Can water resources management alleviate the uncertainty of projected climate change impacts on river discharge?

A comparative study in two hydrologically similar catchments with different level of management

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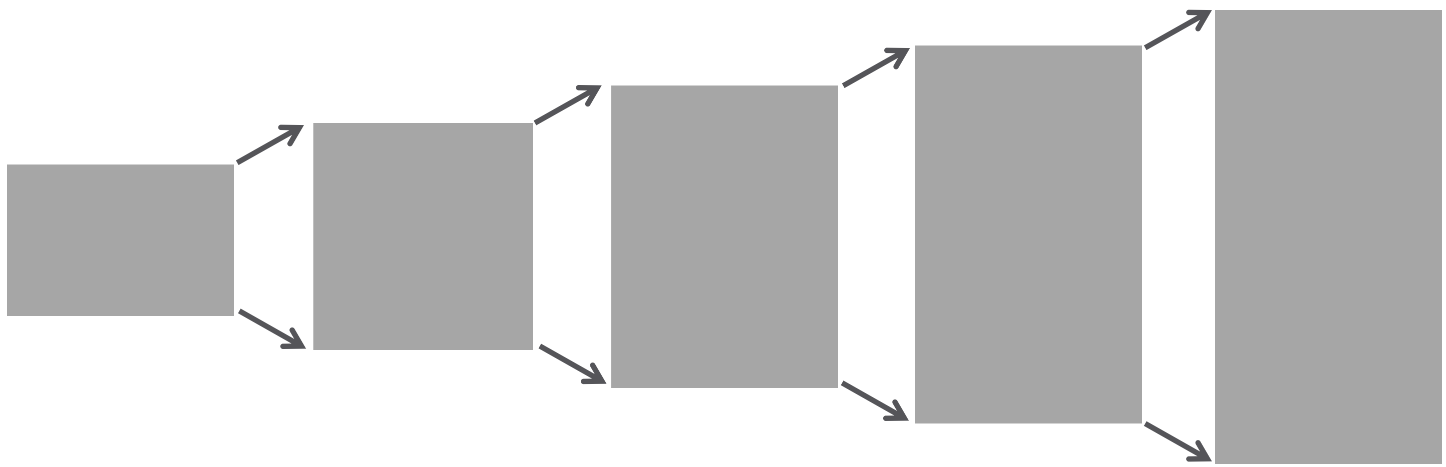
Cascade of Uncertainty in Climate Change Impact Studies



Emission scenarios

Carbon cycle response

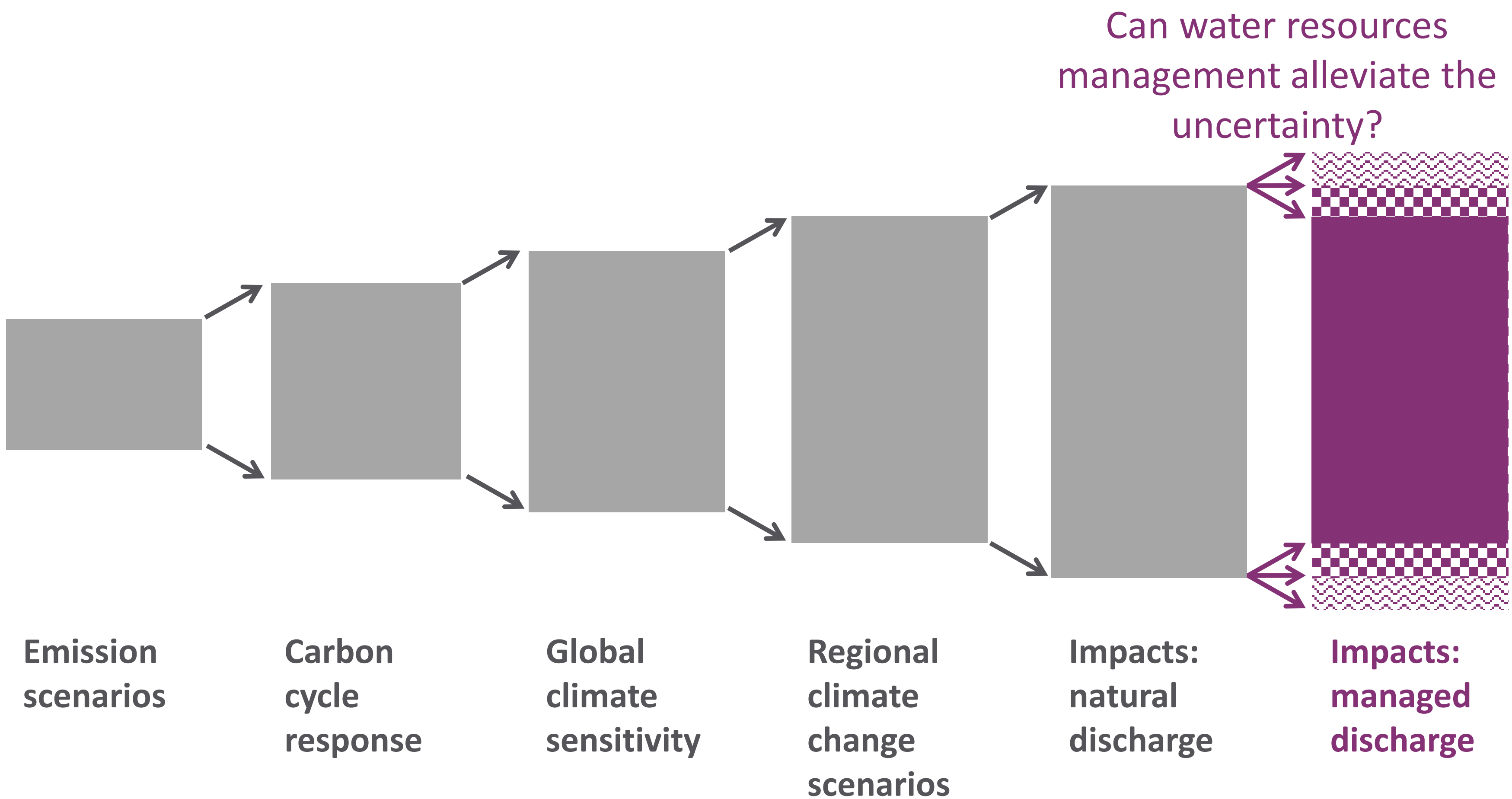
Global climate sensitivity

Regional climate change scenarios

Impacts: natural discharge

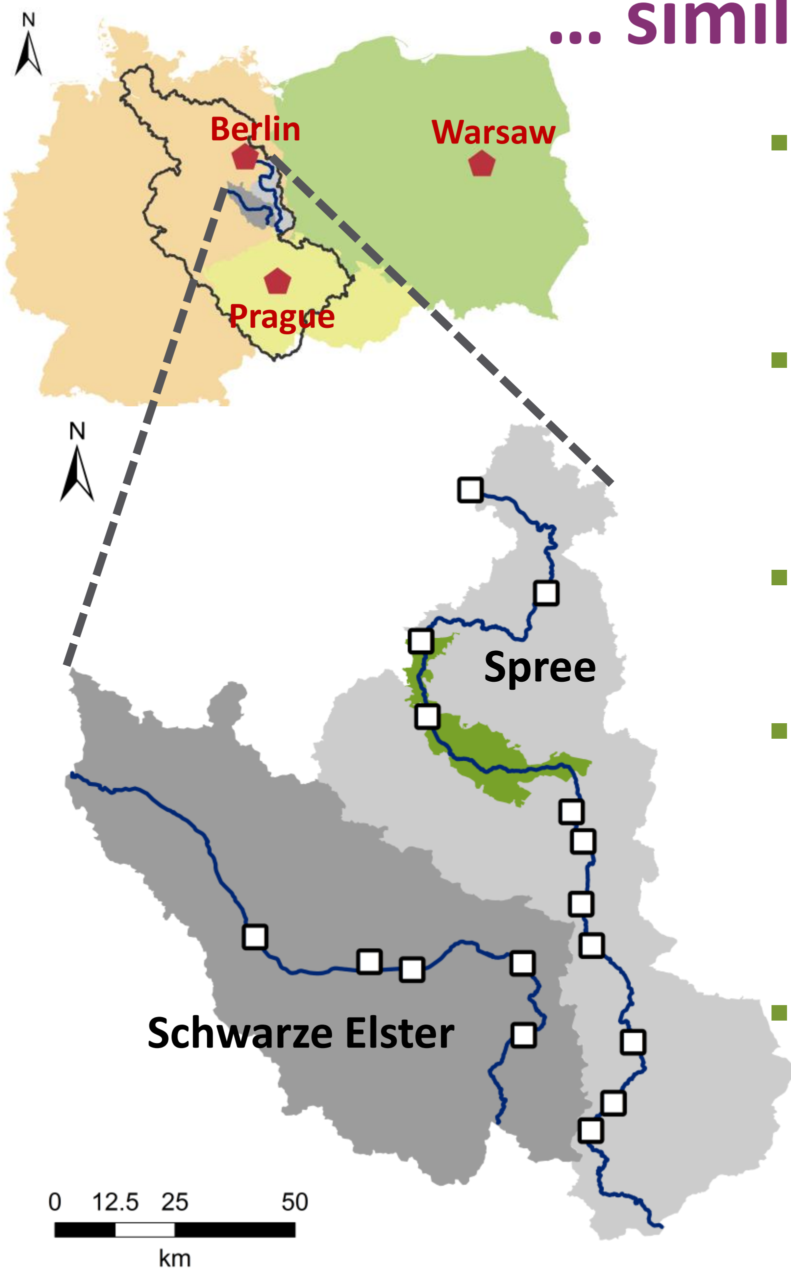
Modified after IPCC 2001

Cascade of Uncertainty in Climate Change Impact Studies



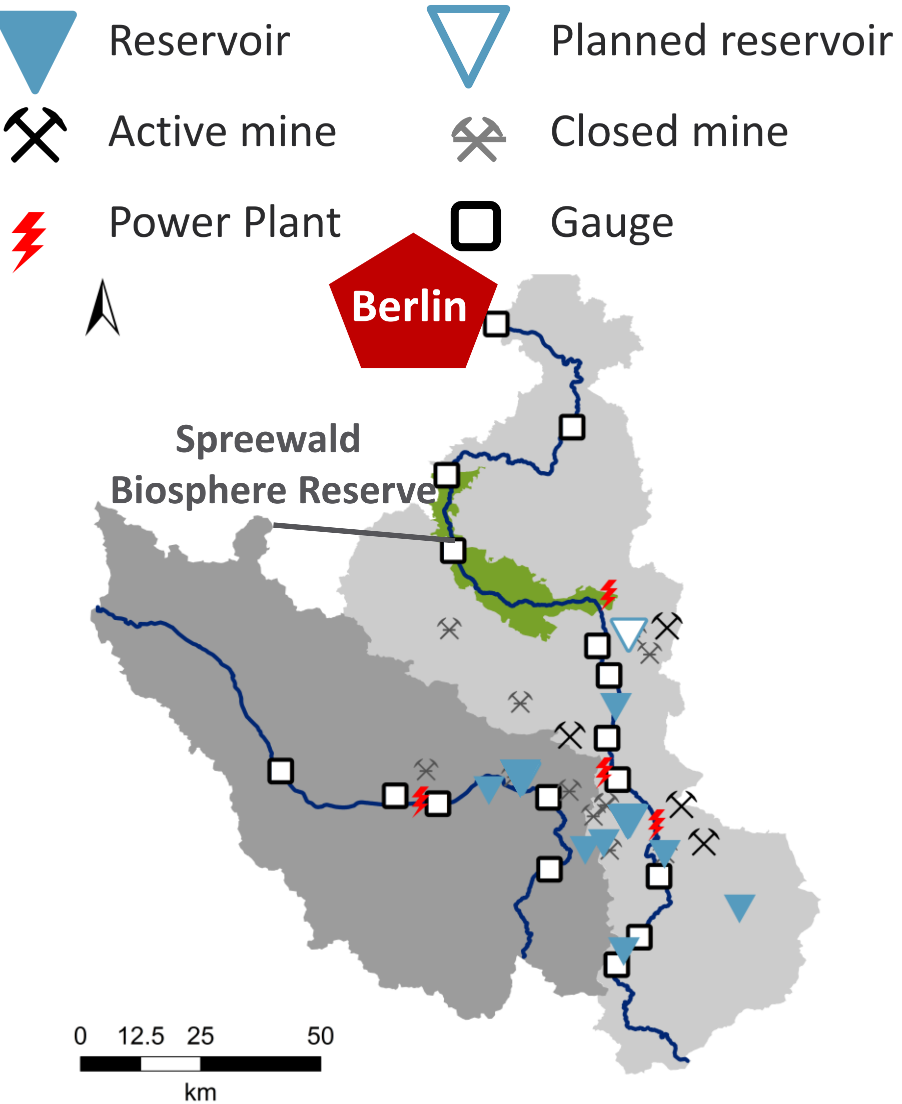
Modified after IPCC 2001

The Schwarze Elster and Spree catchments
… similar in hydrology



- Schwarze Elster: tributary to the Elbe River,
  A = 5700 km²
- Spree: 2nd order tributary to the Elbe River,
  A = 6200 km² (up to G. Tränke gauge station)
- Land cover: mostly cropland + forests
- Sandy soils (brown earth, allovial soil, podzol & stagnosol, similar proportions in both catchments)
- Climate: humid continental (Dfb),
  ann. average (1961-90): T = 8.8 °C, P = 650 mm

The Schwarze Elster and Spree catchments
… different level of water resources management



- Mining influences discharge regime (open cast lignite mining)
- Water supply of Berlin strongly depends on the Spree River
- Reservoir management:
  - Low flow augmentation
  - Reduction of overall discharge variability

Research questions

1. How did water resources management influence discharge variability in the past?

2. What are potential future climate change impacts on the regional water resources?

3. Which role does water resources management play regarding uncertainties of climate change impacts?

1. How did water resources management influence discharge variability in the past?

Approach

Observed discharge of gauge stations along the Schwarze Elster & Spree Rivers

Influenced by natural discharge & water resources management

Discharge simulated by SWIM (parameterised by regionalisation, Pohle et al. 2015)

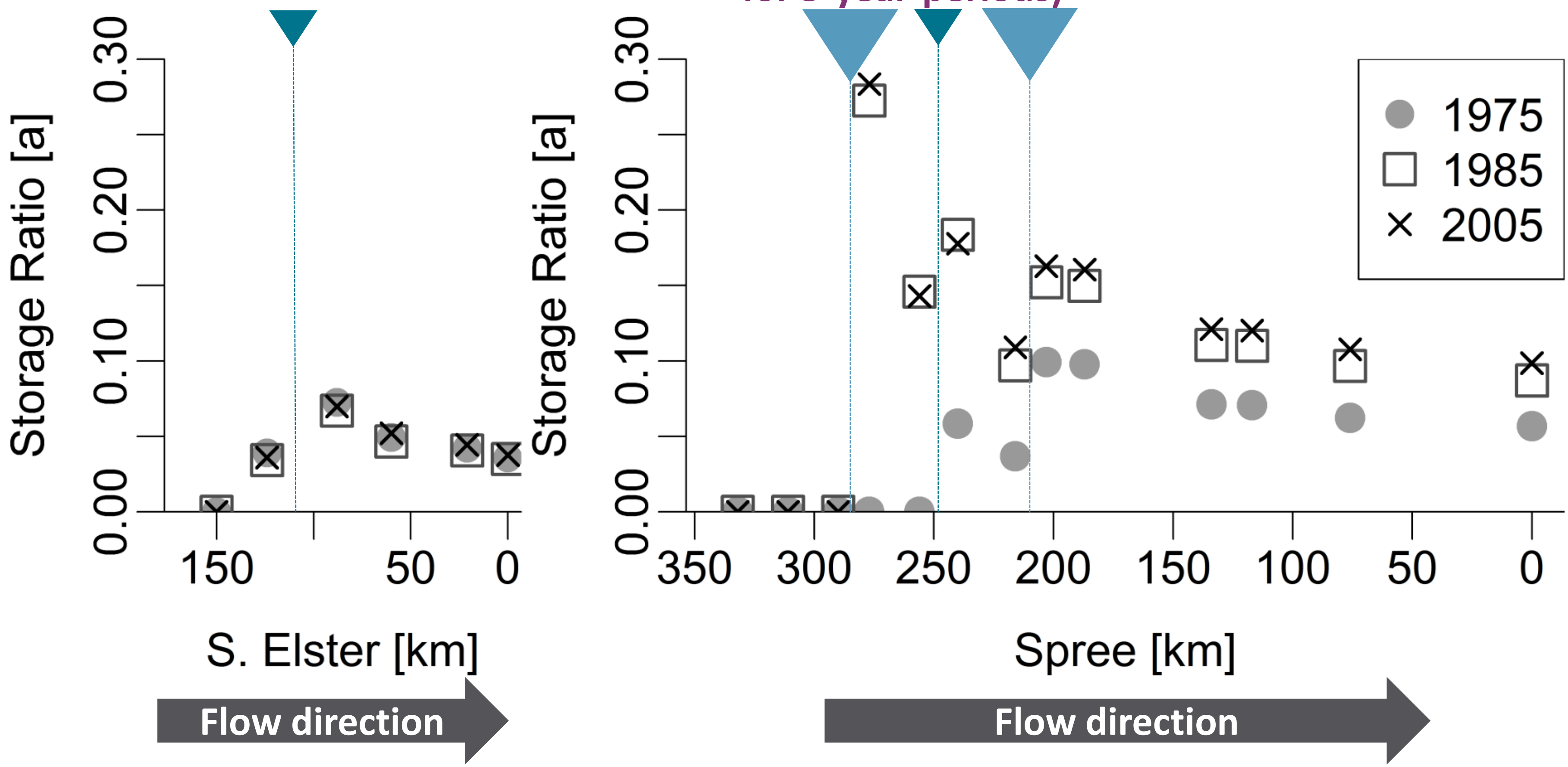
Natural discharge, no management influence

Comparison of annual values and variability indices

Storage Ratio of the Schwarze Elster & Spree

$$\text{Storage Ratio} = \frac{\text{Storage Capacity}}{\text{MQ}}$$

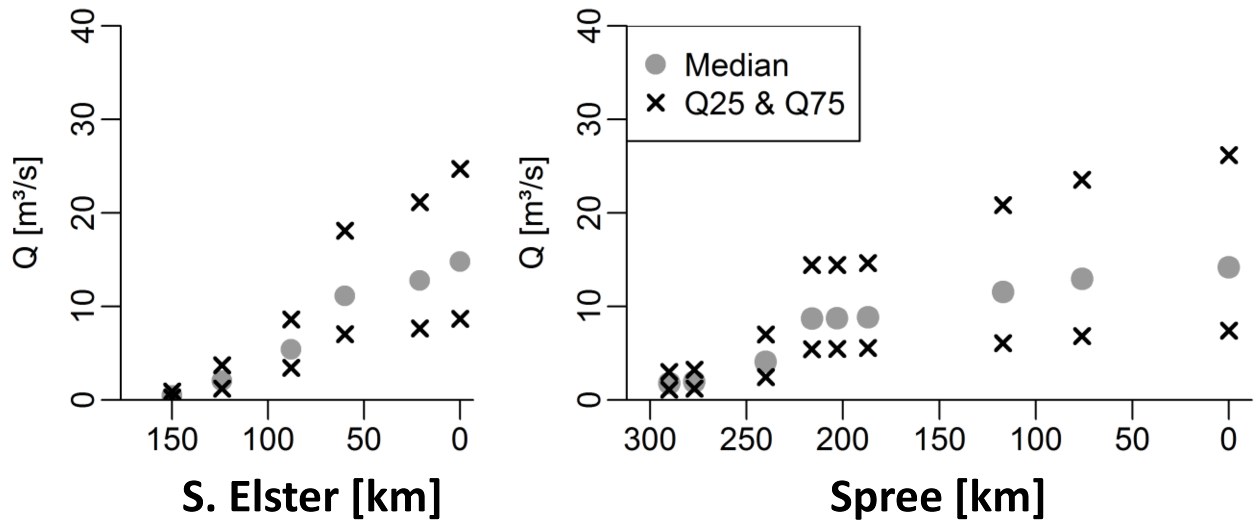
(Natural MQ as simulated by SWIM for 5-year-periods)



Large reservoirs (main river) Large reservoirs (tributaries)

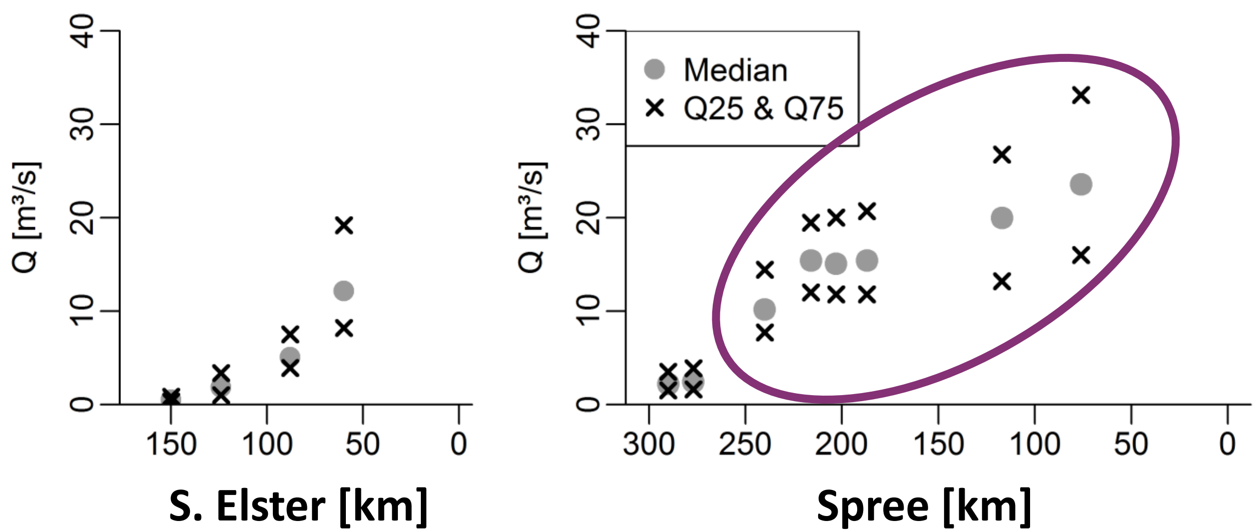
Natural and observed discharge (1971/2000, weekly)

Natural (SWIM)



➔ Natural discharge of both rivers at the outlets comparable

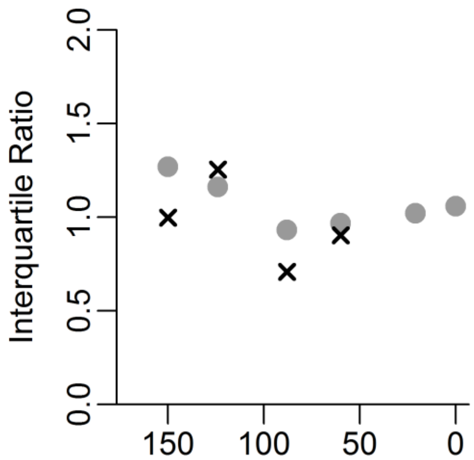
Observed



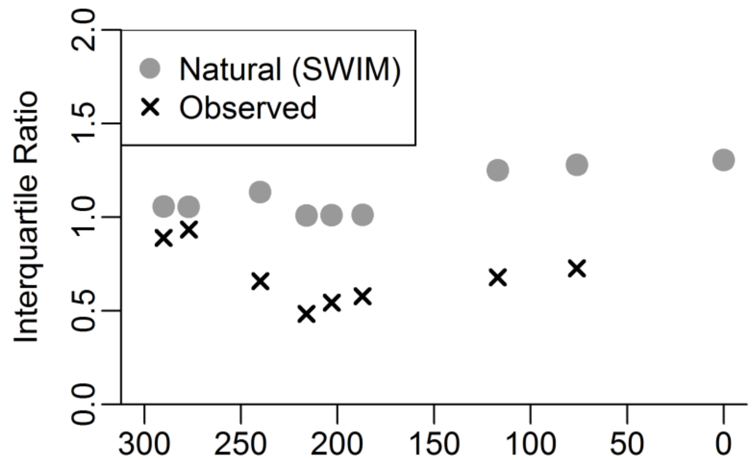
➔ Observed flow higher than natural flow (mining influence)

Variability: distribution (1971/2000, weekly)

$$\textbf{Interquartile Ratio} = \frac{|Q25 - Q75|}{Q50}$$



S. Elster [km]

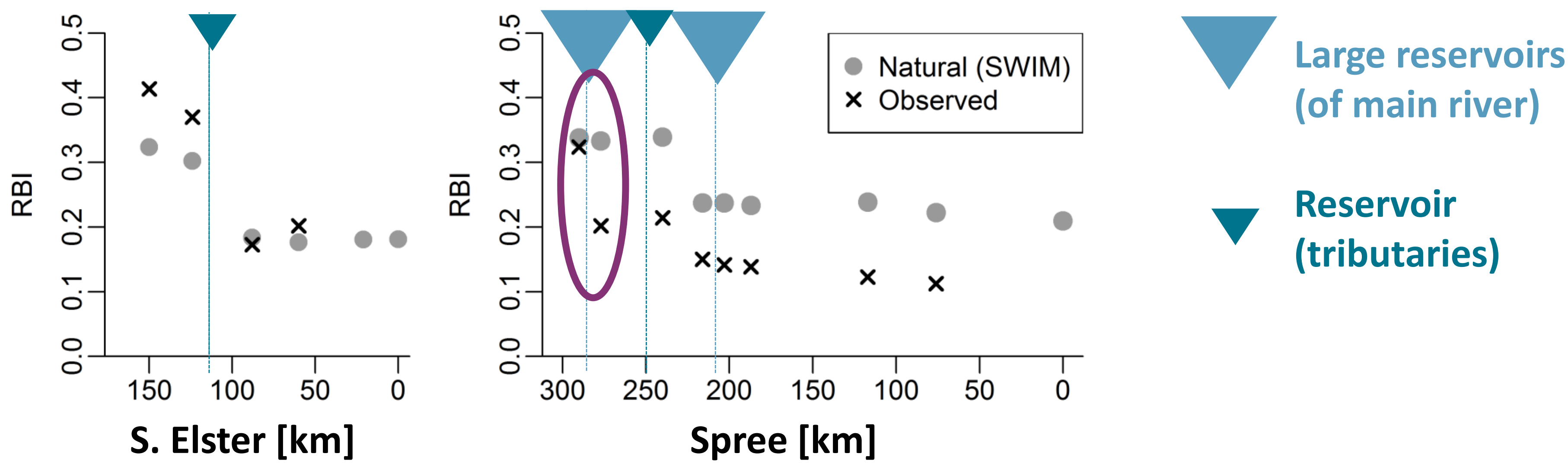


Spree [km]

➔ **Observed discharge shows lower variability in the overall distribution compared to natural discharge (especially in and downstream of the mining region)**

Variability: oscillation (1971/2000, weekly)

Richards Baker Flashiness Index (Baker et al. 2004): $RBI = \frac{\sum_{i=1}^{n} |Q_i - Q_{i\_1}|}{\sum_{i=1}^{n} Q_i}$



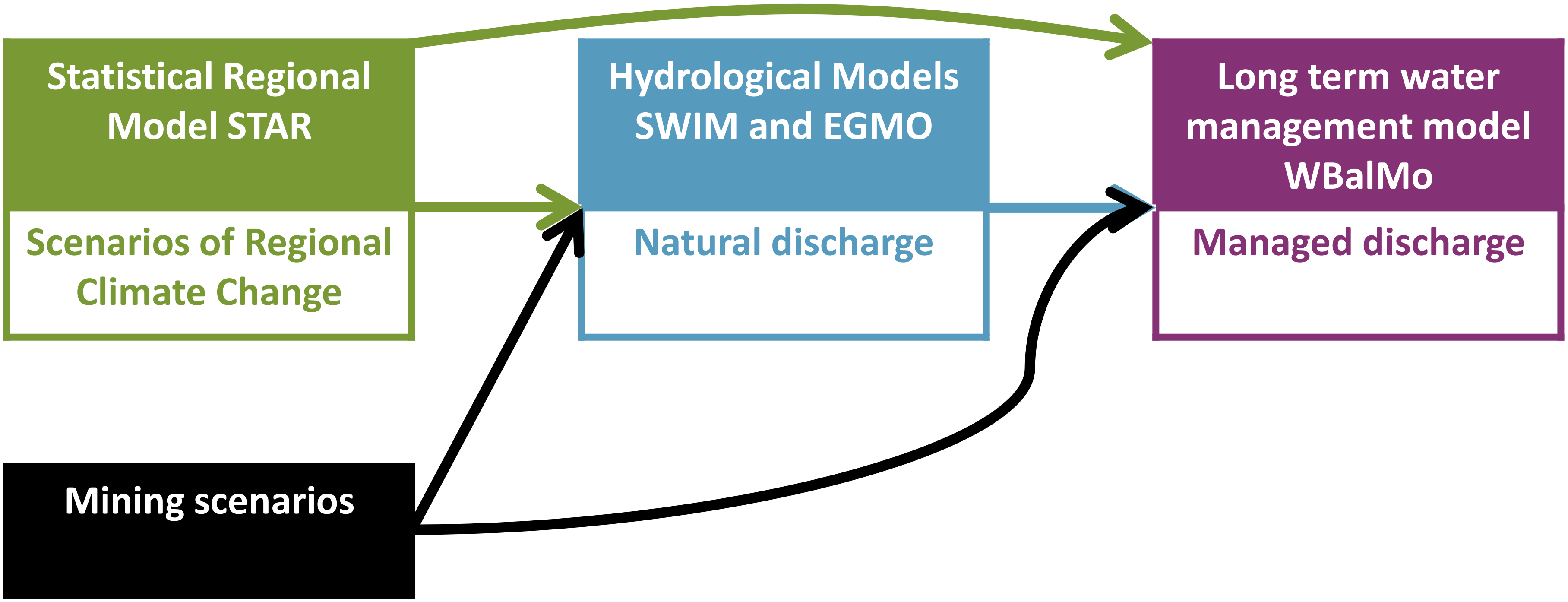
- ➔ Flashiness of natural discharge decreases along the river course
- ➔ Sudden decline in flashiness of observed flow after headwater reservoirs

1. How did water resources management influence discharge variability in the past?

- Comparison of observed discharge and simulated natural discharge helps to distinguish influences of water resource management from other factors (e.g. climate)
- Reservoir management
  - Decrease of oscillation (flashiness)
  - Decrease of overall variability (distribution)
  - Decrease of seasonality
  - Decoupling between consecutive gauge stations
- Mining water
  - Higher mean discharge
  - Decrease of overall variability (distribution)
  - Decrease of seasonality

2. What are potential future climate change impacts on the regional water resources?

Simulation Studies (Pohle et al. 2015 & 2016)



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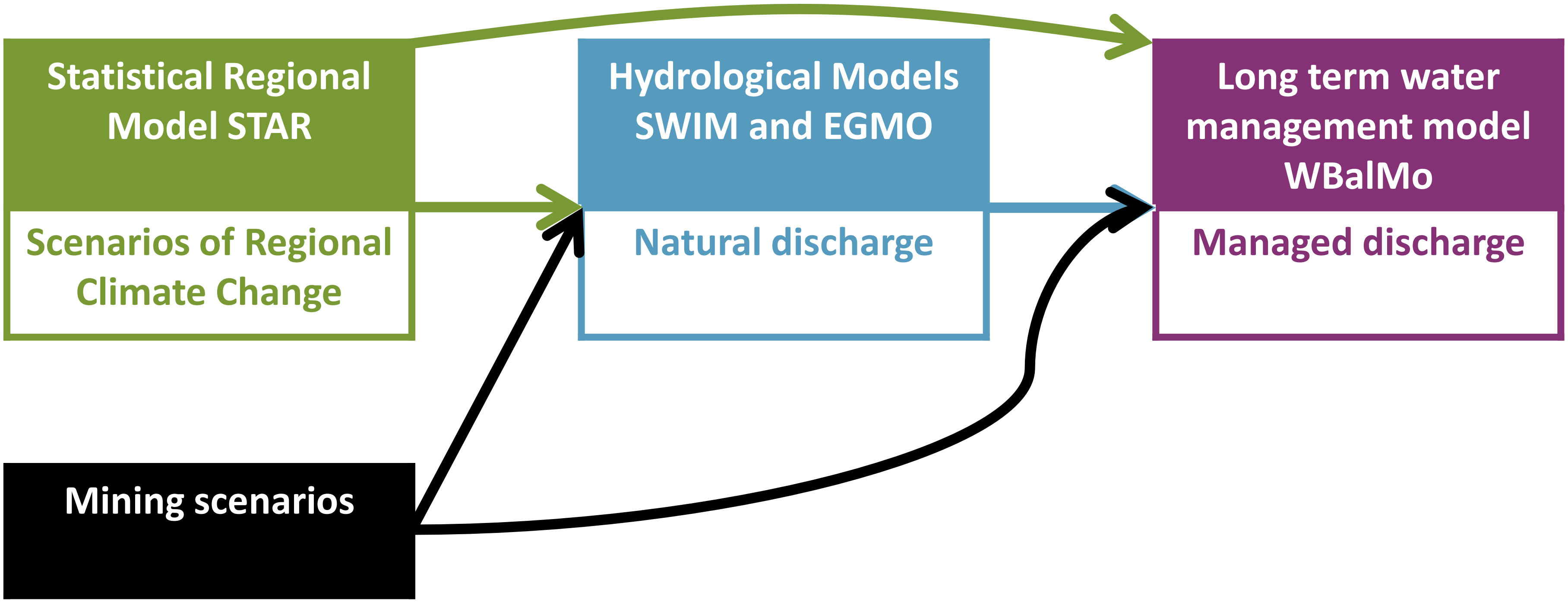
2. What are potential future climate change impacts on the regional water resources?

Simulation Studies (Pohle et al. 2015 & 2016)

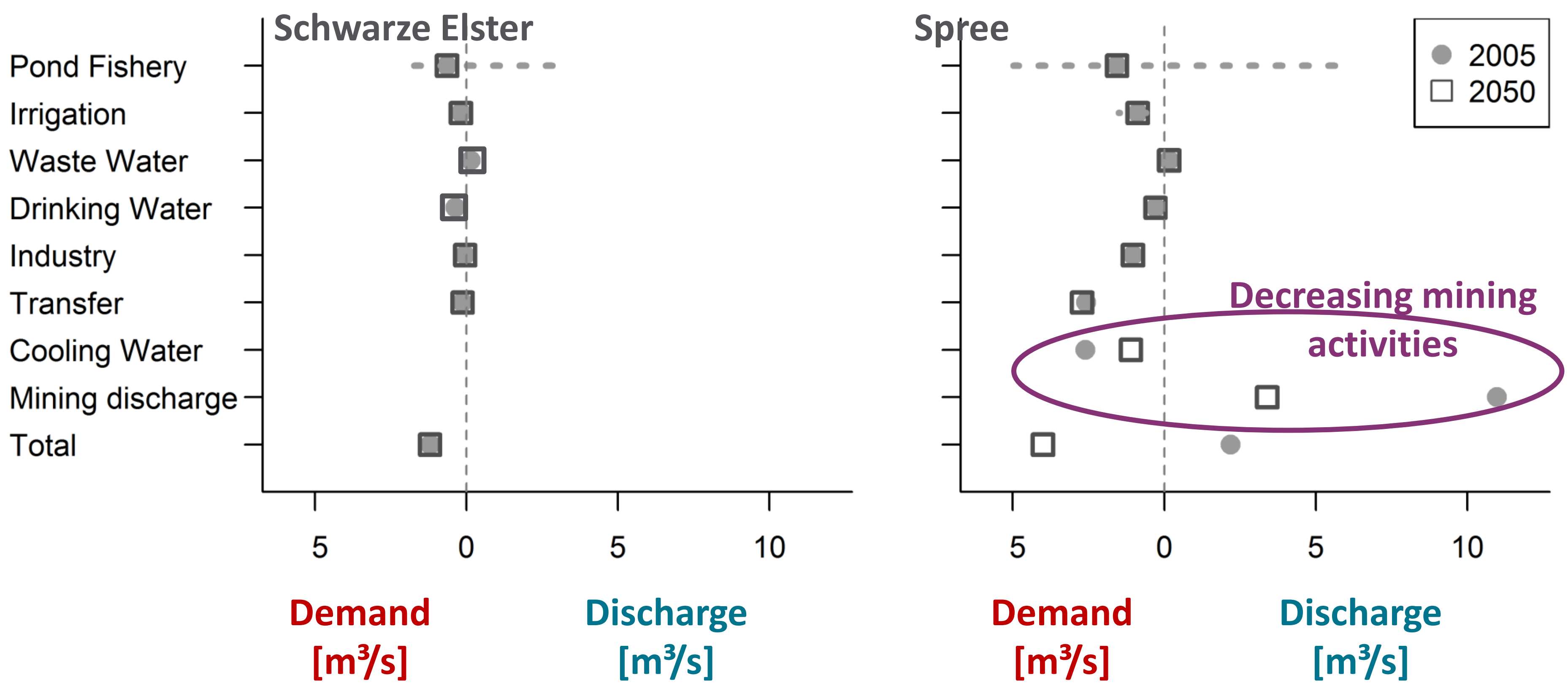
- Compared to „current“ climatic conditions (S 0K) scenarios with increasing annual temperature and decreasing annual precipitation (S 2K & S 3K) show
  - Increasing potential ET, but actual ET limited by availability of water
  - Decreasing natural discharge
  - Decreasing managed discharge (climate impacts & reduced mining activities)
  - Lower reservoir volumes
  - It will take longer to fill the mining pit lakes
  - More severe mining-related water quality issues
  - Only small differences between the hydrological models (SWIM & EGMO)

3. Which role does water resources management play regarding uncertainties of climate change impacts?

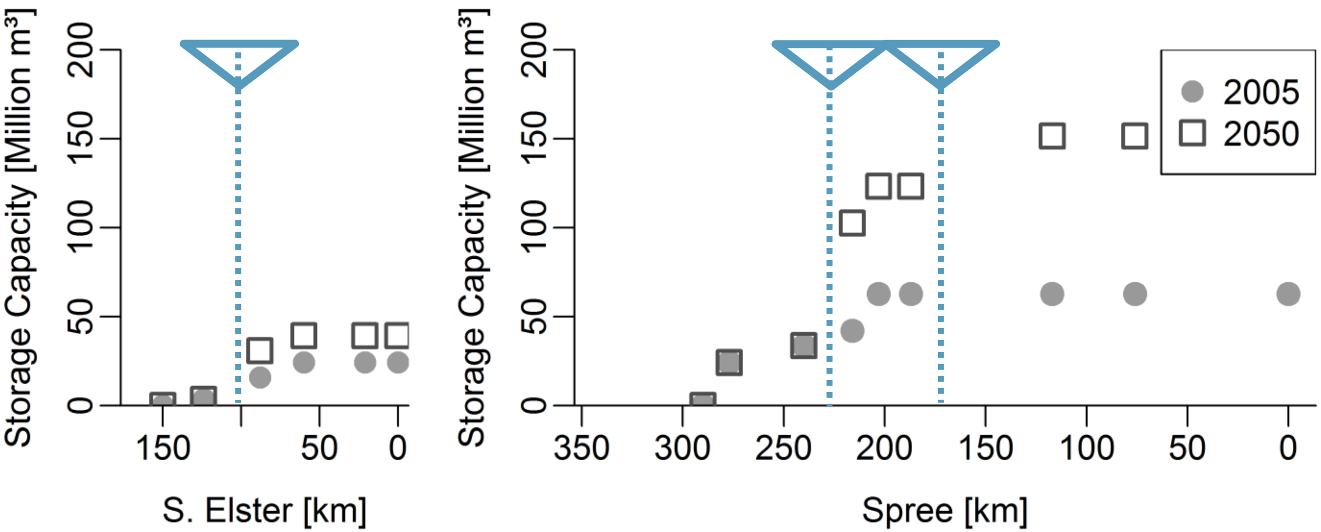


Simulation Studies (Pohle et al. 2015 & 2016)

Water use in the future

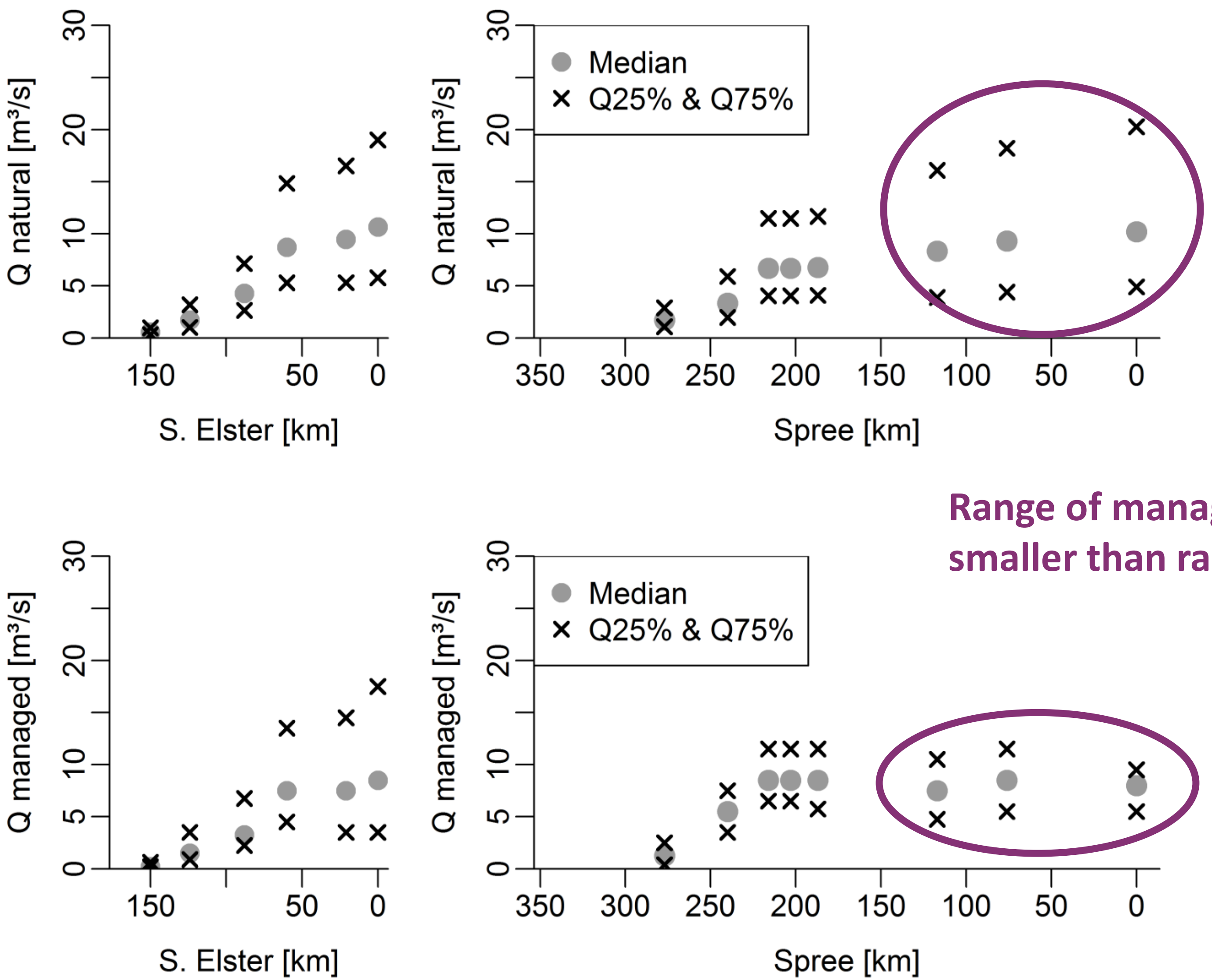


Changes in storage capacity: “Current” and planned reservoir volumes



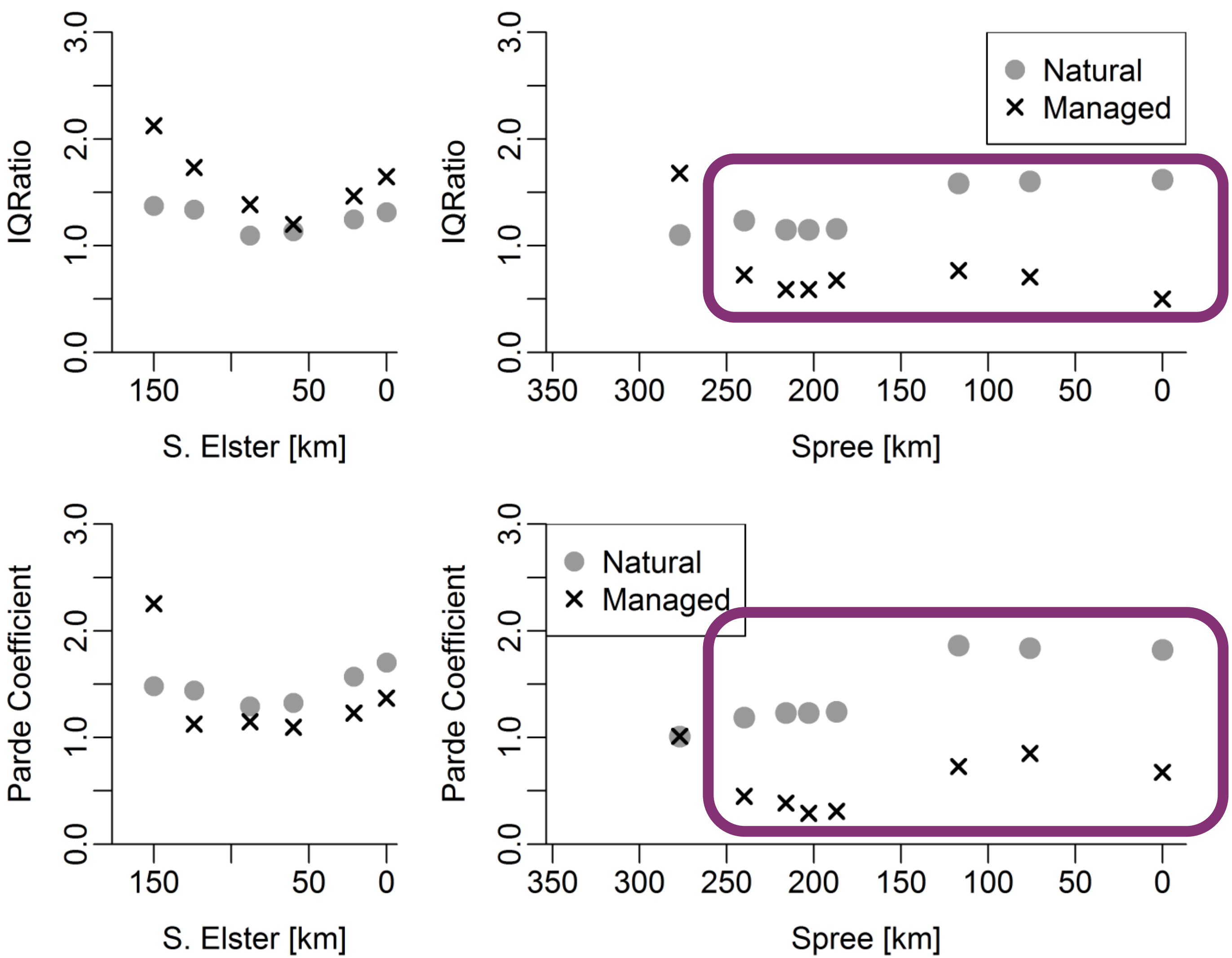
 Future reservoirs (mining pit lakes)

Discharge in scenario STAR 2K (weekly, 2048-2052)



Range of managed discharge much smaller than range of natural discharge

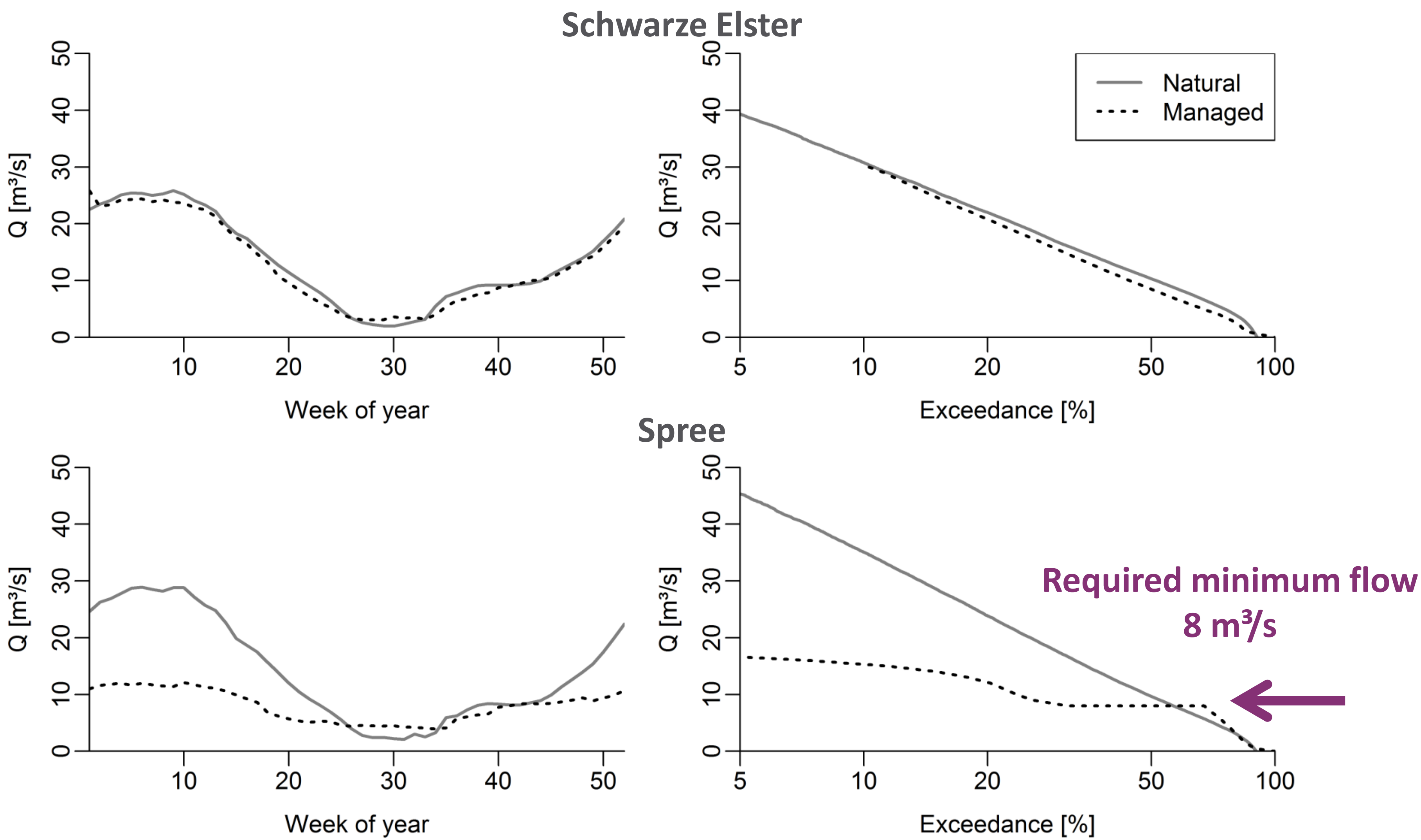
Interquartile Ratio and Parde coefficient scenario STAR 2K (weekly, 2048-2052)



Intense water resources management in the Spree catchment reduces interquartile ratio and seasonality

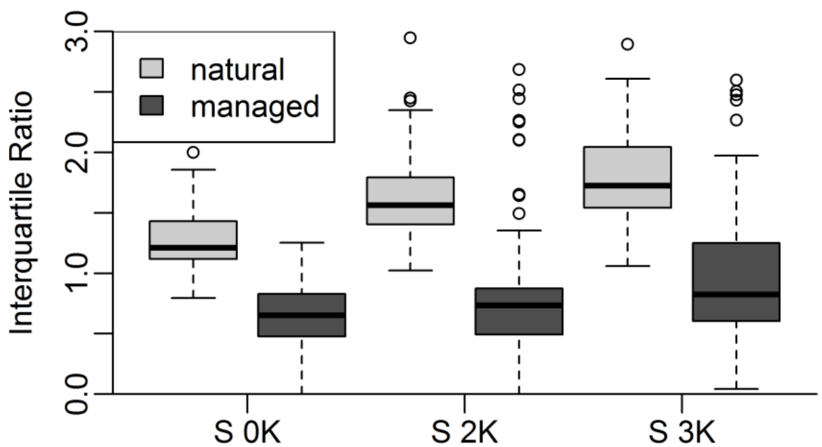
Mean annual course and flow duration curve

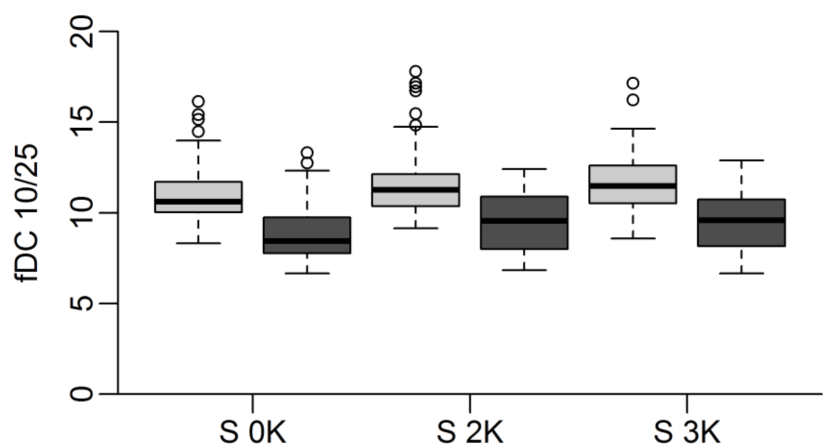
(2048-2052, weekly values from 100 realizations for STAR 2K)

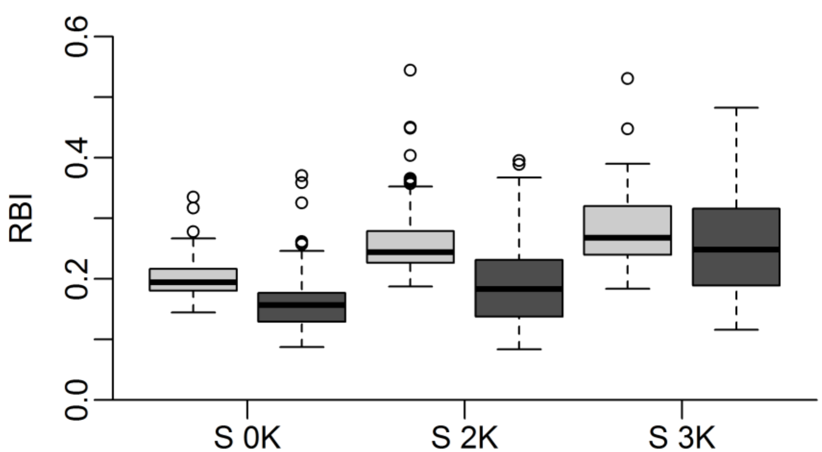


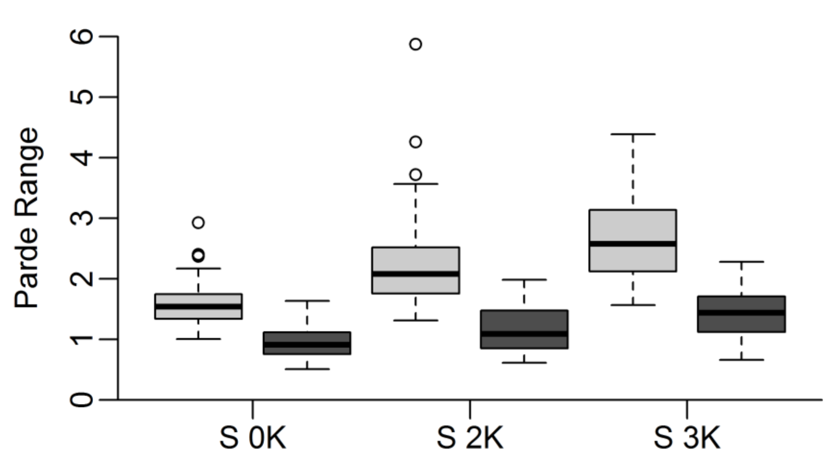
Variability indices of individual realisations

(2048-2052, Spree, weekly values from 100 realizations)



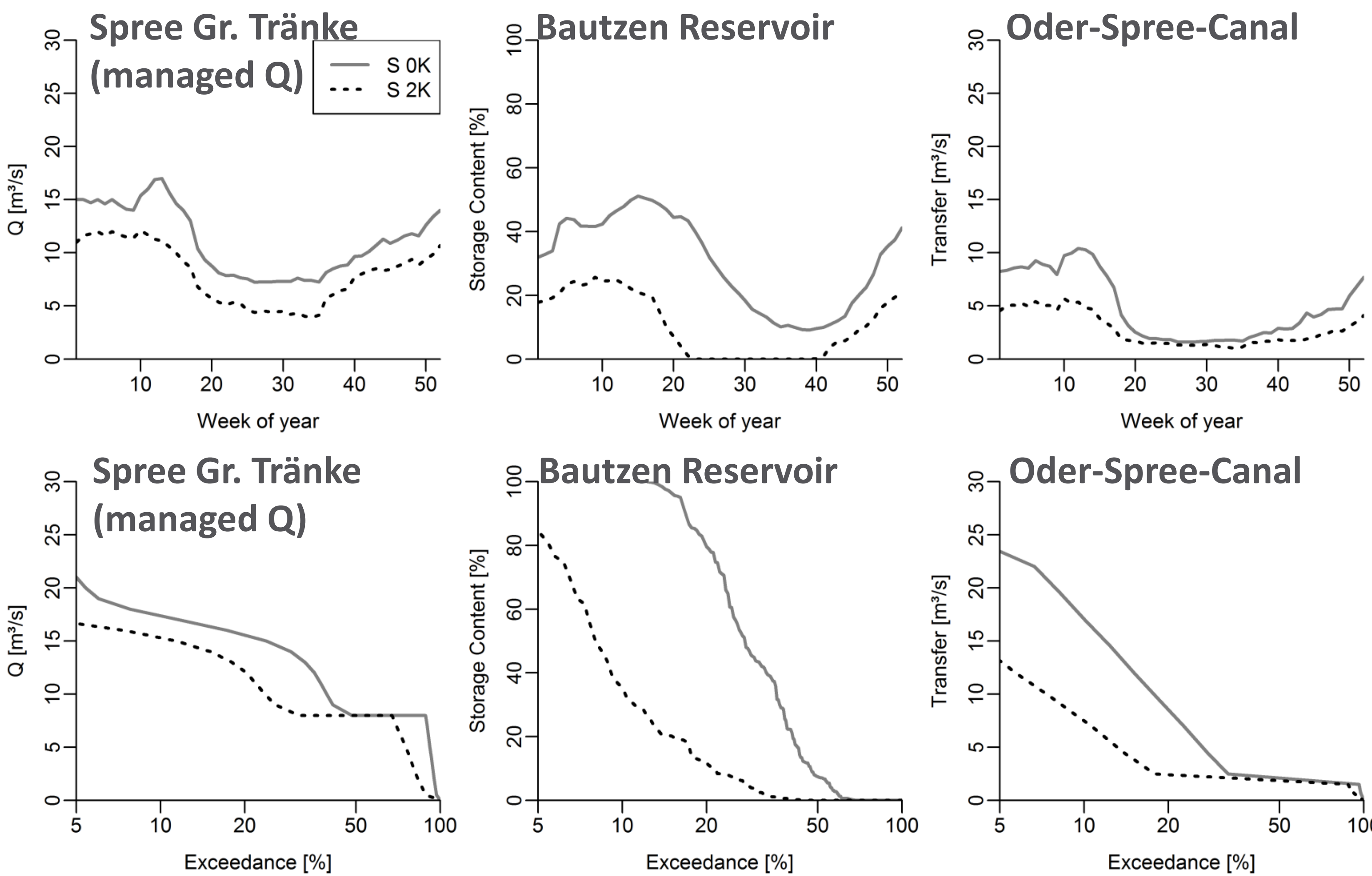






Contribution of storage and transfer

(2048-2052, weekly values from 100 realizations)



3. Which role does water resources management play regarding uncertainties of climate change impacts?

- Water resources management can alleviate the uncertainty of projected climate change impacts on river discharge to a certain degree
  - Effective reservoir management
  - In the Spree catchment, the highest priorities are on the river discharge – the variability and uncertainty of river discharge is reduced at the expense of water transfers and water users
- Yet, due to decreasing reservoir volumes in drought periods, reservoir management alone cannot compensate strong changes in climate conditions over long time periods (this can already be seen by comparing STAR 2K and STAR 3K results).

Conclusions

- Influence of water resources management is evident when comparing observed discharge and simulated natural discharge
- Potential future natural discharge shows high uncertainty related to climate scenarios & realizations
- Effective reservoir management reduces discharge variability AND can reduce uncertainty related to climate change impacts
- Catchments with a high storage ratio are less vulnerable to changing climate conditions
- Reservoir management is a suitable tool for climate change adaptation

Outlook

- Water management needs to be explicitly considered in climate change impact studies

- This is also possible in SWIM & SWAT by using routines for water withdrawals and reservoir management (e.g. the reservoir model of SWIM developed by Koch et al. (2013))

- (Water management in the Spree & Schwarze Elster catchments difficult for SWIM & SWAT due to priority setting, with senior users/water rights downstream prohibiting withdrawals of upstream junior users/water rights)

Thank you!

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- We thank C. Jaunich for initial calculations of variability indices in the Spree River Catchment.

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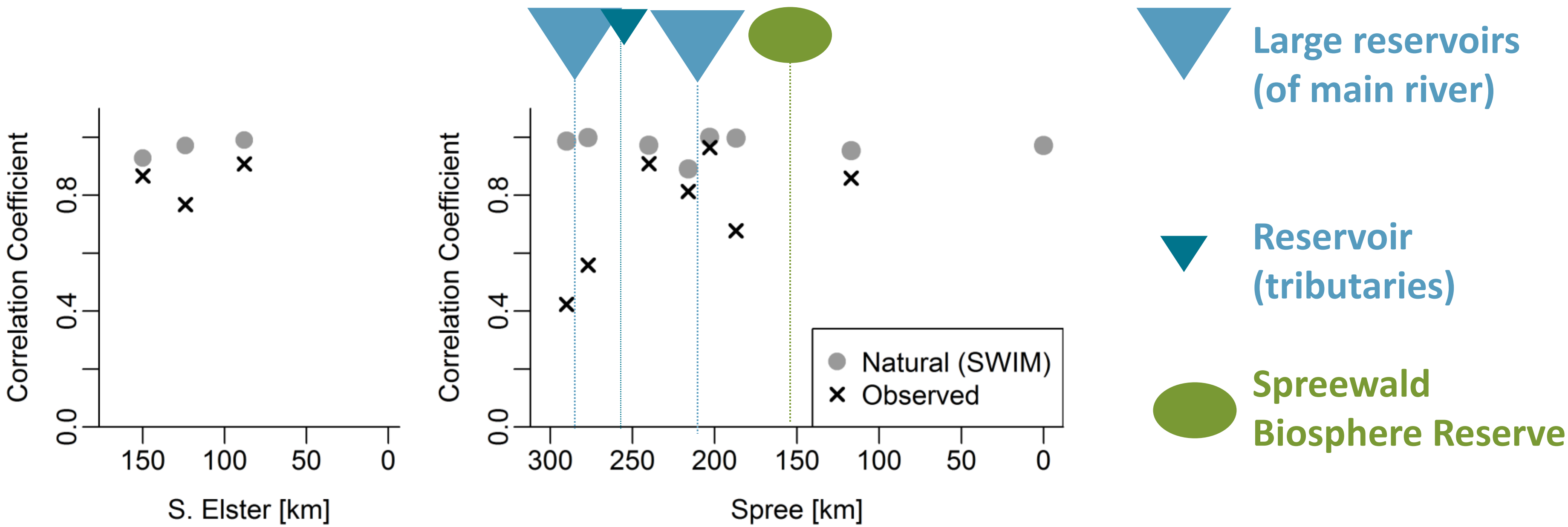
Correlation between discharge of consecutive gauges
(weekly, 1971/2000)



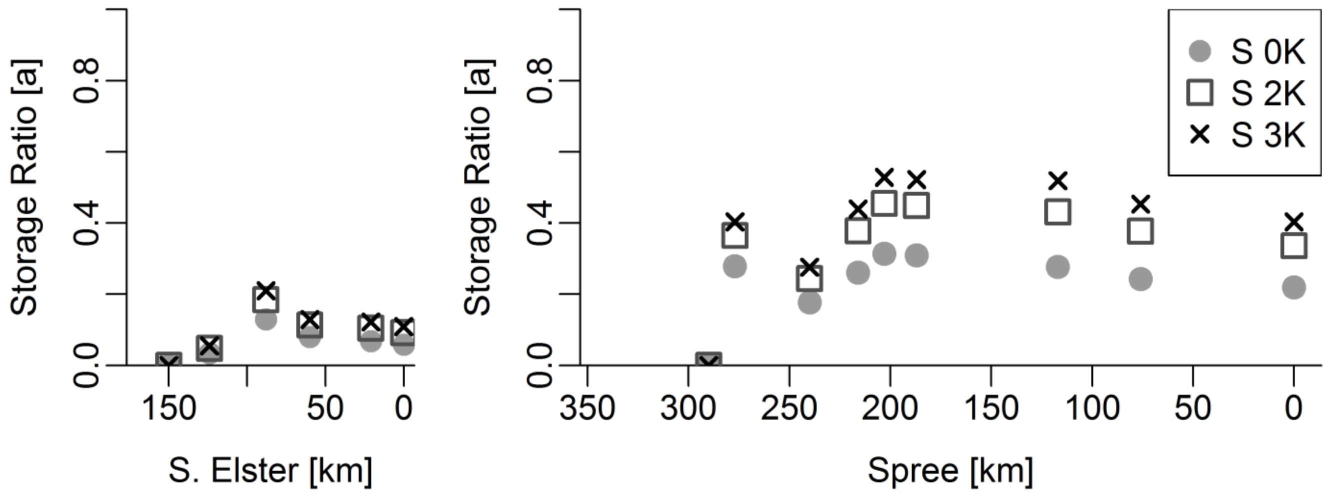
➔ **Natural discharge between one gauge and the next is highly correlated**

➔ **Observed discharge: correlation is not pronounced in the presence of reservoirs & the Spreewald Biosphere Reserve between gauges**

Storage ratio 2047-2052 (mean value of 100 realisations each)

$$\text{Storage Ratio} = \frac{\text{Storage Capacity}}{\text{MQ}}$$

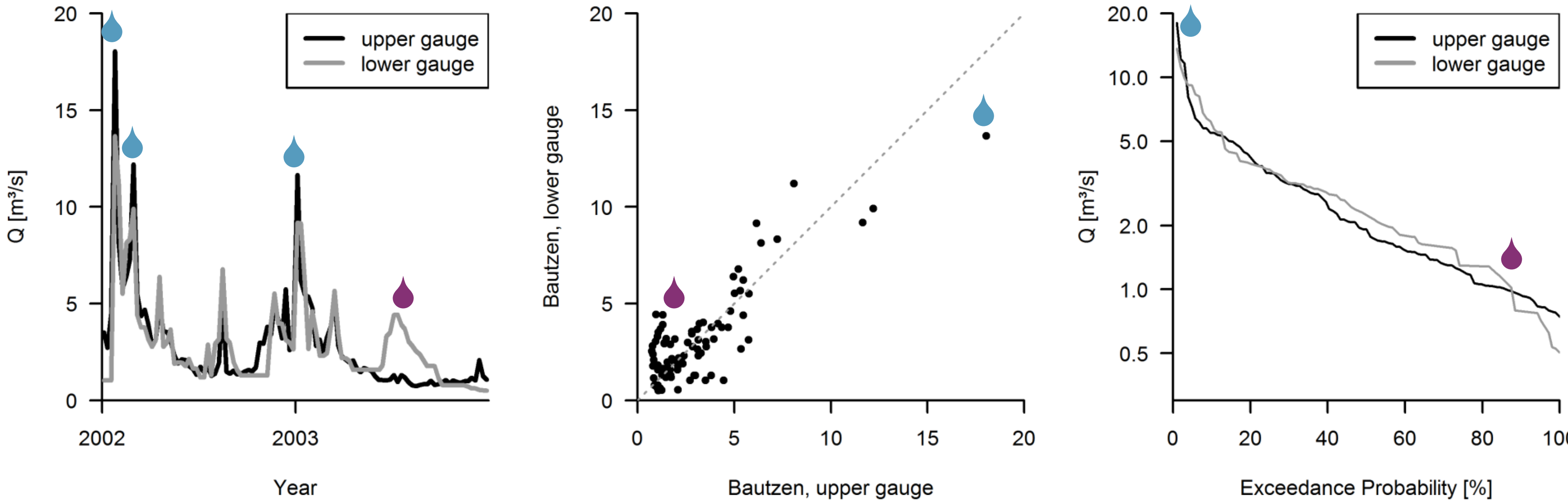
(Natural MQ as simulated by SWIM)



Increase of the storage ratio compared to the recent past in the Spree River catchment:

- By ca. factor 2 due to increase in reservoir capacity
- Additional effects of decreasing natural discharge

Influence of a reservoir on discharge dynamics
- Bautzen Reservoir (2002/2003, weekly)

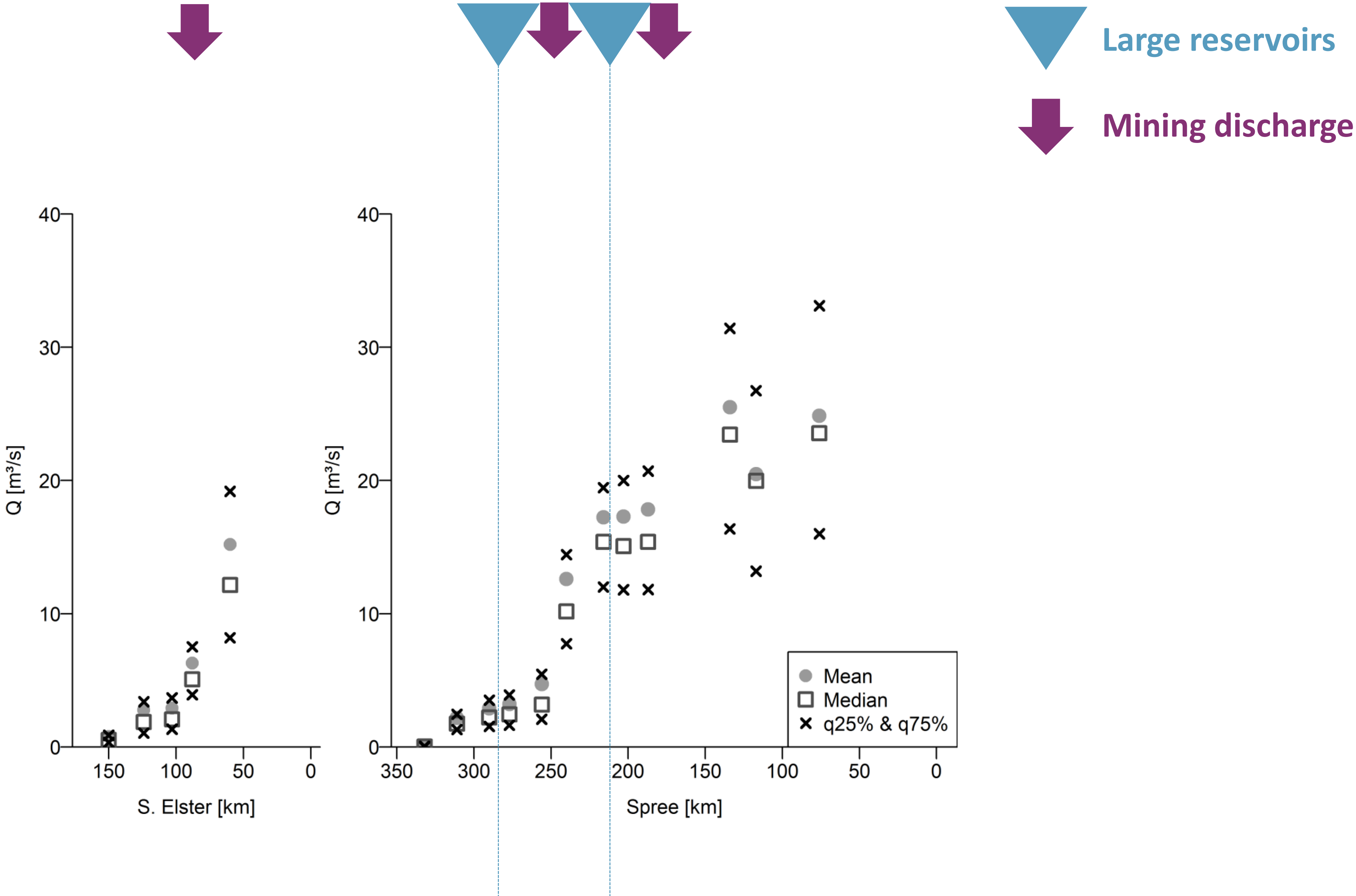


Reduction of flood peaks ( )

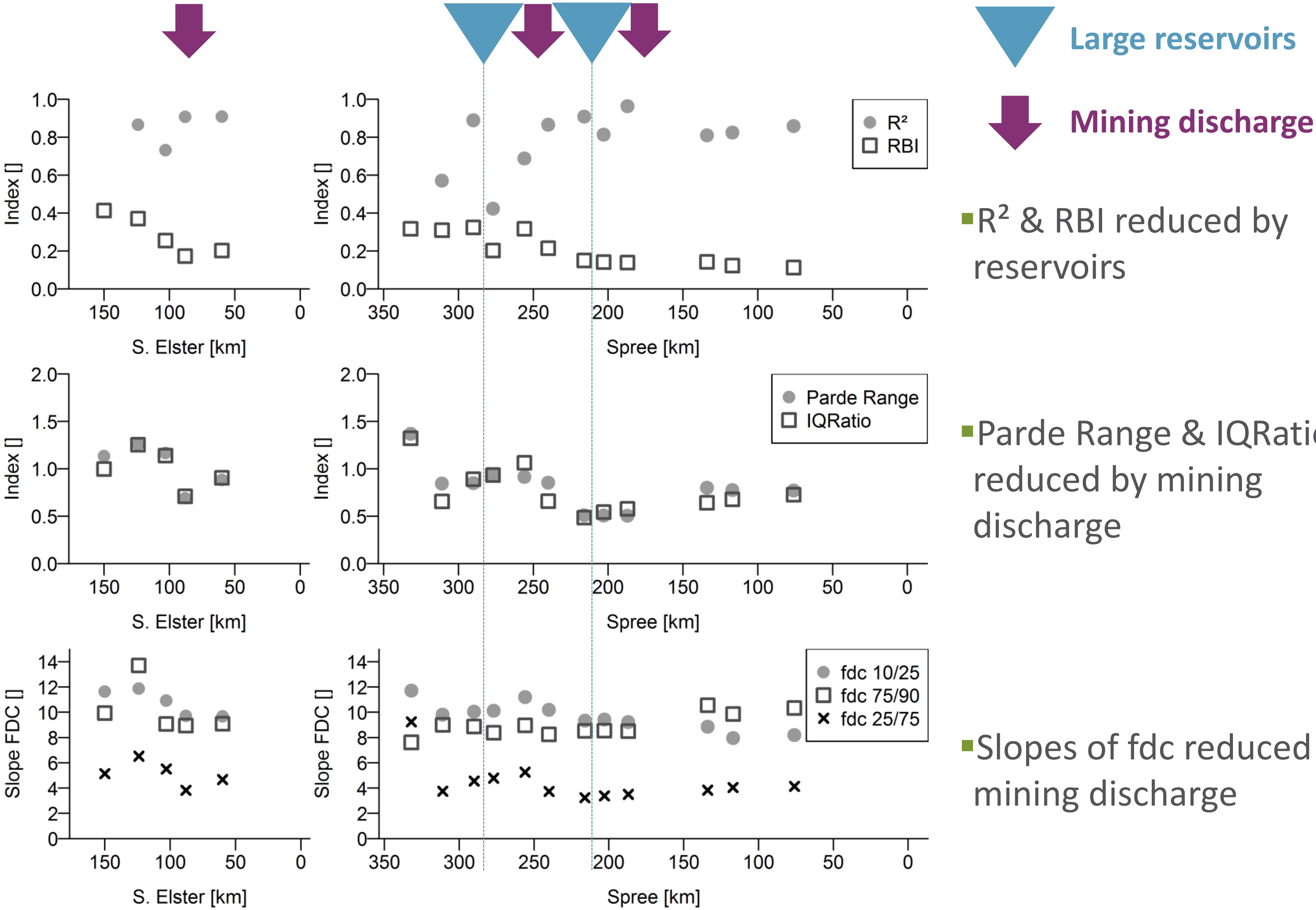
Low flow augmentation ( )

Water stored in winter to be released in summer

Observed discharge (1971-2000, weekly)

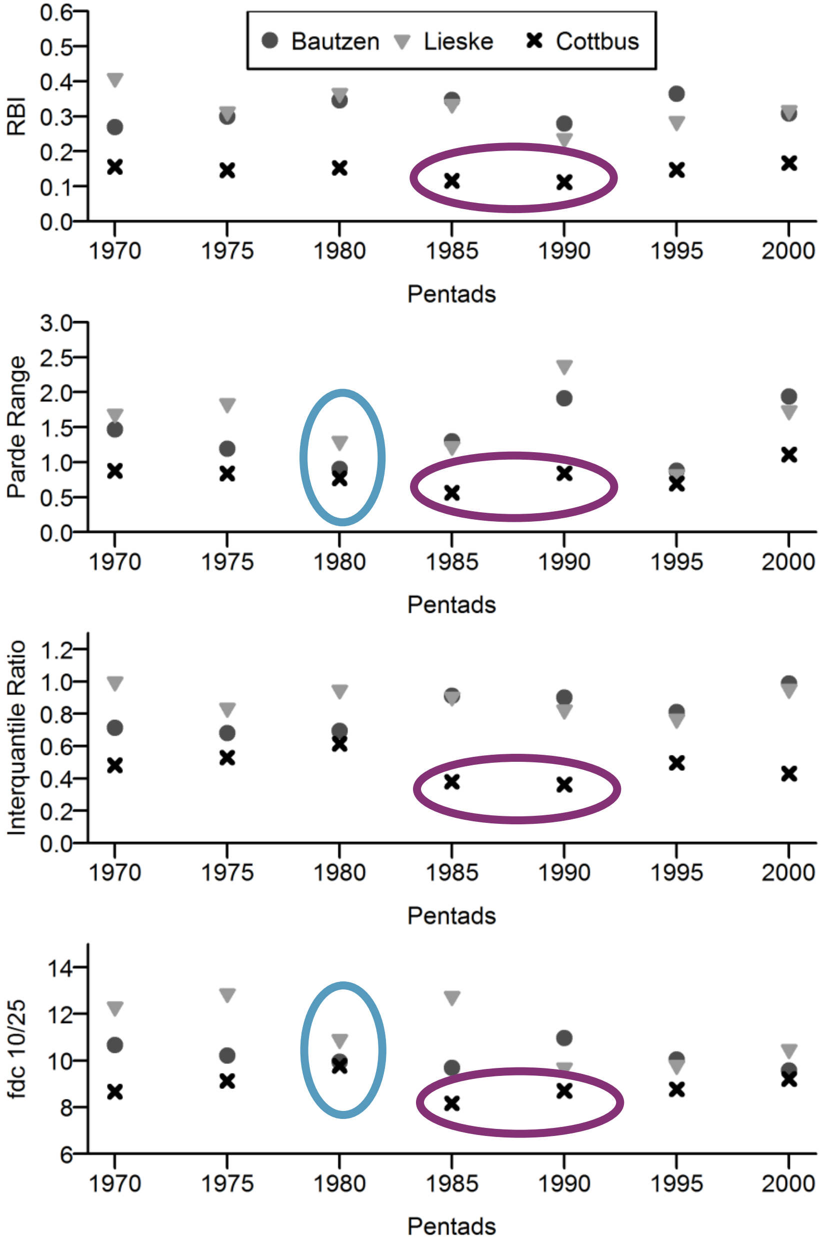


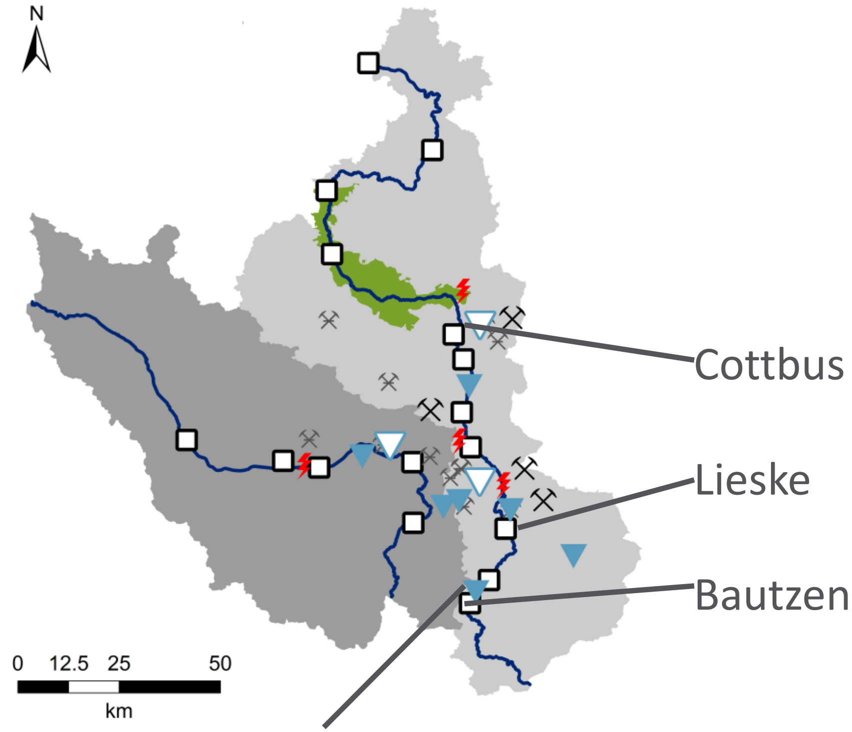
Variability of observed discharge (1971-2000, weekly)



- R^2 & RBI reduced by reservoirs
- Parde Range & IQRatio reduced by mining discharge
- Slopes of fdc reduced by mining discharge

Variability changes over time (pentads, weekly)





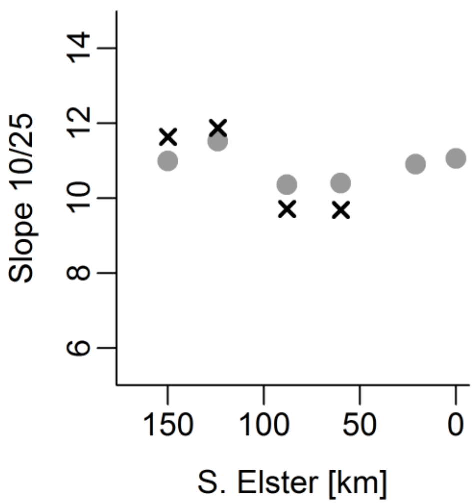
- **1977 – Bautzen Reservoir**
  ➔ RBI & Interquartile ratio in Lieske reduced

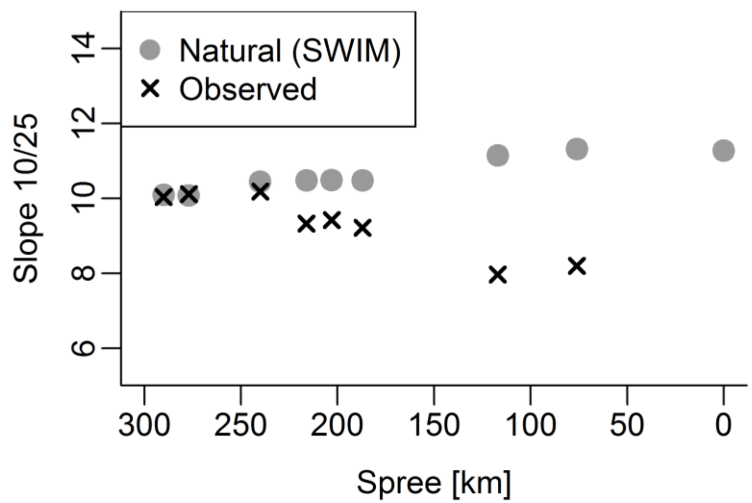
- **1980s highest mining discharges ➔ lowest variability of discharge in Cottbus**

- **Declining mining activities after 1990 ➔ increasing discharge variability in Cottbus**

Variability: distribution (1971/2000, weekly)

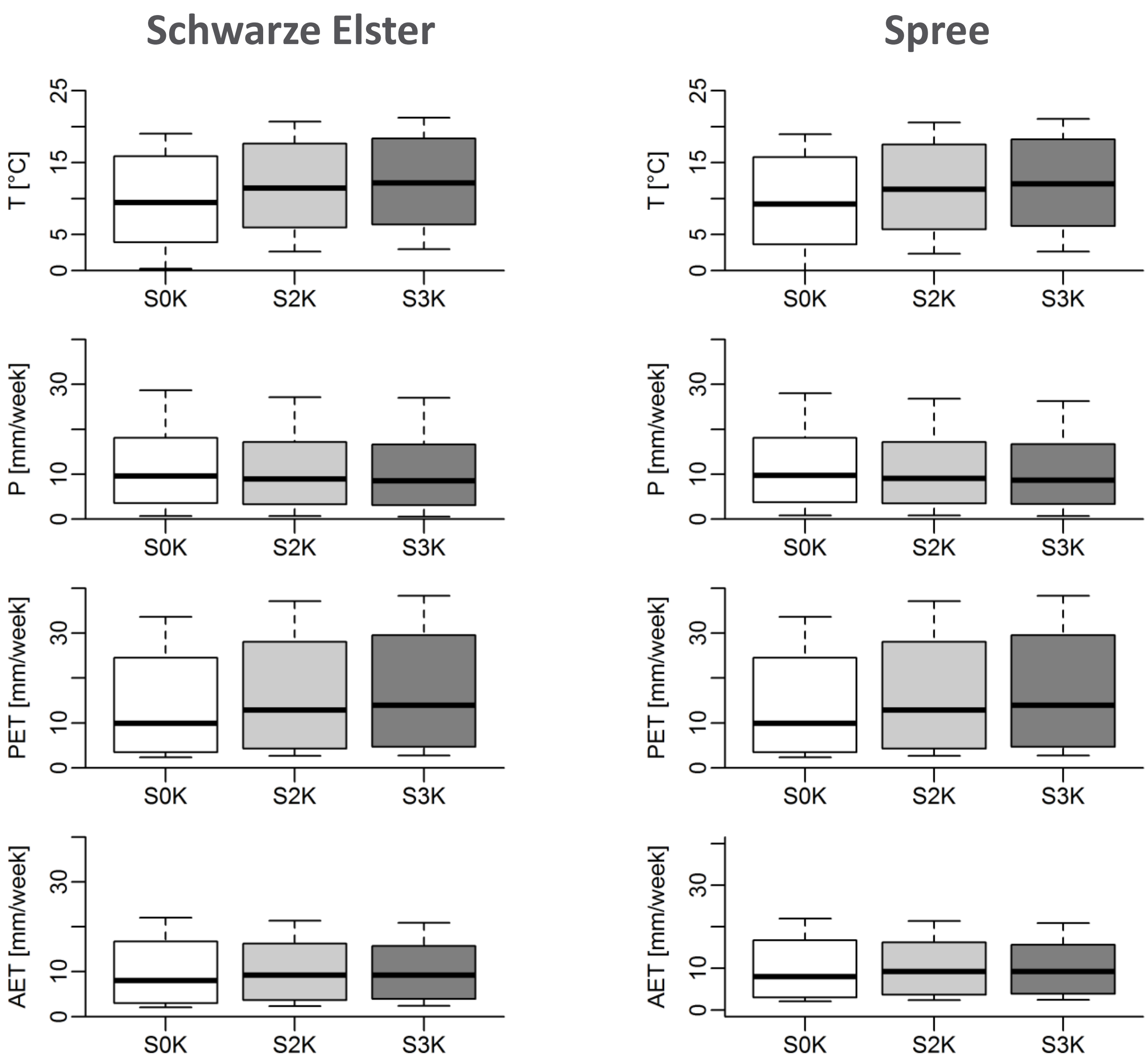
Slope 10/25 = slope between the 10th and the 25th quantile of exceedance (standardised by the mean)





➔ **Observed discharge shows lower variability in high flows compared to natural discharge (especially in and downstream of the mining region)**

Climate change & impacts
(pentad 2050, weekly values from 100 realisations each)



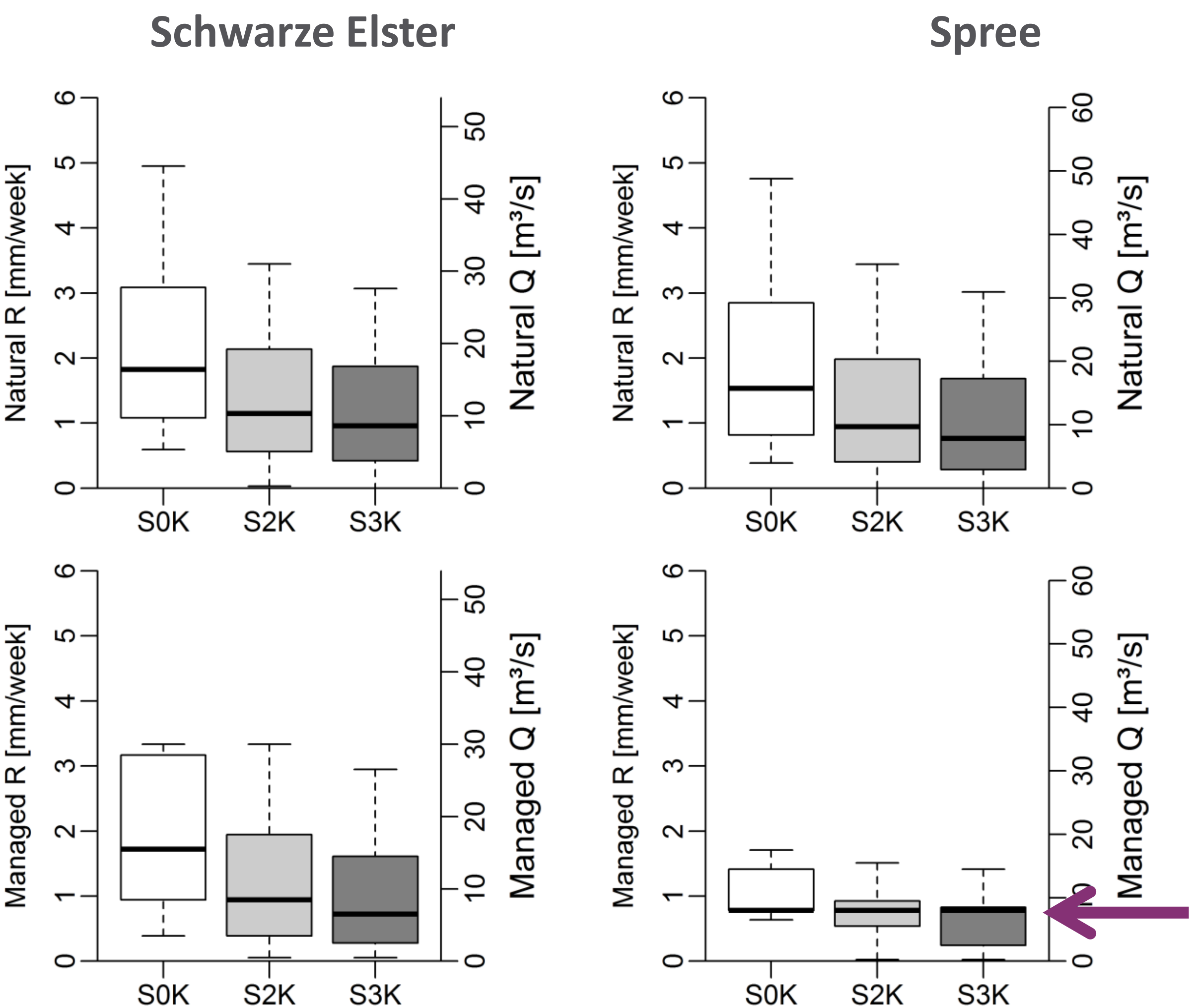
Compared to S 0K (baseline) scenarios S 2K and S 3K show:

- Higher temperature
- Lower precipitation
- Higher PET and more variability in PET
- Similar AET (but less variability of AET)

- Differences between the catchments are not pronounced

Climate change & impacts

(pentad 2050, weekly values from 100 realisations each)

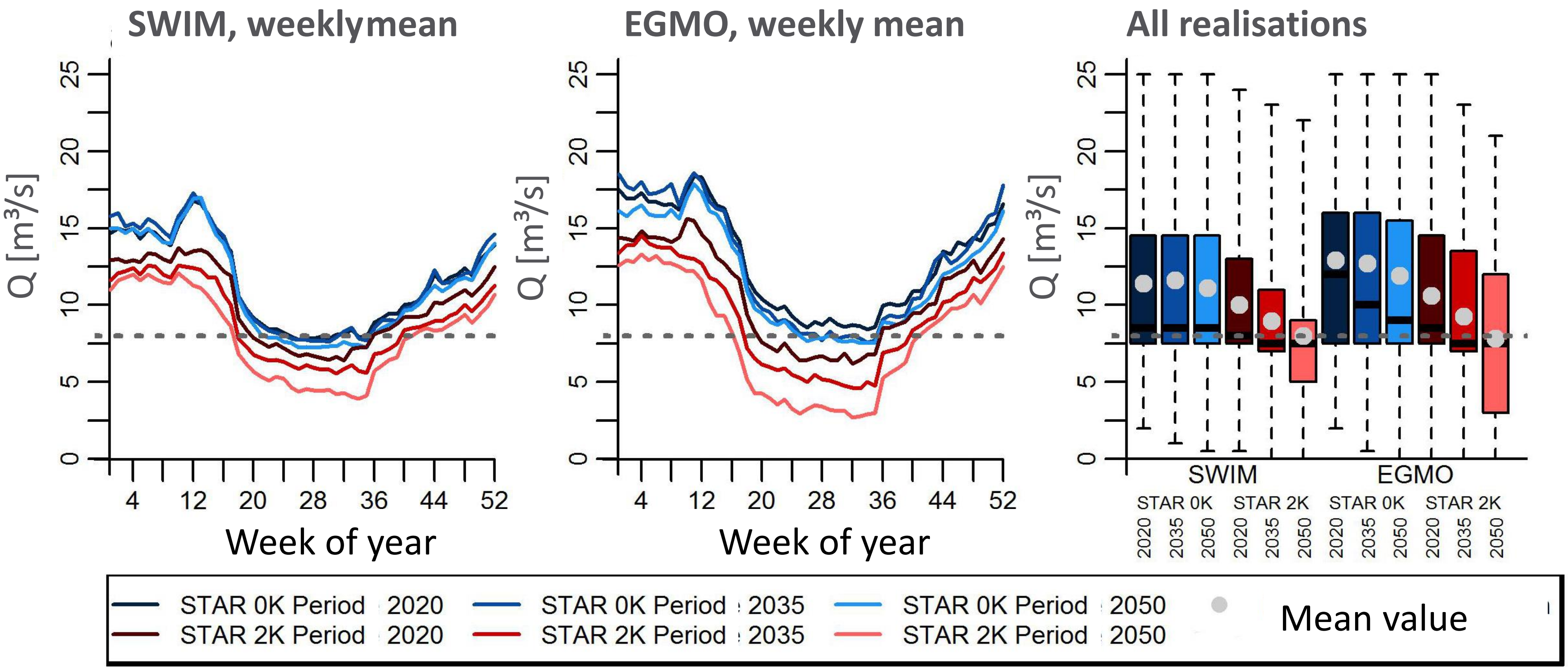


Required minimum Q for Spree at Gr. Tränke: 8 m³/s

Compared to S 0K (baseline) scenarios S 2K and S 3K show:

- Natural discharge: lower mean and lower range (comparable for both catchments)
- Managed discharge: lower mean
- Schwarze Elster: natural discharge and managed discharge very similar
- Spree: Managed discharge shows very small variation

Differences between projected discharge by two conceptually different hydrological models: SWIM and EGMO

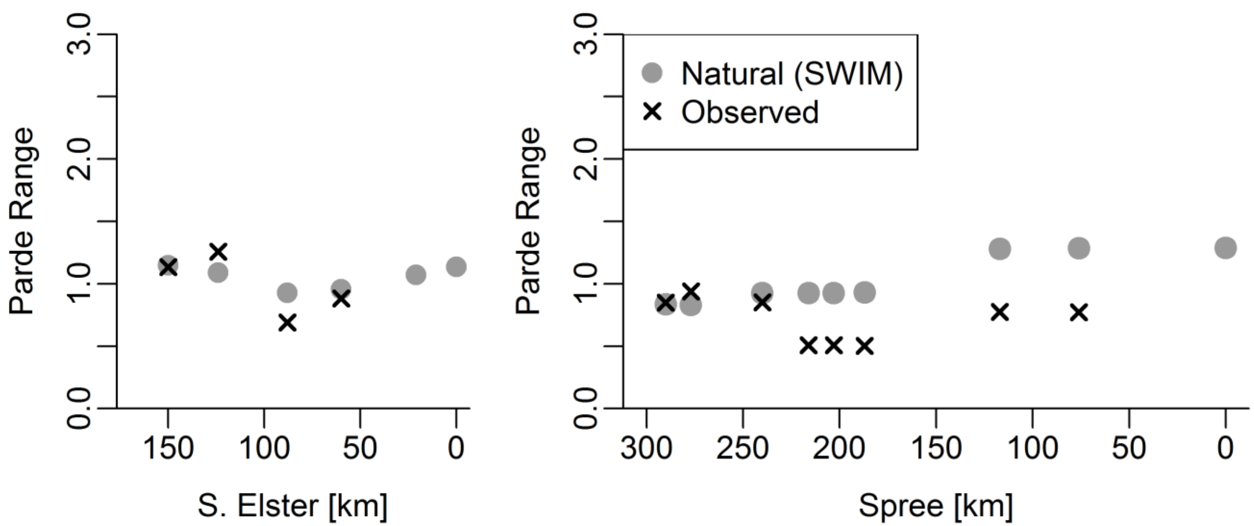


Pohle et al. 2016

➔ **In terms of mean values and distributions the choice of the hydrological model adds little uncertainty compared to the climate scenario**

Variability: seasonality (1971/2000)

Pardé Index (Pardé 1947): long term mean monthly / long term mean annual values
➔ Range of the Pardé index describes variation of the monthly contributions to flow



➔ **In and downstream of the mining region the observed discharge shows smaller seasonality than the natural discharge**