Comparing WaSiM-ETH to HBV-light in Climate Change Impact Assessments – Advantages and Disadvantages

WaSiM User Conference
20. – 21. February 2014

Anne Gädeke[1], Hagen Koch[2], Ina Pohle[1] und Uwe Grünewald[1]

1) Department of Hydrology and Water Resources Management, Brandenburg University of Technology

1) Potsdam Institute for Climate Impact Research, RD Climate Impacts and Vulnerability

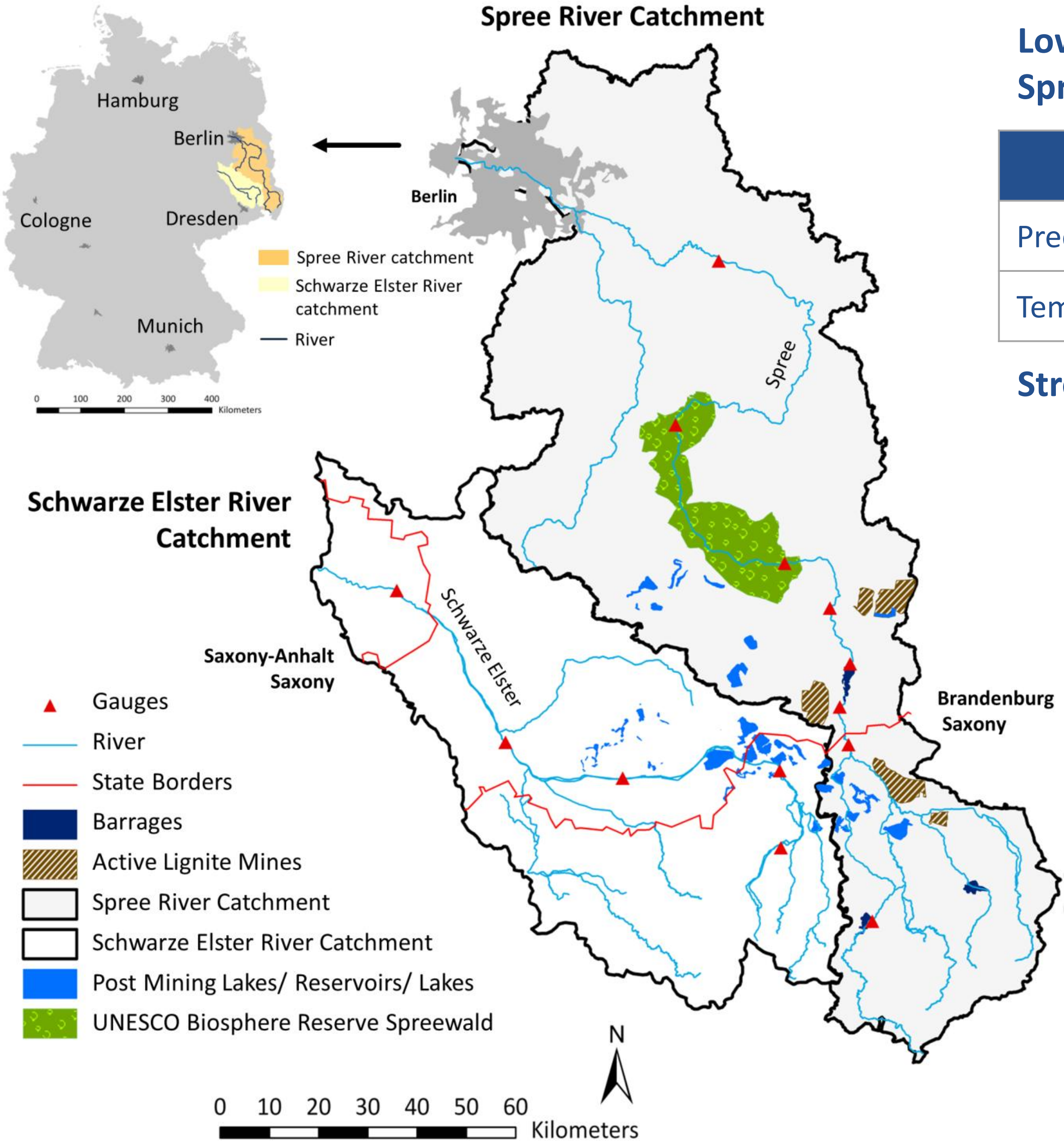
Background of the study

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

This is especially true for highly anthropogenically impacted catchments such as the Lusatian river catchments of Spree and Schwarze Elster

Characteristics of the study catchments



Low natural water availability in the Spree river catchment (1961-1990):

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

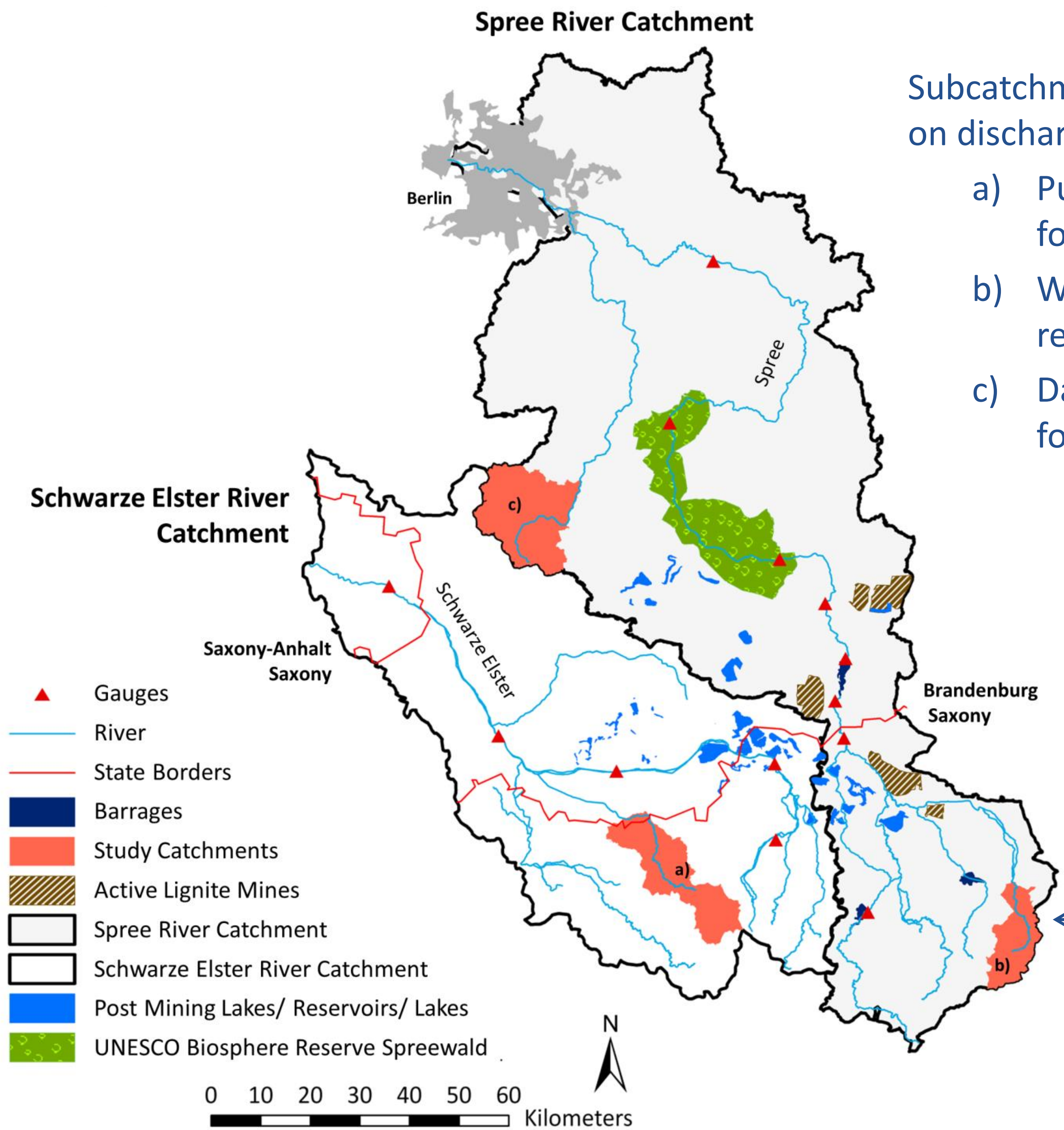
Strong impact due to mining activities

Problems related to:

- → **Water quality (pH in post mining lakes, sulfate and iron)**
- → **Water quantity**

- → Natural rainfall-runoff process strongly impacted anthropogenically
- → Calibration on the measured discharge is not possible

Selection of study catchments



Subcatchments where anthropogenic impact on discharge is relatively low:

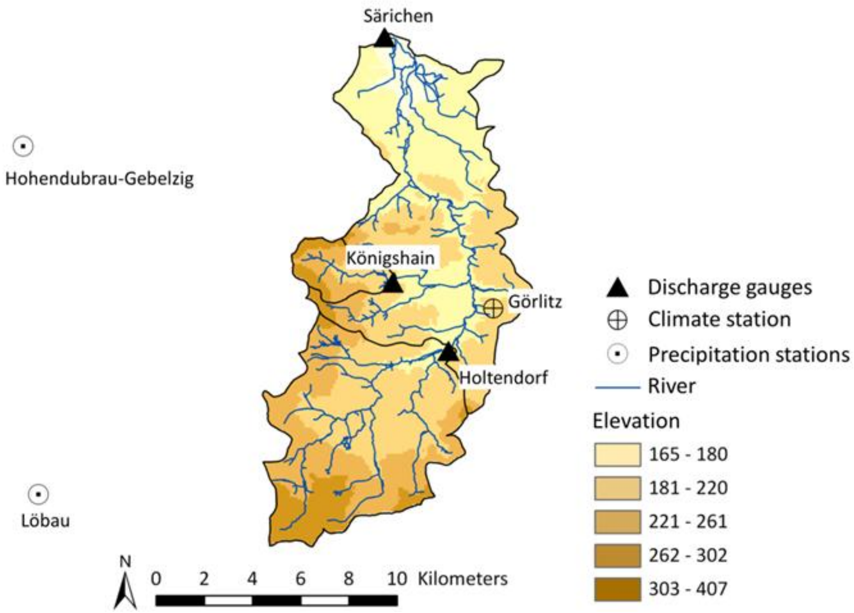
a) Pulsnitz (≈ 245 km² - representative for the Schwarze Elster)

b) Weißer Schöps (≈ 135 km² - representative for the upper Spree)

c) Dahme (≈ 300 km² - representative for the lower Spree)

This presentation only focusses on results of the Weißer Schöps river catchment

Characteristics of the Weißer Schöps river catchment

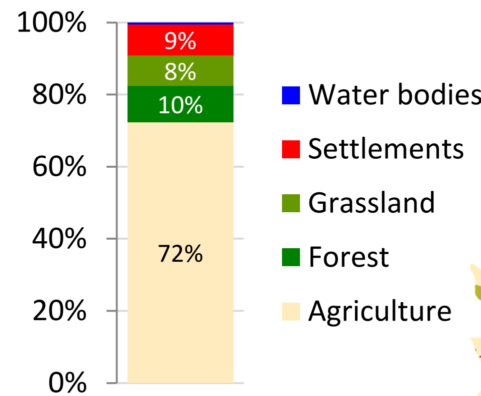


Climatic conditions (1963-2006)

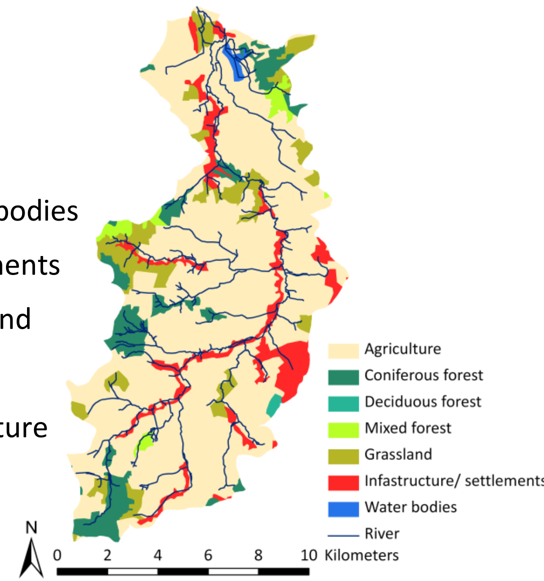
*ETP: Turc-Wendling

Catchment	T [°C]	P_{cor} [mm/a]	ETP* [mm/a]	CWB [mm/a]
Weißer Schöps	8.5	818	696	122

Land use

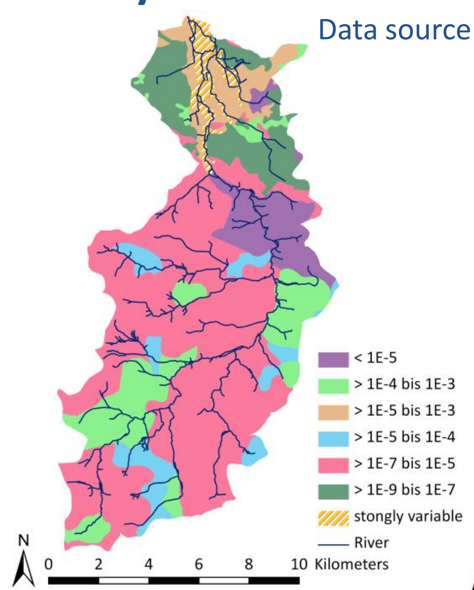


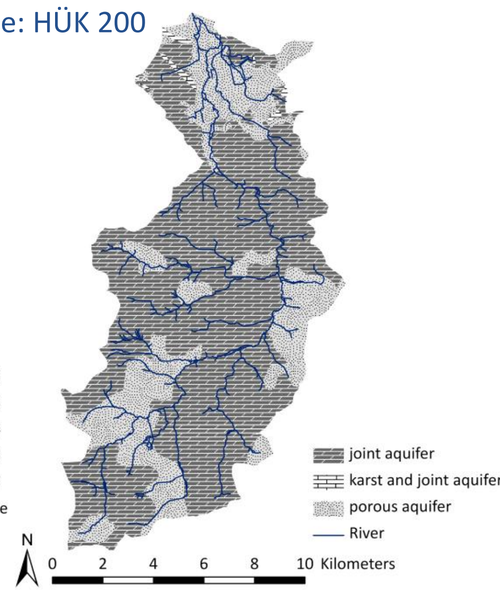
Data source: CORINE land cover



Hydraulic conductivity and aquifer type

Data source: HÜK 200





- Catchment representative for the conditions in the upper Spree
- Climate: transition zone between continental and maritime climate (runoff regime strongly influenced by evapotranspiration)
- Land use: mostly agriculture
- Geology: mostly joint aquifers with medium to low hydraulic conductivities

Aim of the study

- Calibration of two conceptually different hydrological models (WaSiM-ETH and HBV-light) on measured discharge
- Validation based on discharge and groundwater levels (for WaSiM-ETH)
- Estimation of the uncertainty related to the choice of the hydrological model within climate change impact assessments
  - Mean flow conditions
  - Low flow conditions

Hydrological models

Characteristic	WaSiM-ETH (8.05)	HBV-light (3.0)
Model type	Process based	Conceptual
Spatial reference	Fully distributed (uniform grid, 100 grid size)	Lumped
Temporal resolution	Daily	Daily
Meteorological data input	Precipitation, temperature, air humidity, wind speed, global radiation, sunshine duration	Precipitation, temperature and potential evapotranspiration
Interpolation	Inverse distance approach	Manually during pre-processing
ETP/ETA	Penman–Monteith approach, ETP is reduced to ETA using the Feddes approach	ETP is an input data set; ETA is calculated on the basis of soil water storage content
Interception	LAI-dependent Bucket approach	Not considered
Infiltration	Green-Ampt approach modified after Peschke (1987)	Not considered
Unsaturated zone	Richards equation parameterized on the basis of van Genuchten (1980)	Linear storage approach
Saturated zone	Integrated 2D groundwater model	Linear storage approach
Routing model	Kinematic wave approach based on flow velocity of the Manning-Strickler equation	Runoff transformation by triangular weighting function

Model parameterization

→ Same input data - in order to concentrate on structural difference between the hydrological models

WaSiM-ETH

↓

Precipitation correction

↓

Interpolation of meteorological input data

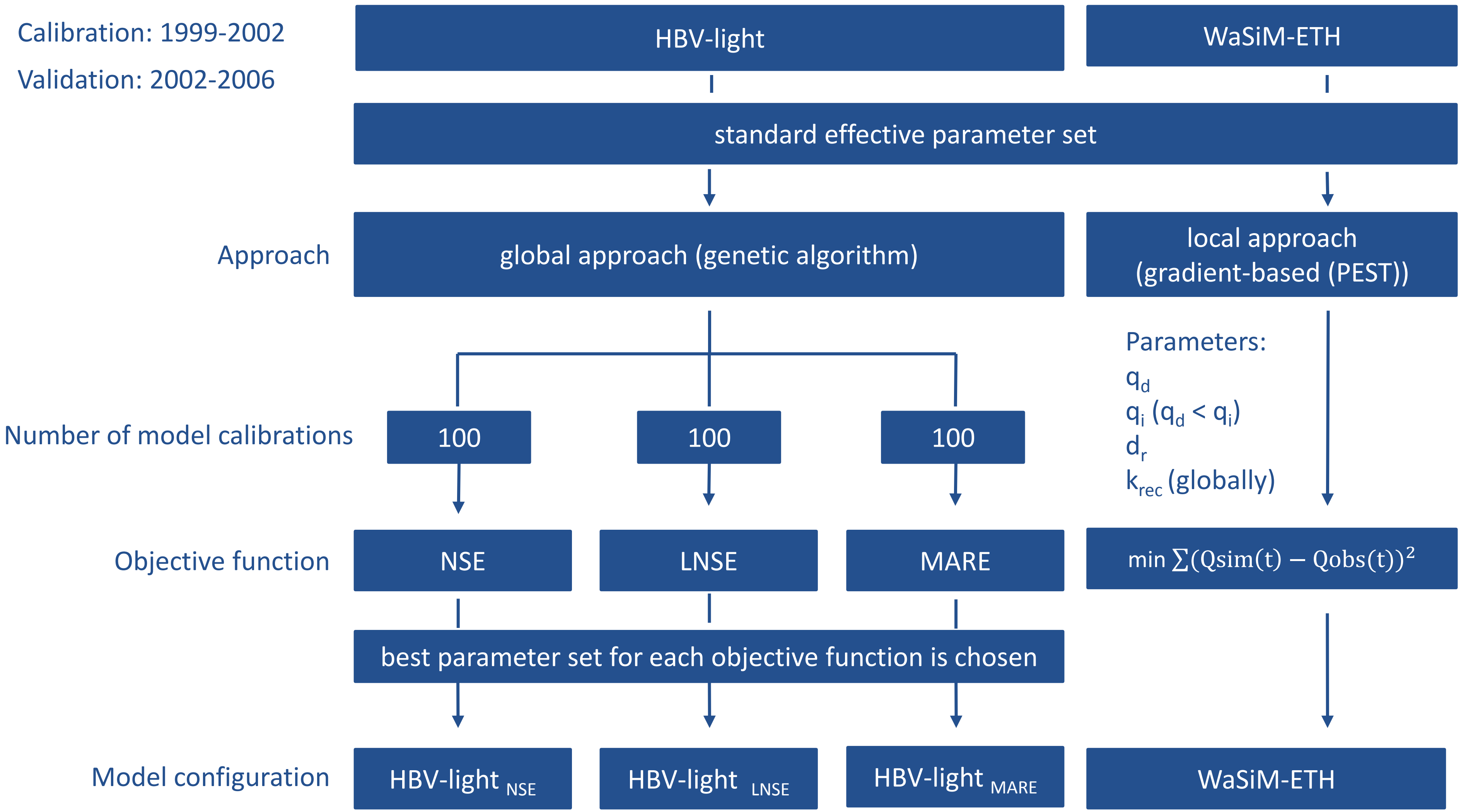
→ precipitation, temperature, potential evapotranspiration → **HBV-light** ↓ **No manual model parameterization**

↓

Careful manual model parameterization:

- **Land use (based on CORINE 2006, parameters: suggested values in WaSiM-ETH control file and Scherzer et al. 2006)**
- **Soil (Soil maps (1:200,000 and 1:300,000) van Genuchten soil hydraulic parameters based on DIN 4220)**
- **Groundwater (based on HÜK200 and advise from Dr. Schulla (1 unconfined aquifer, no boundary conditions specified)**

Hydrological model calibration



NSE: Nash Sutcliffe Efficiency LNSE: Nash Sutcliffe Efficiency using logarithmic discharges MARE: Mean absolute relative error

Modified from Gädeke et al. (2013)

Study approach for climate change impact assessment

Temporal focus:

Reference Period: 1963-1992
Scenario Period: 2031-2060

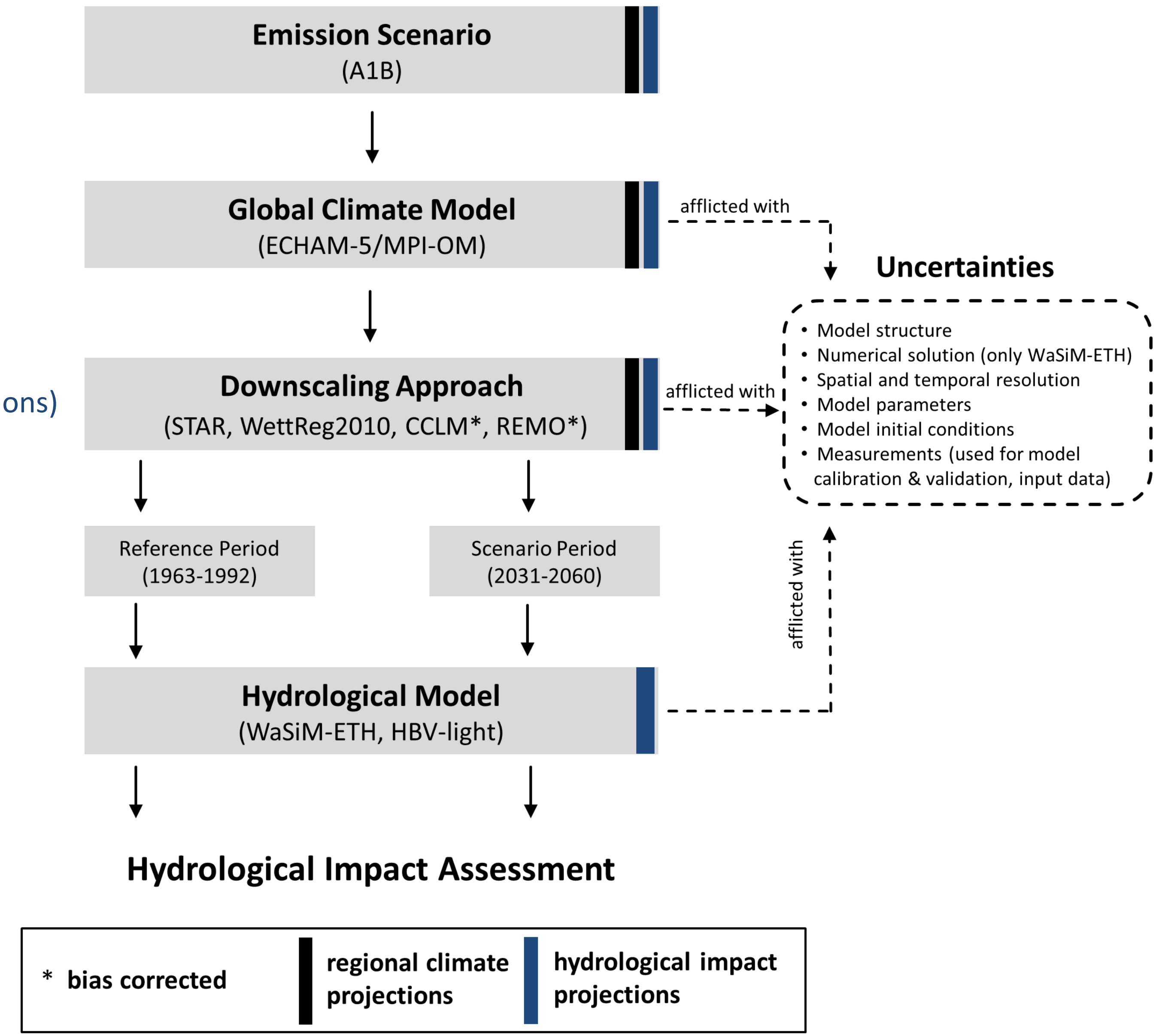
BIAS correction (linear scaling):

REMO: Temperature, Precipitation, Radiation

CLM: Temperature, Precipitation, Radiation, Humidity (transfer functions)

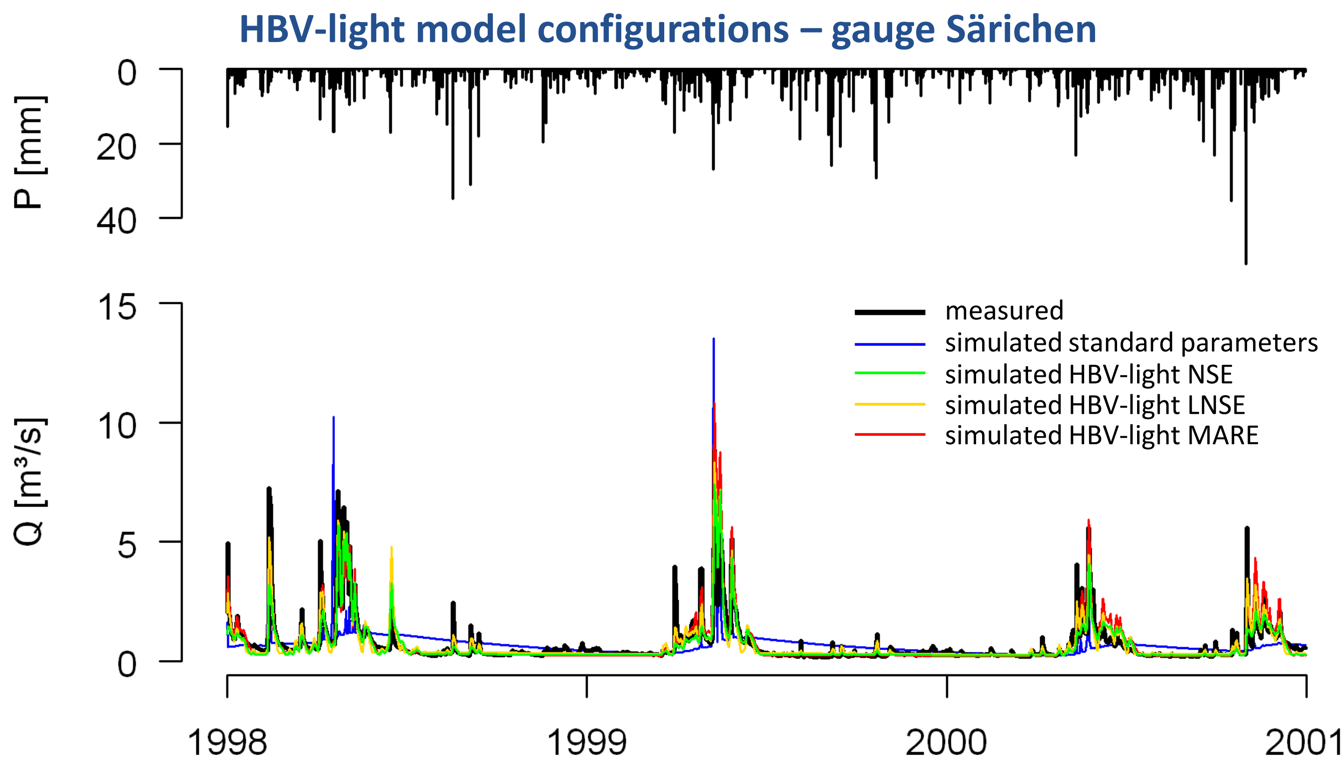
Downscaling Approach:

- STAR (100 Realisations of +2K)
- WettReg (10 Realisations of A1B)
- CCLM (2 Realisations of A1B)
- REMO (1 Realisation of A1B)



Results

Results – Weißer Schöps : calibration (1999-2001)



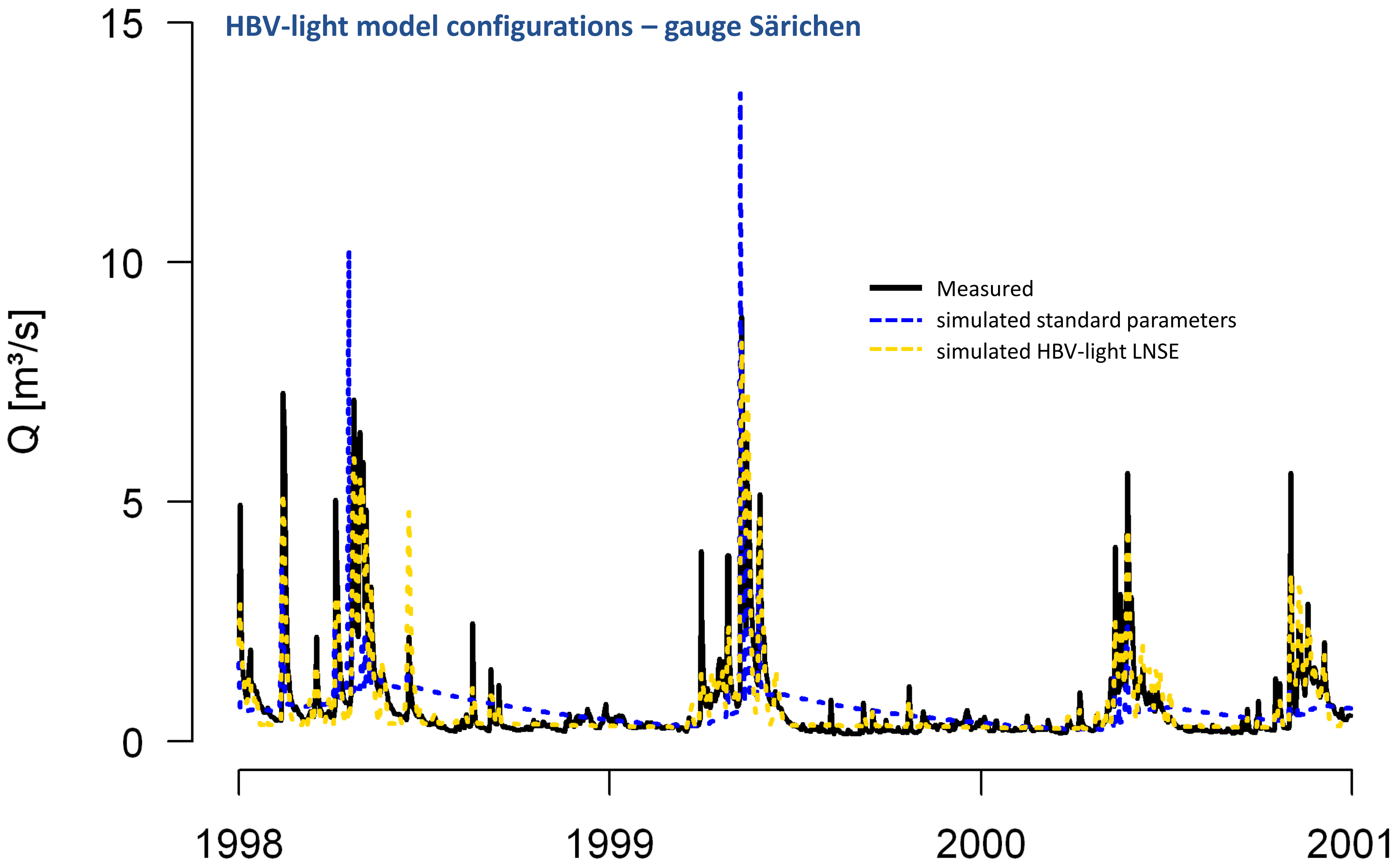
Data source measured discharge: LfULG 2009

- Only poor agreement based on HBV-light standard parameters
- After automated calibration high performance indicators are achieved

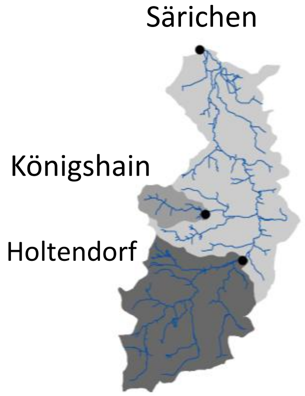
	HBV-light - Standard Parameters	HBV-light $_{NSE}$	HBV-light $_{LNSE}$	HBV-light $_{MARE}$
r^2	0.16	0.8	0.85	0.8
NSE	0.09	0.76	0.85	0.79
LNSE	0.07	0.79	0.8	0.8
MBE [%]	-2.94	2.35	-0.47	-10.8

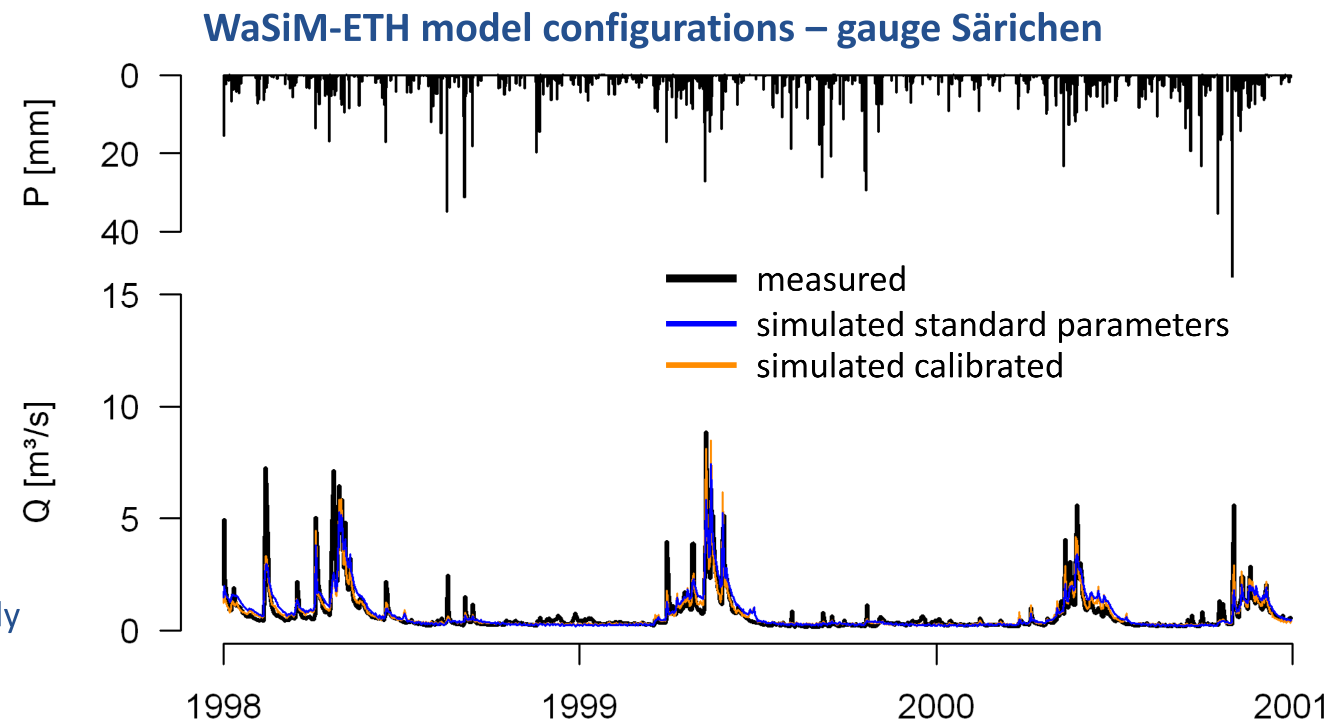
NSE: Nash Sutcliffe Efficiency LNSE: Nash Sutcliffe Efficiency using logarithmic discharges MARE: Mean absolute relative error MBE: Mass Balance Error

Results – Weißer Schöps : calibration (1999-2001)



Results – Weißer Schöps: calibration (1999-2001)





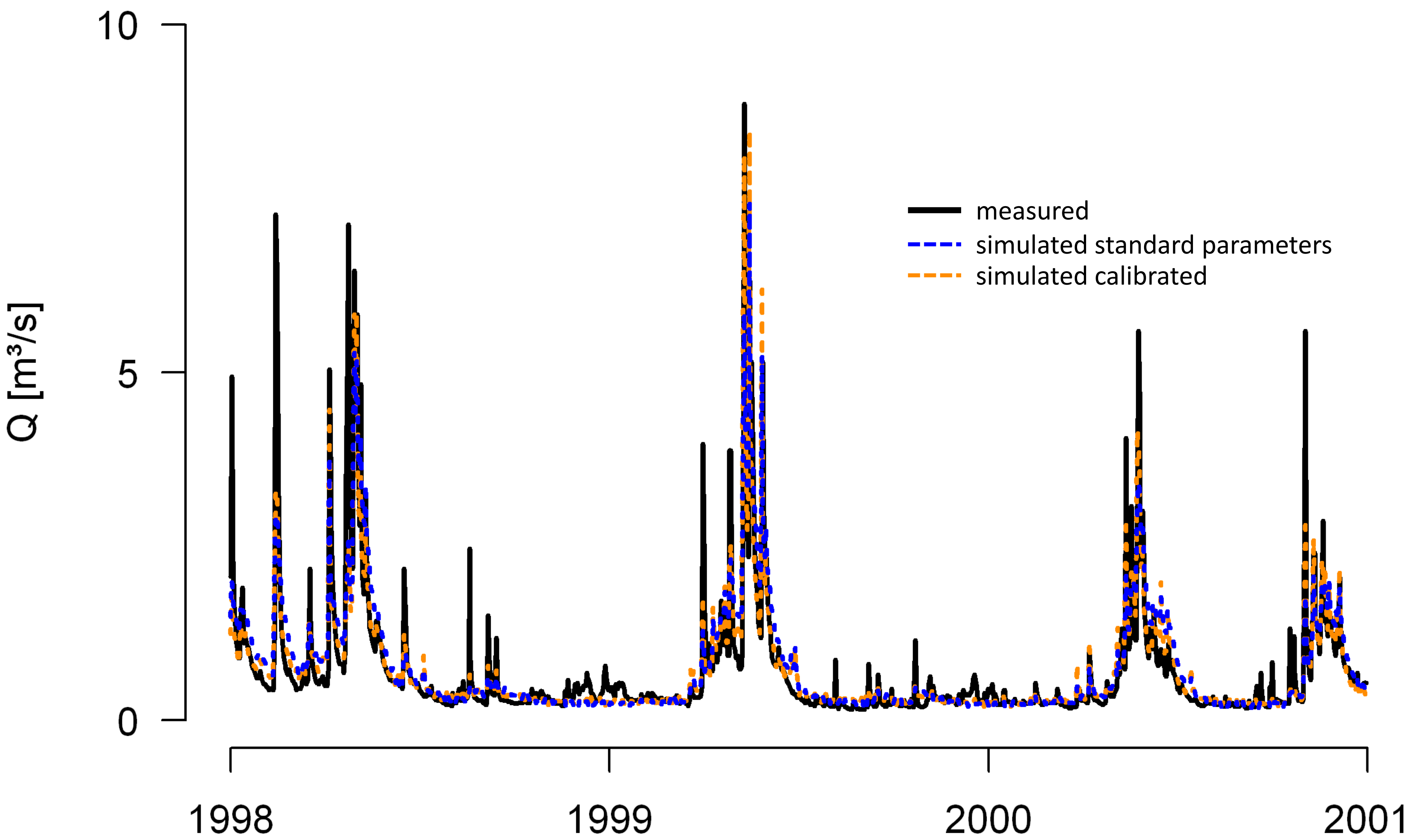
- After careful model parameterization, high performance indicators are obtained (attributed to: 2D groundwater approach)
- Automated calibration (PEST) only marginally increases model performance

	WaSiM-ETH Standard Parameters (gauge Särichen)	WaSiM-ETH calibrated (gauge Särichen)	WaSiM-ETH Standard Parameters (gauge Königshain)	WaSiM-ETH calibrated (gauge Königshain)	WaSiM-ETH Standard Parameters (gauge Holtendorf)	WaSiM-ETH calibrated (gauge Holtendorf)
r^2	0.74	0.81	0.40	0.6	0.75	0.8
NSE	0.74	0.81	0.38	0.51	0.74	0.8
LNSE	0.81	0.82	0.79	0.87	0.78	0.84
MBE [%]	5.91	-3.53	-6.97	-14.26	0.86	-5.09

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

Results – Weißer Schöps: calibration (1999-2001)

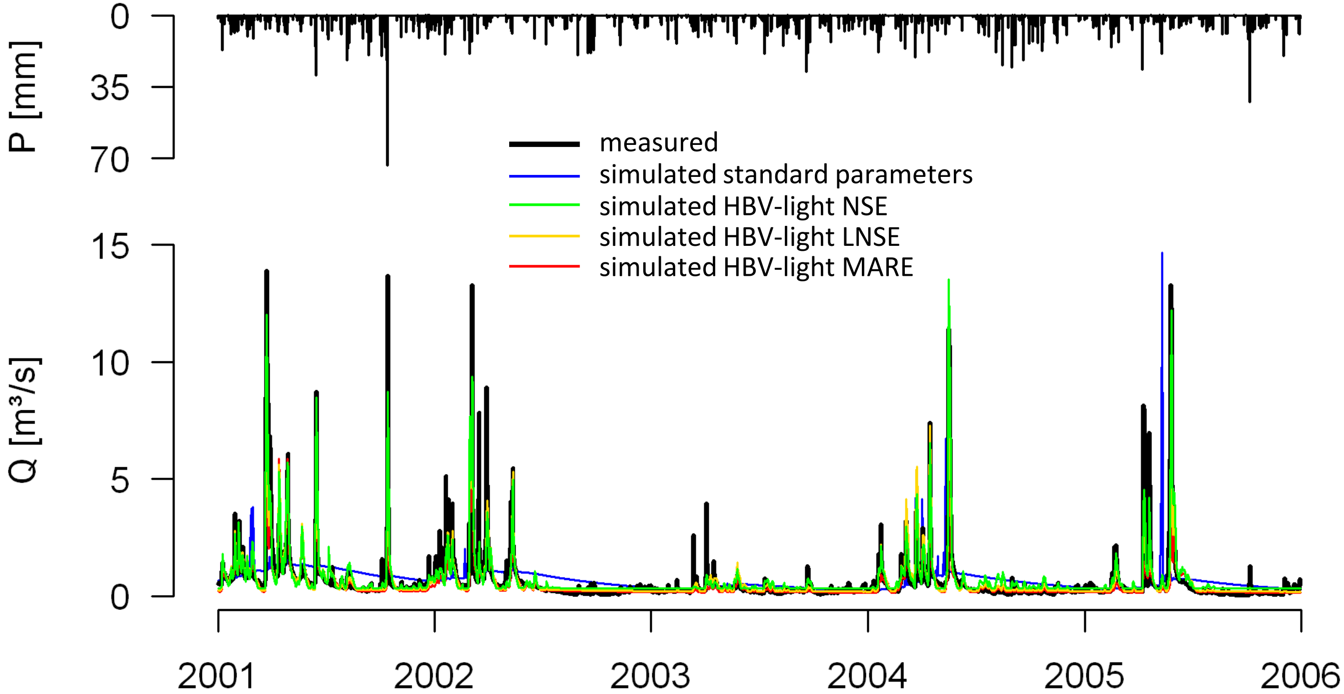
WaSiM-ETH model configurations – gauge Särichen



Results – Weißer Schöps: validation (2002-2006)

Särichen

HBV-light model configurations – gauge Särichen

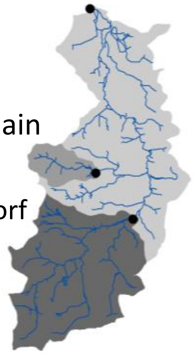


→ Generally lower performance during validation compared to calibration period

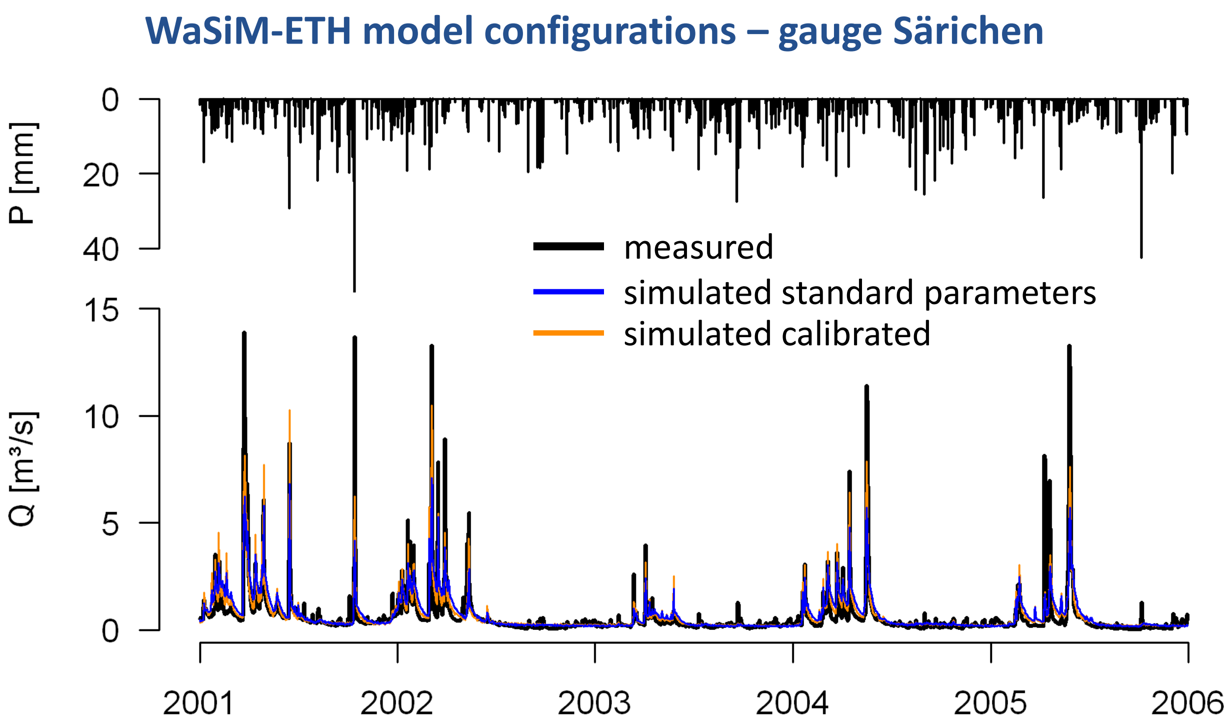
	HBV-light - Standard Parameters	HBV-light $_{NSE}$	HBV-light $_{LNSE}$	HBV-light $_{MARE}$
r^2	0.11	0.72	0.74	0.7
NSE	0.07	0.71	0.74	0.7
LNSE	-0.09	0.66	0.54	0.6
MBE [%]	10.72	-0.83	5.75	-4.84

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

Results – Weißer Schöps: validation (2002-2006)



→ Generally lower performance during validation compared to calibration period

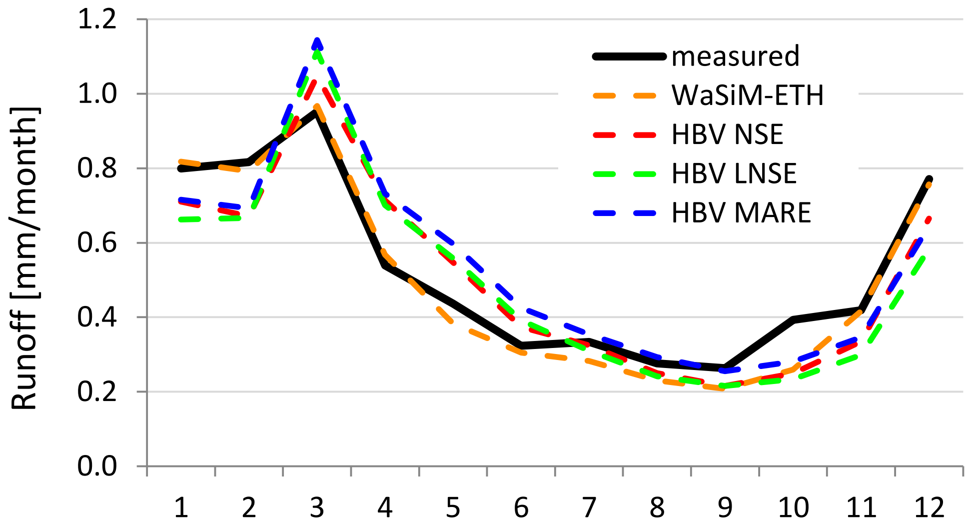


	WaSiM-ETH Standard Parameters (gauge Särichen)	WaSiM-ETH calibrated (gauge Särichen)	WaSiM-ETH Standard Parameters (gauge Königshain)	WaSiM-ETH calibrated (gauge Königshain)	WaSiM-ETH Standard Parameters (gauge Holtendorf)	WaSiM-ETH calibrated (gauge Holtendorf)
r^2	0.69	0.78	0.51	0.58	0.65	0.73
NSE	0.66	0.77	0.45	0.54	0.59	0.68
LNSE	0.71	0.65	0.56	0.56	0.78	0.81
MBE [%]	9.23	5.37	-26.14	-28.98	-9.80	-12.28

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

Additional model validation

Model validation based on monthly runoff (1963-1992)



	WaSiM-ETH	HBV-light $_{NSE}$	HBV-light $_{LNSE}$	HBV-light $_{MARE}$
r^2	0.98	0.83	0.77	0.79
NSE	0.95	0.81	0.7	0.74
LNSE	0.87	0.77	0.67	0.78
MBE [%]	-5.31	-3.48	-5.47	2.48

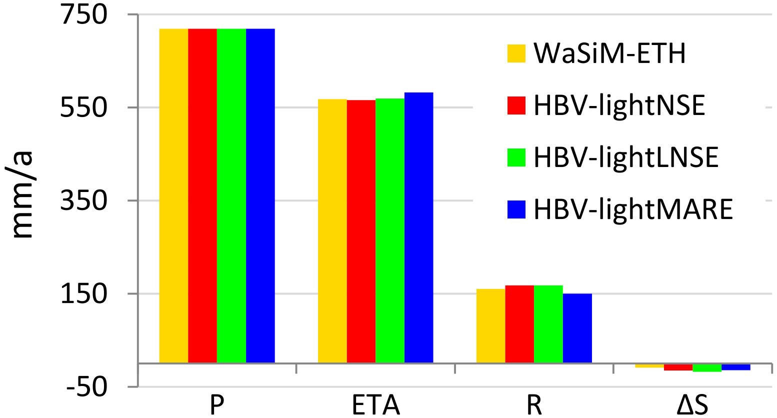
NSE: Nash Sutcliffe Efficiency LNSE: Nash Sutcliffe Efficiency using logarithmic discharges
MARE: Mean absolute relative error MBE: Mass Balance Error

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

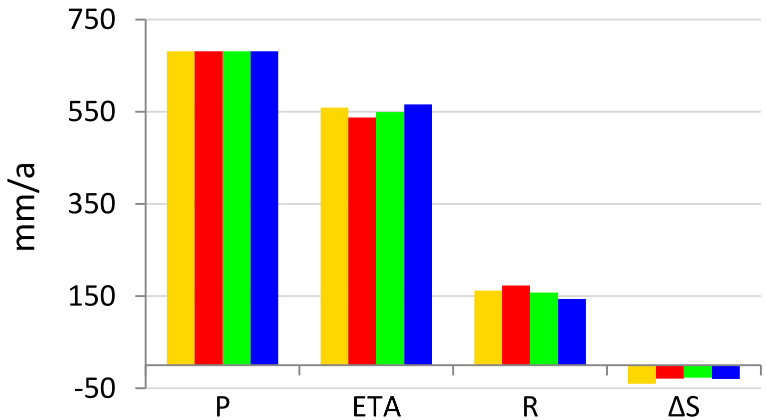
Modified from Gädeke et al. (2013)

Water balance components

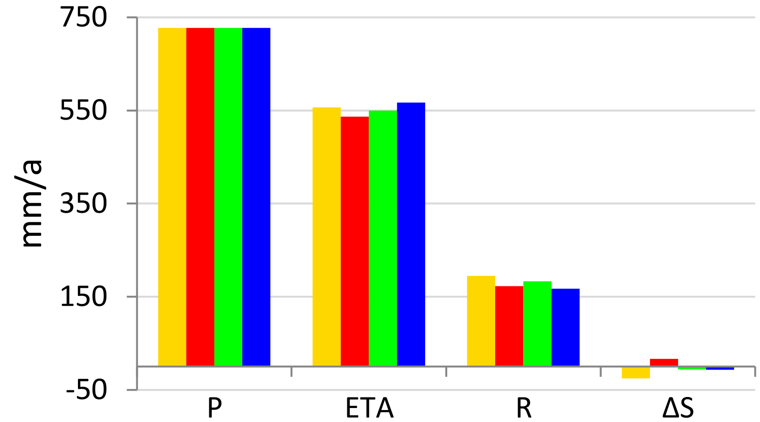
Calibration (1998-2001)



Validation (2002-2006)



Additional Validation (1963-1992)

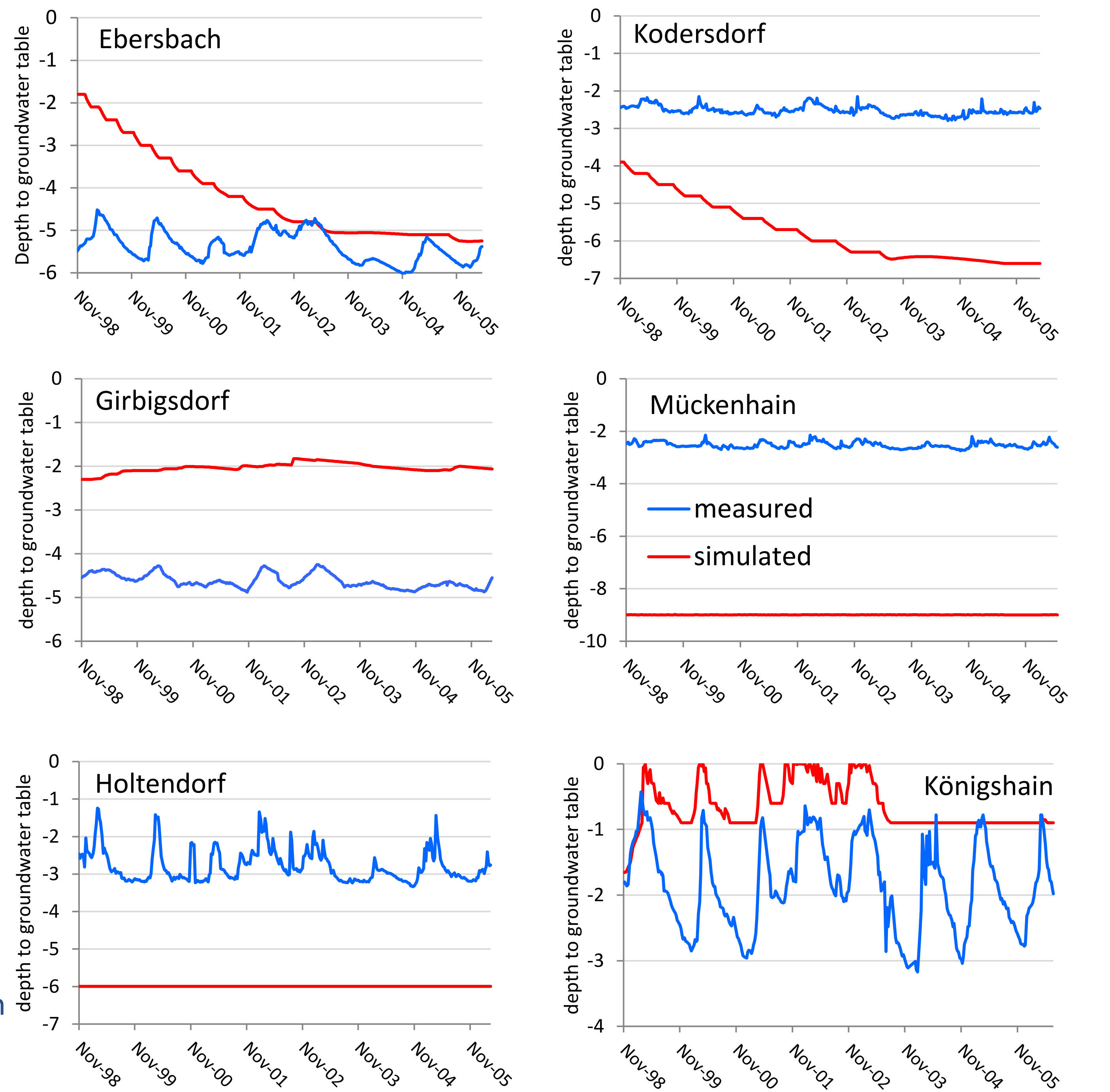


→ Differences in the water balance components based on the calibrated models are relatively low for the Weißer Schöps river catchment

→ For the other two subcatchments, difference are larger

Groundwater levels WaSiM-ETH

Weißer Schöps

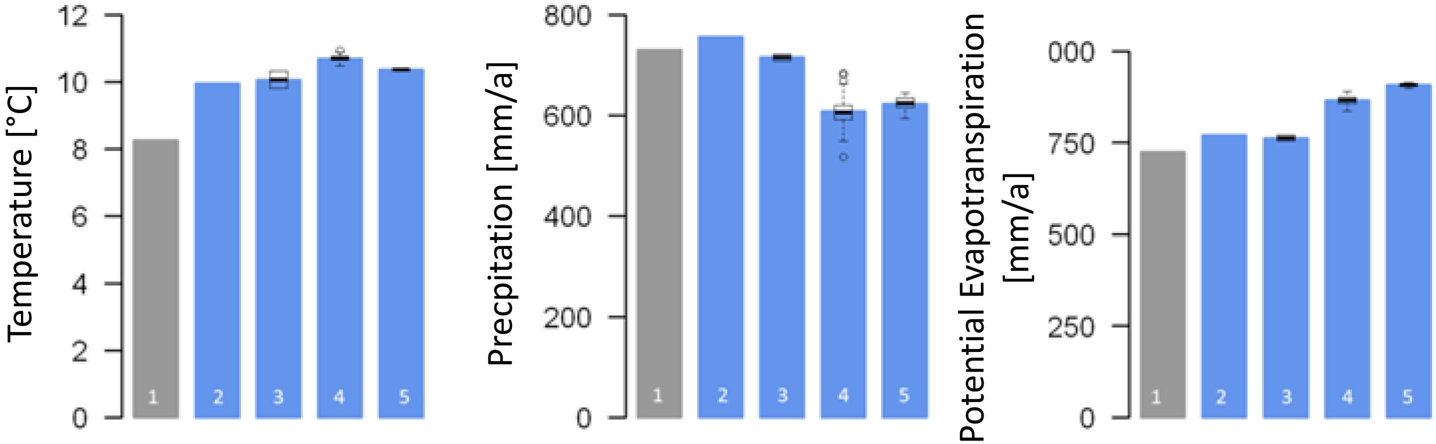


→ Poor agreement between measured and simulated groundwater levels

Groundwater levels simulated with WaSiM-ETH

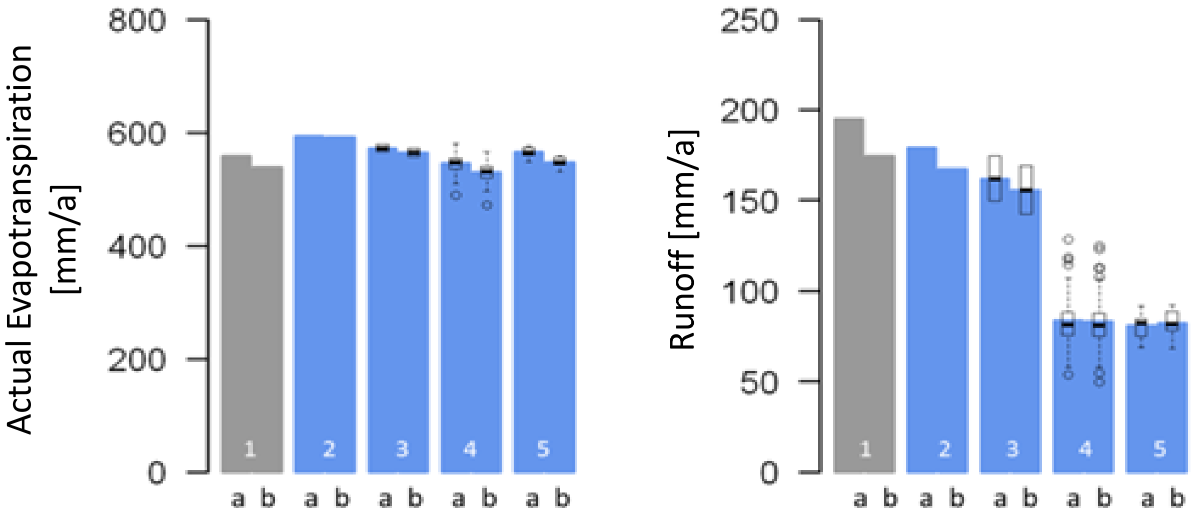
- Is my model “right for the wrong reasons”?
- Is it realistic to match the groundwater levels? (mostly joint aquifers and very simplified model parameterization of 2D groundwater model)

Climate change impact analysis



→ Increase in temperature and potential evapotranspiration

→ Opposing precipitation signal (increase in precipitation based on REMO and CCLM, decrease based on STAR and WettReg)



reference (1963-1992)
based on meteorological measurements

scenario (2031-2060)

1) meteorological measurements
2) REMO (1 realisation)
3) CCLM (2 realisations)
4) STAR (100 realisations)
5) WettReg (10 realisations)

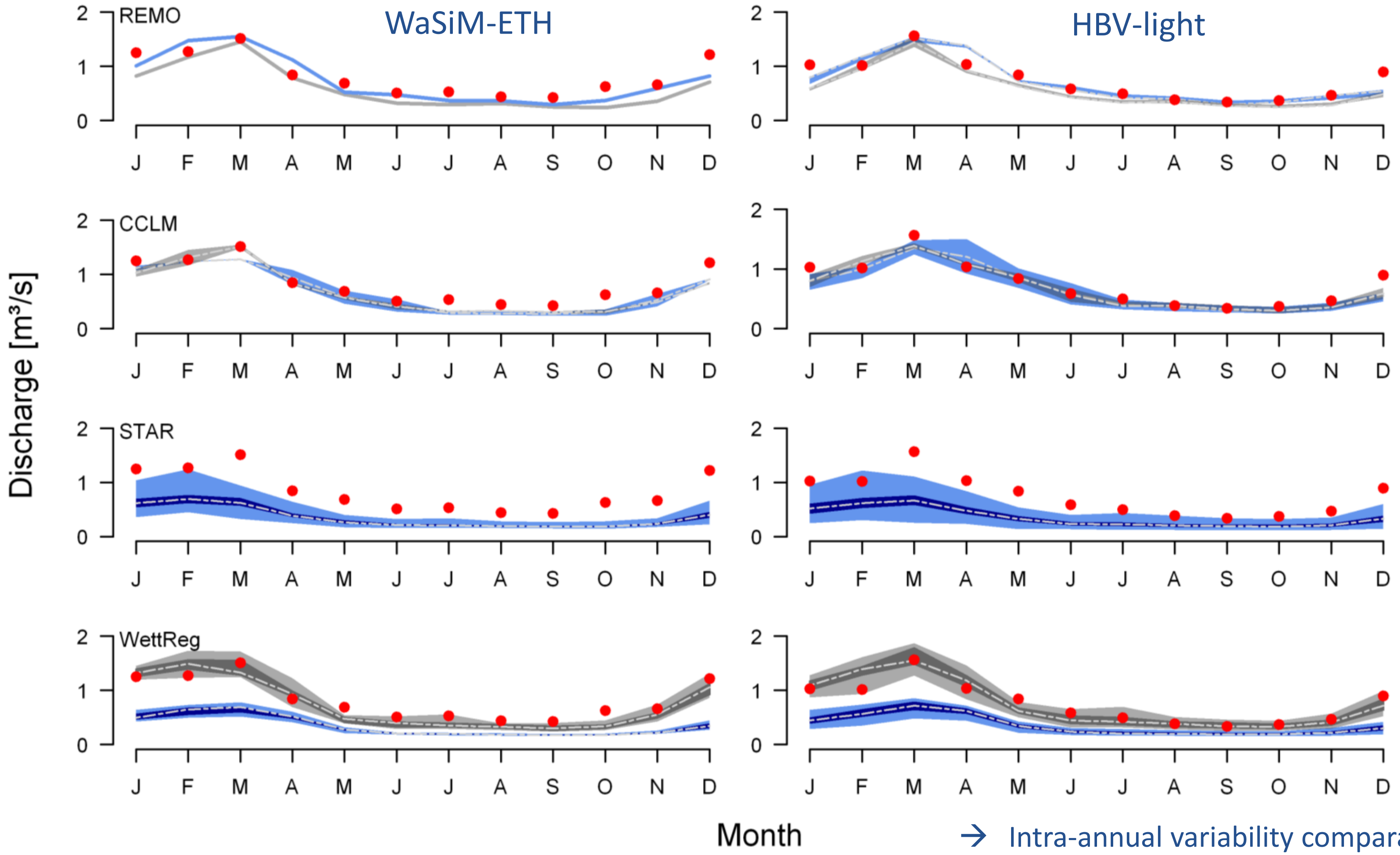
a) WaSiM-ETH
b) HBV-light

→ Large difference in runoff based on choice of downscaling approach (statistical or dynamical)

→ Difference between hydrological models relative low

Modified from Gädeke et al. (2013)

Climate change impact analysis



reference (1963-1992)

scenario (2031-2060)

● HBV-light and WasiM-ETH driven by meteorological measurements

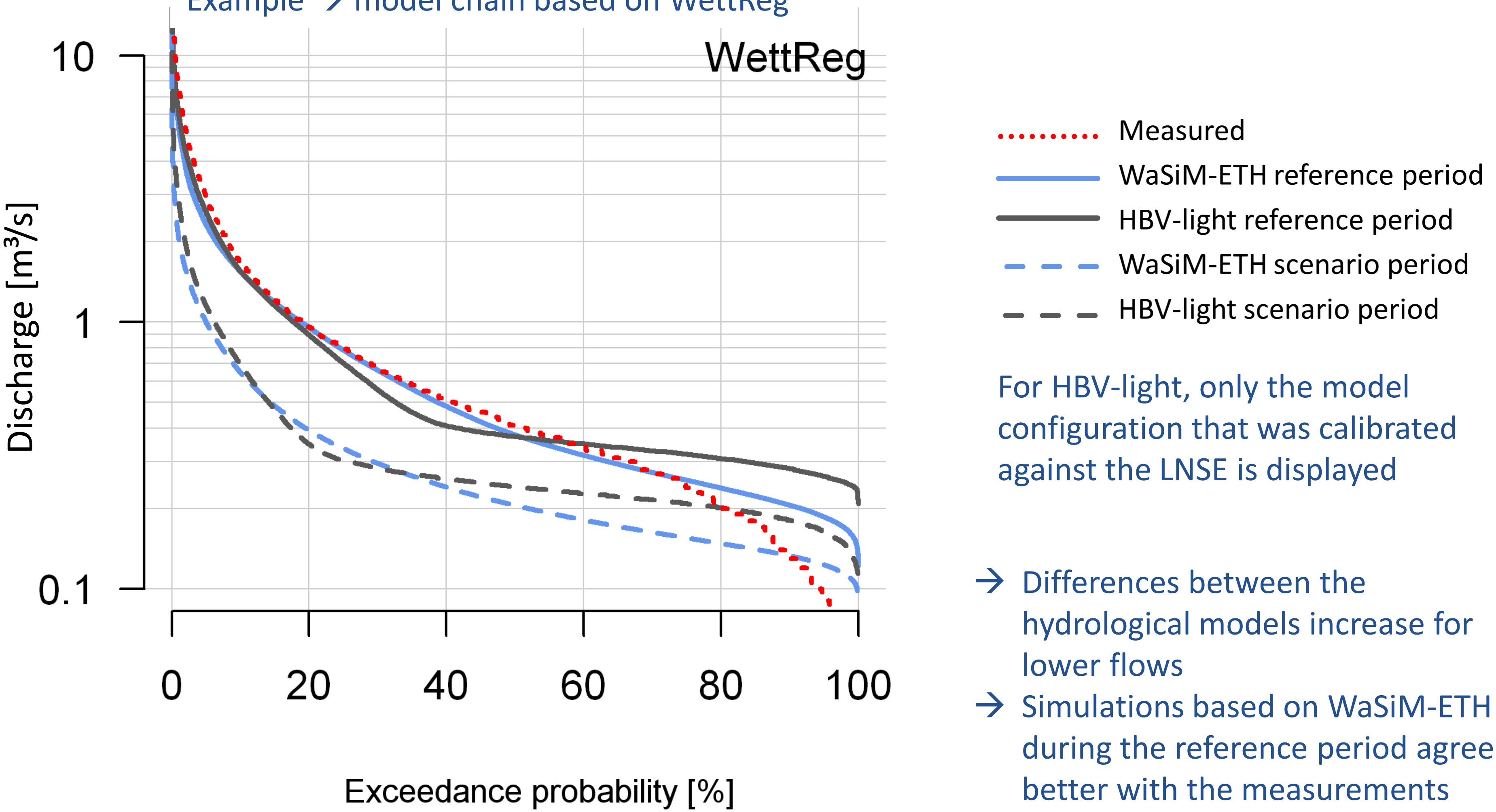
→ Intra-annual variability comparable between WaSiM-ETH and HBV-light

→ Large difference based on the driving climate downscaling approach

Modified from Gädeke et al. (2013)

Low Flow Analysis

Example → model chain based on WettReg



For HBV-light, only the model configuration that was calibrated against the LNSE is displayed

→ Differences between the hydrological models increase for lower flows

→ Simulations based on WaSiM-ETH during the reference period agree better with the measurements (up to 80 % exceedance probability)

Low Flow Analysis

P-value of Wilcoxon test comparing simulated discharge between the hydrological models in the reference (ref: 1963-1992) and scenario period (scen: 2031-2060)

		Mean yearly discharge	Minimum yearly discharge	AM7*
REMO	ref	0.83	< 0.01	< 0.01
	scen	0.99	< 0.01	< 0.01
CLM	ref	0.55	< 0.01	< 0.01
	scen	0.58	< 0.01	< 0.01
STAR	ref	0.91	< 0.01	< 0.01
	scen	< 0.01	< 0.01	< 0.01
WETTREG	ref	0.24	< 0.01	< 0.01
	scen	0.31	< 0.01	< 0.01

* AM7: annual minimum 7-day mean flow

→ Uncertainty related to the hydrological model increases for low flows

Summary

- WaSiM-ETH and HBV-light were calibrated and validated based on measured discharge
- Hydrological models performed similar based on daily discharge for the period 1999-2006 (validation slightly lower compared to validation, for internal gauges based on WaSiM-ETH also slightly lower model performance)
- WaSiM-ETH performed considerably better outside of calibration and validation period (evaluated based on monthly discharge 1963-1992)
- Validation on measured groundwater levels could not be achieved with WaSiM-ETH
- In the climate change impact assessment, hydrological models perform almost equally well when long term average flow conditions are considered
- Uncertainty related to hydrological model increases when low flows are considered
- Larger difference between the results of the hydrological models expected when different approaches for ETP were used

Conclusion

- Through the application of WaSiM-ETH, a deeper process understanding was gained
- With WaSiM-ETH, internal catchment process can be analysed – high relevance for integrated catchment planning and management, also with respect to the formulation of climate change adaptation strategies
- WaSiM-ETH drawback: data requirements, parameterisation effort, calculation time
- HBV-light: suitable to get “fast” mean discharge predictions
- Comparison still very subjective based on the modeller

For the Lusatian river catchments:

- Uncertainty related to climate change impact assessments relatively high based on the climate downscaling approaches used
- Trend analysis of measured meteorological time series have shown that temperature has increased significantly since the 1950
- Precipitation has not changed considerably (→ nature of statistical downscaling approaches needs to be considered)

References

Gädeke, A., H. Hölzel, H. Koch, I. Pohle, and U. Grünewald (2013), 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*, early view: 10.1002/hyp.9933.

CORINE Land Cover (2006), European Environment Agency. http://www.eea.europa.eu/data-and-maps/data/corine-land-cover-2006-raster-2 (last access: 03.12.2013).

HÜK 200 (2007), Hydrogeologische Übersichtskarte Deutschlands 1:200000, Sächsisches Landesamt für Umwelt, Landwirtschaft und Geologie (LFULG). Referat 105, Freiberg.

LfULG (2009), Sächsisches Landesamt für Umwelt, Landwirtschaft und Geologie, Dresden.

Thanks for your attention!