EDITORIAL: RESEARCH FRONTIERS AND PRACTICAL CHALLENGES IN KARST HYDROGEOLOGY

UVODNIK: MEJE RAZISKOVANJA IN PRAKTIČNI IZZIVI V KRAŠKI HIDROGEOLOGIJI

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Keywords: karst aquifer, groundwater, drinking water, contamination problems, climate change, soil erosion, ecohydrology.

Ključne besede: kraški vodonosnik, podtalnica, pitna voda, težave z onesnaževanjem, klimatske spremembe, erozija prsti, ekohidrologija.

The title photo of a glacier overlying a karst aquifer in the Swiss Alps was taken in September 2009. The red number on the polished limestone surface in the foreground indicates the position of the glacier in 2003. Since then, the glacier has lost ca. 182 m in length and 9 m in thickness. If retreat continues at this rate, most of this small glacier will have vanished by approximately 2035 (while most large glaciers will probably shrink but still exist). The spring draining the aquifer supplied by this glacier is used for drinking water supply and irrigation.

How will the retreat of this glacier affect the availability and temporal variability of freshwater from the spring? More generally, how, and to what extent, will impacts of the predicted climate change affect water resources from karst aquifers? This question represents one of several "research frontiers and practical challenges in karst hydrogeology" discussed in this special issue, which has been prepared by the Karst Commission of the International Association of Hydrogeologists, IAH (www.iah.org/karst).

Climate change currently receives much attention in the scientific community, in political spheres, and in the public media. In some regions, climate change impacts on groundwater resources could be severe, while insignificant or even favourable changes might occur in other regions, but these predictions generally involve a high degree of uncertainty (Holman 2006).

Besides the possible future impacts of climate change, there are many other urgent groundwater-related environmental problems. Accessibility to safe drinking water in sufficient quantities for human needs is threatened by different types of contamination, overexploitation, saltwater intrusions, and inappropriate irrigation practices. Soil erosion, natural disasters, and the protection of ecosystems and biodiversity are other important water-related issues. These problems exist today, but will get worse in many regions according to the current climate change scenarios.

All of these issues are interrelated and are especially relevant in karst areas. For example, deforestation leads to ecosystem degradation and a loss of biodiversity, but also promotes soil erosion (Fig. 1), which increases the vulnerability of groundwater resources to contamination, alters recharge processes and reduces the water storage and buffering capacity of the hydrogeologic system, thus posing a threat to quality and quantity of drinking water and ultimately to public health. Furthermore, the degradation of soil and vegetation also releases CO_2 and reduces the efficiency of karst processes as a natural sink of this greenhouse gas (Liu & Zhao 2000). Finding solutions to all of these problems requires a multidisciplinary approach, to which karst and groundwater researchers could and should contribute more than they currently do.

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The Blacksmith Institute has published a report on the "World's Worst Pollution Problems" (Ericson *et al.* 2008) that lists groundwater contamination among the severest problems and notes that "contaminated drinking water is one of the major causes of infant diseases". Hydrogeologists help to lay the scientific basis for the protection and sustainable management of water resources from aquifers, among which karst aquifers take an important place (Fig. 2), supplying 25% of the global population with drinking water according to an often cited estimation by Ford and Williams (2007). Hydrogeological research should contribute to finding solutions to concrete and serious present-day problems related to groundwater, although our contributions will mostly be local – often at the scale of an aquifer or catchment.

Fig. 1: Soil erosion in a Chinese karst area. Soil erosion also influences recharge processes aquifer vulnerability, groundwater quality and the carbon cycle; it consequently represents an interdisciplinary research frontier and a practical challenge in karst hydrogeology (Photo: N. Goldscheider).

The title photo also has an additional metaphoric meaning: the juncture of glacier and bedrock represents "frontiers", while the high mountains symbolize "challenges" that we are currently facing in karst hydrogeology. The papers presented address several of the water-related challenges and problems mentioned above, some through fundamental and theoretical research and others through practical case study analyses and test site applications.

The relations between geologic structure and underground drainage are often highly complex in karst aquifer systems. In the first paper, **Goldscheider** and **Neukum** apply multi-tracer tests in a karst area in the western Austrian Alps to study these relations in detail, as a basis for the delineation of effective groundwater source protection zones.

Jemcov and **Petrič** use time series analyses to study the temporal variability of a karst aquifer system in Serbia and illustrate how this technique can contribute to achieve a better management and sustainable exploitation of this resource.

Kovačič also applies time series analyses to a regional karst aquifer system in Slovenia. He compares the temporal variability of rainfall, flow at swallow holes and spring discharge in order to establish hydraulic relations and characterise the dynamic system behaviour.

Malík and **Švasta** evaluate a large number of hydraulic data from the Slovakian national borehole database and use these data to characterise hydraulic properties of limestone and dolomite aquifers in comparison to crystalline rock aquifers. This study helps to achieve better and more sustainable management of karst aquifers.

Fig. 2: Karst spring captured by means of inclined drillings and used for the drinking water supply of Yverdon-les-Bains, Switzerland. Providing safe drinking water at sufficient quality and quantity for all people is the major task and a permanent challenge for (karst) hydrogeologists (Photo: N. Goldscheider).

Sass and **Burbaum** map and analyse the damage to buildings and infrastructure in a small historic town in Germany caused by ill-planned geothermal drillings through anhydrite. The causes and processes of the swelling in the underground and the resulting uplift are discussed, and the lessons learned from this avoidable disaster are exposed.

Wang and co-workers study hydrochemical variations in a travertine-depositing stream in the Huanglong Ravine, a UNESCO World Natural Heritage site in Southwestern China. Besides its scientific interest, this study also illustrates another important aspect of karst: the beauty and ecological significance of the landscape and its economic value for tourism (Fig. 3).

Mudarra and **Andreo** use total organic carbon, natural flourescence and hydrochemical tracers to assess the hydrogeologic functioning of a karst aquifer in Southern Spain, where freshwater resources are scarce and under pressure resulting from the Mediterranean climate and the rapidly growing water demand due to population growth and irrigated agriculture.

Malík and **Michalko** propose a new hydrograph separation method for limited datasets. Hydrograph separation is a commonly used method; however, when discharge records are sparse, the evaluation of flow components can lead to invalid results. This work presents a promising approach for future applications and interpretations of limited dataset results.

Fig. 3: Scene from the Plitvice Lakes National Park in Croatia (similar to the study site presented by Wang et al. in this volume), illustrating the intense groundwater-surface water interactions in karst area, as well as the ecological and touristic value of these landscapes (Photo: N. Goldscheider).

Gremaud and **Goldscheider** study the glacierised karst aquifer system in the Swiss Alps shown on the title photo and discussed above. They conclude that the dynamics and variability of the spring draining the system, which is used for drinking water supply and irrigation, will significantly change when the glacier disappears, resulting in temporal water shortages during long dry summer and autumn periods.

Kogovšek and **Petrič** study a landfill on top of a karst aquifer in Slovenia and assess the impact of contaminants on groundwater quality, mainly by means of tracer tests. They also discuss general aspects of monitoring strategies for karst aquifers, taking into account their high degree of heterogeneity.

Stevanovic, **Milanovic** and **Ristic** present several specific methods for the assessment of groundwater storage in karst aquifers and demonstrate their application on selected karst systems of Serbia, Montenegro and Algeria with the goal of achieving a more effective utilisation of groundwater. The high degree of heterogeneity and hydrologic variability of karst aquifers are major challenges in this context.

Hickey uses several investigation methods to better characterize lowland karst in Ireland. The combination of various research techniques assists in revealing a great quantity of information that enhances knowledge on the functioning of lowland karst and made it possible to set up a detailed conceptual model.

Karst landscapes in Southwestern China are widespread and they hold important groundwater resources. These areas are also densely populated. **Guo**, **Yuan** and **Qin** summarise karst groundwater contamination problems of this region and present various case studies. The authors propose countermeasures to prevent further contamination of these groundwater resources and provide a framework for overall management of karst water resources in Southwestern China.

The paper by **Hu** represents more fundamental research, investigating flow and transport in karst aquifers by means of experimental studies in the laboratory and numerical simulations. Such studies help to better understand the specific processes of contaminant propagation and attenuation in karst aquifers.

Understanding sinkhole-drainage capacity and function is important for the management of sinkhole-flooding problems. **Field** developed mathematical models to simulate drainage from inflowing water for the prediction of sinkhole flooding, and discusses the variables that must be considered.

Criss proposes an analytical model for the simulation and prediction of spring discharge and hydraulic head in karst aquifers and applies this model to a karst system in Missouri. The high degree of temporal variability of spring discharge, and thus, available drinking water quantity, is a major challenge in the management and utilisation of karst water resources. Models helping to predict spring discharge are thus of high practical relevance.

Last but not least, **Ford** reviews a book edited by Kresic and Stevanovic, "Groundwater Hydrology of Springs: Engineering, Theory, Management, and Sustainability". Most springs discussed in this book are karst springs and used for drinking water supply, so this book and the present special issue nicely complement each other.

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FOLD AND FAULT CONTROL ON THE DRAINAGE PATTERN OF A DOUBLE-KARST-AQUIFER SYSTEM, WINTERSTAUDE, AUSTRIAN ALPS

VPLIV GUB IN PRELOMOV NA NAČIN ODVAJANJA VODA V DVOJNEM KRAŠKO-VODONOSNEM SISTEMU, WINTERSTAUDE, AVSTRIJSKE ALPE

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Abstract UDC 911.2:551.435.8:556.3

Nico Goldscheider & Christoph Neukum: Fold and fault control on the drainage pattern of a double-karst-aquifer system, Winterstaude, Austrian Alps

Lithostratigraphy and geologic structures are major controls on groundwater flow in alpine karst systems. Understanding these factors is important for the delimitation of drinking water protection zones. The Winterstaude mountain chain, western Austria, belongs to the Helvetic nappes and consists of Cretaceous sedimentary rocks, including two karstifiable formations: Örfla and Schrattenkalk Limestone (lower and upper karst aquifer), separated by 60 m of marl. Strata are folded and cut by faults with displacements of 40–70 m. Folded carbonate rocks continue below the alluvial valley floor so that the karst system can be subdivided in shallow and deep phreatic zones. This area is suitable for studying the combined influence of folds and faults on groundwater flow in a double-aquifer system. A multi-tracer test with seven injections aimed at characterising hydraulic connections and linear flow velocities. Results show that (i) plunging synclines form the main drainage pathways in the upper karst aquifer, with maximum linear velocities of 91 m/h, while anticlines act as water divides; (ii) recharge into the lower aquifer, which forms the central ridge of the mountain chain, contributes to springs discharging from the upper aquifer near the foot of the mountain (local flow systems); (iii) the two aquifers are hydraulically connected, presumably via faults, because their displacements are in the same order of magnitude as the thickness of the intervening marl; (iv) flow in the upper aquifer continues below the valley floor toward the river, with maximum velocities of 22 m/h (intermediate flow system).

Keywords: alpine hydrogeology, multi-aquifer system, cross-formational flow, fold tectonics, multi-tracer test, Austria.

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Nico Goldscheider & Christoph Neukum: Vpliv gub in prelomov na način odvajanja voda v dvojnem kraško-vodonosnem sistemu, Winterstaude, Avstrijske Alpe

Litostratigrafija in geološke strukture so poglavitne za vpliv na tok podzemne vode v alpskih kraških sistemih. Razumevanje teh faktorjev je pomembno za razmejitev vodovarstvenih pasov. Gorska veriga Winterstaude v zahodni Avstriji pripada Helvetskemu pokrovu in se sestoji iz krednih sedimentnih kamnin, vključno z dvema zakraselima formacijama apnencev: Örfla in Schrattenkalk (spodnji in gornji kraški vodonosnik), ki ju ločuje 60 m laporja. Plasti so nagubane in prekinjene s prelomi in premikom za 40–70 m. Nagubane karbonatne kamnine se nadaljujejo pod dnom aluvialne doline, tako da je kraški sistem razdeljen na plitvo in globoko freatično cono. Takšno območje je primerno za proučevanje vpliva gub in prelomov na tok podzemne vode v dvojnem vodonosnem sistemu. Cilj večsledilnega poskusa s sedmimi injicirnimi točkami je bil označitev hidravličnih povezav in linearnih hitrosti toka. Rezultati so pokazali, da (i) potopljene sinklinale tvorijo glavne odvodne poti v gornjem kraškem vodonosniku z najvišjimi linearnimi hitrostmi 91 m/h, medtem ko antiklinale predstavljajo razvodnice; (ii) napajanje spodnjega vodonosnika, ki oblikuje osrednji greben gorske verige, prispeva k izvirom, ki iztekajo iz gornjega vodonosnika ob vznožju gora (lokalni pretočni sistem); (iii) oba vodonosnika sta hidravlično povezana, domnevno preko prelomov, saj je njihov zamik istega velikostnega razreda, kot je debelina vmesnega laporja; (iv) tok v gornjem vodonosniku se nadaljuje pod dnom doline proti reki z najvišjimi hitrostmi 22 m/h (vmesni pretočni sistem).

Ključne besede: alpska hidrogeologija, sistem večih vodonosnikov, tok preko formacij, prelomna tektonika, večsledilni poskus, Avstrija.

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