Assessment of the combined effects of climate and land use changes in Lusatia, Central Europe

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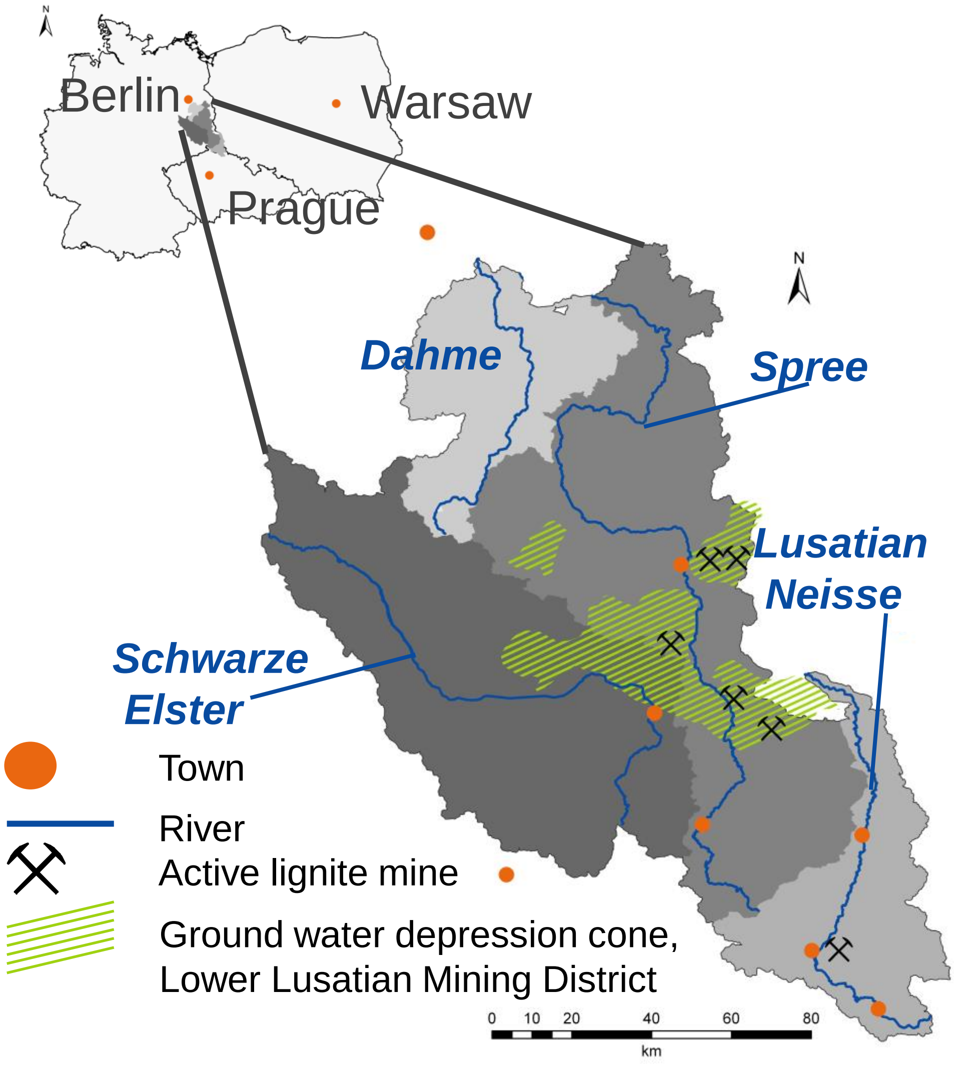
Background

Lignite mining and water management in Lusatia

Discharges increased, groundwater depression cone

Strong anthropogenic influence on the rainfall – runoff – relations

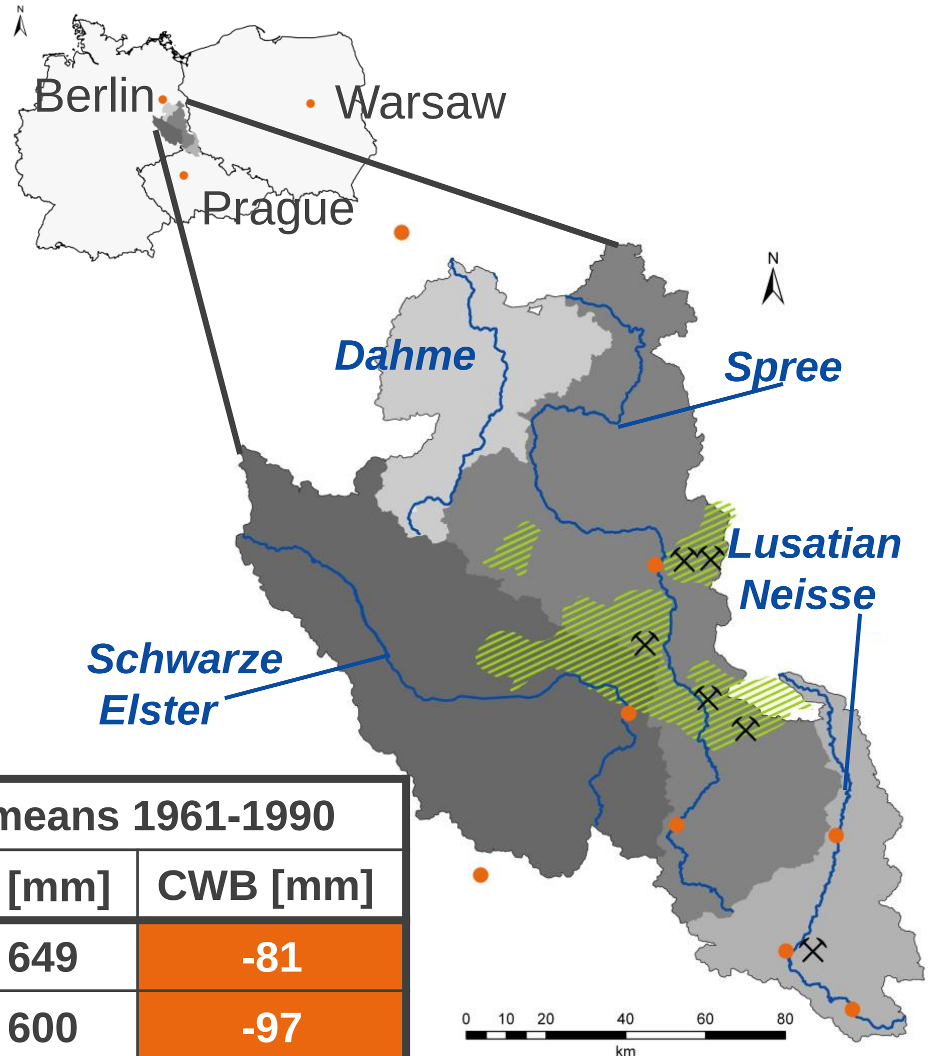


Background

Lusatia: continental climate

Relatively high summer temperature, low precipitation

Negative climatic water balance



Catchment	A [km²]	Alt. [m]	Annual means 1961-1990		
			T [°C]	P [mm]	CWB [mm]
Schwarze Elster	**5,700**	**120**	**8.81**	**649**	**-81**
Dahme	**2,000**	**54**	**8.71**	**600**	**-97**
Spree (Gr. Traenke)	**6,200**	**110**	**8.73**	**640**	**-59**
Lusatian Neisse (Steinbach)	**2,100**	**330**	**7.12**	**892**	**212**

Background

Potential future challenges

Potential climate change:

- Higher temperature
- Less precipitation

Potential land use changes:

- Less mining activities
- **More energy crops**

Aim: Quantification of potential impacts on water balance components

Approach

Model set up of the Soil and Water Integrated Model, SWIM (Krysanova et al. 1998, 2000), by model parameter regionalization

Combined climate and land use change impact study

Approach

Model set up of the Soil and Water Integrated Model, SWIM (Krysanova et al. 1998, 2000), by model parameter regionalization

Calibration of SWIM for subcatchments without influences of mining and water management

↓

Identification of the most sensitive model parameters (groundwater recession, corr. saturated conductivity, corr. potential evaporation, riparian zone param.)

↓

Model parameter regionalization:

physical similarity, spatial proximity

↓

Quasi-natural water balance components

(no water management, no mining discharges)

Approach

Combined climate and land use change impact study

Statistical **A**nalogue **R**esampling Scheme **STAR** scenarios

- assuming temperature increase of 0 K, 2 K, 3 K until 2055
- 100 realizations each

- Mining activities
- **Energy crops**

Climate change scenarios

Change in temperature T, precipitation P, climatic water balance CWB

Scenario (2051-55, median of realizations),

Reference (1961-90, observed climate)

	Scenario	Schwarze Elster	Dahme	Spree	Lusatian Neisse
ΔT [°C]	STAR 0K	**0.8**	**0.8**	**0.9**	**0.7**
	STAR 2K	**2.8**	**2.8**	**2.9**	**2.7**
	STAR 3K	**3.4**	**3.3**	**3.4**	**3.3**
ΔP [mm]	STAR 0K	**-7**	**-7**	**-4**	**17**
	STAR 2K	**-41**	**-30**	**-39**	**-46**
	STAR 3K	**-59**	**-46**	**-67**	**-77**
ΔCWB [mm]	STAR 0K	**-40**	**-35**	**-37**	**-24**
	STAR 2K	**-193**	**-173**	**-187**	**-206**
	STAR 3K	**-257**	**-229**	**-247**	**-281**

Land use change scenarios: Energy crops

- Extreme scenarios considering a complete change of the dominating crop (reference: winter wheat)
- Dynamical crop growth based on climate parameters
- Crop parameters taken from SWIM crop database
- Nutrients – standard parameters, no calibration

Combined climate and land use change impacts

Percentage change in water balance components of STAR and energy crop scenarios

actual evapotranspiration ET_a, discharge Q and groundwater recharge GWR

Scenario (2051-55, median of realizations, crop as specified),

Reference (1961-90, observed climate, winter wheat)

Scenario		Schwarze Elster			Dahme			Spree (Grosse Traenke)			Lusatian Neisse (Steinbach)		
Crop	**STAR**	ΔET_a	ΔQ	ΔGWR	ΔET_a	ΔQ	ΔGWR	ΔET_a	ΔQ	ΔGWR	ΔET_a	ΔQ	ΔGWR
Winter	**0K**	1	-13	-19	2	-17	-20	1	-12	-18	3	1	-3
Wheat	**2K**	5	-48	-48	5	-48	-47	4	-46	-50	9	-27	-33
	3K	3	-56	-54	3	-54	-54	2	-55	-57	8	-33	-40

Combined climate and land use change impacts

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Crop	**STAR**	ΔET_a	ΔQ	ΔGWR	ΔET_a	ΔQ	ΔGWR	ΔET_a	ΔQ	ΔGWR	ΔET_a	ΔQ	ΔGWR
Winter Wheat	**0K**	1	-13	-19	2	-17	-20	1	-12	-18	3	1	-3
	2K	5	-48	-48	5	-48	-47	4	-46	-50	9	-27	-33
	3K	3	-56	-54	3	-54	-54	2	-55	-57	8	-33	-40
Silage Maize	**0K**	1	-12	-17	1	-13	-17	1	-9	-13	1	5	1
	2K	7	-55	-54	6	-55	-53	6	-56	-57	11	-30	-36
	3K	5	-64	-60	5	-62	-59	5	-67	-66	12	-38	-44

Combined climate and land use change impacts

Percentage change in water balance components of STAR and energy crop scenarios

actual evapotranspiration ET_a, discharge Q and groundwater recharge GWR

Scenario (2051-55, median of realizations, crop as specified),

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Scenario		Schwarze Elster			Dahme			Spree (Grosse Traenke)			Lusatian Neisse (Steinbach)		
Crop	**STAR**	ΔET_a	ΔQ	ΔGWR	ΔET_a	ΔQ	ΔGWR	ΔET_a	ΔQ	ΔGWR	ΔET_a	ΔQ	ΔGWR
Winter Wheat	**0K**	**1**	**-13**	**-19**	**2**	**-17**	**-20**	**1**	**-12**	**-18**	**3**	**1**	**-3**
	2K	**5**	**-48**	**-48**	**5**	**-48**	**-47**	**4**	**-46**	**-50**	**9**	**-27**	**-33**
	3K	**3**	**-56**	**-54**	**3**	**-54**	**-54**	**2**	**-55**	**-57**	**8**	**-33**	**-40**
Silage Maize	**0K**	**1**	**-12**	**-17**	**1**	**-13**	**-17**	**1**	**-9**	**-13**	**1**	**5**	**1**
	2K	**7**	**-55**	**-54**	**6**	**-55**	**-53**	**6**	**-56**	**-57**	**11**	**-30**	**-36**
	3K	**5**	**-64**	**-60**	**5**	**-62**	**-59**	**5**	**-67**	**-66**	**12**	**-38**	**-44**
Oilseed Rape	**0K**	**-5**	**23**	**13**	**-4**	**21**	**13**	**3**	**36**	**29**	**-6**	**19**	**16**
	2K	**-1**	**-18**	**-21**	**-1**	**-15**	**-17**	**2**	**-5**	**-6**	**-1**	**-6**	**-11**
	3K	**-3**	**-28**	**-29**	**-2**	**-24**	**-25**	**-6**	**-14**	**-18**	**-3**	**-12**	**-18**

Combined climate and land use change impacts

Percentage change in water balance components of STAR and energy crop scenarios

actual evapotranspiration ET_a, discharge Q and groundwater recharge GWR

Scenario (2051-55, median of realizations, crop as specified),

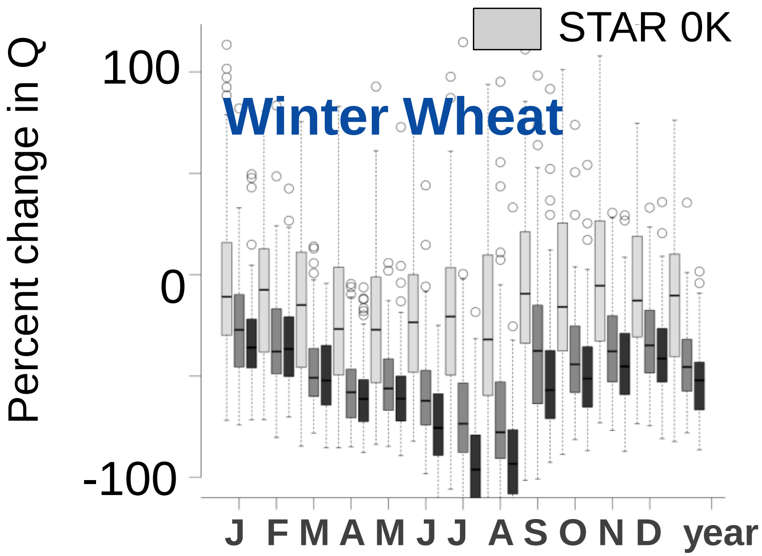
Reference (1961-90, observed climate, winter wheat)

Scenario		Schwarze Elster			Dahme			Spree (Grosse Traenke)			Lusatian Neisse (Steinbach)		
Crop	STAR	ΔET_a	ΔQ	ΔGWR	ΔET_a	ΔQ	ΔGWR	ΔET_a	ΔQ	ΔGWR	ΔET_a	ΔQ	ΔGWR
Winter Wheat	0K	1	-13	-19	2	-17	-20	1	-12	-18	3	1	-3
	2K	5	-48	-48	5	-48	-47	4	-46	-50	9	-27	-33
	3K	3	-56	-54	3	-54	-54	2	-55	-57	8	-33	-40
Silage Maize	0K	1	-12	-17	1	-13	-17	1	-9	-13	1	5	1
	2K	7	-55	-54	6	-55	-53	6	-56	-57	11	-30	-36
	3K	5	-64	-60	5	-62	-59	5	-67	-66	12	-38	-44
Oilseed Rape	0K	-5	23	13	-4	21	13	3	36	29	-6	19	16
	2K	-1	-18	-21	-1	-15	-17	2	-5	-6	-1	-6	-11
	3K	-3	-28	-29	-2	-24	-25	-6	-14	-18	-3	-12	-18
Sunflower	0K	-1	-6	-13	0	-9	-13	-1	-2	-7	-1	7	2
	2K	4	-46	-47	4	-46	-53	3	-43	-46	7	-24	-30
	3K	4	-57	-55	3	-55	-54	2	-56	-57	7	-31	-38
Sorghum	0K	0	-7	-14	0	-10	-14	-1	-3	-9	-1	8	5
	2K	6	-53	-52	6	-52	-52	5	-52	-54	8	-25	-32
	3K	5	-64	-61	5	-56	-60	5	-65	-66	9	-33	-40
Sorghum Hay	0K	-1	-4	-12	0	-7	-12	-2	1	-5	-2	10	7
	2K	5	-50	-50	5	-51	-50	4	-49	-51	7	-23	-30
	3K	5	-62	-59	4	-59	-58	4	-62	-63	7	-31	-38

Combined climate and land use change impacts

Percent change in mean monthly discharge Q, Dahme River catchment,

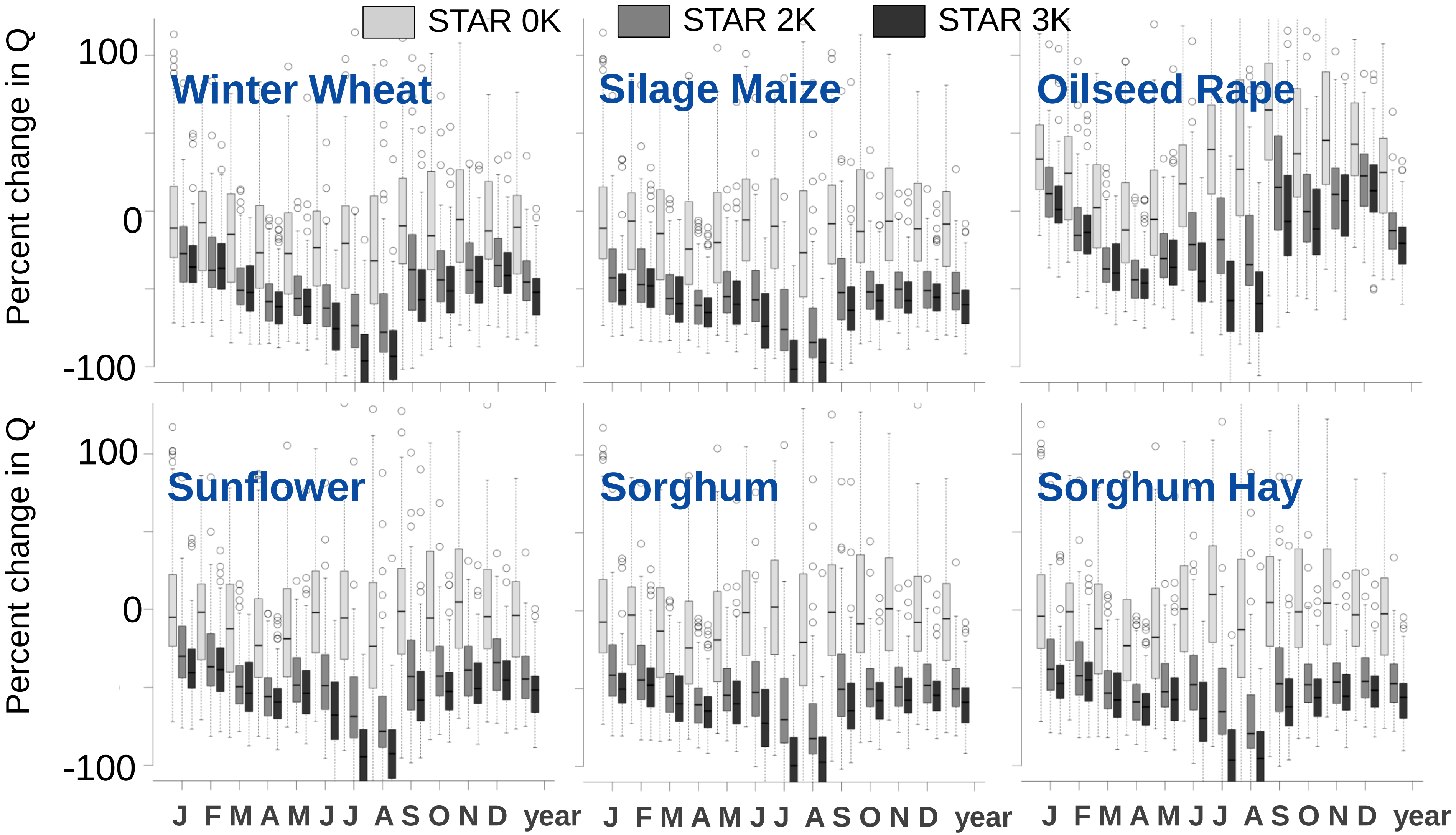
scenario (2051-55, 100 realizations, crop as specified) vs. reference (1961-1990, winter wheat)



Combined climate and land use change impacts

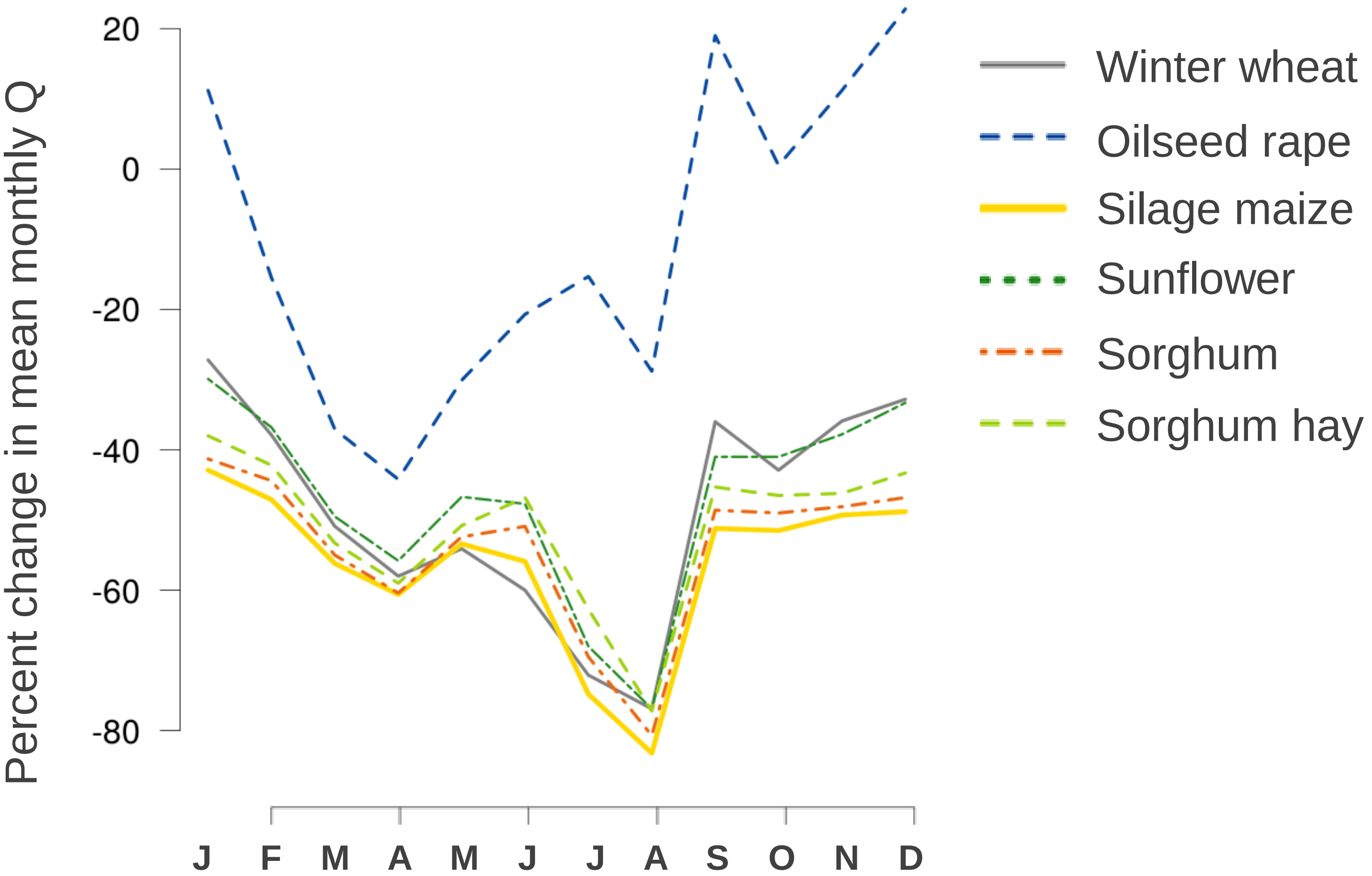
Percent change in mean monthly discharge Q, Dahme River catchment,

scenario (2051-55, 100 realizations, crop as specified) vs. reference (1961-1990, winter wheat)



Combined climate and land use change impacts

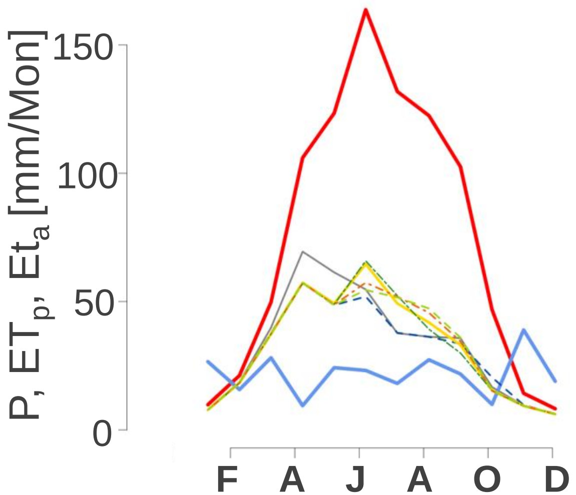
Percentage change in mean monthly discharge Q, Dahme River catchment,
scenario (2051-55, median, STAR 2K, crop as specified) vs.
reference (1961-1990, observed climate, winter wheat)



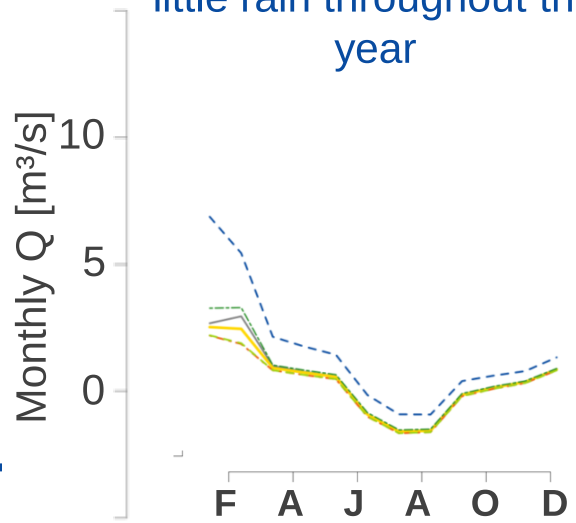
Combined climate and land use change impacts

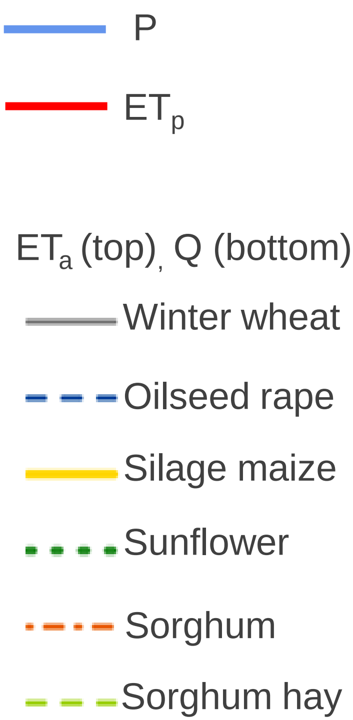
Dahme River catchment, 3K, 2055, selected realizations (R.):

precipitation P, potential evapotranspiration ET_p, actual evapotranspiration ET_a, discharge Q



R. 3, CWB **-638 mm/a**
little rain throughout the year

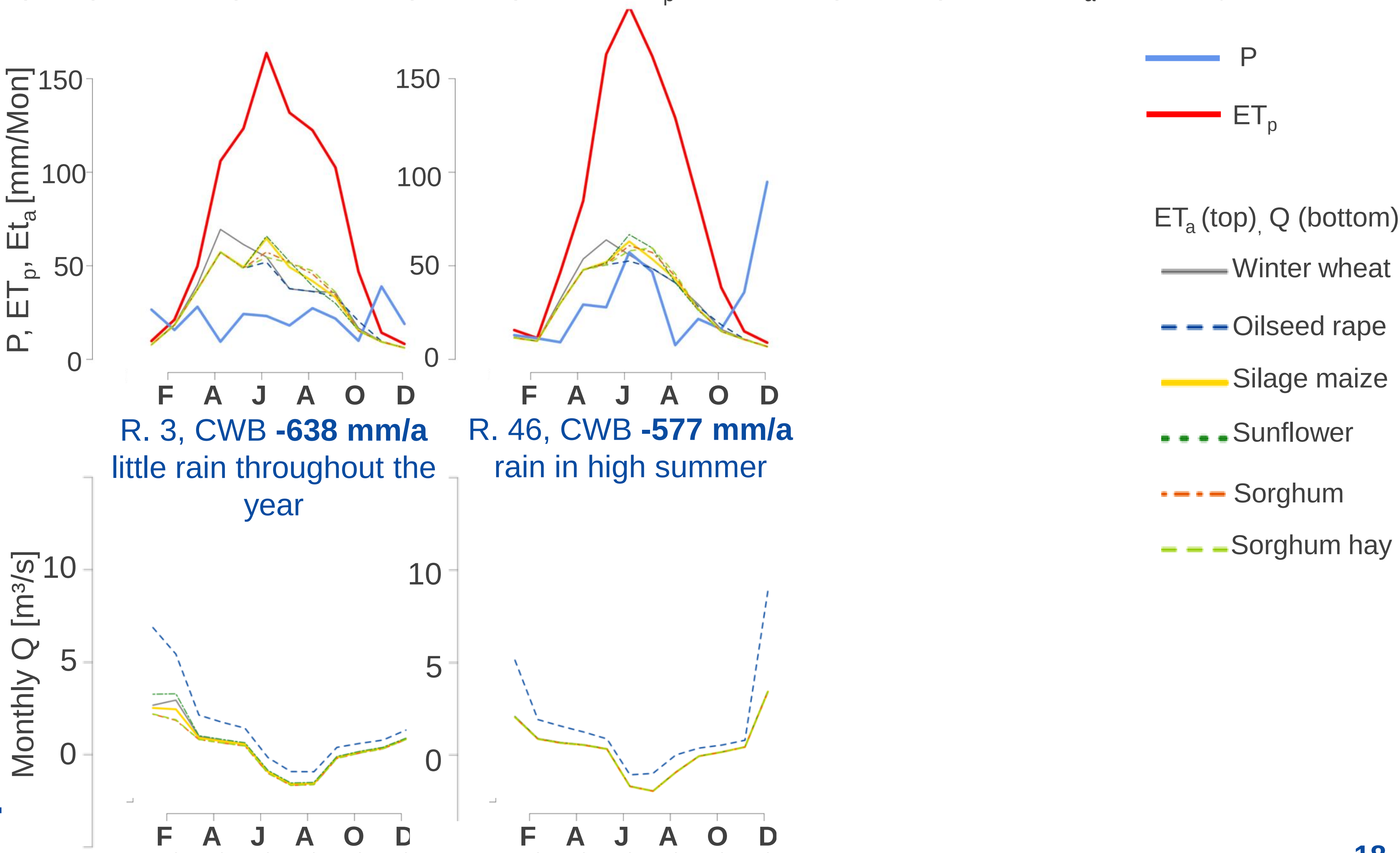




Combined climate and land use change impacts

Dahme River catchment, 3K, 2055, selected realizations (R.):

precipitation P, potential evapotranspiration ET_p, actual evapotranspiration ET_a, discharge Q



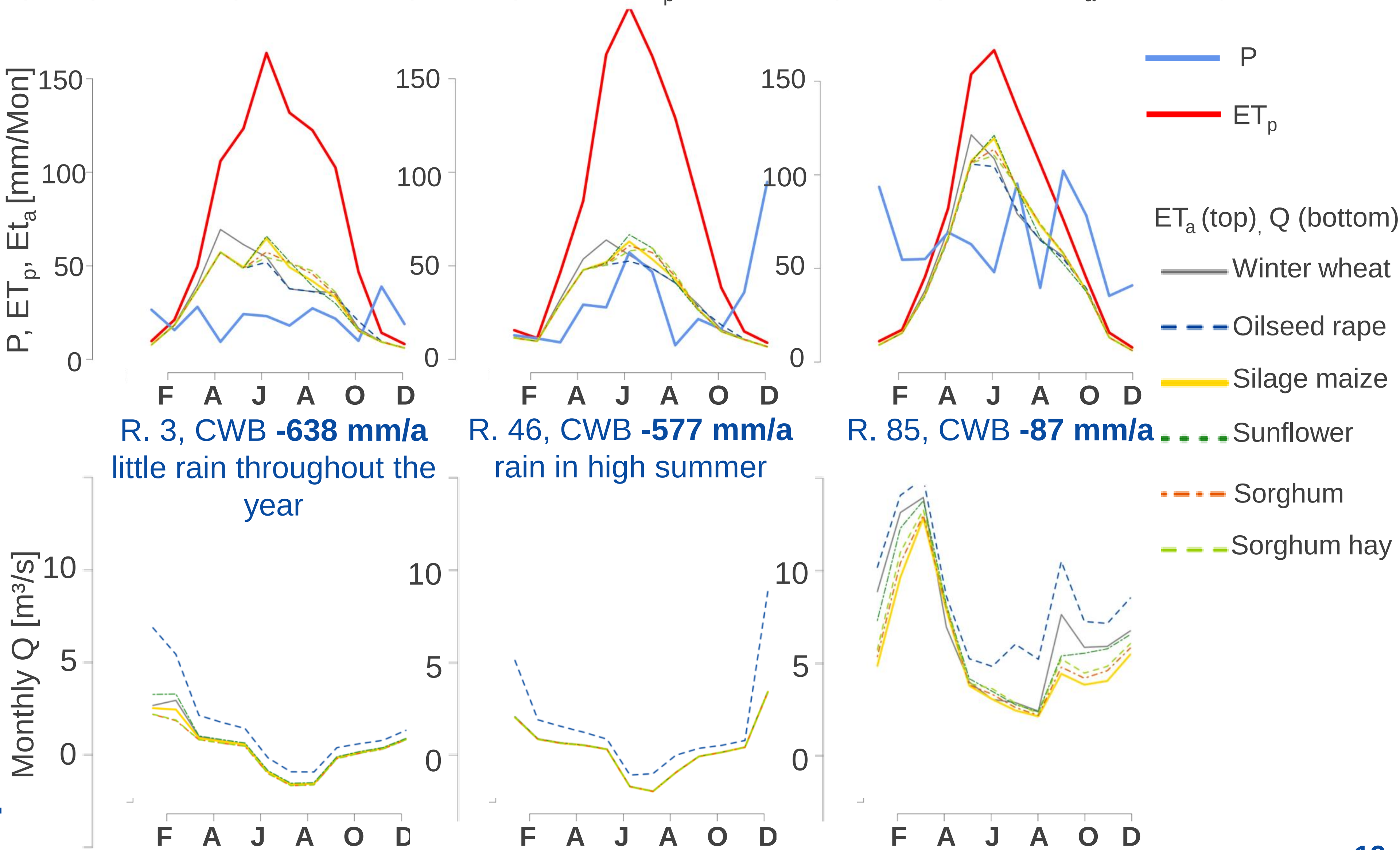
R. 3, CWB **-638 mm/a**
little rain throughout the year

R. 46, CWB **-577 mm/a**
rain in high summer

Combined climate and land use change impacts

Dahme River catchment, 3K, 2055, selected realizations (R.):

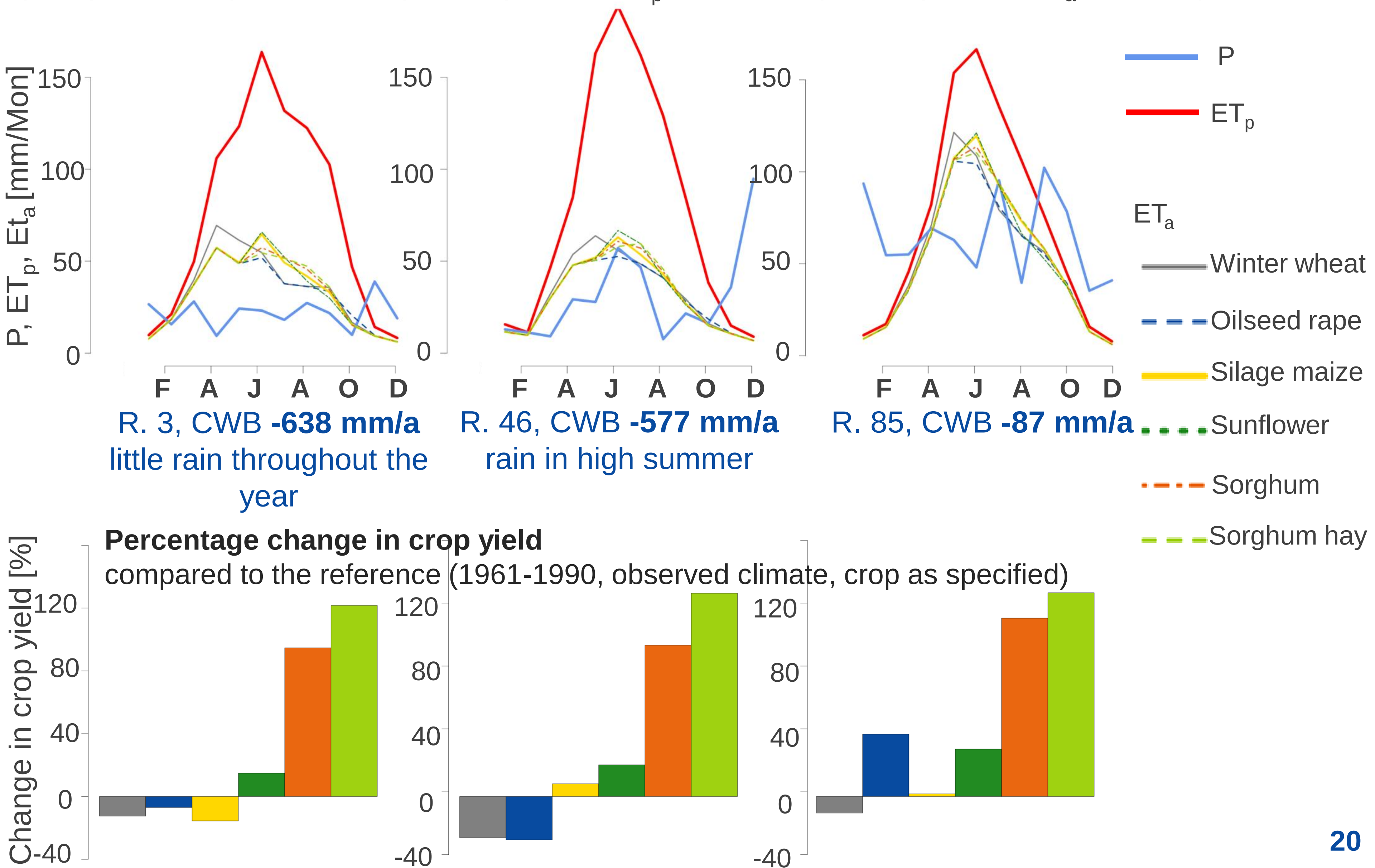
precipitation P, potential evapotranspiration ET_p, actual evapotranspiration ET_a, discharge Q



Combined climate and land use change impacts

Dahme River catchment, 3K, 2055, selected realizations (R.):

precipitation P, potential evapotranspiration ET_p, actual evapotranspiration ET_a, discharge Q



Combined climate and land use change impacts

Percentage change in potential crop yield (limited by temperature and water availability)

scenario (median, 2051 – 2055 , crop as specified) vs.

reference (1961-1990, observed climate, crop as specified)

Scenario Crop	STAR	Schwarze Elster	Dahme	Spree, Grosse Traenke	Lusatian Neisse, Steinbach
Winter Wheat	0K	-2	-2	-2	6
	2K	-10	-10	-10	3
	3K	-13	-12	-12	2
Silage Maize	0K	4	5	5	9
	2K	18	20	22	42
	3K	14	17	20	49
Oilseed rape	0K	-8	-9	-9	-5
	2K	-4	-8	-7	-18
	3K	-1	-2	-2	-17
Sunflower	0K	5	5	6	12
	2K	20	22	22	38
	3K	24	26	27	47
Sorghum	0K	21	22	22	28
	2K	93	102	102	139
	3K	117	126	127	192
Sorghum Hay	0K	23	25	25	32
	2K	110	119	119	168
	3K	139	150	152	237

Conclusions

- Higher temperature and less precipitation (STAR 2K, STAR 3K)

  ➔ Decreasing climatic water balance, discharge and groundwater recharge

- High bandwidths of potential changes associated with the realizations of the scenarios

- Change of the dominating crop towards oilseed rape would partly counterbalance climate change impacts on discharge and groundwater recharge

- Crop yield generally increases with temperature and water availability

  ➔ Higher temperature, less precipitation

  ➔ Decreasing crop yields: winter wheat, oilseed rape

  ➔ Increasing crop yields: silage maize, sunflower, sorghum, sorghum hay

Summary + Outlook

Model set up of the Soil and Water Integrated Model, SWIM, by model parameter regionalization

Combined climate and land use change impact study

➔ Quasi-natural discharge under changing conditions

Long term water management model WBalMo

(including mining discharges, water users, reservoirs)

➔ Managed discharges

Water quality modelling (sulphur, iron, pH)

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Thank you!

Contact: Ina.Pohle@tu-cottbus.de

Sunflowers in front of the Welzow Süd open pit lignite mine

Picture: © Berliner Morgenpost 2013

b-tu Brandenburg University of Technology Cottbus - Senftenberg

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PIK Potsdam Institute for Climate Impact Research

INKA BB Climate Change and Innovation

Sponsored by the Federal Ministry of Education and Research

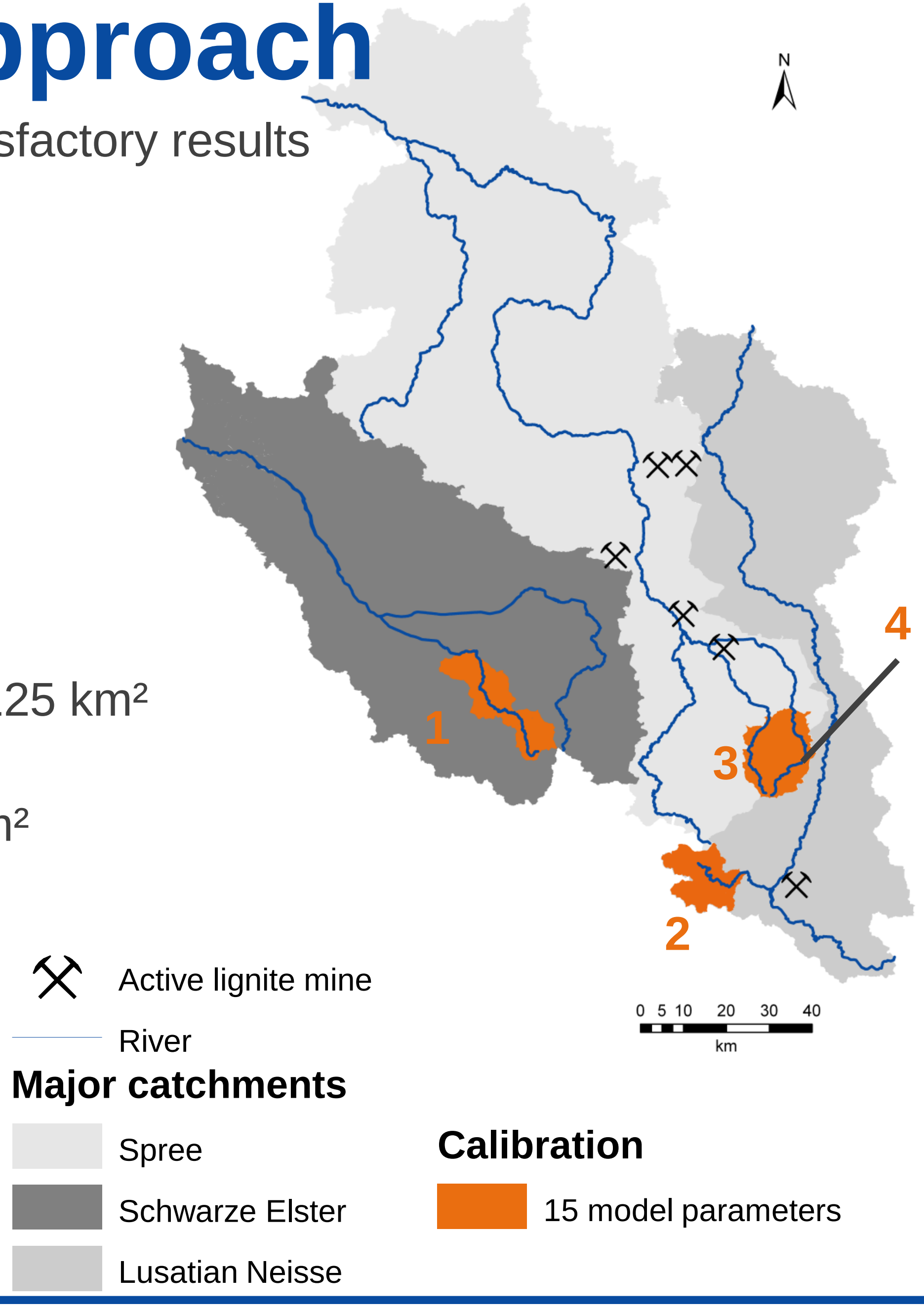
LMBV Lausitzer und Mitteldeutsche Bergbau-Verwaltungsgesellschaft mbH

Regionalization Approach

Calibration of SWIM for subcatchments, 15 model parameters

Satisfactory results

1) Pulsnitz, Ortrand gauge, 245 km²
   Hilly area - lowland
2) Mandau, Großschönau gauge, 160 km²
   Mountainous
3) Schwarzer Schöps, Jänkendorf gauge, 125 km²
   Hilly area
4) Weißer Schöps, Särichen gauge, 135 km²
   Hilly area



Regionalization Approach

Calibration of SWIM for subcatchments, 15 model parameters

Satisfactory results
Very different parameter sets
➔ Hard to find regionalization approach

Sensitive Model Parameters	Value range
Base flow coefficient	0.3 – 0.4
Correction coefficient for potential evaporation	0.8 – 1.3
Correction coefficient for saturated conductivity	1 – 12
Curve numbers (SCS) (3)	50 – 60
Groundwater recession rate, fast Groundwater recession rate, slow	0.01 – 0.03 0.00007 – 0.015
Delay factor, groundwater	1-7
Initial groundwater flow	0.02 – 0.2
Routing factors (2)	1 – 1.2
Snow melt temperature	2 – 3
Snow melt rate	2 – 3
Parameter to access routed groundwater flow	0.6 - 1

Regionalization Approach

Calibration of SWIM for subcatchments, 15 model parameters

Parameter transfer of respective other catchments

Results not satisfactory (volume and dynamics)

Regionalization Approach

Calibration of SWIM for subcatchments, 15 model parameters

↓

Parameter transfer of respective other catchments

↓

Identification of the most sensitive model parameters in the region

→

- **Correction coefficient for saturated conductivity**
  - → Dynamics
  - → Generation of soil maps
  - → Scale problem
- **Correction coefficient for potential evapotranspiration**
  - → Volume
  - → Integrates correction for errors in climate input and simulation of ETP
- **Tuning factor for groundwater recession rates (2 groundwater layers)**
  - → Dynamics
  - → Lack of data concerning groundwater recession
- **Parameter that allows access of routed groundwater flow in riparian zones**
  - → Low flow periods of interior catchments

Regionalization Approach

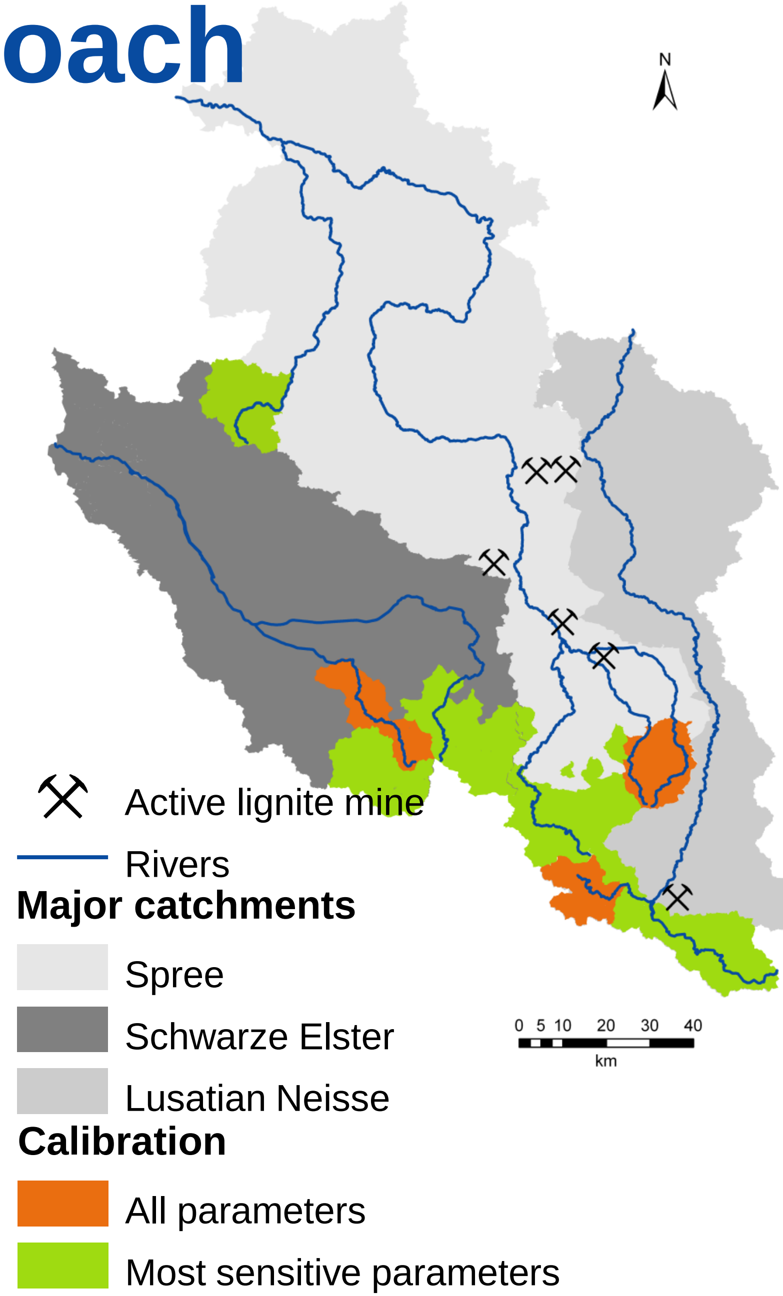
Calibration of SWIM for subcatchments, 15 model parameters

Parameter transfer of respective other catchments

Identification of the most sensitive model parameters in the region

Calibration of most sensitive parameters for further subcatchments

Results satisfactory



Regionalization Approach

Calibration of SWIM for subcatchments, 15 model parameters

↓

Parameter transfer of respective other catchments

↓

Identification of the most sensitive model parameters in the region

↓

Calibration of most sensitive parameters for further subcatchments

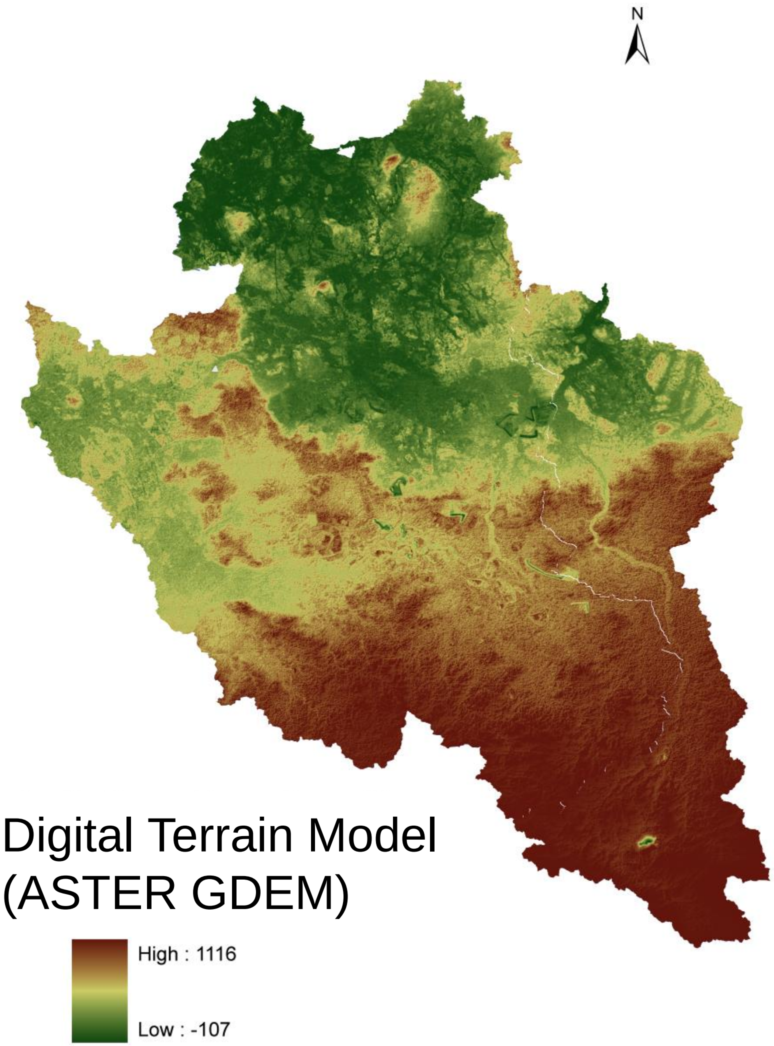
↓

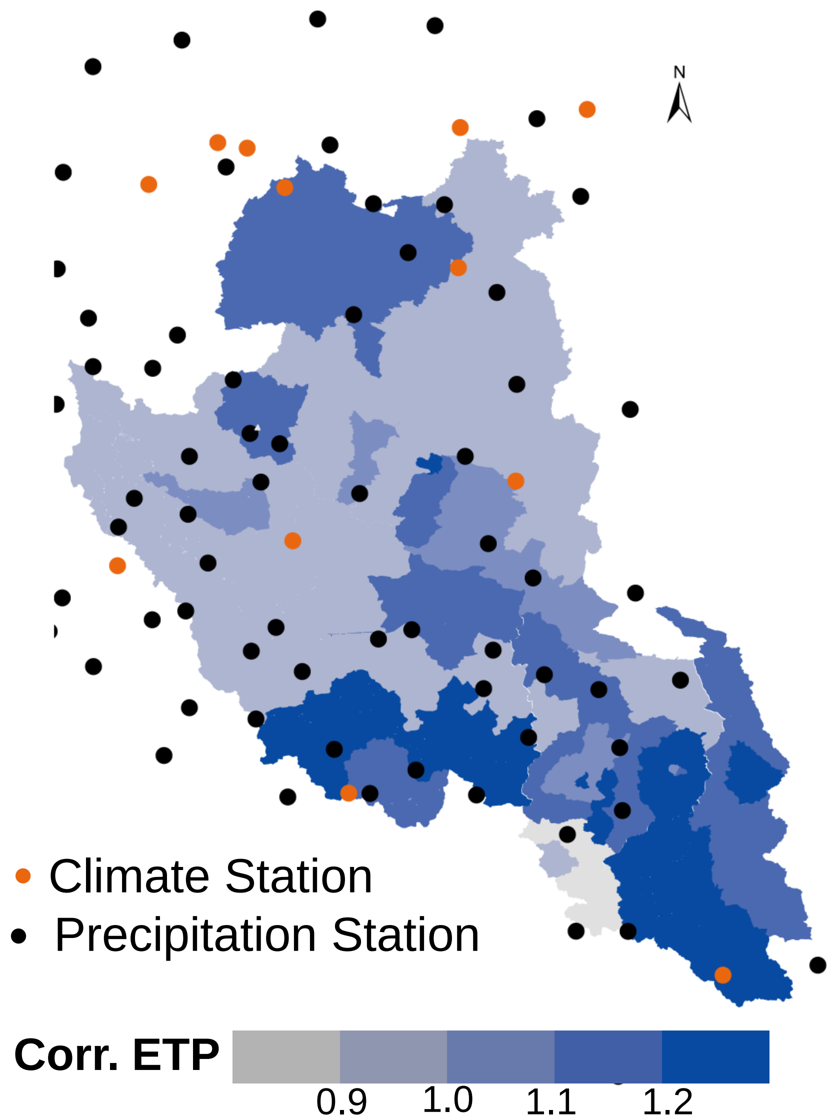
Model parameter regionalisation (spatial proximity, physical similarity)

→

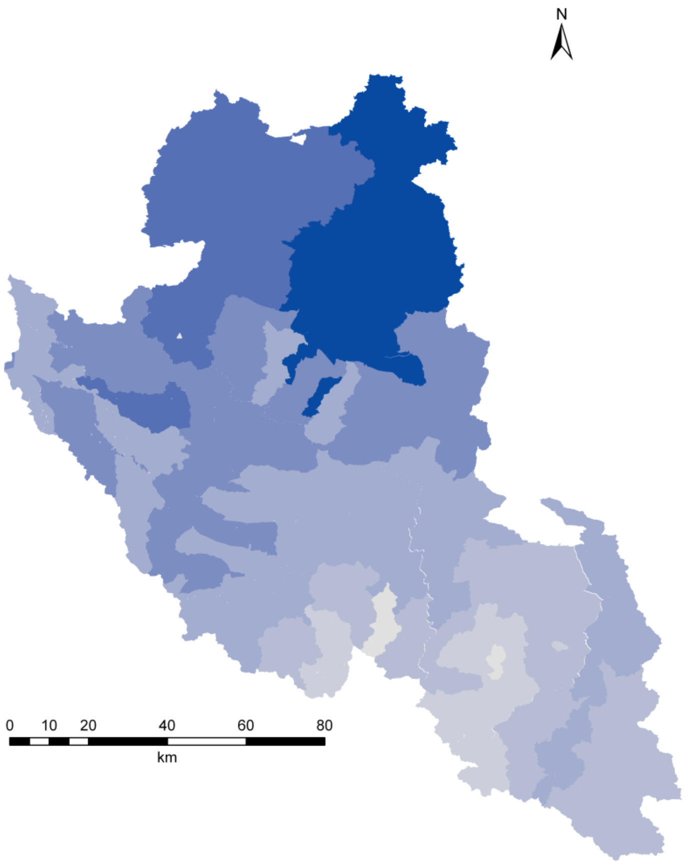
- **Correction coefficient for saturated conductivity**
  → Spatial proximity
- **Correction coefficient for potential evapotranspiration**
  → Minimization of differences in discharge to N-A-U-Map (pre-mining state) within a „reasonable“ range
- **Tuning factor for groundwater recession rates (2 groundwater layers)**
  → Spatial proximity, slope
- **Parameter that allows access of routed groundwater flow in riparian zones**
  → Threshold value of slope

Regionalization Approach





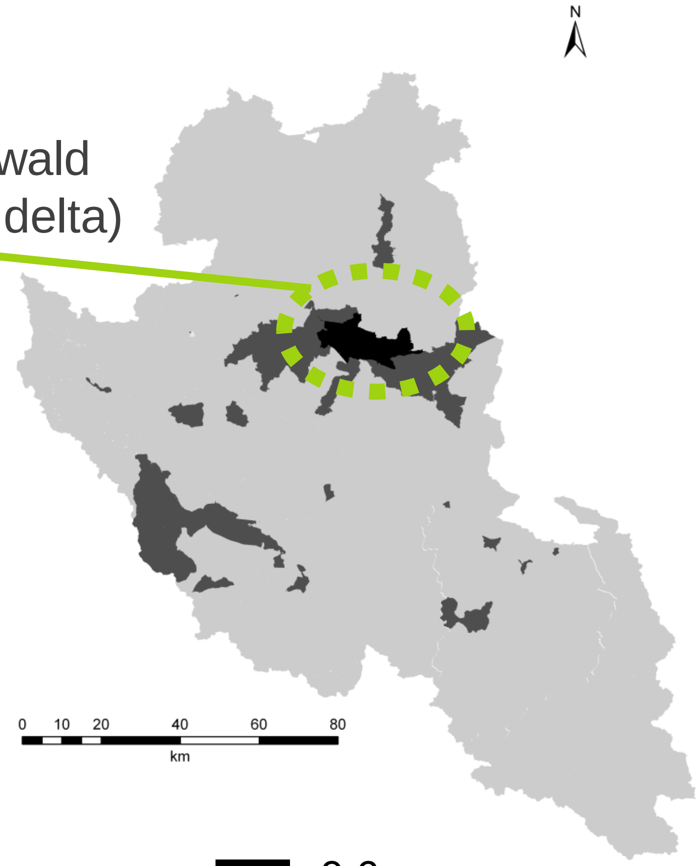
Regionalization Approach



Groundwater recession α1

0.010 0.050 0.100

$\alpha 1 / \alpha 2 = 20/1$



Riparian zone parameter

0.6
0.9
1.0

Regionalization Approach

Comparison with

- Simulation results of WaSim-ETH and HBV for subcatchments
- Naturalised discharges of the WBalMo Spree-Schwarze Elster
- Water balance components of DIFGA (differenciated hydrograph)

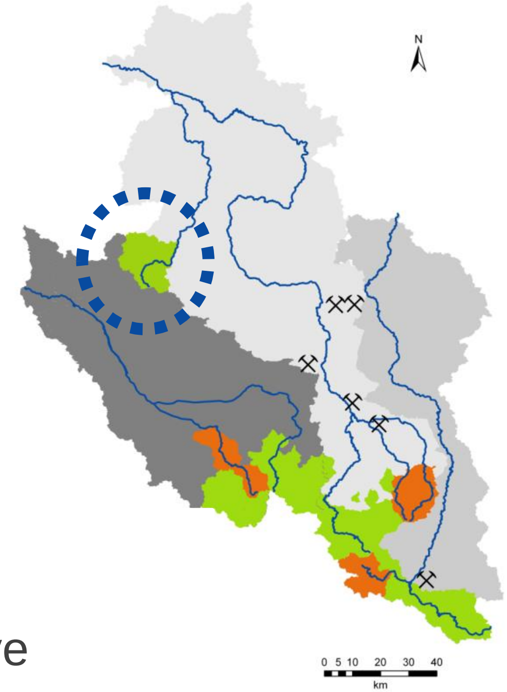
Regionalization Approach

- Simulation of an anthropogenically more impacted catchment: Dahme, Prierow gauge station
- Model comparison with WaSim-ETH and HBV light

- Significant deviations between observed discharges and the long-term annual mean (especially after 1990)
- Model calibration of SWIM not possible

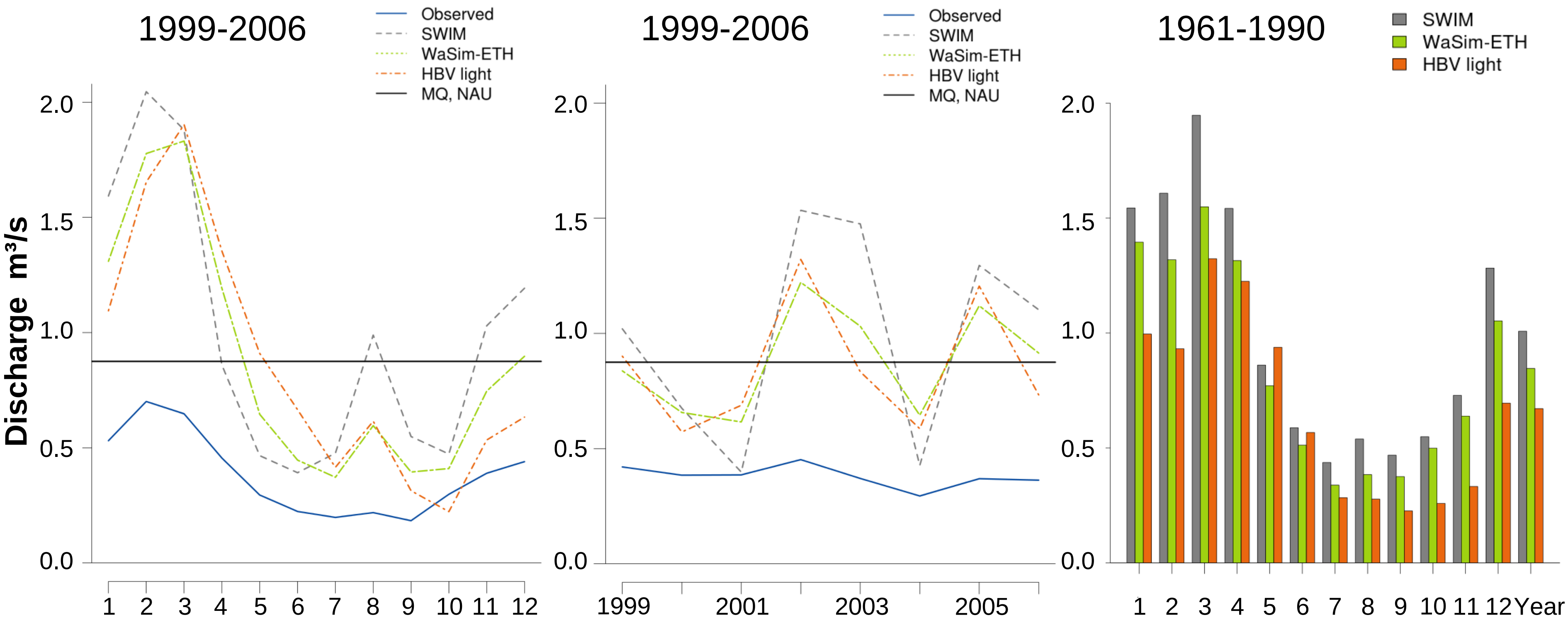
➔ Assumption: volume of observed discharges not representative

➔ Regionalization SWIM (3 most sensitive parameters), Calibration WaSim-ETH, HBV light – daily time step considering
  - Dynamics of observed discharge,
  - Volume of long-term annual mean (approx.)



Regionalization Approach

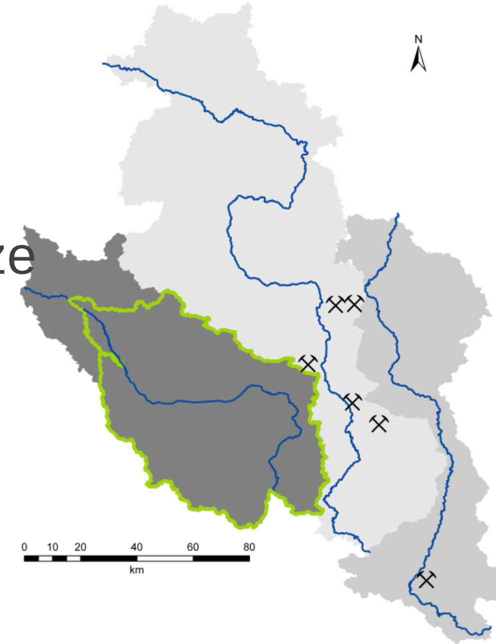
- Simulation of an anthropogenically more impacted catchment: Dahme, Prierow gauge station
- Model comparison with WaSim-ETH and HBV light

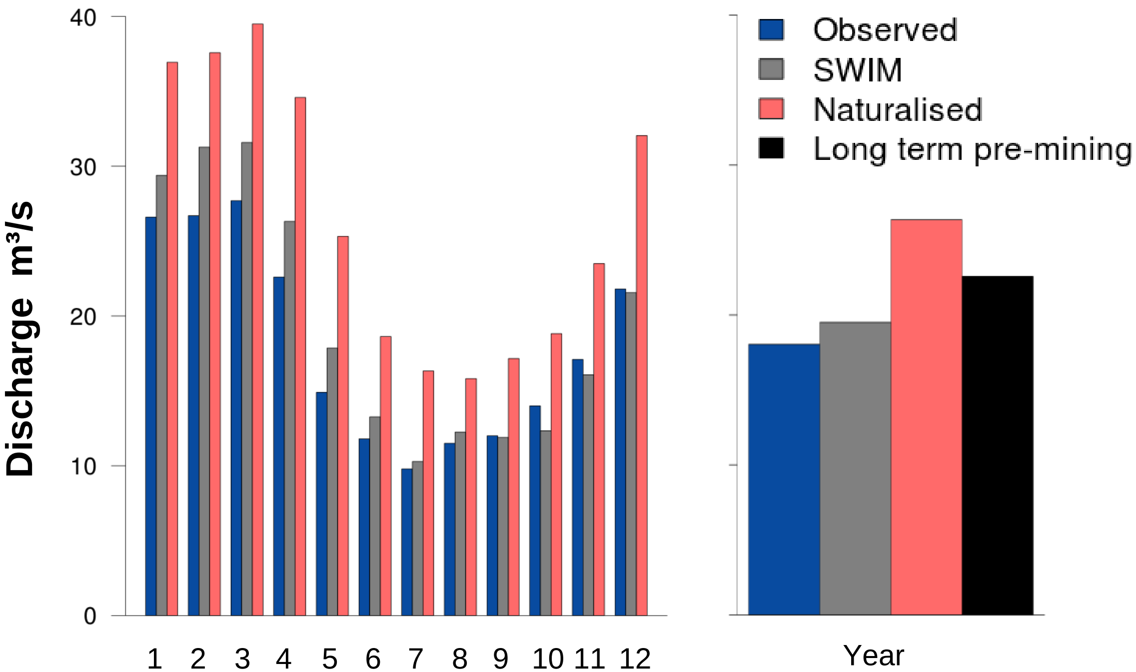


Regionalization Approach

Comparison with observed discharges, naturalised discharges of the “Ländermodell” WBalMo Spree/Schwarze Elster and long term pre-mining observed discharges

Schwarze Elster, Loeben Gauge Station





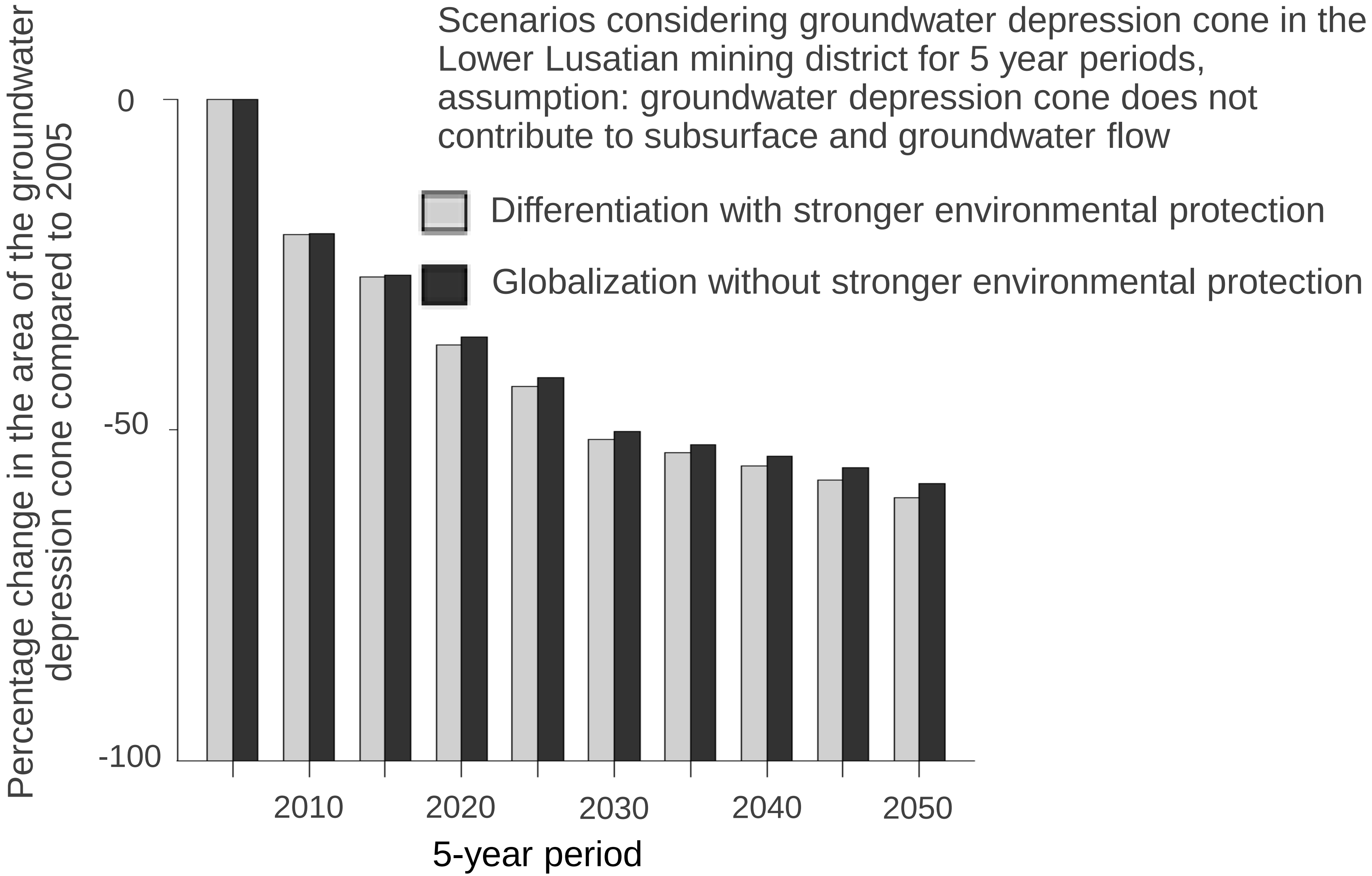
Combined climate and land use change impacts

Percentage change in potential crop yield (limited by temperature and water availability), q25, q50 and q75 of the scenario (2050 – 2055) compared to the reference (1961-1990, observed climate, crop as specified)

Scenario		**Schwarze Elster**			**Dahme**			**Spree**			**Lusatian Neisse**		
Crop	STAR	q_{25}	q_{50}	q_{75}	q_{25}	q_{50}	q_{75}	q_{25}	q_{50}	q_{75}	q_{25}	q_{50}	q_{75}
Winter	0K	-4	-2	0	-4	-2	0	-4	-2	0	3	6	8
Wheat	2K	-13	-10	-8	-12	-10	-8	-12	-10	-8	1	3	5
	3K	-15	-13	-10	-15	-12	-10	-14	-12	-10	-1	2	4
Silage	0K	2	4	7	2	5	7	2	5	8	3	9	13
Maize	2K	14	18	22	17	20	23	19	22	25	38	42	45
	3K	9	14	17	14	17	21	17	20	24	45	49	53
Oilseed	0K	-13	-8	-3	-14	-9	-2	-13	-9	-3	-12	-5	-1
rape	2K	-10	-4	-1	-12	-8	-4	-12	-7	-4	-23	-18	-14
	3K	-5	-1	7	-8	-2	3	-8	-2	3	-20	-17	-14
Sunflower	0K	1	5	7	2	5	8	2	6	8	5	12	15
	2K	18	20	23	19	22	25	20	22	26	35	38	42
	3K	22	24	27	23	26	28	25	27	30	43	47	50
Sorghum	0K	10	21	28	12	22	31	12	22	32	14	28	41
	2K	85	93	105	91	102	115	92	102	113	123	139	268
	3K	107	117	123	116	126	134	117	127	135	175	192	207
Sorghum	0K	11	23	32	13	25	35	14	25	35	18	32	50
Hay	2K	98	110	124	105	119	137	107	119	135	148	168	192
	3K	129	139	147	138	150	161	141	152	161	217	237	256

Land use change scenarios: Mining activities

Scenarios considering groundwater depression cone in the Lower Lusatian mining district for 5 year periods, assumption: groundwater depression cone does not contribute to subsurface and groundwater flow

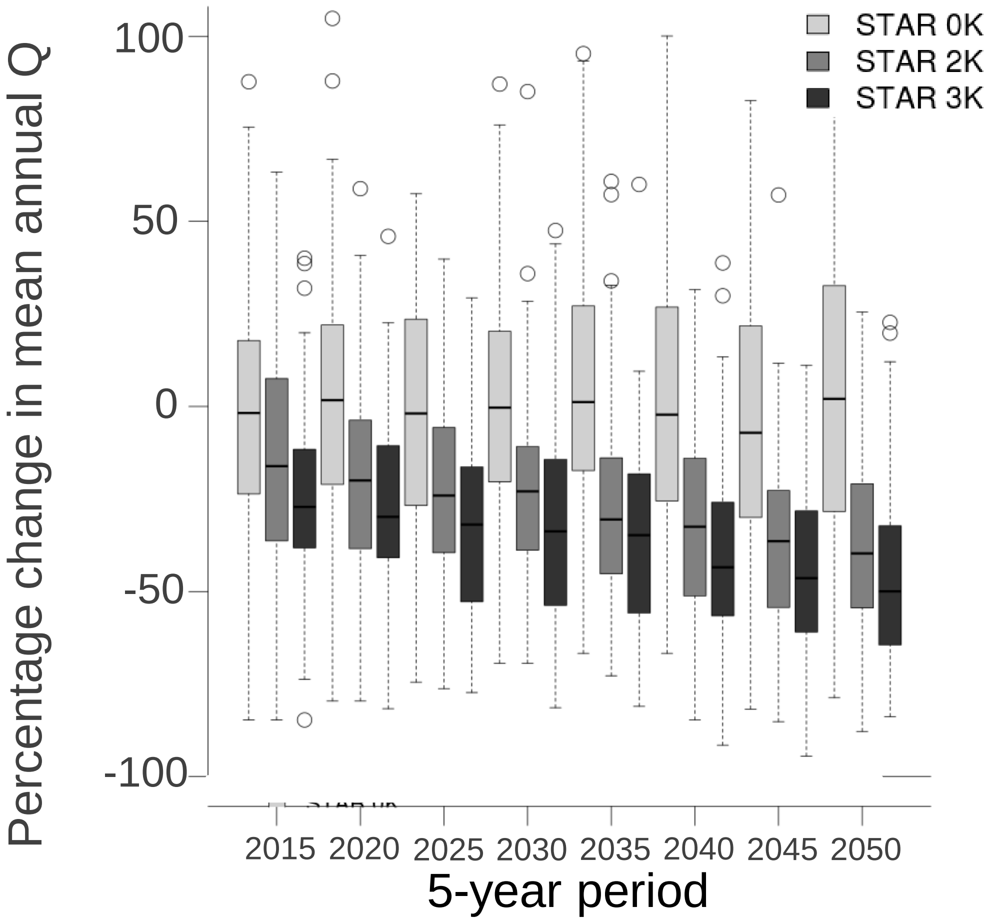


Combined climate and land use change impacts

Schwarze Elster River catchment, outlet

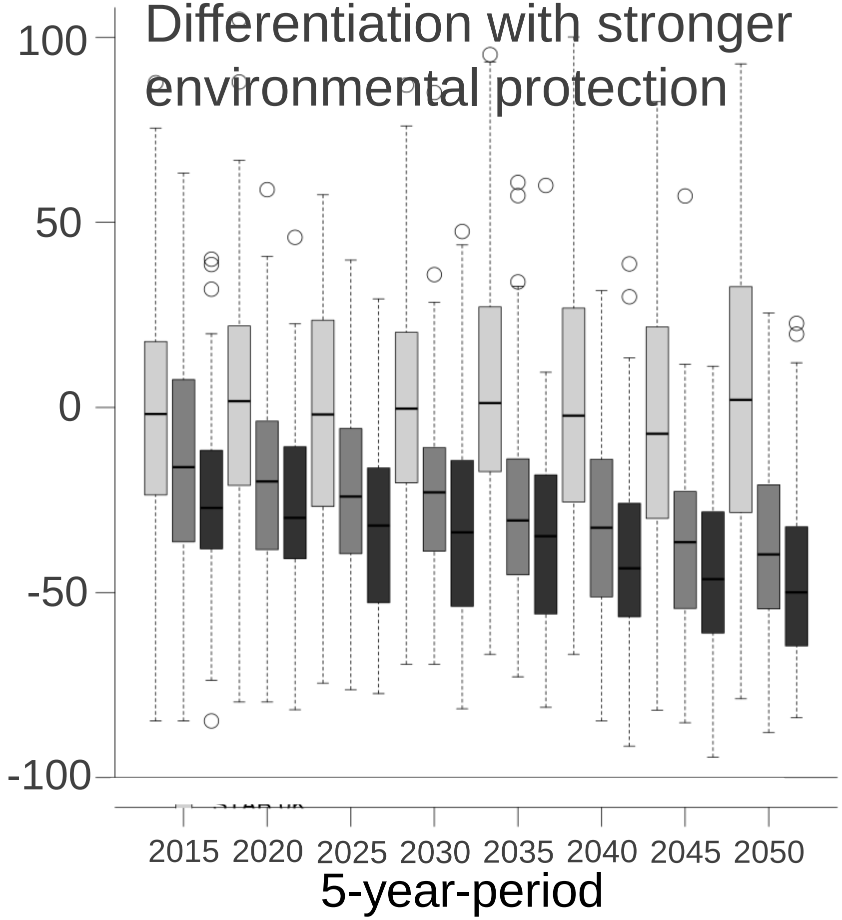
Percentage change in mean annual discharge

Only climate change



Climate change +

Differentiation with stronger environmental protection

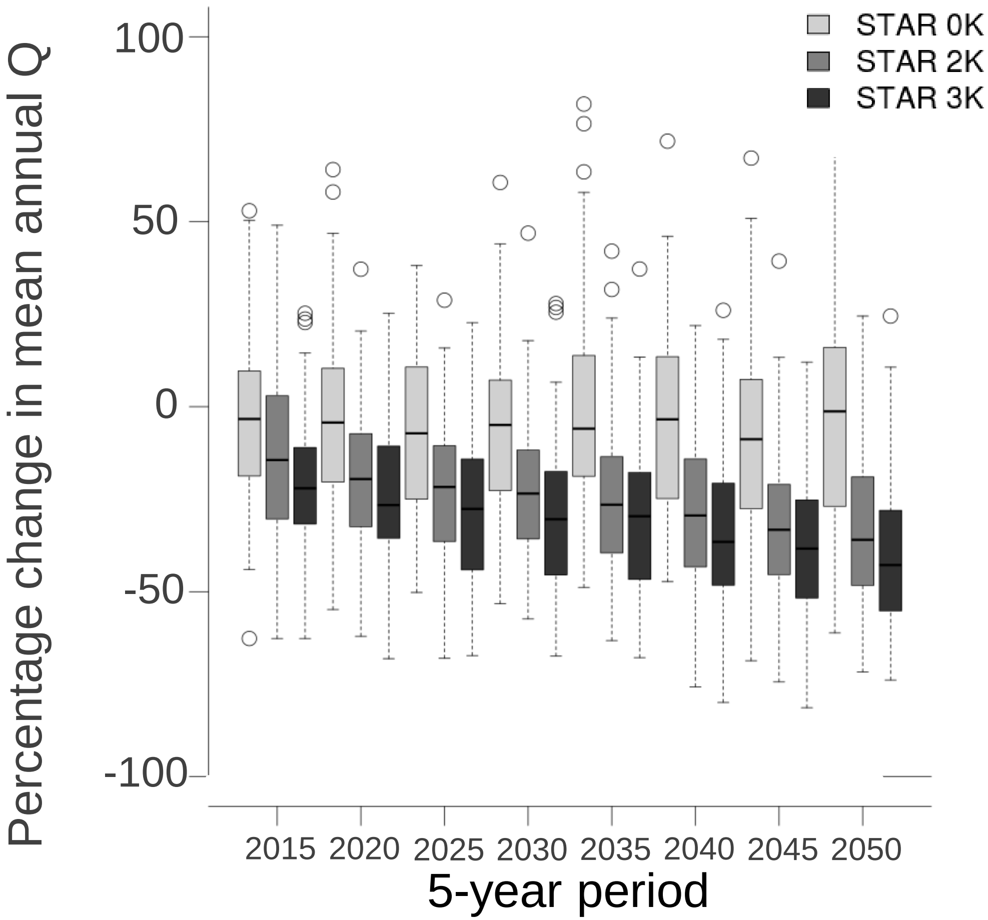


Combined climate and land use change impacts

Schwarze Elster River catchment, Lauchhammer gauge

Percentage change in mean annual discharge

Only climate change



Climate change +

Differentiation with stronger environmental protection