Quantification of groundwater inflow in a complex river system (Ammer, Tübingen, SW Germany) using environmental and wastewater-derived tracers

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Aim and research question

Aim: Characterization of groundwater-surface water (GW-SW) interactions in a heavily modified and geologically complex river system

Research questions:

1. Can GW inflow be quantified using environmental tracers in a karstified river system?
2. Are "quasi-conservative" organic micropollutants emerging from WWTP suitable tracers for modelling groundwater inflow?

Methods

Sampling/Measurement: 6 km reach along Ammer River

- Environmental tracers (^{222}Rn, SO_4^{2-} , Cl^-, Mg^{2+}) and electrical conductivity at 44 locations in groundwater and surface water
- Quasi conservative organic micropollutants (carbamazepine, tramadol) at 11 locations following a Lagrangian sampling scheme in river, additionally groundwater samples
- Discharge measurements (ADCP + ADC)

Modelling: Quantification of GW inflow using environmental tracers and organic micropollutants with an implicit finite element mass balance model (FINIFLUX[1])

Results

Radon

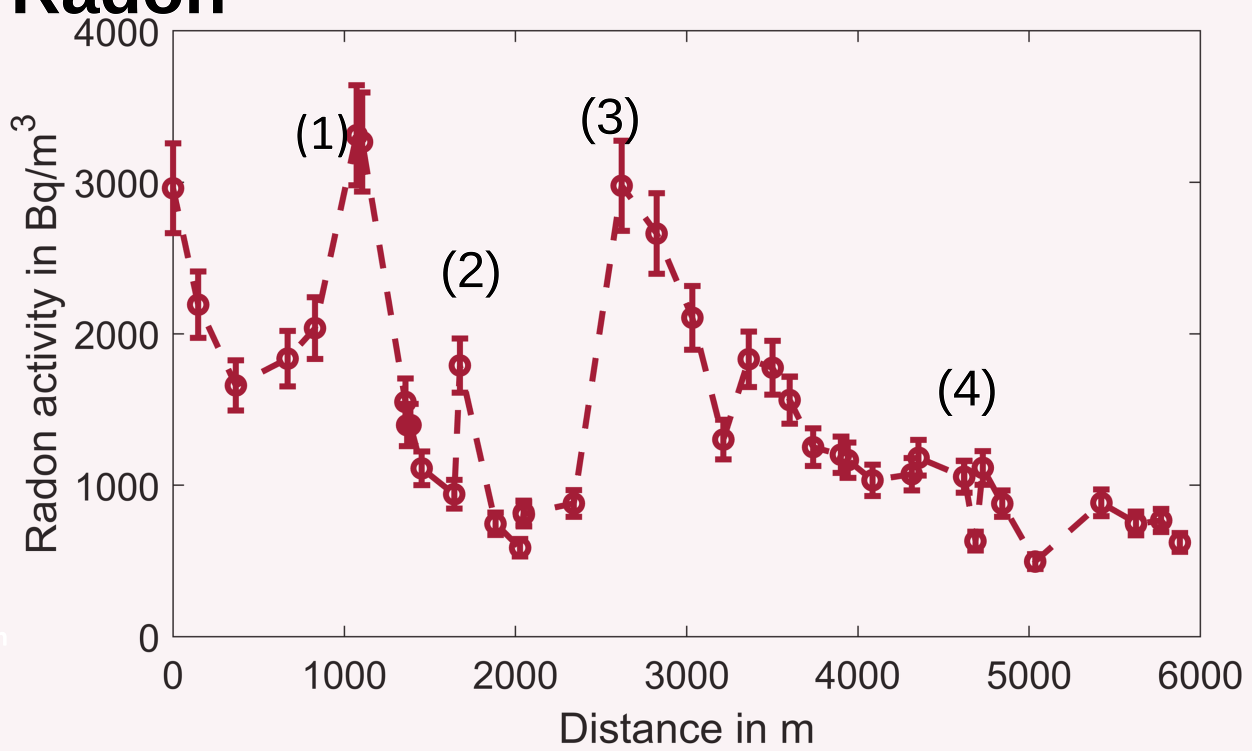

Fig. 1: ^{222}Rn activities along the investigation reach (numbers represent sampling locations, cp. Fig. 4):

- Rising ^{222}Rn activities indicate major local GW inflows
- Major increase at location (3): "Schwärzenbrunnen"
- Decline due to degassing and radioactive decay

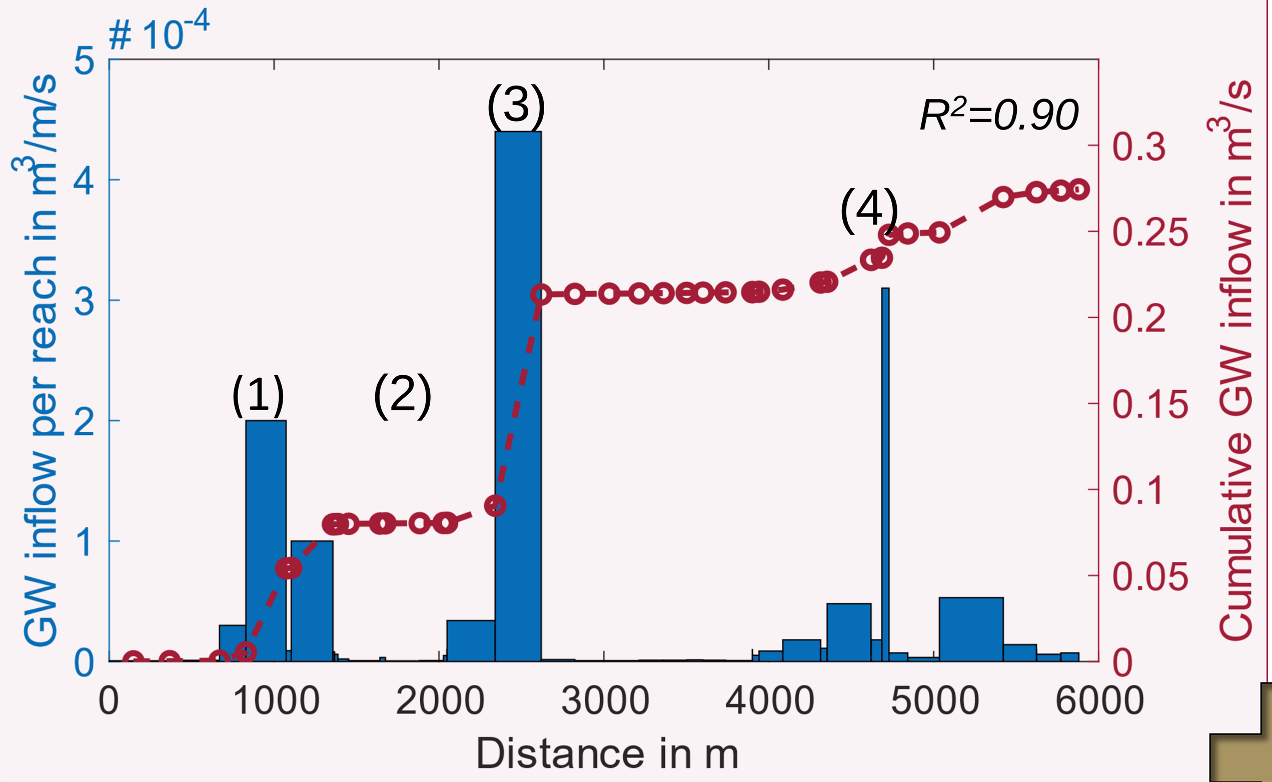

Fig. 2: Modelled GW inflow using FINIFLUX based on ^{222}Rn results:

- Cumulative inflow of 0.27 $\frac{m^3}{s}$ (~ $\frac{1}{3}$ of total Q)
- Modelling indicates that inflow from Schwärzenbrunnen (3) is higher compared to other modelled ^{222}Rn peaks
- FINIFLUX disregards some activity changes (2)

Organic contaminants

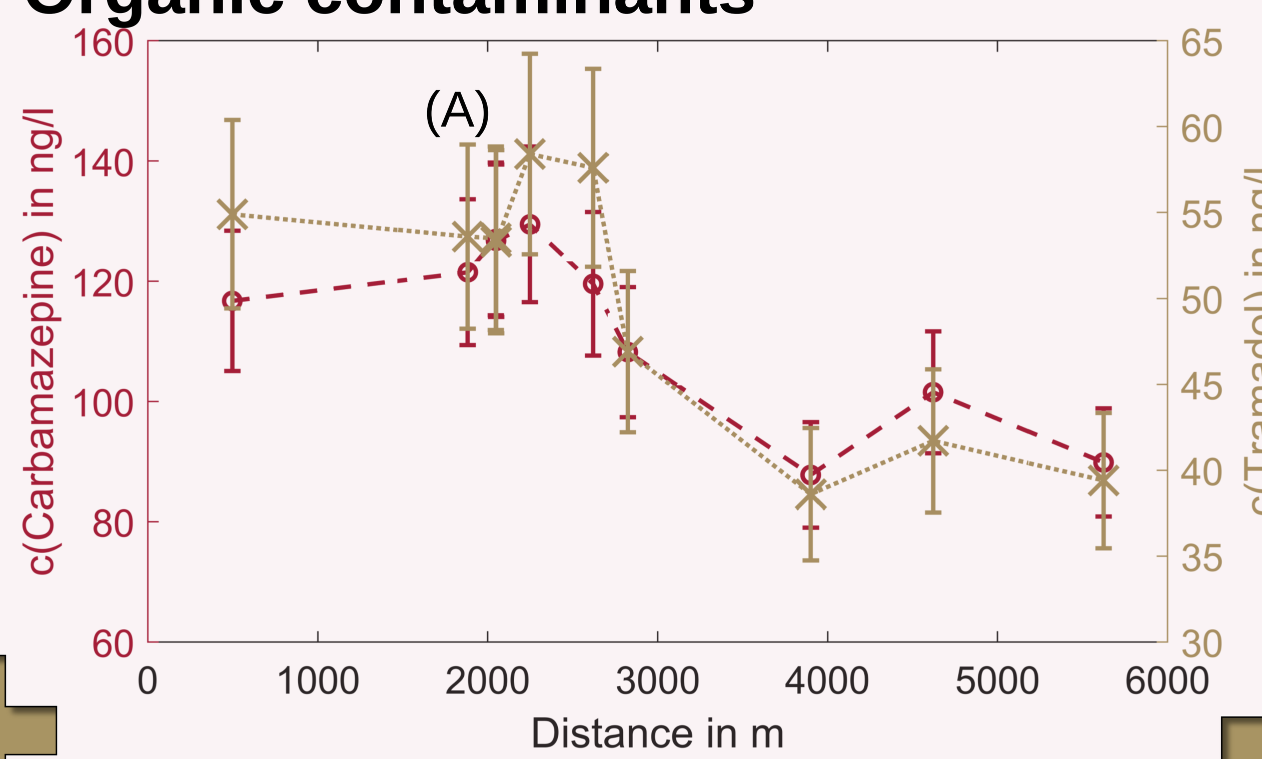

Fig. 3: Pollutant concentrations along the investigation reach:

- Modelling with FINIFLUX difficult due to abundance in GW
- Declining trend of contaminants indicates dilution from GW
- Rising concentrations of contaminants (A) indicate inflow by contaminated GW

Geological features

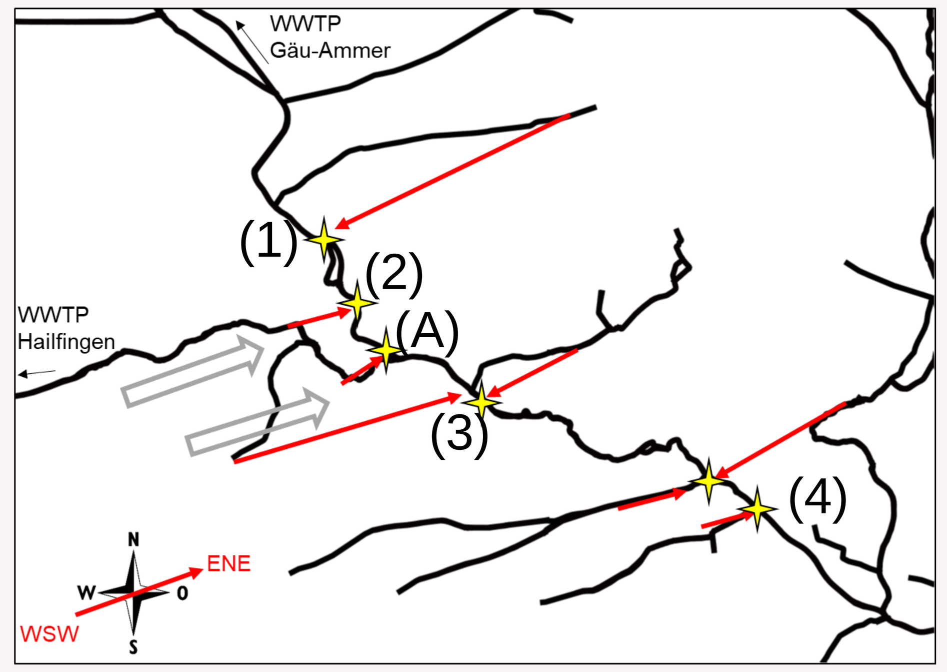

Fig. 4: Conceptual model for main inflows:

- Extension of fault zones alongside tributaries (WSW-ENE) match (bedrock) steps in the channel (✧)
  - ➢ Main GW inflows at karstified fractures (→)
- GW may include wastewater from WWTP Hailfingen (A) → rising organic micro-pollutant concentrations in the river

Conclusion

1. Only ^{222}Rn based modelling results in reasonable estimations of GW inflow despite uncertainties in degassing and endmember concentrations
2. For other tracers, poor optimization due to small concentration differences between SW & GW
3. Only multitracer approach can account for complexity of river systems and shows origin of GW
4. GW inflow to the Ammer River controlled by geological features (e.g. faults/ fractures)

References

[1]Frei, S., & Gilfedder, B. S. (2015). FINIFLUX: An implicit finite element model for quantification of groundwater fluxes and hyporheic exchange in streams and rivers using radon. *Water Resources Research*, *51*(8), 6776-6786

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