EVALUATING THE ADDED VALUE OF YOUNG WATER FRACTION FOR DETERMINING WATER TRANSIT TIMES IN DIVERSE CATCHMENTS

Arianna Borriero[1], Rohini Kumar[2], Tam. V. Nguyen[1], Jan H. Fleckenstein[1,3], and Stefanie Lutz[4]

[1]Department of Hydrogeology, Helmholtz-Centre for Environmental Research - UFZ, *Leipzig*, *Germany*
[2]Department of Computational Hydrosystems, Helmholtz-Centre for Environmental Research - UFZ, *Leipzig*, *Germany*
[3]Bayreuth Centre of Ecology and Environmental Research, University of Bayreuth, *Bayreuth*, *Germany*
[4]Copernicus Institute of Sustainable Development, Department Environmental Sciences, Utrecht University, *Utrecht*, *the Netherlands*

PROBLEM STATEMENT

- **Transit time distributions** (*TTDs*) of streamflow are important descriptors of hydrological functioning and solute mobilization in catchments
- Transport models based on StorAge Selection (SAS) functions are a promising tool for characterizing non-stationary *TTDs*
- Model parameters are typically calibrated against observations of long-term and high-frequency tracer concentration in the inflow and outflows
- Economic and management effort to acquire tracer data with a sufficient temporal resolution → risk to hamper robust estimated *TTDs*

OUR QUESTION

- Constraining parameters with alternative methods

OUR SOLUTION

- The young water fraction (F_{yw}) is the average fraction of the streamflow that is younger than a specified threshold age which is roughly 2–3 months

- Advantages of using F_{yw}:

→ easy to retrieve from short-term and low-frequency tracer data

→ directly estimated from the amplitude ratio of the cycles in stable water isotopes in precipitation and streamflow

→ alternative descriptor for *TTDs*

→ robust metrics under both spatially heterogeneous and non-stationary conditions

→ less prone to large aggregation bias than *TTDs*

RESEARCH GAP

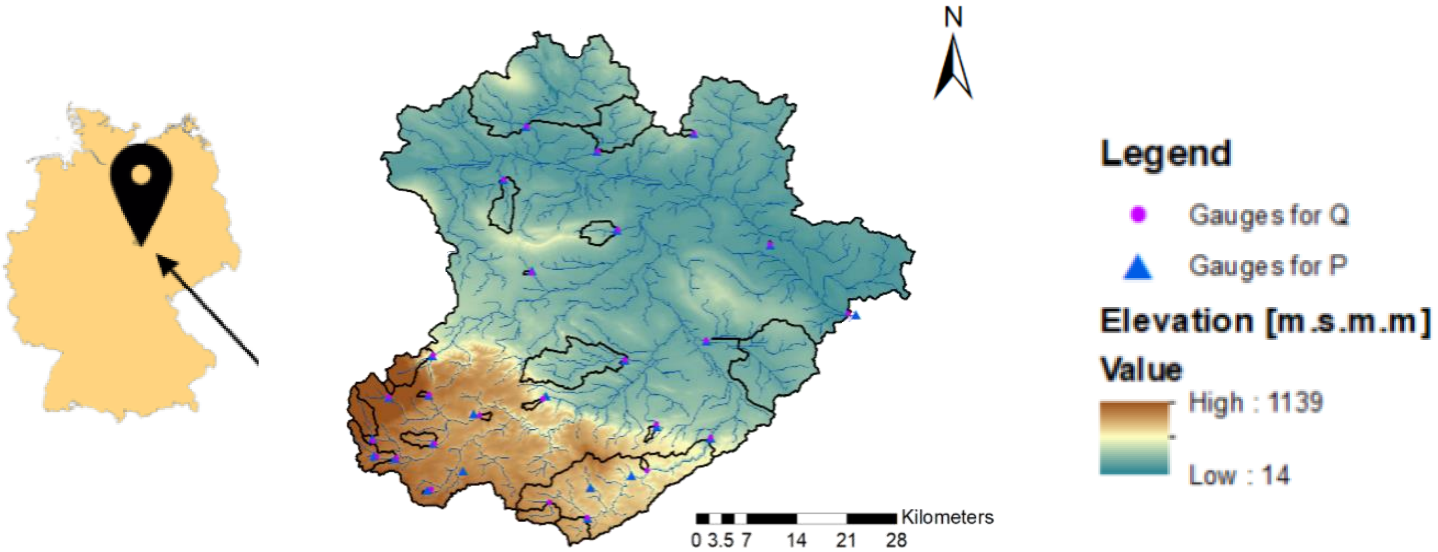
- Relevance of F_{yw} as an additional indicator for improving catchment-scale flow and transport description in *TTD* modelling is not yet well established

OBJECTIVE

- Explore if and to what extent F_{yw} is valuable to infer model parameters and simulate *TTDs* in multiple contrasting sub-catchments
- Showcase if the effectiveness of F_{yw} in identifying *TTDs* is related to the catchment size, annual precipitation, flow rates, soil or vegetation
- Identify potentials and gaps in the use of F_{yw} in isotope-based *TTD* models

STUDY SITE

- 24 diverse sub-catchments in the Bode region, Germany



DATA

- Hydroclimatic data of precipitation (*P*), streamflow (*Q*) and evapotranspiration (*ET*)
- Observed oxygen isotopes ($\delta^{18}O$)

METHODS

ESTIMATION OF F_{yw}

- Input data: observed $\delta^{18}O$ in P and Q
- Equations (*Kirchner, 2016a*):

→ Seasonal cycle in $\delta^{18}O$ in P and Q (‰):

$$\boldsymbol{\delta^{18}O_P = a_P \cdot \cos(2\pi f t) + b_P \cdot \sin(2\pi f t) + k_P} \qquad \text{(Eq. 1)}$$

$$\boldsymbol{\delta^{18}O_S = a_S \cdot cos(2\pi f t) + b_S \cdot sin(2\pi f t) + k_S} \qquad \text{(Eq. 2)}$$

where a (-) and b (-) are regression coefficients, t (decimal yr) is the time, f (yr⁻¹) is the frequency, and k (‰) is a constant describe the vertical offset of the isotope

→ Coefficients a and b are obtained through an iteratively re-weighted least squares (IRLS), a robust estimation that minimizes the influence of any potential outliers

→ In estimating a_P and b_P, Eq. (1) was volume weighted with monthly cumulative precipitation to avoid giving undue leverage to low precipitation periods

- Output data: $\boldsymbol{F_{yw}}\ (-) = \frac{\sqrt{\boldsymbol{a^2{}_S + b^2{}_S}}}{\sqrt{\boldsymbol{a^2{}_P + b^2{}_P}}}$ (Eq. 3)

Uncertainties in the calculated F_{yw} are expressed as standard errors (*SEs*) and are estimated using the Gaussian error propagation

METHODS

SIMULATION OF TTDs

- Input data: P, Q and ET + observed $\delta^{18}O$ in P and Q
- Equations (*tran-SAS v1.0* model; *Benettin and Bertuzzo, 2018*):

→ Water age balance:

$$\frac{\delta S_T(T,t)}{\delta t} + \frac{\delta S_T(T,t)}{\delta T} = P(t) - Q(t) \cdot \Omega_Q(S_T, t) - ET(t) \cdot \Omega_{ET}(S_T, t) \qquad \text{(Eq. 4)}$$

where S_T (mm) is the age-ranked storage, and Ω_Q (-) as well as Ω_{ET} (-) are the SAS functions for Q and ET

→ SAS beta function $\omega(P_s(T,t),t) = \frac{P_s(T,t)^{\alpha-1} \cdot (1-P_s(T,t))^{\beta-1}}{B(\alpha,\beta)}$ (Eq. 5)

→ *TTD* of streamflow (d^{-1}): $p_Q(T,t) = \frac{\delta \Omega_Q(S_T,t)}{\delta S_T} \cdot \frac{\delta S_T}{\delta T}$ (Eq. 6)

- Output data: F_{yw} (-): $P_Q(T,t) = \int_0^T p_Q(T)\, dT$ (Eq. 7)

where T is set to roughly 2–3 months

METHODS

EXPERIMENTAL DESIGN

- Simulation of *TTDs* with 10,000 different SAS parameters set (i.e., α and β) generated by the Latin Hypercube Sampling approach

- The parameter sets producing a marginal *TTDs*, thus F_{yw} (Eq. 7), falling within $F_{yw} \pm SE$ (Eq. 3) were considered as acceptable

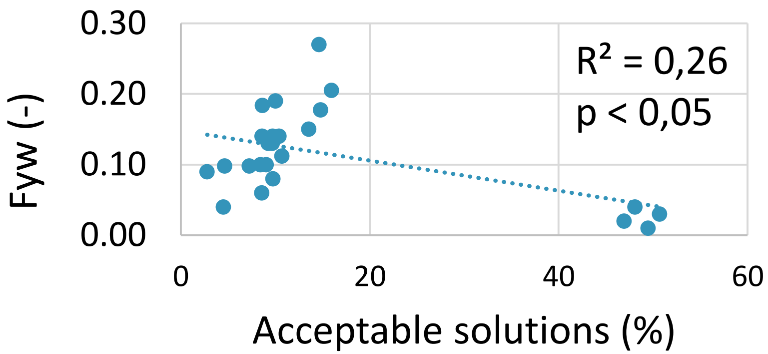
- From the cumulative daily *TTD*, we extrapolated the daily median transit time (i.e., TT_{50}; time until 50 % of the infiltrated water ends up in the output flux)

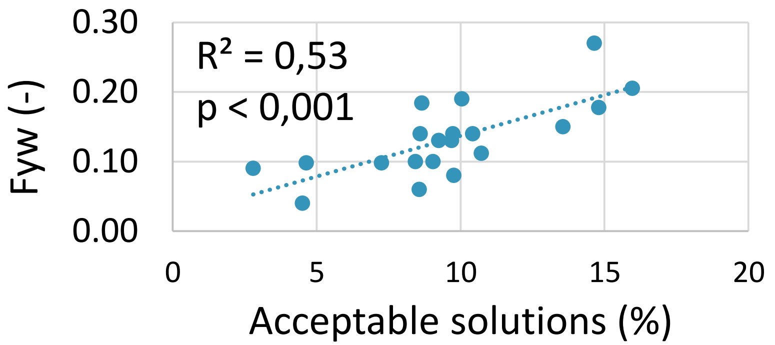
- We constructed the 95 % prediction uncertainty (95PPU) to refine limits of TT_{50}

RESULTS

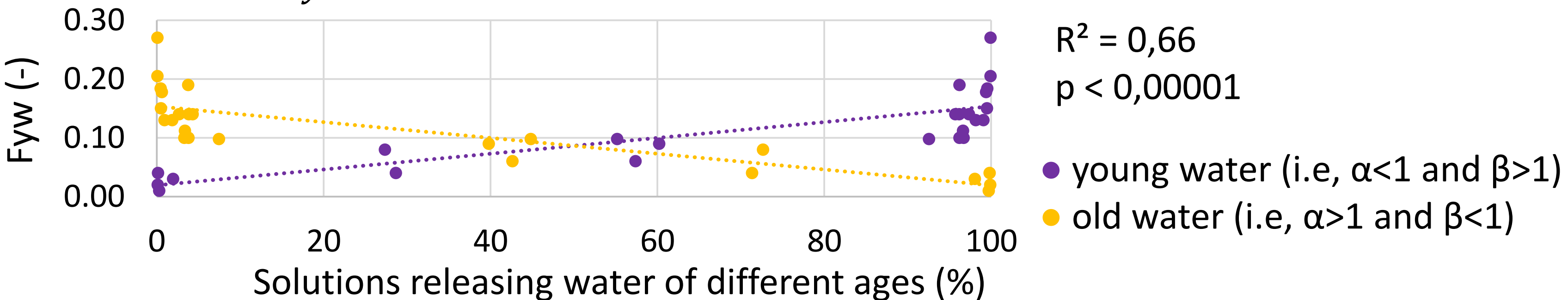
EFFECTIVNESS OF F_{yw} TO SIMULATE *TTDs*

- Accetpable solutions ranges from 49% to 3% (mean of 16%) of the initial 10,000 parameter sets
- The lower F_{yw}, the less the acceptable solutions; however, when F_{yw} > 0,04 the trend reverses





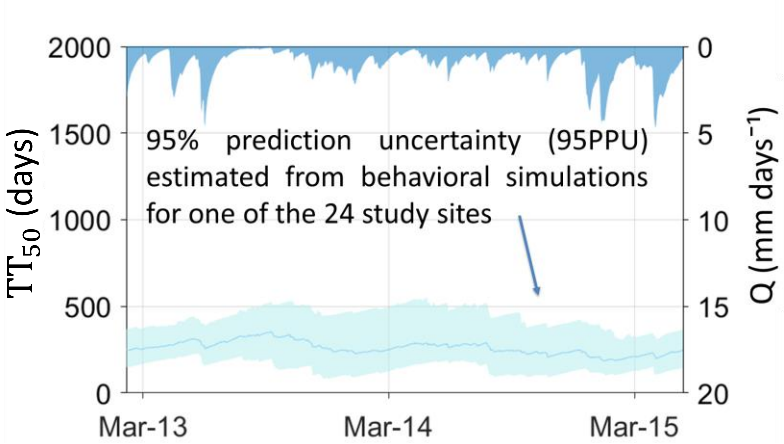
- The higher (lower) F_{yw}, the narrower (wider) the 95PPU and the shorter (longer) the simulated TT_{50}
- F_{yw} and solutions releasing water of different ages correlate well: this corroborates F_{yw} functioning



RESULTS

SIMULATED TT_{50}

- Relatively constant with little temporal fluctuations as TT_{50} tend towards the average catchment discharge behavior



- Mountain areas:

→ Slight trend towards short F_{yw} and long TT_{50} which might be due to rapid vertical infiltration caused by drainign soil

- Lowland areas:

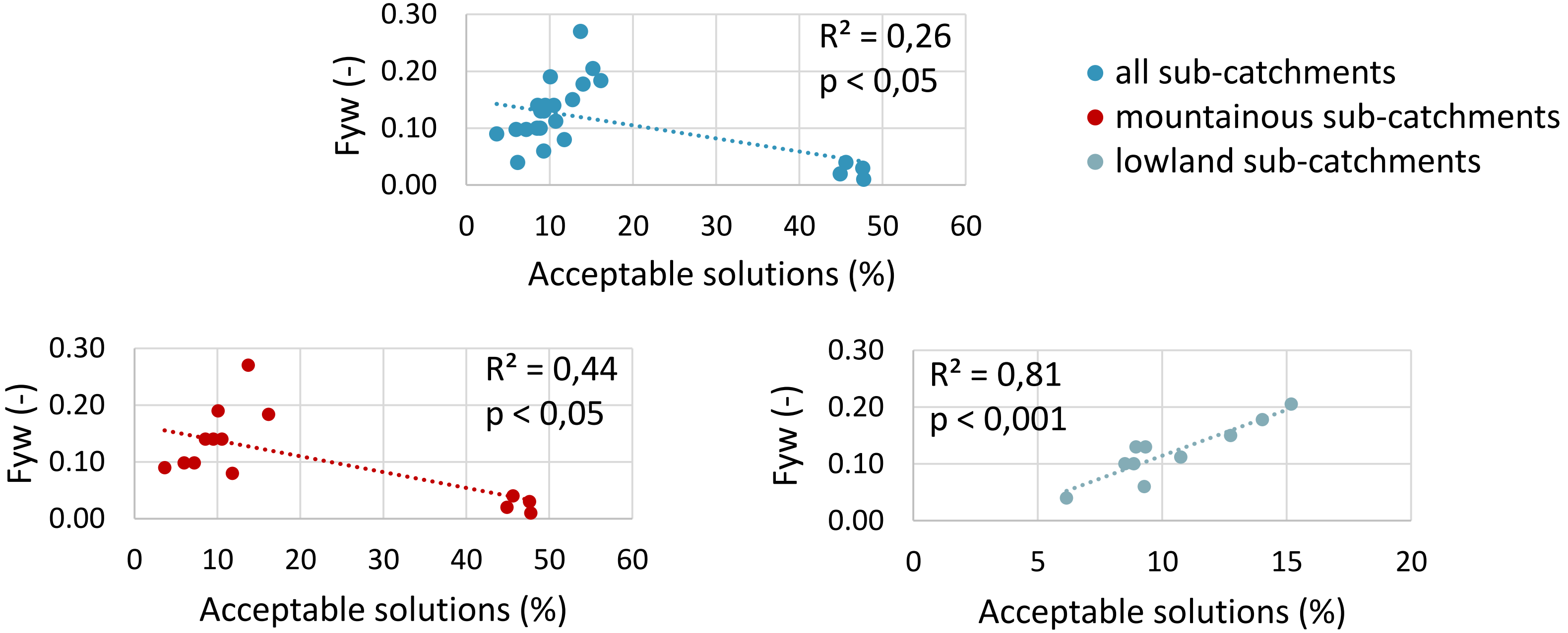
→ Large F_{yw} and short TT_{50} which might be due to artificial drainage

→ Small F_{yw} and long TT_{50} which might be due to deep groundwater flowpaths

RESULTS

CATCHMENTS ATTRBUTES

- F_{yw} exhibits correlation with *P*, *Q*, and mean altitude in mountain areas only



- Greater ability to infer SAS parameters and *TTDs*:

→ Small F_{yw} (but F_{yw} > 0,04) in low-elevated mountain sites with modest *P* and Q

→ Small F_{yw} in lowland sites

CONCLUSIONS

- Information on F_{yw} largely reduces uncertainty in *TTDs* and equifinality in model parameters
- The value of F_{yw} really matters as the number of solutions and the values of *TTDs* change accordingly
- Information on F_{yw} helps interpret transport processes in catchments
- Effectiveness of F_{yw} in inferring *TTDs* is a function of the catchments attributes

Thank you for your attention

Any questions?

Display Material

https://meetingorganizer.copernicus.org/EGU22/EGU22-4898.html

This presentation participates in OSPP

EGU

Outstanding Student Poster & PICO Contest

arianna.borriero@ufz.de