Untangling transient groundwater mixing and travel times with noble gas time series and numerical modeling

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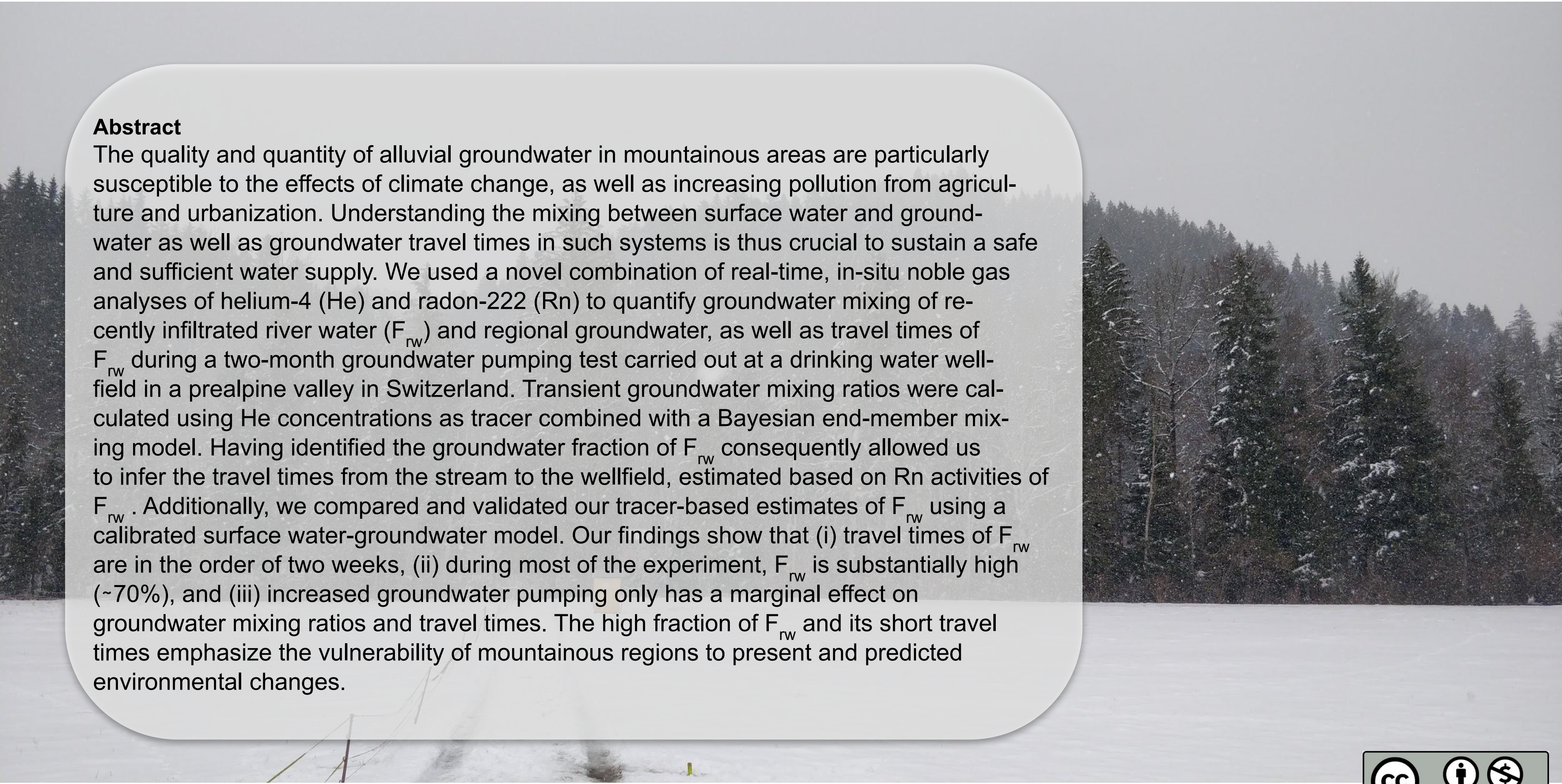


Abstract

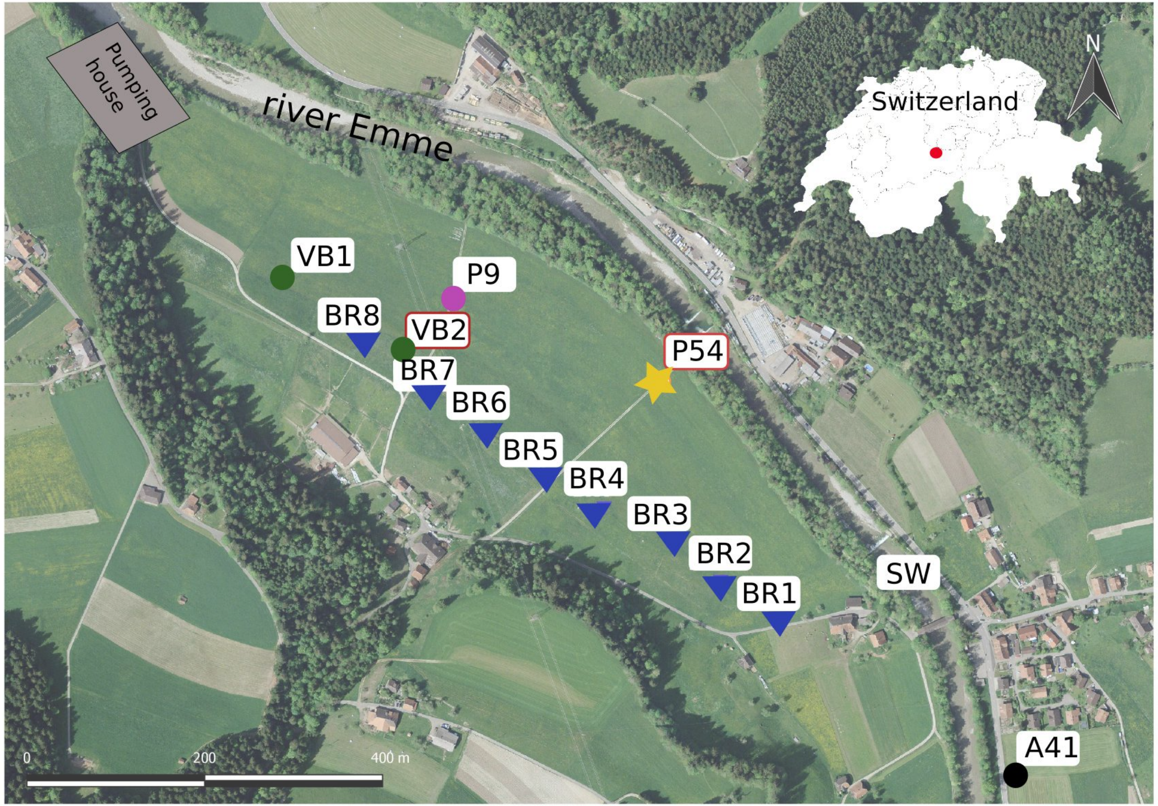
The quality and quantity of alluvial groundwater in mountainous areas are particularly susceptible to the effects of climate change, as well as increasing pollution from agriculture and urbanization. Understanding the mixing between surface water and groundwater as well as groundwater travel times in such systems is thus crucial to sustain a safe and sufficient water supply. We used a novel combination of real-time, in-situ noble gas analyses of helium-4 (He) and radon-222 (Rn) to quantify groundwater mixing of recently infiltrated river water (F_{rw}) and regional groundwater, as well as travel times of F_{rw} during a two-month groundwater pumping test carried out at a drinking water wellfield in a prealpine valley in Switzerland. Transient groundwater mixing ratios were calculated using He concentrations as tracer combined with a Bayesian end-member mixing model. Having identified the groundwater fraction of F_{rw} consequently allowed us to infer the travel times from the stream to the wellfield, estimated based on Rn activities of F_{rw} . Additionally, we compared and validated our tracer-based estimates of F_{rw} using a calibrated surface water-groundwater model. Our findings show that (i) travel times of F_{rw} are in the order of two weeks, (ii) during most of the experiment, F_{rw} is substantially high (~70%), and (iii) increased groundwater pumping only has a marginal effect on groundwater mixing ratios and travel times. The high fraction of F_{rw} and its short travel times emphasize the vulnerability of mountainous regions to present and predicted environmental changes.

Introduction

- Age-dating tracers are valuable tools to better understand and protect groundwater resources.
- Interpreting such tracers is, however, inherently challenging because every water sample consists of a mixture of waters with various ages.
- We present an approach to untangle groundwater mixing and travel times!

What is the fraction and travel time of recently infiltrated river water of an alluvial aquifer?

Study Site: Emmental, CH



Alluvial aquifer in a pre-alpine valley used for drinking water supply of Bern.

Figure shows the river Emme, the pumping well gallery (BR1-BR8), two newly installed pumping wells (VB1 and VB2), piezometers P54, P9, the background well A41 and the pumping house.

Environmental changes impacting the region

Abo

Den Fischen geht es schlecht – vor allem im Emmental

Im ganzen Kanton trocknen die Bäche aus. Besonders betroffen sind solche im Emmental. Sogar in der Emme musste ausgefischt werden.

Susanne Graf
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Abo

Die Trockenheit greift um sich

Bäche werden zuhauf ausgefischt, die Gefahr von Waldbränden steigt von Tag zu Tag. Doch noch ist die Situation nicht gleich prekär wie in anderen Kantonen.


Streambed in summer 2019, source: Berner Zeitung (BZ)

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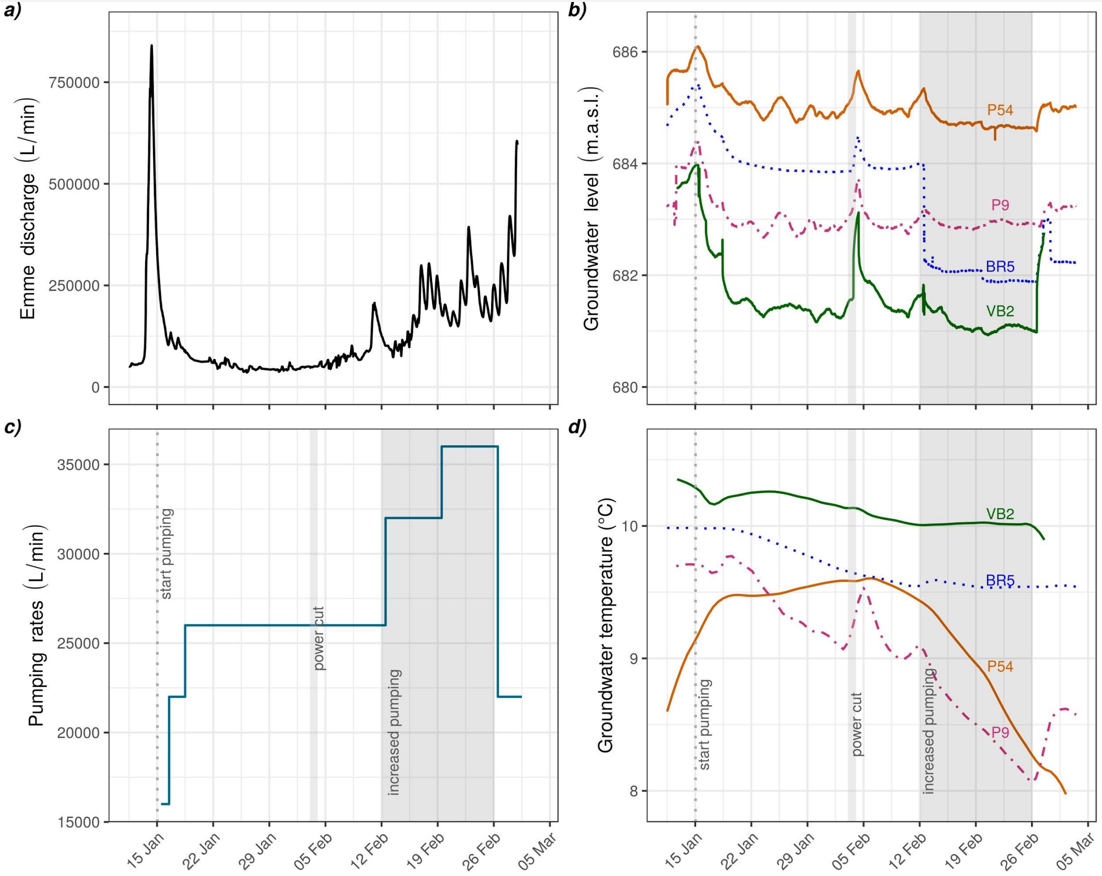
Abkühlung für die Fische

Seit Freitag pumpt der Wasserverbund Region Bern kaltes Grundwasser in die nur noch spärlich fliessende Emme – in der Hoffnung, damit Forellen zu retten.

Susanne Graf
Publiziert am 27. Juli 2018 um 19:09 Uhr

Controlled Forcing of the System through a Pumping Test



Prevailing conditions during the the 2 months experiment. The gray segment indicates the period of maximum pumping. Light gray bands indicate an electric power cut occurring at the study site, which caused a shutdown of all wells for ~12 hours.

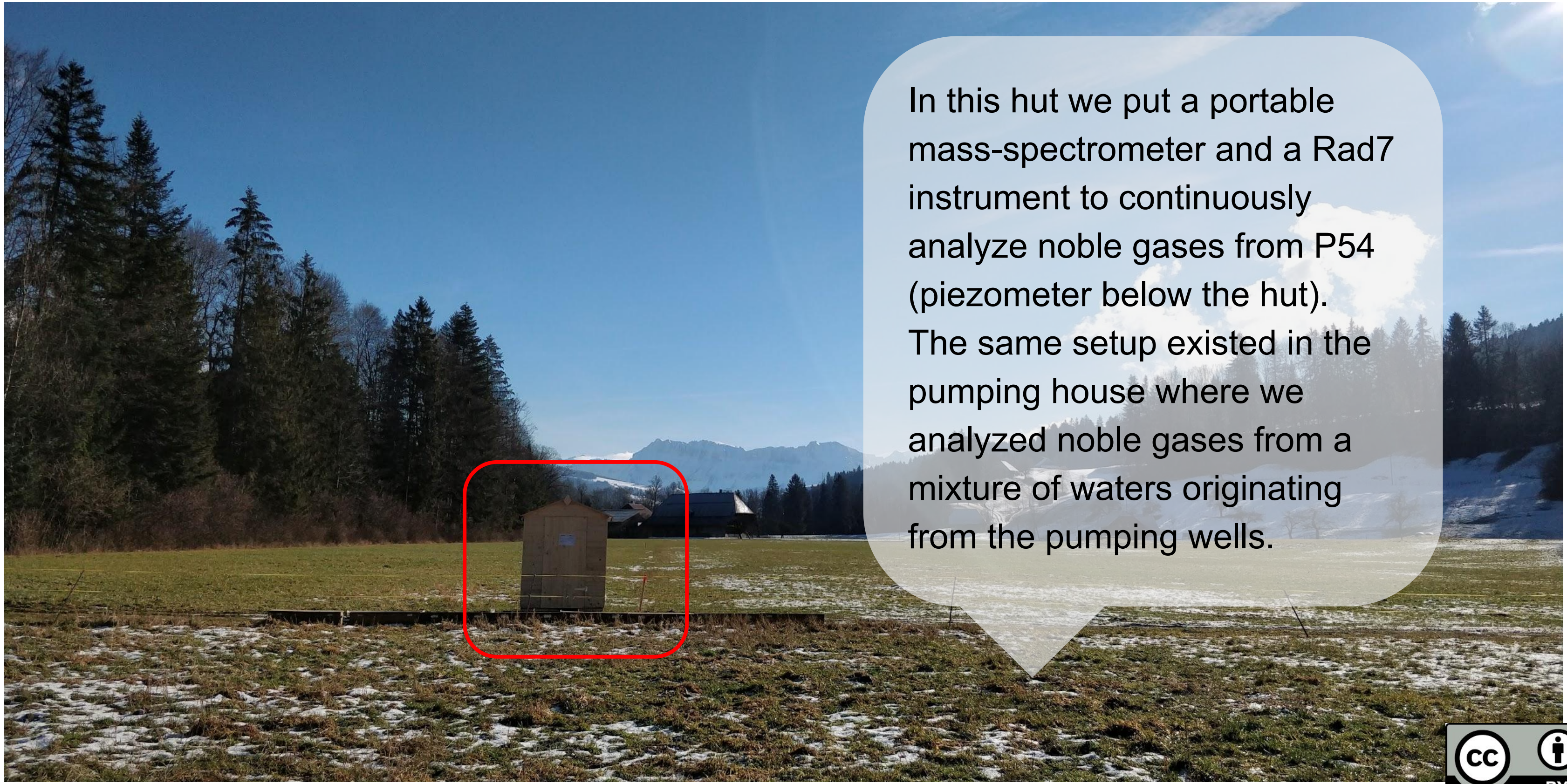
Methods I: estimate mixing ratios

- Tracer-based approach: quasi-continuous noble gas measurements of helium analyzed in water from piezometer P54 and water from the pumping house (i.e., a mixture of water originating from pumping wells), combined with a Bayesian end-member mixing model (end-member 1 = P54, end-member 2 = background well)

- Simulation-based approach: HydroGeoSphere & Hydraulic Mixing-Cell flow tracking tool

Mixing ratios between recently infiltrated river water (F_{rw})
and regional groundwater

Noble gas measurements



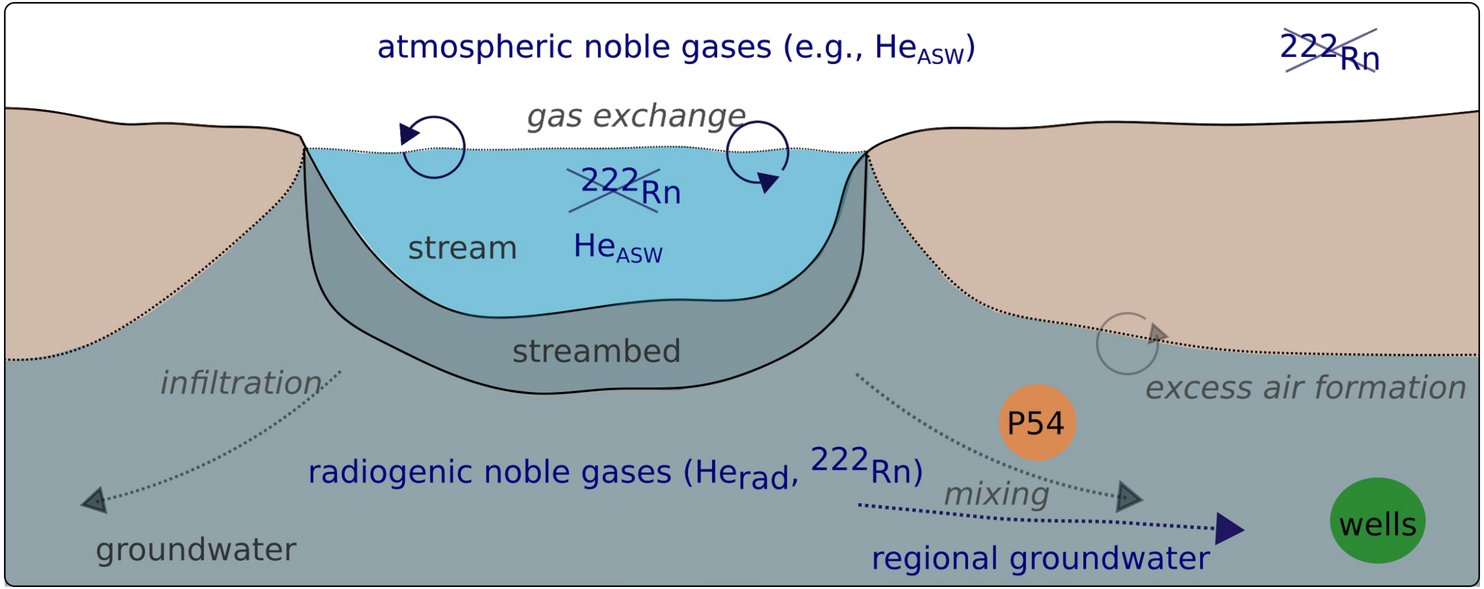
In this hut we put a portable mass-spectrometer and a Rad7 instrument to continuously analyze noble gases from P54 (piezometer below the hut). The same setup existed in the pumping house where we analyzed noble gases from a mixture of waters originating from the pumping wells.

Methods II: estimate travel time

Quasi-continuous radon measurements at P54 and the pumping house as well as grab sampling of the stream and in the background well (A41)

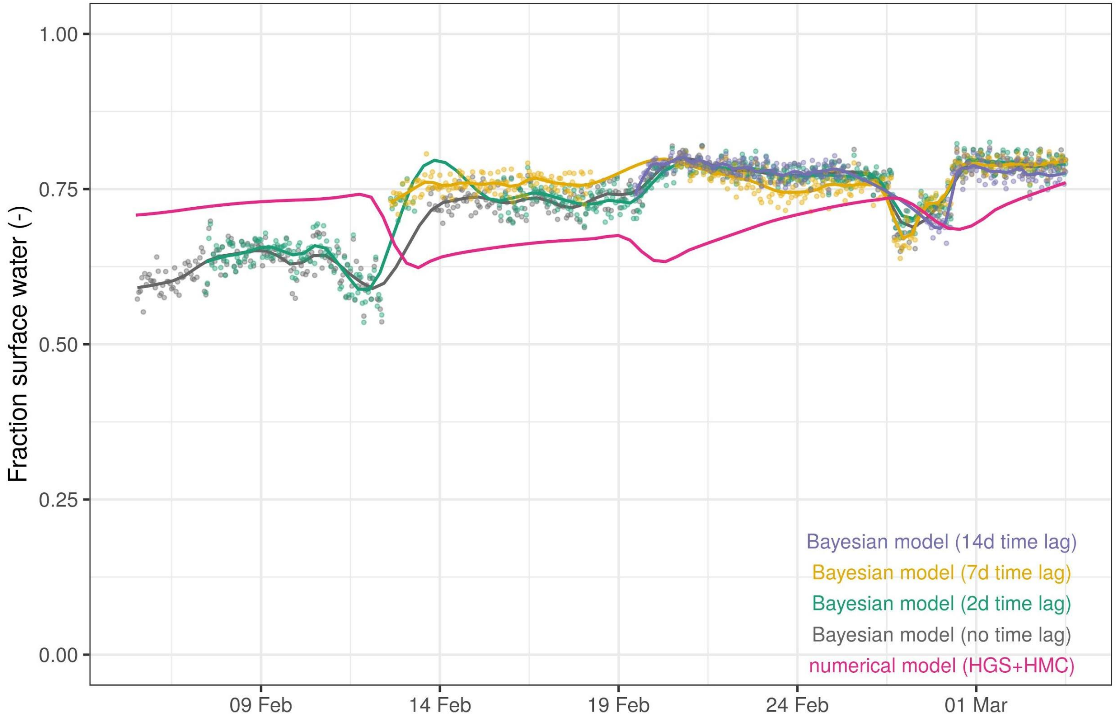
Mean travel time of F_{rw} based on Rn in-growth

Conceptual Model



Conceptual model of processes (in italic) affecting the noble gas composition of groundwater: the helium-4 concentration of the stream is solely affected by gas exchange with the atmosphere; once stream water infiltrates, helium-4 is added due to excess air formation. The admixture of terrigenic helium-4 enriched older groundwater causes a further increase in helium-4 concentrations. Radon starts to accumulate once streamwater infiltrates.

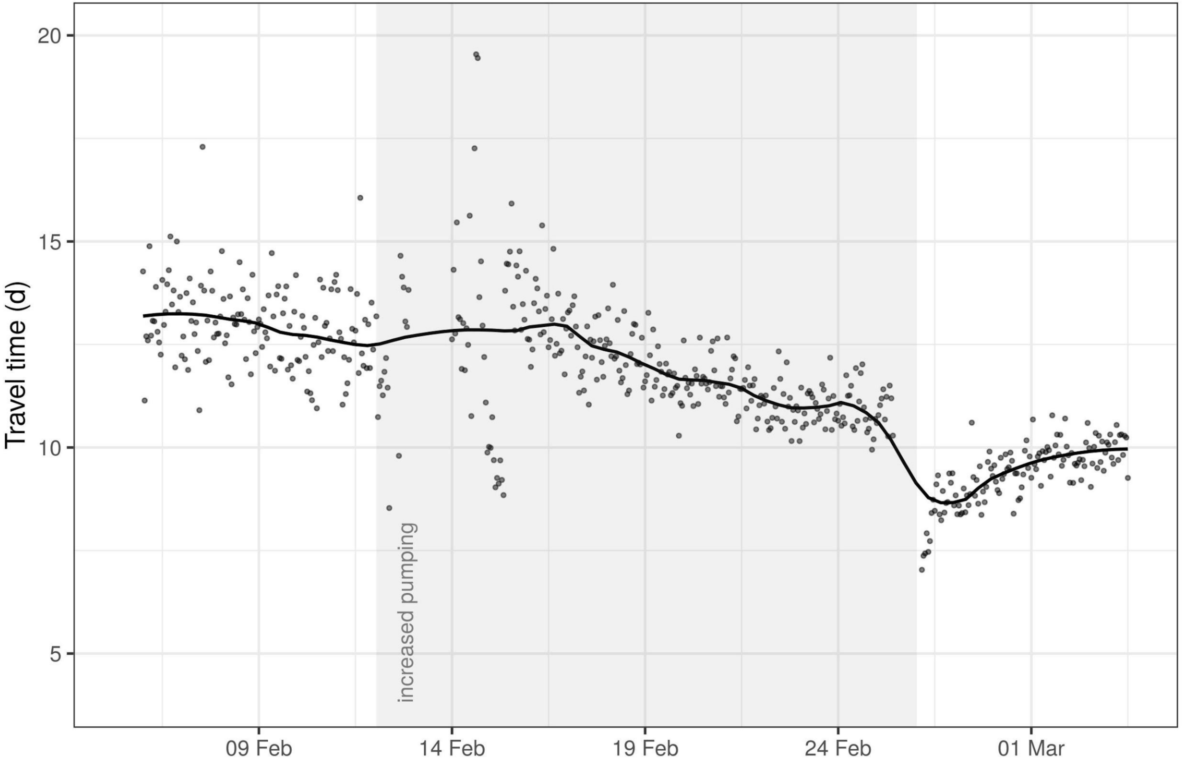
Results & Discussion I



Comparing simulated and tracer-based mixing ratios of the recently infiltrated water fraction. Note that travel times from P54 to the wellfield are unknown. We thus simulated a range of plausible travel times (0-14 days). This approach showed that any imposed time lag has only a marginal effect on F_{rw}.

- ➔ Acceptable agreement between simulated and tracer-based mixing ratios
- ➔ No considerable influence of increased pumping
- ➔ F_{rw} is substantially high (~70%)

Results & Discussion II



Knowing the fraction of river water (i.e., F_{rw}) present in the wellfield, we can use the Rn activities of F_{rw} to infer the travel times of F_{rw} to the pumping house.

- ➔ Mean travel times of F_{rw} are in the order of two weeks
- ➔ Travel times generally decrease over the duration of the experiment (most likely an effect of increasing discharge)
- ➔ Travel times of F_{rw} can be as low as 7±1 days

Conclusions

- ➔ Increased groundwater pumping only has a marginal effect on groundwater mixing ratios and travel times, indicating a low sensitivity of F_{rw} to groundwater pumping.
- ➔ Travel times of F_{rw} are generally low (~13±2 days) making it susceptible to increasing pollution.
- ➔ F_{rw} represents ~70% of alluvial groundwater rendering the drinking water supply system susceptible to the effects of global warming.

Acknowledgments

MARIE CURIE ACTIONS

hypo TRAIN

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