba, Brazil
* camilavmuller@ufpr.br

Keywords: nitrate, fractured aquifer, Brazil

Systematic monitoring of nitrate concentrations in 37 tubewell wells in a volcanic fractured aquifer located in southern Brazil revealed the element's presence in all sampled sites, with levels ranging from 1.02 to 27.78 mg L^{-1}. Notably, the highest concentrations areas coincide with the most productive wells zones (up to 200 m^3 h^{-1}), posing a direct challenge to regional water security. Quarterly hydrogeochemical monitoring since 2019 (January, April, July, and October) indicates that nitrate fluctuations are linked to aquifer recharge periods. This dynamic is evidenced by lower concentrations during October samplings and by increased surface water concentrations driven by runoff in a monitored first order basin. Boron and nitrogen isotopes identified distinct nitrate sources: domestic chemical detergents and synthetic fertilizers prevail in urban sectors, whereas septic tanks, animal manure, and fertilizers dominate rural areas. Wells with active hydraulic zones shallower than 50 meters display higher nitrate levels compared to those with main flows exceeding 120 meters. In these shallow flows, correlation analyses associate nitrate with potassium and phosphate, alongside a higher occurrence of emerging micropollutants (herbicides, hormones, and lifestyle compounds) at maximum nanogram per liter concentrations. Conversely, groundwater with lower percentages of modern carbon (between 12% and 55%) exhibits the lowest concentrations of nitrate and micropollutants. Integrating hydrogeochemical and isotopic data successfully delineated the sources and pathways of nitrate into the groundwater system. These findings provide critical insights for protecting an aquifer that supplies 90% of the local population.

LID 1014
Scaling up hydrogeological science: How 8 years of aquifer monitoring drove research in Paraná state, Brazil

Gustavo Athayde[1]*, Camila Müller[1]

[1] Hydrogeological Research Laboratory - UFPR, Curitiba, Brazil
* gustavo.athayde@ufpr.br

Keywords: monitoring, fractured aquifer, Brazil

Effective management requires the continuous refinement of conceptual models using empirical monitoring data. This study presents the evolution of aquifer monitoring in Paraná, integrating the HIDROSFERA and SEG.HIDRO Projects. The Hydrogeological Research Laboratory created a framework for fractured aquifers in volcanic rocks that incorporates data acquisition, processing, and interpretation. It combines hydrodynamic data (static level fluctuations), hydrogeochemical data (quarterly multielement monitoring), and remote sensing to estimate monthly potential recharge. In the HIDROSFERA Project, static level variations ranged from 0.6 to 10.2 meters, with the smallest amplitudes trending north-northwest. Hydrochemical monitoring showed mainly calcium-bicarbonate water in shallow flows (to 50 meters), and sodium-bicarbonate water, higher pH, more sulfate, carbonates, vanadium, and older C14 ages (near 10,000 years) in deeper flows over 120 meters. In shallow flows, nitrate levels exceeded 20 mg/L and appeared with micropollutants such as hormones, lifestyle compounds, and herbicides. Nitrogen and boron isotopes pointed to sewage contamination in urban areas and agricultural sources in rural wells. Public dissemination included e-books, an atlas, and documentaries. The SEG.HIDRO Project expanded hydrochemical analysis to 1,250 wells and 60 springs, building a regional hydrodynamic monitoring network. The methodology now characterizes porous aquifers through well logging and X-ray microtomography (microCT) to refine parameters and improve the Water Table Fluctuation (WTF) method. CFC, SF6, and tritium data will track short transit times. Acquiring primary, systematic data remains key to improving conceptual models and ensuring a reliable baseline for groundwater governance. Thanks to all the researchers from the HIDROSFERA and SEG.HIDRO projects.

LID 1017
Groundwater resource assessment for sustainable livestock water supply in Khanbogd Soum, Mongolia

Buyankhishig Nemer[1]*, D. Enkhbayar[1], M. Aley[1], B. Uugankhuu[1]

[1] Mongolian University of Science and Technology, Ulaanbaatar, Mongolia
* bbn@must.edu.mn

Keywords: nomadic pastoralism, rangeland degradation, water-point management, shallow aquifer

Mongolia is one of the few countries where nomadic pastoralism remains the dominant livestock production system. This traditional system relies on natural rangelands and has long supported the sustainable use of arid and semi-arid environments. However, livestock production is highly dependent on water resources and is particularly vulnerable to climate change. Inadequate groundwater development practices, including drilling wells without hydrogeological investigations, constructing duplicate wells, and developing low-yield wells, have contributed to localized rangeland degradation. This study aimed to assess groundwater resources for sustainable livestock water supply in Khanbogd soum, Umnugobi aimag, Mongolia. Livestock water demand and groundwater quality were evaluated, and the potential of shallow aquifers was assessed to determine appropriate water-point management strategies. According to the 2023 livestock census, Khanbogd soum had 164,176 livestock distributed among five administrative units. Estimated water demand analysis showed that camels account for 64.4% of total livestock water consumption, followed by small ruminants (21.3%), horses (8.6%), and cattle (5.7%). The total livestock population requires approximately 3,449 m^3/day (39.92 L/s) of water. The hydrogeological assessment revealed renewable groundwater resources of 191,160.85 m^3/day (2,212.5 L/s) and exploitable groundwater resources of 58,470.34 m^3/day (676.74 L/s), both substantially exceeding current livestock water demand. Hydrochemical analyses indicated that shallow groundwater is predominantly of the sodium-bicarbonate type with relatively good quality, whereas deeper groundwater is characterized by sodium-sulfate and sodium-chloride facies with higher mineralization. The results demonstrate that existing groundwater resources are sufficient to support current livestock water demand in Khanbogd soum. Nevertheless, more detailed assessments are recommended in areas with concentrated grazing pressure to improve water management, reduce rangeland degradation and desertification, and enhance the resilience of pastoral systems to climate change.

LID 1018
Process-based MODFLOW assessment of river–aquifer–coast interactions and recharge sensitivity in the Al-Hsain Coastal Basin, Syria

Mahmoud Ahmad[1]*, Katalin Bene[1], Richard Ray

[1] Széchenyi István University of Győr, Győr, Hungary
* mahmoud.ahmad@sze.hu

Keywords: MODFLOW, coastal aquifer, river–aquifer interaction, recharge sensitivity, groundwater management

Coastal aquifers in the Mediterranean are increasingly affected by seasonal recharge variability, agricultural groundwater use, and interactions among rivers, shallow aquifers, and the sea. In the coastal plain of the Al-Hsain Basin, Syria, previous hydrogeological studies have shown clear spatial differences in groundwater levels. However, the processes controlling groundwater-flow paths, river–aquifer exchange, coastal discharge, and recharge sensitivity remain poorly quantified. This study develops a MODFLOW groundwater-flow model to improve understanding of the basin and support groundwater management decisions. The model combines groundwater-head observations from the monitoring-well network with geological and hydrostratigraphic information, topography, rainfall-derived recharge, river geometry, and coastal boundary conditions. These data are organized within a GIS-supported workflow and used to build the conceptual and numerical models. The conceptual model represents the main Quaternary, Neogene, and carbonate units, while the numerical model simulates groundwater flow under recharge, river, lateral-flow, and coastal constant-head boundary conditions. Calibration against observed heads is supported by residual mapping, water-budget analysis, and sensitivity tests for recharge, hydraulic conductivity, riverbed conductance, and abstraction assumptions. The study evaluates groundwater flow directions, the gaining or losing behavior of the Al-Hsain River, the main components of the water budget, and the areas most sensitive to reduced recharge and abstraction stress. Expected outputs include hydraulic-head maps, groundwater flow directions, river-leakage estimates, recharge and discharge zones, stress-scenario water budgets, and management-priority maps. Overall, the framework provides a practical basis for assessing groundwater dynamics in data-limited Mediterranean coastal aquifers and supporting groundwater-management decisions.

LID 1019
High-resolution conceptual modeling for improved numerical simulation of seawater intrusion in karst coastal aquifers

Mostafa F. Mostafa[1]*, Isabella Serena Liso[1], Hervé Jourde[2], Mario Parise[1]

[1] Earth and Environmental Sciences Department, University Aldo Moro, Bari, Italy
[2] HSM, Univ Montpellier, CNRS, IRD, IMT Mines Alès, Montpellier, France
* mostafa.mohammed@uniba.it

Keywords: karst aquifer, Seawater Intrusions (SWI), numerical modeling, conceptual model , Random Forest (RF)

Karst aquifers show strong spatial contrasts in hydraulic and petrophysical properties, even during early karstification. Numerical simulation is difficult where structural and tectonic controls vary with depth and where surface and subsurface karst features influence groundwater flow. This is especially relevant for density-dependent modeling of seawater intrusion. This study presents a workflow for developing a groundwater model from a high-resolution conceptual model integrating digital elevation data, geological maps, borehole data, and geomorphological analysis. The model was discretized into eleven vertical slices, from +130 to −250 m MSL, to represent 3D aquifer architecture. Boundary conditions included constant-head coastal boundaries for marine interaction and spatially distributed land-surface recharge. Hydraulic conductivity was parameterized in 3D using geostatistical interpolation. The steady-state simulation produced hydraulic heads from −0.002 to +10.61 m MSL. The near-zero coastal minimum indicates groundwater levels close to sea level, whereas the maximum head represents inland recharge-influenced zones. The numerical net imbalance was -2.2038×10^{-5}, indicating negligible mass-balance error and a stable solution. Model performance was evaluated against observed heads from seven monitoring wells using mean and median values. Simulated and observed heads agreed well, with residuals mostly within ±1 m. The largest deviations, about 0.8–0.9 m, occurred at few sites and are reasonable for a subregional fractured/karst coastal aquifer, where local gradients may reflect structural heterogeneity, anisotropy, recharge variability, and scale-dependent conductivity contrasts. Overall, the residual distribution supports the model as a physically plausible baseline for transient and density-dependent seawater-intrusion simulations, while indicating that local fit could be improved by refining hydraulic conductivity, recharge, and boundary representation.

LID 1020
Hydrogeological controls on cover clay performance in the Oyu Tolgoi tailing storage facilities, Mongolia

Buyankhishig Nemer[1]*, A. Erdenetsetseg[1], M. Tulga[1], A. Khandsuren[1], T. Tamir[1]

[1] Mongolian University of Science and Technology, Ulaanbaatar, Mongolia
* bbn@must.edu.mn

Keywords: groundwater, pond water, clay behavior, hydrochemical interaction

The long-term integrity of tailings storage facility cover systems in arid regions is influenced by the interaction between cover materials, tailings pond water, and regional groundwater. This study investigates the hydrogeological and geotechnical characteristics of cover clay used in the Oyu Tolgoi tailings, located in the South Gobi region of Mongolia. Regional groundwater is characterized by Na–Cl–SO_4 hydrochemical facies with total dissolved solids (TDS) ranging from 1.7 to 4.3 g/L. In contrast, tailing pond water exhibits higher salinity and alkalinity, with TDS values of 5.1–6.4 g/L, Na concentrations of 1380–1742 mg/L, SO_4 concentrations of 2179–2510 mg/L, and pH values reaching 10.7. These hydrochemical conditions indicate a persistent sodium-rich environment that may influence the long-term behavior of clay barriers. The cover material is predominantly fine-grained, with an average fines content of 86.6%, liquid limit of 57.4%, plasticity index of 33.0%, and specific gravity of 2.72. More than 90% of the samples were classified as CH (high-plasticity clay). Field measurements showed an average relative compaction of 98.5%, while consolidated-undrained triaxial tests yielded effective friction angles of 9.9–25.9° and effective cohesion values of 9.6–70.6 kPa. The results indicate that the cover clay provides favorable hydraulic barrier characteristics and adequate mechanical performance under current conditions. However, the coexistence of naturally saline groundwater, highly saline pond water, and an extreme arid climate characterized by strong evaporation, seasonal drying, and freeze–thaw cycles may promote shrink–swell behavior, desiccation cracking, and preferential flow development. These processes could locally reduce barrier effectiveness and influence long-term seepage pathways. This study demonstrates the importance of integrating hydrogeological and geotechnical assessments to improve understanding of cover system performance and long-term containment reliability in arid-region tailing storage facilities.

LID 1021
Coupling SWAT-MODFLOW for assessing surface-groundwater nitrate pollution in a semi-arid region

Valentina Urrea[1,2]*, Laura Del Val[1]

[1] Eurecat, Centre Tecnològic de Catalunya, Water, Air and Soil Technological Unit, Manresa, Spain
[2] Departament d'Enginyeria Civil i Ambiental, Universitat Politècnica de Catalunya (UPC), Campus Diagonal Nord, Edifici C2, Jordi Girona, 1-3 Barcelona, Spain
* valentina.urrea@eurecat.org

Keywords: groundwater-surface water coupling, complex hydrogeology, SWAT-MODFLOW

Integrated modelling of surface and groundwater hydrological processes is essential for assessing water dynamics and nitrate transport in agricultural catchments subject to high climatic variability. This study develops and applies a coupled SWAT-MODFLOW model to the Sió and Ondara-Corb catchment areas, as well as to their groundwater body associated with the Tàrrega calcareous aquifer, in Catalonia, Spain. The study area represents a complex hydrogeological system, characterised by predominantly agricultural activity, the presence of shallow alluvial aquifers in the river valleys, and a deep calcareous aquifer, partially confined by discontinuous layers of marl. Added to this structural complexity is a Mediterranean climate with marked interannual variability, alternating episodes of heavy rainfall and prolonged periods of drought, during which the water table may drop and create conditions of hydraulic disconnection between the river and the aquifer.

Within this framework, SWAT is applied at the catchment scale to simulate surface hydrology, agricultural management, recharge, and diffuse nitrate leaching, while MODFLOW is implemented as a nested model within a critical zone distinguished by high hydrogeological vulnerability and elevated nitrate concentrations. The assessment of the applicability of the SWAT-MODFLOW coupling focuses on a Mediterranean agricultural system where river-aquifer connectivity is not permanent but varies temporally in response to droughts, recharge events, and changes in hydraulic gradients. Under these conditions, river–aquifer exchanges cease to respond linearly to the hydraulic gradient and may be controlled by limited losses from the river, storage in the unsaturated zone, and temporal variations in hydrological connectivity.

This coupling allows for a spatially and temporally distributed analysis of the processes that govern hydraulic gradients, groundwater flows, and the transfer of NO_3^- from agricultural areas to aquifers, river courses, and their exchange. This approach provides a tool for assessing the system's response to droughts, recharge events, and changes in river-aquifer connectivity, helping to improve our understanding of the mechanisms regulating nitrate pollution in agricultural systems with complex hydrogeology.

LID 1022
Probabilistic assessment of fault-controlled hydraulic connectivity in Tunisian aquifer systems using a Monte Carlo-machine learning workflow

Khaoula Charrek[1,2,3]*, Thomas Hermans[2], Kristine Walraevens[2], Hakim Gabtni[1]

[1] Georesources Laboratory, Research Center for Water Technologies, Soliman, Tunisia, Soliman, Tunisia
[2] Laboratory for Applied Geology and Hydrogeology, Department of Geology, Ghent University, Campus Sterre, Krijgslaan, Gent, Belgium
[3] Faculty of Sciences of Tunis, Tunis El Manar University, Tunis, Tunisia
* khaoula.charrek@ugent.be

Keywords: aquifer systems, fault hydraulic behavior, probabilistic hydrogeology, Monte Carlo simulation, machine learning, groundwater connectivity

Groundwater management in multilayer sedimentary basins requires understanding fault hydraulic behavior, yet potential hydraulic connectivity remains poorly constrained at regional scale. In the Sahel of Sousse (Tunisia), the DGRE's 2024 transition toward an aquifer-system framework has made structural controls on inter-unit communication a priority for groundwater management and hydrogeological subdivision.

This study presents a probabilistic workflow combining spatially correlated Monte Carlo simulation and machine learning to evaluate potential fault-controlled hydraulic connectivity at basin scale. Fault traces derived from gravity-based Euler deconvolution and tilt-derivative analysis constrained by structural-geological setting were sampled at 100 m intervals across six depth slices (100–1200m). Lithological juxtaposition was assessed using a 3D stratigraphic model integrating the Oligocene to Quaternary successions, while Shale Gouge Ratio quantified fault-sealing potential. A spatially correlated Monte Carlo framework (500 realizations) propagated uncertainty through stratigraphic surfaces, producing probabilistic connectivity classes for each fault segment. An XGBoost surrogate model enabled rapid regional screening without rerunning the full stochastic workflow. UMAP clustering identified four recurrent classes of fault hydraulic behavior: conduit, barrier, transitional, and depth-dependent.

Results indicate predominantly barrier-like behavior across much of the fault network, whereas higher probabilities of hydraulic communication are concentrated within localized structural corridors and decrease with depth. The probabilistic framework provides new structural constraints for aquifer-system delineation and uncertainty-aware groundwater conceptualization within the evolving DGRE hydrogeological framework.

LID 1023
A flowchart-based framework for decision-support groundwater modeling

Alexandre Pryet[1]*

[1] EPOC Laboratory UMR 5805, Univ. Bordeaux, CNRS, Bordeaux INP, Pessac, France
* alexandre.pryet@bordeaux-inp.fr

Keywords: groundwater modeling, decision support, history matching, uncertainty quantification, data-worth

Groundwater models developed for decision support must provide robust estimates of variables of interest using transparent and reproducible methods. This study proposes a workflow in which the modeling process is organized as a flowchart integrating model development, history matching, uncertainty quantification, and data-worth analysis.

The workflow starts with the definition of the variable of interest with stakeholders, which guides the initial data collection strategy. Model development is then focused on estimating this variable given the available information. Once model development is completed, an algorithm is used for history matching. The first decision node concerns the outcome of this step. If an acceptable fit to relevant observations cannot be achieved through parameter adjustment, it suggests structural deficiencies in the model and the conceptualization must be revised. If history matching is successful, uncertainty quantification is performed for the variable of interest.

The second decision node evaluates whether predictive uncertainty is sufficiently small to support decision. If uncertainty remains too large, additional data collection is required. Data-worth analysis is used to identify the observations most likely to reduce uncertainty in the prediction of interest. The workflow is then iterated through data acquisition, model updating, and uncertainty quantification until it reaches an acceptable level. The resulting estimate can then be delivered to stakeholders together with a quantitative measure of confidence.

The proposed framework links groundwater modeling and supporting algorithms within a coherent decision-support strategy. It has been successfully implemented using open-source software in a real-world groundwater management study aimed at estimating sustainable yield. The workflow provides practitioners with a practical methodology for model development, targeted data acquisition, and the delivery of defensible predictions for groundwater management.

LID 1024
The hot side of geothermal applications

Arpad Forberger[1]*

[1] SciEngineer Kft., Budapest, Hungary
* arpad.forberger@sciengineer.com

Keywords: heat exchanger, enhanced geothermal systems, subsurface

Geothermal energy systems involve strongly coupled thermal, hydraulic, mechanical, and chemical processes that span multiple spatial and temporal scales. As the geothermal industry advances from conventional hydrothermal resources toward enhanced geothermal systems (EGS), superhot rock technologies, and integrated subsurface energy platforms, predictive multiphysics simulation has become essential for design, optimization, and long-term performance assessment. COMSOL Multiphysics® provides a unified framework for modeling these complex interactions, enabling researchers and engineers to analyze heat transfer, porous and fractured media flow, rock mechanics, groundwater transport, and coupled thermo-hydro-mechanical-chemical (THMC) phenomena within a single simulation environment.

COMSOL's capabilities support a broad range of geothermal applications, including shallow borehole heat exchangers, hydrothermal doublets, groundwater-assisted heat extraction systems, and next-generation EGS reservoirs. The platform allows users to couple conductive, convective, and dispersive heat transport with fluid flow in porous and fractured formations while accounting for temperature-dependent material properties, permeability evolution, and geomechanical effects. Such multiphysics coupling is increasingly critical for evaluating reservoir connectivity, conductivity, and conformance—key factors governing geothermal system efficiency and sustainability.

Recent insights from the 51st Stanford Geothermal Workshop highlight the growing need for integrated simulation workflows as geothermal development targets deeper, hotter, and more complex reservoirs. COMSOL enables the investigation of fracture stimulation, well placement strategies, thermal recovery, reservoir depletion, and superhot rock concepts by combining advanced finite-element methods with flexible multiphysics coupling. Example applications include modeling thermal interactions among borehole arrays, groundwater-driven heat transport, fractured reservoir behavior, and long-term thermal performance under realistic environmental conditions.

By providing a comprehensive environment for coupled geothermal analyses, COMSOL Multiphysics serves as a powerful tool for reducing uncertainty, accelerating design decisions, and supporting the development of scalable, data-driven geothermal technologies. Its ability to integrate multiple physical domains within a single model makes it particularly well suited for addressing the challenges of next-generation geothermal energy systems and advancing the transition toward reliable, low-carbon baseload energy production.

LID 1026
Hydrochemical and isotopic evidence of groundwater connectivity in Caroch Sur aquifer (SE Spain)

Jorge Hornero[1*], Bruno Ballesteros[2], Luis Solis[3], Marta Domínguez[2], José Antonio Domínguez[2]

[1] Instituto Geológico y Minero de España-CSIC, Murcia, Spain
[2] Instituto Geológico y Minero de España-CSIC, Valencia, Spain
[3] Senior Hydrogeologist Consultant, Murcia, Spain
* j.hornero@igme.es

Keywords: hydrogeochemistry, environmental isotopes, Caroch Sur

This study investigates the hydrogeological functioning of the Caroch Sur aquifer (SE Spain) through the integration of hydrochemical and environmental isotopic data collected from wells, boreholes and springs distributed across the aquifer system. The main objective is to improve the understanding of groundwater flow patterns, recharge areas and hydraulic connectivity between the different hydrostratigraphic units that compose the fractured rock system.

Hydrochemical and isotopic information was used to refine the hydrogeological characterization, providing insights into groundwater origin, circulation pathways and recharge conditions. Particular attention was given to assessing the potential hydraulic relationship between the Aptian aquifer and the Upper Cretaceous carbonate formations.

The spatial distribution of hydrochemical and isotopic signatures was analysed to identify possible groundwater transfers from formations located to the north and northwest of the aquifer and to define the main groundwater flow directions. In addition, the study aims to discriminate groundwater sources and flow trajectories within the aquifer system.

The resulting hydrogeological conceptual model provides new evidence regarding groundwater circulation and aquifer connectivity within Caroch Sur aquifer. Particular emphasis is placed on evaluating whether the identified flow systems can explain groundwater discharge in strategic sectors of the aquifer, principally the Los Santos spring area.

The results demonstrate the value of combining hydrochemical and isotopic tracers to support groundwater resource assessment and improve the understanding of complex carbonate aquifer systems. To further assess the consistency of the interpretations derived from hydrochemical and isotopic evidence, an independent groundwater flow model will be developed. Numerical flow simulations will be used to test the conceptual model, providing an additional information for the validation of the study results.

LID 1029
Tracking isotope and nitrate patterns of subsurface pathways in hilly catchments heavily affected by agriculture

József Deák[1]*, Zsolt Jolánkai[2], Adrienne Clement[2], Máté Kardos[2], Elemér László[4], László Palcsu[4], Mihály Molnár[4], István Fórizs[3], István Gábor Hatvani[3]

[1] GWIS Ltd, Veszprém, Hungary
[2] Budapest University of Technology and Economics, Budapest, Hungary
[3] Institute for Geological and Geochemical Research, HUN-REN Research Centre for Astronomy and Earth Sciences, Budapest, Hungary
[4] HUN-REN Institute for Nuclear Research, Debrecen, Hungary
* deak47jozsef@gmail.com

Keywords: groundwater nitrification, environmental isotopes, ^{14}C groundwater dating

In watersheds under agricultural cultivation, a significant proportion of the nitrogen load in watercourses originates from groundwater via base flow. This study aimed to understand the contribution of groundwater pathways to the riverine nitrogen load in the hilly Koppány catchment in Hungary, an area covering 660 km^2.

A targeted survey measuring nitrate content and environmental isotopes (^3H, ^{14}C, $\delta^{13}C$, δ^2H, $\delta^{18}O$, $\delta^{15}N_{NO3}$ and $\delta^{18}O_{NO3}$) of groundwater has been carried out in the Koppány catchment during the 2023-2024 period. Water samples have been collected from river base flow (67 samples), from shallow boreholes (48 samples) and deep wells (17 samples).

Strong negative gradient of nitrate was found towards the streams in water samples taken from the upper 1 meter of groundwater using manual groundwater exploration boreholes. Nitrate isotope analyses indicate denitrification in many cases similar to shallow groundwater monitoring wells.

Tritium and stable isotope studies have revealed very old, sometimes glacial infiltration water even in the upper 1 meter of the groundwater near the streams, indicating groundwater upwelling.

The ^{14}C age of the groundwater from the operating water production wells in the catchment area increases towards the Koppány stream, where it reaches the age of 20 thousand years. The ice age origin of these deeper groundwaters is also proven by the strongly negative δ^2H and $\delta^{18}O$ isotope data.

The research is co-funded by the National Research, Development and Innovation Office (OTKA project grant number SNN 143868), the National Agricultural Environmental Impact Monitoring and the IAEA RER7017 projects.

LID 1030
Use of isotope tools to prove the ice age origin and pristineness of the Minera mineral water in Albertirsa (Hungary)

József Deák[1]*, István Fórizs[2], Endre Csiszár[3], László Palcsu[4]

[1] GWIS Ltd., Veszprém, Hungary
[2] Institute for Geological and Geochemical Research, HUN-REN Research Centre for Astronomy and Earth Sciences, Budapest, Hungary
[3] Freelance hydrogeological engineer, Szeged, Hungary
[4] HUN-REN Institute for Nuclear Research, Debrecen, Hungary
* deak47jozsef@gmail.com

Keywords: Ice age groundwater, ^{14}C groundwater ages, noble gas temperature, stable isotopes, tritium

A recent survey of Pesticide Action Network Europe detected TFA (a pesticide derivative) in 10 out of 19 mineral waters (Perkins 2024; Pesticide Action Network Europe 2024). This startling finding calls the attention for the necessity to determine the origin and pristineness of the bottled mineral waters using scientific methods.

For this purpose, detailed investigation of the origin and pristineness of the Minera mineral water abstracted and bottled in Albertirsa (Hungary) was carried out, applying different methods: conceptual hydrogeological model. environmental isotopes, water chemistry and noble gas temperature (NGT).

The recharge area (Gödöllő Hills) of Minera water and the groundwater flow path were designated by conceptual hydrogeological model, and confirmed by the water isotopes and Noble Gas Temperature (NGT) data. The linear increase of ^{13}C corrected radiocarbon groundwater ages (from zero to 28 ka BP) indicated 1.5 m/a flow velocity along the flow path.

The decrease of NGT from 10.7 °C to 3.3 °C along the flow path, and the extreme negative δ^2H = -101.6 ‰ and $\delta^{18}O$ = -14.1 ‰ content (different from the values of δ^2H = -65‰ and $\delta^{18}O$ = -9.3 ‰ of the Holocene infiltration groundwaters in Hungary) confirm that the Minera groundwater was infiltrated during the Last Glacial Maximum (LGM).

Non detectable (<0.5 TU) tritium content of groundwater along the flow path proves the pristineness of Minera mineral water.

Based on the results of the above research, the bottler of Minera mineral water was granted permission to label its bottles as "pristine ice age water."

The research has been financed by the company Aqua Lorenzo Ltd, bottler of Minera mineral water.

LID 1031
Restoring hydrological balance through Nature-Based Solutions: Addressing groundwater overuse and rainfall underutilization

Musaed Aklan[1,2]*

[1] Sana'a Center for Strategic Studies, Sana'a, Yemen,
[2] Water and Environment Center, Sana'a University, Sana'a, Yemen
* musaedaklan@gmail.com

Keywords: Yemen, Nature-Based Solutions (NBS), groundwater depletion, rainwater harvesting, sustainability

Yemen is one of the most water scarce countries, facing severe water crises, driven by chronic groundwater overexploitation, limited surface water resources, and highly variable rainfall. Decades of unsustainable abstraction for agriculture, and urban expansion have led to rapidly declining aquifer levels, increasing pumping costs, and localized water scarcity across many governorates. Despite the country receiving episodic but often intense rainfall events, the potential for rainwater harvesting and natural recharge enhancement remains largely untapped.

This paper explores the role of Nature-Based Solutions (NBS) in restoring hydrological balance in Yemen by linking groundwater stability and recharge with improved management of rainfall. It examines practical interventions such as watershed restoration, terracing, reforestation, soil and water conservation measures, and the rehabilitation of indigenous water harvesting systems. These approaches can enhance infiltration, reduce runoff losses, and contribute to the gradual recovery of depleted aquifers while increasing community resilience to climate variability.

The study also highlights institutional, technical, and socio-economic barriers that limit the adoption of such NBS solution in Yemen, including climate change impacts, conflict-related governance constraints, lack of investment, and limited local capacity. Finally, it proposes an integrated water management framework that combines decentralized NBS interventions with community-based governance mechanisms to improve water security and long-term sustainability. The findings suggest that scaling up nature-based approaches offers a cost-effective and climate-resilient pathway for addressing Yemen’s groundwater crisis while maximizing the benefits of scarce and variable rainfall.

LID 1032

The potential impact of sand mining on water resources: A case study in the Mahalapye River Sub-Catchment as a conceptual foundation for numerical modelling of the Limpopo River Basin

Gaël Kobessen[1]*, David Walker[1], Sithabile Tirivarombo[1], Syed Mustafa[1]

[1] Wageningen University, Wageningen, The Netherlands

* gael.kobessen@wur.nl

Sand mining in southern Africa, driven by the construction sector's demand for river sediments, adversely impacts both water quality and quantity. The extraction, particularly through destructive methods like channel-wide instream mining, poses serious threats to river ecosystems, groundwater resources, and the livelihoods of communities dependent on them. This study aims to understand and evaluate both qualitative and quantitative impact of sand mining on the groundwater availability in the Limpopo River basin. A combined approach of field measurements, local community consultation, and numerical modelling is used to achieve the objectives. River sand extraction in the Mahalapye catchment was found to be extensive, in some cases reaching down to the crystalline basement material, severely altering the in-channel sediment thickness, and reducing the channel storage. Evaporation seems to be the main mechanism through which the channel-stored water is lost, as suggested by local people. Implementation and simulation of the evaporation processes showed a negative impact, leading to a decrease in groundwater level proportional to the simulated vertical mining extent. Upscaling this shows a significant decrease in groundwater level across the basin. These effects are recognized and validated by accounts of encountered local people. Additionally, the spatial severity of the impact is dependent on the surface geology, with the most severe impact occurring in ephemeral river channels. The study also showed that integrating local people's knowledge is crucial in conceptualizing and modelling sand mining processes. The findings of this study will aid in better understanding of the effect of sand mining in southern Africa or other semi-arid regions, thereby contributing to sustainable water resources management.

LID 1033
Groundwater-dependent ecosystems are a missing component of global research and policy agendas

Xander Huggins[1-4]*, Melissa M. Rohde[5], Robert Reinecke[6], Sebastian Gnann[7], Mattia Saccò[8-10], Grant C. Hose[11]

[1] School of Geographical and Earth Sciences, University of Glasgow, United Kingdom
[2] Institute for Resources, Environment, and Sustainability, University of British Columbia, Vancouver, Canada
[3] High Meadows Environmental Institute, Princeton University, Princeton, United States
[4] Stockholm Resilience Centre, Stockholm University, Stockholm, Sweden
[5] Rohde Environmental Consulting, Seattle, United States
[6] Institute of Geography, Johannes Gutenberg-University Mainz, Mainz, Germany
[7] Chair of Hydrology, University of Freiburg, Freiburg, Germany
[8] School of Molecular and Life Sciences, Curtin University, Perth, Western Australia, Australia
[9] Department of Chemistry, Life Sciences and Environmental Sustainability, University of Parma, Parma, Italy
[10] Laboratoire de Biologie des Organismes et des Ecosystèmes Aquatiques (BOREA), Paris, France
[11] School of Natural Sciences, Macquarie University, Sydney, New South Wales, Australia
* xander.huggins@glasgow.ac.uk

Keywords: groundwater-dependent ecosystems, global change, policy integration

A groundwater-dependent ecosystem (GDE) can be a stream sustained by groundwater, plants and terrestrial landscapes that rely on groundwater for root water uptake, or the biodiversity that lives within aquifers. These ecosystems perform a wide range of ecological, hydrological, biodiversity, and climate functions, and are places that are meaningful to people who interact with them through recreational, spiritual, and cultural practices. Traditionally studied at the local scale, GDEs are largely overlooked in global-scale research programmes and currently lack adequate incorporation in global environmental and sustainability policy agendas despite holding vast potential to enhance their outcomes. A number of global GDE studies have recently emerged, which have collectively highlighted how GDEs are globally prevalent, ecologically significant, and increasingly under threat. Here, we first synthesize early insights from this emerging set of global GDE studies and highlight fundamental contributions possible through global-scale GDE research. Secondly, we identify several global pressures facing GDEs and develop hypothetical hysteretic cause-effect relationships between external drivers and GDE conditions to stimulate future work. Thirdly, we highlight key interdisciplinary policy agendas whose robustness would be enhanced through the inclusion of GDEs. Fourthly, we conclude with key open research questions to guide a productive, policy-relevant, and needs-based future in global GDE scholarship.

LID 1034
Estimation of groundwater potential for solar pumping systems in Southern Madagascar using large water points database and machine learning

Fabio Fussi[1]*, Victor Gomez-Escalonilla[1], Miharitiana Virginie Ramanampihery[1], Jean-Jacques Rahobisoa[2], Pedro Martinez Santos[1]

[1] Departamento de Geodinámica, Estratigrafía y Paleontología, Facultad de Ciencias Geológicas, Universidad Complutense de Madrid, Madrid, Spain
[2] Department of Earth Sciences and Environment, Faculty of Sciences, Université de Antananarivo, Madagascar
* fabiofussi@gmail.com

Keywords: water supply, developing countries, machine learning

The semi arid region of Southern Madagascar shows a difficult situation in terms of access to safe drinking water,.The installation of solar pumps and small distribution system is one strategy (at the moment highly promoted in various African countries) that the Government of Madagascar, in collaboration with UNICEF is adopting through the project Mionjo.

But a large implementation of solar-powered water supply must be based on a preliminary analysis of two key aspects to achieve effective and sustainable results:

- the estimation of the potential yield and water quality that can be obtained from existing water points equipped with hand pumps
- the assessment of hydrogeological context and the identification of suitable zones for new water points

The estimation of potential yield and water quality of existing water points has been obtained through the the collection of pump tests and water quality parameters of existing boreholes (from different data sources and directly with new field observations) in a database of more than 3000 water points and a semi-automatic interpretation with a specifically designed algorythms.

The identification of suitable zones for new solar powered water points has been achieved through a specific tool (MLMapper v2.0) developed by the Complutense University. This tool employs supervised machine learning algorithms to predict target variables based on spatially distributed conditioning factors. The control points for the target variable were obtained from the database after a cleaning process to select those pump tests providing reliable estimation for 2m3/h, considered the minimum yield for the installation of solar pumps.

The results were validated both by machine learning metrics and by expert judgment in the case of the final predictive maps.

This research demonstrated that a data driven approach, supported by AI and machine learning tools, could improve water resource management in arid and vulnerable regions

LID 1036
Research on big data and physics model co-driven technologies for refined characterization of site contaminant plume

Han Xiao[1]*

[1] Chinese Research Academy of Environmental Sciences, Beijing, China
* xiaohan@craes.org.cn

This study addresses the challenges of non-intrusively and precisely characterizing contaminant plumes at active petrochemical sites contaminated by benzene-series compounds, and to develop a three-dimensional fine characterization technology jointly driven by big data and physical models. By integrating multi-source data, including boreholes, monitoring wells, hydrogeo-physical surveys, membrane interface probe (MIP)-based detection, and dynamic groundwater monitoring, this study applies data fusion, Bayesian updating, cooperative inversion, and uncertainty analysis to finely characterize the coupled relationships among subsurface hydrogeological structures, parameter distributions, and contaminant migration processes. Meanwhile, a multiphase flow–hydrogeo-physical coupling model involving solid, liquid, and non-aqueous phase liquid (NAPLs) phases is constructed for iterative simulation and validation of the groundwater flow field, hydro-chemical field, and contaminant concentration field. This enables fine characterization of plume boundaries and morphology, as well as high-precision identification and prediction of plume extent and migration trends, thereby providing technical support for pollution source tracing, risk assessment, and remediation of petrochemical contaminated sites.

LID 1037

Reactive sulfur species generated from elemental sulfur disproportionation: A potential pathway for stabilization metals in alkaline solid wastes

Yali He[1*], Yuanyuan Sun[1], Mingxia Zheng[1]

[1] State Key Laboratory of Environmental Criteria and Risk Assessment, and State Environmental Protection Key Laboratory of Simulation and Control of Groundwater Pollution, Chinese Research Academy of Environmental Sciences, Beijing, China

* heyali18@mails.ucas.edu.cn

Keywords: elemental sulfur, abiotic disproportionation, reactive sulfur species, alkaline solid wastes, groundwater protection

Long-term heavy metal leaching from alkaline solid waste sites threatens soil and groundwater quality. As a key sulfur cycle pathway, elemental sulfur disproportionation produces reactive sulfur species to modulate environmental redox conditions and metal speciation. This reaction thus offers a viable geochemical strategy to immobilize heavy metals in alkaline solid wastes and mitigate their leaching hazards. This study examined the feasibility of abiotic disproportionation of elemental sulfur in the absence of microorganisms. Results indicated that elemental sulfur initiated disproportionation at 25 °C once the solution pH was increased to 11, although the reaction rate remained low. Increasing the reaction temperature to 90℃ could further lower its critical disproportionation pH to 6.0. The disproportionation products were identified to be S^{2-}, $S_2O_3^{2-}$, SO_3^{2-} and SO_4^{2-}. Model-fitting of the kinetic data showed that the formation kinetics of $S_2O_3^{2-}$ and S^{2-} both followed the zero-order kinetics. In addition to these conventional sulfur species, polysulfides, identified by HPLC after methylation derivatization, constituted another important product group during elemental sulfur disproportionation. HS^- as a typical nucleophile was found to accelerate the disproportionation reaction by assisting the cleavage of S-S bond in elemental sulfur. These findings demonstrate that elemental sulfur can be abiotically transformed into reactive sulfur species under alkaline and thermally assisted conditions. This reaction pathway provided a potential new strategy for stabilizing heavy metals in strongly alkaline solid wastes, such as chromite ore processing residue and red mud. In these scenarios, in-situ generated reduced sulfur may suppress metal mobility and leaching to protect surrounding soil and groundwater.

LID 1039
Reactive Fe colloids at the groundwater-surface water interface: Size-dependent transformation regulated by DOM-microbial-redox coupling

Lina Yan[1]*, Lu Liu[1], Qiang Hu[2], Yuanyuan Sun[1], Mingxia Zheng[1]

[1] State Key Laboratory of Environmental Criteria and Risk Assessment, Chinese Research Academy of Environmental Sciences, Beijing, China
[2] Technical Centre for Soil, Agriculture and Rural Ecology and Environment, Ministry of Ecology and Environment, Beijing, China
* ylina_yan@foxmail.com

Keywords: groundwater-surface water interface, Fe colloids, DOM-microbial-redox coupling

Hyporheic zones are important hotspots for iron (Fe) cycling, where reactive Fe colloids can influence the transport and fate of contaminants through adsorption, complexation, and co-transport processes. However, the contribution of colloidal Fe and the mechanisms controlling its transformation remain poorly understood.

This study investigated the size distribution, chemical reactivity, and biogeochemical controls of Fe fractions in the groundwater-surface water interface. A two-step filtration approach using 0.8 and 0.22 μm membranes, combined with HCl-NH_2OH and DCB extractions, DOM fluorescence spectroscopy, microbial community analysis, and structural equation modeling (SEM), was applied to characterize reactive Fe pools and their controlling mechanisms.

Colloidal Fe accounted for approximately 30-50% of total extractable Fe, demonstrating its importance as an overlooked Fe pool in groundwater systems. Both HCl-NH_2OH- and DCB-extractable Fe fractions exhibited similar environmental responses, indicating that different reactive Fe pools were regulated by common redox-driven processes. SEM revealed that DOM and nitrogen cycling controlled Fe transformation mainly through redox regulation, with decreasing oxidation–reduction potential promoting Fe mineral reduction and redistribution between colloidal and dissolved fractions. DOM fluorescence and microbial network analyses further indicated that humic-like DOM contributed to redox processes, protein-like components were involved in electron transfer, and aromatic components potentially promoted Fe stabilization.

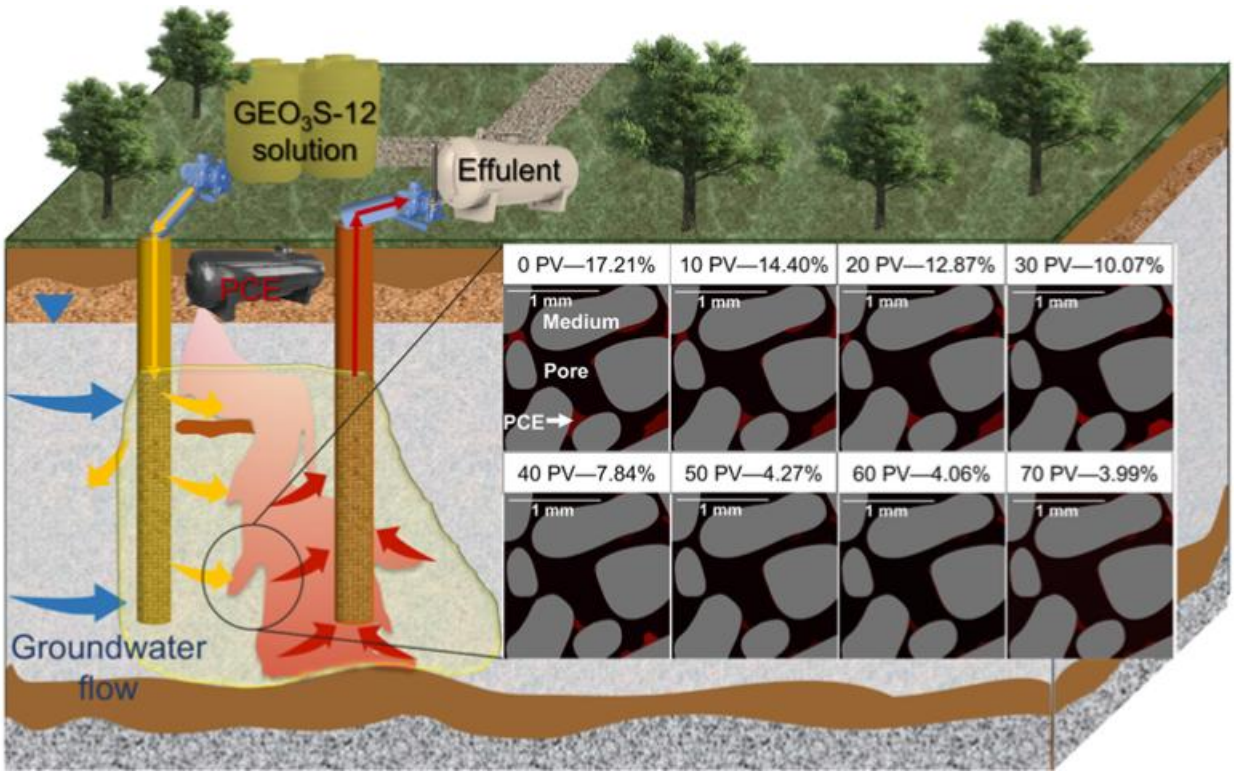
This study highlights the coupled regulation of DOM-microbial-redox processes on size-dependent Fe transformation and provides new insights into the role of reactive Fe colloids in controlling contaminant mobility in groundwater environments.

LID 1040
Efficient solubilization performance and mechanism for chlorinated hydrocarbons in aquifers of anionic-nonionic Gemini surfactants

Xue Liang[1]*, Jing Su[1], Jun Dong[1], Mingxia Zheng[1], Yuanyuan Sun[1]

[1] Chinese Research Academy of Environmental Sciences, Beijing, China
* 2392332835@qq.com

With excellent solubilization capacity and aquifer suitability, GEO3S-12, a novel anionic-nonionic Gemini surfactant, holds great promise in surfactant-enhanced aquifer remediation technology (SEAR) for tetrachloroethylene (PCE) removal from aquifers. However, PCE removal modes, environmental factors, and engineering control parameters affect the removal effect of residual PCE from aquifers. In this work, the main removal mode of residual PCE from the simulated aquifer by GEO3S-12 was characterized using the microscopic model and the macroscopic simulation column of laboratory-scale aquifer cell. The influences of environmental factors and engineering control parameters on residual PCE removal effect were investigated through one-dimensional simulation column. The solubilization remediation effect of the PCE-contaminated simulated aquifer by GEO3S-12 was evaluated in a two-dimensional simulation tank. The results indicated that the solubilization was the dominant mechanism of residual PCE removal by GEO3S-12 when the residual PCE was partially distributed in the aquifer. The environmental factors including particle size of the simulated aquifer, contact time between GEO3S-12 and PCE-NAPL, and saturation of residual PCE jointly control the removal effect of PCE. And a quadratic function model of environmental factors was constructed to predict the PCE removal effect. The optimal PCE solubilization removal effect could be achieved by using the GEO3S-12 injection concentration that was 40 g/L first and then 20 g/L, low injection velocity (1.9 m/d), and intermittent injection mode. The solubilization effect of GEO3S-12 increased the aqueous-phase PCE concentration at the lower right corner of the simulated aquifer that away from the source from 10 mg/L to 10000 mg/L. The percentage of PCE removal amount from the simulated aquifer by GEO3S-12 was 97.11%. The findings provide guidance for how to adjust engineering parameters of SEAR based on the aquifer environmental factors to achieve the best PCE-contaminated site remediation effect.


GEO3S-12 solution
Effulent
PCE
Groundwater flow
0 PV—17.21%
10 PV—14.40%
20 PV—12.87%
30 PV—10.07%
40 PV—7.84%
50 PV—4.27%
60 PV—4.06%
70 PV—3.99%
1 mm
Medium
Pore
PCE

LID 1041
The emergence of groundwater as the most valuable natural resource of the 21st century

James Famiglietti[1]*

[1] Arizona State University, Tempe, United States
* jay.famiglietti@asu.edu

Keywords: groundwater depletion, satellite observations, groundwater management

Depletion of groundwater from most of the world's major aquifers, and thousands of smaller ones, is undermining planetary health, food security, economic growth, energy and mineral production, and water availability for humans. If left unchecked, it will create increasingly complex challenges for drought and climate change resilience, while posing an existential threat to the world's desert cities. Over two decades of satellite observations of continental drying, underpinned by poorly-managed and over-exploited groundwater stores, show that the drying regions of the world are expanding, while the wetting regions are shrinking, putting additional pressure on groundwater and decreasing freshwater availability. As the vast majority of the water that drains from the continents accumulates in the ocean, groundwater depletion is now the single largest contributor to sea level rise from the continents, even larger than the contributions from glaciers and ice caps.

This lecture will review the current status of global groundwater depletion, while making the case for coordinated solution strategies to prevent the exhaustion of non-renewable stores. Importantly, groundwater, and freshwater in general, must take a much-elevated role across all three of the Rio Conventions, i.e. the COPs for climate change, biodiversity, and desertification. As hydrogeologists, we must provide best-available, actionable information that makes a compelling case for enhanced groundwater protection to national water minsters of the world; and we must work together to find entry points for highlighting our work in the global discourse. At the grassroots level, experience suggests that science, policy, or technology alone has not been successful in stemming groundwater depletion: transdisciplinarity may be the key to support sustainability pathways in regional aquifer systems. Examples of both the high-level and grassroots strategies will be discussed. A call-to-action to end non-renewable groundwater depletion will close the lecture.

LID 1042
Impacts of mining on underground water systems: Hydrogeological challenges and sustainable management approaches

Vera Nyamusi Nyabuto[1*], Jane Wambui[2]

[1] Independent Researcher, Nairobi, Kenya
[2] Geothermal Development Company, Nairobi, Kenya
* veranyamusinyabuto@gmail.com

Keywords: mining, groundwater, hydrogeology, water quality, environmental management

Mining activities significantly influence underground water systems through aquifer dewatering, altered groundwater flow, acid mine drainage, and contamination by heavy metals such as arsenic, lead, cadmium, and mercury. This paper reviews the principal hydrogeological impacts associated with both surface and underground mining, emphasizing changes in groundwater quantity and quality, ecosystem degradation, and risks to communities dependent on groundwater for domestic and agricultural use. The study synthesizes findings from published case studies across Africa and other mining regions to identify common contamination pathways, groundwater drawdown mechanisms, and long-term environmental consequences. Results indicate that inadequate mine waste management and poor closure practices can cause persistent groundwater pollution that may continue for decades after mining operations cease. Effective mitigation requires comprehensive hydrogeological investigations before project development, continuous groundwater quality monitoring, engineered waste containment systems, treatment of acid mine drainage, and integrated water resource management involving regulators, mining companies, and local communities. The paper concludes that sustainable mining depends on balancing mineral resource extraction with protection of groundwater resources through stronger environmental governance, adoption of cleaner mining technologies, and science-based monitoring programs.

LID 1043
Verification of the regional groundwater flow system to prove the origin of Minera and Veritas mineral water in Albertirsa (Hungary)

József Deák[1]*, István Fórizs[2], Endre Csiszár[3], László Palcsu[4], Adél Petneházy[2,5,6], Márk Szijártó[2,5,6]

[1] GWIS Ltd., Veszprém, Hungary
[2] Institute for Geological and Geochemical Research, HUN-REN Research Centre for Astronomy and Earth Sciences, Budapest, Hungary; forizs@geochem.hu
[3] Freelance hydrogeological engineers, Szeged, Hungary
[4] HUN-REN Institute for Nuclear Research, Debrecen, Hungary
[5] Department of Geophysics and Space Science, ELTE Eötvös Loránd University, Budapest, Hungary
[6] József & Erzsébet Tóth Endowed Hydrogeology Chair, Department of Geology, ELTE Eötvös Loránd University, Budapest, Hungary

Keywords: 2D conceptual groundwater flow model, Ice age groundwater, ^{14}C groundwater ages, NGT, stable isotopes, tritium

In order to investigate the origin of the Minera mineral waters, a conceptual 2D groundwater flow model was prepared from the presumed recharge area to the place of bottling (Albertirsa). The continuous decrease in piezometric pressure levels along this cross section indicates the groundwater flow.

Isotope and chemistry data along the cross section were used to verify the conceptual model:

- A continuous increase in Na mEq% indicates ion exchange of (Ca^{2+} + Mg^{2+}) for (Na^{+} + K^{+}).
- The linear increase in ^{13}C-corrected radiocarbon groundwater ages (from zero to 28 ka BP) indicates a groundwater flow velocity of approximately 1.5 m/a along the flow path.
- Noble Gas Thermometer (NGT) analyses support the ^{14}C age data; groundwater older than 10 ka infiltrated under colder climatic conditions (during the Ice Age) than those prevailing during the Holocene.
- Stable water isotope and NGT data show an excellent correlation (R^2=0.98), according to the relationships: $\delta^2H = 4.3 \cdot NGT - 117{,}3‰$ and $\delta^{18}O = 0.56 \cdot NGT - 15.9‰$.

δ^2H and $\delta^{18}O$ values of Minera wells are 35‰ and 5‰ more negative, respectively, than the present-day values. These results, together with NGT temperature of 3.3 °C and the ^{14}C age of 28 ka, indicate that the groundwater infiltrated during or close to the Last Glacial Maximum (LGM).

However, the groundwater abstracted from the shallower Veritas wells, located next to the Minera wells, has ~1 ka ^{14}C groundwater age, δ^2H and $\delta^{18}O$ values similar to modern precipitation, and an NGT of 10.8 °C, indicating local recharge under present-day climatic conditions.

The non-detectable Tritium content (<0.5 TU) in the abstracted groundwater demonstrates the pristineness of both Minera and Veritas mineral waters.

Based on the results of this research, the bottler of Minera mineral water was granted permission to label the product as "Pristine Ice Age Water".

The research was funded by Aqua Lorenzo Ltd., the bottler of Minera and Veritas mineral water.

LID 1044
Original purity for natural mineral waters – An evolving concept

Patricia Fosselard[1]

[1] Natural Mineral Waters Europe, Brussels, Belgium
* patricia.fosselard@nmwe.org

Keywords: original purity, natural mineral waters, emerging contaminants, water resilience, biodiversity

Natural Mineral Waters Europe aisbl (NMWE) is an international not for profit organisation federating European producers of natural mineral waters and spring waters. Through its national trade associations, NMWE represents more than 500 producers exploiting more than 2,000 springs at 900 bottling sites.

European packaged water sales represents almost 50% of the total yearly sales of non-alcoholic beverages, with a volume consumed exceeding 60 billion litres. The majority of this volume consists of natural mineral water (> 80%) or spring water (>16%). This is very different from other continents where the bulk of packaged water is processed water, i.e. which is demineralised, disinfected and remineralised for taste.

Under the applicable European legislation (Directive 2009/54/EC, a recast of Directive 80/777 and Directive 96/70), natural mineral waters and spring waters share some characteristics: they must both come from protected underground origin, be bottled at source (no transport in tanks), they may not be disinfected, and only a limited number of processes may be applied to them to separate some naturally present constituents such as iron, fluoride or manganese. However, besides the stable mineral composition and temperature, there is a unique requirement for natural mineral water to be officially recognised as such: original purity at source. This characteristic „*must be preserved intact because of the underground origin of such water, which has been protected from all risks of pollution*".

Retaining original purity is therefore an essential condition for natural mineral water producers' license to operate. At the time of adoption of the first piece of European legislation on natural mineral water in 1980, 'original purity' was widely understood as meaning that no traces of contamination at all should be detected at source. There was a general assumption that the natural protection afforded by the geology around the source combined with producers' own investments towards source protection would suffice to keep all kinds of pollution at bay. As a result, no guide values, all be it at very low level, were set to give flesh to the legal requirement of original purity.

A couple of decades later however, some traces or ultra-traces of pesticides and other families of contaminants started to be detected, as a result of the rapidly increasing sophistication of analytical capabilities and increasing human activity. The realisation came that total absence of detection of anthropogenic contamination in underground water was no longer achievable and that there was a need to better define original purity to reflect the evolving context under which producers were operating. In October 2017, the European Commission and experts from the 27 Member States met and approved 'indications' [1] defining guide values for traces level of four families of anthropogenic contaminants - polynuclear aromatic hydrocarbons (PAHs), volatile organic compounds (VOCs), thrialomethanes (THMs) and pesticides -, which were deemed compatible with the concept of original purity in natural mineral waters. The defined orientations aimed not only to provide guidance to controlling authorities, but also legal certainty to operators and continued high quality to consumers.

Despite the lack of fully harmonised implementation of the EU indications by national competent authorities, the new framework was a very welcome development for natural mineral producers, restoring

the belief that the guidance together with effective protection measures on the ground, would secure the purity of natural mineral waters. De facto, in many catchment areas, producers work in partnership with farmers and local stakeholders to preserve the resource.

The relief was short-lived as new emerging contaminants, such as PFAS, began to be identified in the environment, in food and in water, both surface and underground.

In 2024, the NGO Pesticides Action Network Europe (PAN), published a report [1] according to which low levels of trifluoroacetic acetic acid (TFA) were detected not only in tap water, but also, in some natural mineral waters and spring waters. More reports followed pointing to the presence of TFA in various kinds of foods and beverages.

TFA is a short chain PFAS. It belongs to the sub group of polyfluorinated carboxylic acids. It is the smallest member of that subgroup, having only 2 carbon atoms. TFA is a versatile chemical with several important industrial applications, including pesticides, refrigerants, blowing agents, pharmaceuticals and sewage treatment. TFA is highly soluble in water and highly persistent and mobile in the environment [2]. Much of its presence in the environment is attributable to it being a breakdown product of other chemical substances, such as hydrofluorocarbons (HFCs) commonly used in refrigerants and fire suppressants. Unlike long chain PFAS, TFA accumulates in the environment; it does not degrade.

Until 2024, TFA was not on natural mineral water producers' radar because PFAS are undetected in most natural mineral waters.

Whilst there is no indication of toxicity at the low levels of TFA commonly found in natural mineral waters („significantly lower than in tap water") and while analytical reports are finding much higher levels of TFA in other foods and beverages [3], in the absence of any specific EU guide value for TFA in natural mineral water, the mere detection of this ubiquitous contaminant is again questioning original purity.

The detection of TFA in the most pristine environments in the world, such as the Amazonia or the Arctic, is also shattering producers' long established that they were overall in control of the quality of the water resource under their management; in today's world, even the most effective protection measures won't be able to prevent a field or a source from being contaminated by TFA, and, possibly, more short chain molecules in the future as a result of atmospheric pollution [4]. This means that original purity will need to be revised in the light of latest scientific developments and analytic results in such a way as to maintain the high quality and safety of the product while ensuring legal certainty for producers.

More generally, the time has come to mobilise to ensure the continued availability of high quality water for future generations. From a legislative perspective, this implies adopting effective water protection measures, privileging prevention over remediation (which is prohibited for natural mineral water and very costly financially and environmentally for public water supply), applying the polluter pays principle, fostering the setting up of collaborative platforms and recognising that it is in the public interest to protect all water sources, irrespective of the private or public nature of their management body. Effective prevention measures must include the prohibition of TFA-based and TFA-generations substances and products.

Last but not least: healthy water depends on healthy eco-systems. Protecting biodiversity is also essential to ensuring the future availability of water. Reforestating, removing drainage and restoring wetlands are all nature-based solution which can help retain water.

Natural mineral water producers have a long tradition of investing to protect the environment around the sources they manage. NMWE is dedicated to assisting them to go further. As an example, NMWE partnered with the International Union for the Conservation of Nature (IUCN), on the development of a guidance to measure and increase the sector's contribution to nature positive and is now engaging with

IUCN in a two-year project to test IUCN's guidance for biodiversity in real conditions. The project brings together a group of volunteer companies and associations from across Europe to apply a common biodiversity framework at source level, strengthen the protection and restoration of ecosystems around their catchments and share practical learning [5].

We all depend on the availability of a sufficient quantity of quality water. Ensuring water resilience is essential to nature, to humans and to the economy. It is a collective effort and we all have a role to play!

References:

[1] PAN Europe, *TFA The forever chemical in the water we drink,* July 2024, https://www.pan-europe.info/sites/pan-europe.info/files/public/resources/reports/Report_TFA_The%20Forever%20Chemical%20%20in%20the%20Water%20We%20Drink.pdf

[2] European Commission, *EURL-SRM – Residue Findings Report,* 19.06.2017, https://www.eurl-pesticides.eu/userfiles/file/eurlsrm/eurlsrm_residue-observation_tfa-dfa.pdf

[3] PAN Europe, Global 2000 and Pesticides Action Network Europe, *The forever chemical in our daily bread*, June 2025, New Study Reveals Alarming Levels of 'Forever Chemical' TFA in bread, pasta, and breakfast cereals | PAN Europe

[4] Berg M, Müller SR, Mühlemann J. Concentrations and Mass Fluxes of Chloroacetic Acids and Trifluoroacetic Acid in Rain and Natural Waters in Switzerland. Approximately. Sci. Technol. 2000, 34, 13, 2675–2683 Concentrations and Mass Fluxes of Chloroacetic Acids and Trifluoroacetic Acid in Rain and Natural Waters in Switzerland

[5] https://naturalmineralwaterseurope.org/news/natural-mineral-waters-europe-launches-sources-for-nature-to-pilot-iucn-biodiversity-recommendations-across-europe/

LID 1045
Advanced drilling technologies and a high capacity hybrid geothermal project

Sandor Tiszavari[1]*

[1] Rotaqua Ltd., Hungary
* tiszavari.sandor@rotaqua.hu

Keywords: drilling, geothermal production test, case study

The company was established in 1990. The primary purpose of activity was core drilling for uranium mineral exploration and mines in Hungary. In the mid 90's due to the decreasing activity the government company was sold to private investor. As a result of the expected drilling rig requirement peak due to speeding up geothermal drilling projects in Hungary, government bought the company in Dec. 2023.

The main divisions of the company: deep drilling, mid-size drilling (both for geothermal and hydrocarbon), Geological structure research drilling, drilling for nuclear waste disposal monitoring. The companies rig fleet contains around 20 rigs.

The state of art 1500 HP Drillmec drilling was purchased and spud in the first well this year in Hungary.

So far one geothermal well was drilled with the rig in 2026. The drilling phase was smooth and the drilling progress, the drilling efficiency, rate of penetration reached the expectations. The drilling has reached the reservoir, indicated by total drilling mud losses in the drilling phase.

The Team has faced many challenges in the well test phase. The water was planned to be lifted by ESP (electrical submersible pump) with a planned max. rate of 6000 liter/min. The surface facility layout was designed accordingly, different set ups for 1) well clean up, 2) production test, 3) injection test.

The well clean up was planned to carry out with compressor and air lifting. In a half an hour after the air lifting started, the well started to flow naturally with a high flow rate. The welltest flow rates have to be reviewed and the surface facility modified accordingly. This I will present you with a lots of pictures.

LID 1046
Decentralised wastewater treatment as a tool for local water retention

Anna Krasznói[1]*

[1] Esztergom, Hungary
* krasznoi.anna@gmail.com

Keywords: decentralized wastewater treatment, local water retention, groundwater recharge

Domestic wastewater is generally regarded as pollution to be treated and removed, but is also a continuous local water resource. Drawing on over twenty years of practical experience in Hungary, we show how decentralised biological wastewater treatment in unsewered areas can serve both sanitation and local water retention.

Centralised systems collect, transport and treat household wastewater, then typically discharge it into surface waters. Returning reclaimed water to water-scarce areas may require storage, pumping and redistribution. With decentralised treatment, appropriately treated wastewater can remain where it was originally used. Through soil infiltration, it can return to the local water cycle, support soil moisture and retention and, under suitable hydrogeological conditions, potentially contribute to groundwater recharge.

Decentralisation also changes user behaviour. When homeowners know treated water remains in their own garden, they become more conscious of what they discharge. Our experience shows a significant reduction in household chemical use: users see the consequences of their choices in their own environment.

Regulatory and financial barriers hinder wider implementation in Hungary. While centralised sewerage has received substantial public funding, owners of permanently unsewered properties lack generally accessible direct support for individual treatment systems. Support should be available even to a single property owner, without a municipality-wide programme, allowing them to choose the most suitable certified system for their property. Some local regulations also restrict or prohibit its infiltration even in unsewered areas.

If appropriately treated domestic wastewater can safely remain locally, why transport it away? Decentralised treatment could become part of local water-retention strategies and, under suitable conditions, contribute to groundwater recharge.

LID 1047
Wood (larch) cased wells in Hungary established in the XIX. century

Áron Szlukovinyi[1]*, Gábor Szongoth[1], Sándor Hegedűs[1]

[1] Geo-Log Ltd., Budapest, Hungary
* posta@geo-log.hu

Keywords: well investigation, Vilmos Zsigmondy, well with a wood casing, video recording, Margaret Island

Hungary's eminent well driller—often regarded as the father of Hungarian water-well drilling—carried out pioneering work in thermal-water exploration during the second half of the nineteenth century. His best-known well is Városliget Well No. I, located in Heroes' Square, immediately adjacent to the Millennium Monument. The 680-metre-deep well was drilled between 1855 and 1865. Later, in 1935, a 300-metre-deep well with wooden casing was drilled on Margaret Island. Colour downhole video footage of this well is also presented.

LID 1048
Before me stood the living genius of hydrogeology, Joe Tóth – A personal reflection

Judit Mádl-Szőnyi[1]*

[1] József and Erzsébet Tóth Endowed Hydrogeology Chair, Department of Geology, Institute of Geography and Earth Sciences, Eötvös Loránd University, Budapest, Hungary
* judit.szonyi@ttk.elte.hu

I first met Professor József Tóth in 1994, an encounter that fundamentally changed my scientific career and my way of thinking about groundwater. As my mentor, he introduced me to the systems-based understanding of groundwater flow and taught me not only to look in the field, but to truly see. His knowledge, scientific rigour, trust and encouragement shaped both my own work and the development of modern hydrogeology at Eötvös Loránd University. In this personal reflection, I would like to remember the scientist, the mentor and the person whose intellectual legacy and humanity continues to guide us.



With Professor Joe Toth during a field visit on the Canadian Prairies, 2008

LID 1049
Prof. Joe Tóth's inspiring role in the development of research into groundwater systems on geological timescales in the Netherlands since the late 1980s

Hanneke Verweij[1]*

[1] TNO Geological Survey of the Netherlands, Applied Geosciences, The Netherlands
* hanneke.verweij@outlook.com

Prof. Tóth highly influenced my research direction and thereby also research in the Netherlands since the late 1980s. His hydraulic theory of petroleum migration (Tóth, 1980) introduced me to - and triggered my interest in - the interaction between large-scale groundwater flow systems and petroleum systems. In 1986 this resulted in my first research in the Netherlands concerning fluid flow systems in developing sedimentary basins on geological timescales. Since that time the analysis of large scale pressure and groundwater flow systems and the significance of these systems for the assessment of natural resources were introduced and further developed in a wide variety of research and joint-industry projects in onshore and offshore Netherlands and beyond. Tóth's concept of groundwater as geologic agent has motivated me to always use and integrate a wide variety of data, information, concepts and tools from different geoscience disciplines, including those of petroleum geoscience. I greatly appreciate and have fond memories of Prof. Tóth's inspiring discussions and warm personal interest at conferences and workshops (from 1993 to 2017) and especially his participation in my PhD committee in 2003 in Amsterdam.



Prof. Tóth's participation in my PhD committee in 2003 in Amsterdam

LID 1050
How József Tóth's theory of regional groundwater flow systems helped launch my career

Chunmiao Zheng[1]*

[1] Eastern Institute of Technology, Ningbo, China, and the University of Alabama, United States
* zhengcm@sustech.edu.cn

When I began my PhD studies at the University of Wisconsin–Madison in the late 1980s, the first course I took with my advisor, Professor Mary Anderson, introduced me to József Tóth's landmark 1962 and 1963 papers on regional groundwater flow systems. His theory fundamentally shaped my understanding of hydrogeology and the direction of my career in groundwater flow and contaminant transport modelling. In this talk, I will share some personal reflections on how Tóth's ideas helped launch my career and why his work continues to inspire generations of hydrogeologists.



Professor József Tóth with Chunmiao Zheng in Beijing, China, on June 19, 2013

LID 1051
The “Hungarian Hydrogeology Mafia”

Ladislaus Rybach[1]*

[1] ETH Zurich, Department of Earth and Planetary Sciences, Switzerland
* ladislaus.rybach@eaps.ethz.ch

The “Hungarian Hydrogeology Mafia” – professors of Hungarian origin – assembled at the IAH 1998 Conference in Lausanne, Switzerland: Ladislaus Rybach (ETH Zurich, Switzerland), Imre Müller and László Király (University of Neuchâtel, Switzerland), and Joe Tóth (University of Alberta, Canada). They always helped and supported each other.



The “Hungarian Hydrogeology Mafia”

LID 1052
The 2013 Regional Groundwater Flow Symposium and Prof. Tóth's 80th birthday celebration

Matthew Currell[1]

[1] Australian Rivers Institute, Griffith University, Australia
* m.currell@griffith.edu.au

In 2013, Professor Tóth was the guest of honour at the International Symposium on Regional Groundwater Flow in Xi'an, China, organised by the Regional Groundwater Flow Commission and the China Geological Survey. The symposium was a formative event for many of the early-career hydrogeologists who attended, particularly during the post-conference field trip to the Ordos Basin. Professor Tóth generously shared his insights and his wry sense of humour, demonstrating how groundwater flow-system theory could provide critical insights into the hydrogeological features and processes of large sedimentary basins. The ECHs tried their best to emulate Prof. Tóth's inimitable style, as seen in photos from the event.



With Professor Joe Tóth, 2013

LID 1053
What does it mean to stand in the landscape where a scientific idea was born?

Ádám Tóth[1]*

[1] Utrecht University, Copernicus Institute of Sustainable Development, The Netherlands
* a.z.toth@uu.nl

During the symposium organised by the Regional Groundwater Flow Commission in 2017, I had the unique opportunity to visit the places that inspired József Tóth's pioneering work on regional groundwater flow in Alberta. Revisiting Ghost Pine Creek, the birthplace of the groundbreaking basin-scale groundwater flow theory, with Jóska bá was an unforgettable, once-in-a-lifetime experience. As a fellow Tóth, I have been asked countless times, "Are you related to Joe?" Carrying the Tóth name in hydrogeology is not only a coincidence of family names, but a personal responsibility to honour, continue and contribute to the remarkable scientific heritage he created.



Professor Joe Tóth is standing in front of the famous Ghost Pine Creek, 2017

LID 1054
Celebrating József (Joe) Tóth (1933–2026)

Okke Batelaan[1]*

[1] National Centre for Groundwater Research and Training, Flinders University, College of Science and Engineering, Australia
* okke.batelaan@flinders.edu.au

Joe Tóth embodied for me the beauty of science when it is surprising, inspiring and human. In this tribute, I would like to share my personal experience with Joe Tóth and reflect on what his science and the person meant to me.



Prof. Joe Tóth during the international field trip in the Canadian Prairies, 2017

LID 1055
The eternal secret of ‘Jóska’

János Szanyi[1]*

[1] Geothermal Energy Applied Research Centre, University of Szeged
* szanyijani.szeged@gmail.com

Following Jóska’s forced flight from Hungary, he was known to say: “I made a solemn vow, but what it entails is no one’s concern but my own.” I know not what that vow might have been, but it bore only rich fruit for Hungarian hydrogeology. I bid farewell to my mentor: one final “Jó szerencsét!”



János Szanyi, Joe Tóth and ‘Pista’, István Révész

LID 1056
From basin hydraulics to personal memories: Remembering József Tóth

Brigitta Czauner[1]*

[1] József and Erzsébet Tóth Endowed Hydrogeology Chair, Department of Geology, Institute of Geography and Earth Sciences, Eötvös Loránd University, Budapest, Hungary
* czauner.brigitta@ttk.elte.hu

As a student of Judit Mádl-Szőnyi at Eötvös Loránd University, I had the privilege of 'growing up' in the tradition of the Tóthian flow system theory. Later, during my partial PhD studies at the University of Alberta, I was fortunate to learn the tricks of basin hydraulics directly from Professor Tóth. Through these experiences, I became part of a professional legacy that still hold tremendous, yet largely untapped, potential for future discoveries. Beyond this scientific heritage, Jóska bá' left me with many cherished personal memories. He was not only an outstanding hydrogeologist, but also a very special person.



With Professor József Tóth and Judit Mádl-Szőnyi in Portland, 2009

LID 1057
The lasting legacy of Professor Tóth

Teodóra Szőcs[1]*

[1] Ludovika University of Public Service, Institute for Environmental Sustainability, Budapest, Hungary
* Szocs.Teodora@uni-nke.hu

Professor József Tóth's work had a profound influence on the development of modern hydrogeological thinking in Hungary. His courses on regional groundwater flow systems introduced a new conceptual framework that became fundamental for both research and applied hydrogeology. During more than three decades at the Geological Institute of Hungary, the flow-system approach proved highly relevant to a wide range of practical problems, including the siting of radioactive waste repositories, the characterization of groundwater bodies, geothermal and contamination studies, and the interpretation of hydrochemical evolution along groundwater flow paths. Tóth's influence extended far beyond scientific concepts: he actively supported the Hungarian hydrogeological community and encouraged the establishment of the Hungarian National Chapter of the IAH in 2006. His scientific legacy continues to shape generations of hydrogeologists in Hungary and worldwide, demonstrating the lasting value of groundwater flow-system thinking across both fundamental and applied hydrogeology.

To the memory of Prof. József Toth, my mentor in hydrogeology

Thomas Tetteh Akiti[1]

[1] Formerly: International Atomic Energy Agency, Vienna, Austria and University of Ghana, SNAS, Legon, Accra, Ghana

In my final year of studying geology at the University of Ghana, I wrote to one Dr. Peter Meyboom, of Canada about the possibility of pursuing a post- graduate studies in hydrogeology. When he replied my letter, the first question he asked was, 'Was Dr. Van Landewijk still in Ghana ?' This was in 1969. I was surprised and went straight to see Dr van. He said Peter was his student at the University of Utrecht in the Netherlands. He also said there was one of his students who came from Hungary in 1956 after the Soviets invaded his country. His name was Jozsef Toth.

I was surprised when Prof. Toth visited Ghana in 1972. He was on a Canadian International Development Agency (CIDA) mission to Australia and took advantage to come to see his former student, Mr. Quist, a hydrogeologist in Ghana. You can see Mr. and Mrs Quist in the foreground of photo and Prof. Toth and me in the background. The picture was taken in Cantonments, Accra.

In August of 1972, I enrolled in an MS program at the University of Waterloo, Ontario, Canada. My thesis supervisor, Prof. R. N. Farvolden sent me to the Groundwater Division of the Research Council of Alberta, Edmonton for my project work and Prof. Toth became my mentor.

Prof. Toth took time to explain and educate me on the theory of groundwater movement and gave me papers to read on the subject. He took me to the field and showed me manifestations of groundwater conditions such as discharge area identification and mapping. He taught me the important part that the topography plays in the movement of groundwater. I learnt a lot from my association with Prof. Toth and I imparted this knowledge to my colleagues and students wherever I find myself teaching hydrogeology, laying emphasis on the interpretation of hydrogeochemical and isotopic data using a conceptual flow developed by Prof. Toth.

Let me now talk about the human side of this fine scientist. He liked eating different foods. One day, we talk about Ghanaian dishes. He invited me home and I prepared groundnut soup for his family. I put in a lot of pepper and I was afraid they might find the food too spicy He laughed and said we are from Hungary. The soup was like goulash and of all Europeans Hungarians like spicy food. He missed hunting with his friends when he could'nt visit Hungary because he left his country. Once amnesty was granted, he always came on vacation to go hunting with his friends.

I still remember our last meeting at the 22nd IAH meeting in Lausanne, Switzerland.

This was the Joe I know. Your memory will be with me.

May your Soul Rest In Perfect Peace.



With Professor Joe Toth