Use of helium as an artificial tracer to study surface water/groundwater exchange

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Abstract

Groundwater - surface water interactions (SGI) fundamentally control groundwater recharge. The according dynamics are, thus, key for sustainable (drinking) water management. SGI are particularly relevant in the context of climate change and re-naturalization of canalized rivers, which might affect the availability and quality of groundwater pumped near streams. SGI are often not directly observable due to their complex spatial and temporal patterns. To complement the few available tracer methods (dye, electric conductivity, heat, etc.) to analyze SGI, we developed a novel method to quantify riverine groundwater recharge by using helium (He) as an artificial tracer.

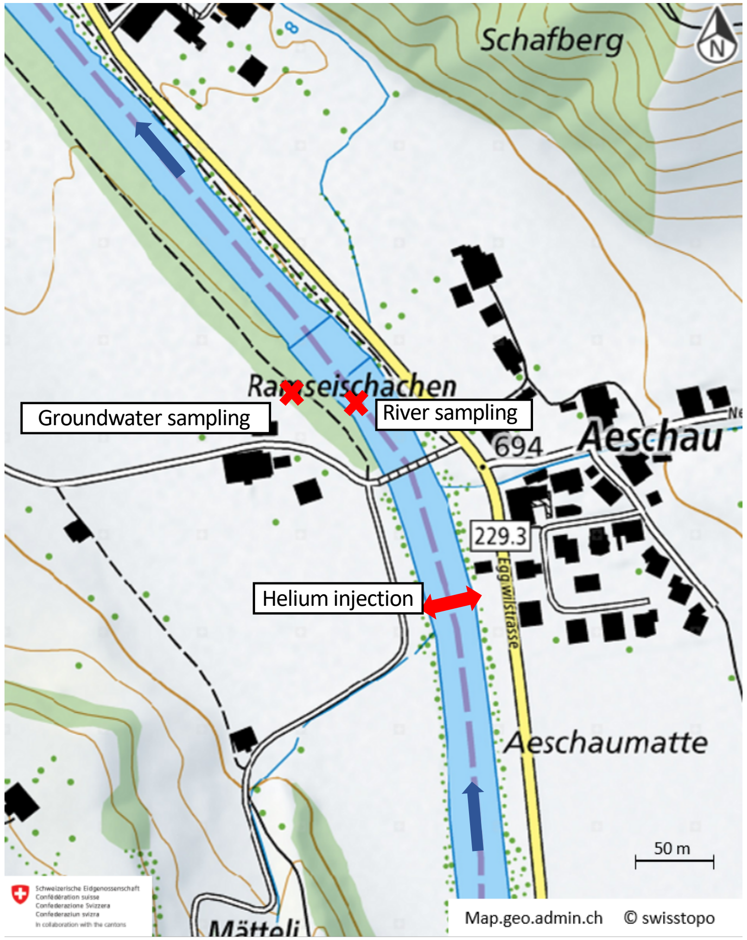
We injected gaseous He into a Swiss pre-alpine river (river Emme, canton of Berne) through perforated tubing which was placed on the riverbed. Dissolved He (as well as Ar, N2 and O2) concentrations were continuously monitored in the river (200 m downstream of the injection point) and in a piezometer (30 m away from the river) using a portable mass spectrometer allowing quantitative gas determination under field conditions (miniRUEDI, gas-equilibrium membrane-inlet mass spectrometer (GEMIMS), Gasometrix GmbH, Brennwald et al. (2016)). The He injection consisted of two pulses, each lasting around 8 hours, during which dissolved He became supersaturated by up to three orders of magnitude compared to the natural (atmospheric) He abundance in surface waters (concentration of air saturated water (ASW)). The two associated He pulses were clearly identifiable in the groundwater and appeared in the piezometer approximately one day after the injection phases. The measured He concentrations in the groundwater were four to six times higher than ASW.

In conclusion, our experimental setup allows the identification of the freshly infiltrated river water in an adjacent groundwater body in a concise, robust and straightforward manner. Our new method is also non-toxic and can thus often be implemented with minimal constraints. Such tracer methods provide useful observations to constrain physically based, surface water/groundwater models.

Experimental approach

Experiment: Injection of gaseous He into a river to achieve a dissolved helium concentration orders of magnitudes higher than natural background. Measurement of dissolved He downstream, both in river water and in groundwater.

Location: pre-alpine region of Emmental, BE, Switzerland.



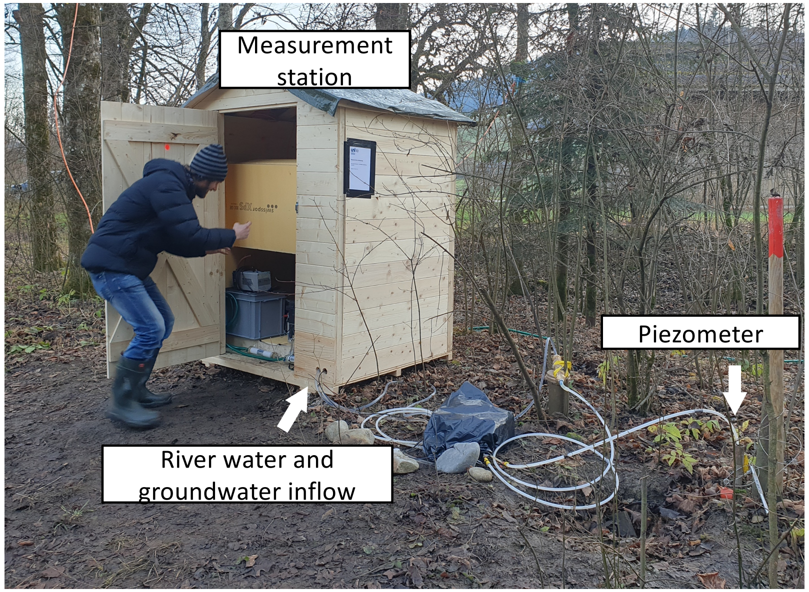
Injection

The tubing was attached to the riverbed and covered the entire width of the riverbed

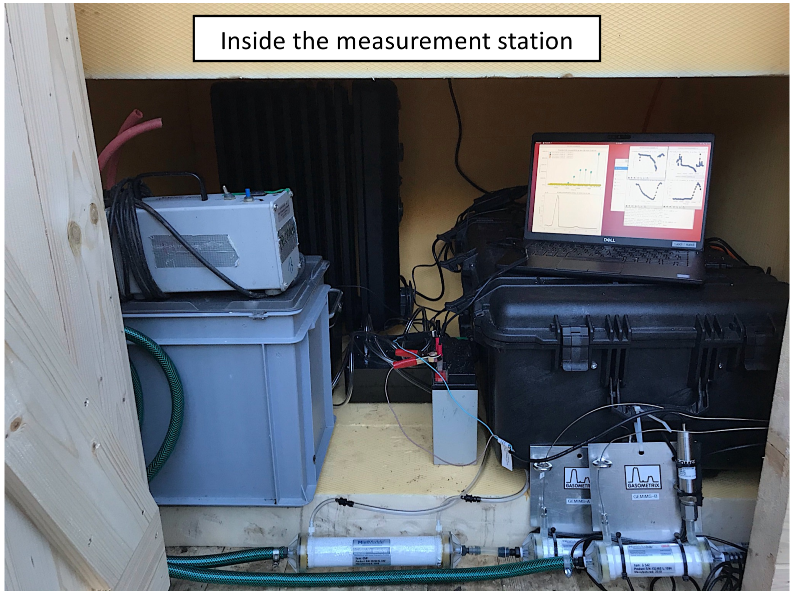
Two injection pulses, each lasting around 8 hours

We used perorated tubing connected to helium gas tanks

Dissolved gas concentration measurement

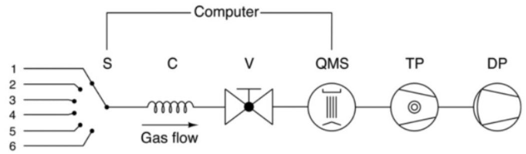


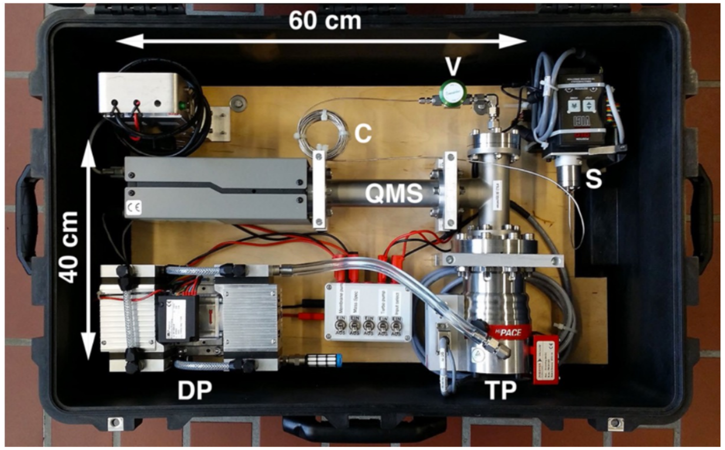
We measured both riverine water and groundwater.



We used a portable gas exchange, membrane-inlet mass spectrometry setup (GEMIMS) which provides countinuous field measurement.

The miniRuedi



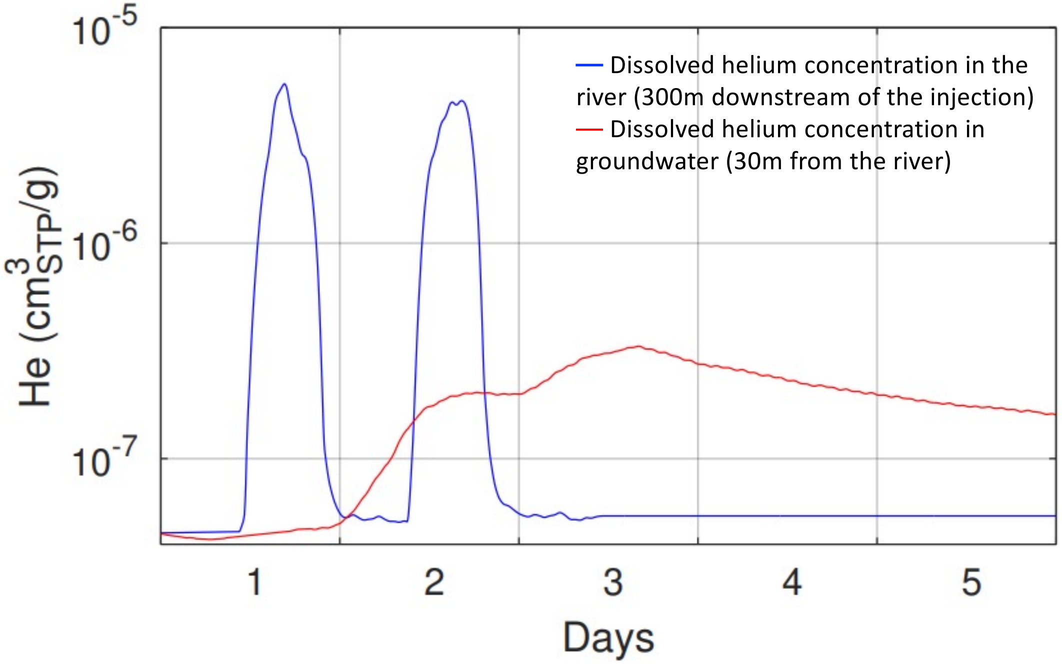


Schematic overview (left) and photo (right) of the miniRuedi mass-spectrometer system (*Brennwald, M et al. (2016)*): 6-port inlet selector valve (S), capillary (C), inlet valve (V), quadrupole mass spectrometer (QMS), turbomolecular pump (TP), and diaphragm pump (DP). The inlet selector valve and the quadrupole mass spectrometer are controlled by a computer. The photo shows the miniRuedi mounted in a wheeled hardshell suitcase for transport and protection.

A solubility equilibrium is established between the sampling water and a gas phase separated by this gas-permeable membrane. This membrane is connected to the portable gas spectrometer by one of its capillaries.

Results

Dissolved helium concentration in river water and groundwater



The injection consisted of two pulses, each lasting around 8 hours

300 meters downstream of the injection point, the dissolved helium concentrations of the river water (blue) and the groundwater (red) were one to two orders of magnitude higher than natural background concentrations.

The peak travel time from the river to the piezometer is approximately one day. Two separate He peaks were clearly visible in the piezometer.

Conclusions

- Our method allowed the identification of the freshly infiltrated river water in an adjacent groundwater body in a concise, robust and straightforward manner.
- Such tracer methods provide useful observations to constrain physically based, surface water/groundwater models
- The injection method can be improved by using permeable silicone tubing. This would allow longer injection using much less gas.

Articles and links

- Brennwald, M. S., Schmidt, M., Oser, J., and Kipfer, R. (2016). A portable and autonomous mass spectrometric system for on-site environmental gas analysis. *Environmental Science & Technology*, 50(24):13455–13463. PMID: 27993051.

- Morgan Peel's presentation at Goldschmidt2021 Lyon France, Session 11b: Innovative use of (gas) tracers in aquatic systems, *Using Helium as artificial tracer to characterize surface water - groundwater interactions*.