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Computer modelling deciphers the important role of the river-groundwater interface as a hot spot for arsenic release

Naturally occurring (geogenic) groundwater arsenic contamination is a problem of global significance, with noteworthy occurrences in large parts of the alluvial and deltaic aquifers in South and Southeast Asia. To address this problem tremendous research efforts have been dedicated over the last two decades to better understand the sources and distribution of arsenic-polluted groundwater. Now, an Australian team of scientists from Flinders University, CSIRO and the University of Western Australia, together with their colleagues at the Swiss Federal Institute of Aquatic Science and Technology (Eawag), have used computer modelling to integrate much of what has been learned over the years into computer simulations that mimic the complex interactions between groundwater flow, solute transport and geochemical reaction mechanisms. Such models are important to analyse field observations, to unravel which chemical and physical processes play a role, and to predict the behaviour of arsenic within aquifers – where and when pollution may occur in the future. The results of their study have now been published in the latest issue of Nature Geoscience.

Reconstructing the past to predict future arsenic behaviour

The research team selected a highly arsenic polluted site near Hanoi (Vietnam) to develop and test their computer model. In a first step they used the tiny concentrations of tritium that had entered the groundwater system from the atmosphere during the times of nuclear bomb testing, and its decay product helium, a noble gas, to reconstruct how fast and where the groundwater was moving over the last 5 decades. Once the model simulations were able to match the concentrations that were measured, additional complexity was added to the model in order to simulate how arsenic was mobilised and transported in the Holocene aquifer.

The river-groundwater interface acts as reaction hotspot

At the study site, changes in groundwater flow occurred over the past 50 years since the city of Hanoi markedly increased the extraction of groundwater to satisfy its steadily increasing water demand; this showed to be the main trigger for arsenic pollution in the aquifer. The computer modelling allowed the researchers to pinpoint the source of arsenic down to the river muds that are regularly deposited at the more slow-flowing zones of the Red River. The organic matter contained in those muds fuelled a biogeochemical reaction that led to the release of arsenic and its km-long transport into the aquifer underlying the Van Phuc village, a process that continues to this day. Employing their developed computer model in predictive mode the researchers were able to illustrate the interplay of four key factors on the evolution and longevity of arsenic release at surface water/groundwater interfaces, (i) the abundance of reactive organic matter; (ii) the abundance of iron oxides; (iii) the magnitude of groundwater flow; and (iv) river mud deposition rate.

Arsenic

Arsenic is one of the most common inorganic contaminants found in drinking water worldwide. This metalloid occurs as a natural component in many sediments. Where arsenic becomes dissolved into the groundwater this can cause extensive groundwater pollution. The inorganic salts of arsenic are tasteless and odourless, but highly toxic to humans. If ingested over long periods, even low concentrations can cause damage to health, including hyperpigmentation of the skin, hyperkeratosis on the palms and soles, disorders of liver, cardiovascular and kidney function, and various types of cancer. Problems arise from the fact that, firstly, arsenic concentrations can vary widely at the local level and, secondly, people in many areas are completely unaware of the risk because their groundwater wells have never been screened for arsenic. Concentrations below 10 µg/L are considered safe. This concentration is therefore recommended by the World Health Organization as a guideline value for arsenic in drinking water.

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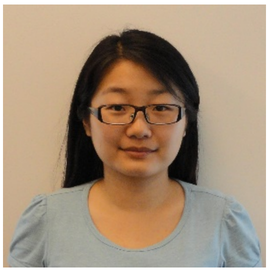
Dr Ilka Wallis is a Senior Lecturer at Flinders University, Australia and a research scientist at the National Centre for Groundwater Research and Training (NCGRT). Ilka received her diploma in hydrogeology from the University of Kiel, Germany and her PhD from Flinders University. Ilka focuses on the development of reactive transport models which integrate fundamental hydrogeological, geochemical and microbiological processes that traditionally have been studied in isolation. She is particularly interested in how the interaction between physical flow and biogeochemical reaction processes reactions affects the mobility of contaminants in aquifer systems.

Henning Prommer is a Research Professor with the School of Earth Sciences at the University of Western Australia (UWA) and a Principal Research Scientist and Team Leader at CSIRO Land and Water (Australia) who received his Dipl.-Ing. from the University of Stuttgart and his PhD from UWA. He is mainly working on the development and application of reactive transport models to a wide range of groundwater quality issues. He has a strong interest in integrating hydrological, geochemical and microbiogical datasets to derive a process-based quantification of redox processes and the associated fate of organic and inorganic pollutants at both the laboratory and field-scale.

Dr Michael Berg is head of the department water resources and drinking water at the Swiss Federal Institute of Aquatic Science and Technology (Eawag). He earned a PhD in environmental geochemistry at the Karlsruhe Institute of Technology, Germany. His research focuses on the occurrence, fate and behavior of organic and inorganic contaminants in groundwater and surface water environments, with a specific interest in biogeochemical processes at local to regional scales. In the last two decades he was engaged in various studies on water quality and mitigation in Asia where geogenic groundwater contamination is of major concern.

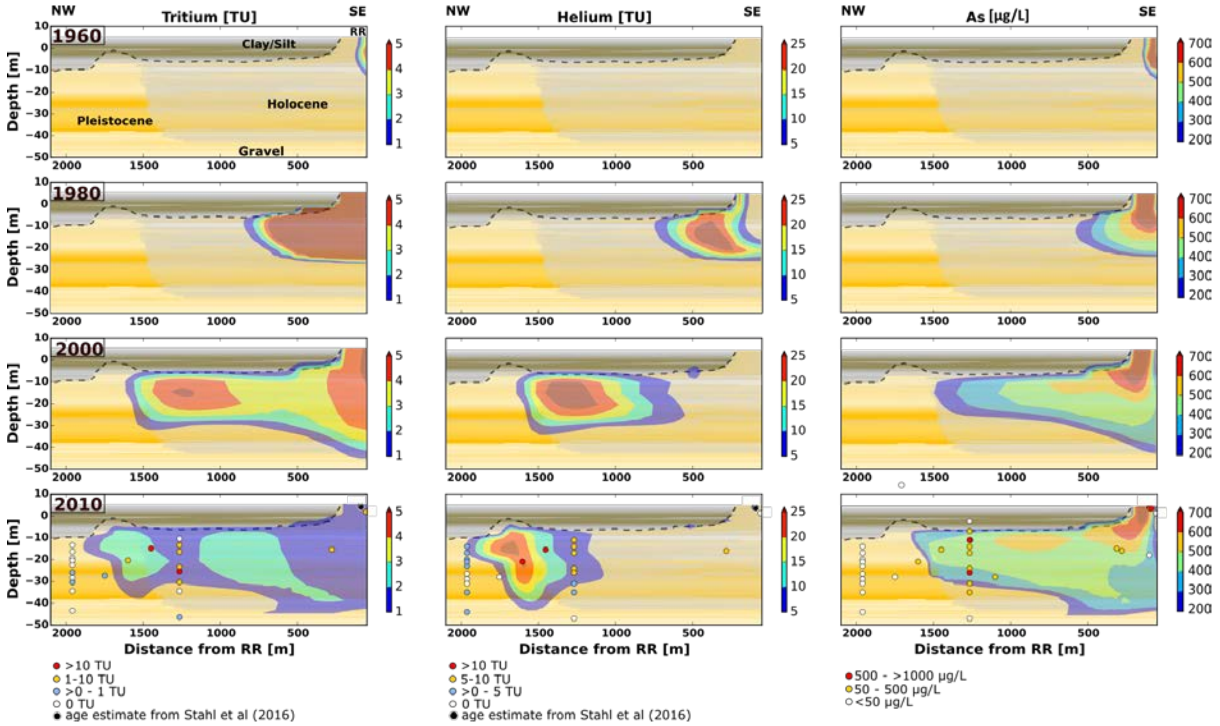
Dr Adam Siade is a Research Fellow with the School of Earth Sciences at the University of Western Australia and a Visiting Scientist with CSIRO Land and Water. He received his BS from Humboldt State University and both his MS and PhD from the University of California, Los Angeles. He is mainly working on inverse modelling and predictive uncertainty quantification analyses associated with various numerical groundwater models, including applications to reactive solute transport. Overall, his research is aimed at developing operational models for groundwater management in order to minimise risk. Primary focusses of his research are reducing uncertainty through experimental design and using surrogate modelling to reduce computational demands.



After completing here postdoctorial position with the University of Western Australia, **Jing Sun** is now a Research Professor with the State Key Laboratory of Environmental Geochemistry at Chinese Academy of Sciences. Jing received her PhD in biogeochemistry from Columbia University (USA). Her research centers on the role of iron cycling and mineralization on the environmental fate of toxic metal(loid)s. She intergrates laboratory experiments, field experiments, analytical techniques, and reactive transport models to examine the type and rates of the redox reactions that occur at the interfaces between mineral surface, water, and microorganisms, and to design remediation strategies.

Prof. Rolf Kipfer holds a PhD in Natural Science from the Swiss Federal Institute of Technology (ETH), where he lectures on aquatic physics and tracer hydrology in the Department of Environmental System Sciences. He is senior scientist at the Department of Water Resources and Drinking Water of the Swiss Federal Institute of Aquatic Science and Technology (Eawag) where he leads the Environmental Isotopes research group. His research extensively uses noble gases as tracers in aquatic environments, such as fluid inclusions in stalagmites, the porewater of unconsolidated lacustrine sediments and aquifers.

Red River near Van Phuc, Vietnam: Surface water started to infiltrate into the Holocene aquifer as a result of Hanoi's increasing groundwater abstraction.



Simulation results illustrating the reactive transport of tritium, helium and arsenic from the Red River into the Holocene aquifer underlying Van Phuc village.