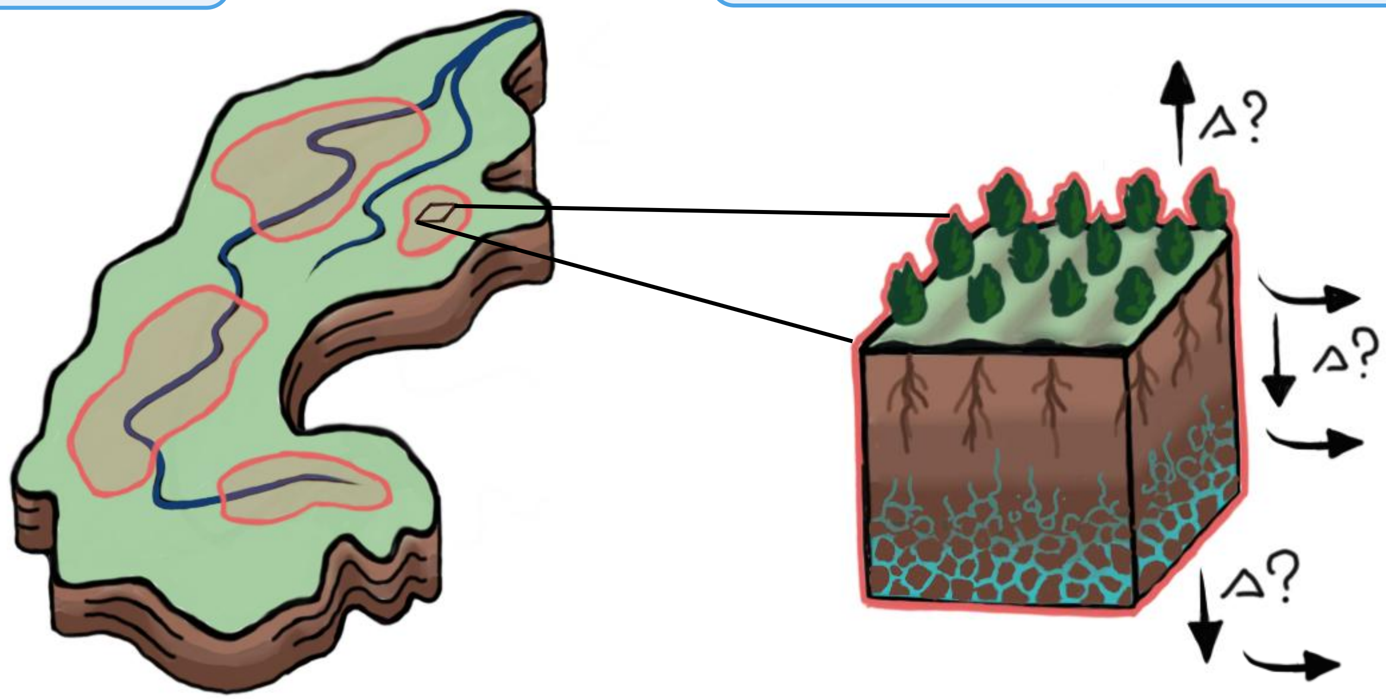
From Field to Catchment: Evaluating the Hydrological Effects of Soil Organic Carbon Increases

Malve Heinz[1,2,3], Annelie Holzkämper[1,2], Sélène Ledain[1], Pascal Horton[2,3], Rohini Kumar[4], Bettina Schaefli[2,3]

Assumption: Management adaptation leads to change in soil hydraulic properties

Expectation: Impact on states, fluxes, discharge and water balance

- \+ **Soil organic carbon**
- − **Bulk density**
- \+ **Sat. hydraulic conductivity**
- \+ **Plant available water**



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4 Hydrosystem modeling, UFZ Helmholtz-Centre for Environmental Research Leipzig, Germany

Sharing is encouraged

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Results: Impacts on states, fluxes, discharge and water balance:

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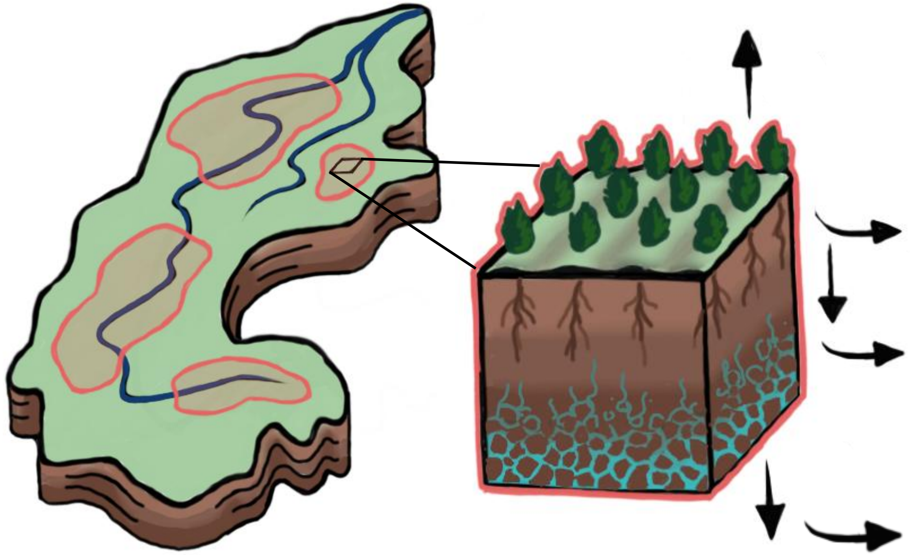

- \+ Actual evapotranspiration
- \+ Soil water content
- − Groundwater storage
- − Total runoff & discharge
- − Peak flows
- \+ Low flows

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Context

Increasing duration and magnitude of agricultural and hydrological droughts

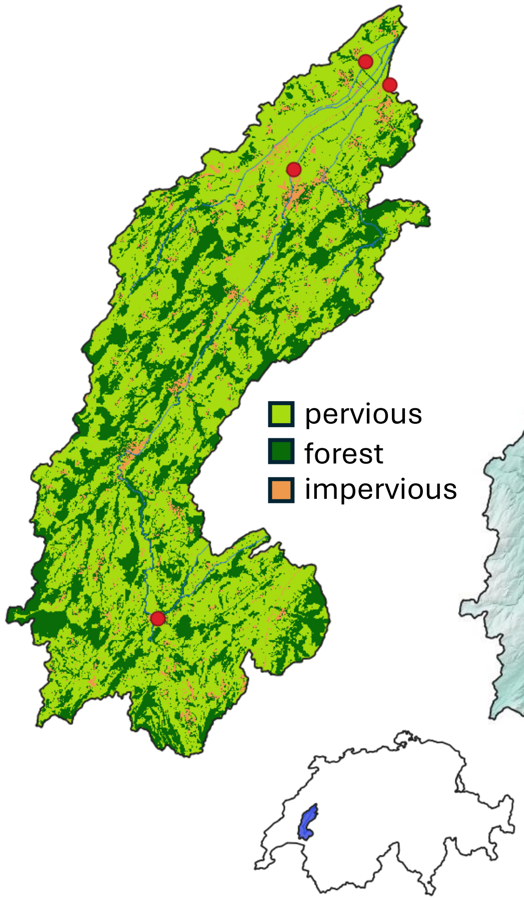
Declining yields and reduced irrigation possibilities

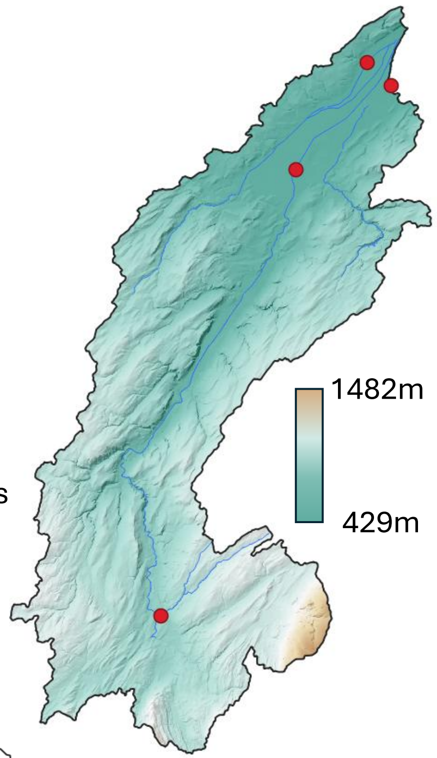
Management measures increasing soil organic carbon (SOC) can enhance soil water retention

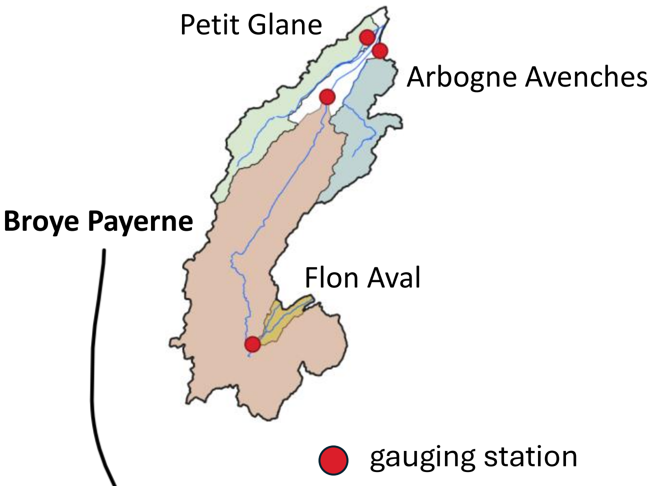
How would a large scale implementation of such measures affect hydrological processes at catchment scale ?

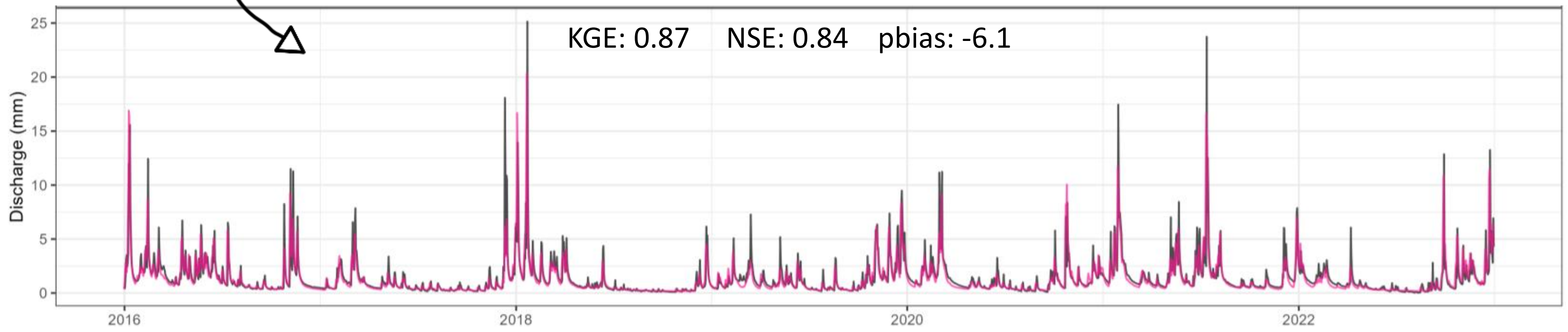
Case study and model

Broye catchment: lowland, mid-sized (~600km^2) with large share of agricultural use (~70%)









Mesoscale hydrological model mHM (Samaniego et al. 2010)
Open-source, process-based distributed, rainfall-runoff model.

Literature review: management

Management adaptations such as cover crops or organic amendments can lead to changes in soil hydraulic properties:

- **+ 0.65** to **1 %** mass Soil organic carbon **SOC** or increase by **7 to 220%**

  (Haruna et al. 2020, Hao et la. 2023, Blanco-Canqui et al 2009 , Blanco-Canqui et al 2023 & Shi et al. 2016)

- **10** to **20 %** decrease in bulk density **BD**

  (Haruna et al. 2020, Veetil et al. 2024, Hao et al. 2023, Blanco-Canqui et al 2009 , Blanco-Canqui et al 2023 & Shi et al. 2016)

- **40** to **360 %** increase in saturated hydraulic conductivity **Ksat**

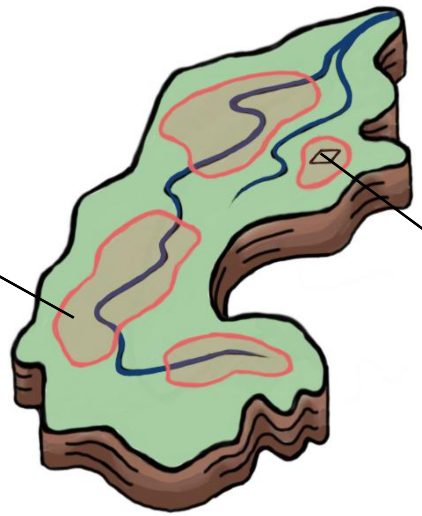
  (Rawls et al. 2004, Haruna et al. 2020, Veetil et al. 2024, Hao et al. 2023, Blanco-Canqui et al 2009 , Blanco-Canqui et al 2023)

- **4** to **65 %** increase in plant available water **PAW**

  (Haruna et al. 2020, Hao et al. 2023, Blanco-Canqui et al 2009 , Blanco-Canqui et al 2023 & Shi et al. 2016)

Implementation of management in the model (mHM)

„pervious“ landcover cells (e.g. cropland)



Required input for each cell: soil texture and bulk density

Default model run (no management)

SOC → BD

PTF: Manrique & Jones 1991

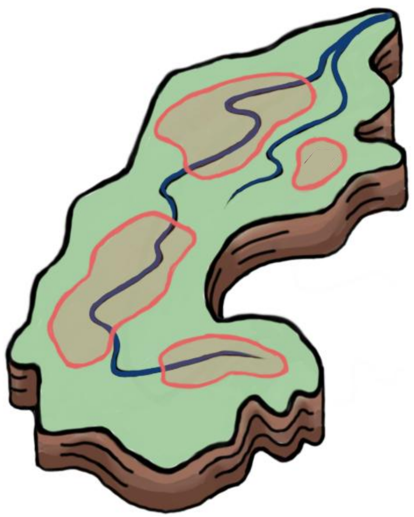
Management scenario run: +1% SOC (mass) for all pervious landcover cells

Δ SOC → Δ BD

PTF: Manrique & Jones 1991

Implementation of management in the model (mHM)

Impact of +1% SOC (mass) on key parameters:

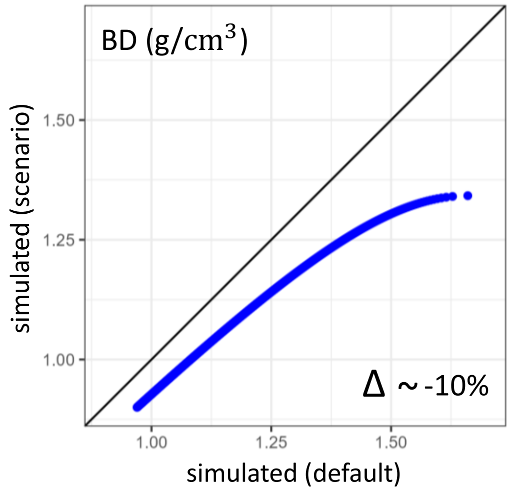


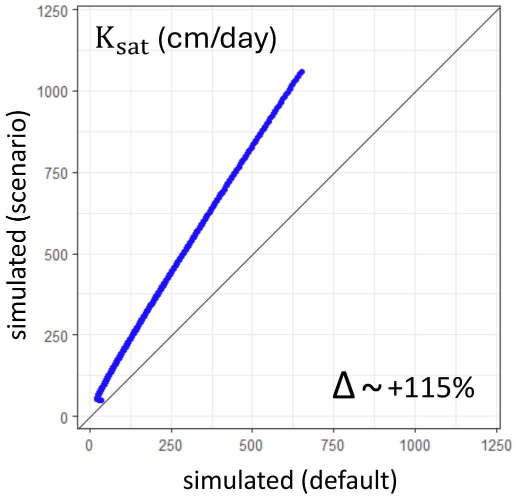
Δ SOC → Δ BD

PTF: Manrique & Jones 1991

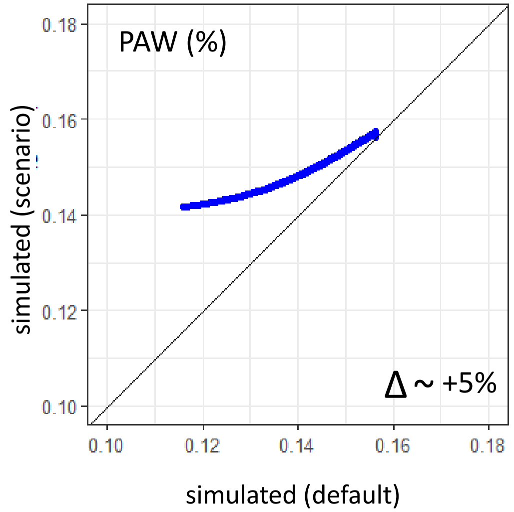
Sand
Clay
Δ SOC
Δ BD
→ Δ K_{sat}

PTF: Vereecken et al. 1990





Assuming an inital range of 0-5% SOC for an example soil (loam)



→ Magnitude of changes is consistent with reported changes from literature

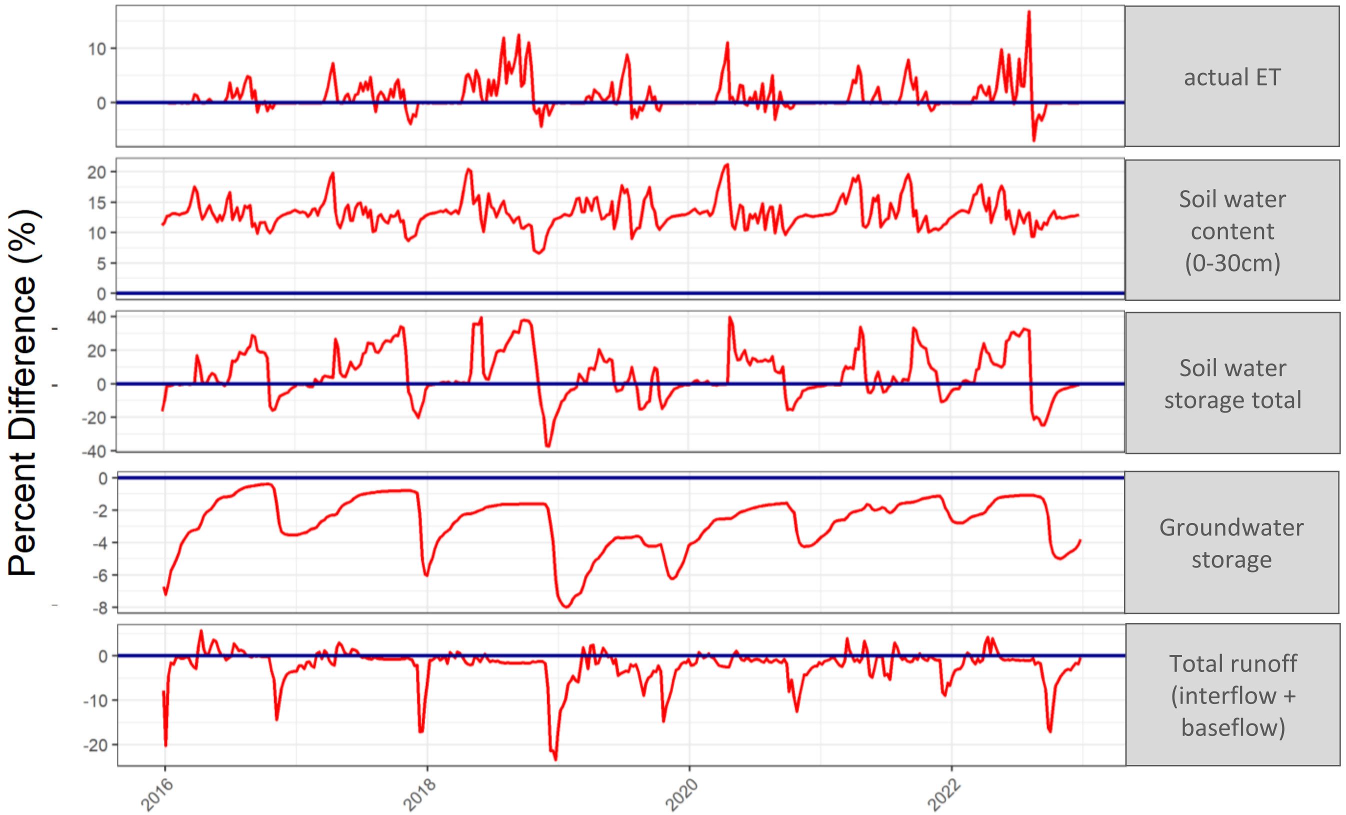
Impact on states and fluxes

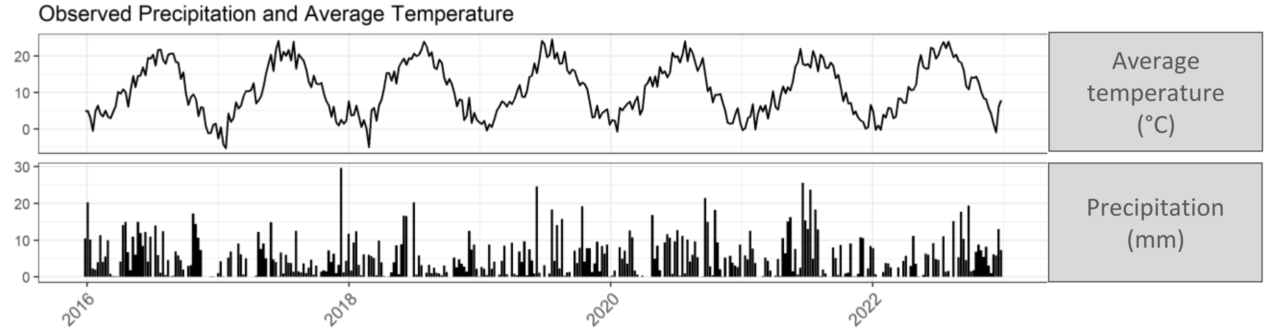
% difference in states and fluxes of management scenario run relative to default run

(→ positive: increased under management)

- Seasonal pattern, larger effect in summer
- increased aET
- higher soil water content
- lower groundwater storage
- decreased total runoff

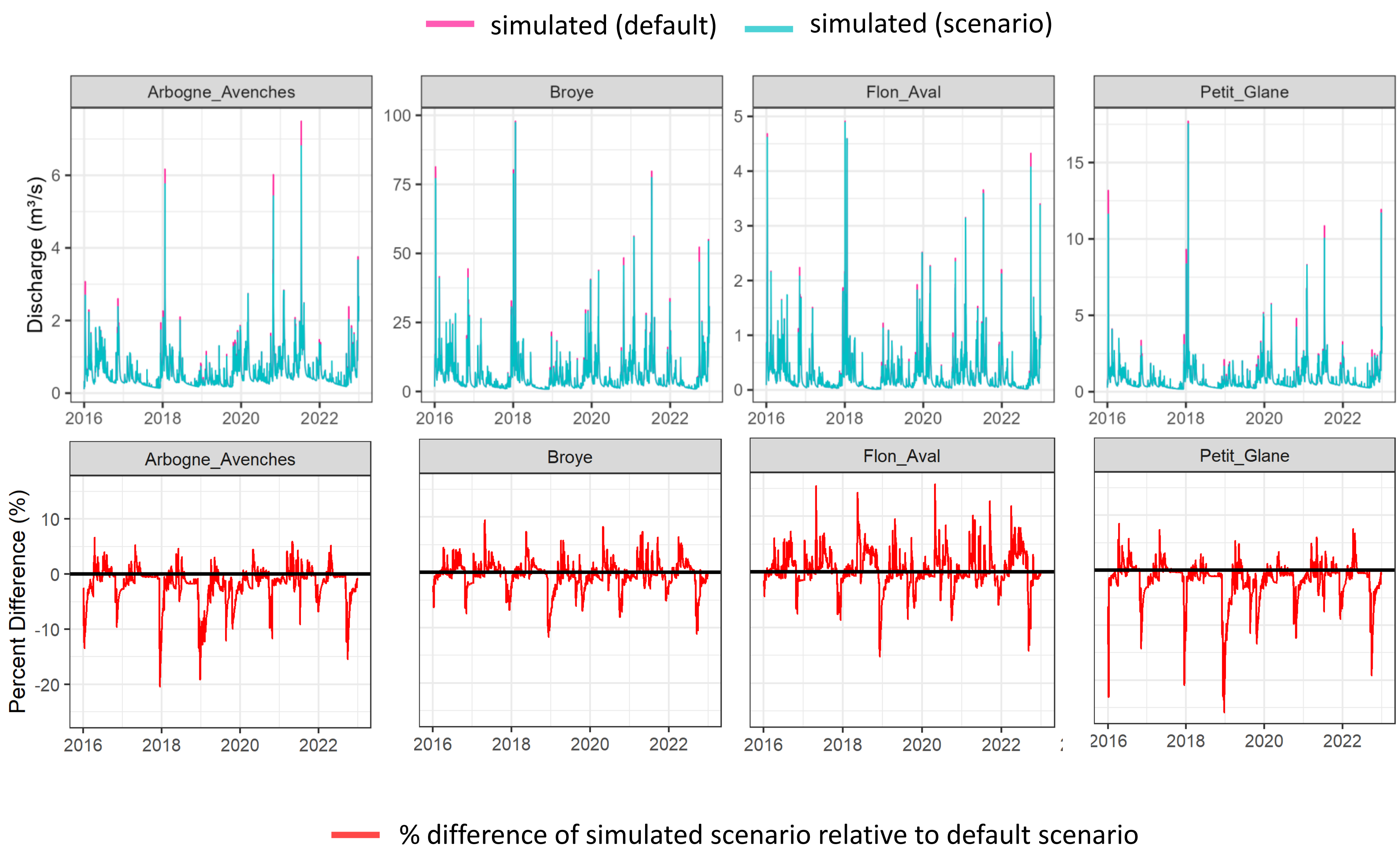
(weekly aggregation for example cropland cell)

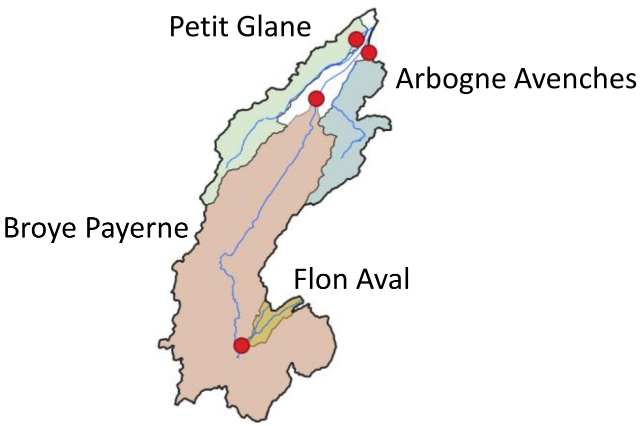




Impact on discharge

- Overall slightly reduced
- Seasonal pattern: biggest impact in winter
- Peak flows are reduced





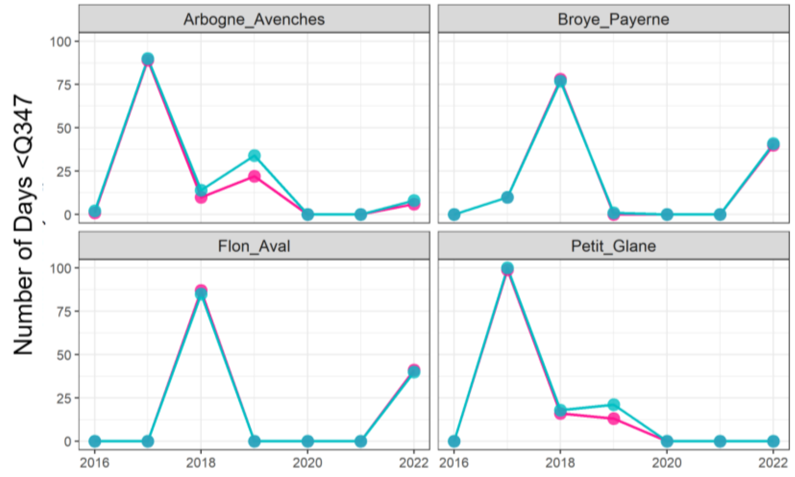
Impact on peak and low flows

Low flows

Days with flow < 95^{th} percentile are mostly **increasing** under the management scenario

Peak flows

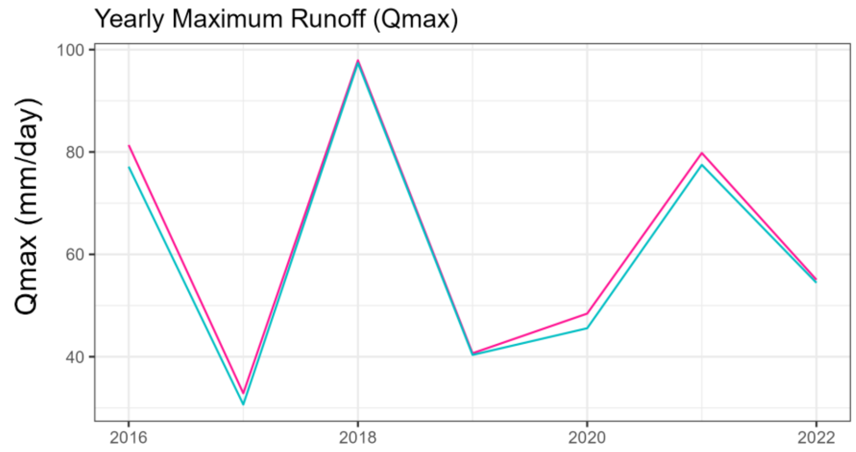
Yearly Q_{max} and peak flows are mostly **reduced** under management scenario

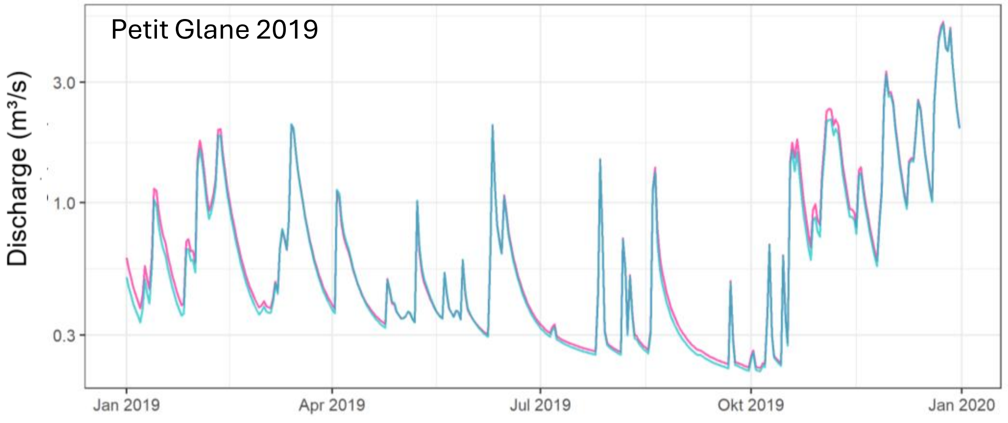


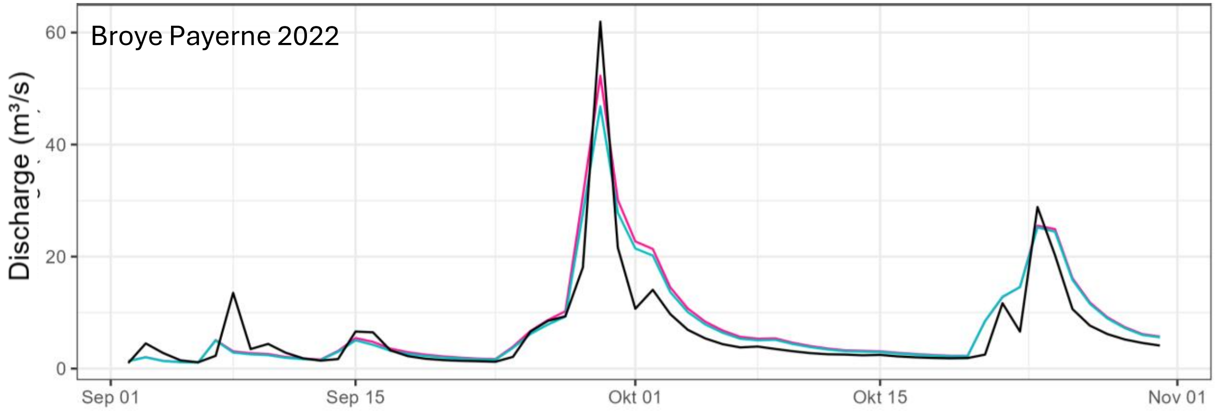
observed

simulated (default)

simulated (scenario)



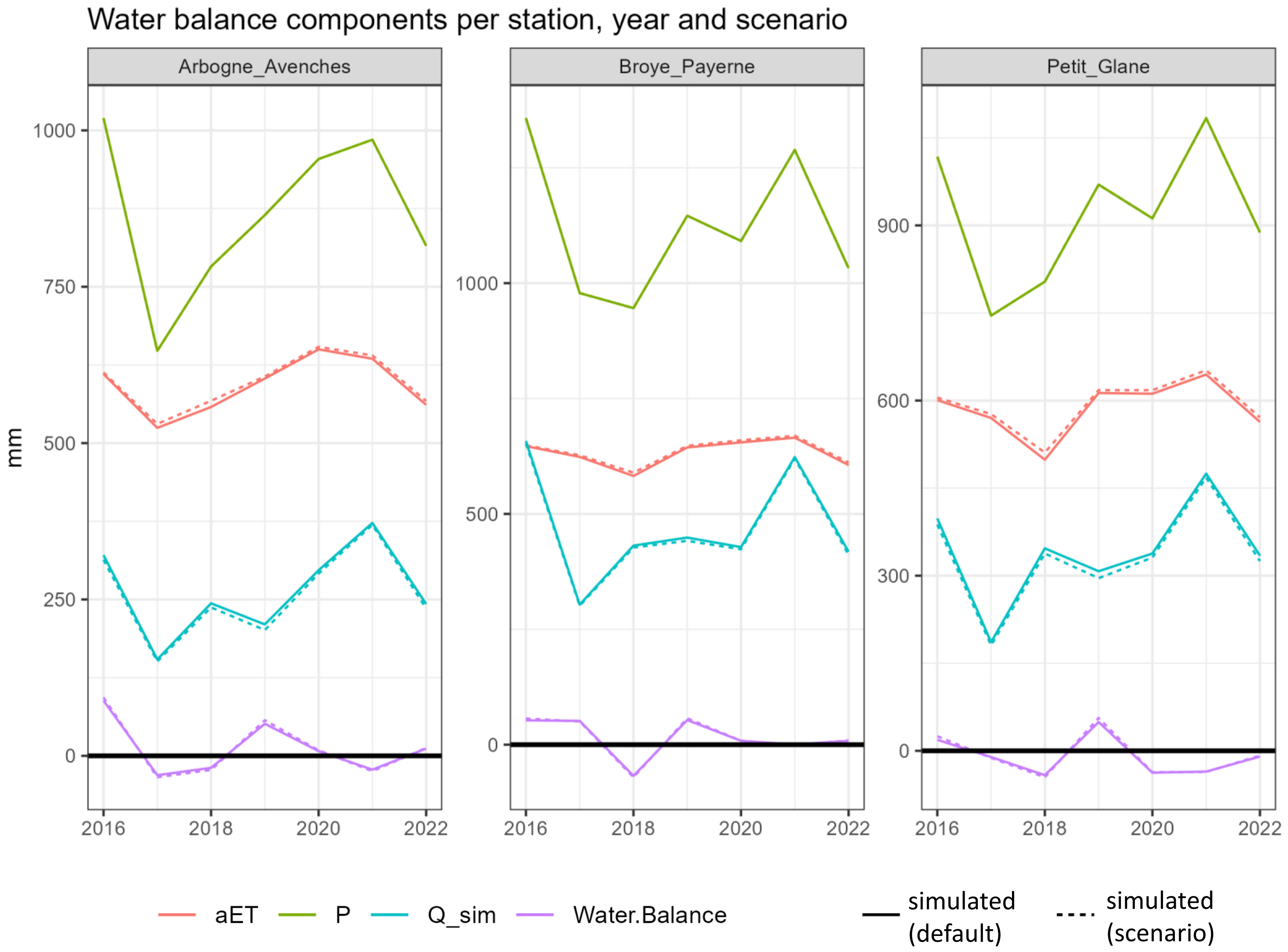




Impact on water balance:

Absolute impacts are in general quite marginal, water partitioning is changed:

- aET is increased
- discharge is reduced



Summary & Conclusion

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→

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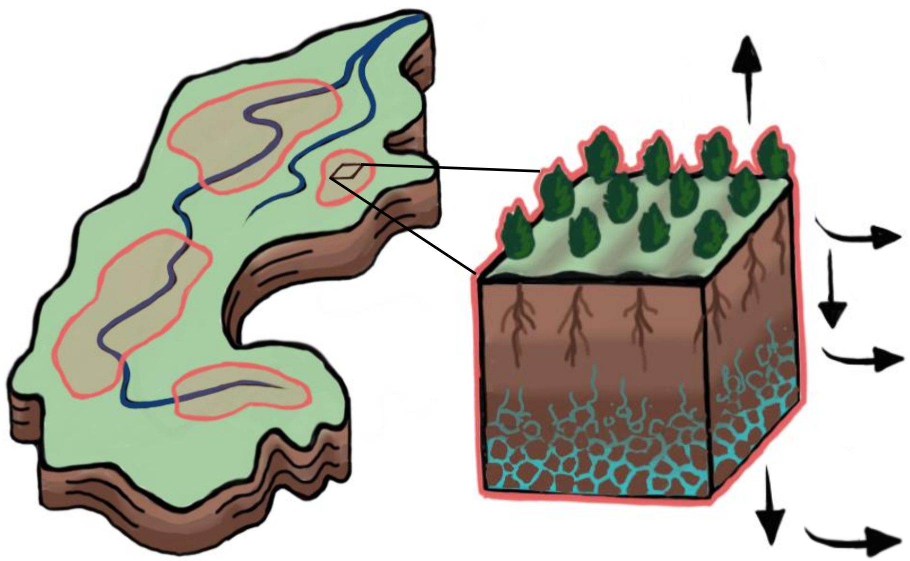

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Overall: rather minor impacts although assumption is optimistic

Positive side effect: reduced peak flows

Tradeoff: even more low flows in water scarce summer month