Comparing the eco-hydrological model SWIM to conceptually different hydrological models for climate change impact assessments on low flows

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Background of the study

Climate change impact assessments are nowadays a prerequisite

- for a successful integrated river basin planning and management
- for the development of suitable climate change adaptation strategies

→ especially relevant for highly anthropogenically impacted catchments which are prone to low flows already under current climate conditions

Schwarze Elster, 2006

Development of post mining lake

Problem statement

Climate change impact assessments on regional water resources are highly uncertain

→ even opposing results are reported in the scientific literature (Teutschbein et al. 2011, Gädeke et al. 2014, Huang et al. 2013)

→ uncertainty increases for extreme events, such as low flows

→ uncertainty increases the smaller the scale of interest –> adaptation strategies are generally implemented on a smaller scale

BUT regional stakeholder want to have "robust" projections due to economic relevance!!

Aim of the study

- Evaluation of future low flow conditions using different climate downscaling approaches (statistical and dynamical)
- Evaluation of uncertainties related to conceptually different hydrological models

Prerequisites:

- Good data base
- Calibrated and validated hydrological models
- Consistent output from climate downscaling approaches

Study Area

Study area

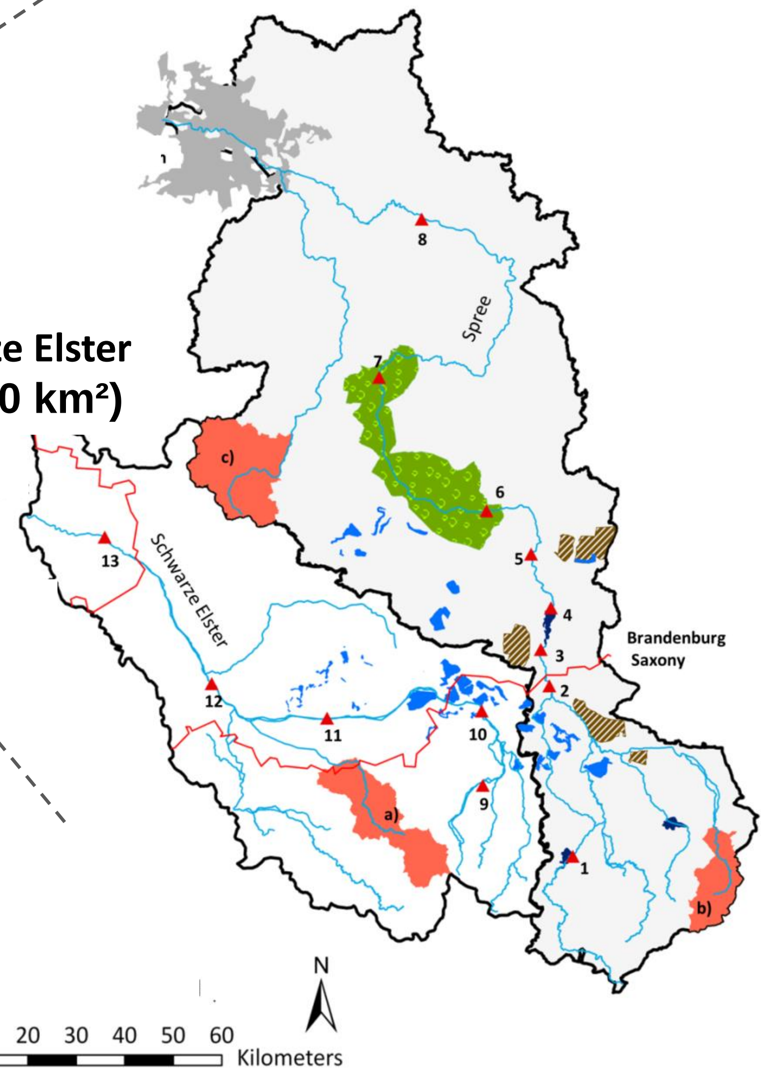
Europe

Germany

Study catchments

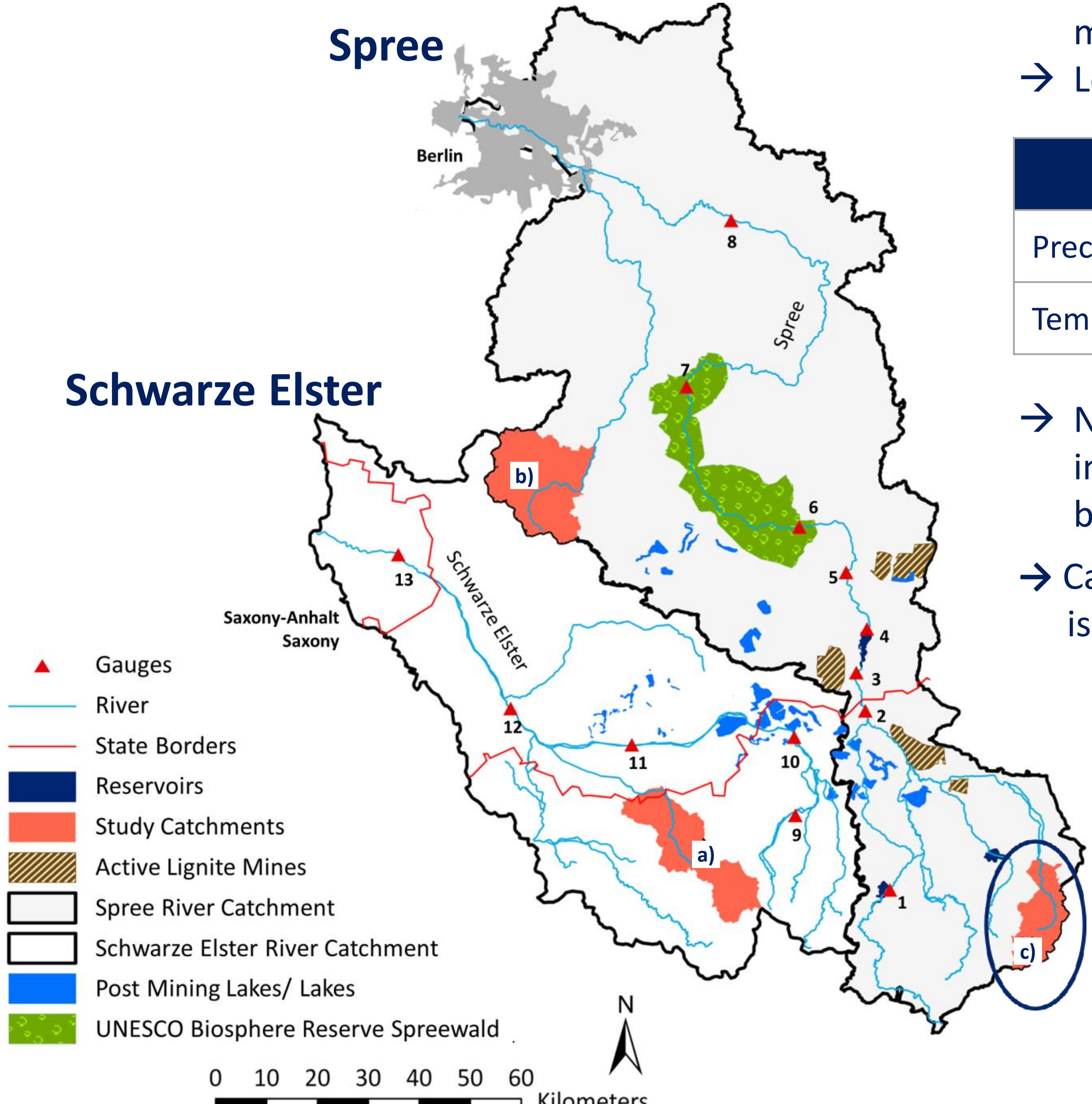
Spree (≈ 10,000 km²)

Schwarze Elster (≈ 5,500 km²)



- Spree river catchment
- Schwarze Elster river catchment
- Gauges
- River
- State borders
- Reservoirs
- Study catchments
- Active lignite mines
- Post mining lakes/ lakes
- UNESCO biosphere reserve Spreewald

Characteristics of the study catchments



→ Location in a transition zone between maritime and continental climate

→ Low natural water availability (1961-1990)

	Spree	Germany
Precipitation [mm/a]	587	789
Temperature [°C]	8.7	8.2

→ Natural rainfall-runoff process strongly impacted anthropogenically (especially by lignite mining activities)

→ Calibration on the measured discharge is not possible

Subcatchments chosen where anthropogenic impact on discharge is relatively low:

a) Pulsnitz river catchment (≈ 245 km²)

b) Dahme river catchment (≈ 300 km²)

c) Weißer Schöps river catchment (≈ 135 km²)

Materials and Methods

Study approach

Climate change impact assessment

Downscaling approaches:

<u>dynamical</u>

– REMO (1 realisation)

– CLM (2 realisations)

<u>statistical</u>

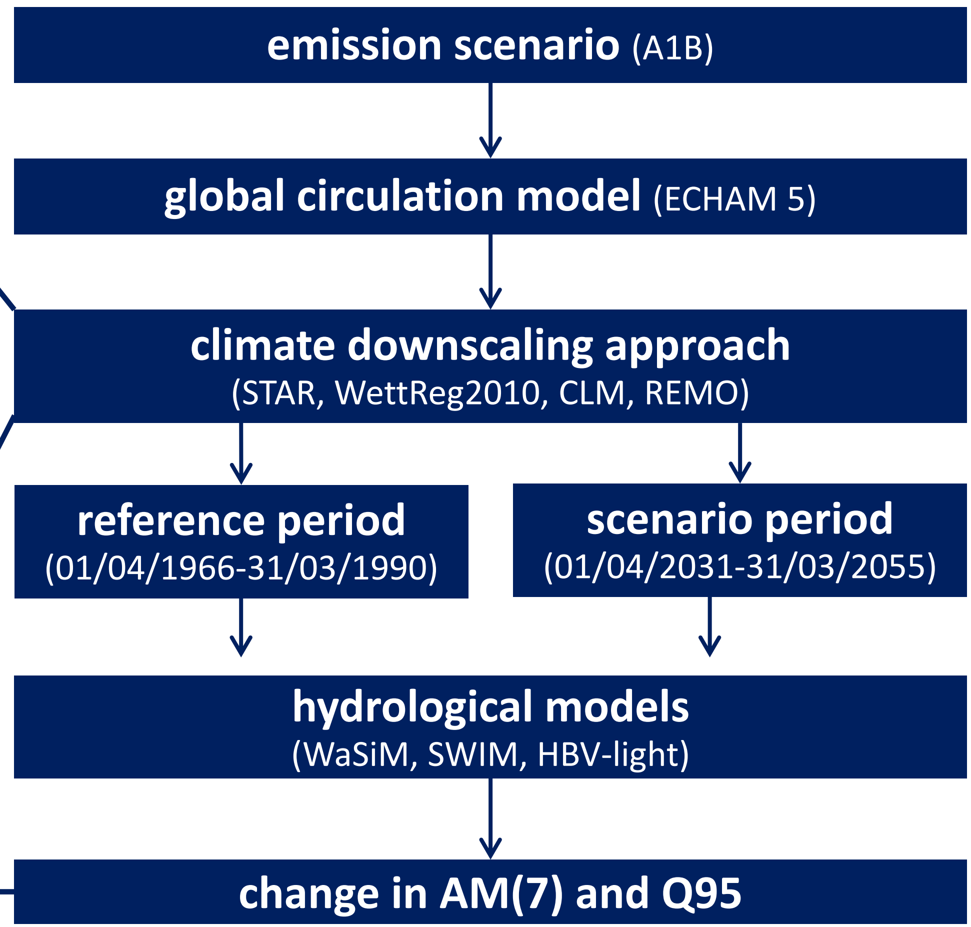
– STAR (100 realisations)

– WettReg (10 realisations)

Raster-based dynamical DAs were interpolated onto the station based statistical Das

AM(7): annual minimum 7-day flow

Q95: ninety-five percentile flow



Daily simulation time step (low flow year (April-March))

Hydrological models

Decreasing level of complexity →

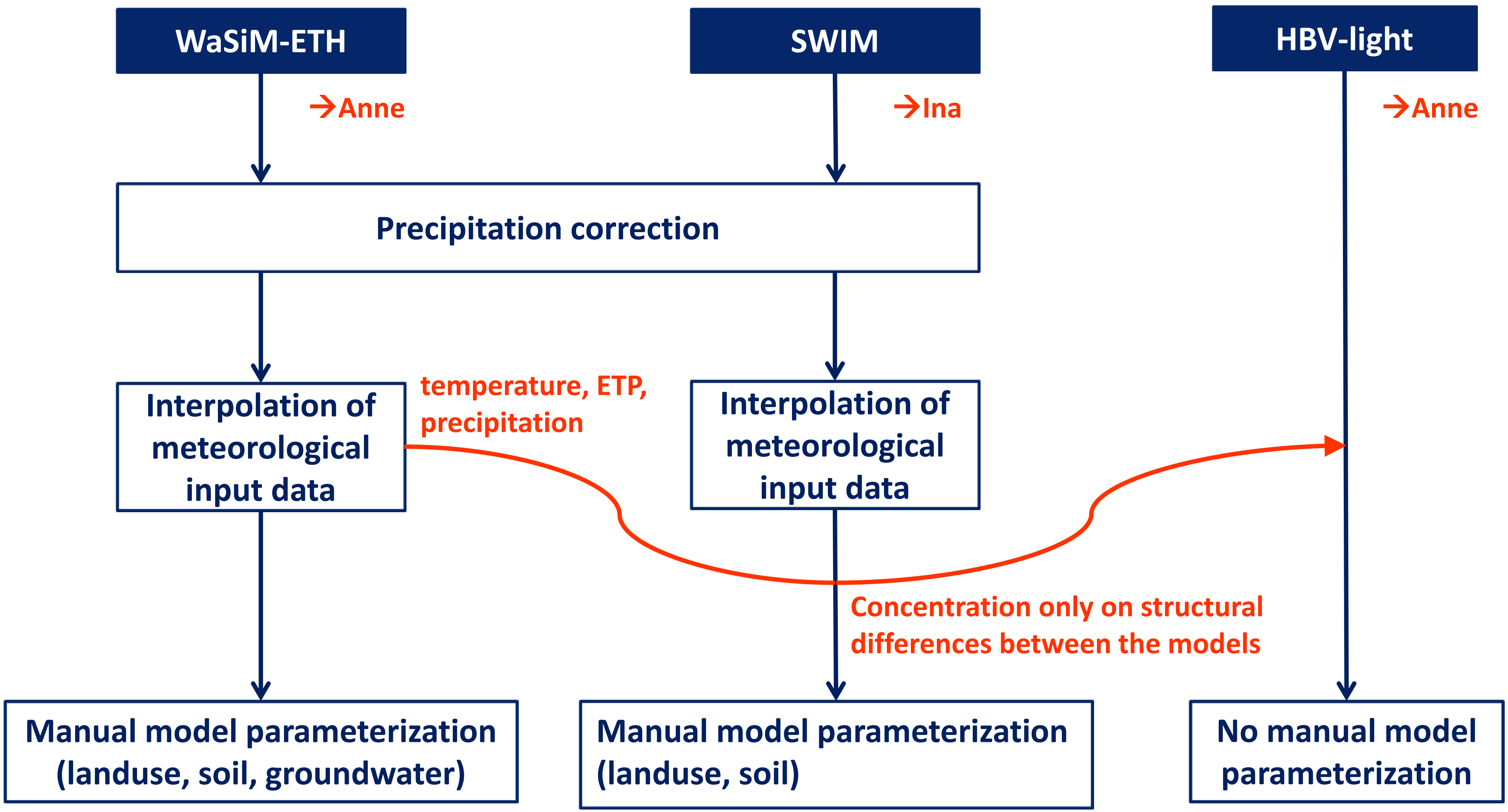
	+++	++	+
	WaSiM (Water Balance Simulation Model)	**SWIM (Soil and Water Integrated Model)**	**HBV-light (Hydrologiska Byråns Vattenbalansavdelning)**
Conceptual basis	physically-based	process-based	conceptual
Spatial distribution	fully-distributed	semi-distributed (HRU)	lumped
ETP/ETA	Penman-Monteith/ reduction to ETA depending on matrix potential	Turc-Ivanov/ Ritchie Concept	Calculation of ETP not included, ETA is calculated based on soil water storage
Interception	LAI dependent bucket approach	not included	not included
Infiltration	Green-Ampt approach modified by Peschke [1987]	SCS curve number method	not included
Unsaturated zone	Richards equation parameterized based on van Genuchten [1980]	similar to SWAT	based on a linear storage approach
Saturated zone	integrated 2D groundwater model	linear storage approach (shallow and deep)	linear storage approach
Routing	kinematic wave approach/flow velocity after Manning-Strickler	Muskingum	runoff transformation by triangular weighting function

Hydrological models

Decreasing level of complexity →

	WaSiM (Water Balance Simulation Model)	SWIM (Soil and Water Integrated Model)	HBV-light (Hydrologiska Byråns Vattenbalansavdelning)
Decreasing level of complexity	+++	++	+
Two modelers:	**Anne**	**Ina**	**Anne**

Hydrological model set up and parameterization



Hydrological model calibration

	WaSiM-ETH	SWIM	HBV-light
Approach	automated: local approach (gradient-based (PEST))	manual	automated global approach (genetic algorithm)
Objective function	$\min \sum(\mathrm{Qsim}(t) - \mathrm{Qobs}(t))^2$	NSE, LNSE, r^2, MBE	LNSE

NSE: Nash Sutcliffe Efficiency, LNSE: Nash Sutcliffe Efficiency using logarithmic discharges, r^2: coefficient of determination, MBE: Mass Balance Error

→ After automated calibration, a multi-criteria evaluation was performed (as for SWIM)

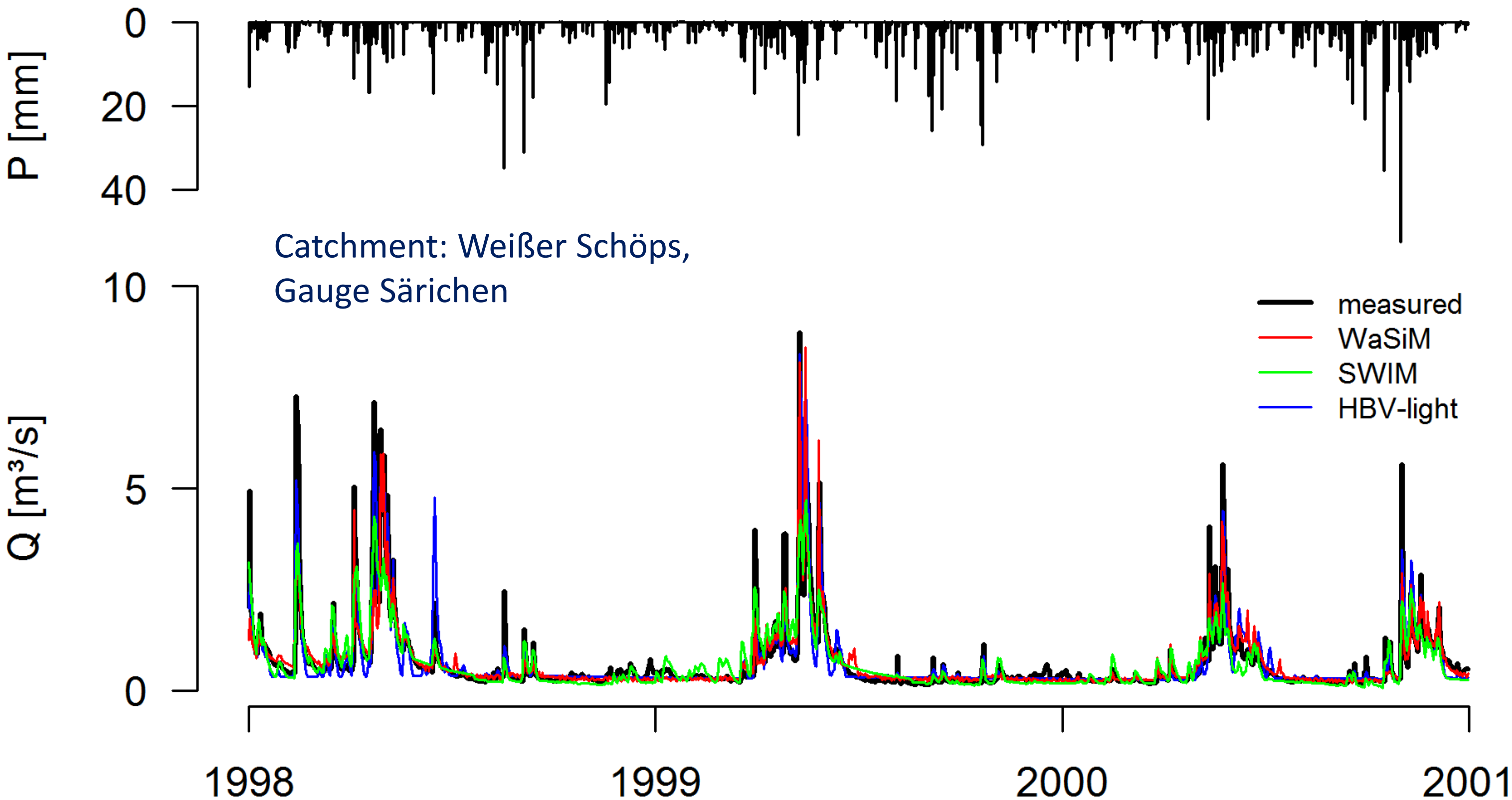
Calibration: 1999-2002

Validation: 2002-2006

Results

Model Calibration and Validation

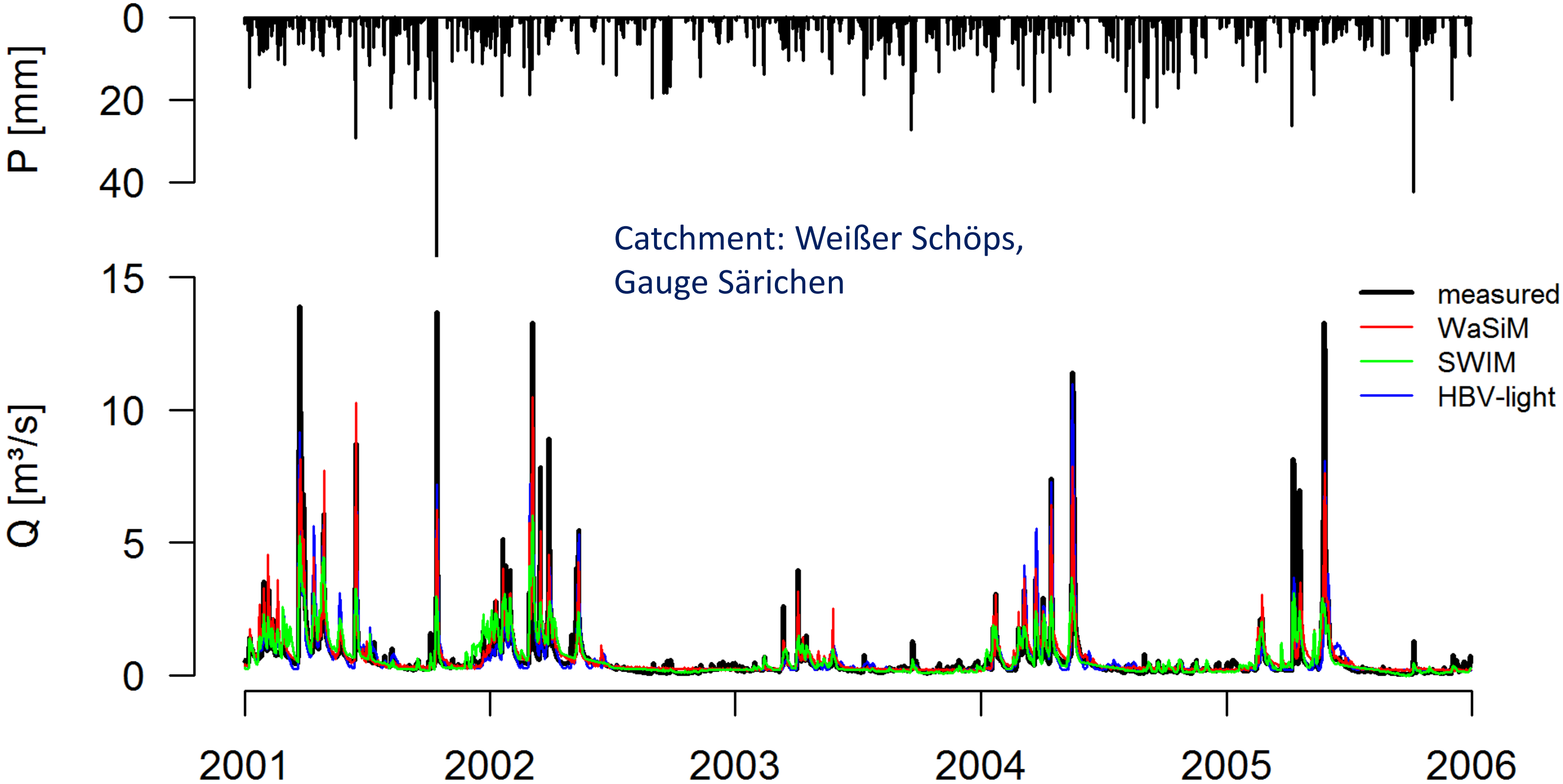
Results – Calibration (daily time step)



	r^2	NSE	LNSE	MBE
WaSiM	0.81	0.81	0.82	-3.5
SWIM	0.76	0.74	0.68	-7.5
HBV-light	0.85	0.85	0.80	-0.5

r^2 = coefficient of determination, NSE = Nash-Sutcliffe Efficiency, LNSE = Nash Sutcliffe Efficiency using logarithmic discharges, MBE = Mass Balance Error

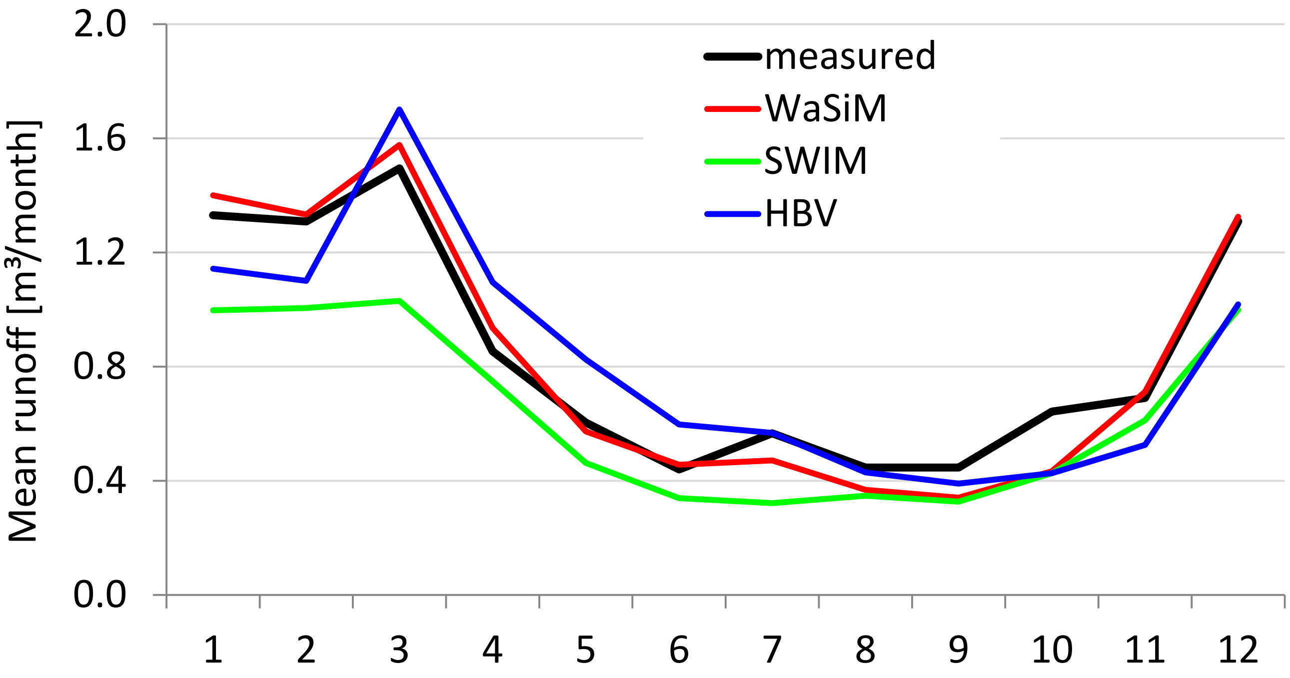
Results – Validation (daily time step)



	r^2	NSE	LNSE	MBE
WaSiM	0.79	0.77	0.65	5.4
SWIM	0.55	0.53	0.54	-3.1
HBV-light	0.72	0.71	0.70	-0.8

r^2 = coefficient of determination, NSE = Nash-Sutcliffe Efficiency, LNSE = Nash Sutcliffe Efficiency using logarithmic discharges, MBE = Mass Balance Error

Performance outside calibration and validation (mean monthly flow, 1966-1990)



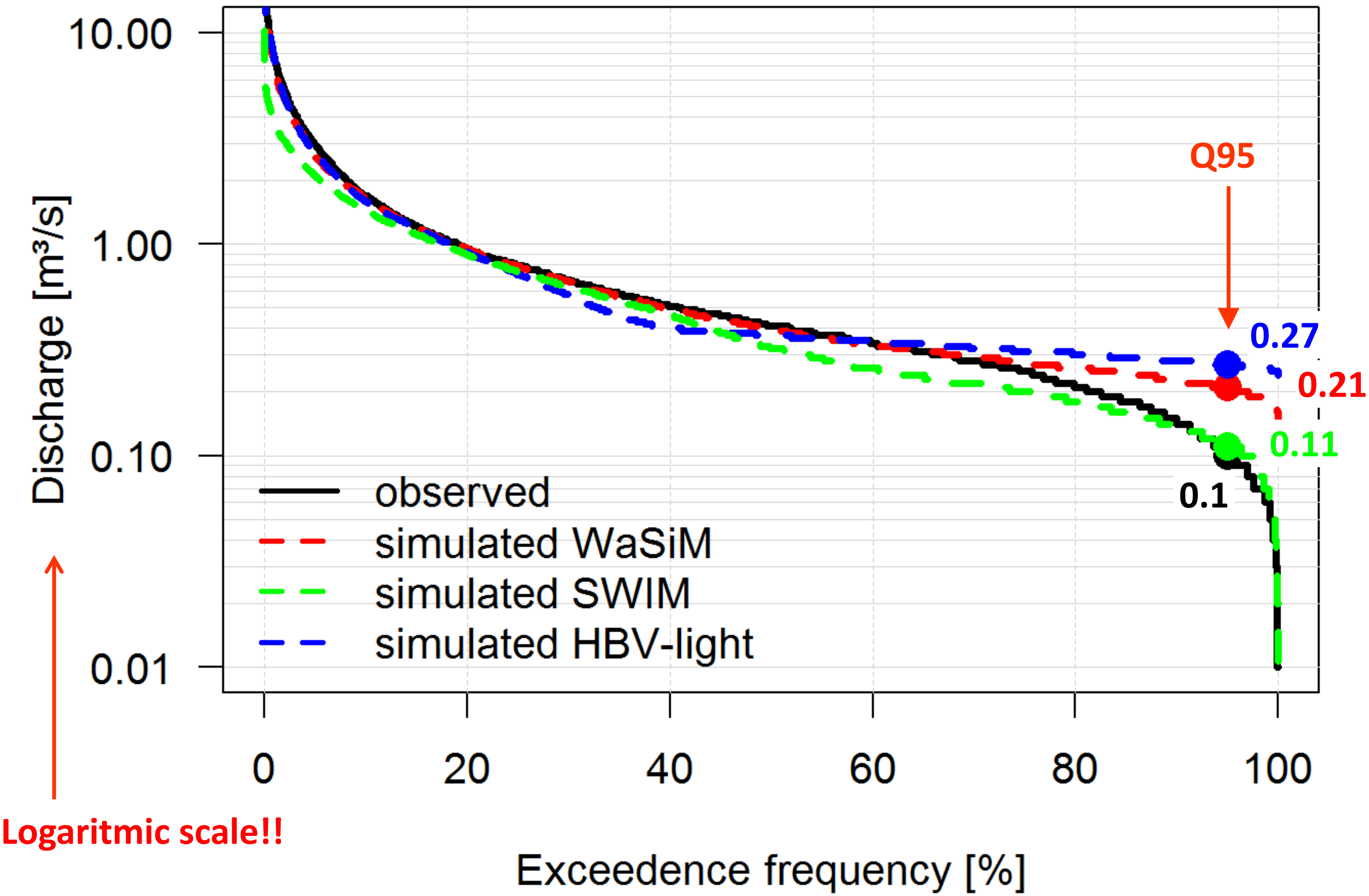
Catchment: Weißer Schöps, Gauge Särichen

	WaSiM	SWIM	HBV-light
r^2	0.98	0.96	0.77
NSE	0.96	0.31	0.77
LNSE	0.91	0.56	0.75
MBE [%]	-2.1	-33	-3.2

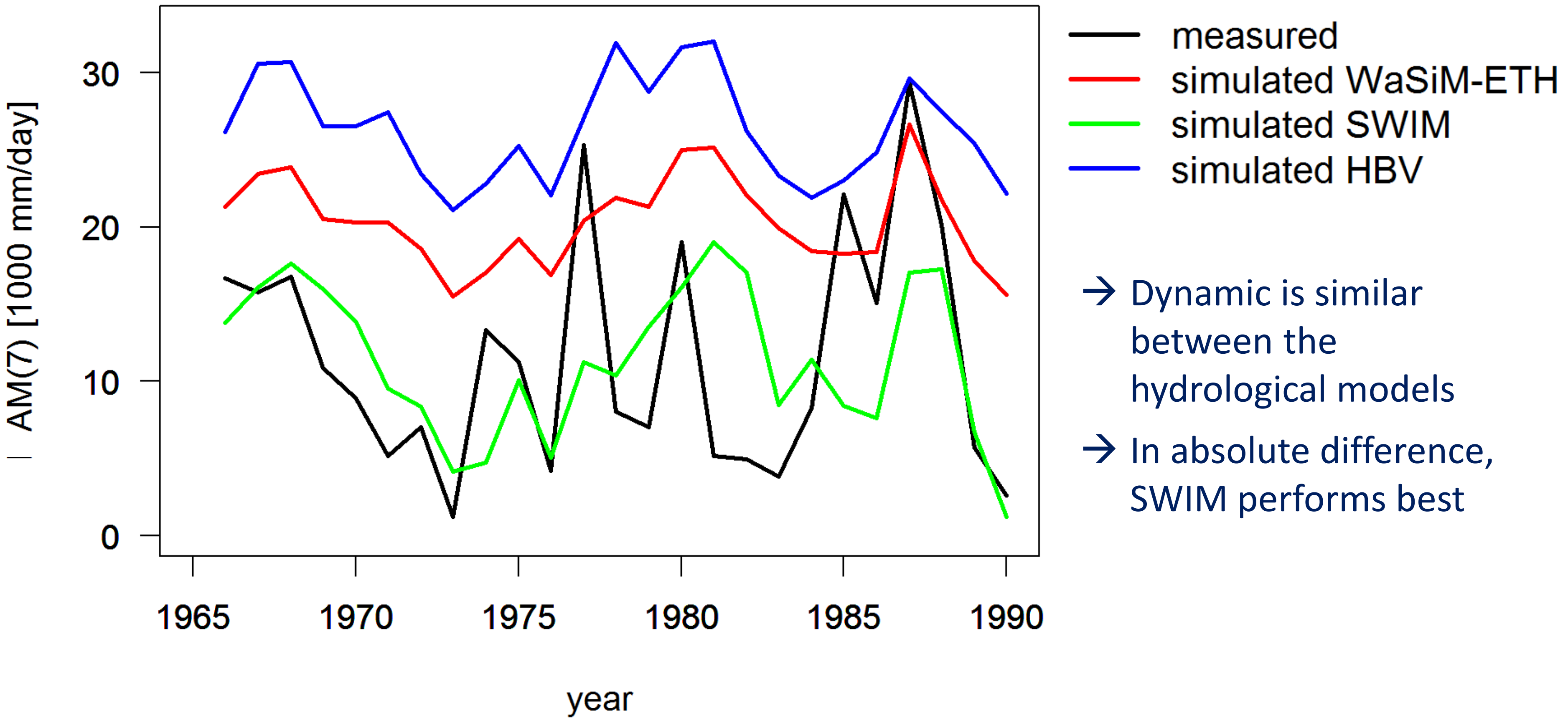
→ WaSiM-ETH performs better outside of the calibration and validation period

NSE: Nash Sutcliffe Efficiency   LNSE: Nash Sutcliffe Efficiency using logarithmic discharges
MARE: Mean absolute relative error   MBE: Mass Balance Error

Performance outside calibration and validation
Flow duration curve (Q95, 1966-1990)



Performance outside calibration and validation mean of AM(7) during 1966-1990



→ Dynamic is similar between the hydrological models

→ In absolute difference, SWIM performs best

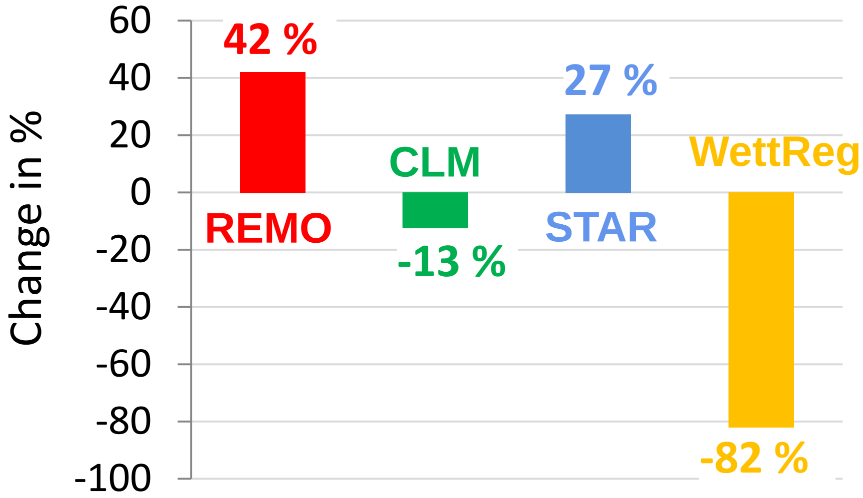
	Measured	WaSiM	SWIM	HBV-light
mean of AM(7) during 1966-1990	11.2	20.4	11.4	26.3

Climate Change Impact Assessment

Same hydrological model (SWIM), different climate downscaling approaches

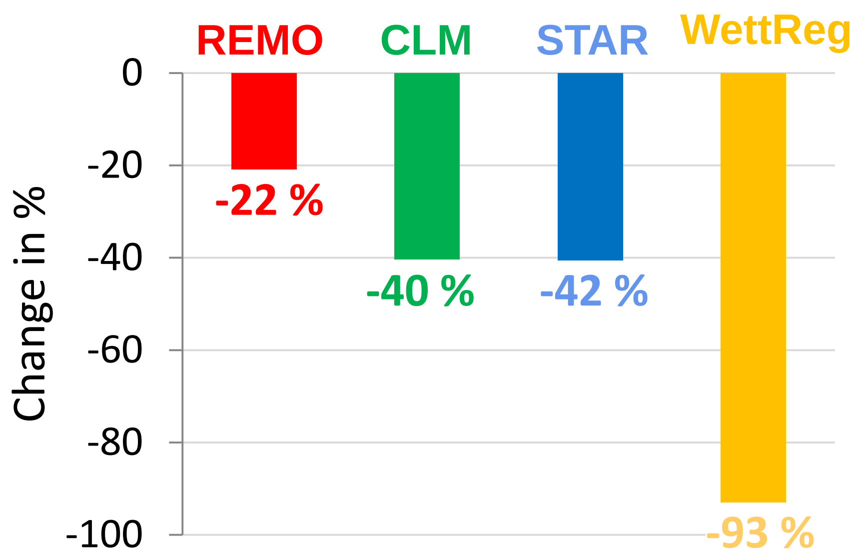
Low flows under different climate change scenarios based on SWIM (2031-2055 compared to 1966-1990)

Q95



→ deviations up to 120 %

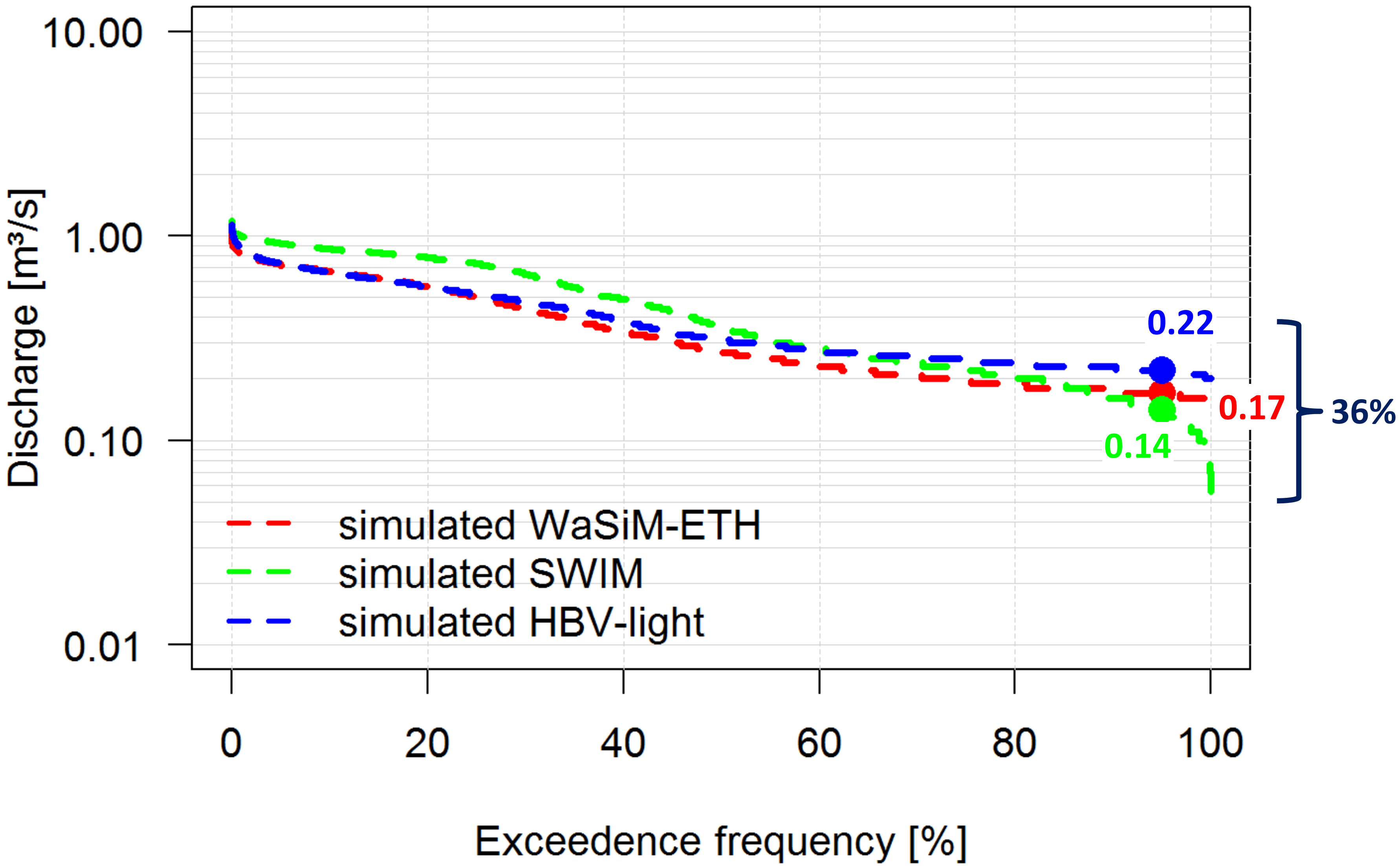
AM(7)



→ deviations up to 71 %

Different hydrologicals, same climate downscaling approach (STAR)

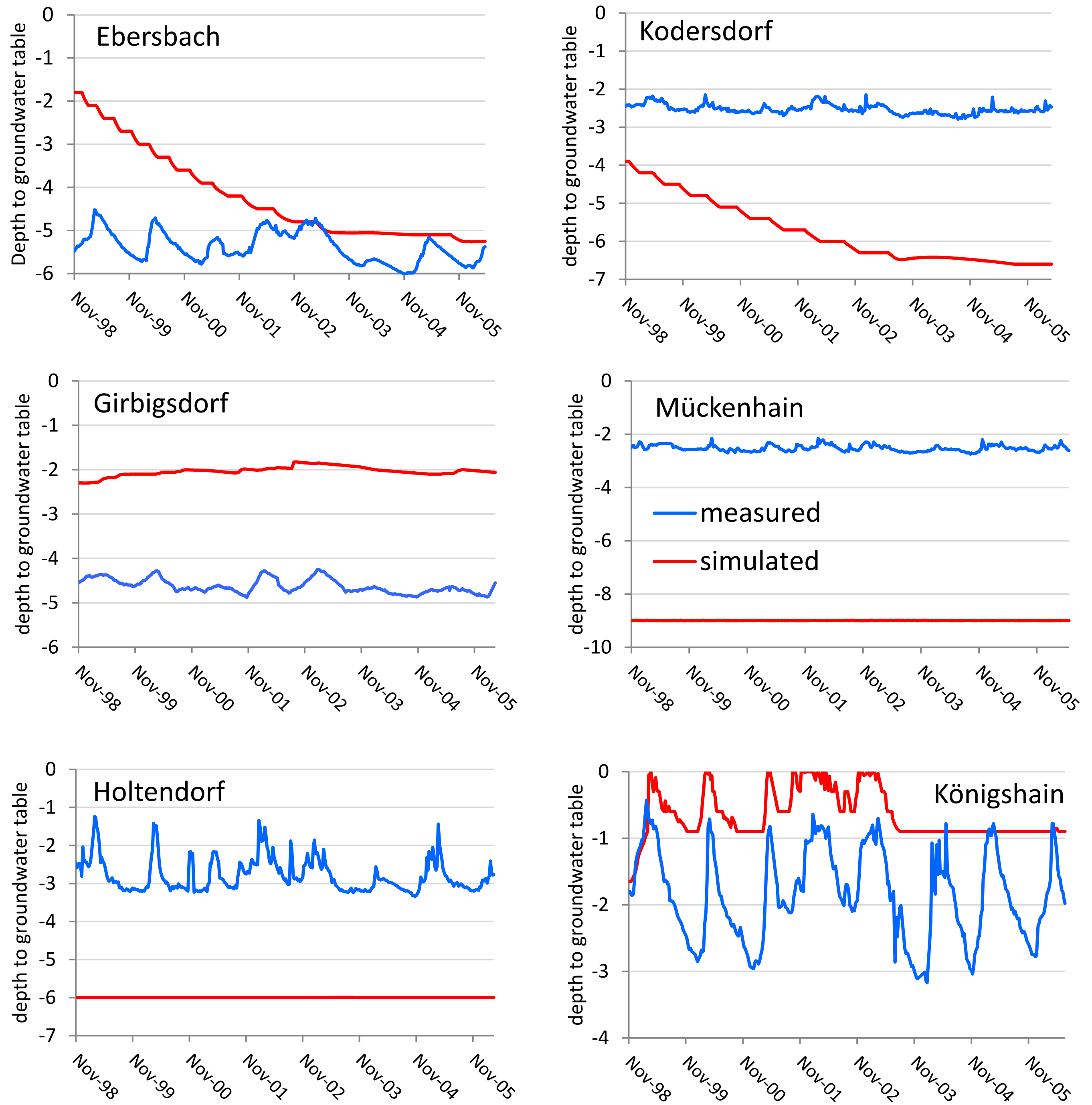
Difference between hydrological models
Results based on STAR (2031-2055)



One reason of poor agreement of WaSiM……

Groundwater levels WaSiM-ETH

Weißer Schöps



→ Poor agreement between measured and simulated groundwater levels

Summary

- WaSiM and HBV-light outperformed SWIM during model calibration and validation based on daily time step
- Outside of the calibration and validation period, WaSiM outperformed the more conceptual models for mean monthly flow (1966-1990)
- Concerning the low flow indicators AM(7) and Q95, SWIM outperformed WaSiM and HBV-light – even though WaSiM uses a 2D groundwater approach
- For the climate change impact assessment, the choice of the climate downscaling approach adds the largest share of uncertainty to the final results (even opposing trends for Q95)
- The analysis of measured and simulated groundwater levels based on WaSiM reveals that the internal processes are not simulated reliably yet

Conclusion

- During model calibration, the modeller has to make sure the model functions well for the purpose that the model will be used later on
- Setting up a model which works well for all flow conditions (high, mean, low flows) is difficult to achieve in most cases
- Weaknesses of statistical performance criteria need to be considered during model calibration and validation
- For climate change impact assessments focussing on low flows, the choice of the hydrological adds less uncertainty to the final results than the climate downscaling approach

Thank You!
Question?

References:

Gädeke, A., H. Hölzel, H. Koch, I. Pohle, and U. Grünewald (2014), Analysis of uncertainties in the hydrological response of a model-based climate change impact assessment in a subcatchment of the Spree River, Germany, Hydrological Processes, 28(12), 3978–3998.

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Teutschbein, C., F. Wetterhall, and J. Seibert (2011), Evaluation of different downscaling techniques for hydrological climate-change impact studies at the catchment scale, Climate Dynamics, 1-19.