Christian-Albrechts-Universität zu Kiel

KLIMAWERK WASSER:LANDSCHAFT

Setting up a SWAT+ model to study low flow conditions and measures to increase drought resilience

Sven Grantz, Paul Wagner, Jens Kiesel, Nicola Fohrer

Department of Hydrology and Water Resources Management

WaX Wasser-Extremereignisse

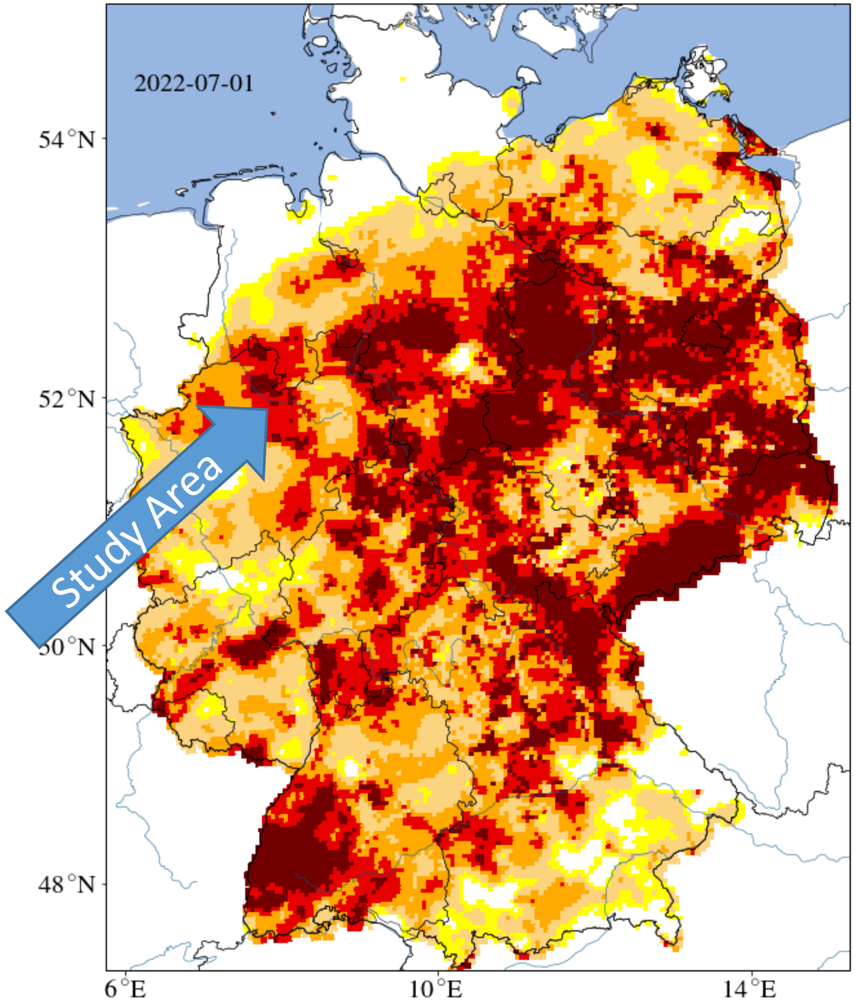
Das Verbundvorhaben wird vom Bundesministerium für Bildung und Forschung (BMBF) innerhalb der Fördermaßnahme Wasser-Extremereignisse (WaX) gefördert

FONA Forschung für Nachhaltigkeit

GEFÖRDERT VOM Bundesministerium für Bildung und Forschung

INR

Impacts of drought in the catchment

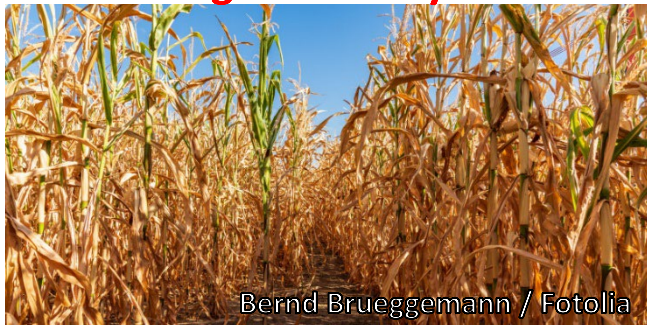


UFZ Drought Monitor Germany 2022 - 2023

Endangered water supply

Low water table at Talsperre Hullern, 2019

Reduced agricultural yields

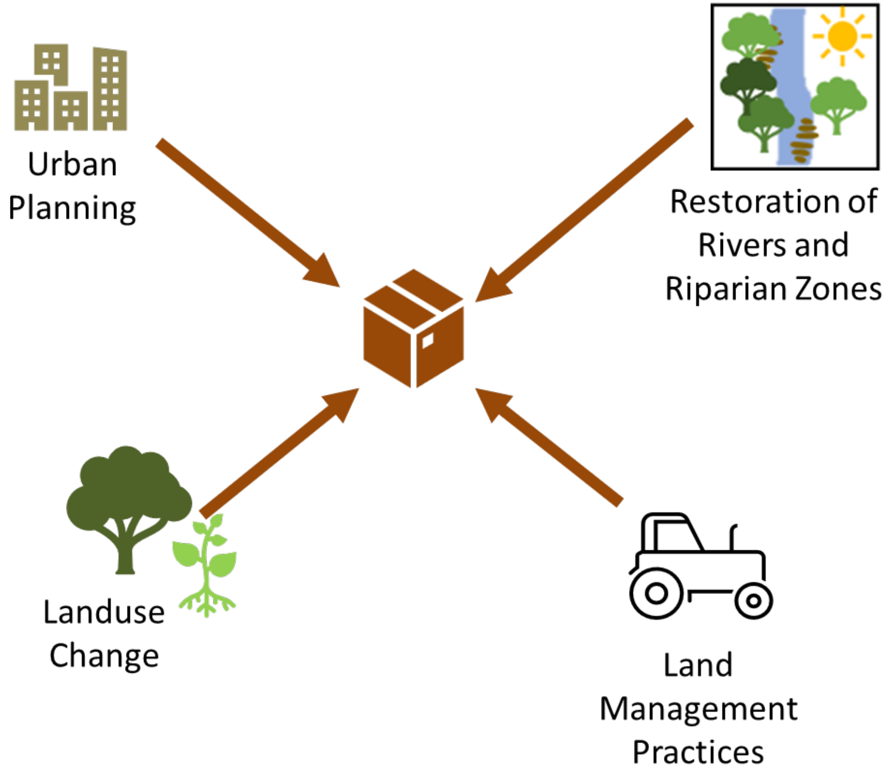


Degradation of ecosystem services

Dried up river Rotbach in Dinslaken, 2022

Developing and Modelling of Climate Resilience Measures

KLIMAWERK
WASSER:LANDSCHAFT



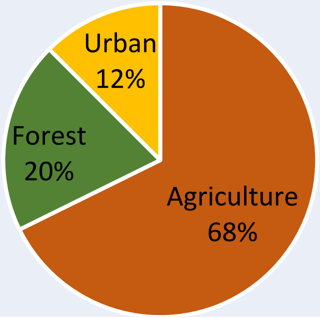
Scientific benefits:

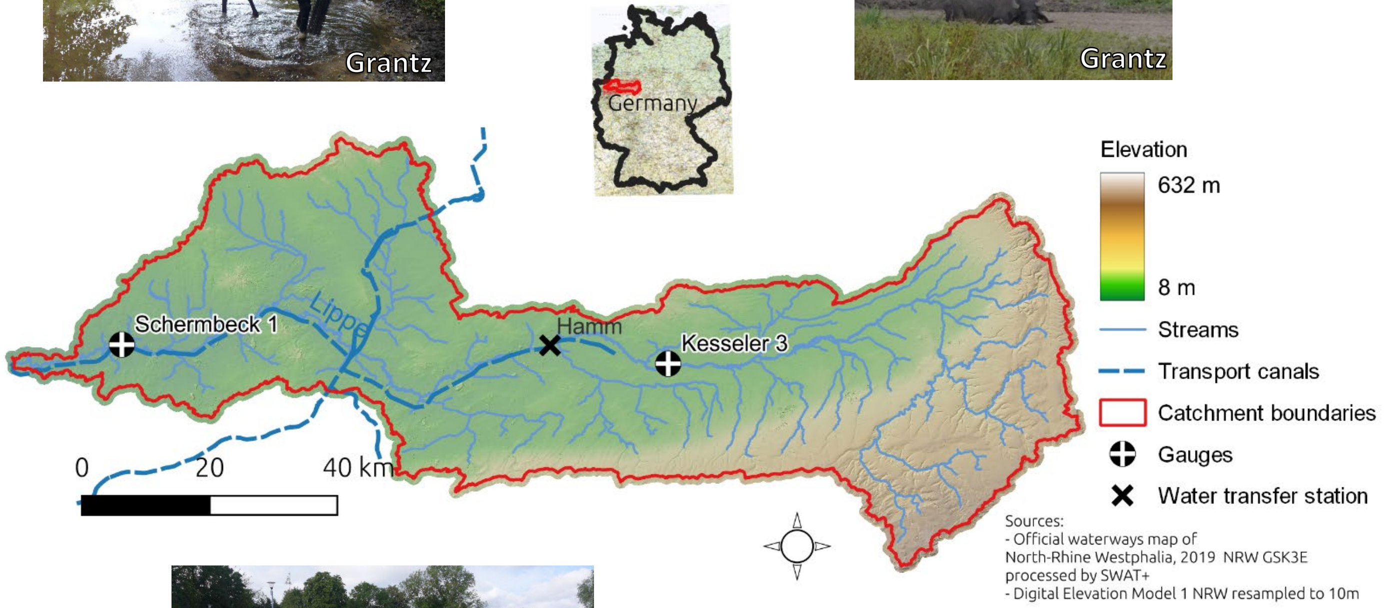
- Knowledge building on climate adaptation
- Modelling of combined measures in climate and socio-economic scenarios

Knowledge Transfer

- Preservation / improvement of ecosystem services
- Climate resilience of water supply
- Avoidance of climate damages and economic losses

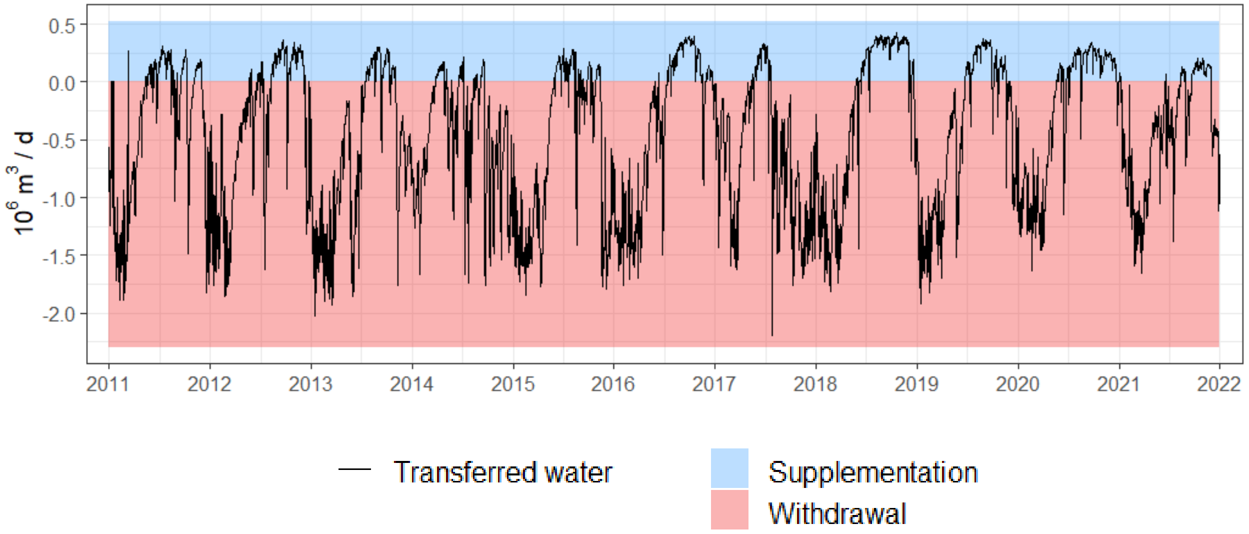
A rural catchment, dominated by agriculture

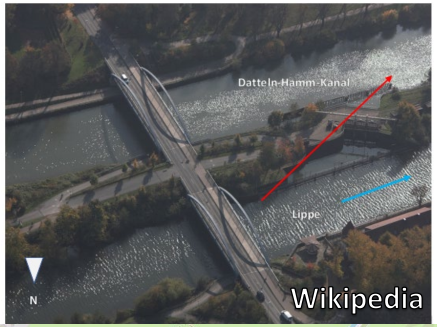
Lippe Catchment Description	
Location:	Germany, North Rhine-Westphalia
Length, Confluence:	220 km, Wesel, River Rhine
Area:	4,860 km²
Discharge (MQ):	42 m^3s^{-1} (1965-2020, Gauge Schermbeck 1)
Elevation range:	614 m
Population:	1.9 M, 382 P/km2
Landuse:	
Particularities:	• Traversed by transport canals • Reservoirs Hullern (11 Mio. m^3) and Haltern (20 Mio. m^3) • Land subsidence from underground coal mining



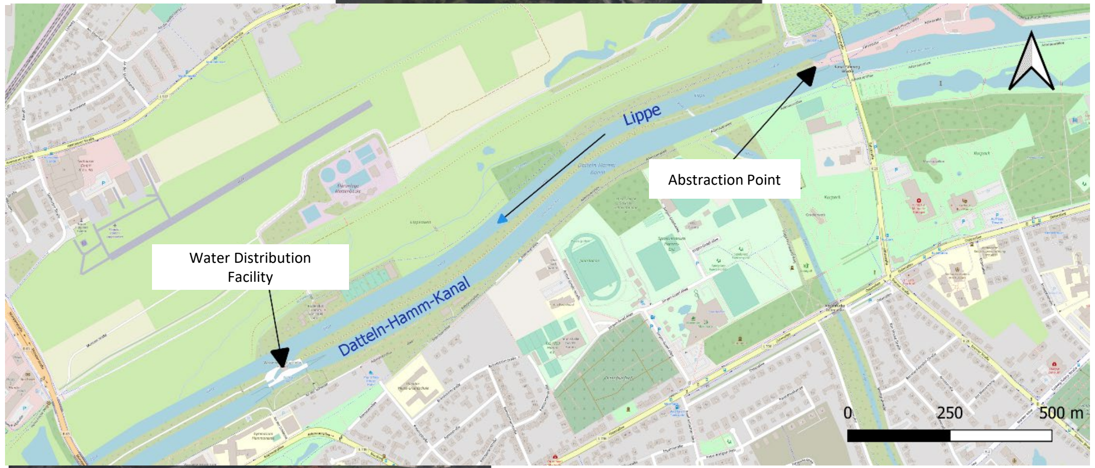
Water used for shipping canal network

- Ø 37 % of discharge transferred at Hamm into the Datteln-Hamm Canal
- Ø 32 % of the Lippe discharge supplemented from the canal network to ensure minimum discharge of 10 m^3/s
- Modelled annual average change at the catchment outlet: + 5 m^3/s
- **Water transfer needs to be considered for calibration**





Canal feeding structure



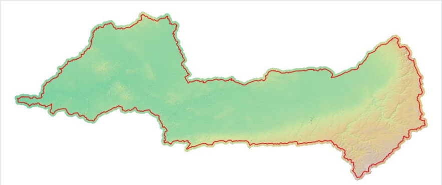
Water distribution facility and pumping station for the Lippe supplementation

Model setup with publicly available input data

SWAT+

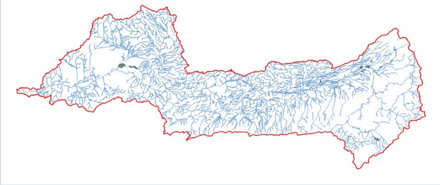
Water Transfer Data

Topography



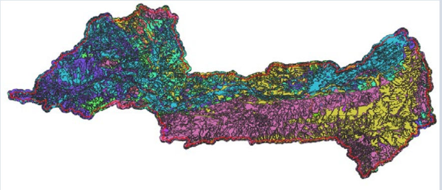
DEM10

Rivernetwork



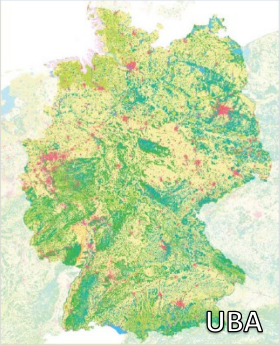
Official waterways map of North-Rhine Westphalia, 2019

Soils



Soil Map 1 : 50,000
BK 50 of NRW

Landuse



CORINE Landcover 2018

Weather

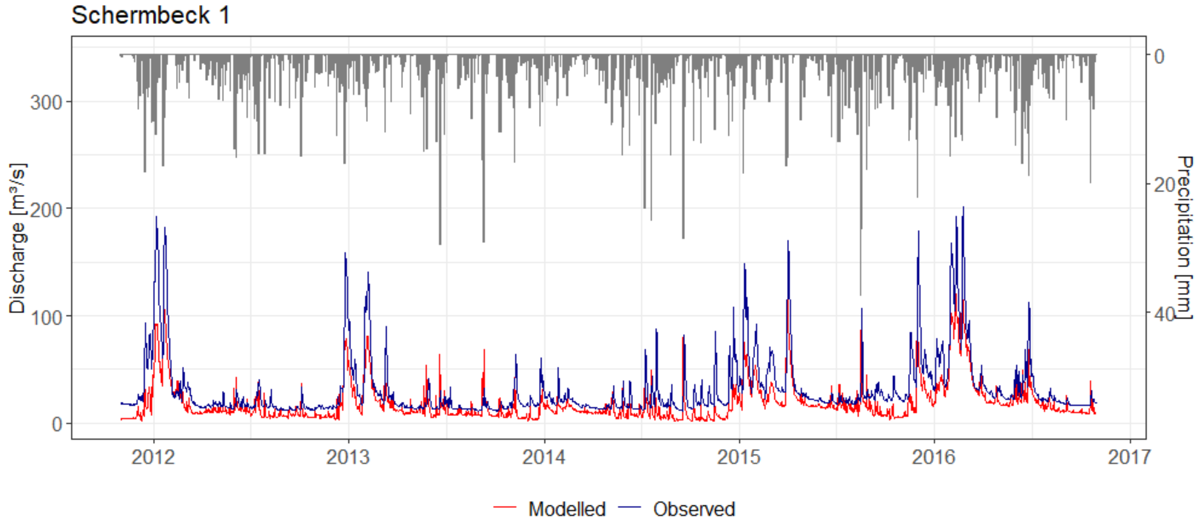
DWD

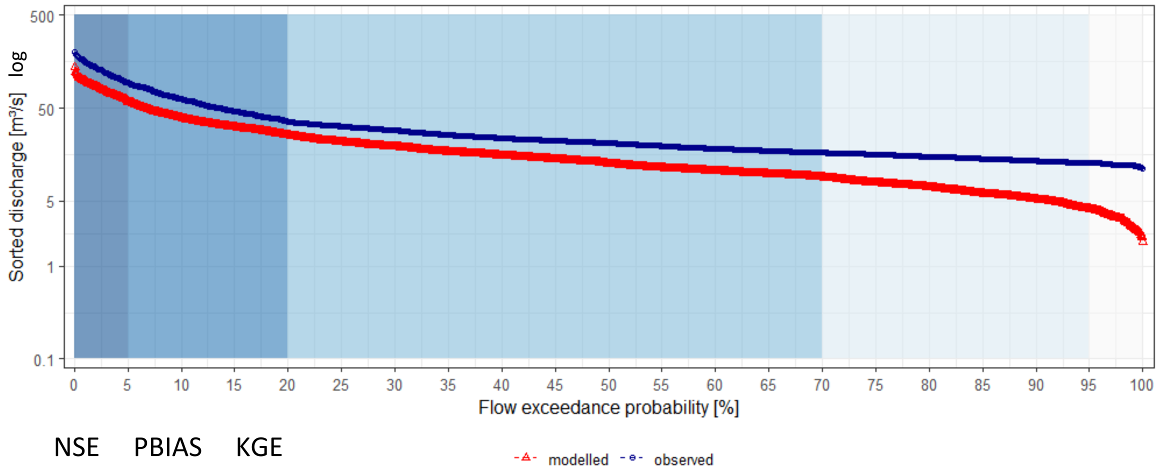
HYRAS Product and temperature station data of the German Weather Service

Warm-Up Period:	2009 – 2011
Modelling Period:	2012 – 2021
Calibration Period:	2012 – 2016
Validation Period:	2017 – 2021

Low model performance of initial setup

- Calibrated for two gauges (upper and full catchment)
- Applied R-packages: Latin Hypercube Sampling (lhs) and goodness-of-fit evaluation (hydroGOF)
- Discharge is strongly underestimated at both gauges
- Problems with low flow representation





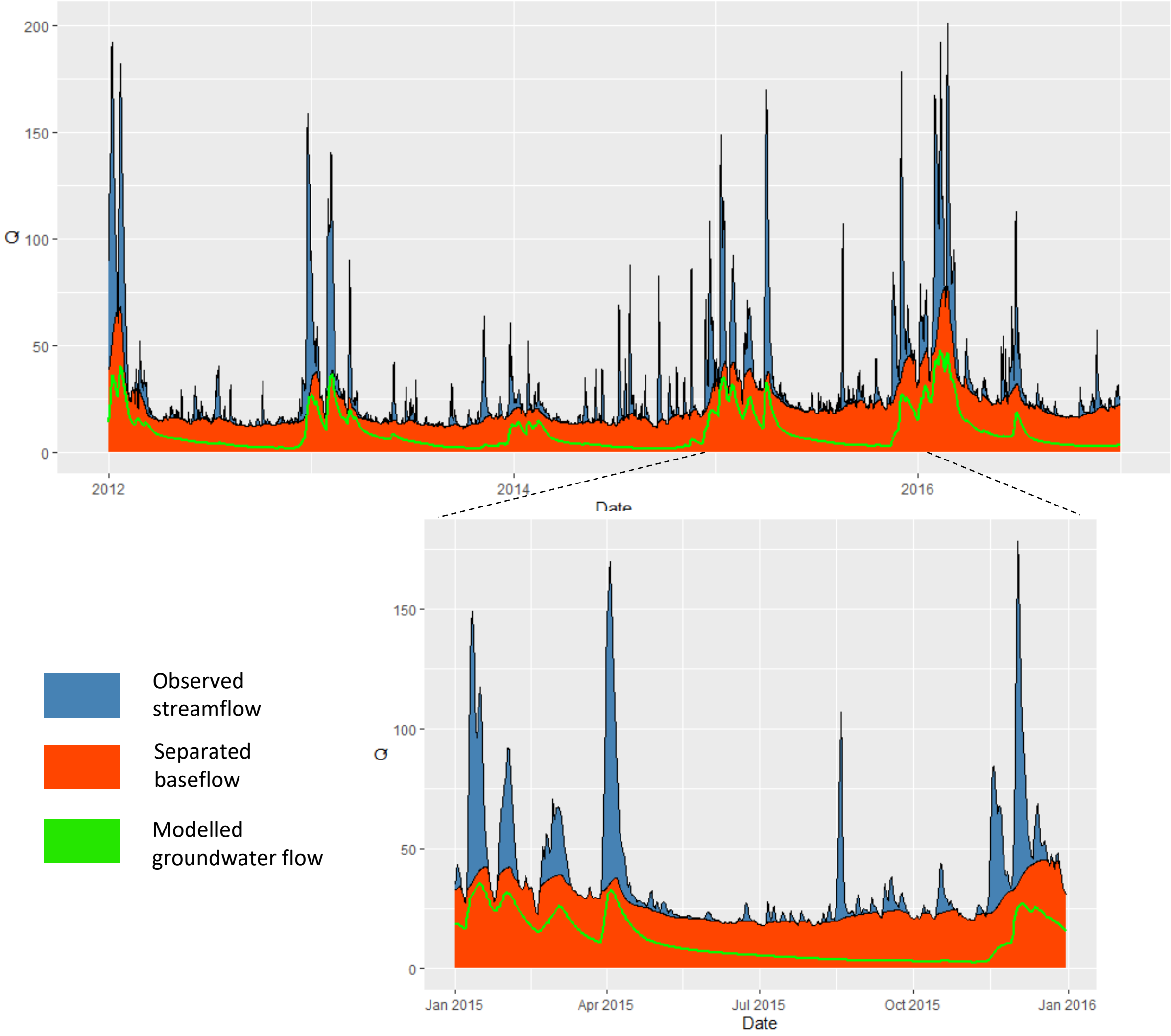
NSE	PBIAS	KGE
0.49	-39.12	0.55

Segmentation of the flow duration curve based on: Pfannerstill et al. 2014

Baseflows are insufficiently represented in the model

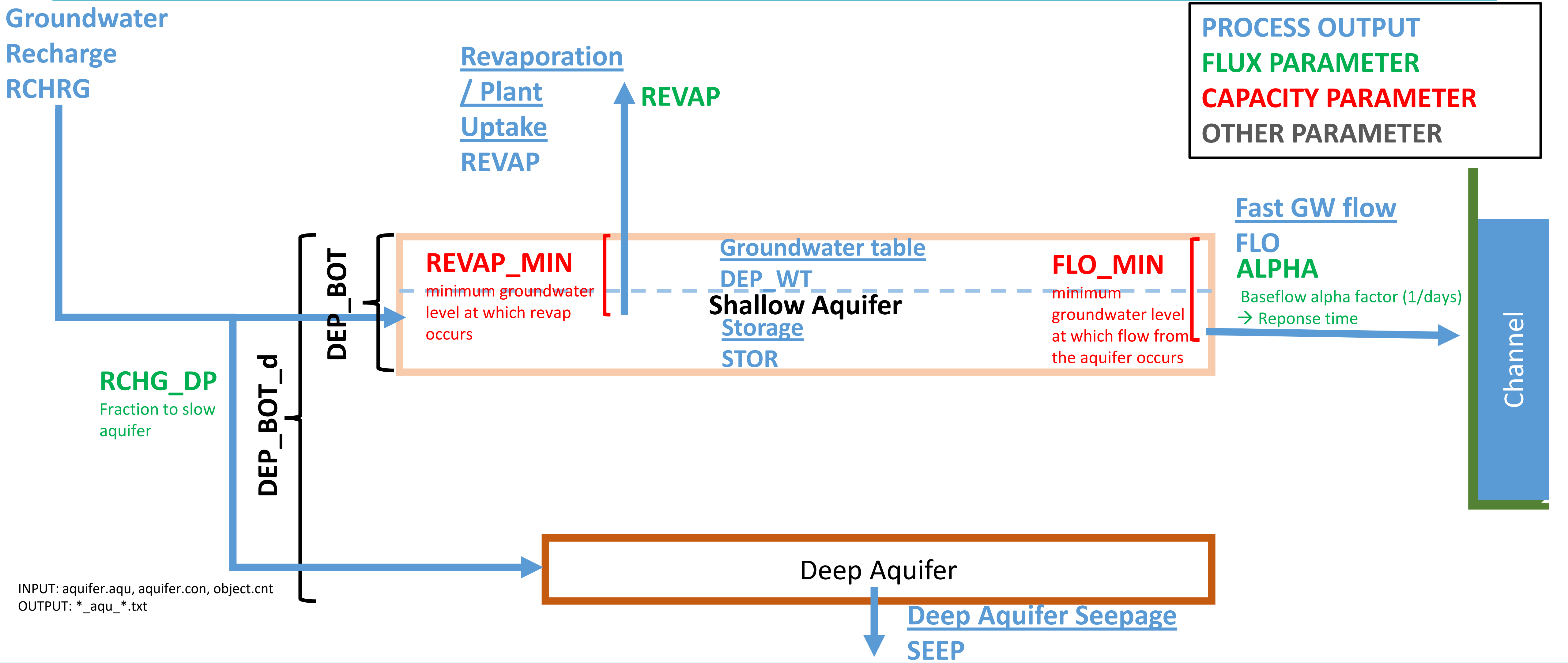
- Baseflow separation according to Lynne-Hollick (1979) with R-Package “grwat”:
    - **72% baseflow at the gauge Schermbeck 1**
    - **75% baseflow at the gauge Kesseler 3**

- <u>SWAT+ model, annual averages:</u>
    - 52 mm aquifer discharge (flo_cha)
    - 68 mm surface (surq_gen) and 41 mm lateral flow (latq)
    - **32% groundwater flow**



Standard concept of groundwater storage

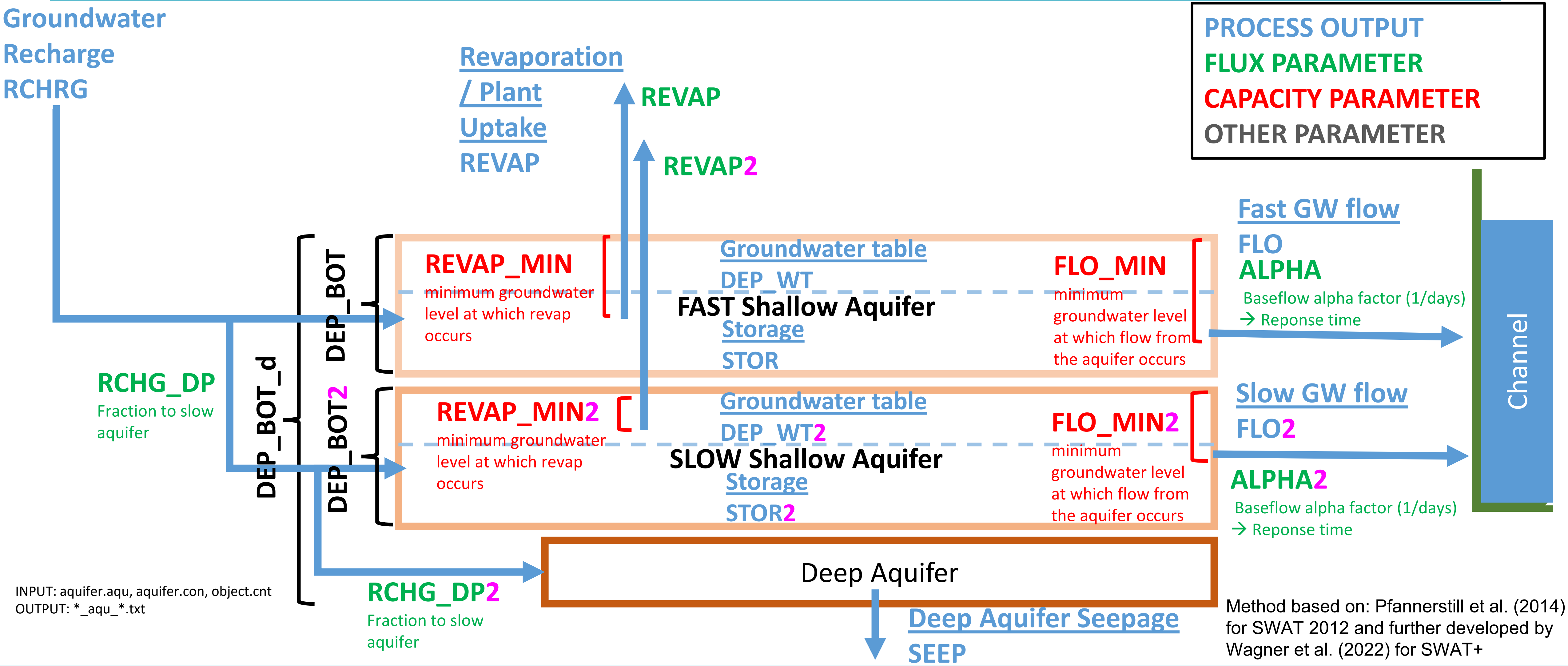
SWAT+



INPUT: aquifer.aqu, aquifer.con, object.cnt
OUTPUT: *_aqu_*.txt

Separating fast and slow groundwater storage

SWAT+



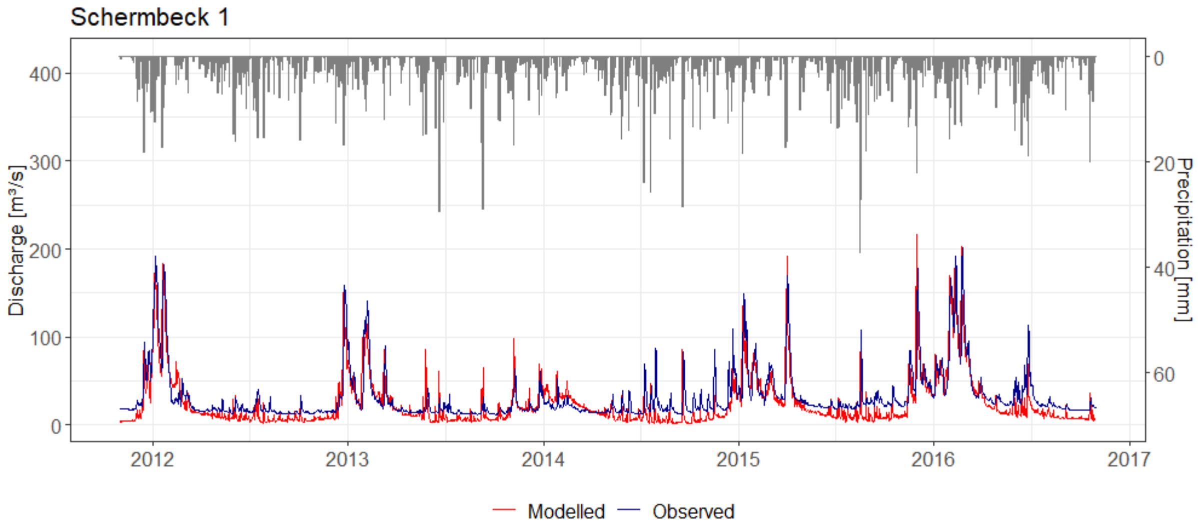
INPUT: aquifer.aqu, aquifer.con, object.cnt
OUTPUT: *_aqu_*.txt

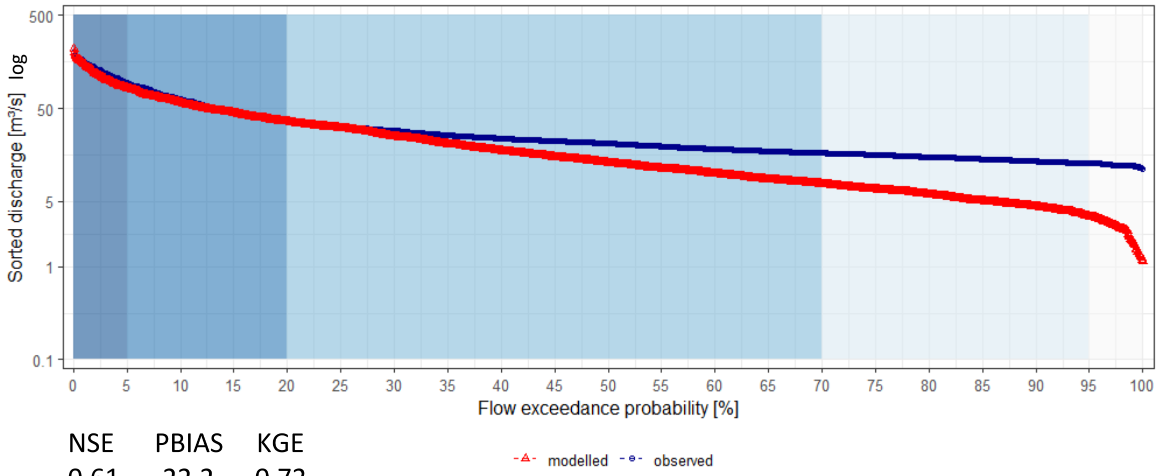
Method based on: Pfannerstill et al. (2014) for SWAT 2012 and further developed by Wagner et al. (2022) for SWAT+

Some improvements w. split aquifers

Changes to aquifer.aqu			
Parameter	**Fast shallow**	**Slow shallow**	**Type**
ALPHA	0.76	0.05	Auto calibration
RCHG	0.38	0	Auto calibration
FLO_MIN	2	7	Manual
DP_WT	2	7	Manual
DEP_BOT	5	10	Manual
REVAP	0	0	Manual

Goodness-of-fit comparison				
Setup	**NSE**	**PBIAS**	**RSR**	**KGE**
1 shallow aquifer	0.49	-39.12	0.71	0.55
2 shallow aquifers	0.61	-22.2	0.62	0.72
Satisfactory model performance threshold (Moriasi et. al 2007	>50 ✓	< +/-25 ✓	≤0.70 ✓	-





NSE 0.61 PBIAS -22.2 KGE 0.72

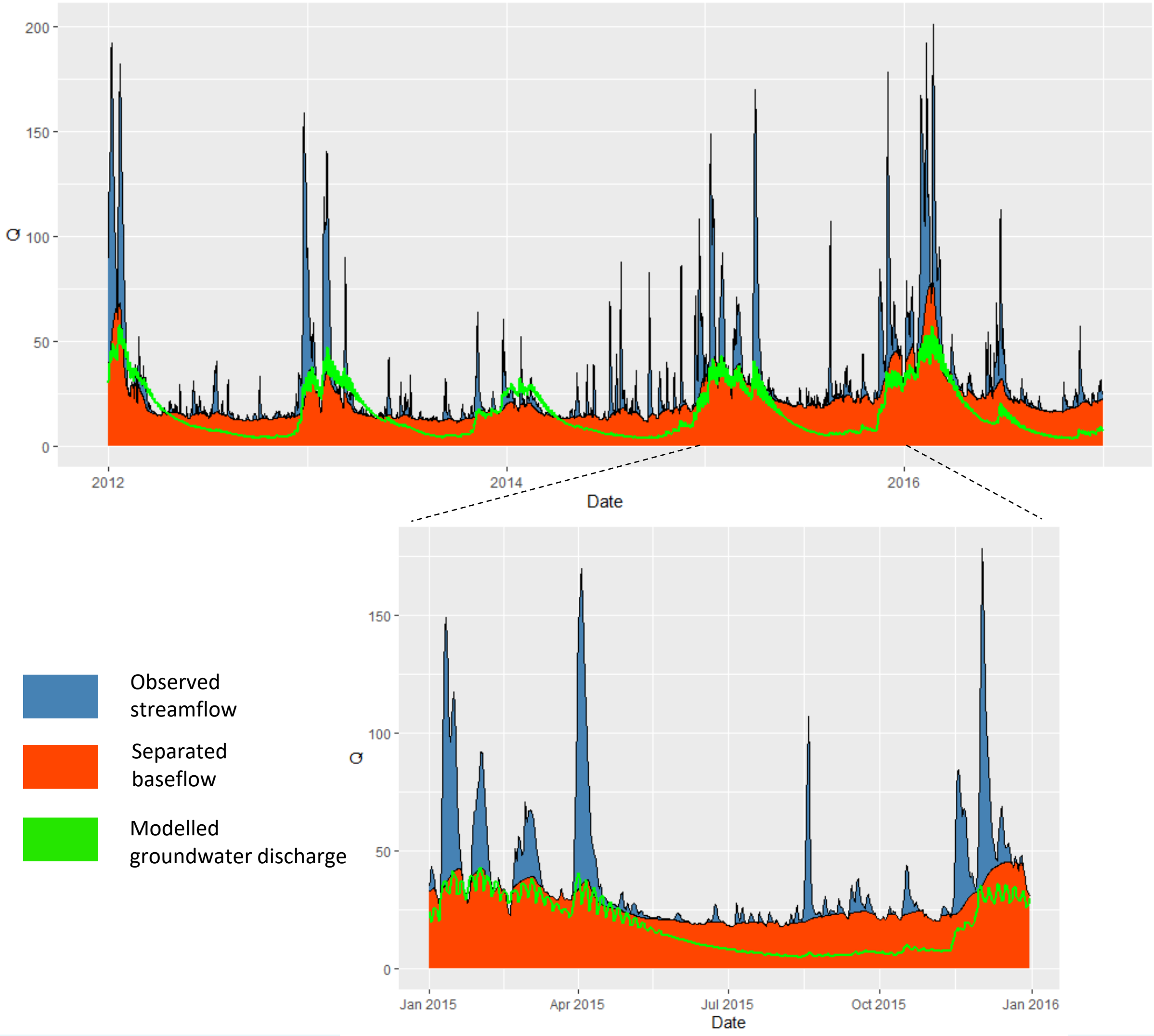
Segmentation of the flow duration curve based on: Pfannerstill et al. 2014

Fast groundwater discharge is better represented, but low flows are still underestimated

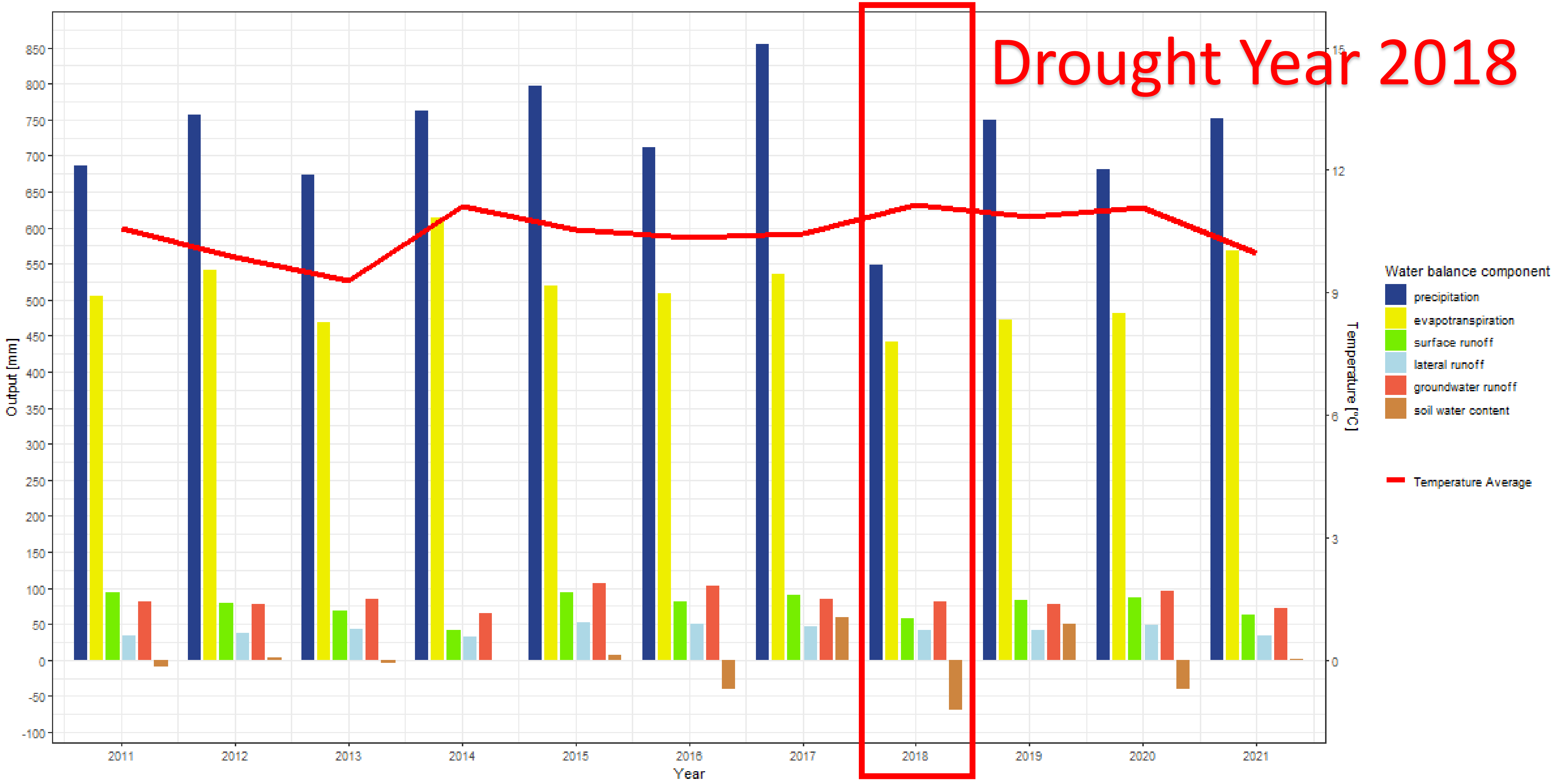
- <u>SWAT+ model, annual averages:</u>
  - 84 mm groundwater discharge (aquifer flo_cha)
  - 76 mm surface (surq_gen) and 42 mm lateral flow (latq)
  - 41% groundwater flow (+9%)

- **Improved groundwater flow characteristics for fast groundwater components**

- **Problems with low flow representation remain**



Outlook: Studying droughts with SWAT+ as a basis for modelling climate resilience measures



Key messages

- Anthropogenic changes to the water balance (here: for a shipping canal system) can have relevant impacts on streamflow – even in large catchments – and should therefore be considered in model setup
- Low flow representation is crucial to studying drought situations
- Baseflow separation with observed data and comparison with SWAT+ model outputs shows differences in groundwater dynamics
- Implementing fast and slow aquifers in SWAT+ can improve fast GW flow representation and model performance
- Substantial changes to aquifer parametrization are a “low-cost” alternative to coupling SWAT+ with a groundwater model
- But currently limitations regarding low-flow situations are apparent

References

Lyne, V., and M. Hollick. 1979. “Stochastic Time-Variable Rainfall-Runoff Modeling.” In *Australian National Conference Publication*, 79:89–92.

Moriasi, D. N., et al. “Model Evaluation Guidelines for Systematic Quantification of Accuracy in Watershed Simulations.” Transactions of the ASABE, vol. 50, no. 3, 2007, pp. 885–900. doi:10.13031/2013.23153.b

Pfannerstill, M., Guse, B., & Fohrer, N. (2014). Smart low flow signature metrics for an improved overall performance evaluation of hydrological models. Journal of Hydrology, 510, 447-458.

UFZ Helmholtz Center for Environmental Research. Drought Monitor Germany. https://www.ufz.de/index.php?en=37937

Wagner, Paul D., et al. “Representation of Hydrological Processes in a Rural Lowland Catchment in Northern Germany Using SWAT and SWAT +.” Hydrological Processes, vol. 36, no. 5, 2022, doi:10.1002/hyp.14589.