Groundwater recharge estimates in agriculturally managed site in NE Germany: combining Cosmic ray neutron sensing and soil hydrological modelling

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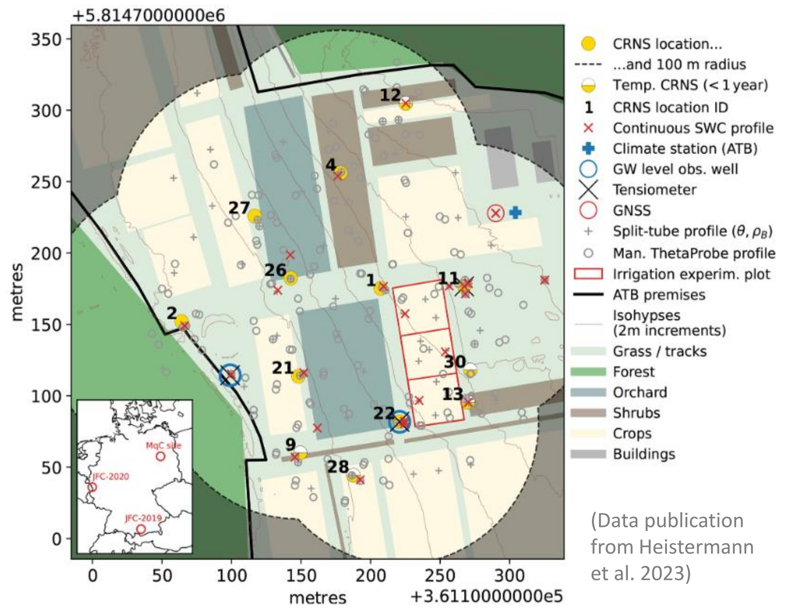
Methods and data

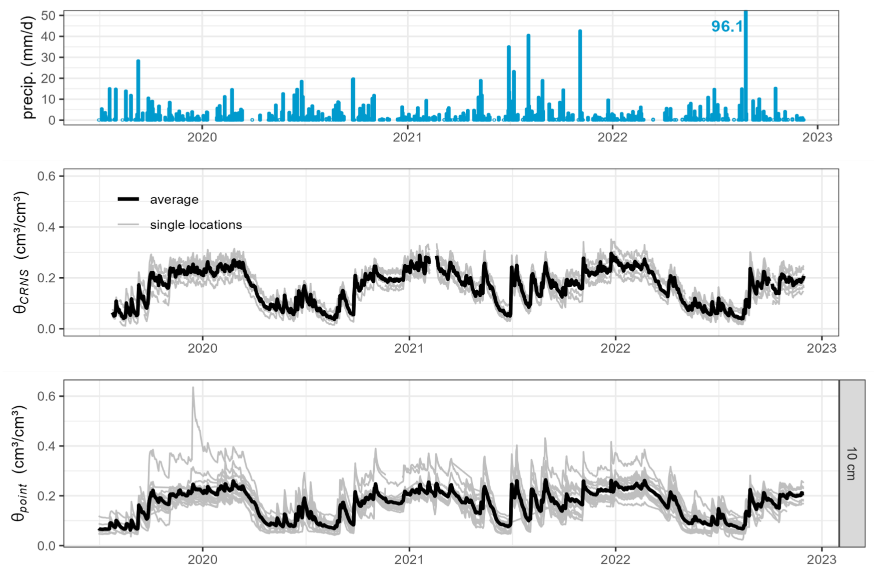
Marquardt Cluster, Potsdam, NE Germany

- Area 10ha; diversity of agricultural plots
- Sandy soils
- Gentle hillslope over a glacial till aquifer
- Distance to water table 1.5 – 10 m
- Subsurface water storage monitoring:
  - 13 CRNS
  - 23 point-SM-profiles with different measurement depths

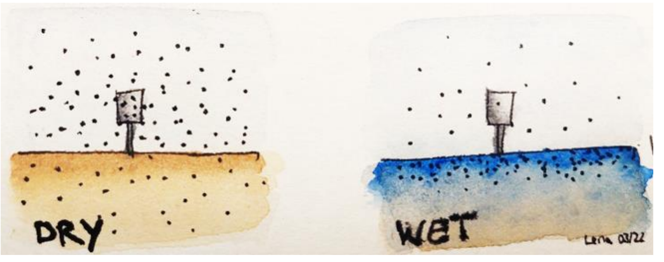


(Data publication from Heistermann et al. 2023)

Map of the study site



Precipitation, soil moisture from CRNS and from point sensors



Basic principle of CRNS. Neutrons scattered back from the soil are counted in the passive detector, neutron abundance depends on SM state

Cosmic-ray neutron sensing (CRNS)

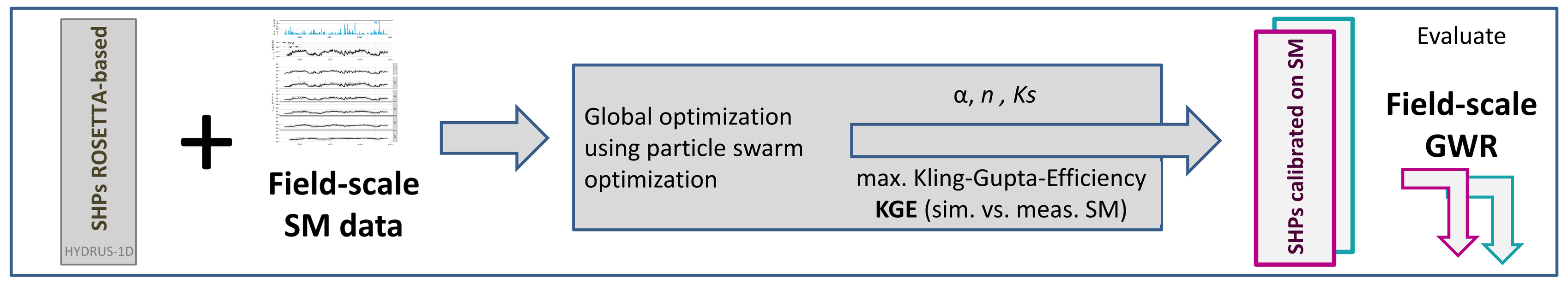
- Passive neutron probe to measure **soil moisture (SM)**
- Non-invasively, installed above ground
- Inverse relationship neutrons ~ SM
- Integral field water content
  - Depth of 15 – 80 cm
  - Horizontal radius 150 -240 m

Model setup and calibration

Calibration data

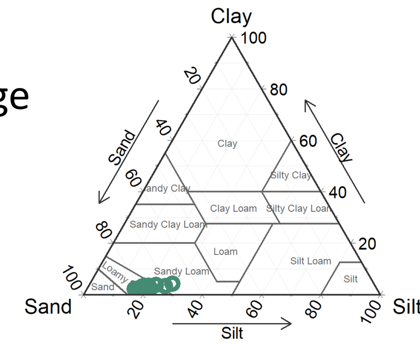
- A **combination of CRNS and point-scale SM** observations provide field-scale **representative calibration data**
- CRNS SM from different locations showing comparable dynamic between each other
- Higher variability in point sensors show subsurface heterogeneity

Calibration approach



HYDRUS-1D Model setup

- Daily input, atmospheric boundary, free drainage
- 6-month spin-up period
- 200 cm model domain, discretization 1cm
- Van-Genuchten-Mualem model (initial **soil hydraulic properties (SHPs)** derived from texture data using ROSETTA (Zhang and Schaap 2017)



Layer (cm)	θr (cm³/cm³)	θs (cm³/cm³)	α (1/cm)	*n* (-)	*Ks* (cm/d)	*l* (-)
0- 30	0.02	0.45	0.0258	1.75	185	0.5
31 – 200	0.03	0.38	0.0242	1.60	110	0.5

Initial SHPs for the two layered model

Aims and objectives:

Explore the potential of CRNS and soil hydrological modelling to derive **groundwater recharge (GWR)** estimates as downward water fluxes below the root-zone in a highly instrumented site

(i) Calibrate HYDRUS 1D with >3 years of CRNS and point scale SM

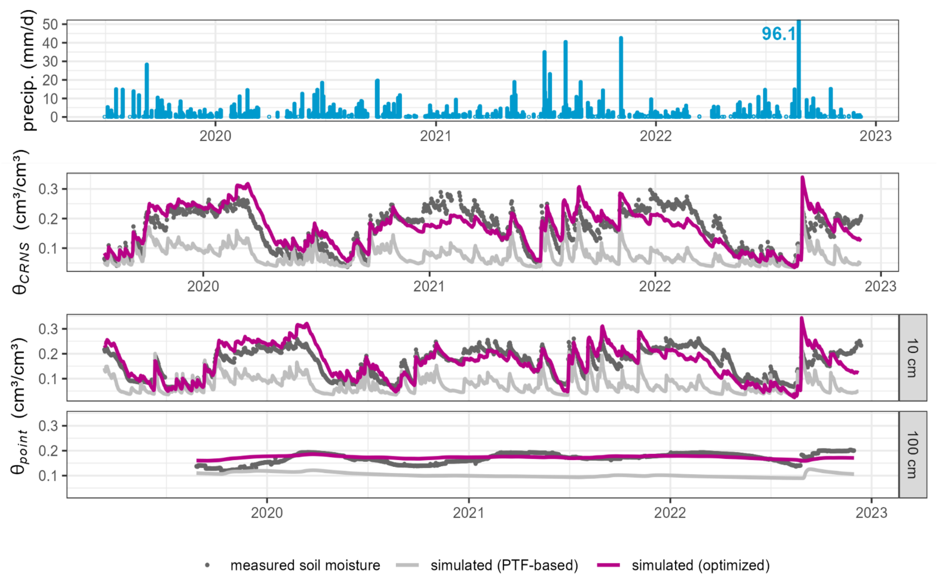
(ii) Assess influence of equifinality, spatial heterogeneity and vegetation properties on calibration result and GWR estimates

(iii) Based on a calibrated model assess long-term changes of GWR

Motivation: sustainable water supply from vadose zone passage

Calibration results

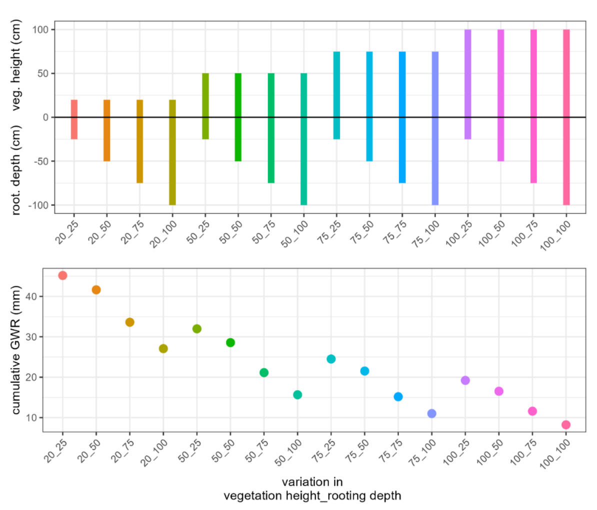
Calibration compared to initial estimate



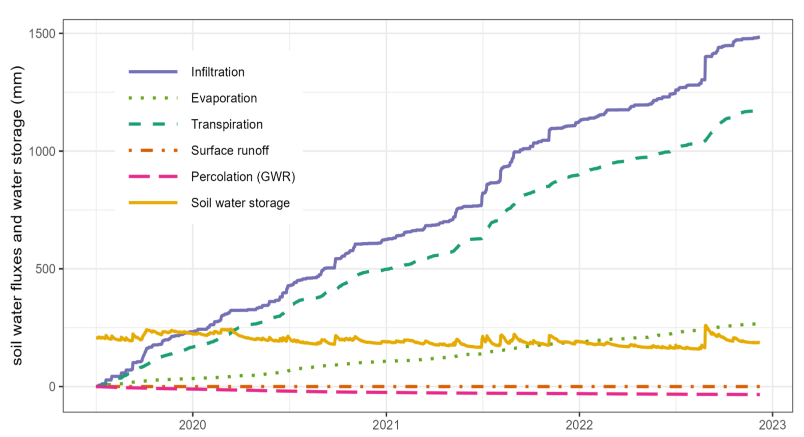
	KGE (-)	RMSE (cm³/cm³)
ROSETTA-based	0.23	0.10
SM-calibrated	0.73	0.04

Sensitivity to vegetation properties

- S-shape root water uptake
- Variation in vegetation height and rooting depth
- Constant over time



Exemplary water balance for 3 years

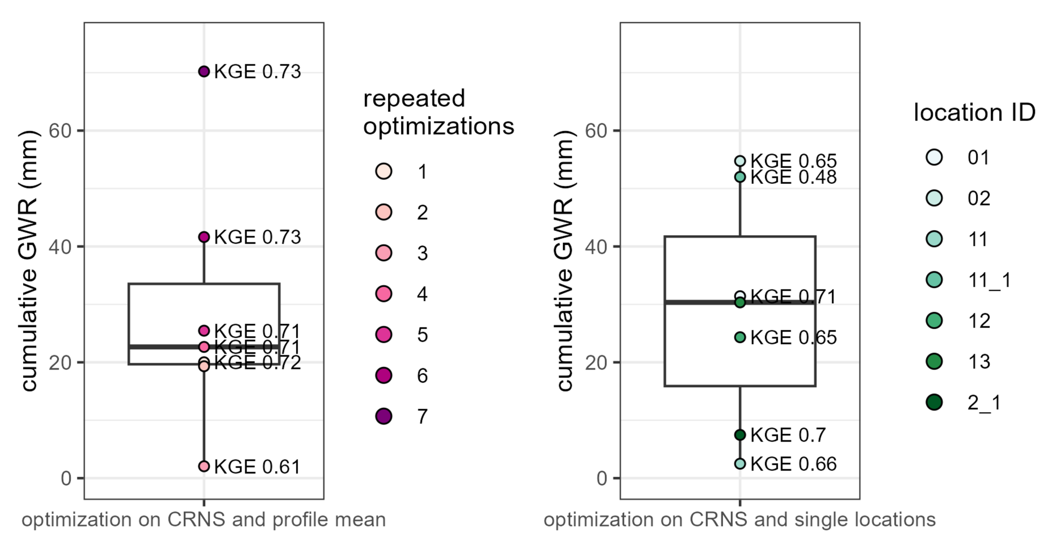


- ➢ Clear improvement after model calibration
- ➢ No surface runoff, high fraction of ET, low GWR
- ➢ Both, increased vegetation height and rooting depth reduce cumulative GWR to a similar extent
- ➢ Parameter ranges from equifinality smaller than from heterogeneity but similar range in GWR for both

Equifinality of calibration and spatial heterogeneity

- **Equifinality**: the same performance in the calibration from different parameter combinations: repeat calibration several times
- **Heterogeneity**: use single locations in calibration (in combination with CRNS) instead of mean soil moisture from sensor network

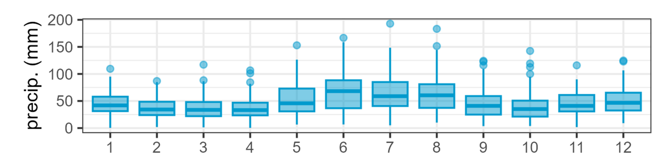
Lower KGE resulting in lower GWR estimates

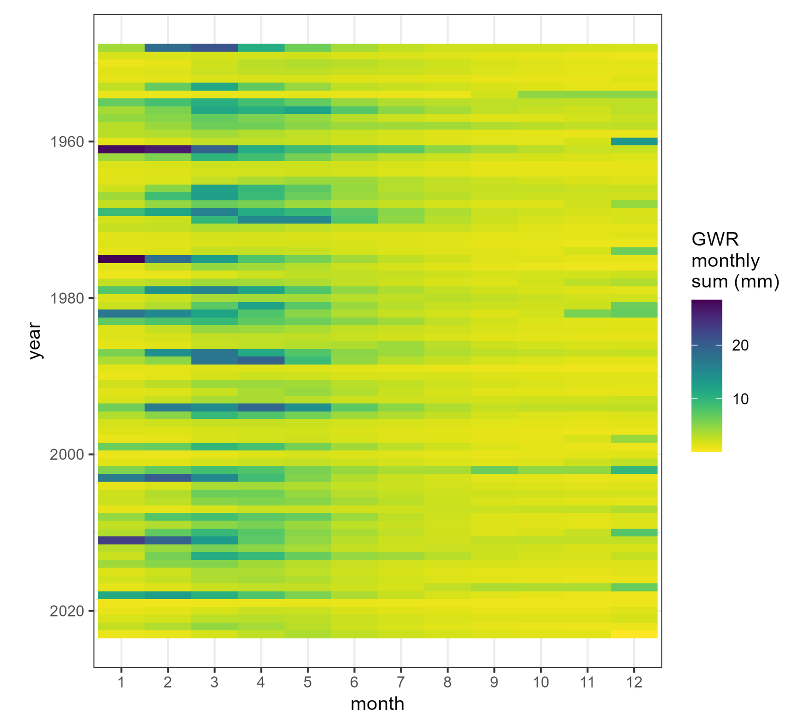


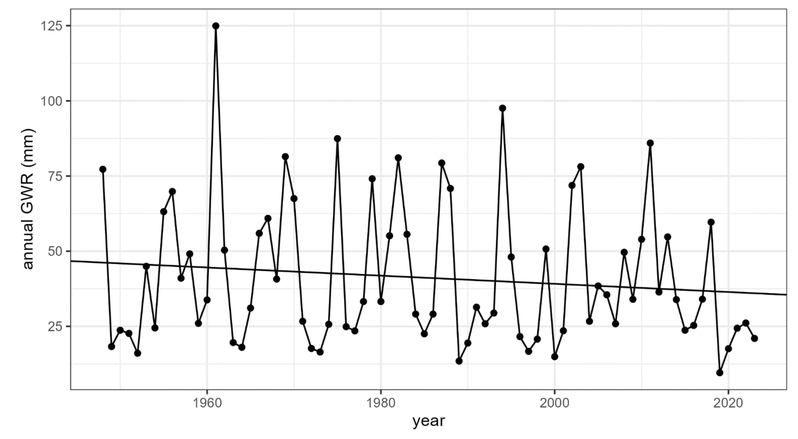
Simulated cum. GWR from single calibrations

Long term groundwater recharge

- Calibrated model, climate data Potsdam 1948 to 2023
- Main recharge period in winter to spring
- Declining linear trend (46 to 36 mm/year)







- ➢ Declining trend in deep water storage
- ➢ No clear change in pattern

CRNS provides hectare-scale water fluxes replenishing the storage of the vadose zone and aids GWR estimation

Outlook for model improvement and application:

- Calibration on models with varying vegetation properties
- Varying distance to groundwater
- Compare to other methods for GWR estimation at Marquardt
- Apply approach for regional estimates in Brandenburg, including deep vadose zones

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References

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