International Symposium on Hierarchical Flow Systems in Karst Regions

In honour of Professor József Tóth
in celebration of his 80th birthday

Symposium program, abstracts and field trip guide

4-7 September 2013
Budapest, Hungary
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This Volume is dedicated to Professor József Tóth

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Welcome note of the International Association of Hydrogeologists

Dear Colleagues and Honoured Birthday Guest,

On behalf of the International Association of Hydrogeologists (IAH), it is my great pleasure to provide a presidential welcome to all delegates attending KarstFlow2013, the first “International Symposium on Hierarchical Flow Systems in Karst Regions”. This is a very special meeting on many accounts and I’m truly grateful for the invitation to attend.

Much of the scientific work of IAH is conducted through its Commissions and Networks, a program of activity that has undergone considerable reform during the past ten years. The Budapest meeting represents one of the many anticipated fruits of this restructuring process as it creates the opportunity for a new and exciting synergy between one of IAH’s newest and most promising Commissions, the “Commission on Regional Groundwater Flow“ and the “Karst Commission” one of our oldest and most productive Commissions. I congratulate the organisers on their foresight and vision. I wish you great success!

I am especially pleased that this meeting will allow us to celebrate the 80th year of József Tóth, an outstanding hydrogeologist, inspirational teacher and a very good friend to many of us. Joe, on behalf of IAH and its members throughout the world, I am pleased to convey our heartiest congratulations!

This promises to be an exceptional meeting and I look forward to meeting all of you.

Ken Howard

President of the International Association of Hydrogeologists (IAH)

Department of Physical and Environmental Sciences

University of Toronto Scarborough (UTSC)

Toronto, Canada
Welcome note of the Regional Groundwater Flow Commission of the International Association of Hydrogeologists

The Regional Groundwater Flow Commission (RGFC) of the International Association of Hydrogeologists (IAH) was launched in 2011. The main mission of the Commission is to internationally foster teaching, research and practical application of regional groundwater flow. The concepts and methods of groundwater flow system evaluation are critical and helpful in the understanding of geologic processes, such as fluid flow in sedimentary basins, in carbonate systems, in surface water - groundwater interaction, regional heat and solute transport, and in the understanding of groundwater flow in the generation of ore deposits and petroleum accumulations. However, the concept and theory are not well-recognized yet, although they were introduced half a century ago. For these reasons one of the main tasks of the Regional Groundwater Committee is to organize international symposia concerning the subject.

Therefore it is my pleasure to welcome you on behalf of the RGFC and the local organizers to the "International Symposium on Hierarchical Flow Systems in Karst Regions". The declared objective of this Symposium is to introduce the concept of gravitational groundwater flow systems in the thinking and practice of the karst community. As a result of the Symposium we hope to encourage the integration of karst research with traditional groundwater flow theory, by comparing the hierarchical nature of flow and mass transport in both fields.

I would like to welcome geologists, speleologists and hydrogeologists who arrived from 30 countries and are interested either in karst or in regional groundwater flow, respectively or together. Whether you are a karst specialist or simply interested in the subject, I am sure you can contribute to the dialogue of how karst fits into the broader framework of flow systems and modern hydrogeology.
This Symposium is dedicated to Professor József Tóth, in celebration of his 80th birthday. Professor Tóth is a pioneer in the theory of regional groundwater flow. His concept of hierarchy is essential to a full understanding of groundwater flow. This exceptional occasion served as the inspiration for this Symposium. Moreover Professor József Tóth spent two and a half years here at Eötvös Loránd University, Budapest as a honorary professor and has been in contact with the local hydrogeological research group for more than 15 years.

The location is also significant. Budapest is well known for its examples of hypogene karst, thermal springs and many pioneering studies in this field. It is also a city of exceptional resources – scientific, historical, and cultural. Many karst examples are easily accessible within the city and its surroundings as you will see at the field trip.

Dear friends of Regional Groundwater Flow and Karst, I wish to all a successful Symposium in Budapest.

Judit Mádl-Szőnyi

Chair of the Symposium
Chair of the IAH Regional Groundwater Flow Commission
Department of Physical and Applied Geology
Eötvös Loránd University
Budapest, Hungary
Welcome note of the Karst Commission of the International Association of Hydrogeologists

The theory of gravitational groundwater flow systems by József Tóth is among the most important and influential fundamentals of modern hydrogeology. The theory differentiates local, intermediate and regional flow systems and also recognizes groundwater as a geologic agent with important roles in solution, transformation, transport and deposition of geochemical material. Furthermore, Tóth’s theory also addresses the ecological significance of groundwater flow systems.

Although this theory does not originate from karst science, it is perfectly applicable to karst hydrogeology. However, to date, the linkage between karst hydrogeology and flow system theory has not been fully developed. Therefore, the IAH Karst Commission has readily accepted to support and co-chair the Symposium on Hierarchical Flow Systems in Karst Regions. We hope that this symposium will explore and reveal the multiple connections between flow system theory and karst hydrogeology, and will also prepare the ground for future multidisciplinary research.

Nico Goldscheider

Co-Chair of the Symposium

Chair of the IAH Karst Commission

Institute of Applied Geosciences, Division of Hydrogeology
Karlsruhe Institute of Technology (KIT)
Karlsruhe, Germany
Welcome note of the Karst Hydrogeology and Speleogenesis Commission of the International Union of Speleology

Historically, karst studies were mainly concerned with shallow, unconfined hydrogeological settings, supposing that karstification is inherently related to direct recharge from the overlying surface. The possibility of deep-seated karst development was generally deemed to be low to nonexistent within the dominant “superficial” paradigm of karst. Solutional porosity features and associated hydrogeological anomalies at greater depths, below upper regionally extensive confining units, have commonly been interpreted as paleo-(epigenetic) karst, i.e. karst that had commenced in exposed settings but later buried under younger strata.

The last decade has witnessed a burst in the recognition of importance of hypogene speleogenesis that develops by upwelling flow, without direct genetic relationship to the surface. Karst science now came to realize that hypogene karst is one of the fundamental categories of karst, at least of equal importance with conventional epigene karst, not just an aberrant curious phenomenon. This signifies an ongoing major shift in the overall paradigm of karst.

The logic of hypogene karst studies leads karst scientists to look at regional hydrogeology, at hydrogeology of deeper parts of the hydrolithosphere, and at regional geodynamic / hydrogeological evolution – some of the most acute problems of the mainstream hydrogeology. In particular, the theory of hierarchical gravitational groundwater flow systems by Prof. József Tóth appeared to be of fundamental importance for understanding regularities of hypogene speleogenesis. On the other hand, hypogene karst development itself can play significant roles in the formation of regional flow patterns and of many ore and hydrocarbon deposits, so that better understanding of hypogene speleogenesis is needed for hydrogeologists and geologists concerned with regional studies and economic geology. This requires more intense interaction and cooperation be
tween specialist groups concerned. Therefore, the Commission on Karst Hydrogeology and Speleogenesis of the International Speleological Union was happy to closely cooperate with the Regional Groundwater Flow Commission and Karst Commission of the International Association of Hydrogeologists in supporting the Symposium on Hierarchical Flow Systems in Karst Regions, organized by Hungarian colleagues in one of the world’s foremost regions of hypogene karst – marvelous Budapest. I am sure that the Symposium will greatly enrich scientific experience of every attendee and result in a significant advancement in our understanding of hypogene speleogenesis and hierarchical flows systems in karst regions.

Alexander Klimchouk

Co-Chair of the Symposium
Chair of UIS Commission on Karst Hydrogeology and Speleogenesis
Ukrainian Institute of Speleology and Karstology
Taurida National University
Simferopol, Ukraine
Sponsor of the Symposium:
Hungarian Oil and Gas Public Limited Company

MOL Group is one of Central Europe's leading international oil and gas companies with operations in 40 countries in Europe, the Middle East, North Africa and CIS member countries. It employs almost 31,000 people worldwide. MOL is presently conducting exploration activities in 11 and production in 7 countries worldwide. The Group also operates five refineries and two petrochemical units under integrated supply chain management, in Hungary, Slovakia, Croatia and Italy. MOL Group also owns a network of over 1,700 filling stations in Central & South Eastern Europe in 11 countries with 8 brands operated in a multi-brand strategy. Through FGSZ (Földgázszállító Zrt.), its 100%-owned member company, it operates a 5,800 km long high pressure gas pipeline system in Hungary.
Budapest, Hungary

Hungary is a landlocked country of 93,030 km² area in Central Europe, in the middle of the Carpathian Basin. It is bounded on the north by Slovakia; on the northeast by Ukraine; on the east by Romania; on the south by Serbia, Croatia, and Slovenia; and on the west by Austria. Plains and gentle hills of the Pannonian Basin dominate its surface. Some inselbergs form 600-900 m high mountain ranges. Temperate grasslands, agricultural land, meadows and non-coniferous forests characterise the landscape. Two major rivers: the Danube and the Tisza flow across the country from north to south. Lake Balaton, the greatest lake in Central Europe is a favourite target of tourists because of its warm water and nice landscape.

During its more than 1000 years of existence Hungary has experienced every possible historical ups and downs. It was several times invaded by different empires, occupied neighbouring areas, suffered several subdivisions, won battles and campaigns, lost world wars, survived civil wars and fallen revolutions. Since 2004 Hungary has been a member of the European Union.

Hungary has a slowly diminishing population of 10 million. The capital: Budapest is the most densely populated area with its 1.7 million inhabitants. Major cities of over 100,000 inhabitants are Debrecen, Miskolc, Szeged, Pécs, Győr, Nyíregyháza, Kecskemét and Székesfehérvár.

The dominant Hungarian (Magyar) population arrived from the east, from the Ural region. Its Finno-Ugric language and its traditional folklore is different from those of the surrounding Slavic, German and Romanian populations. Today's Hungary hosts ethnic minorities (altogether 10%) including Roma (Gipsies), Germans, Slovaks, Croatians, Serbs, Romanians etc. Nearly 3 millions Hungarians live outside Hungary as minorities, mostly in the immediate neighbourhood.
Budapest, the capital of Hungary, is an economic, financial and cultural centre with two million inhabitants. The city, known by many as the "Pearl of the Danube", is undoubtedly one of the most beautifully located capitals in the world. Budapest has a history dating back over 2000 years: there are ruins from the times of the Roman Empire as well as from the Middle Ages.

Its main characteristics reflect the atmosphere of the end of the 19th century when the millennium of the Hungarian state was celebrated. It boasts a number of museums, theatres, concert halls, a lot of restaurants and other amenities.

Due to the favourable geological setting, there are more than 100 thermal springs and wells in the town producing more than 30,000 m$^3$ of thermal water feeding 12 medicinal baths. In recent years several parts of the city became added to the World Heritage list of UNESCO.

The venue, the University Congress Centre, is equipped with a complete range of conference facilities and is easy to access by public transport. It is situated in a peaceful park on the Danube embankment, enriched by the pleasant atmosphere on the Buda side of the river. It is fully equipped with state-of-the-art technology.

*Room 0.823*: Keynote lectures, Invited speaker’s lectures, Symposium lectures, meeting of Regional Groundwater Flow Commission

*Room 0.817*: Early Career Hydrogeologists’ Session, meeting of Karst Commission
Members of the Honorary Committee

Yuan Daoxian  
*Karst Dynamics Laboratory, Guilin, China*

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*McMaster University, Orillia, Canada*

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*University of Toronto, Toronto, Canada*

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*University of Neuchatel, Neuchatel, Switzerland; Eötvös Loránd University, Budapest, Hungary*

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*State University of New York, New York, USA*

Ladislaus Rybach  
*ETH Zurich, Switzerland; Eötvös Loránd University, Budapest, Hungary*

Viktor Sőreg  
*MOL, Budapest, Hungary*

Heinz Surbeck  
*ETH Zurich, Switzerland*

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*University of Alberta, Edmonton, Canada; Eötvös Loránd University, Budapest, Hungary*

Renquan Zhang  
*China University of Geosciences, Wuhan, China*

Francois Zwahlen  
*University of Neuchatel, Neuchatel, Switzerland*

William B. White  
*Pennsylvania State University, State College, USA*
Scientific Committee

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*Chair of the Symposium*  
*Eötvös Loránd University, Budapest, Hungary*

Alexander Klimchouk  
*Co-Chair of the Symposium*  
*Taurida National University, Simferopol, Ukraine*

Nico Goldscheider  
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Biography of Derek Ford

Dr. Derek Ford was born in the limestone city of Bath in southwest England in 1935, educated at the local grammar school and Oxford University (BA Hons. 1958; DPhil. 1963). He and his wife, Margaret, emigrated to Canada in 1959, where he taught at McMaster University, Hamilton, until taking early retirement from undergraduate teaching in 1996, but continuing graduate and post-doctoral supervision until 2009. Their four children are Hamilton-born and educated, and they have six grandchildren, five of whom are also living in Ontario.

Dr. Ford is a physical geographer and environmental geologist specializing in geomorphology (the study of landforms) and water flowing through rocks and soils (hydrogeology). His principal specialty is ‘karst’, the study of landforms such as sinkholes at the surface and systems of caves underground, that are created by dissolving comparatively soluble rocks like limestone, dolomite and gypsum, and the associated groundwater systems. Dr. Ford has studied or directed graduate study of these features in every province of Canada, in Nunavut and the Northwest Territories, throughout the USA, and in more than 30 other countries around the world. With McMaster colleague, Henry Schwarz, and their graduate students he was a pioneer of U series dating and paleo-environmental studies of speleothems. He has published more than 300 papers and letters in scientific journals, written, edited or contributed to a dozen technical books, many consulting reports, one coffee table book of photographs to celebrate the centennial of Parks Canada, and produced one movie for the National Film Board of Canada. Dr. Ford has 25 academic honours and awards from 14 different countries.
The Fords retired to Orillia (Ontario) to be near their daughter and two grandchildren, and now live on Pumpkin Bay, Lake Couchiching, where he keeps a sailboat at the bottom of the garden. Dr. Ford continues to be active in research and lecturing around the world, consulting for Parks Canada, the UNESCO World Heritage programme, other governmental agencies in Canada and abroad, and for the private sector. Two recent matters of particular interest for Dr. Ford are the big expansion of South Nahanni National Park in 2009 that incorporated the most accentuated karstland known in arctic and sub-arctic regions, and in 2011 the creation of a provincial park that protects a beautiful marl lake in Manitoba; he was deeply involved in both.
Arthur N. Palmer is former director of the Water Resources program at the State University of New York (SUNY) at Oneonta, where he is Professor Emeritus of Hydrology and Geochemistry. He and his wife Peggy have been involved with cave and karst studies for several decades. Together they have written various articles and books on the geology and origin of caves and karst. Art is the author of *A Geological Guide to Mammoth Cave National Park* and, recently, *Cave Geology*. He has received the Science Award from the National Speleological Society, the Lifetime Achievement Award from the Karst Waters Institute, SUNY Chancellor’s Awards for teaching and research and a Distinguished Teaching Professorship. He is also a fellow of the Geological Society of America (GSA) and of the American Association for the Advancement of Science, and has received the GSA Kirk Bryan Award for his work in cave science. Art and Peggy are co-editors of the book *Caves and Karst of the USA*, prepared for the International Congress of Speleology held in Texas in 2009. Most of their research is with the National Park Service at Mammoth Cave, Kentucky, Wind Cave and Jewel Cave, South Dakota, and Carlsbad Caverns in New Mexico, which span a broad range of karst processes, from epigenetic to hypogenetic. They also teach a summer field course in Karst Geology at Mammoth Cave National Park for Western Kentucky University.
Biography of Ladislaus Rybach

Born in Sopron/Hungary, is geophysicist, currently emeritus professor at ETH Zurich and Scientific Advisor of Geowatt AG Zurich, Switzerland.

He is active world-wide as expert and lecturer; his research work extends from general geothermics over sustainability issues to application (geothermal heat pump systems as well as EGS/HDR modelling). Author of 400+ publications and various textbooks.

He was Chairman 1997-2004 and Vice-Chairman of the IEA Geothermal Implementing Agreement Executive Committee 2002-2009.

L. Rybach is Honorary Guest of the University of Zurich, Foreign Member of the Hungarian Academy of Sciences, Honorary Member of the Hungarian Geophysical Association, Recipient of the Patricius Medal of the German Geothermal Society, of the Japanese Government Research Award, of the IGA International Summer School Award, of the Unione Geotermica Italiana Honorary Award, and of the GRC Henry Ramey Geothermal Reservoir Engineering Award. He is Honorary Professor of the Technical University of Oradea/Romania and Honorary Doctor and Professor of the Eötvös University Budapest/Hungary. President 2007-2010 and currently Director of International Geothermal Association (IGA).
Biography of József Tóth

Professor József Tóth was born in Békés, Hungary, in 1933. Ten years later, shortly after he started secondary school, Hungary was occupied by the Soviet Union during World War II, and he had no hope of ever entering a university. Consequently after matriculation in 1951 he started to work as a gauge- and template-making apprentice in the country's largest metal works at Budapest, which seemed to be his only chance to academe: become a proletarian. As a result, he was admitted at the School of Mining and Geodesy of Sopron one year later. Because of his active participation in the Hungarian Revolution of 1956, after four and a half years of education in exploration geophysics, with less than a half year remaining to graduation, Erzsébet, his forestry-engineering student fiancée, and Dr. Tóth were among those who left the country. They settled in the Netherlands where his former Hungarian academic studies were not accepted, thus Dr. Tóth started to learn geophysics from year #1 at the State University of Utrecht. Four years later, with two infant daughters, a "Doctorandus" degree (Ph.D. without thesis), and knowledge of Dutch, French, English, Spanish, and German languages, he decided to move to North America. He joined to the Research Council of Alberta in Edmonton. However, geophysics proved to be inefficient for looking after the groundwater problems of farmers, towns, and industries, thus Dr. Tóth started to investigate hydrogeology in 1960. By realizing that M. King Hubbert's (1940) flow model was a postulate, not a result, and by solving the Laplace equation for the "unit basin's" geometry (Tóth, 1962), than for the same basin with sinusoidal surface (Tóth, 1963), Dr. Tóth set up his flow system theory. This fundamental concept...
of hydrogeology now also called as the "Tothian flow system theory". The 1963 paper won the first "O.E. Meinzer Award" of the Geological Society of America in 1965, "In recognition of Distinguished Contribution to Hydrogeology". As first application of the theory, Dr. Tóth explored and developed groundwater supplies for Olds (Alberta, Canada), while this project formed the basis of his Ph.D. thesis, which he defended in Utrecht, in 1965. In the same year, he introduced hydrogeology at the Geology Department of the University of Alberta (U of A). In 1968, Dr. Tóth was appointed head of the Groundwater Division of the Research Council, and thus gave up teaching. During he was supervising the 10-year-long hydrogeological mapping program of Alberta covering 660,400 km², he also volunteered to organize the Canadian National Chapter of the International Association of Hydrogeologists (IAH) in 1972, of which he remained the president until 1984. After he directed and/or personally carried out projects in India, Sri Lanka, Kenya, Ghana, and was continuously developed the theory of gravitational flow systems as a fundamental geologic agent, generating and modifying natural processes and phenomena of scientific, practical and economic interest, he joined the University of Alberta, now full time, in late 1980. Additionally, he gave his basic course of petroleum hydrogeology, as well as others in Canada, the United States, Mexico, Australia, China, Thailand, and in various European countries. After his retirement in 1996, he became emeritus professor at the U of A. In 1995, returning to the region of his youth, he started a 3-year petroleum hydrogeological research-cum-exploration project on the Great Hungarian Plain commissioned by the Hungarian Oil and Gas Company Plc. Also, he introduced his hydrogeological views at the flagship Eötvös Loránd University (ELTE) in Budapest through many short courses and as a visiting professor during a full-term course in 1996. To name but a few among his awards from the subsequent years: the IAH chose him for their "1999 President's Award", in 2002 the Geotechnical Society of Canada for the "Robert N. Farvolden Award", in 2003 the National Ground
Water Association for the "M. King Hubbert Award", and in 2004 the American Institute of Hydrology for the "C. V. Theis Award 2004". As a long-term consequence, after 48 years, Dr. Tóth resettled to Hungary with his wife in 2005 and became an "active" emeritus professor at ELTE. During that time Dr. Tóth was also working on his text book "Gravitational Systems of Groundwater Flow" as his "scientific autobiography", which finally came out in 2009. In 2008 they decided to go back to Edmonton, Canada, where he is still active nowadays. For instance, he founded the "József Tóth and Erzsébet Tóth Graduate Scholarship in Hydrogeology" for Hungarian students, as well as became one of the founders and first chairman of the Regional Gravitational Flow Commission of the IAH in 2012. Furthermore, at the 2012 IAH Congress, on the 40th anniversary of the Canadian National Chapter of IAH, Dr. Tóth was chosen for the IAH's "Award of Honorary Membership".

Biography of Renquan Zhang

Prof. Renquan Zhang was born in 1932 in China.
1950-1954 University study, Department of Geology and Mineral Resources Survey, Northeast College of Geology, Changchun, Jilin, China
1954-1956 postgraduate study in hydrogeology (no degree), Beijing College of Geology, Beijing, China
1956-1980 Teacher in Hydrogeology, Wuhan College of Geology, Wuhan, China
1980-1985 Associate Professor in hydrogeology and Environmental geology in China, University of Geosciences, Wuhan, China
1985-1994 Professor in hydrogeology and Environmental geology in China University of Geosciences, Wuhan, China
1994 Retired as emeritus professor
Biography of Mihael Brenčič

Hydrogeologist employed since 2008 as associated professor of hydrogeology and karst geology at the Department of Geology, Faculty of Natural Sciences and Engineering, University of Ljubljana, Slovenia. At present acting as a head of the department. Part time research contract with Department of Hydrogeology – Geological Survey of Slovenia (full time employed between years 1993 – 2008).

PhD in hydrogeology in year 2000 – »Hydrogeology of Big Karstic Springs«. Engineering experiences in landfill hydrogeology, radioactive waste management, application of hydrogeology in engineering geology and construction works, water resources investigations and management, groundwater protection.

Research interests: groundwater hydrology, karst hydrogeology, isotope hydrogeology, hydrogeochemistry, mass transport in porous media.
Biography of Neven Kresic

Dr Neven Kresic is Hydrogeology Practice Leader at AMEC, an international consulting and engineering company. He has worked for numerous clients worldwide and is author of seven books including his latest "Water in Karst: Management, Vulnerability and Restoration" by McGraw Hill. Neven is co-chair of the IAH Karst Commission.
Biography of John Molson

Dr. Molson is an Associate Professor in the Department of Geology & Geological Engineering at Université Laval, Quebec City, Canada, and holds a Tier II Canada Research Chair in Quantitative Hydrogeology of Fractured Porous Media. He is also an Adjunct Professor in the Department of Earth & Environmental Sciences at the University of Waterloo, Ontario, collaborating on research, student supervision and teaching. Dr. Molson's research focuses on the development and application of numerical models for simulating coupled hydrogeological processes including groundwater flow and aquifer protection, transport and biodegradation of organic contaminants, heat transport, geochemical systems and acid mine drainage. He teaches courses in physical and chemical hydrogeology, aquifer restoration and numerical modelling. He is currently serving on the Quebec Shale Gas Strategic Environmental Evaluation Committee and on the Council of Canadian Academies Shale gas Panel.
Main topics and sessions

1. *Groundwater flow patterns and hydraulics in karst*
   Theoretical issues, flow characterization and modeling, specific attributes of recharge and discharge regions

2. *Recharge and discharge processes and parameters*
   Hydrologic, hydraulic, long and short-term signals and changes; reorganization of drainage basins

3. *Epigene and hypogene karst systems*
   Definitions-characteristics, differences, examples of hierarchical approaches

4. *Flowing groundwater as a geologic agent*
   Alteration of karst-rock matrix by groundwater flow, processes of dissolution and precipitation, development of solution porosity and caves, cave minerals, karst morphologies of recharge and discharge areas

5. *Aqueous geochemistry and microbial karst processes*
   Chemical characterization, natural and environmental tracers, statistical methods, microbial processes in karstification

6. *Managing and economic aspects of karst regions*
   Contaminant problems, vulnerability, petroleum migration and entrapment, thermal and mineral waters, geothermal installations, Mississippi-valley-type ore deposits, CO$_2$ sequestration in flow system context

7. *Significance of flow system approach*
   Theoretical and practical aspects of regional groundwater flow in different systems
## Symposium program - overview

### Tuesday, 3 September 2013

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<tr>
<th>Time</th>
<th>Event</th>
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<tbody>
<tr>
<td>16:00-19:00</td>
<td>Registration</td>
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<tr>
<td>18:00-20:00</td>
<td>Ice-breaker party</td>
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### Wednesday, 4 September 2013

<table>
<thead>
<tr>
<th>Time</th>
<th>Event</th>
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<tbody>
<tr>
<td>8:00-18:00</td>
<td>Registration</td>
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<tr>
<td>8:30-9:00</td>
<td>Opening ceremony – Room 0.823</td>
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<tr>
<td>9:00-10:00</td>
<td><strong>Keynote presentation – József Tóth</strong></td>
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<tr>
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<td>The place and era of the REGFLOW theory’s birth: cause, circumstances, consequences – Room 0.823</td>
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<tr>
<td>10:00-10:20</td>
<td>Coffee break + poster session</td>
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<tr>
<td>10:20-12:00</td>
<td>Oral presentations</td>
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<td></td>
<td><strong>Topic 7:</strong> Significance of flow system approach – Room 0.823</td>
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<tr>
<td>12:00-12:30</td>
<td><strong>Invited speaker – John Molson</strong></td>
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<td></td>
<td>Groundwater age simulations in regional scale flow systems and for groundwater protection in discretely-fractured porous rock – Room 0.823</td>
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<tr>
<td>12:30-13:00</td>
<td>Poster session</td>
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<td>13:00-14:00</td>
<td>Lunch break</td>
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<tr>
<td>14:00-14:45</td>
<td><strong>Keynote presentation – Renquan Zhang</strong></td>
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<td>Tóthian theory is the paradigm of modern hydrogeology Room 0.823</td>
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<tr>
<td>14:45-15:45</td>
<td>Oral presentations</td>
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<td><strong>Topic 3:</strong> Epigene and hypogene karst systems – Room 0.823</td>
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<tr>
<td>15:45-16:10</td>
<td>Coffee break + poster session</td>
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<tr>
<td>16:10-16:40</td>
<td><strong>Invited speaker – Mihael Brenčič</strong></td>
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<tr>
<td></td>
<td>Regional groundwater flow in karstic regions of Slovenia and Istria – Room 0.823</td>
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<tr>
<td>16:40-18:20</td>
<td>Oral presentations</td>
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<td></td>
<td><strong>Topic 7:</strong> Significance of flow system approach – Room 0.823</td>
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<tr>
<td>18:30-</td>
<td>Meeting of Karst Commission of IAH – Room 0.817</td>
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### Thursday, 5 September 2013

<table>
<thead>
<tr>
<th>Time</th>
<th>Oral Presentations</th>
<th>Oral Presentations – Early Career Hydrogeologists’ Session</th>
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<tbody>
<tr>
<td>8:00-10:10</td>
<td><strong>Topic 5:</strong> Aqueous geochemistry and microbial karst processes</td>
<td><strong>Topic 1:</strong> Groundwater flow patterns and hydraulics in karst</td>
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<td>Room 0.823</td>
<td>Room 0.817</td>
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<tr>
<td>10:10-10:30</td>
<td>Coffee break + <strong>poster</strong> session</td>
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<tr>
<td>10:30-11:00</td>
<td><strong>Keynote presentation – Derek Ford</strong></td>
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<td>Karst hierarchical flow systems in the Western Cordillera of North America – Room 0.823</td>
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<tr>
<td>11:00-13:00</td>
<td>Oral Presentations</td>
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<tr>
<td></td>
<td><strong>Topic 1:</strong> Groundwater flow patterns and hydraulics in karst</td>
<td><strong>Topic 4:</strong> Flowing groundwater as a geologic agent &amp; <strong>Topic 6:</strong> Managing and economic aspects of karst regions</td>
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<td>Room 0.823</td>
<td>Room 0.817</td>
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<tr>
<td>13:00-14:00</td>
<td>Lunch break</td>
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<tr>
<td>14:00-14:30</td>
<td><strong>Invited speaker – Neven Kresic</strong></td>
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<td></td>
<td>Challenges and solutions in numeric modeling of regional karst aquifer systems – Room 0.823</td>
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<tr>
<td>14:30-16:30</td>
<td>Oral Presentations</td>
<td>Oral Presentations – Early Career Hydrogeologists’ Session</td>
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<td><strong>Topic 1:</strong> Groundwater flow patterns and hydraulics in karst</td>
<td><strong>Topic 2:</strong> Recharge and discharge processes and parameters &amp; <strong>Topic 7:</strong> Significance of flow system approach</td>
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<td>Room 0.823</td>
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<tr>
<td>16:30-16:50</td>
<td>Coffee break + <strong>poster</strong> session</td>
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<td><strong>Topic 2:</strong> Recharge and discharge processes and parameters</td>
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<td>Room 0.823</td>
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<tr>
<td>18:30</td>
<td>Departure to the <strong>Széchenyi Spa</strong> - optional program</td>
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</table>
## Program overview

**Friday, 6 September 2013**

<table>
<thead>
<tr>
<th>Time</th>
<th>Event</th>
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<tbody>
<tr>
<td>7:30-8:45</td>
<td>Meeting of Regional Groundwater Flow Commission of IAH</td>
<td>Room 0.823</td>
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<tr>
<td>8:45-9:30</td>
<td>Joint meeting of KC &amp; RGFC of IAH and KHSC of UIS</td>
<td>Room 0.823</td>
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<tr>
<td>9:30-10:00</td>
<td><strong>Keynote speaker – Ladislaus Rybach</strong>&lt;br&gt;Sustainable energetic use of a karstic/fractured deep aquifer-</td>
<td>Room 0.823</td>
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<td>10:00-10:30</td>
<td>Coffee break + <a href="#">poster</a> session</td>
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<tr>
<td>10:30-13:00</td>
<td>Oral presentations&lt;br&gt;<strong>Topic 6</strong>: Managing and economic aspects of karst regions</td>
<td>Room 0.823</td>
</tr>
<tr>
<td>13:00-14:00</td>
<td>Lunch break</td>
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<tr>
<td>14:00-16:00</td>
<td>Oral presentations&lt;br&gt;<strong>Topic 4</strong>: Flowing groundwater as a geologic agent</td>
<td>Room 0.823</td>
</tr>
<tr>
<td>16:00-16:20</td>
<td>Coffee break + <a href="#">poster</a> session</td>
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</tr>
<tr>
<td>16:20-18:15</td>
<td><strong>Wrap up presentation – József Tóth</strong>&lt;br&gt;Random memories from 50 years of Chasing Groundwater Flow-Systems – Room 0.823</td>
<td></td>
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<tr>
<td></td>
<td><strong>Keynote presentation – Arthur Palmer</strong>&lt;br&gt;Central Concepts of Karst Hydrology – Room 0.823</td>
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<tr>
<td></td>
<td><strong>General Discussion &amp; Brain Storming</strong>&lt;br&gt;What can the karst and regional groundwater flow societies learn each other?&lt;br&gt;Conveyors: Nico Goldscheider, Alexander Klimchouk &amp; Judit Mádl-Szőnyi – Room 0.823</td>
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<tr>
<td>18:20</td>
<td>Departure to the Gala Dinner with bus</td>
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<tr>
<td>19:00</td>
<td><strong>Gala Dinner</strong> – in honour of Professor József Tóth, in celebration of his 80th birthday – optional program&lt;br&gt;Paulay Event Hall</td>
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</table>
Saturday, 7 September 2013

<table>
<thead>
<tr>
<th>Time</th>
<th>Event</th>
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</table>
| 8:30-9:30 | **Introduction to the field trip:** characteristics of the two sub-systems within the Buda Thermal Karst  
|         | Anita Erőss & Judit Mádl-Szőnyi – Room 0.823                          |
| 9:45   | Departure of the buses                                               |
| 10:00-13:00 | The South System:  
|           | discharging waters and caves of the Gellért Hill area                |
| 13:00-14:00 | Picnic Lunch in the Pálvölgy quarry                                |
| 14:00-17:30 | The North System:  
|           | discharging waters and caves of the Rózsadomb area                   |
| 18:00-22:00 | **Boat trip** on the Danube with farewell dinner                     |
Symposium program – detailed

**Tuesday, 3 September 2013**

<table>
<thead>
<tr>
<th>Time</th>
<th>Activity</th>
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<tbody>
<tr>
<td>16:00-19:00</td>
<td>Registration</td>
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<tr>
<td>18:00-20:00</td>
<td>Ice-breaker party</td>
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**Wednesday, 4 September 2013**

<table>
<thead>
<tr>
<th>Time</th>
<th>Activity</th>
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<tbody>
<tr>
<td>8:00-18:00</td>
<td>Registration</td>
</tr>
<tr>
<td>8:30-9:00</td>
<td>Opening ceremony – <em>Room 0.823</em></td>
</tr>
<tr>
<td>9:00-10:00</td>
<td><strong>Keynote presentation – József Tóth</strong>&lt;br&gt;The place and era of the REGFLOW theory’s birth: cause, circumstances, consequences&lt;br&gt;<em>Chairs: Ken Howard, Neven Kresic – Room 0.823</em></td>
</tr>
<tr>
<td>10:00-10:20</td>
<td>Coffee break + <strong>poster</strong> session</td>
</tr>
<tr>
<td>10:20-12:00</td>
<td>Oral presentations&lt;br&gt;<strong>Topic 7</strong>: Significance of flow system approach&lt;br&gt;<em>Chairs: Ken Howard, Neven Kresic – Room 0.823</em></td>
</tr>
<tr>
<td>10:20-10:40</td>
<td><strong>Menggui Jin</strong>: Reconstruction of multi-stage groundwater flow systems in Hebei Plain, China</td>
</tr>
<tr>
<td>10:40-11:00</td>
<td><strong>Carlos Molano</strong>: The use of spreadsheets for groundwater flow system analysis: a simple efficient resource for teaching and practice</td>
</tr>
<tr>
<td>11:00-11:20</td>
<td><strong>Nico Goldscheider</strong>: Groundwater flow and mixing in the complex karst aquifer system feeding the carbogaseous mineral springs of Stuttgart, Germany</td>
</tr>
<tr>
<td>11:20-11:40</td>
<td><strong>Leyla Abukova</strong>: Hydrodynamic models of hydrocarbon deposits on the Vilyuiskaya syneclise and Nepa-Botuobinsk uplift</td>
</tr>
<tr>
<td>11:40-12:00</td>
<td><strong>Xiao-Wei Jiang</strong>: Theoretical and field studies on hydraulics and chemistry of groundwater around stagnation points in nested flow systems</td>
</tr>
<tr>
<td>12:00-12:30</td>
<td><strong>Invited speaker – John Molson</strong>: Groundwater age simulations in regional scale flow systems and for groundwater protection in discretely-fractured porous rock – <em>Room 0.823</em></td>
</tr>
<tr>
<td>Time</td>
<td>Event</td>
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<tr>
<td>12:30-13:00</td>
<td>Poster session</td>
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<tr>
<td>13:00-14:00</td>
<td>Lunch break</td>
</tr>
<tr>
<td>14:00-14:45</td>
<td><strong>Keynote presentation – Renquan Zhang</strong>&lt;br&gt;Tóthian theory is the paradigm of modern hydrogeology&lt;br&gt;<strong>Chairs: József Tóth, Nico Goldscheider – Room 0.823</strong></td>
</tr>
<tr>
<td>14:45-16:05</td>
<td>Oral presentations&lt;br&gt;<strong>Topic 3:</strong> Epigene and hypogene karst systems&lt;br&gt;<strong>Chairs: József Tóth, Nico Goldscheider – Room 0.823</strong></td>
</tr>
<tr>
<td>14:45-15:05</td>
<td><strong>Alexander Klimchouk:</strong> Hydrogeological approach to distinguishing hypogene speleogenesis settings</td>
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<tr>
<td>15:05-15:25</td>
<td><strong>Hans Machel:</strong> Episodic fluid flow, hypogene and epigene karstification and dolomitization in an accretionary prism setting, Barbados, West Indies</td>
</tr>
<tr>
<td>15:25-15:45</td>
<td><strong>Marco Menichetti:</strong>&lt;br&gt;Hypogene speleogenesis in Italy</td>
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<tr>
<td>15:45-16:10</td>
<td>Coffee break + <strong>poster</strong> session</td>
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<tr>
<td>16:10-18:20</td>
<td>Oral presentations&lt;br&gt;<strong>Topic 7:</strong> Significance of flow system approach&lt;br&gt;<strong>Chairs: Ladislaus Rybach, Alexander Klimchouk</strong>&lt;br&gt;<strong>Room 0.823</strong></td>
</tr>
<tr>
<td>16:10-16:40</td>
<td><strong>Invited speaker – Mihael Brenčič</strong>&lt;br&gt;Regional groundwater flow in karstic regions of Slovenia and Istria – <strong>Room 0.823</strong></td>
</tr>
<tr>
<td>16:40-17:00</td>
<td><strong>Xing Liang:</strong> Direct observation of Tóthian hierarchical groundwater flow-systems using sandbox</td>
</tr>
<tr>
<td>17:00-17:20</td>
<td><strong>Judit Mádl-Szőnyi:</strong> Thermal springs and hypogenic karstification processes in flow system context</td>
</tr>
<tr>
<td>17:20-17:40</td>
<td><strong>Szilvia Simon:</strong> Scale effect in hydrostratigraphic classification in karst and porous environment</td>
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<tr>
<td>17:40-18:00</td>
<td><strong>Brigitta Czauner:</strong> Hydraulic behaviour of low-permeability formations in regional context</td>
</tr>
<tr>
<td>18:00-18:20</td>
<td><strong>Sultan Hasan AlSultan:</strong> Source of flooding identification by the application of the flow system theory, Dammam, Saudi Arabia</td>
</tr>
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<td>18:30-</td>
<td>Meeting of Karst Commission of IAH – <strong>Room 0.817</strong></td>
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<tr>
<td>8:00-10:10</td>
<td><strong>Topic 5</strong>: Aqueous geochemistry and microbial karst processes&lt;br&gt;Chairs: Imre Müller, Jacques Mudry</td>
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<tr>
<td>Room 0.823</td>
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<tr>
<td>8:10-8:30</td>
<td>József Deák: Thermal karstwater ages around Bükk Mountains (Hungary) as evidences of the gravitational flow system</td>
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<tr>
<td>8:30-8:50</td>
<td>István Fórizs: Characterisation of the gravitational flow system in the Buda Thermal Karst, Hungary, by environmental isotopes</td>
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<tr>
<td>8:50-9:10</td>
<td>Anita Erőss: Radionuclides as natural tracers for identification of mixing of thermal waters</td>
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<tr>
<td>9:10-9:30</td>
<td>Marco Tallini: The gravity-driven flow of the Gran Sasso carbonate aquifer (Central Italy) fine-tuned through hydrochemistry</td>
</tr>
<tr>
<td>9:30-9:50</td>
<td>Peter Buzzacott: Hydrothermal irregularity in Weebubble Cave, Nullarbor karst plain, Australia</td>
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</table>
## Program Overview

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<tr>
<th>Time</th>
<th>Session</th>
<th>Speakers/Topics</th>
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<tbody>
<tr>
<td>9:50-10:10</td>
<td><strong>Chris Groves</strong>: Water-gas-rock interactions and seasonal control of geochemical environments in the epikarstic zone of the Pennyroyal Plateau, Kentucky, USA</td>
<td><strong>Ildikó Erhardt</strong>: Hydraulic processing of Buda Thermal Karst, Budapest, Hungary</td>
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<td>11:00-11:20</td>
<td><strong>Attila Kovács</strong>: Hydrograph analysis for the estimation of hydraulic and geometric parameters of karst systems</td>
<td><strong>Magdolina Virág</strong>: Unusual speleothems from a non-speleal environment - Mineral precipitates of the Széchenyi Spa (Buda Thermal Karst, Budapest, Hungary)</td>
</tr>
<tr>
<td>11:20-11:40</td>
<td><strong>Peter Malík</strong>: Karst springs' hydrograph separation into flow components using parameters of the master recession curve</td>
<td><strong>Julie Jeanpert</strong>: Sinkholes as markers of karstic activity in the peridotites of New Caledonia (SW Pacific)</td>
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<td>11:40-12:00</td>
<td>John Gunn: What's behind the spring? Exploring very short-term signals in two flooded conduits</td>
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<td>12:00-12:20</td>
<td>Igor Jemcov: An approach to the simulation of karst spring discharge</td>
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<td>12:20-12:40</td>
<td>Stéphane Binet: Hydraulic boundary conditions as a controlling factor of water exchanges between a saturated karst conduit and its surrounding host rock</td>
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<td>12:40-13:00</td>
<td>Hakim Benabderrahmane: Modelling of the predictive hydrogeological impacts of the radwaste geological repository construction on limestone aquifers of the Meuse/Haute-Marne site (France)</td>
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<td>14:00-14:30</td>
<td>Invited speaker – Neven Kresic: Challenges and solutions in numeric modeling of regional karst aquifer systems</td>
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Chairs: Derek Ford, François Zwahlen – Room 0.823
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<td>14:30-14:50</td>
<td>Owen Naughton: Groundwater flooding mechanisms in lowland karst: a case study from Ireland</td>
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<td>14:50-15:10</td>
<td>Éva Kun: Modelling effect of climate change on Bükk karst system</td>
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<td>15:10-15:30</td>
<td>Laurence Gill: Determination of a conduit network in a lowland karst catchment by modeling ephemeral lake (turlough) fluctuation</td>
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<td>15:30-15:50</td>
<td>Zoran Stevanovic: Tectonic fabric as the main factor for privileged groundwater pathways, discharge regime and thermal properties within the same karstic system of Vidlic Mt. (Serbia)</td>
</tr>
<tr>
<td>15:50-16:10</td>
<td>Caoimhe Hickey: The national karst water tracing database of Ireland</td>
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<td>Chairs: Bartolomé Andreo, John Molson, Menggui Jin</td>
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<td>14:30-14:50</td>
<td>Wei Liu: Discussion on the classification for epikarst flow by discharge and coefficient of variation</td>
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<td>14:50-15:10</td>
<td>Aurore Perineau-Barbel: Characterisation of flows in the vadose zone by direct measurements in karst aquifer</td>
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<td>15:10-15:30</td>
<td>Junzhi Wang: An analytical study on stagnation points in drainage basins with injection/pumping wells</td>
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<td>15:30-15:50</td>
<td>Tímea Havril: Understanding the hydraulic position of paleo-maar lakes in groundwater flow systems, Tihany Peninsula, Hungary</td>
</tr>
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<td>15:50-16:10</td>
<td>Ádám Tóth: Groundwater flow pattern in a complex volcanic, carbonate and siliciclastic environment, Tihany Peninsula, Hungary</td>
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<td>16:10-16:30</td>
<td>Jawad Hasan: Tracing the sources of groundwater salinization in karstic aquifer the example of Ein Feshcha springs at the Lower Jordan Valley</td>
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| 16:50-18:20| Oral presentations  
**Topic 2:** Recharge and discharge processes and parameters  
**Chairs:** John Gunn, Heinz Surbeck  
*Room 0.823* |
| 16:50-17:10| Andrea Mindszenty: Anthropogenically modulated hydrological changes as recorded by a 120 year old flowstone-like travertine (Rudas Spa, Budapest, Hungary)  
**Zoltán Sávoly:** Chemical characterization of bio-films formed in hypogene spring caves of Budapest |
| 17:10-17:30| Pierre-Yves Jeannin: Role of soil cover and epikarst on karst groundwater recharge: an experimental approach conducted on the Milandre underground laboratory (Jura Mountains, Switzerland)  
**Gabriella Büki:** Bacterial diversity and community structure of biofilm and thermal water found in spring caves of the Buda Thermal Karst System |
| 17:30-17:50| Bartolomé Andreo: Evaluation of recharge processes and flow dynamics in a karst complex system by using environmental isotopes and chemical characteristics of waters  
**Ágnes Freiler:** Comparision of radioactivity of biofilm and thermal water, Buda Thermal Karst, Hungary |
<table>
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| 17:50-18:10 | **Sylke Hilberg:** Identification of a deep flow system in a dolomitic Alpine aquifer  
                   – Case study Wimmerbauern Spring, Bad Ischl, Austria |
| 18:10-18:30 | **Francesco Fiorillo:** The role of endorheic areas on recharge processes of karst massifs |
| 18:30     | Departure to the **Széchenyi Spa** – optional program                   |

Early Career Hydrogeologists’ Poster Session
### Friday, 6 September 2013

<table>
<thead>
<tr>
<th>Time</th>
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| 7:30-8:45  | Meeting of Regional Groundwater Flow Commission of IAH  
*Room 0.823*                                                                                     |
| 8:45-9:30  | Joint meeting of KC & RGFC of IAH and KHSC of UIS  
*Room 0.823*                                                                                     |
| 9:30-10:00 | **Keynote speaker – Ladislaus Rybach**  
Sustainable energetic use of karstic/fractured deep aquifers  
**Chairs: Zoran Stevanovic, Chris Groves – Room 0.823**                                          |
| 10:00-10:30| **Coffee break + poster session**                                                                                                                |
| 10:30-13:00| Oral presentations  
**Topic 6: Managing and economic aspects of karst regions  
Chairs: Zoran Stevanovic, Chris Groves – Room 0.823**                                          |
<p>| 10:30-10:50| <strong>Pierre-Yves Jeannin:</strong> Towards a sustainable development of geothermal and hydropower plants in a karst environment: Examples from Switzerland |
| 10:50-11:10| <strong>Philippe Meus:</strong> From flow uncertainties to resource management: the example of the Carboniferous limestone aquifer in the international Scheldt river basin |
| 11:10-11:30| <strong>György Tóth:</strong> Thermal-karst modeling for an action plan to sustain the water characteristics of Hévíz-lake                              |
| 11:30-11:50| <strong>Ezzat Raeisi:</strong> Hydrogeological causes of water crisis in karst and alluvium aquifers                                                        |
| 11:50-12:10| <strong>Ken Howard:</strong> Karst as a constraint on aggregate mining along the Niagara Escarpment, eastern Canada                                             |
| 12:10-12:30| <strong>Željko Zubac:</strong> Multipurpose system of hydropower plants on the river Trebisnjica                                                            |
| 12:30-12:50| <strong>Ognjen Bonacci:</strong> Possible negative consequences of underground dam and reservoir construction in coastal karst area: example of HEPP Ombla near Dubrovnik (Croatia) |
| 13:00-14:00| Lunch break                                                                                                                                     |</p>
<table>
<thead>
<tr>
<th>Time</th>
<th>Session</th>
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<tr>
<td>14:00-16:00</td>
<td>Oral presentations&lt;br&gt;&lt;br&gt;&lt;strong&gt;Topic 4:&lt;/strong&gt; Flowing groundwater as a geologic agent&lt;br&gt;&lt;br&gt;&lt;strong&gt;Chairs: Andrea Mindszent, Viktor Sőreg&lt;/strong&gt; – Room 0.823</td>
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<tr>
<td>14:00-14:20</td>
<td>Hans Machel: The Grosmont: the worlds largest unconventional oil reservoir hosted in polyphase-polygenetic karst</td>
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<td>14:20-14:40</td>
<td>John E. Mylroie: A hypothesis for carbonate island karst aquifer evolution from analysis of field observations in northern Guam, Mariana Islands</td>
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<td>14:40-15:00</td>
<td>Alexander Klimchouk: Isotopically altered wallrock of the hypogene conduits in the Crimean Piedmont, Ukraine</td>
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<td>15:00-15:20</td>
<td>Udo Weyer: Confluence of regional ground water flow systems in karst at Pine Point Mines' lead zinc ore deposits</td>
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<td>15:20-15:40</td>
<td>Philippe Audra: Uncommon cave minerals associated to hypogene speleogenesis in Southern France</td>
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<tr>
<td>15:40-16:00</td>
<td>Szabolcs Leél-Őssy: Minerals of the Józsefhegyi Cave</td>
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<td>16:00-16:20</td>
<td>Coffee break + poster session</td>
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<tr>
<td>16:20-18:15</td>
<td><strong>Wrap up presentation – József Tóth</strong>&lt;br&gt;Random memories from 50 years of chasing groundwater flow-systems – Room 0.823</td>
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<td><strong>Keynote presentation – Arthur Palmer</strong>&lt;br&gt;Central concepts of karst hydrology – Room 0.823</td>
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<td><strong>General Discussion &amp; Brain Storming</strong>&lt;br&gt;What can the karst and regional groundwater flow societies learn each other?&lt;br&gt;Conveyors: Nico Goldscheider, Alexander Klimchouk &amp; Judit Mádl-Szőnyi – Room 0.823</td>
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<tr>
<td>18:20</td>
<td>Departure to the Gala Dinner with bus</td>
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<td>19:00</td>
<td><strong>Gala Dinner</strong> – in honour of Professor József Tóth in celebration of his 80th birthday – optional program&lt;br&gt;&lt;br&gt;&lt;em&gt;Paulay Event Hall&lt;/em&gt;</td>
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### Program overview

**Saturday, 7 September 2013**

<table>
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<tr>
<th>Time</th>
<th>Activity</th>
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</table>
| 8:30-9:30 | **Introduction to the field trip**: characteristics of the two subsystems within the Buda Thermal Karst  
Anita Erőss & Judit Mádl-Szőnyi – Room 0.823 |
| 9:45    | Departure of the buses                                                   |
| 10:00-13:00 | The South System: discharging waters and caves of the Gellért Hill area |
| 13:00-14:00 | Picnic Lunch in the Pálvölgy quarry                                    |
| 14:00-17:30 | The North System: discharging waters and caves of the Rózsadomb area  |
| 18:00-22:00 | **Boat trip** on the Danube with **farewell dinner**                    |
Hydrodynamic models of hydrocarbon deposits on the Vilyuiskaya syncline and Nepa-Botuobinsk uplift

Leyla Abukova, Yuri Yakovlev
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Keywords: groundwaters, oil and gas accumulation, hydrocarbon migration, hydrodynamic conditions, hydrodynamic potentials

Nepa-Botuobinsk uplift and Vilyuiskaya syncline are most explored areas in the East Siberia concerning oil-and-gas-bearing capacity. They are an excellent example, that the local hydrodynamic flows are determining a location of major zones of the oil-and-gas accumulation.

In the Nepa-Botuobinsk uplift particularly in the sub-salt part of sequence the formation pressures are decreasing from the local salt-bearing section’s bottom to the basement. A deficit of the formation pressure in some structures is amount to 7-8 megapascal. The hydrocarbon migration and hidden discharge of the water are realized through the faults to the bottom of the sedimentary cover and basement rocks (in such fields as Srednebotuobinskoe, Verhne-Viluchanskoe, Vilyuisko-Dzherbinskoe, Taas-Yuryahskoe and others). The lowest values of the hydrodynamic potential are limited to the most ancient Vendian-Riphean deposits, which contact with Nepa-Botuobinsk uplift’s crystal base.

There is expelling water drive in the Vilyuiskaya syncline. Upward migration of the hydrocarbons and groundwaters are predominated here. The migration is grown by the super-hydrostatic formation pressure development in the bottom of the sedimentary cover and by the sub-hydrostatic formation pressure development in the subpermafrost part of sequence. In the Vilyuiskaya syncline a safety of the hydrocarbon fields (Srednevilyuiskoe, Talon-Maactahskoe, Soboloh-Nedzhelinskoe, Srednetungskoe and others) is provided by the fluid-resistant properties of the cap rocks. And on the contrary, the hydrodynamic conditions didn’t ministerial to maintenance of the hydrocarbon accumulation in commercial measures. Because the hydrodynamic conditions are stimulated the hydrocarbon dispersal processes. This is reflected in the fact that there are a lot of oil and gas shows here.

Therefore, in the Nepa-Botuobinsk uplift the upward migration of the hydrocarbons became agent for attraction of the oil fringes to faulted zone, hydrocarbon accumulations confinedness to the most ancient deposits, on the areas where the lowest hydrodynamic potentials are found. In the Vilyuiskaya syncline, where the expelling water drive is developed, the hydrocarbon accumulations could keep granting the large and mature impermeable beds only.
Source of flooding identification by the application of the flow system theory, Dammam, Saudi Arabia

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²Instituto de Geografía, Universidad Nacional Autónoma de México, Coyoacán, México
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Keywords: discharge, recharge, vegetation, soil, chemistry, desert environment

The dependence on groundwater in Saudi Arabia has prompted environmental and governmental authorities to encourage the study of the flow systems. The relation between groundwater and other components of the environment needs to be fully understood. Population in Greater Dammam has grown from 1.5 million (1980) to 3.5 million (2005), its associated economic expansion has also increased, water desalinization has augmented from 200 to 1050 MCM/y and its overall water needs from 210 to 550 MCM/y (1980 to 2005). All associated development activities have generated a ≈17 m water-table drawdown and an associated salinity increase (2000 to 5700 mg/l, TDS). However, unexpected flooding has been reported in sites of Greater Dammam area. The effects of this lack of understanding is by far connected to the drying of springs (oases), disappearance of rivers and associated water bodies; soil logging; loss of natural vegetation; etc. The Saudi Arabia Water Centre of Excellency & College of Water is aware of the importance of generating the required understanding which might assist in reaching a sustainable water use. A research work will start defining groundwater functioning associated with flooding in Greater Dammam area. The definition of the influence in terms of type of flow system (local, intermediate or regional) from the chemical perspective are to be supported by the interpretation of water-soil interaction in the prevailing geological environment (lithology and structure); indirect evidence will be provided by vegetation and soil characteristics. Water samples collected from wells, surface-water and springs, are to be analyzed for 64 metals, anions, stable isotopes and ³H. Results are expected to suggest the nature of the groundwater flow discharging in the plain. The evolution of the chemical quality of water will be obtained as extraction time progresses, different discharge rates will be also tested to enquire on the response to extraction. Saudi Arabia past, present and future sustainable water management and policy will be discussed.
Hydrodynamic characterization of karst systems by monitoring natural organic tracers evolution and physico-chemical spring responses

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Keywords: karst, springs, TOC, fluorescence, hydrochemistry

This work presents the results of the hydrochemical monitoring conducted in the karstic springs of La Leze and Arbara, that constitute the main discharge points of the Egino karstic subunit. This subunit is associated with a limestone outcrop of 3.6 km², belonging to the Aizkorri karst unit (Araba, Basque Country).

Although monitoring covers two hydrogeological cycles, special attention is given to an storm event registered after a summer low water level period. In this episode the monitoring consisted of a direct control of discharge, conductivity, temperature, pH and turbidity in both springs. Complementarily, samples were taken hourly and natural tracers, TOC and fluorescence, and major components (Ca²⁺, Na⁺, K⁺, Mg²⁺, Cl⁻, SO₄²⁻, NO₃⁻ and Total Alcalinity) were measured.

The integrated analysis of this data allows us to establish remarkable differences in the behavior of the systems drained by the two springs monitored. In both cases responses could be separated into different stages informing on different infiltration and transport ways in the systems.

La Leze spring is associated to a clear binary karstic system and shows a great influence of allogenic recharge in an evident conduit controlled karst system, presenting a high degree of functional karstification in the unsaturated zone. On the contrary, in the Arbara system a higher regulation capacity is evidenced, related to the existence of a mixed flow system.

Overall, the determination of the evolution of natural tracers, TOC and fluorescence, in karst springs allows completing the characterization derived from hydrochemical analysis of major elements. These measurements are particularly useful in the analysis of water evolution in karst systems after heavy rainfall events. In these cases, as outlined in this work, it is possible to differentiate between origins and patterns of infiltration and water flow in both the saturated and unsaturated zone. Consequently, it could help to evaluate the vulnerability of the aquifers to the contamination and contribute to a proper management.
Uncommon cave minerals associated to hypogene speleogenesis in Southern France

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Keywords: cave minerals, hypogene speleogenesis, sulfide oxidation, hydrothermal weathering, hydrothermal minerals

Five hypogenic-origin caves from Southern France are presented. Investigations using XRD, SEM and Raman spectroscopy, reveal the presence of uncommon cave minerals. Oilloki Cave is a small lead ore mine-cave containing galena, cerussite, and bismuth (present as native element or as sulfide). La Baume Cave is a hydrothermal breccia-pipe, filled with colorful (red, green, white) clays. Some of the clay minerals (clinochlore-sepiolite), could originate from hydrothermal weathering of clastic material. The Malacoste Quarry, harbors a hydrothermal chimney with enlarged vugs lined with calcite spar and filled with iron oxyhydroxides poolfingers (goethite-hematite) and manganese oxides (birnessite, todorokite). Deposition of iron and manganese oxides results of the pH-Eh evolution along the hydrothermal chimney. Pigette Cave is a hydrothermal vertical maze with calcite lining and small iron oxyhydroxides and manganese oxides masses. The hydrothermal weathering of the walls deposited grains of lithiophorite, barite, and celadonite, which could originate from glauconite. Baume Galinière Cave is a small horizontal maze originating from the oxidation of sulfide masses of pyrite. Beside the common byproducts (gypsum, goethite, sulfur), the six members of the jarosite subgroup are present: jarosite, ammoniojarosite, argentojarosite, hydronium jarosite, natrojarosite, plumbojarosite, together with fibroferrite. In these caves, three minerals are new cave minerals (bismuth, celadonite, argentojarosite); some others have been mentioned before only in a few caves worldwide (clinochlore, lithiophorite, ammoniojarosite, hydronium jarosite, natrojarosite, plumbojarosite, fibroferrite). The mineralogenesis involves different processes: (i) Deposition in mixing zone from species carried by rising deep flow (barite, galena, bismuth, birnessite, todorokite, lithiophorite); (ii) Hydrothermal weathering of clay minerals contained in host rock or present as clastic sediments (clinochlore, sepiolite, celadonite); (iii) Oxidation of sulfide masses (goethite, cerussite, jarosite subgroup minerals, fibroferrite).
Multi-tool geophysical survey and hydrogeological exploration in cross-border karst systems

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Keywords: geophysics, karst, hydrogeology, vulnerability, modelling

Karst is one of the most challenging environments in terms of groundwater, engineering and environmental problems. Geophysical methods can provide useful information to characterize hydrostratigraphic features of the vulnerable karst aquifer systems. In general the different hydrogeologic units of the aquifers have a predictable difference in electrical resistivity based on their mineralogy, rock type, fracturing rate and water content.

The Vertical Electrical Sounding (VES) method is very flexible to be used for measurements on difficult terrains, where it is not possible to make the standard drilling. The values of resistivity can establish the type of the covering and its structure, the thickness of covering sedimentary rock, and the morphology of the limestone floor at the measurement sites. The VLF-R method significantly enhanced the horizontal resolution for vertical structures as fractures and faults, but could not separate horizontal layers at very shallow depths. The Radiomagnetotelluric (RMT) device using different frequencies, and provided from the measured values both apparent resistivity and phase-shift between the horizontal, magnetic and electric field component. These two parameters allowed data interpretation based on magnetotellurics (MT) to calculate specific resistivity-depth-distribution. Moreover the multi-direction RMT results are used for calculating anisotropy arrows. The SP (IP) technique is sensitive to all the characteristic features of a karstic terrain like block structures separated by more fractured zones and strong spatial variation of fracture distribution. These methods can be applied for the exploration of fractured zones in limestone filled with clay.

The geophysical survey has been a part of an integrated approach including research on geomorphology, transport-processes, chemistry and numerical modelling of karst hydrodynamics.

Using different geophysical methods at different sites allowing in-situ validation demonstrate its efficiency and reliability. High and rapid spatial sampling (dense spatial coverage), low cost and fast data interpretation are the main advantages of geophysical methods. Finally, 3D data acquisition and inversion development for many geophysical methods as boreholes geophysics seems to be extremely promising for karst system exploration. Our company is experienced of implementation in EU-cofinanced karst explorational cross-border projects.
Evaluation of recharge processes and flow dynamics in a karst complex system by using environmental isotopes and chemical characteristics of waters

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²Institute of Hydrology, Freiburg University, Freiburg, Germany
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Keywords: karst hydrogeology, water isotopes, recharge processes, flow dynamics, aquifer behaviour

The functioning of a karst system can be characterized by different hydrogeological methods. This work demonstrates the usefulness of isotopic methods for karst hydrogeology during almost three years of field investigations in a karstic aquifer at southern Spain. δ²H and δ¹⁸O isotopes were measured at five selected karst springs (Cañamero, Carrizal, Ventilla, Barranco and Prado Medina -overflow spring-), an outflowing borehole (Cerezo) and meteoric waters. The aims were to precise the water origin, the recharge processes and the behaviour of the aquifer. Atlantic (prevailing) and Mediterranean fronts constitute main recharge waters in the studied aquifers. A comparative computation using weighted mean seasonal isotopic compositions (δ¹⁸O and δ²H) was used to estimate the average recharge contribution of the autumn (26-37%) and winter rains (50-59%) to springs flow. Strong evaporation effects were observed, mostly in the northern part of the study area. This indicated important losses of effective rainfall occurring in the shallow areas of this aquifer sector. Variability of δ¹⁸O and temperature data suggested short residence times of waters drained by the majority of karstic springs. Isotopic composition and water mineralisation evidenced different flow patterns among groundwater monitoring points. Cañamero and Prado Medina springs showed a marked karst behaviour and a highly developed conduit network which provoked a rapid transferring of isotopic signals from recharge to discharge areas.
Estimation of discharging karstic and alluvial springs by means of hydrochemical techniques: case study Feshcha in Palestine and Chaouia in Morocco

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Keywords: coastal aquifer, seawater intrusion, over-pumping, Feshcha

Most of the available groundwater discharges throughout highly developed karstic towards the Sea without interception for domestic and agricultural uses. This phenomenon takes place in Feshcha and Chaouia aquifers which is considered as one of the most important places in the study area. Feshcha spring group discharge 45–65 MCM of mixed water (fresh and saline) to the sea. The only water resource available in the Chaouia plain is obtained from shallow groundwater. Thus, the present study indicates the hydrochemical tests and dye tracing techniques that were used for measuring the amount of water discharges of these two aquifers. Comparison of the Electrical Conductivity (EC) of the karst springs which have a background concentration of 2-50 mS/cm, with the EC of the recharging water is also considered as an important tool for identifying the percentages of the fresh-water available in a certain volume of saline water discharge from the alluvial springs.

The amount of fresh water that discharges throughout the springs can be calculated from the hydrochemical investigations. This amount is bigger than the other determinant from the hydrogeological budget. This may be related to the small percentage of infiltration that were considered as the recharge ratios of different highly fractured limestone units covering such coastal karstic region.
Modelling of the predictive hydrogeological impacts of the radwaste geological repository construction on limestone aquifers of the Meuse/Haute-Marne site (France)

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²Centre of Hydrogeology and Geothermics, University of Neuchâtel, Neuchâtel, Switzerland
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Keywords: modelling, limestone, karst, repository, impacts

The French National Agency for Nuclear Waste Management (Andra) conducted a site investigations program within the project of a deep geological disposal of radioactive waste in the Meuse/Haute-Marne region. The construction of the tunnels and the shafts to access the repository located in the clay host formation of Callovo-Oxfordian age, will lead to the perturbations of the groundwater flow fields. The prediction of the behaviour of these perturbations is needed to support: (i) the engineering and monitoring operations, and (ii) the assessment of the consequences on groundwater resources. A variably-saturated flow model of a local multi-layered aquifer system is developed. It integrates the Oxfordian aquifer (limestone), the Kimmeridgian aquitard (marl) and the Barrois limestone aquifer including the karst conduits network previously modelled by Jacquet (Jacquet et al. 2004).

The variably-saturated flow Richard’s equation is solved with the finite element simulator GroundWater (Cornaton 2003). Prior to the simulation of the predictive repository impacts, a transient flow model is calibrated with respect to Underground Research Laboratory (URL) construction data. The results are analysed and evaluated by the use of performance measures.
Hydraulic boundary conditions as a controlling factor of water exchanges between a saturated karstic conduit and its surrounding rock

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Keywords: karst hydrology, isotopes, water exchanges, saturated conduit

The exchanges of water between the conduits and its surrounding rock in karstic aquifer are key parameters to understand the changes of water quality at the outlet of these aquifers.

The mechanisms controlling these exchanges under saturated conditions are explored using a 2D coupled continuum-conduit flow model (Feflow®). The flows in the conduits and in the surrounding rock are described by the Manning-Strickler equation and the Darcy law respectively. We choose fluid transfer conditions to describe the aquifer boundaries, which imply that the hydraulic heads at the boundaries of the conduit are not fixed. Thus the model can calculate freely the amounts of water exchanged between the two domains.

Isotopic (δ¹⁸O and 2H) and discharge measurements were conducted on the Val d’Orléans karstic aquifer (France), during the 2008 hydrologic cycle. The aims were (1) to estimate the amounts of water exchanged between the two domains and (2) to validate the proposed model.

The modelled amounts of exchanged water between the two domains are consistent with those derived from the monitoring. The steady flow results show a spatial variability of the water exchanges from recharge to discharge areas that are controlled by the turbulent head loss in the conduit and by the boundary conditions. The transient calculation shows a zone where the water is mixed at the interface between the conduit and the rock. Only the point recharge in the conduit controls the observed transient changes of water exchanges between the two domains.
Possible negative consequences of underground dam and reservoir construction in coastal karst area: example of HEPP Ombla near Dubrovnik (Croatia)

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Keywords: karst aquifer, grout curtain, Ombla Spring, ecology, karst hydrology

The Ombla Spring represents a typical karst spring with limited maximum and minimum outflow capacity. The exit of Ombla Spring is at an altitude of 2.5 m above sea level (m a.s.l.) and the water from it immediately flows into the Adriatic Sea. The minimum measured discharge is 3.96 m$^3$/s. The maximum discharges never exceeded a value of 117 m$^3$/s, despite of fact that the spring catchment area is large and is assessed to cover an area of about 1000 km$^2$. The precipitations on it are very abundant and intensive. The mean annual discharge after canalization of the more than 60 km long Trebišnjica River watercourse with spray concrete (from 1981 till 2011) is 24.05 m$^3$/s. Before this massive civil engineering works in 1968-1980 period mean annual discharge was 28.35 m$^3$/s. There is a project for construction of the hydro electric power plant Ombla, which will exclusively use groundwater from a karst aquifer which feed Ombla Spring. The underground dam will be constructed 190 m behind the existing karst spring outflow in the karst massif. It will be performed by injection as grout curtain. Projected total curtain area is about 300,000 m$^2$. Total length of the curtain will be about 1470 m, while its maximum depth will be 410 m. Installed discharge of the HEPP Ombla is 70 m$^3$/s. Present-day ecological aspect of grouting has attracted little attention. Grouting is an extremely expensive and hardly foreseen procedure. In many cases it is not successful from the engineering perspective. After the construction of the grout curtain, the hydrostatic pressure upgradient of the curtain is increased to levels never previously encountered. This increased pressure can result in “clay plugs” being expunged from some of the cavities adjacent to the penetration of the grout, thus opening up new cavities that are gradually enlarged as effective conduits. In the paper will be explained many possible, but very probable, negative consequences of the HEPP Ombla construction and development as for example: induced seismicity, intrusion of sea water in coastal karst aquifer, overflow of groundwater from Ombla Spring catchment to neighbouring karst spring catchments, landslides provocation, dangerous changes of suspended sediment deposition, collapse of dolines, induced subsidence, pollution of vulnerable and valuable karst underground environment etc.
New conceptual understanding of groundwater flow in Lebanon

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Keywords: groundwater, karst, messinian salinity crises, shallow/intermediate/deep groundwater flow

Lebanon, an eastern Mediterranean country has more than 65% of its surface area consisting of karst terrains. These karst beds extend from the high tops of Mounts of Lebanon, around 3088 m asl, to depths reaching 1000 m bsl. Although the oldest exposed and identified beds date to the lower Jurassic, both Jurassic and Cretaceous aged rocks form the main groundwater towers of Lebanon. New emerging evidence on the depth of karstification (as a result of the Messinian Salinity crisis) from deep wells, from cave speleogenesis and from a new classification of springs, have revealed that the groundwater circulation in these karstic rocks follow three lines of movement: shallow, intermediate and deep flows.

Shallow groundwater flow follows a fast cycle of movement with recharge occurring several hours after precipitation events. In this case the groundwater emerges as boundary springs issuing at different levels in the exposed karstic beds. In this case the recharge area is several hundred of meters away from these emerging springs. Intermediate groundwater flow following a cycle with recharge occurring several months after precipitation events. These can be observed as overflow springs issuing close to the coastal area near the steeply dipping coastal beds. In this case the recharge area is several 10’s of kilometers away from the coastal springs. Although sometimes there might be intermediate and shallow flows overlapping in those coastal springs, but the dominant flow is intermediate. Deep groundwater flow follows a deep cycle, with recharge occurring years after precipitation events. In this case the groundwater follows a deep cycle and emerges as either karstic submarine springs or as diffused flow. In this case the recharge area is also several 10’s of kilometers away from the coastal springs.
Regional groundwater flow in karstic regions of Slovenia and Istria

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Keywords: gravity driven flow, regional groundwater flow, karstic aquifer, Dinaric karst, Slovenia

In well developed karstic aquifers groundwater flow is usually very complex and seasonal fluctuations of groundwater level can reach up to several tens of meters. At regional scale groundwater spatial distribution is often discerned based on the tracing experiments conducted with tracer injection at one point (e.g. swallow holes, boreholes) and observing its arrivals and breakthrough curves at several places (e.g. resurgences, potholes, boreholes) in down-gradient directions. Such experiments often reveal interpretations of bifurcated groundwater flow and flow dispersion in opposite directions as well as water flow on very long distances. In some literature these phenomena are very often misleadingly interpreted even obeying physical law (e.g. wrong understanding of “vertical” groundwater flow). These shortcomings and interpretational mistakes can be easily overtaken with the help of regional groundwater flow concept.

Karst of south-western and southern part of Slovenia is part of large Dinaric system karst stretching from Italy on the north-west through Croatian, Bosnia and Herzegovina, Montenegro and Albania to south-east direction. In this region big regional nappes structures are presents as well as strong regional faults oriented in north – west to south – east direction. Such geological conditions consequently caused groundwater flowing in the directions parallel to regional faults. At some places water breaks through these structures and flows in the perpendicular direction forming complex spatial pattern of groundwater distribution and its outcrops in caves and big karstic springs. In the development of these patterns high relief has important role.

In the paper groundwater distribution Slovenian karst and karst of Istria shared between Republics of Slovenia and Croatia is explained with the concept of regional groundwater. Hydrological connections between large Ljublanica system, Karst and Istria will be illustrated based on the past tracing experiments result.
Feeling the heat: Cave divers detect water temperature changes <1 °C

Peter Buzzacott

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Keywords: water temperature, cave diving

Water of differing temperatures in a flooded cave is of geologic interest. The author dived a flooded former pit coal-mine with shafts in the walls at between 15-30m depth. In 1 of 5 shafts at 18 m he ‘felt’ the rock overhead was warmer than the surrounding water, (confirmed by his buddy). The diver returned with 5 Sensus data-loggers (ReefNet, Canada) to record water temperature at resolution of 0.01 °C and accuracy of +/-0.8 °C. The loggers were lowered to 6 m for 1 hour to equilibrate. Temperature data was recorded every ten seconds and compared from 3600 to 3900 seconds (n=31 per logger) from initial immersion. Standard deviation within each logger ranged from 0-0.01 °C and overall SD between loggers was 0.08 °C. The loggers were raised to 1 m at which time logging ceased, they were swum across the lake and taken to the westernmost shaft on the north face of the underwater cliffs. Two loggers were inserted to a distance of 3 m. Two loggers were hung in front of the shaft, 1 m apart. The 5th logger measured the water temperature against the rock above the mouth. The divers again felt a temperature difference. The loggers were in place for 3.5 hours to equilibrate and were retrieved after 3.8 hours. Temperature data were downloaded for between 210-215 mins, post re-immersion. SD ranged from 0-0.01 °C within loggers. Mean temperature in the lake was 13.15 °C, above the shaft 13.45 °C and inside 13.96 °C. As the inter-logger variation was 0.08 °C during the pre-dive measurement, this difference in temperature between inside and outside (0.81 °C) equates to 10. SD therefore water inside the shaft was significantly warmer than outside (p<0.01). This suggests a perceptive cave diver has the potential to detect water temperature differences <1 °C. Cave divers exploring karst systems should remain vigilant for differences in water temperature and, when feeling warmer or cooler water, record the location for scientific investigation.
Hydrothermal irregularity in Weebubbie Cave, Nullarbor karst plain, Australia

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Keywords: hydrothermal, Nullarbor, loggers, temperature, groundwater

The Nullarbor is one of the largest contiguous karst plains in the world, an unaltered horizontally-beded Tertiary sheet ~200,000 km² in area that contains many large caves along its southern coastal margin. Weebubbie Cave reaches the greatest depth, penetrating the regional groundwater basin near sea level to ~50 m depth in a large underground lake and submerged tunnel system. Since the mid-Miocene the Nullarbor has largely had an arid to semi-arid climate. There is almost unrestricted heat exchange between the cave, its lake surface and the atmosphere.

This study investigated if water temperature is uniform throughout the system and commensurate with ambient air temperature recorded daily at nearby Eucla village. Fixed loggers recorded temperatures laterally through the main lake and in the water column to ~30 m depth; another traversed part of the submerged tunnel system attached to a diver [PB]. While lake and water column temperatures remained within 0.5 °C of the average (18.6 °C; SD 0.1 °C), both divers [PB and IDL] felt a distinct temperature rise within 7.6 m of the isolated pool in the inner Air Dome which the logger recorded as 19.3 °C on ascent and 19.5 °C on descent (p<0.0001).

Though the source of this warm water has not been identified, it may be entering the cave through the floor in zones which may be geomorphically identifiable and rising to be trapped in the Air Dome. This may have significant implications for possible hydrothermal cave inception at depth, in conjunction with a similar warm-water zone of large Nullarbor caves ~300 km to the west.
Origin of the water in Cocklebiddy Cave, the Nullarbor Plain, Australia

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Keywords: speleogenesis, tertiary, climate

Cocklebiddy Cave, located on the Nullarbor Plain in the south, is Australia’s longest flooded cave (>6 km). The entry lake, 100 m below the surface, is only ~1 m above mean sea level (MSL) and reaches 18 m below MSL. The cave is oriented along a N-S axis and it is not known if there is ingress from the sea, 35 km to the south; however, the cave’s water is brackish (10.5 g.L⁻¹). There is no geologic evidence of flow and the direction of any gradual flow has not been measured. The location below mean sea level as well as the low coastward slope of the plain (only ~1 m per 20 km), arid climate (233 mm/yr), little landscape relief and lack of evidence of water course did not help to ascertain obvious sources of the cave’s water. We collected 17 water samples from the entry lake to 660 m inside the cave with temperature, depth and distance also recorded. Following 9 mm of rainfall in a single day (20 days prior sampling) there was a 1.5 m deep lens of cool (15.5±0.01 °C) freshwater (volume around 5-10 k m³) on top of the warmer (19.4±0.3 °C) saline water found through the cave. The stable isotope composition of six top freshwater samples was very consistent (-4.86±0.03 ‰ δ¹⁸O, -31.3±1.3 ‰ δ²H) and marginally different from deeper more saline water (-4.83±0.06 ‰ and -34.1±1.1 ‰). However, d-excess was significantly different: 4.5±1.1 ‰ for top freshwater and 7.5±1.4 ‰ for water from deeper parts of the cave. Moreover, significant relationship (R²=0.50, p=0.05) was observed between water temperature and δ¹⁸O for samples collected at depths 7.4-10.5 m along 560 m section of the cave, suggesting progressive but slow mixing. These results suggest prevailing meteoric origin of the cave’s water. However, seepage from deeper groundwater aquifers or ancient seawater cannot be excluded at this stage of the study. Efforts to identify the source of the water in Cocklebiddy Cave continue.
Bacterial diversity and community structure of biofilm and discharging thermal water found in spring caves of the Buda Thermal Karst System

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Keywords: thermal water discharge, biofilm, bacterial diversity, molecular cloning, DGGE

The Buda Thermal Karst System is an active hypogenic karst area where microbes may participate (Borsodi et al. 2011) in the development of precipitates and in hydrothermal cave formation as well (Erőss 2010). The Southern discharge region is characterized by one-component thermal water discharge, regional karst and additional basinal fluid component. The cave forming processes here can be closely connected to the biofilms which can be considered as a specific biogeochemical discharge feature (Mádl-Szőnyi and Erőss 2013). The aim of this study was to examine the microbial communities developed as biofilm on the cave walls, on calcite rafts and in the discharging water by molecular methods. The iron hydroxide precipitates developing on cell surfaces were studied using microscopy and spectroscopy methods. DGGE analysis of samples taken from the same sites showed a significant difference between water and biofilm communities, where biofilm samples proved to be more diverse. The first clone libraries were constructed from three sample types (biofilm, calcite rafts and water) from a site of the southern discharge area. The 16S rRNA sequences of the representative clones belonging to 15 major taxa showed the closest relation to uncultured clones from different environmental sources. The microbial community of the biofilms proved to be somewhat more diverse than that of the calcite rafts, while water showed a very simple community structure. The following taxa proved to be dominant: Alpha- and Betaproteobacteria, Nitrospira and Chloroflexi. Considering the metabolic characteristics of known strains related to the clones, it can be assumed that these communities may participate in the local sulfur and iron cycles, and may contribute to biogenic cave formation, as it was already indicated by Erőss (2010). On the cross-section electron microscope images made using FIB-SEM technique, an outer coat of varying thickness rich in minerals developed on filamentous bacteria of the biofilm. During the EDX analysis, the presence of iron was verified in the amorphous and globular-shaped substances excreted on the surfaces of the filamentous bacteria of various diameter and appearance. This confirms the presence and bacterial origin of iron-oxihydroxide already verified by other methods.
Marine seismic-reflection data from the southeastern Florida Platform: a case for hypogenic karst

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Keywords: carbonates, hypogene karst, marine seismic-reflection, Florida

Recent acquisition of twenty marine seismic-reflection profiles suggests a hypogenic karst origin for the Key Biscayne sinkhole located on the seafloor of Miami Terrace at the southeastern part of Florida Platform. Analysis of the seismic-reflection data strongly suggest the submarine sinkhole was produced by dissolution and collapse of Plio(?)-Pleistocene age carbonate strata. A complex fault system that includes compressional reverse faults underlies the sinkhole, providing a physical system for the possible exchange of groundwater with the sinkhole. One seismic profile is suggestive of a master feeder pipe beneath the sinkhole. The feeder pipe is characterized by seismic-reflection configurations that resemble megabreccia and stratal collapse. The sinkhole is located at a depth of about 365 m below sea level. The record of sea-level change during the Plio(?)-Pleistocene and amount of subsidence of the Florida Platform during this span of time indicates that the sinkhole has always been submerged at a water depth of about 235 m or more. Thus, the near-surface epigenic karst paradigm can be ruled out. Possible hypogenic models for sinkhole formation include ascending fluids along the fault system, such as, dissolution related to the freshwater/saltwater mixing at a regional groundwater discharge site, or processes related to gases derived from generation of hydrocarbons within deep Mesozoic strata. Hydrocarbon-related karstification provides several possible scenarios: (1) oxidation of deep oil-field derived hydrogen sulfide at or near the seafloor to form sulfuric acid, (2) reduction of Cretaceous or Paleocene anhydrite or both by oil-field methane to form hydrogen sulfide and later oxidation to form sulfuric acid, and (3) carbon-dioxide charged groundwater reacting to form carbonic acid. Further, anaerobic microbes could form methane outside of a hydrocarbon reservoir that ascends through anhydrite to form hydrogen sulfide and later oxidized to sulfuric acid.
Hydraulic behaviour of low-permeability formations in regional context

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Keywords: low-permeability, hydraulic behaviour, scale-dependence, fluid-potential, faults

Hydraulic behaviour of low-permeability formations is in the fore-front of hydrocarbon exploration, radioactive waste disposal and carbon dioxide geological storage site-characterization as well. However, spatial extrapolation of the pointwise measured or locally estimated permeability values into larger (i.e. field or basinal) scale is generally questionable. Furthermore, it requires differing approaches in porous and fractured rocks, as well as in local and regional scale. Regarding the scale-dependence problem, two examples will be presented from the Pannonian Basin, Hungary. First, a local scale (study area ~1800 km²) approach will be shown with a detailed hydrostratigraphic investigation, then a larger scale (study area ~10400 km²) research with a less detailed hydrostratigraphic analysis. In both cases, in lack of sufficient permeability data hydraulic characterization was based fundamentally on the analysis of the fluid-potential field, while fractures and faults proved to be the key geological factors in low-permeability formations’ hydraulic behaviour.
Hierarchization of groundwater flow paths and scale dependency of the hydrodynamic properties in karst

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Keywords: Karst, groundwater flow paths, scale dependency, permeability field, pumping tests

Karst aquifers represent an important groundwater resource, and understanding how they function is thus a major socio-economic challenge. This is particularly true in Mediterranean regions where anthropic pressure has significantly increased in the last 50 years. However, because of the marked heterogeneity of karst aquifers, managing the resource is not easy. An enhanced understanding of the links between the structure and functioning of this type of aquifers, including characterization of field permeability are thus key steps for optimal exploitation.

This study focuses on the use of hydrodynamic information to identify the hierarchical properties of the main flow paths, which we discuss based on the geological and structural characteristics of the karst reservoir.

The field test site is located in the South of France in a typical Mediterranean karstic carbonate aquifer, the Lez karst aquifer, where groundwater is pumped in the terminal conduit of the drainage network, upstream from the main karst outlet. The hydrodynamic properties of the aquifer were inferred from the hydrodynamic response to pumping at reservoir scale measured on distinct piezometers. Change in the hydrodynamic properties then were analyzed according to both the type of boundary condition (constant head or constant flow rate at the Lez spring) and the location of the piezometer.

Changes in hydrodynamic parameters revealed marked disparity between the different parts of the aquifer. These discrepancies depended both on the scale of the hydrological analysis and on the connectivity between the different compartments of the karst aquifer.

This work allowed us to quantify the permeability field at different time and space scales. Understanding their shape provided new insights into the organization and functioning of the reservoir. This analysis is a first step towards multiscale modeling using conceptual models to represent the characteristics of the main flow paths.
Thermal karstwater ages around Bükk Mountains (Hungary) as evidences of the gravitational flow system

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Keywords: ¹⁴C groundwater ages, thermal karstwater, ice-age infiltration

The conceptual model suppose a gravitational karstwater flow regime recharging in the higher elevations of Bükk Mountains, following the deep lying, covered and karstified carbonate aquifer and discharging in the lukewarm springs of Eger and Miskolc-Tapolca. This conceptual model was tested and verified using ¹⁴C groundwater ages calculated by δ¹³C correction considering to the surplus CO₂ of metamorphic origin. Corrected karstwater ages present a continuous increase of the corrected karstwater ages from recharge area (karst outcrops in Bükk Mountains) to the deep lying thermal waters (50 to 65 °C) through the lukewarm (30 °C) springs of Eger and Miskolc-Tapolca. Joint evaluation of groundwater ages with hydraulic and geothermal considerations suggests that lukewarm springs are the mixtures of the old, thermal karstwater and the young, cold karstwater. Both components recharge from the cold karstwater infiltrating on the Bükk Plateau lying about 700 m higher elevation as lukewarm springs. ¹⁴C groundwater “ages” of these springs (4 to 7 ka) are fictitious, and the results of mixing process. Acceptability of ¹⁴C ages of thermal karstwater in the surrounding wells as 13 to 15 ka is proven by δ²H, δ¹⁸O and noble gas thermometer data verifying that these karstwater were infiltrated at +5 to +7 °C annual mean temperature. Such a cold climate appeared in Hungary only in the “ice-age” i.e. more than 10 ka ago. The verified transit time exceeding 15 ka will be invoked to the mathematical modeling of the Bükk thermal karstwater system.
Hydraulic processing of Buda Thermal Karst, Budapest, Hungary

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Keywords: Buda Thermal Karst, hydraulic evaluation, faults, gravitational flow system

The Buda Thermal Karst area is in the focus of research interest mainly because of the on-going hypogenic karstification processes. The aim of the present study was the hydraulic evaluation of the flow systems based on measured, archive well data. According to previous studies a northern (Rózsadomb area) and a southern (Gellért Hill area) system can be distinguished with a hypothesized structural and hydraulic boundary between them. This study aimed the evaluation of this boundary as well.

Considering the data distribution, pressure and hydraulic head vs. elevation /p(z) and h(z)/ profiles, tomographic fluid-potential maps and hydraulic cross-sections were constructed in order to study the vertical and lateral flow directions. As a result, it could be concluded that the hydraulic behaviour of the local-scale study areas shows robust correspondence with the topographic conditions, thus represents gravitational flow systems. This conclusion is supported by the results of the p(z) and h(z) profiles as well as the hydraulic cross-sections. Furthermore, fluid-potential anomalies can be observed around faults and in areas where faults are not known, but based on the hydraulic interpretation their presence could be presumed. Regarding the differences in temperature, hydrochemistry, and discharge between the northern and southern systems, these deviations could be caused presumably by the "Northeastern Margin-fault" running between the two systems. With the help of a hydraulic cross-section and the potentiometric maps the barrier function of this fault could be established.

This study contributed to the better understanding of the hypogenic karstification processes and demonstrated that the hydraulic evaluation based on measured, archive data could be crucial in order to detect the faults and to determine the hydraulic function of them.

The Hungarian Scientific Research Fund (OTKA) has provided financial support to the project under the grant agreement no. NK 101356.
Radionuclides as natural tracers for identification of mixing of thermal waters

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Keywords: radionuclides, mixing of fluids, thermal waters, caves

Radionuclides of the $^{238}\text{U}$ decay series, i.e. uranium, radium and radon, are ubiquitous in groundwater. As these radioisotopes are members of the same decay chain, they are interdependent of each other. Moreover, they have different geochemical behaviour. For this study, we used uranium, radium and radon to characterize the fluids in the Buda Thermal Karst system (Budapest, Hungary). High radioactivity, reported already by Weszelszky (1912), especially around the Gellért Hill, supported the idea of the application of radionuclides. Hence in the Buda Thermal Karst mixing of lukewarm and thermal karst waters was assigned to be responsible for cave formation (e.g. by Takács-Bolner and Kraus 1989; Leél-Őssy 1995), we used uranium, radium and radon to identify mixing of fluids and to infer the temperature and chemical composition of the end members based on the different geochemical behaviour of these radionuclides.

The dissimilarity of the discharging lukewarm and thermal waters within Budapest was long ago recognized on the basis of hydrogeochemical studies (e.g. Papp 1942; Alföldi et al. 1968). Likewise, differences were identified regarding the radionuclide content of the waters in the investigated discharge areas during this study.

As the result of this study, it was possible to characterize the mixing end members for the Rózsadomb area, whereas for the Gellért Hill discharge zone, mixing components could not be identified with the aid of radionuclides. Therefore, it is suggested that different processes are responsible for cave formation in the two areas. In the Rózsadomb area, structurally-controlled mixing is the dominant cave forming process, whereas in the Gellért Hill area, due to the lack of mixing members, other processes must be found, which were responsible for the formation of the caves. The application of radionuclides thus further supported the differences between these two areas and improved our understanding about the fluids of the Buda Thermal Karst. The Hungarian Scientific Research Fund (OTKA) has provided financial background to the project under the grant agreement no. NK 101356.
The role of endorheic areas on recharge processes of karst massifs

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Key words: endorheic area, recharge, karst, Italy

In central-southern Italy, karst massifs are generally characterized by wide endorheic zones, which can constitute the major part of spring catchments. The origin of these endorheic zones is connected to tectonic activity during upper Pliocene-Pleistocene, which has caused a general uplift by direct faults, and formation of graben zones. During the following continental environment (Pleistocene-Holocene), karst processes have transformed these zones in endorheic ones, allowing the complete absorption of runoff, and the formation of seasonal lakes.

The wide endorheic zones constitute the most important recharge areas of karst massifs of central-southern Italy, and have also an important role in the groundwater protection.

Two main karst systems will be considered about the role of their endorheic zones: the Matese massif and the northern sector of Picentini mountains, Campania Region. From a morphological viewpoint, these mountains are primarily characterized by steep slopes and elevations up to 2050 m a.s.l. for Matese massif and 1809 m a.s.l. for the Picentini Mountains. Flat zones are limited to the bottom of endorheic areas and are the Matese lake, Letino lake, Gallo lake, Campo Figliolo, Campitello, Campo Rotondo, Campo Braca, (and others) for the Matese massif and the Laceno lake, Piana del Dragone, Piano di Verteglia (and others) for the Picentini massif.

These karst massifs feed many basal karst springs with discharge up to thousands of litres per second, and constitute the main water resource in Campania.

The hydrological and hydrogeological role of the endorheic areas on the spring discharge regime will be analysed, evaluating the recharge and using spring discharge as output data.
Karst hierarchical flow systems in the Western Cordillera of North America

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Keywords: unconfined flow, confined flow, inter-formational flow

By definition, karstic flow systems are networks of solutional conduits. Their spatial patterns and hierarchical organisation are strongly affected by differing lithology and geologic structure, and by the location and modes of recharge – unconfined, confined, interformational. For purposes of discussion, this paper will review six examples ranging across platform and reefal limestones and dolostones, dolostone breccias, gypsum and salt, in widely differing structural, geomorphic and hydrologic settings: (1) The Carcajou River karst at Lat. 65° N in the Mackenzie Mountains, where leaky permafrost superimposes a frozen ground hierarchy on those due to lithology, structure and topography: (2) The S Nahanni River karst at Lat. 62° N, with an intrusive-derived local thermal system and lengthy, strike-oriented meteoric flow systems that contribute to an outlet H2S thermal system at the basin topographic low: (3) Castleguard Mountain Karst (Lat. 52° N) in massive Main Ranges structures of the Rocky Mountains, with a complex alpine hierarchy of base-flow and overflow springs: (4) Crowsnest Pass, in steep thrust structures in the Rocky Mountain Front Ranges, where regional strike-oriented flow systems extending between Lats. 49° and 50° N and paired above and below a major aquitard have been disaggregated by glacial cirque incision: (5) The Black Hills geologic dome at Lat. 44° N in South Dakota, USA, with a sequence of hot springs at low points around the perimeter, discharging through sandstones but with some of the world’s most extensive hypogene maze caves formed in a limestone karst barré setting behind them: (6) The Sierra de El Abra, at Lat. 23° N in Mexico, a deep and lengthy (100 km) reef-backreef limestone range being progressively exposed and karstified by stripping of a cover of clastic rocks; the springs are few but amongst the largest known in karst anywhere, located at the northern and southern low extremities along the strike of the reef, plus breaches (windows) in the cover further south.
Characterisation of the gravitational flow system in the Buda Thermal Karst, Hungary, by environmental isotopes

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Keywords: environmental isotopes, excess carbon dioxide, dissolved sulphate, thermal karst

Construction of a gravitational groundwater flow system can never be perfect, especially not in karstic areas, where the conduits make up a very complex system. Environmental isotopes and chemical data have been applied to characterise the regional groundwater system in the Buda Thermal Karst and the related cold karst. Radiocarbon ages (corrected by $^{13}\text{C}$) indicate that waters of $>40$ °C were infiltrated during the Ice Age (more than 10 thousand years ago) on the higher elevations of Buda-Pilis Hills (cca. 300 m), while waters of lower temperatures were infiltrated during the Holocene. Water isotopes ($^2\text{H}, ^{18}\text{O}$), which are the most conservative natural tracers, confirm the above statement and indicate that in many cases the luke-warm waters along the fault zone at Danube (T=25 to 40 °C) are mixtures of cold (young) and warm (old) karstic water components. The tritium content of tepid waters is also a good indication for the contribution of very young (modern) water. The thermal karstic water is characterised by elevated amount of bicarbonate, because ascending excess CO₂ mixes to the deep flowing groundwater making it able to dissolve even more carbonate rock (limestone and dolomite). The comparison of $\delta^{13}\text{C}_{\text{DIC}}$ and $1/c_{\text{DIC}}$ revealed that this excess CO₂ is of thermometamorphic origin ($\delta^{13}\text{C}_{\text{excess CO2}}=+3$ $\text{‰}$PD). The significant amount of sulphate (up to 400 mg/l), dissolved in the thermal karstic water, proved to be of marine origin (dissolved from the Permian evaporates), by $\delta^{34}\text{S}$ data.
Early Career Hydrogeologist – 5. Aqueous geochemistry and microbial karst processes

Comparison of radioactivity of biofilm and thermal water, Buda Thermal Karst, Hungary

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Keywords: thermal water discharge, biogeochemical precipitates, radon and radium activity

Systematic study for the waters of the South System of Buda Thermal Karst (BTK) by Erőss et al. (2012) revealed that they are characterized by high radium (221-870 mBq/l) and radon (3-963 Bq/l) and low (11-33 mBq/l) uranium content. Some anomalously high (up to 963 Bq/l) radon concentrations could also be observed. Moreover, a precipitate as the source of radioactivity was found in spring caves. This precipitate consists of calcite rafts and poorly crystallized iron-hydroxides and is characterized by microbial activity (Borsodi et al., 2012). Gamma-spectroscopy measurements of the precipitate revealed high radium activity (up to 1830 Bq/kg) compared to the dolomite host rock (45 Bq/kg). That suggests that the adsorption of radium on the precipitate continuously facilitates radon and causes elevated radon activity concentrations in the spring waters. The examination of the discharge features in flow system context modified the former concept and evaluated the precipitates of the South System as a specific “biogeochemical” discharge feature in a one-component thermal water discharge, where the mixing agent is the oxygen content of the air (Mádl-Szőnyi and Erőss 2013). The goal of this study was to compare the radioactivity of the biogeochemical precipitate of the South System, and the discharging thermal water to acquire better understanding on the relationship between them. The precipitates were examined by radiological methods and also mineralogical investigations were carried out. The specific $^{222}$Rn exhalation of the samples was measured by RAD7 radon monitor. These data confirmed that the source of the elevated $^{222}$Rn content of the thermal water is not directly the $^{220}$Ra activity of the discharging water. It can be explained only by the adsorption of the radium by the biogeochemical precipitate. The research was supported by OTKA NK 101356.
Hydrogeological characterization and water management model for underground karst aquifers in the city of Sete Lagoas, Brazil

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Keywords: karstic hydrogeology, water resources, exploitation

The city of Sete Lagoas, located in the southwestern region of Brazil, has experienced strong and rapid population and economic growth, aggravating resource problems resulting in increased demand for water, drawn from a karstic aquifer, restriction in the public supply, contamination of soil and aquifer, and reduced flow to surface water. This study aims to evaluate the groundwater resources, both quantitatively and qualitatively, in order to identify and delineate areas of groundwater recharge, potential sources of contamination, and geological hazard areas in the city. For this reason, studies are being carried out through pumping tests on wells, remote sensing, geological mapping, environmental isotopes, and finally, creating systems of water resources management for the county.
Consideration of scale effect in the evaluation of pumping tests for carbonate aquifers based on analytical and numerical solutions

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Keywords: hydrostratigraphy, scale effect, pumping tests

Hydrostratigraphy means the characterization of rock matrix based on its hydraulic properties. The hydrostratigraphic assignment can be used for hydraulic data analysis and numerical modeling during regional groundwater flow evaluation. Formerly the hydraulic properties were defined as lithological constants independently from the volume of the rock matrix. Modern hydrogeology defines the representative elementary volume (REV) for which the hydraulic parameters have to be considered as constant. Since that it has been known that hydrogeological parameters depend on the scale of the examination. The carbonate aquifers can be characterized from fractured to hierarchical permeability structures. Therefore their hydraulic conductivity highly depends on the scale of the evaluation.

The goals of the study were the re-evaluation of the pumping test data for the carbonate aquifer system of Buda Thermal Karst: i) to compare the parameters derived from single pumping test data and an interference test; ii) to evaluate the effect of double porosity of carbonate aquifers on hydraulic parameters (K, T and S); iii) to compare the efficiency of analytical and numerical methods in the evaluation.

The applied analytical method was based on the Theis-Jacob recovery test and in the evaluation the Aquitest software was used. The Visual Two-Zone model was applied for numerical simulation in the carbonate sequence. The software handles the heterogeneity as anisotropy.

The derived hydraulic parameters from analytical and numerical solutions and from short and longer term tests were compared in the study. The research was supported by OTKA (No: NK101356).
Feasibility study of scale continuous characterization of karst aquifers applying large scale pumping tests

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Keywords: karst aquifer, pumping test, feasibility study, numerical modeling

In general, karst aquifers are characterized by a dual flow system consisting of low permeability fissured matrix blocks, which represent the main storage of a karst aquifer system and highly permeable karst conduits, which drain the aquifer system. The characterization of karst aquifers at catchment scale is therefore still a challenge and requires the development of large scale characterization techniques in order to deal with heterogeneity. The present work describes a feasibility study of characterization of complex karst aquifers at catchment scale applying pumping test in order to characterize both fissured matrix and karst conduits hydrodynamic properties.

An important and inexpensive tool for method development and prediction purposes is a numerical model, which allows process-based simulation of different experimental arrangements. In the present study, large scale pumping tests with different geometrical set ups of conduit networks, matrix geometries, and boundary conditions are simulated with the recent numerical model MODFLOW 2005 Conduit Flow Process (CFP). The pumping well is directly connected to the conduit system and large pumping rates are applied over several weeks, which result in a large scale drawdown in the whole model domain. Observed drawdown curves in the pumping well and observation boreholes are systematically evaluated employing diagnostic plots (e.g. derivative method) and flow dimension analysis. Modeling results show that different flow regimes during pumping can be detected: 1) early time, mainly influences by well bore storage, 2) middle time, mainly influenced by unrestricted reservoir flow, 3) late time, mainly influenced by boundary conditions. Furthermore the study reveals that the application of numerical models has an advantage over analytical solutions because catchment properties (e.g. boundary conditions, conduit networks) can better be adapted.
Determination of a conduit network in a lowland karst catchment by modeling ephemeral lake (turlough) fluctuation

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Keywords: lowland karst, turlough, pipe-network model, conduit sizing

The lowland karst area of Galway in the west of Ireland provides a challenging setting for karst hydrogeological studies due to its low-lying nature whereby the main spring from this area discharges slightly below mean sea level at the coast which, critically, means that it is not possible to measure the net flows from the karst network. However, this low-lying landscape does provide unique karstic hydrogeological signatures in the form of fluctuating water levels in intermittently flooded topographic depressions - temporary lakes known as turloughs. This research has used continuous water level measurements in a linked network of five turloughs in the lowland area of south Galway over a 6 year period (2007 to 2012), with measurements of rainfall, tide level data and continuous monitoring of river inputs draining the Old Red Sandstone hills which feed the karst network. Water quality samples were also taken from turloughs, rivers and boreholes. These field data have then been used to develop a numerical model of the system which has been constructed and calibrated using a pipe network model (Infoworks CS). The model also simulates the contribution to the karst network from diffuse flow through the epikarst via the matrix and fracture flow. The linkages comprising the network system were determined from: previous tracer studies; net flows into/out of the karst conduits as a function of turlough water level and; time series analysis applied to the non-stationary turlough water level profiles; and hydro-chemical mass balance analysis. The generally excellent calibration of the model to the measured turlough water levels yields insights on the physical linkages and sizes of the main conduits in the karst network. The need for the modelling has been in helping to investigate and understand the ecohydrological relationships within the turloughs (a protected habitat), and the causes of significant groundwater flooding which has been a feature of the area in recent years.
Groundwater flow and mixing in the complex karst aquifer system feeding the carbogaseous mineral springs of Stuttgart, Germany

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Keywords: artesian karst system, mineral water, carbon dioxide, tracer tests, contaminants

The carbogaseous mineral springs of Stuttgart, Germany, issue from a Middle Triassic limestone karst aquifer (Upper Muschelkalk), near the Neckar River that represents the regional base level. The total discharge of 500 l/s is similar to that at Budapest, but temperatures are lower. Between the recharge area 20–30 km to the SW and the discharge zone, low permeability formations confine the aquifer. There are two groups of springs: Low mineralized springs in the northern sector with 0.5–1.6 g/l total dissolved solids (TDS), CO\textsubscript{2}<250 mg/l and temperatures of 12–17 °C; and highly mineralized springs in the south, used for cures and leisure baths, with 3–7 g/l TDS, 1.3–2.4 g/l CO\textsubscript{2} and 17–20 °C.

The mineral water forms by mixing of several components: groundwater from the karst aquifer, sulfate-rich water from overlying evaporitic formations, highly-mineralized waters from deeper aquifers, and CO\textsubscript{2} from the Earth's mantle. Cross formation flow can be deduced by means of sulfur and strontium isotopes, the latter confirming participation of brines from the crystalline basement.

Since 1984, chlorinated solvents at low concentrations have been detected in some of the springs. This was the starting point of a comprehensive research program including several tracer tests. In the zone of highly mineralized springs, the tracer test revealed maximum flow velocities of up to 230 m/day (first detection), dominant velocities of 36 m/day (peak) and 29 % recovery. The tracer was detected at eight springs, demonstrating that a single contamination source in the city area could impact most of the medicinal springs. The breakthrough curves displayed very long tails, some lasting up to two years, suggesting intermediate storage of tracer (or contaminants) in large cavities and subsequent slow release into the active conduit network. The supposed caves are probably the result of hypogenic speleogenesis due to mixing processes and CO\textsubscript{2} from the mantle.
Hydrogeological conditions of Paleozoic complex in Novoportovsk oil and gas condensate field

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Keywords: Paleozoic complex, geochemical analysis, carbonates, geochemical processes, decarbonization

The Novoportovsk field has been characterized by the complex geology structure. The field’s basement contains the blocks which are heterogeneous in age and composition. The paleo-hydro-geological analysis has demonstrated the existence of infiltration mode during the Early Mesozoic. The water of infiltration was able to penetrate deep enough into the carbonate rocks massif, causing the decarbonization (carbon-bearing karst). The occurrence of numerous karst caverns of the Paleozoic carbonate solid massif has been confirmed by the independent studies (Kuzminov et al. 2000). Also it has been determined that the caverns in the Paleozoic carbonate rocks of Novoportovsk oil and gas condensate field were formed along the ancient north-east faults and increased in the places of their intersect with the fractures of submeridional strike, emphasizing the draining character of these faults (Kuzminov et al. 2000, Zhuravlev, Oblekov, 2000).

The process of the water/carbonates interaction in the Novoportovsk field has been studied using the geochemical modeling analysis. The main evaluative parameter was the code of saturation of water with carbonates (Ssat).

These processes can be interpreted so that the sedimentation water will penetrate into the underlying rocks through the carbonate rocks massif, besides the fact that it will develop its cavitations. With the depth of 2500 m and deeper the carbonates will drop out, making worse the filtration-capacity properties, especially of Paleozoic basement (with a depth of more than 3000 m).

These points to the fact that from the hydro-geological perspective it is hardly correct to look for the good reservoir with the immersion depth of Paleozoic deposits. The geochemical processes with the participation of free and bound waters contributed in forming of reservoir voids in Novoportovsk field.
Water-gas-rock interactions and seasonal control of geochemical environments in the epikarstic zone of the Pennyroyal Plateau, Kentucky, USA

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Keywords: karst, epikarst, geochemistry, CO$_2$, limestone

An extensive karst landscape/aquifer system with a well-developed epikarstic zone has developed within nearly horizontal, lower Carboniferous limestone of the St. Louis and Ste. Genevieve Formations over several thousand square kilometers of Kentucky’s Pennyroyal Plateau. High-resolution geochemical dynamics of epikarst water typifying the region were measured over one year at an epikarst drain 25 meters below the surface in Crumps Cave in northern Warren County. Knowledge of the geochemical environment in the epikarstic zone is critical for understanding microbial ecology, carbon cycling dynamics, and the fate and transport of contaminants associated with recharge water, in this setting dominated by agricultural land use.

A series of variations in the sequence: 1) outside air temperature $\rightarrow$ soil temperature $\rightarrow$ soil gas CO$_2$ pressure quickly propagate changes in the epikarst water below, in turn causing variations in CO$_2$ pressure and pH, thus creating variations in the water-rock interactions expressed as changes in specific conductance, calcite saturation indices (SI$_{calc}$), and limestone dissolution rates. A hysteretic threshold in outside air temperature results in four distinct geochemical seasons: a late summer/early autumn warm season where epikarst water has continuously high PCO$_2$ and low pH, a winter cool season with low PCO$_2$, and spring and fall seasons where diurnally fluctuating outside air temperatures create rapid swings in epikarst water chemistry. These swings can cause epikarst water PCO$_2$ to vary from near atmospheric background levels to 80 times that, and pH to vary by more than one pH unit, in a short period.

Water-rock interactions in the epikarstic zone are governed by different factors at different times of year. The water stays uniformly undersaturated and thus actively dissolving the rock matrix for most of the year. This is due to dilute, low PCO$_2$ water in winter but higher ionic strength, yet more acidic, water in the warm season.
What’s behind the spring? Exploring very short-term signals in two flooded conduits

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Keywords: spring, conduit, flow-periodicity

Springs are to karst hydrogeologists what boreholes are to hydrogeologists working in other lithologies and many attempts have been made to develop models that allow flow from springs to be predicted from effective precipitation over the catchment. However, springs represent the ‘lumped’ response of the karst hydraulic system and monitoring in upstream conduits can provide additional data.

The Castleton karst (Derbyshire, UK) contains over 25 km of ‘input’ and ‘output’ cave. The input has two components: allogenic water from streams that sink at 15 points and autogenic water fed by rain and snow falling onto the limestone outcrop. Water output takes place from three springs which together form the Peakshole Water. The Peak-Speedwell Cave system which is upstream of the springs has around 50 inlet streams of which 20 are permanently water-filled ‘sumps’. Cave divers have explored over 1000 m of these sumps one of which descends to a depth of at least 76 m. Over 50 water-tracing experiments have revealed the broad outline of the underground hydrology but there is a great deal of internal complexity that is yet to be fully understood. Water depth and temperature in the two main inlet sumps in Speedwell Cavern have been measured at 1-minute resolution since July 2012 and the combined spring output has been measured at 5 minutes resolution. The sumps, several hundred metres apart and at different elevations, exhibit both flow switching (the bulk of the flow sometimes entering via one and at other times via the other) and nonlinearity (rapid changes of depth and temperature but with no consistent periodicity). Some of the complexity is retained in the spring output response but much is lost.
4. Flowing groundwater as a geologic agent

Epigene karst system below a regional bauxitic unconformity

– Origin of the enigmatic red calcite of the Transdanubian Range (TR), Hungary

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Keywords: paleokarst, bauxite, speleothem, solid inclusions, fluid inclusions

Unconformities and related karst systems are studied worldwide. Here we describe a unique red calcite generation filling fractures/cavities both in Upper Triassic and in Lower Cretaceous carbonates. Stratigraphic relations and structural data suggest that the red calcite formed both in Late Cretaceous and Eocene times. All samples show growth zoning due to distribution of <100 μm-sized solid inclusions. Hematite gives the red colour of the calcite. Gibbsite, goethite, kaolinite, smectite, illite, monacite, xenotime, zircon, apatite, and Ti-oxide were also detected in the HCl-insoluble residue of the calcite. This mineral assemblage is very similar to that of karst- bauxites associated with Cretaceous and Eocene unconformities in the TR. The calcite is non-luminescent. Primary, aqueous, all-liquid fluid inclusions indicate low-temperature origin (<50 °C). Salinity of the parent fluid (from 0 to 0.17 NaCl eq. w%) implies precipitation from meteoric water. Stable isotope values fall along the meteoric water line (δ¹⁸O from -6.07 to -4.47 ‰, δ¹³C from -11.71 to -3.55 ‰) supporting the meteoric origin of the fluid. Traces of bauxite, calcite-cemented bauxitic clay, and collapse breccias are associated with the red calcite. The areal extent, the morphology, the intense red colour, and the stable isotope values of the calcite are all suggesting that at the time of its precipitation, bauxite must have been present on the land surface and meteoric fluids could percolate through fractures and cavities, transporting bauxitic particles in the form of fine suspension into the karst. Therefore red calcites are interpreted as being speleothems, vestiges of the subterranean part (recharge zone) of the pre-Middle Eocene karst. The infiltrated, fine bauxite particles enclosed by the calcite are the witnesses of the once areally extensive pre-Middle Eocene bauxitic blanket that became partially eroded by the time of the deposition of the cover beds.
Constant head tests simulations in non circular domain double-porosity continuum: a boundary element method application

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Keywords: dual medium, interference test, transition flow, derivative, BEM

Double-porosity approaches help to investigate groundwater flow behaviour in heterogeneous aquifers such as karst aquifers. Indeed these aquifers have heterogeneous hydraulic conductivity fields that induce complex groundwater flow behavior. Double-porosity solutions were initially developed to analyze pressure transient tests assuming bounded and unbounded circular domains. Most models consider pressure difference between each continuum to control the exchange flux. Our objective is to simulate flow and pressure behaviour under the influence of a constant pressure test in non circular domains with a double-porosity model. We used a numerical method to set efficient boundary conditions and domain geometry. We applied the Boundary Element Method (BEM) with a known analytical solution adapted to analyze flow and pressure transient analysis in double-porosity media. The integral equation is derived and the BEM is used in Laplace space. In the Laplace space the time dimension is replaced by a parameter. This allows to find a fundamental solution to the modified Helmholtz operator used in the equation. Real space solution is obtained by numerical inversion of the Laplace space solution. Transient flow results are analyzed according to two specific derivatives. These results show good agreement when compared to known reference cases. Both derivatives of the flow show flow transition periods and boundary influences. Thus, the BEM is effective to model transient flow in double-porosity continuum with irregular domain geometry. In addition, it allows to investigate the effects of multiple constant head tests conducted in a double-porosity domain. The observed transition in the flow regime depends on the double-porosity parameters, the boundaries influence the latter part of the flow. This numerical method can be useful to help analyze complex flow behavior in karst aquifers.
Tracing the sources of groundwater salinization in karstic aquifer the example of Ein Feshcha Springs at the Lower Jordan Valley

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Keywords: Feshcha springs, ultra filtration, groundwater exploration, MgCl₂ water types

The carbonate Mountain Aquifer is the largest (quantity) and best (quality) fresh water resource in the region with a typical karst aquifer system. The Jordan Valley depends entirely on karst aquifer groundwater for domestic and agricultural use. An understanding of the chemical evolution of the groundwater provides insight into the interaction of water with the environment and contributes to better resource management. Chemical analysis and water isotope data were used to gain an understanding of the hydro-chemical processes of the groundwater’s exposed in Ein Feshcha springs. As a result of the drop in the level of the Dead Sea this leaded to the migration of fresh/saline water interface, hence the fresh water is becoming salinized due to the residuals of Dead Sea water in the aquifer matrix, not only but also its mixing with old water bodies and dissolution from Lisan formation. Therefore the springs themselves are highly saline. Nevertheless it is believed that the water receives its salinity only in the direct vicinity of the springs, being of better quality in the Cretaceous mountain reservoir.

The main processes influencing the water chemistry in Ein Feshcha springs are salinisation, mineral precipitation and dissolution, cation exchange and mixing with up flowing waters. The ionic, oxygen and hydrogen stable isotope composition of the groundwater suggests that the effects of localized topography are one of the overriding factors controlling the groundwater chemistry. Examination of the composition of the saline water in Ein Feshcha, may lead to the source and the distribution of the saline water and its mixing points with fresh water. Hence, this may allows us to capture the fresh water before its mixing with the brines.
Understanding the hydraulic position of paleo-maar lakes in groundwater flow systems, Tihany Peninsula, Hungary

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Keywords: maar lakes, flow systems, underground flow connection, wetland, flownet simulation

Groundwater-influenced lakes and wetlands are hydrologically and ecologically linked to adjacent groundwater bodies, but the degree of their interactions is highly variable in space and time (Born, 1979, Winter, 1998). The relationship depends on the water table configuration, location of stagnation points, relation of the lake water level to the water table and to the subsurface potential field, the geological framework, climate, and the vegetation (Winter, 1976, 1979).

The lakes of Tihany Peninsula, Hungary are located in Neogene paleo-maar structures filled with lake sediments (Németh et al. 2001). The lakes were assumed to be recharged exclusively from precipitation (Bilik, 1970). However, based on the above mentioned considerations, and on the numerical and theoretical studies of Winter (1976 etc.), connection of the lakes with the groundwater can be presumed. The goals of our study were to understand the hydraulic position of these lakes in the flow systems of the Peninsula and to find explanations for their different hydrological behaviour.

Cadastral- and topographic map analysis, radio-magnetotelluric (RMT) measurements, hydraulic-, geochemical methods, time series analysis and two-dimensional numerical flow-simulations (FLONET/TR2 [Molson, Frind 2012]) were used to understand the hydraulic position of the lakes.

As a result, a hydraulically continuous subsurface flow field was recognised for the area, which is driven by topographic gradients. The geometry and hydraulic behaviour of the near-surface sediments was described with the help of the geophysical (RMT) measurements. Seasonal variability of the subsurface potential field and the groundwater-chemistry was revealed by the hydraulic and hydrogeochemical field data analyses. Based on this insight, a two-dimensional numerical simulation was carried out. The model indicated the different hydraulic position of the lakes, in good agreement with the field measurements.
The national karst water tracing database of Ireland

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Key words: water tracing, flow rates, flow directions, Irish karst hydrogeology

In 2007, The Geological Survey of Ireland established a database compiling and detailing water tracing experiments carried out in the Republic of Ireland. The primary purpose of creating this database is to serve as an inventory of known water tracing experiments and to store details of the traces. Data are compiled from numerous sources including maps, academic and caving journals, company reports and personal communication. The database contains specific details for each tracing experiment. There are 20 fields, which can be searched and queried by a certain topic, locality or catchment. The database is populated with all known traces and currently contains details of more than 350 individual water traces. This paper presents the main findings of analyses of this water tracing database and what it tells us about Irish karst hydrogeology. Flow rates are compared to flow directions, apparent groundwater gradients, geological and structural controls, weather conditions, subsoil permeability and thicknesses, and groundwater catchments. The results show that flow rates vary greatly under different geological conditions and in different types of karst systems.
2. Recharge and discharge processes and parameters

Identification of a deep flow system in a dolomitic Alpine aquifer – Case study Wimmerbauern Spring, Bad Ischl, Austria

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Keywords: Northern Calcareous Alps, dolomitic aquifer, hydrochemical modelling, isotope hydrology, thermal karst springs

In the context of a regional study about the aquifer characteristics of dolostones along the northern margin of the Northern Calcareous Alps (NCA) some remarkable properties of the spring “Wimmerbauernquelle” (WQ) in Bad Ischl, Austria were detected. Moderately increased water temperatures of 11.0 to 11.5 °C and Tritium values in the range of 4TU evidenced a significant contingent of deep circulating thermal influenced submodern waters. Comparably low electric conductivities in the range of 270 μS/cm and a hydrochemical characterisation as Ca-Mg-HCO₃-type water with a balanced Ca-Mg-ratio and a nearly complete absence of other major ions are a sign of a shallow pure dolomitic aquifer. The results seemed contradictory at first glance. Besides hydrogeological mapping and hydrochemical investigations inverse hydrochemical modelling was used to reconstruct the history of the spring waters and leads to a mix of 50 % to ~85 % of obviously deep circulating water. Interpretation of Tritium and SF6 measurements leads to a composition of 69 % (+/-5 %) of the spring water with a mean residence time of more than 60 years. A conceptual model of the aquifer based on hydrochemical and isotopic data and the approach of two combined flow systems leads to the interpretation that WQ can be seen as the geothermally influenced drainage of a deep flow system.
Karst as a constraint on aggregate mining along the
Niagara Escarpment, Eastern Canada

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Keywords: karst, aggregate mining, impacts, mitigation

The aggregate industry in southern Ontario, Canada relies heavily on material excavated from the Amabel and Guelph formations, pervasively dolomitised carbonates of Silurian age. These erosionally-resistant formations outcrop extensively along the Niagara Escarpment, a heavily forested ridge that supports many provincially significant wetlands and was recently designated a UNESCO World Biosphere Reserve. Recognising that the Silurian dolomites form important aquifers with varying degrees of karstification and that much of the quarrying takes place within a short distance of the escarpment edge, much concern has been expressed over the potential impacts of quarry development on local wells, springs and wetlands. The aggregate industry has tried to respond to these concerns with proposals that include more intensive hydrogeological studies, sophisticated modelling, adaptive management plans and novel, albeit expensive, mitigation techniques. However, recent applications for quarry licences have met with somewhat limited success. The primary problems seem to relate, in the short-term, to uncertainties of risk associated with preferential “karstic” pathways and, in the longer term, with post-extraction quarry rehabilitation. There appears to be a greater opportunity for success in situations where permits are sought to extend existing quarries. In such cases, data collected during the life of the operating quarry can provide useful insights on the likely impact of quarry growth.
Comparative application of vulnerability mapping methods on Hungarian karst areas

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Keywords: vulnerability mapping, groundwater protection, land use, karst

In Hungary, 65% of the drinking water is supplied from vulnerable aquifers. Our karst aquifers are important and valuable water resources, but due to their 3D impact surface, they are especially sensitive to contamination. To protect the quality and quantity of these water resources, it is essentially important to understand the functioning, processes and behaviour of the hydrological-geological-ecological system. Vulnerability methods consider and summarize every important determining data and property, which makes them appropriate and expressive tool of water management and protection. Many methods exist to analyze and map vulnerability, but for now in Hungary there is no generally adopted method to assess this property of the groundwater resources.

To examine the intrinsic resource vulnerability of two typical karstic areas, we applied different vulnerability mapping methods (e.g., COP Method, Slovene Approach). Following the analysis and comparison of the resulting maps, the aim of our study was to test the applicability of these methods in Hungarian test sites, and bring into light their deficiencies, as a first step to develop a vulnerability mapping method appropriate for the Hungarian circumstances, taking into account the special characteristics of Hungarian karst aquifer systems and data availability.

Our test sites are the non-confined Kis-fennsík in Bükk National Park with developed karst surface features and the semi-confined Tapolcai-karst, which is strongly influenced by various anthropogenic effects and processes.
Combining 3D geological boundaries and fundamental hydraulic principles (KARSYS) in a GIS procedure to depict flow-systems in a karst region

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Keywords: flows, drainage-axes, 3D, GIS, Switzerland

One of the key-aspects of the KARSYS approach, developed for the documentation of the karst aquifers of Switzerland, is to provide a pragmatic and systematic way to basically depict and characterize flow systems in a karst region. The presence of low-permeability formations (aquicludes) and the development of a high-transmissivity network in karstified formations strongly control the shape of flow systems in karst. The first step is to assess the geometry of the karstified formation (aquifer) by introducing all existing geological information into a 3D geological model-builder. The second step is to assess the geometry of the phreatic zone within the karstified formation. This can be achieved by assuming a low (or flat) hydraulic gradient upstream from the main karst springs (water table). The volume of karstified formation below the water table is assumed phreatic; the volume above it is vadose. The respective vadose and phreatic volumes can thus be represented in 3D. From this data the GIS software automatically computes the main drainage axes of the systems by assuming: (i) a vertical flow through the unsaturated part of the aquifer until reaching the aquiclude surface or the saturated zone, (ii) a down dip flow on top of the aquiclude, and (iii) flow towards the spring(s) in the flooded part, at least by the mutual shortest way. Flow paths from various parts of the system, or from major swallow-holes can be constructed following this rule which leads to the delineation of the catchment and the schematic representation of the main drainage axes of the karst system. This pragmatic, systematic and automatic process provides a concrete overview of karst flow systems with minimal effort and data. As the process is automatic, each new data or measurements (faults, overflow springs, etc.) playing as parameter in the flow organization can be introduced to improve the model.
Role of soil cover and epikarst on karst groundwater recharge: an experimental approach conducted on the Milandre underground laboratory (Jura Mountains, Switzerland)

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Keywords: groundwater recharge, soil, epikarst, hydraulics experiments, Switzerland

The Milandre underground river is recognized as a site of high patrimonial value and is monitored for many parameters since 1990. The recent construction of a highway including a tunnel portal 50 meters above the cave galleries induced a series of dedicated observations. Among them, was the monitoring of flow conditions at a series of inlets at cave roof in the part of the cave located directly below the road. Water discharge and CO$_2$ concentrations have been monitored for 5 years before the highway construction, 5 years during the road construction and 3 years after. The effects of the removal of the soil and epikarst, as well as the sealing of the surface could be observed in the cave, implying significant changes in the regime of the water inlets in the cave. As this effect was predicted and confirmed by observations, it was decided to build an injection system below the road in order to artificially feed this part of the cave which is highly decorated with active speleothems. The injection system is operating since October 2011 and several tests are being conducted in order to adjust discharge and CO$_2$ concentrations of the injected water. Cave inlets clearly react to injections, but the control of CO$_2$ concentrations is still difficult to fix. A modeling of recharge before, during and after the road construction has been attempted. Changes in the recharge parameters according to the three situation of the construction could be assessed. The model should be improved in order to take CO$_2$ and possibly temperature transfer into account. Investigations related to the dimensioning and construction of the injection system, as well as experiments, which can be conducted using this system are very valuable for better characterizing diffuse recharge of karst systems.
Towards a sustainable development of geothermal and hydropower plants in a karst environment: Examples from Switzerland

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Keywords: geothermal, hydroelectric, karst environment, Switzerland

Karst environments are concerned with developments of renewable energies (geothermal heat pumps, geothermal plants, hydropower plants or windmills). Authorities are willing to support the development of renewable energy plants, as long as their impact on environment is considered as acceptable. The Swiss speleological Society established general guidelines on the way to assess the impact of such projects on the karst environment. The Swiss Institute for Speleology and Karst-studies is working further in order to provide clear criteria and support stakeholders, who have to deliver permits or make the dimensioning of such projects. Two examples are briefly presented in the paper.

In Switzerland the number of requests for geothermal heat pumps dramatically increased along the last 15 years. Authorities are missing criteria for the dimensioning and the authorization of such devices in karst areas. Parts of karst regions are especially favorable for geothermal heat pumps, and other ones are extremely inadequate. This is mainly related to the drainage structure of karst systems, which leads to a very specific temperature and heat flow distribution in depth. The dimensioning of heat exchangers should take this fact into consideration. Another aspect is the danger of significant changes in the drainage pattern of karst flow systems due to intensive drilling.

Other expectations from stakeholders and practitioners deal with the development of hydropower plants in karst environments, more precisely of the exploitation of perched karst groundwater as a source of energy. Some sites may be interesting in this respect as they may offer significant discharge and height denivellation to produce electricity. A first assessment of the potential has been carried out in the Vaud canton (~600 km²) leading to a global potential of 40 GWh/year according to various capture devices. Among the 80 first selected sites, 7 have been recognized as economically feasible within a short term and two or three of these sites will probably be equipped soon. A dedicated environmental assessment will be carried out for each site.
Sinkholes as markers of karstic activity in the peridotites of New Caledonia (SW Pacific)

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Keywords: non limestone karst, sinkhole, peridotite, New Caledonia

Olivine which is the main constituent of peridotites is known to be an unstable mineral in tropical climate. Moreover, peridotites are estimated to dissolve from hard rock to ferricrete under meteoric water with nearly 90% volume loss. The peridotites are observed on nearly 30% of the Grande Terre Island of New Caledonia (SW Pacific) and they host nearly 30% of the world’s nickel reserve. At the outcrop, these peridotites present a karstic landscape resulting from weathering including enlarged fractures by dissolution. One of the most extensive karstic features of New Caledonia is a network of sinkholes (dolines), which correspond to temporary or permanent ponds. The question of the existence and characteristic of an underground karstic drainage system in the peridotites still remains an open question and the sinkholes might constitute a way to probe this karstic system. Moreover, the sinkholes constitute a specific environment for vegetation and aquatic life. Sinkholes are extensively developed in the Southern Massif of Grande Terre where our study is focused. We present an automatic mapping procedure of these sinkholes from remote sensing data: orthophotographs, DEM provided by the Government of New Caledonia and Lidar data provided by Vale. The Lidar data have proved to be very efficient in detecting both the shape of the sinkholes and their topography. Different detection methods are illustrated with emphasis on their complementary aspects. Distribution of sinkholes is compared with the geological structures. Finally a preliminary attempt of classification of the sinkholes based on remote sensing and field observations is proposed.
An approach to the simulation of karst spring discharge

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Keywords: simulation model of spring discharge, effective infiltration, base-flow, fast-flow

The paper intends to contribute to the study of simulation of karst spring discharge, emphasizing importance of transformation of the input components (recharge) for the two types of interconnected flows (base and fast). The input parameters are of a great importance, and they were determined by the means of correction of the obtained values of precipitation to the effective infiltration. Further, the input component is transformed into the components which simulate the functioning of karst hydrogeological system; introducing two functions – Kfun-base and Kfun-fast – which are related to the base-flow and fast-flow components. Schematically, the outflow is not depending only on the infiltration values – it also depends on previously accumulated water (storage). For that reason, a fictive state of storage $V_{S,0,i}$ was introduced. The effective infiltration $R_{f,0,i}$ is reduced for the value of fictive outflow of the previous day – $K_{fun-base/fast,0,i}$. The value of fictive outflow is a result of the values of fictive state of storage, multiplied by $\lambda$ coefficient, which simulates a fictive depletion correlated with the base-flow ($\lambda_b$) and the fast-flow ($\lambda_f$). The fictive depletion coefficients are estimated by the calibration process.

This simple model was successfully applied on two Serbian karst aquifers – Nemanja and St Petka.
A hypothesis for carbonate island karst aquifer evolution from analysis of field observations in northern Guam, Mariana Islands

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Keywords: carbonate island karst; eogenetic karst; coastal discharge; tidal attenuation; triple-porosity aquifers

Field studies of coastal discharge and aquifer properties on northern Guam, an uplifted eogenetic karst plateau, suggest carbonate island karst aquifers undergo profound reorganization of porosity and permeability and develop complex but predictable patterns of hydraulic conductivity, internal transport, and coastal discharge. Discharge features along the coast can be classified into four geomorphic categories: beach seeps and springs, reef seeps and springs, fracture springs, and cave springs. The styles and distribution of discharge among these four categories suggest that in aquifers composed of uplifted geologically young limestone matrix, fracture, and conduit porosity each play significant but varying roles. Analyses of tidal attenuation in wells across the plateau indicate that hydraulic conductivity near the periphery is two orders of magnitude lower than in the interior: 20-800 m/day, compared to 2000-90000 m/day. We propose a conceptual framework that relates the four categories of coastal discharge to the evolution and reorganization of porosities in the aquifer, and offer a hypothesis for the general distribution of hydraulic conductivity on uplifted carbonate island aquifers, in particular the juxtaposition of high conductivity in the interior against lower conductivity in the periphery: (1) dissolutional enhancement of horizontal hydraulic conductivity in the interior; (2) concurrent reduction of local hydraulic conductivity in the cliffs and steeply inclined rocks on the periphery by case hardening and perhaps other karst processes that promote occlusion of primary porosity on and inland of the rampart; and (3) the stronger influence of higher-conductivity regional-scale features in the interior relative to the periphery. Complexity is further increased by glacioeustasy and tectonic fluctuations that moved the freshwater lens vertically through the bedrock column and forced reorganization of porosities within horizontal planes at different levels.
Theoretical and field studies on hydraulics and chemistry of groundwater around stagnation points in nested flow systems

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Keywords: stagnation point, flow system, groundwater age

The stagnant zones in nested flow systems have been assumed to be critical to accumulation of transport matters, such as metallic ions and hydrocarbons in drainage basins (Toth, 1980). However, little quantitative research has been devoted to verify this assumption due to limited understanding on the hydraulics of groundwater around stagnation points. This presentation divides into three parts.

In the first part, we present some analytical studies on the hydraulics of groundwater around stagnation points in nested flow systems. By deriving analytical solutions of hydraulic head and stream function in a complex basin, we found that there three kinds of stagnation points. The first one is called interior stagnation point, which is located inside the basin due to convergence of divergence of four flow systems. The second one is called convergent basin-bottom stagnation point, which is located at the basin-bottom due to convergence of two flow systems. The third one is called divergent basin-bottom stagnation point, which is located at the basin-bottom due to divergence of two flow systems.

In the second part, we present some numerical studies on accumulation of age mass around stagnation points. By solving the equation of age mass transport, we obtained the distribution of groundwater age in complex basins and found that old groundwater exists around all of the three kinds of stagnation points.

In the third part, we present two field studies on accumulation of age mass and chemical components around interior stagnation points in the Ordos Basin, Northwest China. In the first field study, the anomaly of groundwater age in different sections of a borehole is successfully explained using the existence of an interior stagnation points. In the second field study, the anomalies of groundwater chemical components and stable isotopes in different sections of a borehole are also successfully explained using the existence of an interior stagnation points.
Groundwater geochemistry in the High Atlas Mountains Karstic system of the Ziz-Ghris basins

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Keywords: kast of High Atlas Mountains, geochemistry, water quality, Ziz and Ghris Basin

The study area lies between latitudes 29°30' and 32°30' and located in arid and semi-arid regions. The Atlas Mountains ensure the permanent groundwater’s recharge and major part of the surface waters. This work aims to understand the geochemistry of those waters, their extension, and the possible links existing by different aquifers, and finally to prospect the water quality. The stratigraphy ranges from Precambrian to Quaternary. Jurassic rocks constitute the major High Atlas lithology.

Both of the oued ziz and ghriss take origin in the karstic systems of High Atlas. The shallow waters are located along valleys and characterized by their small size and their direct dependence on the variation of the climate and exploitation. The deep aquifers that are divided from north to south into three hydrogeological units well separated: The High Atlas karstic system, the Cretaceous basin of Errachidia and the Anti-Atlas. The Errachidia basin includes two aquifers The Senonian, and the Infracenomanien. The springs in the area have different origin and evolve in different lithologies. The waters from Paleozoic and Jurassic aquifers are HCO₃⁻ Ca²⁺ facies, they become richer in sulfate in the Anti-Atlas where the geological formation has intense hydrothermal activity. In some areas, mineralization on baryte, galena, and gypsum are identified on surface, the Tismoumine and Tasblbat sources flow through this mineralization. The Infracenomanien, the Senonian and the Quaternary aquifers show a mixed facies.

The inorganic quality of the water is bad to very bad, the salinity of this water is the principal responsible. Some major cations and anions exceed the recommended OMS daily value for drinking waters. Except for the Ain El Ati and Tasblbat source, they could be toxic. The presence of some heavy and trace elements deteriorate its quality. Water’s salinity contributes to the soil salinization, where agriculture is a source of income for one million inhabitants.
Estimation of groundwater mean residence time in karstic aquifers using recession curves

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Keywords: mean residence time, master recession curve, dye-tracing, karst aquifer

A parsimonious simple method is proposed to estimate the mean residence time (MRT) of groundwater emerging from a karst spring during recession periods. The proposed method is capable of estimating MRT for karstic aquifers with no-flow boundaries that all groundwater is discharged from a spring. The required data are only spring hydrograph and the relevant precipitation data that are readily available for lots of karst springs. Water emerging from a karstic spring is composed of billions of water molecules, relevant to the several previous precipitation events. Significant precipitation events produce individual spring hydrographs; however, each of the hydrographs doesn’t have a complete recession, because the next event will cause interruption. Providing a long enough recorded discharge data, the Master Recession Curve (MRC) can be precisely constructed. The MRC is used to extrapolate incomplete recession curves to any desired time. In other words, the recorded composite hydrograph is separated into individuals, using MRC. Then, the discharge component relevant to each previous event can be calculated at a specific time. The Residence Time (RT) can be also considered as the elapsed time since the time of event centroid. Finally, the MRT is calculated using a discharge weighting average equation. The proposed method is evaluated for the Sheshpeer karst spring in the south central of Iran, and the results is compared to an available sink to spring dye-tracing. The calculated MRT by the proposed method is about two months longer than the estimated mean transit time of tracer. The mean transit time of tracer is representative of groundwater MRT in conduits, but the calculated MRT is representative of active circulating water through both conduit and diffuse flow systems.
3. Epigene and hypogene karst systems

Hydrogeological approach to distinguishing hypogene speleogenesis settings

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Keywords: karst hydrogeology, hypogene karst, hypogene speleogenesis, hydrogeological settings

The hydrogeological approach to defining hypogene speleogenesis (HS) relates it to ascending groundwater flow (AF). HS develops where AF causes local disequilibrium conditions favoring dissolution and supports them during sufficiently long time in course of the geodynamic and hydrogeological evolution. The disequilibrium conditions at depth are invoked by changing physical-chemical parameters along an AF paths, or/and by the interaction between circulation systems of different scales and hydrodynamic regimes. The association of HS with AF suggests a possibility to discern regularities of development and distribution of HS from the perspectives of the regional hydrogeological analysis. In mature artesian basins of the cratonic type, settings favorable for AF and HS, are as follows: 1) marginal areas of discharge of the groundwater of the 2nd hydrogeological story (H-story), 2) zones of topography-controlled upward circulation within the internal basin area (at the 1st and, in places, at the 2nd H-stories; 3) crests of anticlinal folds or uplifted tectonic blocks within the internal basin area where the upper regional aquitard is thinned or partially breached; 4) linear-local zones of deep-rooted cross-formational faults conducting AF from internal deep sources across the upper H-stories. Hydrodynamics in the 3rd and 4th stories is dominated by ascending circulation strongly controlled by cross-formational tectonic structures. Specific circulation pattern develops in large Cenozoic carbonate platforms (the Florida-type), side-open to the ocean, where AF across stratified sequences in the coastal parts, driven by both topography-induced head gradients and density gradients, involves mixing with the seawater. The latter can be drawn into a platform at deep levels and rise in the platform interior (the Kohout’s scheme). In folded regions, AF and HS are tightly controlled by faults, especially those at junctions between large tectonic structures. In young intramontaine basins with dominating geostatic regime, HS is favored at marginal discharge areas where circulation systems of different origins and regimes may interact, such as meteoric waters flows from adjacent uplifted massifs, basinal fluids expelled from the basin’s interiors, and endogenous fluids rising along deep-rooted faults. Specific and very favorable settings for HS are found in regions of young volcanism with carbonate formations in a sedimentary cover.
Isotopically altered wallrock of the hypogene conduits in the Crimean Piedmont, Ukraine

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Keywords: stable isotopes, isotopic alteration, water-rock interaction, hypogene speleogenesis, Crimea

The Crimean Piedmont stretches along the tectonic suture separating the fold-and-thrust structure of the Crimean Mountains from the Scythian Plate. It comprises two cuesta-like ridges whose structural slopes are built up of homoclinal limestone beds of the Paleocene- Eocene (the Inner Range), and the Neogene (the Outer Range) ages. Abundant relicts of the hypogene karst have been identified recently in steep cuesta cliffs of the Piedmont. The hypogene cavities formed in confined to semi-confined hydrological conditions due to interaction of the deep-seated waters, ascending along cross-formational fracture conduits, with the strata-bound lateral filtration flow. The ongoing geomorphological dissection of the stratified structure of the Piedmont commonly follows the pre-formed hypogene conduits, resulting in the development of the pronounced cuesta relief with steep cliffs featuring massive exposure of the hypogene karst conduit paleo-walls with specific morphologies.

Movement of deep-seated fluids through carbonate wallrock may cause isotopic alteration of the later. We have studied isotopic composition of C and O along nine cores drilled into the walls of the cliffs decorated with hypogene solutional features, as well as in two hypogene caves. Data from all cores show the presence of a wide isotopic alteration halo, whose thickness exceeds the core length (max. 40 cm). In this zone, the rock is slightly depleted in $\delta^{18}$O (ca. 1-2 ‰) relative to the “pristine”, unchanged values of a given rock unit. In most cores the rock is also depleted in $^{13}$C but two cores show higher $\delta^{13}$C values. In addition to this low-gradient alteration, most of the cores also show a narrow (4-50 mm) zone of the high-gradient alteration, across which $\delta^{18}$O and $\delta^{13}$C drop by respectively, 2.0–4.9 ‰ and 0.7–4.5 ‰. At three localities, the walls of the hypogene cavities were coated with phreatic calcite. Isotopic composition of this calcite corresponds to the lowermost values of the altered rock. In one core, the rock in the high-gradient alteration zone is depleted in $^{18}$O but enriched in $^{13}$C. In yet another core the rock is enriched in both $^{18}$O and $^{13}$C. The results corroborate the hypogenic origin of conduits and suggest that the wallrock was exposed to, and interacted with, geochemically different waters after the main volume of cavities had been created by dissolution.
Hydrograph analysis for the estimation of hydraulic and geometric parameters of karst systems

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Keywords: karst, spring hydrograph, well hydrograph, hydrograph analysis, conduit network, parameter estimation

Spring and well hydrographs contain important information about the hydraulic parameters and geometric characteristics of karst aquifers. The spatial geometry of karst conduits and the hydraulic properties of matrix blocks determine the hydraulic behaviour of karst hydrogeological systems, and thus information about these properties is crucial for the adequate characterisation of karst systems. This paper provides an overview of novel quantitative tools for the estimation of hydraulic and geometric parameters of karst systems by means of spring and well hydrograph analyses. The analytical formulae provided in this study establish links between aquifer properties and hydrograph recession coefficients, and describe the spatial and temporal variations of the water table. A first set of equations describe the recession limb of hydrograph peaks, while another formula provides a quantitative characterisation of entire hydrograph peaks as a response to diffuse recharge. While spring hydrograph analytical techniques provide information on the overall characteristics of a karst catchment, well hydrograph analysis provides information on the hydraulic and geometric characteristics of individual matrix blocks.

The combination of the spring and well hydrograph analytical techniques provides a powerful tool for the characterization of the structure and hydraulic behaviour of karst systems.

A new approach to well hydrograph decomposition is presented, which makes the estimation of exact block geometry possible. In most cases both spring and well hydrograph peaks can be decomposed into three exponential segments. These segments however do not represent different types of storage as suggested by previous studies.

The analytical solutions presented in this study represent powerful tools for parameter estimation in karst systems. The proposed investigation method provides useful information for water resource assessment, flood prediction, vulnerability assessment, contamination risk assessment, geotechnical and speleological studies.
Challenges and solutions in numeric modeling of regional karst aquifer systems

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Keywords: karst aquifers, numeric models, conduit flow, unstructured grids

Groundwater flow in karst aquifers is notoriously difficult to characterize in the field at both regional and locals scales and is even more difficult to describe with numeric models. Most numeric models of karst groundwater flow are still based on the equivalent porous medium (EPM) approach, which has numerous limitations. Most notably, grid design constraints at practical modeling scales can cause conduits represented by high conductivity zones to be much larger than reality, often approaching the absurd. At the same time, use of very low effective porosity in cells representing virtual conduits does not have hydrogeologic sense. The Conduit Flow Process (CFP) for the United States Geological Survey’s program MODFLOW and the recently-released MODFLOW USG (UnStructured Grids) offer viable alternatives to the EPM approach. Use of these programs enable physically-based simulation of flow through rock matrix and in the karst conduits. Additionally, MODFLOW USG allows realistic representation of geologic structures at any scale including faults with large offset. Local flow fields within regional models can be easily described with embedded grids providing for great efficiency and versatility. Comparative case studies of using EPM versus physically-based models are presented including simulated transient conditions including major recharge events, groundwater extraction, and regional re-distribution of flows due to varying hydraulic role of geologic structures.
Modelling effect of climate change on Bükk karst system

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Keywords: climate change, karst spring discharge, moisture balance, lumped parameter, deterministic model

Groundwater is representing outstanding natural resource in Hungary. More than 95 % of drinking water is supplied from groundwater, and among this about one sixth from karst water. Climate change affects fresh water resources and may have significant influence on public drinking water supply, and also on the ecosystems related to the karst springs, creeks.

The impact of climate change was investigated on a test area in Bükk Mountains with modelling the relation of rainfall and karst spring's discharge. The modelling of the discharge of karst spring was divided in two sub models.

Firstly the recharge was calculated based on the moisture balance of the soil cover by the commercial software HELP initially developed by U.S. EPA. It accepts weather and soil data and uses solution techniques that account for the effects of surface storage, snowmelt, frozen soil, runoff, infiltration, evapotranspiration, soil moisture storage, and leakage through soil. HELP was applied for homogenous areas (according to topography, land use, soil type, meteorological data) and then the elements of water balance were summed for a larger area with GIS tools.

Secondly the groundwater discharge was modelled either by complex physically based numerical model or lumped parameter model.

The deterministic regional model (with FEFLOW [DHI-Wasy Ltd] finite-element software) for the karst aquifer calibrated by measured heads and discharge values. Modelling the special nature of karst system such as conduits and caves 1 and 2 dimension(s) net elements were applied based on trace measurements.

If the information is not sufficient for establishing a physically based model, but relatively long measured time series exist, non-linear regression can be set up. Quick flow component was characterised by Gamma function.

In order to get comparable results the temperature and precipitation data of past (1961-1990) and future (2021-2050/2071-2100) derived from the same climate model.
Minerals of the Józsefhegy Cave

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Keywords: hypogene, minerals, X-ray powder diffraction, Rose Hill

On the Rózsadomb (Rose Hill) area there are several hypogene caves. Their known length is altogether more than 50 km at this moment. The most beautiful and valuable crystals can be seen in the Józsefhegy Cave. That cave was explored by the members of the “Rózsadombi Kinizsi Speleological Club” under the guidance of Szabolcs Leél-Őssy and Péter Adamkó in 1984. The mapped length of the cave is at present 6,5 km.

The minerals can be classified into 4 groups:

a) minerals older than the cave itself;
b) minerals precipitated from the warm water (which earlier dissolved the cave passages) directly;
c) minerals precipitated from the vapour of warm water;
d) and minerals originated from the dripping-seeping cold water (they are developing also recently).

To group a) belong the calcite veins, calcite scalenohedral crystals and tabular habit of barite crystals.

Group b) comprises several, different calcite crystals, for example cave rafts, basin fingers, folia, bedded calcite crusts.

Parts of group c) are the frostworks (mainly aragonite needles) and the botryoids (popcorns).

The different gypsum crystals (chandeliers, crusts, gypsum flowers, gypsum hairs), glass-ball botryoids, draft-botryoids and the dripstones belong to group d).

Elements of group b) were subjects to U-series dating, carried out by the Author at the University of Bergen, in the laboratory of Stein-Erik Lauritzen, and at Eötvös Loránd University, Budapest, with the help of Gergely Surányi. According to the dating, the age of cave system is about 600000-700000 years. Macroscopically 6 mineral types (“manganese coating” “limonite”, barite, gypsum, calcite, aragonite, hydromagnesite) could be recognised in the caves. By means of X-ray powder diffraction, 6 further minerals (dolomite, huntite, quartz, kaolinite, illite, montmorillonite) were detected, and 3 other minerals (pyroxene, garnet, zircon) could be demonstrated in the heavy mineral fraction.
4. Flowing groundwater as a geologic agent

Hydrothermal variation in several deep caves of the Nullarbor Karst Plain, Australia

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Keywords: Geothermal, Nullarbor, speleogenesis, temperature, groundwater

The Nullarbor karst plain in Australia contains many large caves along its southern coastal margin, 14 of which penetrate the regional groundwater basin near sea level to depths >10 m. Since the mid-Miocene the Nullarbor has largely had an arid to semi-arid climate. Heat exchange between the atmosphere, the caves and their initial lake surfaces varies between caves.

In the west, divers have recorded water temperatures within the submerged passage systems of a close group of four caves (Cocklebiddy, Murra-El-Elevyn, Pannikin Plains and Tommy Graham’s Caves). These water temperatures vary both within and between caves (range 18-24 °C). Similar effects have been noted in Warbla Cave ~350 km to the east and, in the same vicinity, in Weebubbie Cave.

Specifically, in stable conditions (no recent floods) Cocklebiddy Cave water temperature rises northwards from 18 °C in the entry lake to 24 °C through 6.5 km of flooded passage. In Tommy Graham’s Cave temperature remains a consistent 23.5 °C throughout. In Murra El Elevyn temperature rises from 19.1 °C in the entry lake to 20.5 °C in a narrow passage 300 m inside the system where warmer water appears to enter the cave through the floor. Divers can ‘feel’ this water and a thermocline is clearly visible. In Weebubbie Cave the majority of the system is a consistent 18.6 °C with a distinctly bounded warm zone of 19.4 °C identified.

Though point sources have not been located in all caves, warm water may be entering these caves through their floors in zones which may be geomorphically identifiable via current investigations coupled with water chemistry analysis. This may have significant implications for a possible geothermal inception at depth of large deep Nullarbor caves, in two distinct nodes in the western and eastern ends of the karstfield. Research continues into these phenomena.
7. Significance of flow system approach

Direct observation of Tóthian hierarchical groundwater flow systems using sandbox

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Keywords: sand-box model, groundwater flow, visual physical simulation, hierarchical flow systems

Many students have difficulties to gain intuitive insights into the concept of Tóthian hierarchical flow systems: local, intermediate and regional. They may accept it with confirmations of analytical and numerical simulation, but they find it too “strange” to be sensed by intuitive perception. It is difficult also for many hydrogeologists who deal with practical problems to use the theory and approach of the flow systems. Therefore, we developed a complex Flow-System Sand-Box Model (FSM). It enables the visual observations of the development and characteristics and temporal evolution of complex Tóthian flow systems by laboratory physical experiments. The configuration (order and number) of the flow systems can be controlled in the FSM; hydraulic head, flow direction and travel time can be measured; and the scale and shape of the sub-flow systems, as well as the path-lines and flow lines can be observed directly. The experiments demonstrate the Tóthian flow systems in a small basin with multiple sources and sinks. Greater local topographic (water table) undulation will lead to larger local flow systems. Greater regional and less local topographic undulation will enhance the development of intermediate and regional flow systems. However, water table does not always follow the topography. Flow patterns depend on the ratio of infiltration intensity to hydraulic conductivity when given same basinal geometry and possible potential sinks. The FSM is a useful teaching aid and experimental device to study and develop an intuitive insight into gravity-driven groundwater flow systems. It helps to visualize and understand the hydraulic properties and controlling factors of Tóthian flow systems and may be used to study problems related to the chemical and temperature characteristics of the flow systems as well.
Discussion on the classification for epikarst flow by 
discharge and coefficient of variation

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Key words: epikarst flow, classification, monitoring methods, monthly variation

Friederich and Smart (1982) introduced a classification for vadose flow by the maximum discharge and discharge variability, now one of the most popular ways to classify water movement in epikarst. However, it also has its restrictions. In Velika Pasica Cave, Slovenia, four permanent drips were monitored in order discover water movement in epikarst. According to this research, it arrived at several conclusions: (i) the method applied to collect the discharge of dripwater was an important factor for choosing the right format for classification; (ii) after analyzing these two parameters at monthly intervals, we found the water movement in epikarst varied in response to seasonal weather change, while concurrently the structure of ceiling above the drips was also an important impact factor.
3. Epigene and hypogene karst systems

Episodic fluid flow, hypogene and epigene karstification, and dolomitization in an accretionary prism setting, Barbados, West Indies

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Keywords: episodic fluid flow, karstification, dolomitization, accretionary prism, Barbados

Barbados is a small island located about 125 km east of the Lesser Antilles volcanic island arc. The oldest strata are Eocene sandstones and shales of an accretionary prism complex, overlain by Oligocene-Miocene chalks and marls, in turn overlain by Pleistocene reef and lagoonal limestones that cover ~85% of the island.

One especially interesting location is a large outcrop of chalk at Cove Bay, where replacive dolomite occurs in association with a number of small caves. The oxygen isotope values of the dolomite indicate dolomitization by seawater in a cold seep environment (+4 to +10 °C) with concomitant methane oxidation, while the Sr-isotope ratios of about 0.7086-7089 provide a Late-Miocene to Early Pliocene age. The caves have hypogene and/or epigene characteristics. Swarms of joints that pinch out upward indicate that diagenetic fluids carrying methane were expelled from the clastics of the accretionary prism below. The methane was thermogenic in origin, derived from the oil and gas formed in the accretionary prism sediments. The Sr-isotope data from undolomitized Miocene chalk and from Pleistocene limestones elsewhere provide isotopic evidence for methane expulsion from the accretionary prism having taken place episodically over a period of about 30 my, consistent with the plate tectonic history of the region around Barbados. Mixing zone dissolution then enlarged some of the pre-existing dissolution voids into small caves, which thus form an unusual type of flank margin cave. Some of these caves were overprinted by mechanical and biological erosion and now are sea caves in the current intertidal zone. In addition, there are a few small sea caves in the current intertidal zone. Barbados thus provides an unusual example of localized episodic fluid expulsion of methane-bearing diagenetic fluids with polyphase and polygenetic karstification and dolomitization.
The Grosmont: the world’s largest unconventional oil reservoir hosted in polyphase-polygenetic karst

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Keywords: polyphase-polygenetic karstification, unconventional oil reservoir, Grosmont

The Upper Devonian Grosmont platform in Alberta, Canada, is the world’s largest heavy oil reservoir hosted in carbonates, with 400-500 billion barrels of IOIP at an average depth of about 250 – 400 m. Advanced thermal recovery technologies, such as SAGD and electrical in-situ retorting, much higher world market prices for oil and certain political pressures have led to a flurry of activity in the Grosmont since 2006. The sedimentary stratigraphy of the Grosmont reservoir consists of six stacked carbonate units interbedded with marls and some evaporites. The latter two originally acted as aquitards during diagenesis but are breached or missing in parts of the area today. Dolomitization by density-driven reflux was the first pervasive diagenetic process. A dense fracture network was created in three or four phases. Most fractures probably originated from collapse following subsurface salt dissolution and/or from Laramide tectonics far to the west, whereby pulsed crustal loading in the fold-and-thrust belt created a dynamic forebulge in the Grosmont region via multiple pulses of basin-wide crustal flexing, each followed by relaxation. The fracture network probably was reactivated and/or expanded by glacial loading and post-glacial isostatic rebound in the Pleistocene and Holocene, respectively.

The region experienced three or four prolonged periods of epigene karstification, although there is tangible evidence for only two of them in the Grosmont platform. The first of these episodes was a ‘warm epigene karstification’ during the Jurassic-Cretaceous, and the second was/is a ‘cold epigene karstification’ that started sometime in the Cenozoic and is continuing to this day. In addition, there is circumstantial evidence for hypogene ‘karstification’ (= dissolution) throughout much of the geologic history of the Grosmont since the Late Devonian. Karstification was accompanied and/or by followed by extensive hydrocarbon biodegradation.
Thermal springs and hypogenic karstification processes in flow system context

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Keywords: unconfined and confined carbonate aquifers, regional groundwater flow, thermal springs, hypogenic karstification

Uplifted unconfined and adjoining confined continental carbonate aquifers contain thermal water with marginal thermal springs as decisive discharge features connected to tectonic contact between the unconfined and confined part of the system. These areas are characterised by positive thermal anomaly, particular mineral precipitates and phreatophyte vegetation. These systems are important not only as sources of thermal water but the confined parts of the system can serve as hydrocarbon reservoirs, moreover Mississippi Valley Type (MVT) ore deposits can also be connected to such environments. Hypogenic speleogenesis can be active at such marginal discharge zones of groundwater due to the direct corrosive effect of deep originated fluids. These different processes are known from the literature however their relationships have not been revealed comprehensively. The application of regional groundwater flow system theory and evaluation can give a chance to understand the common origin of these different processes, which is moving groundwater. The Buda Thermal Karst offers an exceptional natural laboratory where groundwater flow systems and their effect on rock matrix and the environment can be examined and proved directly. Moreover as new discharge phenomenon a karst corrosive biofilm was recognized here. The presentation displays the most important conclusions which can be generalized for areas with similar hydrogeological settings. The research is supported by the NK 101356 OTKA research grant.
Study of the relationship between pressure solution and karstification

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Keywords: karst, deformation, stylolites, faults and joints

The karst is strongly influenced by the deformation history and tectonics of the area in which it develops. For this the structural setting of a rock mass (e.g. lithology, porosity primary, environmental conditions etc) affects the circulation, influencing the values of permeability and porosity. Traditionally, in the field of karstology, it is argued that water circulation is essentially related to extensional structures assuming that they are more favourable to water circulation. In fact, the permeability of the fault zone is sufficiently high only in the early stages of the movement because after a short period, deposition of minerals (e.g. calcite) that the underground waters tend to transport, fills the gaps and therefore generates dramatic porosity/permeability reduction.

In this study, conducted in the karst area of Fasano it was verified that the karst develops preferentially along defined tectonic compression, stylolites. Stylolites are created by pressure-solution affecting mainly carbonate rocks and implying the deposition of a residual insoluble material. Indeed, pressure-solution leads to dissolution of soluble elements but enrichment in insoluble elements (i.e. iron and aluminium minerals), these are of finer granularity and therefore are more easily altered and remobilised resulting in fluid flow enhancement. This knowledge allows us to study and reconstruct the underground aquifers that represent about 40% of sources of drinking water and their importance will increase in coming years.

In the study area are the tectonic stylolites revealed the preferential place in the development of karst, underground and epigean. We present the first results of this study.
Groundwater flow regime evaluation and multivariate data analysis on shallow groundwater time series

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Keywords: groundwater flow regime, multivariate data analysis, Neusiedlersee-Seewinkel Austria, Water Framework Directive (WFD)

Preserving the quality of surface and subsurface waters is one of the most important tasks of present-day environmental protection. Therefore in 2000 the European Parliament and Council published Directive 2000/60/EC which formed the framework for a common policy on water protection in the EU; it is called the Water Framework Directive. The aim of which is to prevent further water quality deterioration, to promote sustainable water use, enhance the protection and improvement of aquatic environments; to ensure the progressive amelioration of groundwater quality and prevent its further pollution. To ensure this, many parameters are sampled simultaneously at multiple sampling sites according to the requirements of the Water Framework Directive. In the study questions are raised: can more information be extracted from groundwater data related to this directive and how are the data related to the groundwater flow regime of the area? To answer it a methodology had been developed (with a flowchart representing the necessary steps) that is easy to use and could be implemented into official practice. A case study is presented where the time series of 18 parameters from 23 monitoring wells at eastern side of Neusiedler See were analyzed between 1996 and 2011 using uni- and multivariate methods (descriptive statistics, trend-, cluster-, Wilks’ λ and spatial analysis). As a last step these results were compared with the flow regimes of the area. The study gives a good example that more information can and should be extracted from Water Framework Directive related groundwater data with an easy-to-use methodology; moreover it is also proved that the groundwater flow regime is the basic determining agent regarding the near surface processes.
Evidence for strong diffusion influences on plume characteristics in fractured dolostone aquifer with karst features

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Keywords: fractured carbonate aquifer, DNAPL, matrix diffusion, natural attenuation, high permeability zones

Strong natural attenuation is observed in a co-mingled plume of metolachlor (MET; a halogenated organic herbicide) and trichloroethene (TCE) in a 100 m thick fractured dolostone aquifer supplying water to the city of Cambridge, Ontario, Canada. Initial investigations concluded that it was caused by dissolved-phase transport by groundwater flow down through 30 m of Quaternary overburden into the dolostone aquifer. Subsequent study using conventional methods and the Discrete Fracture Network (DFN) Approach revealed MET throughout the depth of the dolostone aquifer, comingled with TCE from a nearby industrial source. This deep contamination of MET and TCE is attributed to flow of dense non-aqueous phase liquids (DNAPLs) through the overburden to near the bottom of the dolostone aquifer. The site conceptual model incorporates DNAPL dissolution to groundwater flowing through a dense network of discrete fractures and dissolution-enhanced conduits. Solute transport is strongly influenced by diffusion-driven mass transfer from various sized advection pathways into the adjacent low-permeability but porous rock matrix. It has resulted in strong attenuation of source zone concentrations followed by the present day condition in which back-diffusion from the rock matrix results in a persistent, low-concentration, stationary plume. A downgradient transect of five multilevel monitoring systems (MLS) and rock core analyses show depth-discrete concentration profiles with highest MET concentrations coincident with a zone of high permeability, where hydraulic conductivity were above the test limit of 10-5 m/s. This data is consistent with the conventional monitoring well data obtained in the vicinity of the MLSs. The long term monitoring well data of more than 15 years from all monitoring devices indicate that the plume front is strongly retarded and has achieved a quasi-steady state position. This site demonstrates that contaminant transport and fate in this fractured rock aquifer with karst features is strongly influenced by diffusion and the dense network of discrete fractures creating a highly dispersed plume.
Karst springs’ hydrograph separation into flow components using parameters of the master recession curve

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Keywords: hydrograph separation, recession curve, recession parameters, flow components, iteration solution

Presented hydrograph separation principle is based on presumption, that karst spring’s hydrograph is built by superposition of several exponential and linear equation members. Generally, outflows from smaller fissures (laminar flow from karst rock matrix) are exponential and linear equation members describe flow through karst conduits (turbulent flow). Quantitative behaviour (discharge) of karstic aquifer (spring) is described by set of unique constant values of starting discharges \( Q_0 \), as well as set of unique recession coefficients (\( \alpha \) or \( \beta \)) for each detected flow component. The main idea behind the method is based on a simplified understanding of reality: the same discharge should reflect the same water saturation (piezometric) level in the system. Separation method requires detailed studies of spring’s recession to create master recession curve. In the process of hydrograph separation, each measured discharge value is understood as a result of superposition of several flow components, corresponding to the current state of aquifer saturation (general piezometric level). Every measured discharge value \( Q_t \) is then determined just by a representative time \( t \) – theoretically elapsed time from the global maximum discharge \( Q_{\text{max}} \). Subsequently, discharges of different flow components can be calculated by using the \( t \) value in their partial equations, where different partial \( Q_{\text{max}} \) and individual recession coefficients (\( \alpha \), \( \beta \)) are used. As the exponential equation has no analytical solution, each discharge value \( Q_t \) has to be solved by iteration process. However, principle of general piezometric level is only a rough simplification. In real karst aquifers, several piezometric levels should exist at least for each saturated system (small fissures, medium fissures, karst conduits), if not for their different parts. By offering a clear solution for every discharge value, presented method still can be helpful for quantitative referencing of flow components for further interpretations.
Could groundwater discharge contribute to the regional differentiation of vegetation in the Parana River fluvial system (Argentina)?

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Keywords: vegetation, geomorphology, water chemistry, isotopes, groundwater discharge

Despite the well known contribution of groundwater to aquatic ecosystems, such input has not considered in the Parana River fluvial system. This is the third most important river in South America with an extensive floodplain characterized by regional differences in vegetation physiognomies, geomorphological structure and superficial hydrologic dynamics. This work aimed to assess the relationship between vegetation and groundwater discharge in an island which is part of the Parana fluvial system. Eight piezometers were installed in four vegetation communities; their water-table position was recorded weekly for two years. The floristic composition and topographic position were also recorded. Physical-chemical water analyses (major-minor ions and stable isotopes) interpreted within the water-table response suggest the presence of groundwater discharge from different local flows and from an intermediate flow that has travelled from beyond the boundary of the river channel into the island. Willow and Pluryspecific canopy forests are located on the highest topographic positions; the Willow is associated to recharge conditions of a local flow, the canopy forest is linked to transit conditions of an intermediate flow. Tall grassland and Marshy community (found at intermediate and lowest elevation, respectively) were associated to discharge areas of local and intermediate flows. Observations in other locations in this fluvial system could reinforce the detection of groundwater discharge and would suggest a preliminary relationship at regional scale among geomorphological units, vegetation physiognomy and groundwater discharge conditions.
Superficial drain from takirs of Ustyurt Plateau as a source for storage of drinking water

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Keywords: karst, takir, underground water

One of the characteristic elements of natural landscape of deserts is TAKIRS. Takirs are described as open, deprived of the maximum vegetation, strongly leveled flat surfaces combined in the top part by densely connected clay materials. Takirs of Ustyurt are formed at combination of some factors. The main following from them: arid conditions of the climate; the certain orientation of the geological processes, preparing a cover from poorly nontight breeds; deep bedding of underground waters, excluding secondary desalination of soil; small surfaces inclination and obligatory stoppage of superficial waters; absence of the maximum vegetation and presence of the lowest - communities of blue-green seaweed and lichens.

Average of takirs area (1-3 km²) are dated for karstic forms on wings of positive structures, 3-5 km² and more than 5 km² develop on the bottoms of karstic valleys.

The characteristic of takir reservoirs of the Karakalpak Ustyurt on the area, km². In total 1736,42, the number of takirs 5861.

The general physic-geographical conditions of a plateau is the distribution of deposits on seasons of year (including flow making), binding of them to the periods described in rather low temperatures of air and small boiling process, strong humidity of the top layer of takir adjournment and presence of communities of lowering losses, - all this promotes the formation of non permanent superficial drain on takirs, natural reservoirs of stony desert Ustyurt.

The only one way for saving the fresh water is storage it in the karst. For this we need to remove the densely connected clay materials.

By this way we can storage more than 3 millions tons of fresh water annually and then this water can be used for drinking.
Inter-winter recharge and storage within a karstic environment, Vers Chez le Brandt, Switzerland

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Keywords: epikarst, vadose storage, snowmelt, recharge

The present study examined subsurface flow patterns and water storage during inter-winter snowpack melt periods within a low-alpine, karstic environment. The Vers Chez le Brandt research site is comprised of a small recharge zone that drains infiltrating water to an arrival point (VCB1) in a cave 30 m below its source area, and can be viewed approximately as an oversized real-world lysimeter. Discharge or volumetric water content, electrical conductivity and temperature respectively of VCB1 outflow and the surficial meter of soil pore water were evaluated hourly throughout the 2011/12 winter season. Time-series values were qualitatively compared with precipitation and snowpack outflow, the latter of which was approximated using a site-established snow height to snow density-rating curve. Findings showed that the quantity and duration of water input at the soil surface may have a governing role on flow paths within the soil and epikarst. Extended influxes associated with spring snowmelt possibly promote the formation of perched aquifers over saturated clays, which could serve as a baseflow water source during dry periods. These clays are comprised of secondary allochthonous accumulations within the loess soils and chemically weather limestone. Thus an understanding of soil structure and distribution is critical when assessing recharge particularly in karstic environments subject to seasonal snow accumulation.
Hypogene speleogenesis in Italy

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Keywords: speleogenesis, hypogenic caves, hydrogen sulfide, carbon dioxide, Italy

Through more than one century of speleological research in Italy, many hypogenic limestone caves have been explored, mapped and studied. These caves are characterized by a variety of patterns and morphological sizes including three-dimensional maze systems and deep shafts, with both active endogenic CO₂ and H₂S vents.

An integrative approach taking into account geological, hydrological and geochemical settings permit to recognize the main hypogenic speleogenetic processes. The H₂S oxidation to sulfuric acid, by oxygen-rich groundwaters as well as in the atmosphere is actually the main active hypogenic cave-forming processes. Both phreatic and vadose corrosion reactions involve chemotrophic microbial activity, with sulfur-redox bacterial communities that generate sulfuric acid as metabolic product. The bedrock corrosion produces sulfate ions in the phreatic zone and gypsum replacement in the limestone walls of the vadose sectors of the caves. The caves are characterized by both fossil and active passages in which water rich in H₂S as well as endogenic CO₂ plays a determinant role in speleogenesis. Although sulfuric acid-related speleogenesis typically produces gypsum deposits, in caves where the karstification processes are driven by subterranean CO₂ sources, voids and speleothems are the only final products.

In Italy all the end-members of the karst processes can be found, from solution caves to outcrop of carbonate travertine. The hypogenic caves are concentrated for largest and both fossils and active systems in the Tuscany, Umbria, Marche and Latium regions (Menichetti, 2009). These consist of few tens of kilometers of solutional passages with galleries and shafts, which are characterized by large rooms, cupola and blind pits, anastomotic passages, bubble trails roof pendants, knife edges, and phreatic passages. Active smaller karst systems are known in Southern Italy in Apulia, Campania and Sicily, related to the geothermal anomaly associated with CO₂ and H₂S vents.
From flow uncertainties to resource management: the example of the Carboniferous limestone aquifer in the international Scheldt river basin

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Keywords: Scheldt river, Carboniferous limestone, groundwater resource, transboundary aquifer, overexploitation

The Carboniferous limestone aquifer is a complex syncline basin extending 25 km wide and 120 km long from Lille (France) to Namur (Belgium). Its groundwater resource is shared, mainly as drinking water, between France, Flanders and Wallonia. An increasing extraction took place in its western confined part after the 1st world war, leading to a depletion of the water table of several tenths of meters at the beginning of the 90's. At that time it was recognized that only actions coordinated among users could stop this overexploitation. The closure of some extractions in France, together with a voluntary reduction of drinking water intakes in Belgium, could stabilize, and even raise the water table since the years 2000. The total extraction is now around 70 hm³/y. Nevertheless, a better understanding of the recharge and phreatic flow processes, in particular exchanges between unconfined and confined parts, is obviously a prerequisite to a sustainable management of this aquifer. The European SCALDWIN project helped in that way by gathering geological and hydrogeological data across borders and building a large scale numerical groundwater model. Nowadays, in addition to drinking water demand pressure, the water authorities have to cope with emerging threats coming from unbalanced exploitation due to extensive dewatering of the aquifer for quarrying industry, from risks of invasions of the Scheldt waters, or from alteration of water quality when the water table rises too fast. So can a model be reliable enough to control such impacts, keeping in mind the uncertainties caused by the heterogeneity of flow in such karstic aquifer? In this paper, we discuss what kind of data or observations can be the most useful to assess significant changes in the aquifer as well as what can be their sensitivity to management options. Piezometric records are here emphasized as they are lined up to become the most sensitive validation tool.
The use of spreadsheets for groundwater flow system analysis:  
a simple efficient resource for teaching and practice

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Keywords: groundwater spreadsheets, teaching hydrogeology, groundwater flow system analysis

The use of spreadsheets provide a cost-effective means for solving wide range of simple and complex groundwater flow system analysis scenarios, in a very efficient way using dynamic interactive graphics visualizations, with or without any programing. This feature is an extremely useful in flow system analysis in hydrogeology practice, but also for groundwater teaching and learning process at the graduate and undergraduate levels, where the student can efficiently develop his own models for a wide range of flow systems scenarios. There are presented various spreadsheets for gravitational systems of groundwater flow for simple and complex geology, including analytical and numerical analysis, and forward and inverse particle tracking. An application is included for a site located in the Sabana de Bogotá basin, Colombia, showing the pressure dissipation in a heterogeneous flow system.
Groundwater age simulations in regional scale flow systems and for groundwater protection in discretely-fractured porous rock

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Keywords: groundwater age, fractured rock, numerical modelling, regional flow

A three-dimensional numerical finite element model is applied to simulate mean groundwater age distributions in regionally complex steady-state groundwater flow systems. The approach considers advective-dispersive age transport from recharge zones which includes natural mixing of different age waters through hydrodynamic dispersion. Age distributions are shown for different conceptual models in the context of regional scale flow systems through fractured carbonates and low-permeability shales of Paleozoic age within the Saint Lawrence River basin, Quebec, Canada. The region is of interest for shale gas development where groundwater travel times can be of use in determining natural flow paths and environmental risk from possible short-circuiting of deep methane or saline formation water into shallow water-supply aquifers. Issues including effects of dispersivity on simulated ages are discussed. The approach is also extended to include discretely-fractured media in the context of hydrogeological characterization and groundwater protection zones in fractured (karstic) dolomite in southern Ontario, Canada. The model simulates groundwater life-expectancy distributions surrounding pumping wells which provide a more complete outline of capture zones than advective-based particle tracking.
1. Groundwater flow patterns and hydraulics in karst

Characterizing flow and transport in a fractured and karstic aquifer from a tracer test carried out from a borehole located in its recharge area

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Keywords: karst, injection tracer test, transport, flow dynamic, fractured aquifer

This paper presents the results of a test injection conducted in a borehole in the recharge area of Egino karstic subunit. This subunit is associated with a limestone outcrop of 3.6 km², which is part of the Aizkorri karst unit (Araba, Basque Country). In the recharge area of this subunit, a calcitic dyke is located, whose hydrogeological characterization was approached through two reconnaissance boreholes. Subsequently, the boreholes were used to carry out a tracer test with lithium chloride. Accordingly, 2060 liters of solution were injected in the basal section (60 to 100 m depth) of one of the boreholes (Cantera II), with a head pressure of 10 bar, during a time of 45 min. The passage of the tracer across the second borehole (Cantera I) was recorded by a CTD-Diver device placed at 80 meters deep. The arrival of the tracer cloud was clearly recorded, thus allowing recognizing tracer evolution in this sector of the aquifer, which is essentially of fissured nature. We have also recorded a first tracer restitution at La Lece spring, which is one of the main springs of the subunit, with a typical karstic behavior. After the injection test, the CTD-Diver registers a continuous drainage of water with tracer, at a constant concentration, until the first rains are recorded. At that moment, water level rises and the tracer is washed immediately from the borehole and so from this area of the aquifer. Shortly afterwards, a second tracer restitution curve is registered in the spring, which is more marked than the one corresponding to the injection. Overall, this test allows recognizing and characterizing flow pattern and tracer progress in the recharge area of the aquifer, mainly fractured domain, and in the karst drainage network leading to La Lece spring. The transit times and transport characteristics identified are helpful for developing measures for the management of water quality and protection of karst resources in these environments, in which the flow is integrated into a network controlled by conduits, generating a highly functional convergent flow system.
Water flow system within the Cerna Valley graben structure
(SW of the Southern Carpathians, Romania)

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Keywords: Southern Carpathians, Mesozoic limestones, graben, hydrochemistry

After the Late Cretaceous tectonic collisional stage, the large Getic and Danubian nappe systems, from the SW of the Southern Carpathians, were fragmented by the transtensional-transpressional movements, active during the Late Oligocene-Miocene. These movements led to the complex half-graben structure of the Cerna Valley. The eastern fault of the structure presents an uplifted block with high escarpment, while the western one is a strike-slip master fault, sunken along the valley. The very complex structures and morphology have created an intricate system of channels (water flow-paths), dye-traced with fluorescein. Differences between the tectonic behavior of the granitic basement and the Mesozoic sedimentary cover, led to positive and negative flower structures, identified during our recent studies, on the eastern slope of the valley. These structures have been involved in the groundwater flow, leading to the high flow rates recorded for certain karst springs (Pisetori, Sapte Izvoare Reci, Domogled) and to the low flow rates of several cross creeks. On the western slope of the valley, close to the master fault, the karst aquifer complex, developed within the Mesozoic limestone, is strongly influenced by thermal phenomena. On 25 km, to the south, along the valley, 24 thermal sources (10 wells and 14 springs) have been identified up to the Baile Herculane area. Due to the influence of karst water, the thermal sources show important variations of temperature and chemical composition. Structural and tectonic relationships between the deep-seated, brittle, granitic basement and the limestone cover, capped by Cretaceous argillites, are very important for the dynamics of the thermo-mineral reservoir.
1. Groundwater flow patterns and hydraulics in karst

Groundwater flooding mechanisms in lowland karst:
a case study from Ireland

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Keywords: groundwater flooding, lowland karst, Ireland

The EU Floods Directive requires member states to consider all forms of flood hazard, including those from groundwater sources, in the assessment and management of flood risk. The spatial heterogeneity of groundwater flow, particularly in karst, poses unique difficulties in evaluating likely flood occurrence. Unlike fluvial or coastal flooding, where flooding is concentrated along the river network or coastline, groundwater flooding can occur in a discontinuous manner across a wide geographical area. The groundwater flooding mechanism can also vary depending on local hydrogeological conditions. Groundwater flooding in Ireland occurs primarily on the extensive lowland Carboniferous limestones found in the west of the country. These limestone formations have undergone significant karstification and are characterised by relatively low storage and high transmissivity, a high level of interaction between ground and surface waters, and shallow depth to groundwater. Widespread groundwater flooding occurred in the karstic Gort lowlands during the winter of 2009, causing significant disruption and damage to property and infrastructure. The study presented here investigated groundwater flooding during this period in the context of geological, topographic and groundwater conditions, identifying a range of mechanisms responsible. These included:

- Surcharging of conduit networks into topographic depressions
- Flooding within annually inundated depressions (turloughs) exceeding normal levels
- Epikarstic flooding caused by excess diffuse recharge and consequent rapid rises in the unconfined water table
- Backwater flooding caused by excess point recharge (sinking rivers)
- Groundwater-induced flooding downstream of groundwater resurgences

An understanding of the flood mechanisms in the aquifer systems of the lowlands is of particular importance so that existing flood risks may be reduced or addressed, and that future investigations and management plans may be effectively implemented.
7. Significance of flow system approach

Groundwater flow systems manifestation in the Middle Drâa sub-basin (Morocco)

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Keywords: flow systems, discharge zones, land use, vegetation cover, Drâa River

Considering the active role of groundwater in its interaction with environmental components; an interdisciplinary approach was used to study an eventual discharge zone of intermediate and regional flows, and to assess the potential impacts of this discharged groundwater on other environmental components of the Middle Drâa sub-basin. In this study, the analysis of physical and chemical properties, and isotopic signature in regard to geomorphology, topography, vegetation and soil characterization was made to identify the discharge zones of intermediate and regional flow; also an image processing was made to evaluate land use variation under different climate scenarios. The physical-chemical analyses show the existence of different types of flow, with a general evolution towards alkaline water type (0≤TDS≤9 g/l) in the Middle Drâa oases. The anionic composition shows a variation from bicarbonate to sulphate and vice versa; which suggests an induced vertical component from intermediate or regional flow. According to groundwater isotopic signature, water samples from Precambrian rocks show a residence time between (500-2800 years); with a bicarbonate chemical nature due to the supplement of CO₂ coming from the mantle through faults and fractures. The interactive link between discharged groundwater and vegetation cover was noticed in the proximity of the Middle Drâa oases and in Iriki Lake where a dominant autochthon vegetation cover type represented by phreatophytes (Tamarix sp, Acacia sp) and halophytes within an alkaline soil (Sierozem) were mapped. In the oases, the evaluation of crop conditions where the water-table is shallow (discharge areas), through satellite imagery processing shows a slight difference in crops productivity between humid and dry climate conditions; and reveals the importance of groundwater in saving the ecosystem of the oases. However, the lack of appropriate strategies for present and future water management with a wide-view system approach can led to serious troubles concerning soil use and crops diversity and productivity.
Central concepts of karst hydrology

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Keywords: mass transfer, groundwater discharge, dissolution rate, time

The solutional growth of karst features involves a simple mass transfer, in which the mass removed from the walls of a void equals the mass removed in solution by flowing water. Mass removed = volume × rock density, and mass in solution = discharge × solute concentration. Therefore (e.g., in a solution conduit) the rate of volume increase = discharge × gain in dissolved load × time / rock density. Density is essentially constant, so conduit size depends only on the cumulative values of discharge, dissolution rate, and time. All three are essential, and all are equally important.

Discharge in a conduit depends on catchment area and water balance; and the distribution of water among all solution conduits depends on hydraulic variables and conduit geometry. Dissolution rate varies with rock type, undersaturation, and solution kinetics, the last of which can be determined by laboratory and field measurements. Together, they provide a tool for quantifying the local geomorphic history.

These relationships seem simple, but applying them quantitatively is complex. This requires a finely divided 2- or 3-dimensional grid in which each segment varies in discharge and dissolution rate within each of many small time increments. Computer modelers use this approach to simulate conduit growth; but the results depend on the specific boundary conditions of the model.

It is more challenging to use this concept intuitively to solve real field problems, where the variables are only partly understood. In this case, one must show that the water source, dissolution rate, and available time are all great enough to account for the observed solution features. All three variables are closely linked by a web of interactive processes, all of which can be expressed quantitatively. Whether the goal is to understand what is already known, or to predict the unknown, this approach provides a solid basis for interpreting karst systems.
Functioning of gravitational groundwater flow systems in Mesa Central, Mexico

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Keywords: recharge area, discharge area, geothermometers, soil, vegetation

Reported environmental damage related to groundwater usage (ie. human health, agriculture, among others), has created alert in different Mexican communities. Governments have applied programmes attempting to contribute to the conservation of nature. However, in many cases, these programmes are not based on scientific knowledge on groundwater functioning in the environment; such programmes have contributed to the observed deteriorated environment. All elements in nature are related and depending on each other, groundwater is not an exception. It is an agent in the different processes occurring underground and results in different manifestations at surface. The objective of this study is to propose a definition of the original functioning of the gravitational groundwater flow systems in the Mesa Central area of Mexico to demonstrate the underground hydraulic connection among hydrographical basins through Tertiary volcanic rocks and thus, make an additional contribution to the understanding of the environment dynamics. This is meant to provide insights in the functioning of nature from where the definition of sound conservation programmes might be more adequately proposed. The methodology of investigation applies techniques whose results may be validated independently and be fitting to conditions and processes linking them to each other. The techniques involved were the analyses of: i) surface indicators (soil, vegetation, topographic elevation, lithology); ii) hydrogeochemistry (chemical-water groups definition and calculation of its minimum travelling depth with geothermometers); and iii) path characterization (porosity, hydraulic conductivity). Water extracted by wells in most locations was found to be related to regional and intermediate flows travelling about 50-300 km and 15-100 km, respectively. Recharge and discharge areas are located beyond the surface basin limits.
Hydrodynamic characterization of flows in the vadose zone by direct measurements in karst aquifer

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Keywords: vadose zone, karst, flows organisation

The study of the vadose zone of a karst system needs some access to this part of the aquifer. Speleological access is not sufficient because the major part of the water flows is not humanly enterable drains. The Low-Noise Underground Laboratory of Rustrel-Pays d’Apt (LSBB) is an artificial gallery dug in the vadose zone of the Fontaine de Vaucluse karst aquifer catchment area. It intersects arbitrarily fault networks in depth and then the potential areas of flows through the vadose zone.

50 flow points have been identified from 2004 to 2012. Hydrodynamical variations of 3 perennial and 47 temporary flows have been monitored, under variable climatic conditions. This study of the acquired data shows a good relation between flows and geological structures. An organization of flows with depth and geology is also underlined. Flows seem to concentrate from numerous faults networks to a little number of high discontinuities with increasing depth. Effects of climatic conditions (amount versus intensity of rainfall) on the different type of observed flows are also addressed.
Using tracer tests to assess possible impacts of a new railway line on karst water sources

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Keywords: karst, tracer test, monitoring, Slovenia

Tracer tests are one of the most powerful research methods in karst hydrogeology. As an example, they are indispensable in planning of water quality monitoring in the influence areas of various pollution sources. Additional to obtained practical solutions, the results of tracing give important information for general characterization of groundwater flow paths and assessment of solute transport phenomena.

The route of the planned Koper-Divača railway line in southwestern Slovenia bisects the karst aquifer and runs close to a drinking water source. The area is characterized by an imbricate thrust structure, where bands of Eocene flysch are interspersed among carbonate rock — predominantly limestone of Upper Cretaceous and Palaeocene age. The largest spring in this region is the Rižana spring (mean discharge 4.3 m³/s), which has been used to supply water to the Slovene Littoral since 1935. A considerable part of the railway line will run through tunnels. Its possible impacts on karst waters were assessed by three tracer tests with artificial tracers. In the period from 2001 to 2010 the tracers were injected at various locations along the planned line and into different hydrological zones of the karst aquifer: in the first test into the sinking stream at the northern part of the line; in the second directly on the karst surface at the southern part; and in the third in the middle part into a borehole deeper in the vadose zone when the water table was 160 metres below the surface. Based on the results, the main directions and apparent velocities of groundwater flow toward three main karst springs were defined and the possible impact of the railway on karst waters was assessed. Additionally, based on the comparison of hydrographs and breakthrough curves the influence of different modes and conditions of injection on the groundwater flow and transport of substances soluble in water were studied.
Application of hydraulic methods in the exploration of deep carbonate systems for geothermal purposes

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Keywords: hydraulic methods, geothermal doublets, deep carbonate, fault, fluid potential

Hungary has a geothermal potential that is considered significant even on a global scale, allowing for the effective operation of hydrothermal doublet systems on most of the country's area. The most important challenges of the exploration of deep carbonate systems are: the evaluation of the heterogeneity of the system (faults and structures) and the productivity of wells (the hydraulic behaviour of the structures). The application of hydraulic methods can provide important information about the fluid potential field of the system and indirectly can contribute to better geothermal prognosis. Therefore the aim of the research is to amend the exploration of deep carbonate systems for geothermal purposes by hydraulic methods.

The research area is the surroundings of Gödöllő Hills, East of Budapest, Hungary. It is characterized by Paleogene and Neogene sequence, underlain by the Triassic carbonate basin, and faulted by a characteristic structural element, the Szada normal fault zone, along which a 1000 m shift can be detected. Based on literature studies this is expected to have a decisive effect on the flow field around it, and therefore the exploration of geothermal reservoirs. Understanding the hydraulic behaviour of the structure is of primary importance in the interpretation of the whole of the hydrogeological system and geothermal exploration in the surroundings.

The hydraulic evaluation, based on interpretation of pressure-elevation profiles, hydraulic cross sections and potentiometric maps, has shown that the area is situated primarily above a recharge regime with subhydrostatic or close to hydrostatic pressure patterns. Groundwater flow in the investigated 1200 m depth is predominantly gravity driven flow. From depths below 1400 m, thermal water is extracted with temperatures higher than 60 °C. The research is supported by the NK 101356 OTKA research grant.
Hydrogeological Causes of Water Crisis in Karst and Alluvium aquifers

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Keywords: Karst aquifer, groundwater overdraft, water crisis, minimum hydraulic storage

The Jahrum Aquifer consists of two sub-aquifers: one of 450 km² alluvium and the other being 300 km² of karstic carbonate. The karstic sub-aquifer (KA) consists of high mountains, surrounding the Jahrum alluvium sub-aquifer (JAA). The number of wells in these aquifers have increased from 600 to more than 1400 since 1964, resulting in overexploitation, and consequently, drying the karstic springs and resulting in a decreasing trend on the unit hydrograph. As the water table decreased, the exfoliated wells deepened, especially in karst aquifers down to depths of 350 m. This study aimed to find the water source(s) of over-drafting. The water budget was calculated in both sub-aquifers for a period of 13 years, indicating the total inflow of 119 MCM/year, and an estimated overexploitation of 12.5 MCM/year. A water depth of 6.6 m is enough to store the total annual inflow, while the total stored water in the JAA was 810 MCM before over-exploitation. Therefore, 691 MCM of the water is not part of the active recycled water, which is named the Minimum Hydraulic Storage (MHS) in this study. MHS is the volume of water stored in an aquifer to raise the water table head to a level such that groundwater emerges from remote discharge area(s). The MHS has been the source of overexploitation since 1964. Reduction of the MHS has led to some disadvantages such as drying the karst springs and downstream wells, intensified droughts, higher costs of well equipment and energy. The only remedy for these issues is to recover the MHS. This is possible by closing all the illegal pumping wells, monitoring the discharge of the exploiting wells, enhancing irrigation efficiency, and optimizing the crop patterns. The General Circulation Model predicts precipitation reduction in the Jahrum area in the future, therefore, the water crisis will be intensified if over-exploitation is not remedied.
Sustainable energetic use of karstic/fractured deep aquifers

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Keywords: geothermal doublets, tracer test, production sustainability, district heating

Deep aquifers are nowadays increasingly used for geothermal purposes, often to provide combination of power generation and district heating. It is customary to operate with "doublet" systems (pairs of production/reinjection wells). Their sustainable operation means constant fluid production / temperature over long time periods (decades). It is decisive to know whether the cold reinjected water reaches the production well, and if so when and how it cools. This can be clarified by model calculations.

The geothermal district heating system’s doublet in Riehen (Canton of Basel City, Switzerland) utilizes thermal water from the triassic Upper Muschelkalk aquifer (production well 1.55 km deep, 18 l/s, 64 °C; reinjection well 1.25 km deep, 18 l/s, 20 °C). The district heating system was established in 1992/1993 and subsequently extended into Germany. Early 3D finite element calculations, based on an aquifer model with tight boundaries at two opposite margins, showed the start of significant cooling after about 10 years (Mégel & Rybach 1999). Yet there has never been a decline in the production fluid temperature; also the yield remained constant.

In order to investigate residence time and flow velocity of the thermal water, a tracer test was implemented by inserting the fluorescence dye uranine in the injection well in October 2009 (Schill & Klingler 2010). So far, the tracer did not appear in the production well (production-injection well bottom hole distance: 1 km). This implies that there is ample resupply of thermal water (although the deep flow pattern in space and time remains unclear) and that the system’s capacity is larger than expected. Therefore, the system in now being enhanced in capacity and expanded in outreach to serve more users, both in Switzerland and Germany.
Chemical characterization of biofilms formed in hypogene spring caves of Budapest

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Keywords: cave biofilm, TXRF spectrometry, Mössbauer spectrometry

Due to the high number of chelate forming functional groups (e.g. –COOH, –OH) on the extracellular polymer matrix produced by bacteria, the biofilms can bind dissolved inorganic compounds from the water body. The enrichment factors amount to 10⁴-10⁶ for different elements in case of biofilms formed on natural or artificial substrates located in surface waters (Kröpfl et al 2006, Záray et al 2005).

The goal of the study was to understand the binding of inorganic compounds by biofilm developing in one- or two-component discharge systems (Mádl-Szőnyi and Erőss 2013) in spring caves of Budapest. Biofilm samples were dissolved in a mixture (3:1) of HNO₃ and H₂O₂ at 80 ºC for 2 hours. The undissolved part of the samples was digested in a mixture (3:2) of HNO₃ and HF in microwave oven for 40 minutes at 750 W. The measurements were carried out by an Atomika 8030C TXRF spectrometer applying Mo Kα excitation. The concentration of 23 elements was determined from all digested samples using Ga internal standard. For the identification of iron species in selected biofilm samples, Mössbauer spectrometry was used.

The result of the analysis of the first digestion step characterizes particularly the organic component and the carbonates in the biofilm, while the second one is characteristic of the rest. The concentration of elements in biofilms with different colors originating from the same spring cave and simultaneously their nitric acid soluble part showed considerable differences. This latter indicates the presence of different chemical phases of the elements. On the basis of Mössbauer spectroscopic measurements, different iron species were identified (goethite, hematite, ferrihydrite, siderite). These results are in good agreement with the observation of Sawicki and Brown (1998). The project is financed by OTKA (grant no.: NK101356).
Dense non-aqueous phase liquid contamination in the Northern Guam Lens Aquifer

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Keywords: karst, TCE, PCE, DNAPL, natural attenuation, Guam

The island of Guam in the western pacific draws the majority of its municipal water from a sole source karst aquifer known as the Northern Guam Lens. The chlorinated solvents TCE and PCE have been found in water withdrawn from several wells within this aquifer. As dense non-aqueous phase liquids (DNAPLs) these contaminants have the ability to persist for tens to hundreds of years in the subsurface, potentially impacting the island’s water resources well into the future. In 1996 a Long Term Groundwater Monitoring Program was initiated and in 1998 natural attenuation was selected as the best strategy to remediate TCE and PCE within the aquifer. Data from this program are currently being used to develop a conceptual model of DNAPL movement within the Northern Guam Lens. The effectiveness of the natural attenuation strategy is also being assessed using trend analysis of water quality data collected biannually since the monitoring program began. Preliminary data suggest a possible positive correlation exists between water levels in the wells and PCE/TCE concentrations, as well as a negative correlation between chloride concentrations and PCE/TCE concentrations. Studies are continuing to further define these relationships.
Chloride mass balance to quantify recharge and a long-term wastewater impact on karst groundwater resources in a semi-arid environment

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Keywords: groundwater recharge; chloride mass balance; wastewater; monitoring; Jordan Valley

Karst groundwater resources in semi-arid environments are highly vulnerable to anthropogenic impacts, such as wastewater infiltration, because of the small dilution potential and the rapid transport of dissolved substances in highly permeable conduit systems. In this study, the groundwater resources of the western margin of the Lower Jordan Valley are investigated. The region is characterised by a carbonate aquifer system which is mainly discharged via karst springs. Prominent examples are the large oasis-springs of Jericho which are a source of domestic water since the Stone Age. The recharge area of the carbonate aquifer system exhibits an extensive urbanisation. Many springs display a rising chloride concentration, due to anthropogenic impacts. Long-term records of chloride concentration in spring water are available (ca. 1938–2012). Therefore, it is possible to establish pre-impact chloride concentration values for the eight larger springs in the area. Additionally, 25 uninfluenced smaller springs, located within the recharge area of the aquifer system, are analysed. The natural background chloride concentration in the aquifer system ranges between 20 and 40 mg/l. Together with chloride concentration data for local precipitation, the long-term mean natural groundwater recharge is calculated based on the chloride mass balance method. For the total of 33 spring catchments, the recharge fraction ranges between 25 and 50 percent of the precipitation. The larger values are presumably the result of a higher percentage of focussed recharge. The proportion of wastewater-borne groundwater recharge is quantified by a chloride end member mixing model. The springs exhibit a wastewater-borne recharge fraction of 0–22 percent, calculated for recent samples. The study underlines the value of long-term monitoring, even at a comparatively low time resolution.
Scale effect in hydrostratigraphic classification in siliciclastic and carbonate environment

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Keywords: hydrostratigraphy, permeability, scale effect

Hydrostratigraphic classification is the basis of hydraulic data interpretation and numerical flow simulation studies. Based on Darcy’s Law the hydraulic conductivity of the different layers influences the flow intensities and flow directions in porous and fractured, karstified environments. The scale effect in hydraulic conductivity and porosity values were displayed as a function of the examined sample volume for karstic and porous environment by Király (1975) and Garven (1986). Several approaches are used for characterizing the geological units from hydrostratigraphical point of view. The determined hydrostratigraphical classes, and hereby the applied characterizing methods are always dependent on the scale of the problem. Different studies discussed the issue and it could be concluded that toward regional scale the hydraulic conductivity is increasing for aquitards and decreasing for aquifers. Therefore this question has high importance when we try to understand the regional groundwater flow field for carbonate systems. The present work is intended to display the approach representing the hydrostratigraphic classification in a basin margin area composed of carbonate and siliciclastic sediments as well. The research is supported by MOL Plc.
1. Groundwater flow patterns and hydraulics in karst

Tectonic fabric as the main factor for privileged groundwater pathways, discharge regime and thermal properties within the same karstic system of Vidlic Mt. (Serbia)

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Key words: karst, aquifer, tectonics, discharge, thermal flow

Vidlic Mt. is a border region of Serbia and Bulgaria and part of the Carpathian – Balkanides mountain chain. The karstic aquifer of Vidlic and the connected mountain massif of Stara Planina was formed in well-karstified Mesozoic carbonate rocks. It is the main source for the drinking water supply of about 100000 inhabitants of the two large municipalities, Pirot and Dimitrovgrad.

Carbonate rocks mostly of the Upper Jurassic and Lower Cretaceous ages reach a thickness of over 1000 m. The clastic Upper Cretaceous rocks (sandstones, marlstones) do not regularly conform with Lower Cretaceous. The large thrust in the NW-SE direction represents their contact. The carbonate rocks are also covered by younger Neogene and Quaternary sediments of the Pirot basin and several large karstic springs issuing fresh groundwater are located along the Vidlic foothills. Their cumulative discharge varies from around 200 l/s to over 1500 l/s. Another large spring, the Kavak, is located far away, almost in the middle of the Neogene basin with no limestone outcrop around it. However, the anticline in the basin's paleorelief and regional faults created privileged paths for karstic groundwater flow. The Kavak Spring discharge is very stable. The applied stochastic model confirms that no significant depletion of groundwater reserves is envisaged even under a scenario which implies a reduction of aquifer recharge by some 20 %.

Tectonic movements were particularly intensive at the NW rim of the karstic aquifer with non-carbonate clastic rocks. Overthrusting and faulting in this zone created privileged paths for deeper groundwater circulation. Several smaller springs are located along one of the major faults and their water temperatures range widely from 8-31 °C. Although some traces of post-Cretaceous volcanic activity were also found, the water chemistry shows that the main factor causing increased temperatures is related to tectonics.
Groundwater dynamics of the sinkhole caves and surrounding rock mass.  
Case examples of the Lika region in dinaric karst of Croatia

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Key words: karst aquifer, conduit, sinkhole, water level, temperature

Karst aquifers are generally highly heterogeneous and anisotropic medium composed of conduits, fractures of various hydraulic properties and rock matrix. These hydraulically contrast components of the aquifer are in constant interaction and unsteady state. Main hydrogeological implication of this situation is absence of common water table, which is representative for all aquifer components. Therefore, considerations of groundwater level observed in the boreholes in karst areas in a “classical” hydrogeological sense usually cause erroneous interpretation of groundwater dynamics. Simultaneous groundwater monitoring in active conduits and surrounding fractured rocks provide probably the best possible insight of hydrogeological processes in karst system. Water level and temperature loggers were installed in a few sinkhole caves and adjacent boreholes in the sinking area of the Lika and Gacka lost rivers, situated in Croatian Dinaric karst area. Obtained data provide general characteristics of groundwater dynamics in the upstream part of the karst massif, which separate Lika and Gacka karst poljes from the Adriatic coast. Very pronounced heterogeneity of water level, as well as high level gradients was designated. High water level gradients in conduit systems are probably enabled by prevailing influence of vadose flows, especially during the low water conditions. Overflow occurrences in conduits with vadose streams result in creation of numerous hydraulic discontinuities in the conduit network. During high water conditions, conduit flow often transfers from vadose to phreatic, causing better hydraulic integration of the system. Borehole data show water dynamics characteristic dependant of the rock mass properties. Even near boreholes can show very different water level behavior. Described phenomena result in a great variability of underground water flow characteristics, not only considering different components of aquifer (i.e. conduits, fractures, matrix), but also in adjacent parts of conduit systems.
The gravity-driven flow of the Gran Sasso carbonate aquifer (Central Italy) fine-tuned through hydrochemistry

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Key words: gravity-driven flow, carbonate aquifer, temperature, hydrochemistry, central Italy

The Gran Sasso carbonate mountainous aquifer, emblematic of the Mediterranean domain, is considered a quasi-porous partly karstified medium due to the widespread fracturing. It is characterised by a steady total spring discharge of about 23 m³/s and by more than 60 % of net infiltration starting from an average precipitation of 1200 mm/year. The groundwater flow is mostly gravity-driven sensu Toth (1963). It flows from high-altitude and high-infiltration tectono-karstic areas toward the low-altitude no-flow boundaries. This means that the spring altitudes reflect groundwater flowpaths and thus water-rock interaction (i.e. the mineralisation and T, pH and EC). In the Gran Sasso aquifer, a higher spring altitude corresponds to a shorter groundwater flowpath and vice versa. A longer groundwater flowpath results in a longer water-rock interaction time and thus a higher mineralisation and temperature considering rock as a thermal insulant. Moreover, along regional flowpaths, the effects of seasonal recharge cause also dilution of ions and changes in their concentrations over time.
Groundwater flow pattern in a complex volcanic, carbonate and siliciclastic environment, Tihany Peninsula, Hungary

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Keywords: hierarchically nested flow systems, peninsula, complex environment, paleo-maars

The understanding of groundwater flow systems of areas with complex geological settings have high importance in water supply issues, land use planning or in management of conservation areas. Our study concentrates on a protected area, the Tihany Peninsula surrounded by the Lake Balaton, Hungary. In this area, beside the primary effect of the topography, the geology significantly controls the flow systems: the paleo-maar environment, the variation of siliciclastic and carbonate rock formations, and the tectonic features. The main goals of the study were to understand (1) the groundwater flow pattern in that complex geological framework and (2) to evaluate the connection of the groundwater system with Lake Balaton.

The hydraulic data for the whole peninsula are scarce, therefore 3D numerical modeling (Comsol Multiphysics 4.2a [Comsol Ltd. 2011]) was used to achieve our purposes. In order to build up a model, hydrostratigraphic characterization of the geological formations was required. Indirect geophysical methods were used to determine the geometry of the units, the hydraulic conductivity distribution of the area and structures: radio-magnetotelluric (RMT), audio-magnetotelluric (AMT), VLF resistivity, VLF electromagnetics and gradient methods. Hydraulic conductivities were evaluated by a conversion of the measured resistivity values (after Müller et al. 2008). Based on the detailed geological characterization, the flow systems were simulated during different scenarios. The study revealed: i) a hydraulically continuous subsurface flow field driven by topographic gradients for the area, ii) hierarchically nested flow systems in the whole succession, iii) the barrier role of Pannonian Formations in flow field and the hydraulic behaviour of structures, iv) the diffuse discharge at the edge of the peninsula (lack of springs, there is only one), v) groundwater discharge in the Lake Balaton at the edge of peninsula.
Thermal-karst modeling for an action plan to sustain the water characteristics of Hévíz-lake

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Keywords: thermal, karst, subsurface flow modeling, Hévíz, subsurface water protection

The Hévíz town and its region is one of the most scenic parts of Hungary. Hévíz warm lake has a particular importance in the health and wellness tourism of the region supplying cure for patients and secured income for the local employees and companies. This health and water bottling business can reach 50 billion HUF (~170 M EUR) yearly, which based on the water characteristics (temperature, chemistry, inflow rate) of the lake. The sustainability of the characteristics depend on the several factors as infiltration on the recharge of karst-area, water and heat outcome from the whole karst system, subsurface water pollution, etc. A few factors are independent or partly independent of the human impact, but the majority has direct connection to human activity.

Between 2006 and 2009 a regional karst flow project has been done, organized by Hantken Miksa Found and financed by local water user. The main goal was to establish a water usage protocol for the Water Authorities, which can preserve or improve the quality and quantity of water, to establish the useable water income and a fair share between the water users on the region.

The applied and presented methodology is based on the general scheme of subsurface flow modeling: conceptual model → data gathering → numerical model → simulated data checking and interpretation → feedback. During the modeling several scenarios (water withdrawal schemes, natural recharge, etc) were tested. Using these scenarios we chose the most probable one and tried to fine-tuned it. Using the scenarios, we offer a different discharge zones with maximal withdrawals to the water managing authority to harmonize the problem of sustainable thermal water usage and economical demand. To check the water table and temperature, an extended on-line monitoring system was set-up.
The place and era of the REGFLOW theory’s birth: cause, circumstances, consequences

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Keywords: need, ignorance, diligence, intellectual freedom

The theory of gravity-driven regional groundwater flow [“REGFLOW”] was born on the Canadian Prairies in the early 1960s. Prior to 1957, only five geologists were dedicated to the study of the entire country’s groundwater resources, namely those of The Geological Survey of Canada. As demand rose for water supplies especially on the Prairies, provincial governments initiated groundwater exploration programs and mission-oriented research in the 1950s. The Research Council of Alberta created its own Groundwater Division in 1955. However, due to the scarcity of groundwater professionals, the 10 or 15 early staff comprised geologists, geophysicists, engineers, even a paleontologist, from Canada, Europe and the USA. We were all blissfully ignorant of hydrogeology; we were to learn groundwater on the job! Ignorance of hydrogeology turned out later to be a blessing in disguise. It has prompted questions in a hydrogeologic terra incognita and we had to find our own answers. The combination of natural curiosity, youthful energy, unbridled enthusiasm and due diligence has fostered original thinking, inventions and discoveries, and has thus provided the answers. To boot, our masters were even less informed; by default, we were granted intellectual freedom! All this gave rise tacitly to the birth of an informal but de facto Canadian School of Hydrogeology. The School has started the strand of hydrogeology that dealt with the concept, theory, practical applications and geologic agency of gravitational groundwater flow systems.

The rise in quality and broadening of the scope of groundwater studies was fast. Through the 1960s and ‘70s the main topics of interest were: i) Regional groundwater flow systems; ii) Natural effects of groundwater flow; iii) Buried-valley aquifers, hydrogeological mapping; iv) Recharge-mechanisms and water balance; v) Hydraulic parameters of the rock framework; vi) Groundwater chemistry in flow-systems; vii) Air-photo analysis; viii) Overseas projects. Results were published in leading periodicals soon. What produced them? My view: Genuine interest in the science, dedication to work and, most importantly, freedom and opportunity to think and err. Twelve major contributors to early Canadian hydrogeology were: Charron J, Cherry J, Clissold R, Christiansen E, van Everdingen R, Farvolden R, Freeze A, Linsey A, Meneley W, Meyboom P, Mollard J, Tóth J.
The genesis and circulation of fresh and thermal groundwater flows in the same karstic aquifer – Case examples from the Carpathian karst of eastern Serbia

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Keywords: karstic aquifer, fresh water, thermal flow, genesis, east Serbia

The Carpathian – Balkanides mountain chain is a long orogenic belt belonging to the northern branch of the Alpine system. Mesozoic carbonate rocks cover about 3400 km² of its extension in the eastern part of Serbia. In that region, along with numerous large springs with fresh and cold water there are more than 30 registered springs issuing thermal and subthermal water. At some locations at relatively short distances from karst springs with cold and fresh waters, drainage of thermal and subthermal water also occurs.

Thermal waters have a chemical composition relatively similar to the cold spring water, but considerable differences in their temperature ($\Delta T_{\text{min}} \sim 100 ^\circ C$) indicate a deeper siphonal circulation. Krupajsko vrelo Spring, Sisevac and Krivi Vir Spring are the three springs that have undergone the most detailed investigation in the Kucaj and Beljanica massif.

The karstic aquifer formed in well-karstified carbonate rocks is recharged mainly by rainfall and by sinking flows. These waters percolate deep into the ground. The contact with igneous rocks or overthrusted non-carbonates (Permian sandstones) causes longer residence time, and variation in chemical composition and water temperature as well. In order to define infiltration intensity, mean residence time and the character of mixing warmer and cold water, isotopic and chemical analyses have been made. In an attempt to reconstruct the genesis of superimposed flows that drain karstic aquifer, the results of these analyses will be presented in the following extended abstract.
Anthropogenically modulated hydrological changes recorded by a ~120 years old flowstone-like travertine (Rudas Spa, Budapest, Hungary)

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Keywords: recent travertine, thermal water, petrography, anthropogenic influence, Buda Thermal Karst

A small travertine-buildup formed in one of the historic spas of Budapest was studied to reveal the relationship between geometry, surface morphology and internal structure of the precipitate and eventual natural or anthropogenic changes of the chemistry and temperature of the thermal-spring(s) feeding the spa.  
Geometry of the flowstone was found to follow the geometry of the inflow channel and the underlying stone support, however, with remarkable anomalies. On the central part of the overall convex buildup a red-stained groove has developed suggesting dissolution rather than precipitation.  
Diamond coring revealed that the interior of the flowstone is built up by alternating light coloured porous and dark-coloured, greyish “micritic” laminae, the frequency thickness and regularity of which show substantial changes along the core. Petrography, mineralogy and geochemistry of the core were studied and basic hydrogeochemical parameters of the thermal water were measured. Also waterlevel changes of the nearby river, and changes of the level of the spring(s) were monitored.  
Evaluation of the observed textural features suggests that geometry, structure, texture and isotope geochemistry of the Rudas travertine are the results of interaction of natural and anthropogenic processes. Geometry and surface morphology reflect the self-regulating nature of the system. Fine seasonal lamination is supposed to be the result of temperature changes brought about by the hydrostatic effect of the river. Decade-scale variations reflect major technical changes of water supply recorded as changes of growth rate and isotope geochemistry. Imprints of daily scale technical changes could not be deciphered from the precipitate at the resolution of this study.  
The red-stained groove of the central part of the buildup is supposed to be the result of ferrolysis promoted by oxygenation and hydrolysis of dissolved Fe²⁺ species of the water. Financial support was provided by OTKA 72590K.
**Study of a flowstone type speleothem from the hypogene Pálvölgy Cave System (Budapest, Hungary)**

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Keywords: speleothem, hypogene karst, Pálvölgy Cave System, Buda Thermal Karst

Buda Thermal Karst is built up by Mesozoic/Tertiary carbonate rocks. Since Late Miocene times the area has been subject to tectonically controlled uplift and erosion. The created topography resulted in the establishment of a regional groundwater circulation system the regional discharge area of which is now situated within the town of Budapest at the level of the river Danube. Hypogene caves developed as a result of mixing of groundwaters of various origin in the vicinity of discharge points. Because of Pleistocene to Recent uplift of the Buda Hills, these caves have shifted into the vadose zone and are now subject to “degradation” i.e. gradual fill-up mainly by speleothems. A still active flowstone was selected for detailed study with the aim of disclosing mineralogical textural and geochemical documents of the phreatic/vadose transition i.e. the change from cave formation to cave degradation. Discontinuities and growth rate changes were expected to be potentially informative regarding the infiltration history of the degradation phase.

Diamond-coring revealed that the internal structure of the flowstone reflects, indeed, changing conditions of growth. Also a phase of corrosion preceding precipitation was discovered at the contact with the host rock. Combination of the results of petrography, stable isotope geochemistry and U/Th and ¹⁴C dating permitted to distinguish a first stage of supposedly phreatic calcite precipitation at about 200 ky BP followed with a considerable time-gap (from ~50 ky BP on) by laminated flowstone proper precipitated under vadose conditions. Changing thickness of the laminae and several internal discontinuities suggest that both the rate of infiltration and possibly the influence of non-carbonate impurities originating in the overlying soil zone have changed throughout the last 50 ky and controlled the rate of growth of the speleothem.

Financial support was provided by OTKA 72590K.
Unusual speleothems from a non-spelean environment  
– Mineral precipitates of the Széchenyi Spa  
(Buda Thermal Karst, Budapest, Hungary)

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Keywords: speleothem, hypogene karst, thermal water, Széchenyi Spa, Buda Thermal Karst

Széchenyi Spa receives its water-supply from the Városliget-II water well tapping the deep karstic reservoir of the Buda Hills. The yield of the well is 379,5 l/min, temperature: 76 °C, TDS: 1774,5 mg/l. From the well-head water is conducted through 200 mm diameter pipes into cylindric storage tanks from where it is conveyed to the users, according to actual demand. Flow velocity decreases in the tanks and as a result of the sudden pressure drop CO₂ escapes and dissolved solids precipitate. In 2012 as cleaning of the storage tanks became necessary we had the opportunity to descend into one of the empty tanks to investigate the unusually rich, spectacular mineralization on site. Samples were taken and afterwards analysed in the laboratory (optical and CL-microscopy, XRD, SEM, isotope-geochemistry).

The bulk of the precipitate was formed at the bottom and along the lower reaches of the walls of the tank under phreatic conditions. It proved to be low-Mg calcite, forming loose microlsparry „aggregates” the outer surface of which was „encased” by coarse-grained sparry crystals. In the latter, occasionally, fine aragonite-needles could be detected as inclusions. Along the walls of the tank white gypsum crusts of micro-terraced surfaces were also observed. The upper part of the tank, where - as a result of water-level fluctuations - conditions repeatedly changed from phreatic to vadose, varicoloured Fe-Mn oxide crusts developed suggesting that divalent Fe and Mn dissolved in the deep thermal water became oxidized and precipitated on contact with atmospheric oxygen. Abundant vertical dissolutional grooves occurring in this redox zone point to ferrolysis in action accompanying the hydrolysis of these cations.

Macro- and micromorphology and mineralogy of the precipitates and the chemistry and temperature of the thermal water is compared to speleothems known from Pleistocene to Recent caves of the Buda Thermal Karst.

Financial support was provided by OTKA 72590K.
Miocene limestone hydrogeothermal system in Belgrade urban area, Serbia

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Key words: hydrogeothermal resources, Miocene limestone, energy potential, sustainable use

The largest energy consumption, at the world level, is recorded in the field of construction. Almost half of energy needs is related to heating, cooling and lighting in facilities. Belgrade with its population of 2 million falls into European metropolises with constantly increasing energy needs. The growth of energy needs has a negative impact on both the city budget and the quality of the living environment. The sustainable urban development management, certainly, implies the utilisation of renewable energy sources.

The available thermal energy from hydrogeothermal resources formed in limestone of Miocene age at the inner territory of the city is around 30 MW. This energy amount is sufficient for the residential heating of 12 % of the population in the inner-city core in the energy inefficient facilities (the consumption of about 120 W/m²), namely for the residential heating of 25 % of the population in the energy efficient facilities (the consumption of about 60 W/m²).

The temperature of groundwater formed in limestone of Tortonian and Sarmatian age ranges from 17 °C to 24 °C. The average yield per a well amounts 5 l/s, while the average depth of the wells does not exceed 100 m. The utilisation of hydrogeothermal energy is conditioned by the use of heat pumps. Conditions of the exploitation and disposal of hydrogeothermal energy for the heating and cooling of facilities in urban parts of the terrain (the average population density in the study area is 10000 inhabitants per square kilometre) are specific exactly due to limitations of available surfaces.
Modeling of regional groundwater flow and transport in Jinan karst water system, China

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Keywords: Jinan, karst water, groundwater modeling, groundwater quality, FEFLOW

Jinan is a famous city in China with a nickname “City of Springs”, because of the many springs in its downtown and surroundings. But some of the springs dried up in the past decades and the water quality of many springs has been gradually deteriorating since the 1980s with increasing human activities in the region. In order to comprehensively analyze regional groundwater flow and water quality evolution and to create better schemes for efficient management of groundwater quantity and quality in the region, an equivalent porous media model was established to simulate flow and transport in Jinan karst water system using FEFLOW, a finite element simulator. The coupled model of groundwater flow and transport were calibrated and verified according to the long-term monitoring data of rainfall, groundwater levels, groundwater abstraction, spring discharges and groundwater quality. The verified model was used to predict the trend of groundwater quality evolution under different pollution scenarios in next 5 years, which would provide significant information for groundwater protection. The simulated results indicated that karst water quality in Jinan eastern suburb and urban areas would be continuously getting worse but least influenced in western suburb under the present conditions, and karst water quality distributions would be basically unchanged after 5 years in the case of pollutants decreasing by 10% annually. Furthermore, measures to keep the springs flowing and protect groundwater quality were outlined.
An analytical study on stagnation points in drainage basins with injection/pumping wells

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Keywords: drainage basin, flow system, stagnation point, injection/pumping well, release/capture zone

In drainage basins, undulation of water table would result in nested flow systems and stagnation points. However, there are few, if any, studies that account for the impact of injection/pumping on hierarchical basin-scale groundwater flow. In this study, an analytical solution of hydraulic head is derived for an anisotropic drainage basin with injection/pumping horizontal wells. We find that the distribution of hydraulic head is the superposition of the hydraulic head induced by undulating water table only and the one induced by injection/pumping only. In the hypothetical case study, the regional undulation of the water table has a wavelength of $2L$ and the local undulation has a wavelength of $2L/3$, where $L$ is width of the drainage basin. Due to the undulation of water table, there are two stagnation points at the basin bottom and one internal stagnation point inside the basin. As a result of injection/pumping of one well, a new internal stagnation point develops. By tracing dividing streamlines around internal stagnation points, different flow systems (including release/capture zones) are accurately delineated. We also find that internal stagnation points and distribution of flow systems are sensitive to locations of wells, injection/pumping rates and permeability anisotropy. According to the principle of superposition, $n$ well will lead to up to $n$ new internal stagnation points and up to $2n$ new flow systems. The results of this study would lead to a more comprehensive understanding on the pattern of hierarchical groundwater flow in drainage basins with human activities.
Confluence of regional ground water flow systems in karst at Pine Point Mines’ lead zinc ore deposits

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Keywords: MVT, lead-zinc, Pine Point, karst, groundwater flow systems

The genesis of MVT ore deposits, like those at Pine Point Mines in Canada, has been the subject of debate for many years. When, in 1975, mining of ore at open pit R-61 was unexpectedly hampered by rising groundwater, a joint four year investigation was started by Cominco Ltd. (the owner of the Pine Point Mines) and the Hydrology Research Division of Environment Canada.

It turned out that several karstic flow systems with differing chemistry do presently meet at the location of the ore bodies. While some of the flow systems are dominated by sulphur chemistry, a deep flow system penetrates upward from beneath and is dominated by NaCl chemistry. By the example of dewatering the W-17 pit we show that these flow systems meet at ore bodies. At the ore body A-55, igneous rocks of the nearby Canadian Shield were found in the centre of the ore body. This find indicates an effect of the Laurentide ice sheet on the A-55 ore body and by implication also on others. There have been different explanations provided in the literature, all related to the karstic nature of the rock and the position of all ore bodies within karstic features.

At Pine Point groundwater flow within the karst is very pronounced. In fact the mine eventually closed because of dewatering problems. The amount of flow exceeded 3 m$^3$/s at some ore bodies and thereby made mining uneconomical.

After the abandonment of the mine groundwater flow systems reverted close to their original state. Presently part of the area of Pine Point Mines is again a discharge area with artesian boreholes. At pit X-15 one of these boreholes discharges sulphur dominated water, another one nearby discharges black water containing metal sulphides. This would indicate that today’s groundwater flow systems may replicate the situation which led to the genesis of the Pine Point MVT ore bodies. The temperature of the discharging groundwater is about 3 °C. In the area of the ore bodies SO$_4$ is reduced by bacteria to HS$^-$ and H$_2$S.
Reconstruction of multi-stage groundwater flow systems in Hebei Plain, China

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Keywords: groundwater flow systems, multi-stage, reconstruction, Hebei Plain

Hebei Plain is a part of North China Plain and can be divided into piedmont plain in the west, central alluvial and lacustrine plain and coastal plain in the east. Total thickness of the Quaternary ranges from 200 to over 500 m. Based on historical analysis of regional geography and geology, with confirmed evidence from environmental isotopes and succeeding change of continental saline water, it is found that the groundwater flow systems in the Quaternary of Hebei Plain have undergone three major evolution stages since the last glacial maximum (LGM). In the first stage of 18-15 ka BP, the low sea level made the topographic potential difference strong enough to drive groundwater to circulate to the base of the Quaternary system and flow from mountains to the sea, and the regional flow system developed. Recharge from abundant rainfall almost fully replaced the original water in the Quaternary aquifers. In the second stage of 15-12 ka BP, sea level sharply rose, resulting in weak driving force of the flow system, the early intermediate flow systems penetrating to the third aquifer, which was superimposed on the previous regional system, were developed. The regional flow system formed in first stage became stagnant as the flow driven force evidently was weakened. In the third stage of 2.5 ka BP to the present, sea level rose to the present elevation and the recent fluvial morphology were formed. The potential differences between high river beds and low river beds or depressions became a dominated flow driven force, so that the late intermediate flow systems penetrated to the first and second aquifers and was superimposed on the early intermediate flow systems. For all of the three stages, the local flow system has been developing in the piedmont plain because the flow driven force here is controlled by low permeability barrier but not the sea level, thus, the penetrating depth of succeeded flow system is the same as the previous system and the succeeded system always replaces the previous system since LGM.
**Tóthian theory is the paradigm of modern hydrogeology**

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Keywords: Tóthian theory, regional groundwater flow, geological agent, modern hydrogeology, paradigm

Darcy’s law is the foundation of hydrogeology. Tóthian theory provides a new framework for modern hydrogeology. Tóth revealed the complex structure of groundwater flow in the early 1960s: hierarchically nested groundwater flow system even in a homogeneous and isotropic basin. It is a kind of self-organized organism, a temporal and spatial assemblage of flowing groundwater and groundwater flow pattern always follow minimum energy expenditure principle. Another breakthrough of Tóthian theory is to elucidate that groundwater is a geological agent. Tóthian theory provides the basis to interpret or solve various groundwater related phenomena or problems such as soil salinization, vegetation types, groundwater-dependent eco-environment system, stability of building foundations and slopes, geothermal energy and pollutions, migration and accumulation of hydrocarbons and other ores, waste disposal, and so on. The theory systematizes flow, chemical, thermal and microbial fields into a cohesive whole. By integrating the processes, effects and manifestations of moving groundwater, a panorama of ordered spatial and temporal distributions of mutual interactions among different parts of groundwater and its environment has been constructed. It provides a basis for planning and managing water resources and eco-environment which can satisfy the demands of modern hydrogeology. Tóthian theory revealed that groundwater is a general geological agent. Therefore, it becomes a powerful tool to understand the mechanism of a series of processes on and in the earth and triggered the transformation of hydrogeology from a single applied discipline to a fundamental of earth system science. Different from traditional hydrogeology based on Darcy’s law which is the product of observation and experience, Tóthian theory is the fruit of hypothesis deductive approach. Introduction of the powerful scientific approach into hydrogeology, Tóthian theory offers the possibility for hydrogeology to be a leading discipline of the earth science.

Although Tóthian theory has been accepted by hydrogeologists from different countries and successfully used to solve problems in many fields, its potential is still underestimated by the international community of hydrogeology and geology. We are confident that Tóthian theory is the paradigm of modern hydrogeology and no force can block such an irresistible trend.
Comparative analysis of some parametric methods used to assess the karst groundwater vulnerability
– Case example of the Tara Mt. in Western Serbia

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Key words: groundwater vulnerability, karst groundwater, EPIK, sensitivity analysis, Tara Mountain

Methods for assessing the vulnerability of groundwater are increasingly used to determine the areas that are most vulnerable and where the preventive measures are most needed. When it comes to the karst aquifer, because of its specificity, numerous methods have been developed and are still being developed. Parametric methods are frequently used, and each of these methods considers different set of input parameters which are ranked variously. Consequently, as a result of the application of different methods, we have obtained maps of vulnerability, which differ significantly in terms of ranking, i.e. the degree of vulnerability. Moreover it is very difficult to single out a method that gives the most accurate results for karst groundwater vulnerability of certain area. When it comes to a certain method, the problem of compliance differences obtained on the maps can be overcome by using sensitivity analysis. It is necessary to bear in mind that even if the applied methods are called parametric methods, they are statistically non-parametric. For these reasons it is necessary to harmonize the intervals of some parameters with care. On the example of the application of three different methods (EPIK, PI and COP) on the Tara Mountain in western Serbia, the differences in the applied approaches were illustrated, and suggested their adjustments in accordance to the general characteristic of the area.
Multipurpose system of hydropower plants on the river Trebisnjica

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Keywords: karst region, Trebisnjica river, karst poljes, system of HPPs

In the hydrological and hydrogeological respect, The Trebisnjica river basin is one of the most interesting area in the Dinaric karst. The main characteristic of the water system in this area is abundance of water in Fall-Winter seasons and the total lack of it during vegetation period. Water as a natural resource is of special interest bearing in mind that the typical karst region of Eastern Herzegovina (The Republic of Srpska, Bosnia and Herzegovina) is one of the richest in the rainfalls in Europe.

The main criteria applied in creating the concept for the utilization of waters in the wider Trebisnjica river basin was to preserve water as long as possible on the surface in order to enable its consumption, where the greatest water quantities would be held and leaved in the reservoirs, and lead by the shortest way to the cascadely disposed plants and other users of water. All the waters from the karst poljes of Nevesinje (1000 meters above sea level), Gacko, Dabar and Fatnica, brought to a reservoir „Bileća“ could be energy utilized to the sea level, over the existing hydro power plants of HPP Trebinje I, HPP Trebinje II, HPP Dubrovnik and PSHP Čapljina.

The adopted conception of building of multipurpose system with seven hydropower plants and six reservoirs will provide a maximum effects of Hydrosystem Trebisnjica with its part „Upper Horizons“ – water for water supply, hydroenergy, agriculture, tourism.
Ice-breaker Party
Tuesday, 3 September 2013

All participants are invited to attend the Welcome Reception which will take place at the congress venue, at Eötvös Loránd University at 18:00 and is included in your registration fee. This will be an excellent opportunity to network, meet old friends and colleagues, and to make new ones as the Programme begins. This will also be the opportunity to meet the local organizing committee.
Spa program
Thursday, 5 September 2013

Please, join us to the spa program after the sessions and have some rest. We will visit the famous Széchenyi Thermal Bath which is one of the largest spa complexes in Europe and is also the first ever thermal bath of Pest.

Joint departure with public transportation at 18.30 from the registration desk.

Event sponsor:

Budapest Spas cPlc.
Gala dinner in honour of Professor József Tóth

Friday, 6 September 2013

The "International Symposium on Hierarchical Flow Systems in Karst Regions" will honour Professor József Tóth, in celebration of his 80th birthday. So the gala dinner will be dedicated to celebrate his birthday.

It will be held: at 19:00 on Friday, 6 September 2013
in the Paulay Event Hall
1061 Budapest, Paulay Ede str. 9.

Departure by bus from the Danube entrance of the venue at 18:20.
After the dinner, bus transfer will be provided back to the official symposium hotels at about 22:00.

Event sponsors:

MOL Plc.  Békés Drén Ltd.  BGT Hungaria Ltd.
Closing ceremony & Farewell dinner
Saturday, 7 September 2013

All participants are invited to attend the Farewell dinner on Saturday, 7 September where you can say goodbye to new friends after the field trip. This program will be held after the official field trip as a boat ride on the Danube river on board of *Raham.*
Hydrogeological characterisation of the Gellért Hill and Rózsadomb area

Introduction to the field trip in the Buda Thermal Karst area

Anita Erőss, Judit Mád-Szőnyi, Andrea Mindszenty, Szabolcs Leél-Őssy

Schedule of the field trip:

8:30-9:30 Anita Erőss & Judit Mád-Szőnyi: Introduction to the fieldtrip: characteristics of the two sub-systems within the Buda Thermal Karst
ELTE 0.823 lecture room

9:45- Departure of the buses

10:00-13:00 The South System: discharging waters and caves of the Gellért Hill area

Stop 1 Look-out point on the Gellért Hill
Stop 2 Ösforrás (Spring of the Gellért Spa), Gellért Tunnel
Stop 3 Aragonite Cave
Stop 4 Török Spring

13:00-14:00 Stop 5 Pálvölgy quarry: picnic lunch

14:00-17:30 The North System: discharging waters and caves of the Rózsadomb area

Stop 6 Szemlőhegy Cave
Stop 7 Malom Lake
Stop 8 Molnár János Cave
Stop 9 Springs and wells of the Lukács Spa

18:00-22:00 Boat trip on the Danube with farewell dinner

For the location of field stops please refer Fig. 1.
Fig. 1.: Location map of field stops

**Stop 1** Look-out point on the Gellért Hill; **Stop 2** Ösforrás (Spring of the Gellért Spa); **Stop 3** Gellért Tunnel and the Aragonite Cave; **Stop 4** Török Spring; **Stop 5** Párvölgy quarry; picnic lunch; **Stop 6** Szemlő-hegy Cave; **Stop 7** Malom Lake; **Stop 8** Molnár János Cave; **Stop 9** Springs and wells of the Lukács Spa
1. The hydrogeological environment of the Buda Thermal Karst area

1.1. Geological settings

Geologically, the Buda Thermal Karst system (BTK) is the NE extreme of the Transdanubian Central Range (TCR) (Fig. 2) located in the central part of the Pannonian Basin (PB). The Pannonian Basin is a Neogene structure formed as a result of extension-related attenuation of the lithosphere in late Early to Late Miocene times (Royden and Horváth, 1988). In the latest Miocene, inversion of the basin began and contributed to the uplift of certain basement-blocks. The TCR is one of these uplifted blocks. Due to the thin lithosphere, the whole Basin is characterised, even now, by elevated heat flux (~100 mW/m²) as compared to the surrounding regions (Lenkey et al., 2002).

Geological boundaries of the TCR are tectonic lines, namely: Rába Line in the NW, Diósjenő Line in the N and Balaton Line in the S. The exact location of the E-NE boundary is disputed, as yet. The Mesozoic carbonate suite of the TCR is downfaulted and continues deep in the basin to the East of the Danube, under a thick Neogene cover. The basement of the BTK is not known, but like in the whole TCR, Permian siliciclastics and shallow marine evaporitic carbonates are hypothesized also here (Majoros, 1980; Haas et al., 1989).

Fig. 2.: Tectonic boundaries and distribution of Paleozoic-Mesozoic formations of the TCR and the location of the BTK within it (after Fülöp et al., 1987 in Haas, 2001). The main discharge areas in Budapest: a: northern discharge area, b: Rózsadomb discharge area, c: Gellért Hill discharge area
Fig. 3 illustrates the schematic stratigraphic column of the Buda Hills. The oldest known strata in the BTK area are Triassic (Ladinian to Norian) platform carbonates (dolomites and limestones) that constitute the bulk of the area with a thickness of 1500-1800 m (Wein, 1977; Haas, 1988). During this time the TCR was part of the shelf of Neotethys located between the South Alpine and East Alpine Units (Haas et al., 1995). Jurassic and Cretaceous sediments are missing in the BTK area, however, since from the Early Jurassic to Mid-Cretaceous sedimentation had been continuous all over the TCR, it is supposed that these strata were present also in the BTK area, but were removed by subsequent erosion. Triassic carbonates are separated from the overlying Eocene strata by a long-lasting period of tectonically controlled subaerial exposure that spanned probably from Late Cretaceous to Late Eocene (Wein, 1977). The Palaeogene transgressional sequence starts with basal conglomerate and breccia, with erosional remnants of a once continuous bauxitic blanket at its base. This is overlain by Upper Eocene to Lower Oligocene limestone, marls and clays. From the Mid-Eocene to Mid-Miocene times to different depositional environments have developed in the Buda Hills. The dividing line between the two, the Buda Line, was an important paleogeographic boundary (Báldi and Nagymarosy, 1976), interpreted as a paleotopographic high formed above a blind thrust according to Fodor et al. (1994). SE of this antiform sedimentation continued in the pelagic marly-clayey facies from Late Eocene well into the Oligocene with extensive deposits of the Buda Marl, the anoxic Tard Clay and several hundreds of meters of the Kiscell Clay (Báldi et al., 1976; Báldi, 1983). The area NW of the Buda Line became subaerially exposed in latest Eocene earliest Oligocene times. Sedimentation over the eroded surface of Mesozoic and earlier Tertiary formations resumed still within the Early Oligocene with coarse-grained coastal siliciclastics (Hárshegy Sandstone Formation).

Fine-grained sand and silt deposition took place during the Late Oligocene. The area was gradually uplifted along NW-SE oriented normal faults, and became subaerially exposed again by the end of the Oligocene and Early Miocene. From the Miocene on the sedimentation of the area is associated with the evolution of the Pannonian Basin. Along the margins of the Buda Hills “island” coastal and shallow marine siliciclastics and also carbonate sediments were deposited, while the uplifting interior became subject to erosion. Since the basal strata of the shallow marine Neogene sediments around
the Buda Hills do not contain any clasts from either the Triassic or the Eocene carbonates, it is assumed that at this time, these carbonates were still covered by thick Oligocene clays (Wein, 1977).

From the latest Miocene on the deposition of lacustrine limestones and travertines began and continued with changing intensity up to Recent times. They were tentatively associated with thermal waters discharging along the foothills of the uplifting terrains as already suggested by Schréter (1912). Later on, detailed geomorphological, sedimentological, biostratigraphical and geochemical studies by Scheuer and Schweitzer (1988), Müller and Magyar (2008), Korpás (2003), Kele (2009) and many others proved that the early idea of Schréter was right. According to recent results of Kele (2009), travertine formation was most intense in the Middle Pleistocene, suggesting that deep, regional-scale water circulation was already active at that time. However, his latest U/Th datings show that from Late Pleistocene to Holocene times there was no appreciable travertine deposition in the Buda Hills. In order to improve our understanding of the Pleistocene uplift history of the area Szanyi et al. (2012) tried to calculate the uplift rate by speleotheme dating in several former thermal caves. Based on U/Th dated cave rafts they suggest that from 500 to 280 ka BP the area was characterized...
by rather slow uplift (0.06-0.3 mm/y), however, in the 280-70 ka interval this had been accelerated to 0.16 mm/y on the average.

Focussing on karst features it has to be pointed out, that all the Late Triassic to Early Tertiary formations of the Buda Hills are carbonates, highly prone to karstification (Fig. 3). In addition to the limestones and dolomites, the calcareous Buda Marl with its rather high carbonate content (50-80 %; Kleb, 1993) also belongs to the karstic category that is evidenced by the presence of cave passages in it (Leél-Őssy, 1995, Leél-Őssy et al., 2011).

As we have seen above, there were four major tectonic phases to affect the carbonate succession of the study area (Fodor et al., 1994): during the Cretaceous, compressional tectonics was predominant, due to the SE-NW compression, anticlines (with folds and smaller thrusts) and the rigid dolomites became fractured (Wein, 1977). From the Late Eocene to the Early Miocene the area was intermittently affected by large scale strike-slip activity (WNW-ESE directed compression and perpendicular tension). The stress field changed in the Middle Miocene, and until the Quaternary new N-S to NE-SW trending normal faults were formed by ESE-WNW extension. Pleistocene tectonics is characterized by N-S (NE-SW) extension and perpendicular compression.

Due to the complex tectonic evolution of the area, the generated fractures, faults and folds play crucial role in canalizing groundwater flow, and controlling dissolution and precipitation processes.

1.2. Flow regime

The lithological continuity of the Triassic carbonate suite provides for the hydraulic continuity of the large groundwater body of the TCR, which was evidenced by the long-lasting regional dewatering activity related to underground mines in the area. This two-decades long active dewatering may be considered as a long-term pumping-test, which suggested that in this system hydraulic continuity exists, indeed (Mádl-Szőnyi, 1996). Precise delineation of the BTK system in the hydraulic sense is, therefore difficult within this more than 200 km long and about 70 km wide body of the TCR. Because the aquifer system of the TCR is characterized mainly by gravity driven ground-
water flow (Alföldi, 1979), the topographic elevation was taken into account when delineating the surface catchment area of BTK by Mindszenty and Mádl-Szőnyi (1999) (Fig. 4).

![Fig. 4: The morphologically delineated closest recharge area (black line) of the Buda Thermal Karst (after Mindszenty and Mádl-Szőnyi, 1999)](image)

This delineated surface catchment area includes areas also to the East of the Danube, where the exposed Mesozoic carbonate hills and topographically elevated non-carbonate areas (Gödöllő Hills) possibly contribute to the recharge of the Buda Thermal Karst. This contribution has not been formerly investigated. The delineated area by Mindszenty and Mádl-Szőnyi (1999) designates the inner (closest) recharge area of the BTK System. The regional recharge area of thermal waters, which are the source of the discharging waters of the regional flow systems, however, could be found farther on the TCR. The bare karstic surfaces represent 15% of the whole TCR (Lorberer, 1986).
Based on recent hydrogeological studies the new conceptual model of the BTK system is illustrated on Fig. 5.

As a new result the investigations confirmed the contribution of basinal fluids to the BTK fluid system, which is responsible for the Na\(^+\), Cl\(^-\), free CO\(_2\), S\(^2\)- and H\(_2\)SiO\(_3\) content of the BTK waters. The connection is facilitated by high permeability regional structural zones.

The evolution of the BTK started in the late Mid-Miocene with the uplift of the “Buda” part and subsidence of the “Pest” part. Contemporaneously with accelerating uplift, also the erosion of the siliciclastic cover of the Mesozoic-Tertiary carbonate suite accelerated.

During the uplift and erosion, the dominance of the system components and fluids were changed. Firstly, the karstic part had minor role and the basinal fluids were prevalent. The vein-filling paragenesis associated with these fluids is characterized by barite and accessory fluorite (Poros et al., 2012). The driving force for fluid migration was supposedly provided by tectonic compression based on analogues from the Great Hungarian Plain (Mádl-Szőnyi and Tóth, 2009). Direct volcanic contribution to the hydrothermal fluids could not be confirmed. Instead, the elevated heat flux related to
the attenuated lithosphere of the Pannonian Basin was suggested as the heat source of the thermal fluids (Poros et al., 2012). With progressing uplift and erosion the area of exposed carbonates increased and provided increasing direct recharge to the system. This resulted in increasing proportion of karst water at the expense of basinal fluids. Uplift resulted in growing hydraulic potential, i.e. in continuously strengthened gravitational driving force. As the recharge area of the gravitationally driven (karstic) flow system increased, the karstic component became more and more dominant in the system. This is reflected by the increasing occurrence of carbonate mineral precipitates. However the basinal fluid component is still present. Today we can see a “snap-shot” of this transient system.

2. Gellért Hill Area

Stop 1 Look-out point on the Gellért Hill

2.1 Geological build-up of the Gellért Hill

The Gellért Hill (235 m asl) is situated right on the riverside (Fig. 1). It is an almost bare karst area, bordered by tectonic lines and characterized by steep slopes - almost vertical cliffs (Fig. 6).

The bulk of Gellért Hill is built up by Upper Triassic dolomite (Fig. 6) which contains organic-rich marl and clay-marl intercalations. It is unconformably overlain by a Late Eocene transgression sequence beginning with cherty basal conglomerates, breccia or sandstone. The marly matrix of the basal clastics increases upwards and very soon it gives way to the Buda Marl, with sandstone and nummulitic limestone intercalations. The Buda Marl is covered by shallow bathyal clays (Oligocene Tard- and Kiscell Clay) and then by sandstones (Upper Oligocene Törökbálint Sandstone). The Quaternary is represented by travertines, loess, slope scree, fluvial gravel and sand (Korpás et al., 2002). Fig. 7 shows the schematic stratigraphic column of the Gellért Hill area. The geological map on Fig. 6 clearly shows that this area was also highly influenced by tectonics. Three Tertiary stress fields could be identified, and one Triassic event is also supposed. The Tertiary stress fields characterize four deformational events. The oldest, NNE-SSW tension created the E-W trending “Citadella fault”. Due to its dextral normal synsedimentary motion, the SE part of the hill subsided ca. 100 m. The fault de-
formed then the only partly consolidated sediments and induced various soft-sediment deformation features (creeps, slidings, etc) within the Upper Eocene-lowermost Oligocene clastics.

Fig. 6.: Location of the springs at the Gellért Hill discharge zone (geological map is based on Fodor in Korpás et al., 2002).
Faulting resulted in steeply dipping sedimentary dykes with sandy marl and limestone fillings. Most of the dykes and the marl itself were silicified presumably due to hydrothermal fluid circulation along the main fault. After the Early Oligocene, the western segment of the “Citadella fault” was reactivated and connected to another dextral normal fault south of the Gellért Hill. The Ottnangian-Middle Miocene phase induced a large normal slip on the north-eastern boundary fault of the Gellért Hill. The fault crosses the Danube branching to several fault strands. This fault represents the eastern boundary fault of the whole Buda Hills and might have accumulated up to 1000 m separation. The fault was reactivated during the Late Miocene to Quaternary due to ESE-WNW tension.

Fig. 7.: Schematic stratigraphic column of the Gellért-hegy area (modified after Korpás et al., 2002) (Tr: Triassic, E: Eocene, O: Oligocene, Q: Quaternary; 1: Main Dolomite, 2: Basal breccia and conglomerate, 3: Szépvölgy Limestone, 4: Buda Marl, 5: Tard Clay, 6: Kisell Clay, 7: Törökbálint Sandstone, 8: Quaternary sediments: gravel, sand, travertine)
2.2. Groundwater flow regime

Since the current hydrogeological system is characterized by an artificially influenced groundwater discharge the primary discharge features – for instance location of the upwelling, temperature, chemical composition of the springs – were summarized based on the evaluation of historic hydrogeological data by Erőss et al. (2008). In the Gellért Hill discharge zone the springs could be characterized by temporally and spatially uniform temperature (33.5-43.5°C) and chemical composition (1450-1700 mg/l TDS). This study revealed strong structural control on the springs’ locations as well (Fig. 6). The discharge rate of the springs varied between 2390-4022 m³/day (Papp, 1942). Recent geochemical analyses confirmed the similarity of the discharging waters in the Gellért Hill area. With the application of radionuclides (Erőss et al., 2012) it was revealed that in this area the discharge of thermal waters is overwhelming, no mixing components could be identified. The established differentiated conceptual model for the Gellért Hill area is illustrated on Fig. 9.

Hence in the Buda Thermal Karst mixing of lukewarm and thermal karst waters was assigned to be responsible for cave formation (e.g. by Takács-Bolner and Kraus 1989;
Leél-Őssy 1995), while in the Gellért Hill discharge area due to the lack of mixing members, other processes have to be found, which are responsible for the formation of the caves.

Based on hydrogeological and speleo-morphological considerations and recent microbiological investigations (Borsodi et al., 2012), microbially mediated sulphuric acid speleogenesis is suggested as the dominant cave forming process for the area. This process is further supported by recently forming gypsum crusts on the cave walls above the water table.

The springs in the area are influenced by the transient effect of the Danube (discharge rate, chemical composition, temperature), however it was an important observation that the river water never mixes with the spring waters. It is already known from the earlier studies (e.g. Schafarzik, 1920) that the thermal waters discharge directly into the riverbed during normal stage or low-flow conditions (Fig. 10a). However, during flood con-
ditions the discharge of riverbed springs is displaced to the riverbank zone owing to the elevated hydrostatic pressure of the river. At the Gellért Hill discharge zone and to the North this model describes the interaction of discharging thermal waters and the Danube (Fig. 10b).

Fig. 10.: The hydraulic connection between the Danube and groundwater a) during normal stage or low-flow conditions at the whole discharge zone along the Danube in Budapest; b) during flood at the Gellért Hill and to the North (Somogyi, 2009)

**Stop 2 – Ősforrás (Spring of the Gellért Spa) and Gellért Tunnel**

Only one natural spring outlet is known from the Gellért Hill discharge area, which is rather a spring group. The ancestor of the Gellért Spa, the so called „Muddy Spa” was established on this spring (Fig. 11). The place was named after the accumulation of carbonate precipitates. Later on the Gellért Spa (opened in 1918) also used this spring and a capture room was constructed above it, which is a ~ 100 m² pool with trenches, where 17 spring outlet points were detected. The height of the room is 9.5 m, which is located 3.5 m below the street level. The discharge rate of the spring depends on the
level of the Danube, in average 20 L/s. The spa used this springwater until 1978 directly, then it was substituted by wells in the tunnel (Papp, 1942, Schulhof, 1957).

The tunnel was built between 1969 and 1978, in order to capture the water of the riverbed springs in the Danube front of the hill. The tunnel with its 1100 m length connects the Gellért, Rudas and Rácz Spas. 18 wells were drilled on both sides, from which 4 are used for water supply of the Gellért and Rudas Spas.

**Stop 3 – Aragonite Cave**

There is only limited documentation about the caves of Gellért Hill. The reason is probably, that their dimensions are much smaller, and therefore cannot compete with the famous caves of the Rózsadomb. Korpás et al. (2002) in their comprehensive review on the geology of the area provided a summary also about the caves. Cavities open to the surface and small caves can be found at several levels of the Gellért Hill (Papp, 1942) (Fig. 12). Most of them developed in Triassic dolomite, however there are also caves documented in Eocene-Oligocene marl (e.g. Citadella cave) or in Eocene cherty breccia (Szent Iván and Aragonite caves).
Compared to the multi-storey, maze-like pattern of the Rózsadomb caves, the Gellért Hill caves show different and simple morphology. Usually isometric spherical cavities (up to 12 m size) and fracture-related caves are reported (with 5-6 m length, up to 2 m width and up to 3 m height) (Korpás et al., 2002).

The Citadella cave, high upon the hill, developed in the Eocene marl (Leél-Őssy et al., 2007). The lower level of the cave forms a vertical channel (“feeding” channel), which enlarges in the upper level more or less horizontally (Fig. 13). The tectonic control also can be observed (in form of a vertical “feeding” channel), furthermore, a silica vein is also documented in the roof. This cave is situated 65 m (at 182 asl) above the present discharge level of the springs. Spherical cavities were documented from the cave, with diameters of 0.5 to 1 m, but sometimes even 3 m. Scallops and corrosion niches are completely missing. For this cave the abundance of gypsum minerals is characteristic, however aragonite and calcite are also reported. Based on uranium-series dating on calcite rafts, the upper levels of the cave have formed 300-400 ky before present (BP) and the cave became dry later than 200 ky BP (Leél-Őssy et al., 2007).
There are two larger and well known caves at lower levels, but still above the today’s spring discharge level: the Szent Iván (120 asl) and directly below the Aragonite Cave (109 asl) (Kadić, 1914; Kessler, 1963; Szablyár, 2000) (Fig. 14.). Both caves are developed in Eocene breccia and can be characterized as horizontally elongated chambers (Aragonite cave: width (w): 8 m, length (l): 10 m, height (h): 1.5 m; Szent Iván cave: w: 11 m, l: 12 m, h: 8 to 13 m). However, owing to constructional works the original morphologies today are obscured. Kessler (1963) reported aragonite and gypsum minerals from the Aragonite Cave. Oravecz (1970) documented the Aragonite cave and its minerals in details, and described red limonitic clay, above which thick calcite precipitated (Fig. 15). Horusitzky (1938) and Korpás et al. (2002) described these caves as marine phreatic caves formed in an abrasion shoreline. However Kessler (1963, 1965) and Szablyár (2000) attributed these caves to the dissolution effect of thermal waters.
At the recent discharge level almost all springs are situated in small caves. They are only 5 to 6 m long, up to 2 m wide and their vertical extent is about 3 m, and usually connected to faults and fractures.

**Stop 4 – Török Spring**

At the present discharge level the springs discharge from enlarged fractures of dolomite and often form small spring caves. These springs and spring caves were opened during constructional work in the beginning of the 1900’s. Their characteristic feature is that carbonate mud covers the bottom of the caves, which is associated with iron-hydroxide precipitates. Based on the most recent studies (Mádl-Szőnyi and Erőss, 2013) this can be considered as specific “biogeochemical” discharge feature. Microbiological studies revealed complex microbial community from these precipitates (Borsodi et al., 2012), which plays also a role in the radioactivity of the springwater, hence adsorption of radium on the precipitate continuously facilitates radon and causes elevated radon activity concentrations in the spring waters (Erőss et al., 2012).
3. Rózsadomb

Stop 5 – Pálvölgy quarry

The Pálvölgy quarry is an abandoned limestone quarry with several cave entrances.

3.1 The hydrogeological environment of the Rózsadomb area

The Rózsadomb is one of the nearest hills to the Danube, situated on the right bank of the river (Fig. 1). Its highest point is at 376 m above sea level (asl), called Látó Hill, but the central part of the Rózsadomb is built up of small hills, with lower elevations (195 m asl).

The Rózsadomb is bordered by the Ördögárok valley on SW, and by the Danube on the E. It has relatively steep slopes towards the river (104 m asl). Since the 1920s human activities have completely changed this part of Budapest obscuring the "natural conditions". The original vegetation has been destroyed completely, and extensive construction works and limestone quarrying have modified the relief (Hazslinszky et al., 1993). Accelerated urbanization of the capital reached this area in the 1970s. In 1985 85.3% of, and nowadays almost the whole 10 km² area has been completely built over (Mari and Fehér, 1999, Virág et al., 2009).

Fig. 16 shows the schematic stratigraphic column of the Rózsadomb area with the average thickness of the formations (Leél-Őssy and Surányi, 2003).

The oldest known strata are the Triassic Hauptdolomite (platform facies) and Mátyáshegy Limestone Formations (basin facies) (Schafarzik and Vendl, 1929; Horusitzky, 1938; Wein, 1977). The basal conglomerate and breccia (Magyari, 1994) is composed by the fragments of Triassic rocks cemented by micrite, but sometimes contains also volcanoclasts and quartzite.

The Upper Eocene Szépvölgy Limestone is rich in bioclasts, it is often called nummulitic limestone. This formation hosts most of the caves of the Rózsadomb (Leél-Őssy and Surányi, 2003).
Fig. 16.: Stratigraphic column of the Rózsadomb area (Leél-Őssy and Surányi, 2003)

Fig. 17.: Geological sketch of the Rózsadomb area (after Wein, 1977, in Leél-Őssy and Surányi, 2003)
The Buda Marl, the next younger unit in the stratigraphic column is present almost all over the area of Rózsadomb (Fig. 17). It has variable clay (10 to 30 \%) and carbonate (50 to 80 \%) content (Kleb, 1993). Several cave passages have developed in the lowest, so called bryozoan marl horizon (Leél-Őssy and Surányi, 2003). The porosity values are 8 to 13 \% measured by Kleb (1993), due to the microfractures and clayey surfaces. The rock in the outcrops is also intensively fractured, and the fractures are mostly open. In the cave walls, close to the passage, the porosity can reach much higher values (Kleb, 1993).

Clays that follow in the stratigraphic column can be considered as aquitards. Kleb (1993) documented microfractures perpendicular to the lamination of the Tard Clay from some outcrops. Along these microfractures limonite pigmentation was observed, which indicates fluid circulation.

Fig. 17 gives an overview on the areal distribution of the above described formations (after Wein, 1977 in Leél-Őssy and Surányi, 2003) and clearly shows that the bulk of the Rózsadomb is built up by Eocene limestone and marl. The surface of the hill is covered mainly by loess and detritus of the above mentioned formations. At some places travertine deposits can be found at different levels.

On Fig. 18 the structural elements of the Rózsadomb area are illustrated. The directions of the most often repeating tectonic lines are NW-SE, WNW-ESE, E-W, NE-SW and N-S. This figure includes the locations of the cave maps too and clearly reflects that tectonic activity played an important role in the genesis of the caves of Rózsadomb.

Fodor et al. (1991) carried out a detailed study on the role of tectonic phases in the generation of cave passages in the case of József-hegy cave. During the Oligocene-Early Miocene, the NW-SE oriented compression and NE-SW extension resulted in an ENE-WSW-trending shear zone. In this zone, along the second order Riedel shears (E-W-trending dextral faults) and NW-SE tension fractures, cave passages have formed, due to the open fluid circulation along these faults and fractures (Leél-Őssy and Surányi, 2003). The main corridors of the caves follow these second order Riedels displaying “en echelon” geometry. Barite veins are additional evidence of this tectonic phase. Barite veins occur exclusively on walls of NW-SE to E-W trending corridors. Between the Middle Miocene and Quaternary, new N-S to NE-SW-trending normal
faults were formed by ESE-WNW extension. Pleistocene tectonics made no modification on the earlier “en echelon” geometry, only rejuvenated and reopened the faults. Benkovics et al. (1995) documented also detailed structural geological study in the area of the Ferenc-hegy and Szemlő-hegy caves (Fig. 18).

![Fig. 18.: Sketch of the structural deformations in the Rózsadomb area (modified after Benkovics et al., 1995)](image)

3.2 Caves of the Rózsadomb area

In the Buda Hills there are many hypogenic caves, but the largest cave systems can be found in the Rózsadomb area. Takács-Bolner and Kraus (1989), Leél-Őssy (1995 and 2010) and Leél-Őssy and Surányi (2003) and Leél-Őssy et al. (2011) provided detailed description about the caves, their morphologies and specific minerals. The following short summary is based on their work.

The widely accepted theory about the genesis of the caves is that they formed by mixing corrosion at the base level of erosion, where the ascending thermal waters mix with descending colder karst waters. The uplift of the area resulted in the formation of multi-level caves. Finally, as the uplift proceeded, the caves left the cave-forming zone and became dry. Szanyi et al. (2012) provided data regarding the Pleistocene history of the uplift of the Buda Hills based on uranium-series dating of cave rafts.
From this only 5-6 km² large area of the Rózsadomb more than 100 caves and cave indications are known and their explored total length is more than 45 km (Leél-Őssy, 2010). Eight caves have km-long size (Fig. 1). The passages of the caves developed mainly in Eocene limestone, the highest levels in Eocene marl, and in some cases the lowest levels reach the Triassic carbonates.

The most important, common feature of the caves found at Rózsadomb area, which is also clearly visible on the cave maps, is that these caves have strong structural control. The most frequent directions, which are reflected on the maps are NW-SE, WNW-ESE, E-W, NE-SW and N-S (Fodor et al., 1991; Benkovics et al., 1995).

Along with faults and fractures, cave passages often follow bedding planes and also the contact between the Eocene limestone and the Eocene-Oligocene marl (Nádor, 1991). As a result, multi-storey complicated, maze-like cave systems are characteristic of the Rózsadomb area.

Significant morphological characteristic of these caves is the abrupt size change of the passages (Takács-Bolner and Kraus, 1989). Between the 20-30 m long, wide halls, small catwalks occur. The caves of the Rózsadomb share common features of hydrothermal caves (Ford and Williams, 1989): independency from the surface topography; lack of fluviatile sediments; and abundance of hydrothermal minerals. However, it is important to emphasize, that their spring outlets and levels of development occur usually at the present day- or at former fluvial base levels.

The individual passage morphology can be characterized by spherical cavities and corrosion niches, and other, smaller dissolution forms such as convection tubes, ceiling half-tubes and scallops.

The caves usually are rich in minerals, especially the abundance and variety of calcite and gypsum is characteristic. Four generations of minerals can be found in the caves (Leél-Őssy, 1995; Leél-Őssy and Surányi, 2003, Leél-Őssy et al., 2011). To the first generation belong barite, fluorite, calcite and silica veins, which were formed prior to the dissolution of the cave, they are only exposed by the cave. Minerals of the second generation were precipitated after the dissolution of the cave passages, but their precipitation happened in that period, when water was still present in the passages and these
minerals precipitated directly from the cave-filling water. To this group belong the calcite rafts, which were precipitated on the water table by CO$_2$ degassing, and therefore are very important as age indicators. Minerals of the third generation were precipitated from aerosols, not directly from the cave filling water, when air circulated above the (hot) water table. Minerals of the fourth generation are independent from the cave filling thermal water; to this group belong e.g. dripstones. These are epigenic features in the caves. Detailed description is given by Leél-Őssy (1995) and Leél-Őssy and Surányi (2003) and Leél-Őssy et al. (2011).

3.3 Flow regime

The Rózsadomb discharge area is long ago well-known for its springs, which have very different temperatures, though they are located in very close vicinity of each other. Based on the evaluation of historical data there was a very apparent pattern in the distribution of springs regarding their temperatures (Fig. 19a): hot springs (53-63 °C) discharged nearest to the Danube (Fig. 19b), while the lukewarm springs (24-27 °C) came to the surface closer to the foothills. Papp (1942) suggested a primary structural control on the distribution of springs, as he recognized that the distribution of springs is in alignment with the main structural directions (NW-SE and NE-SE) of the Rózsadomb area. There was a so called “Muddy” Lake (Fig. 19a, c), where more than 16 spring groups could be identified within a 385 m$^2$ area, with different temperatures, but next to each other. The lake got its name from the numerous little spring outlets, which were similar to mud volcanoes (Fig. 19c). The hot waters had higher (above 1200 mg/l, up to 1653 mg/l), while the lukewarm-warm waters lower (generally lower than 1000 mg/l) TDS content.
Fig. 19a: Location of the springs at the Rózsadomb discharge area (geological map based on Fodor in Mindszenty and Mádl-Szényi et al. (2000)); b: The foothills of the Rózsadomb at 1836 with hot springs at the Danube (J. Richter from L. Rohbock) c: The Muddy Lake (Schnülke 1957)
The Rózsadomb area was characterized by high natural discharge rates. The discharge of the lukewarm springs was estimated 13120 m³/day, while the hot springs had about 4900 m³/day yield (Papp, 1942). Based on investigations, it was established that the springs’ discharges were naturally influenced by the level of the Danube, but they were not affected by the precipitation (Molnár, 1857; Mádai, 1927; Papp, 1942), similarly to the Gellért Hill area.

Based on the results of the radionuclide study (Erőss et al., 2012), in the area mixing end members were characterized: the cold component with 775 mg/l TDS and 12 °C temperature and the hot component with 76.5 °C temperature and 1440 mg/l TDS. The temperature inferred for the cold component is in accordance with the annual mean temperature of the region, 12 °C.

According to the observed discharge characteristics at the Rózsadomb area, where the discharge of lukewarm and hot springs were clearly separated and tectonically controlled, mixing could only exist either by dispersion or along faults. Therefore the created dissolutional porosity also has a strong structural control, as it can be seen on the cave maps, the distribution of the passages follows the main structural directions.

Based on the radionuclide study it can be confirmed that the dominant cave forming process in the area is, indeed, mixing corrosion.

The differentiated new conceptual flow model based on recent hydrogeological studies is illustrated on Fig. 20.
Stop 6 – Szemlőhegy Cave

The entrance part of the Szemlőhegy cave (Fig. 21) was discovered in 1930 during the foundation works of the house of a pharmacist, Géza Miklóssy. The actual length of the cave is 2.2 km, out of which, since 1986, a 300 m long part is also furnished for visits of tourists. The passages of the cave were produced by the corrosion of upsurging thermal waters. The corridors of the cave are in Eocene limestone and follow the SW–NE striking joints of the rock. The main parallel corridors are connected perpendicularly by short passages. The morphology and the formations of the cave are similar to those of the Ferenchegy and Jőzsefhegy Caves. The walls of the cleft-like corridors are decorated by kettle-like spherical solution forms and by cave popcorns and gypsum crystals. Characteristic plate-like calcite crystals can also be found in several places. Dripstones are present only sparsely in the cave. During the development of the show cave two artificial entrances were constructed: a 60 m long gallery from the Pusztaszeri road and a 45 m deep vertical shaft from the Barlang street side, site of the planned
elevator. Short Tour Tour time is about 2 hours; technical equipment is not necessary. Our tour begins on the hilltop at the Discovery-corridor entrance (Felfedező-ágiebér) or the so-called Vortex Corridor (Örvény-folyosó). After a few m walk on concrete floor we arrive into a tube-like, steeply descending passage. The walls of this ancient thermal water chimney are interesting, because of solution forms. In a distance of about 15 m beyond the entrance a vertical shaft leads into the University Section (Egyetemi-szakasz). We proceed downwards along the stairs. After 50 m we reach the broadest part of the cave: the Giant Corridor (Óriásfolyosó, Fig. 21) and here we enter the parts open for tourist. In the light of lamps peculiar pisolites and huge solution sills occur, product of the inhomogeneous solubility of the limestone. To the right, we can cast glances through windowlike openings towards the other, neighbouring passage, being separated from us by a calcite vein. The height of the 45 m long corridor, formed along a joint, is 15 to 20 m. Descending along some stairs, a great mass of plate-like calcite crystals appears. Overhead high-reaching chimneys lead toward higher levels of the cave. At the end of the Giant Corridor a 7 m long steel ladder offers ascend into the intact Radio Corridor (Rádió-folyosó), discovered in 1958.

Fig. 21. Outline map of the passages of the Szemlőhely Cave (based on the map of János Horváth, 1962, processed by Gyöngyvér Szanyi and Ádám Papp in Leél-Őssy, 2010)
Through a high-reaching cleavage, divided in certain spots by spherical cavities, one can reach the Death Corridor (Halál-folyosó). The name comes from the rather dangerous caving-ins. The loose blocks are now supported by steel scaffoldings. We still climb upwards and then, in a steep clay-bottomed cleft, we descend into the Kadić Hall (for Ottokár Kadić, 1876–1957, geologist, paleontologist, speleologist, who made the first scientific exploration of the cave). From here we either go down into the Snow Palace (Hópalota), covered by white calcite incrustation, unfortunately showing traces of damage. After a short ascent we arrive at the 3 April Corridor (Április 3. folyosó), a broad, hall-like cavity with nice flowstones. Along the left wall descending down to 7 m a small dripstone pool is found. The corridor proceeds between botryoidal and flowstone formations toward the Heart of the Earth (A Földszíve), a red coloured hall. Crawling through above it, we enter the Bell Hall (Harang-terem), full of plate-like calcite crystals, after which the name was given. From its bottom through a tubelike hole we arrive to the SW end of the cave, the Assembly Hall (Közgyűlés-terem), but only very slim cavers can wriggle into it. From this spot we return (along the already described route) to the Giant Corridor and proceeding through it we turn to right in the branching-off Long Corridor (Hosszú-folyosó). After about 40 m walk between rich calcite formations and ascending we reach the entrance into the Crawling Passage (Kuszoda). This part of the cave developed along two parallel joints. The double-level corridor-system is very narrow upstairs, while the lower part is a series of small halls, rich in formations. The two main corridors are interconnected by three narrow, cross-cutting passages. From the Crawling Passage we return to the Long Corridor and proceed in a pisolite-covered cleft getting higher and higher. After a larger hall we get between two concrete walls and from here the 45 m deep vertical shaft leads to the surface. Crossing the Maria Hall (Mária-terem) and admiring the monumental fissure of the Debris Hall (Omladék-terem) we enter the Ferencváros Hall (Ferencvárosi-terem). Its most interesting part is a calcite vein hanging from the ceiling and covered by thick incrustation of botryoidal dripstones. The 60 m long tunnel from the main building, used by everyday visitors, leads here. To the left we climb a high heap of boulders and get into the Clayey Corridor (Agyagos-folyosó), where permanent and intensive dripping of water is observed. (This hall is planned to be used for speleotherapeutic treatment of respiratory diseases.) At the end of the Clayey Corridor we get through a double lock gate and thus
we come to the elevator shaft, to the bottom of which we descend on a steel ladder of 10 m length. From the bottom of the elevator shaft, bypassing the Giant Corridor and climbing up the stairs we reach the surface (Leél-Őssy, 2010).

**Stop 7 – Malom Lake**

In Frankel Leó street, hidden by a glass-wall there is a little lake with a small open water surface bushy with plants (Fig 22a). At the foot of the Rózsadomb, two springs, (Alagút- and Boltív) feed this so called Malom Lake, which was made presumably by Szokoli Mustafa in 1568 by barring the outflow of the spring-water. The lake is drained through a sluice and canal into the Danube. Based on recent discharge measurements about 7000 m³/day lukewarm (20-21 °C) water enters directly into the Danube throughout this canal (Erőss et al., 2013).

**Stop 8 – Molnár János cave**

At the discharge zone of the Rózsadomb area, at the actual base level, behind the Boltív-spring there is a phreatic cave, which is the modern analogue of the already dry caves found at higher levels in the Rózsadomb area (Fig. 1).

The total length of the explored passages exceeds 5.6 km and its explored maximum depth is 100 m (Kalinovits, 2010, pers. comm.). The largest (explored) room, the Kessler Room, is only partly filled with water. It is 80 m long, 16-26 m wide, and the water depth varies between 5m and 24 m. It accommodates about 23 360 m³ (80*21*14.5 m) lukewarm water. The total water volume of the cave is estimated as few hundred thousand m³.

The distribution of the cave passages has a strong tectonic control (Fig. 22). The main and longest corridors of the cave were dissolved along NE-SW fault lines (Fig. 22). Narrower, and therefore probably the youngest passages have N-S direction at the entrance of the cave. The N-S trending normal faults were created in the Quaternary, due to the N-S compression and W-E extension. The cave passages follow the general dip of the host Eocene limestone and the Eocene-Oligocene marl (S-SE) (Surányi et al., 2010).
Fig. 22a: The Malom Lake and Boltív Spring (photo by S. Kalinovits); b: Map view and vertical profile of Molnár János cave developed in the Polygon cave surveying program (National Cave Registry). Colours indicate depth of passages: towards red – shallower; towards blue – deeper (compiled by S. Kalinovits)
Stop 9 – Springs and wells of the Lukács Spa

The lukewarm and hot springs discharging to the surface at the foothills of the Rózsadomb have been in almost continuous use since Roman times. Formerly, this area — where now we find the St. Lukács’s Bath — used to be an untouched, natural wetland. It has flourished as a public bath and water-resource first during the Turkish occupation. The Turks built not only baths, but also several water-mills to utilize the water of the springs (Fig. 19b). Most Turkish baths were destroyed, the only one preserved is that built by Pasha Mustafa in 1570.

At the foothills of Rózsadomb both the Szépvölgy Limestone and the Buda Marl are completely covered by the alluvial gravel of the Danube. Thermal water is upwelling from the karst and forced to reach the surface through this unconsolidated sediment. In the Spas of Budapest most of the natural springs are substituted by wells, and the water supply of the Lukács Spa relies also mainly on wells. Nowadays the water of the hot springs is not used directly. In the Spas of Budapest most of the natural springs are substituted by wells, and the water supply of the Lukács Spa relies also mainly on wells. Drilling of the Lukács-wells began, as early as 1910, and these wells took over the role of the springs completely. A borehole was drilled also into the hottest (50-58 °C) Antal-spring and instead of the spring the water could be
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withdrawn now from the 40 m deep well (Fig. 24). Its water is, however, not in use currently. In the early period of the Lukács Spa, a natural mudpool was established and made available for public use (Fig. 19b). The pool was, however, closed in 1957-58 and its muddy bottom replaced by concrete. In its place you find now the so called fancy or leisure pool. At present the Spa operates only two wells to meet the current hot-water demand. They are Lukács-IV (44-48 °C) and the Lukács-V (33 °C) (Fig. 24).

Among the six lukewarm springs (20-25 ºC) there are only three with really large yield: (1) the Malom-lake- (Boltív- and Alagút-), (2) the Római- and (3) the Török-springs. The yield of the other springs (Szikla-, Kristály- and Timsós-) is much smaller. The first three springs (1-3) could be used any time, however, currently there is no real demand. Therefore, for example, the water of the Török-spring having the largest yield is not used, at all. In order to avoid near-surface contamination of Malom-lake-springs, the water is brought to the surface by a pipeline built into the adjoining phreatic Molnár János Cave. The Római-spring, which is a lukewarm spring, is, however, still in use. The discharge rate of the Római-spring varies between 1065-4176 m³/day (Alföldi et al., 1968). The hot water of the Lukács Spa comes mainly from the Lukács-IV. well. The temperature and chemical components of these latter objects are summarized in Table 1.

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<th>Hungarian names of springs and wells</th>
<th>Field measurements</th>
<th>Cations (mg/l)</th>
<th>Anions (mg/l)</th>
<th>TDS (mg/l)</th>
<th>H₂SiO₃ (mg/l)</th>
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*Table 1 Chemical composition of the Római-spring and the Lukács-IV well (Erőss, 2010)*
Fig. 24.: St Lukács’s Bath: The location of wells and springs (layout is modified after Alföldi et al. 1968)
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References


 Báldi, T., 1983, Magyarországi oligocén és alsómiocén formációk (Oligocene and Lower Miocene Formations in Hungary) [in Hungarian]: Budapest, Akadémiai Kiadó, 293p.


Horusitzky, H., 1938, Budapest Dunajobbparti részének (Budának) hidrogeológiája (Hydrogeology of Buda) [in Hungarian]: Hidrológiai Közlöny, XVIII, 1-404.


Leél-Őssy, Sz., 1995, A Rózsadomb és környékének különleges barlangjai (Particular caves of the Rózsadomb Area) [in Hungarian]: Földtani Közlöny, 125(3-4) 363-432.


Lorberer, Á., 1986, A Dunántúli-középhegység karsztvízföldtani és vízgazdálkodási helyzetfelmérése és döntéslőkészítő értékelése (Assessment report about the karst hydrogeo-


Magyari, Á., 1994, Keső eocén hidraulikus breccásodási jelenségek a Budai-hegység D-i részén (Late Eocene hydraulic rebrecciatition in the Southern Buda Montains) [in Hungarian]: Földtani Közlöny, 124(1) 89-107.


Schafarzik, F., Vendl, A., 1929, Geológiai kirándulások Budapest környékén (Geological excursions in the surroundings of Budapest) [in Hungarian]: Stádium Sajtóvállalat Rt., Budapest, 343 p.

Schauer, Gy, Schweitzer, F., 1988, A Gerecse és a Budai-hegység édesvízi mészkőösszletei (Travertines of the Gerecse and Buda Mountains) [in Hungarian]: Földrajzi Tanulmányok 20, Akadémiai Kiadó, Budapest, 123 p.


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