



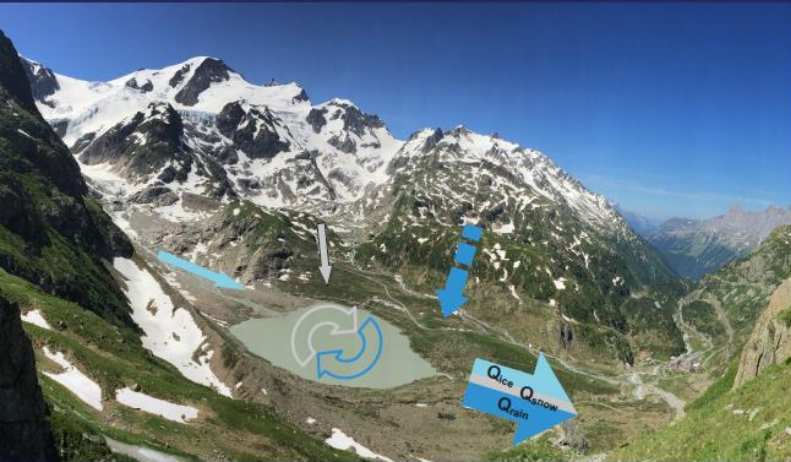
Internationale Kommission für die Hydrologie des Rheingebietes

International Commission for the Hydrology of the Rhine Basin

Impact of climate change on the rain, snow and glacier melt components of streamflow of the river Rhine and its tributaries

Synthesis report

Kerstin Stahl, Markus Weiler, Marit van Tiel, Irene Kohn, Andreas Hänslar, Daphné Freudiger, Jan Seibert, Kai Gerlinger, Greta Moretti



Report No. I-28 of the CHR

# ASG:

## Low and high flows and examples of specific water use thresholds

Markus Weiler



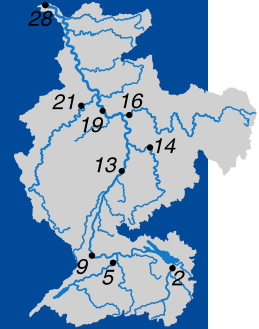
Universität  
Zürich<sup>UZH</sup>

HYDRON  
UMWELT und  
WASSERWIRTSCHAFT

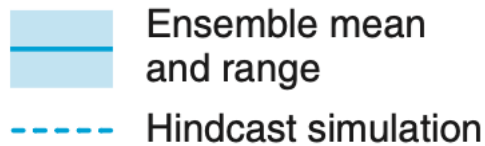


# Annual 7-day-minima, AM7

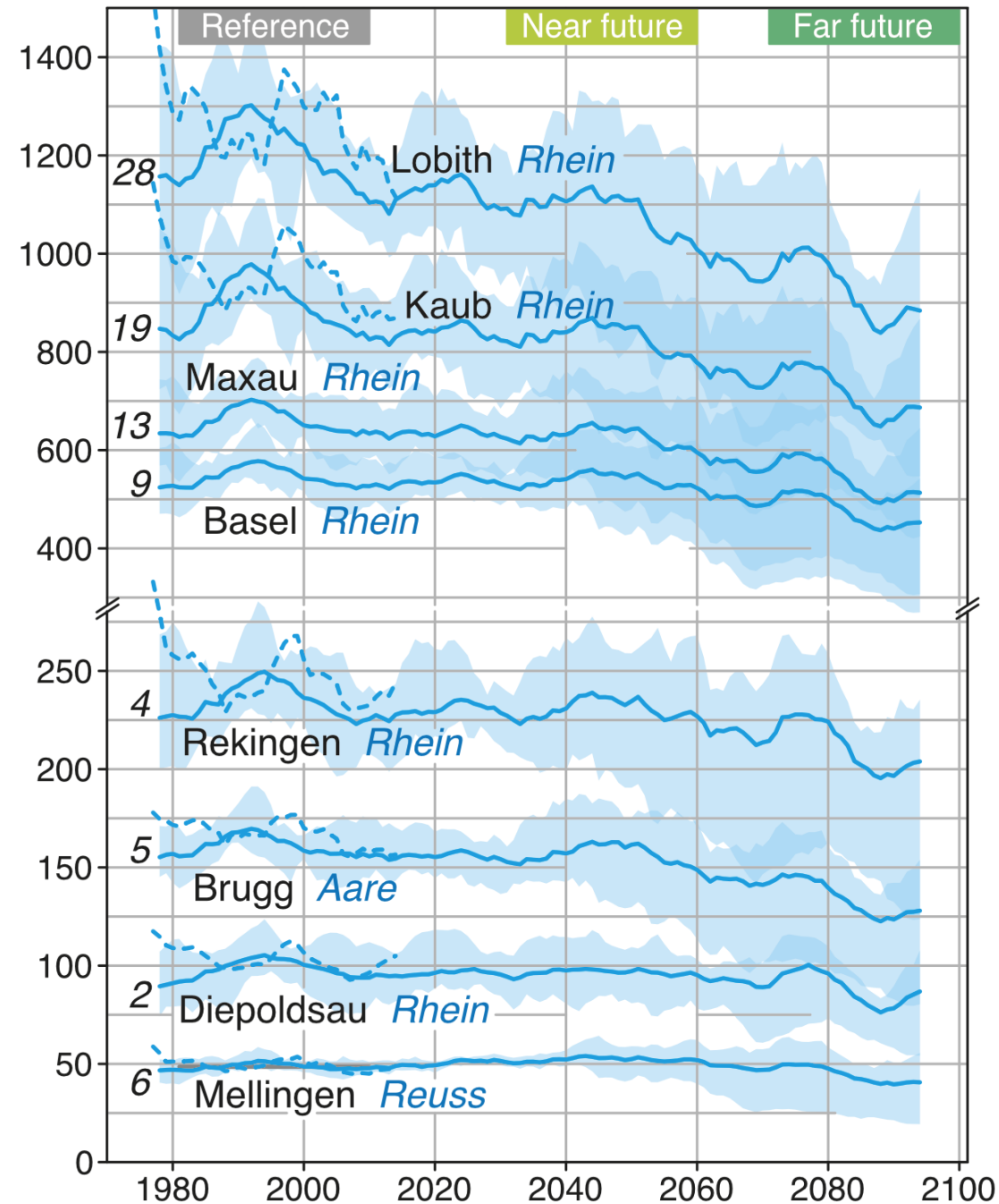
- General decreasing
- Large Uncertainty from climate ensembles



Rhine Basin & Gauges



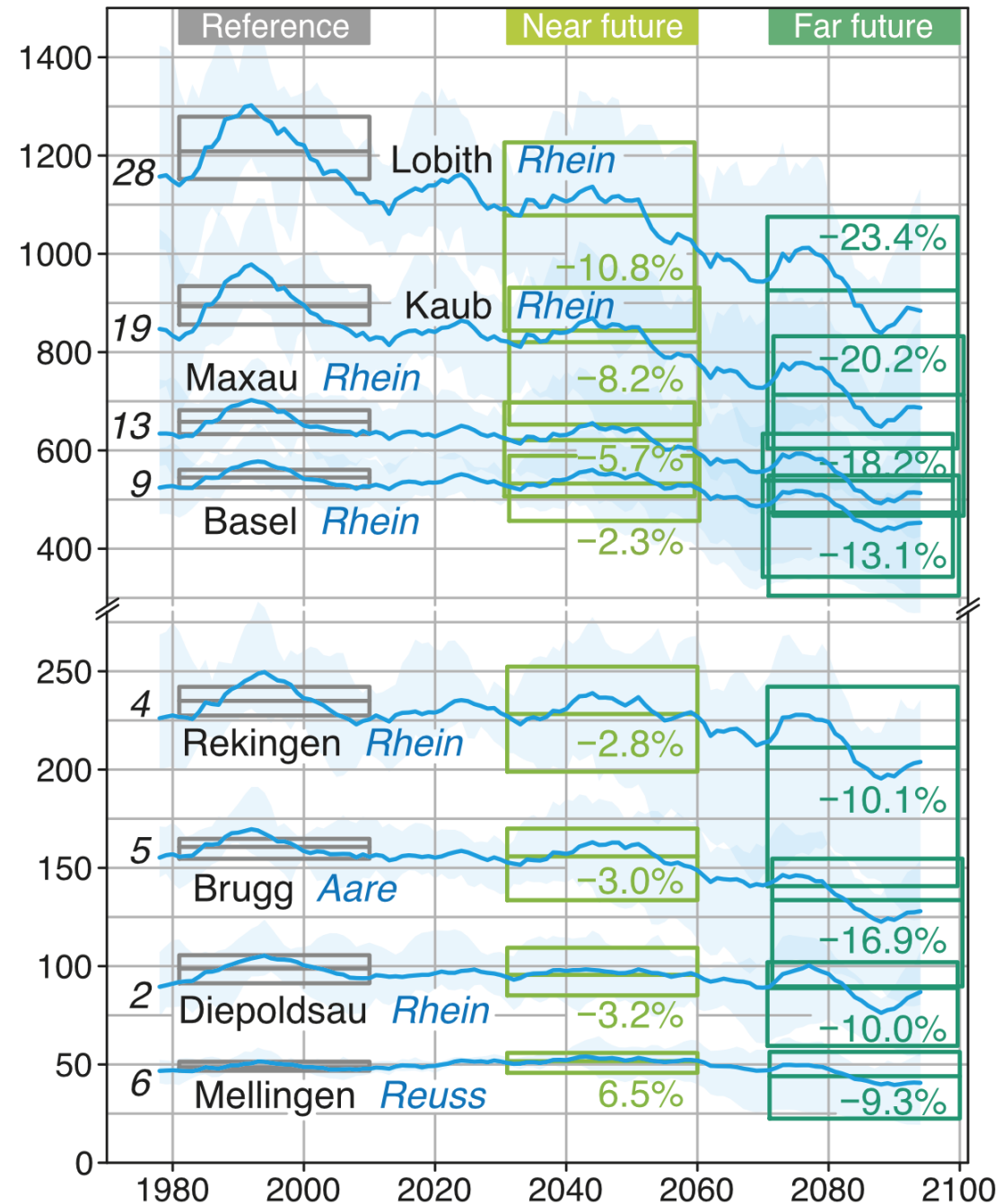
AM7 [m<sup>3</sup>/s]



# Annual 7-day-minima, AM7

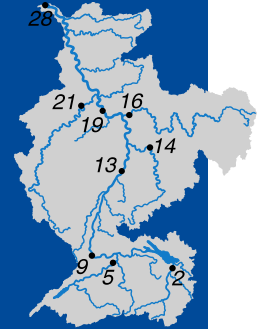
- Near Future: minus 2-10%
- Far Future: minus 10-25%

AM7 [m<sup>3</sup>/s]



Ensemble mean and range  
 Hindcast simulation

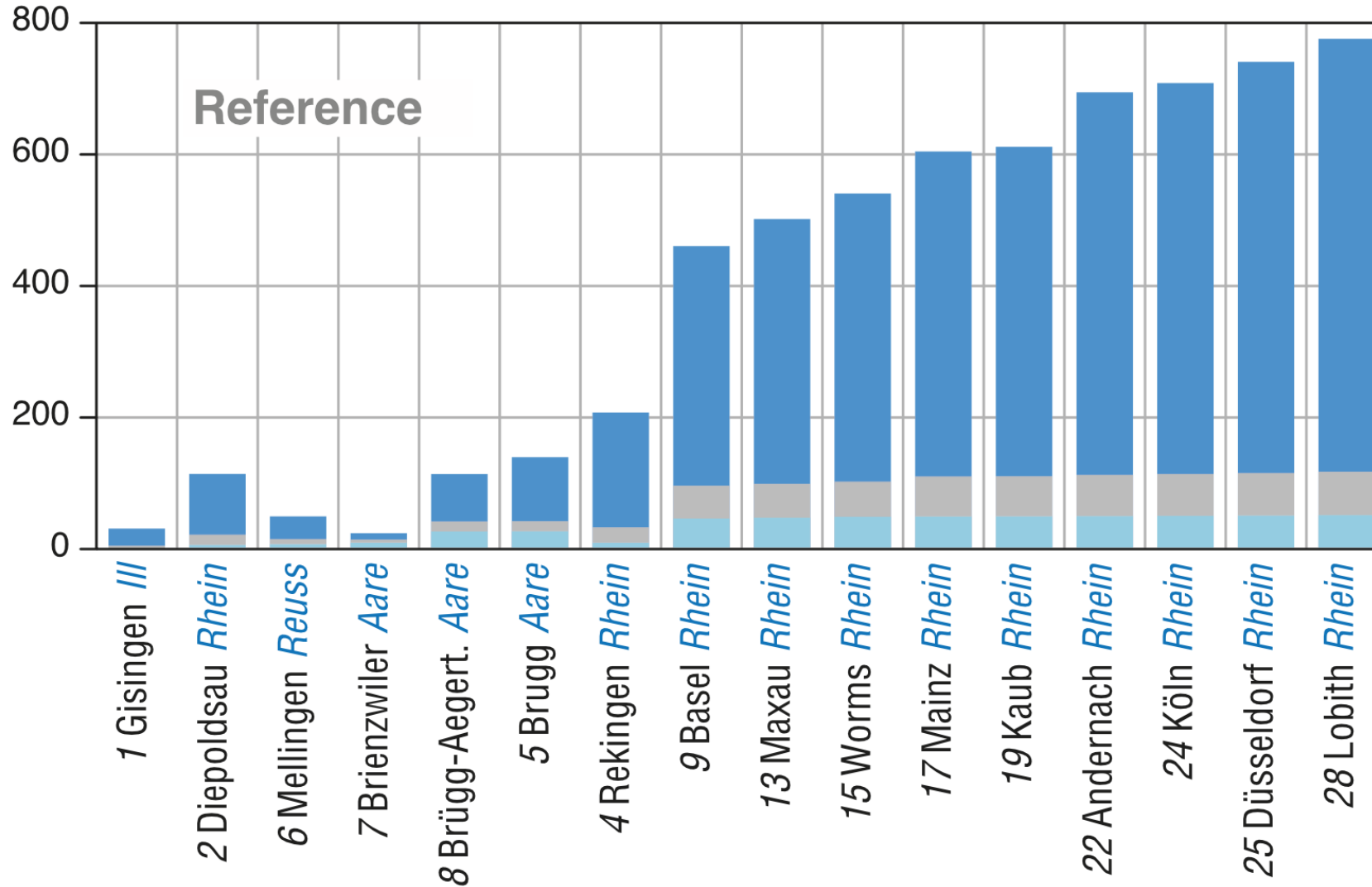
**Average for period**  
 Ensemble  
 Maximum  
 Mean  
 Minimum



Rhine Basin & Gauges

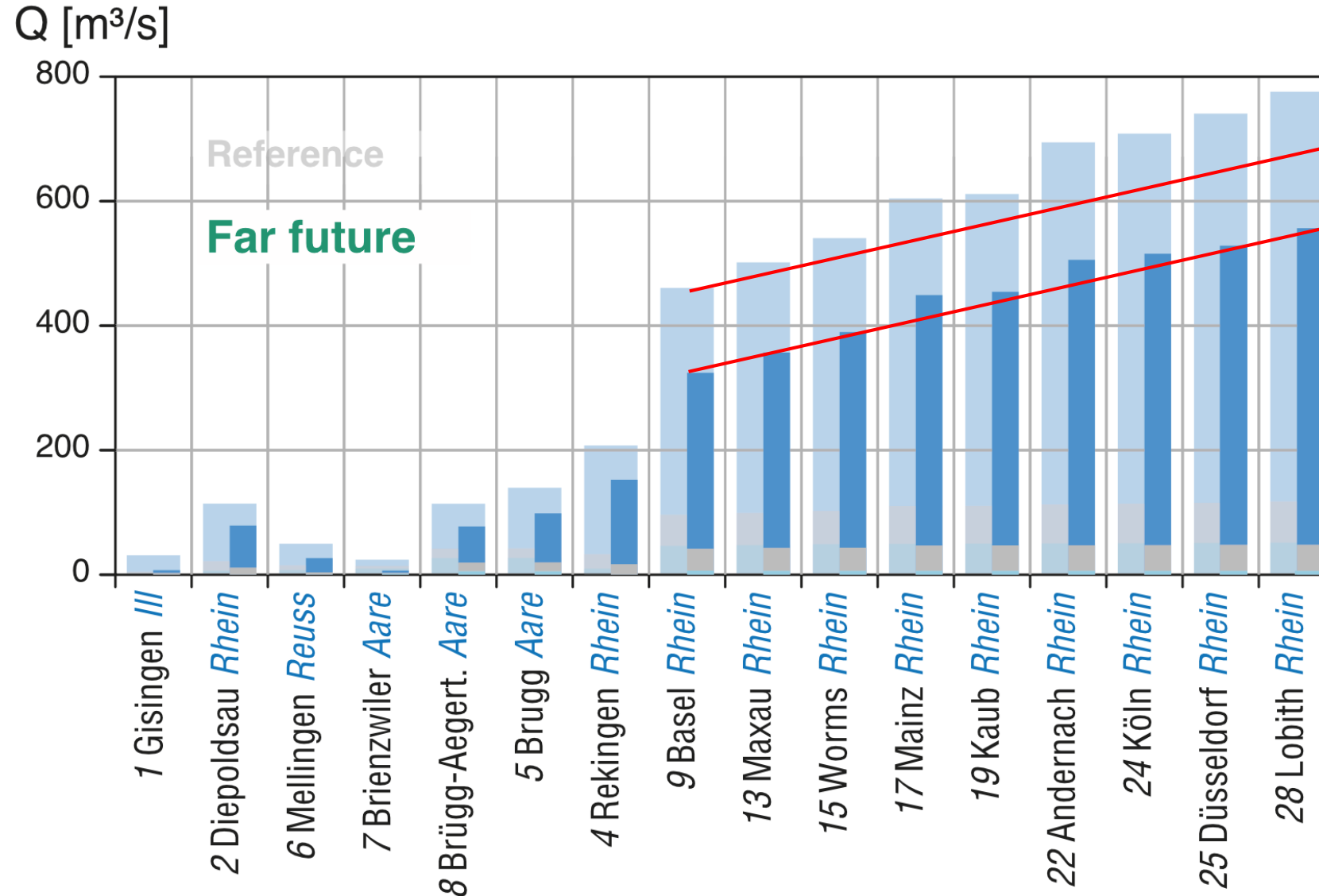


# Annual summer low flow along the Rhine

Q [m<sup>3</sup>/s]

Ensemble mean modeled annual summer low flows (April–Oct) and corresponding streamflow components

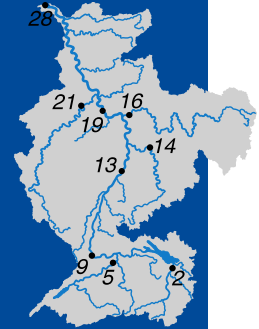
# Annual summer low flow along the Rhine



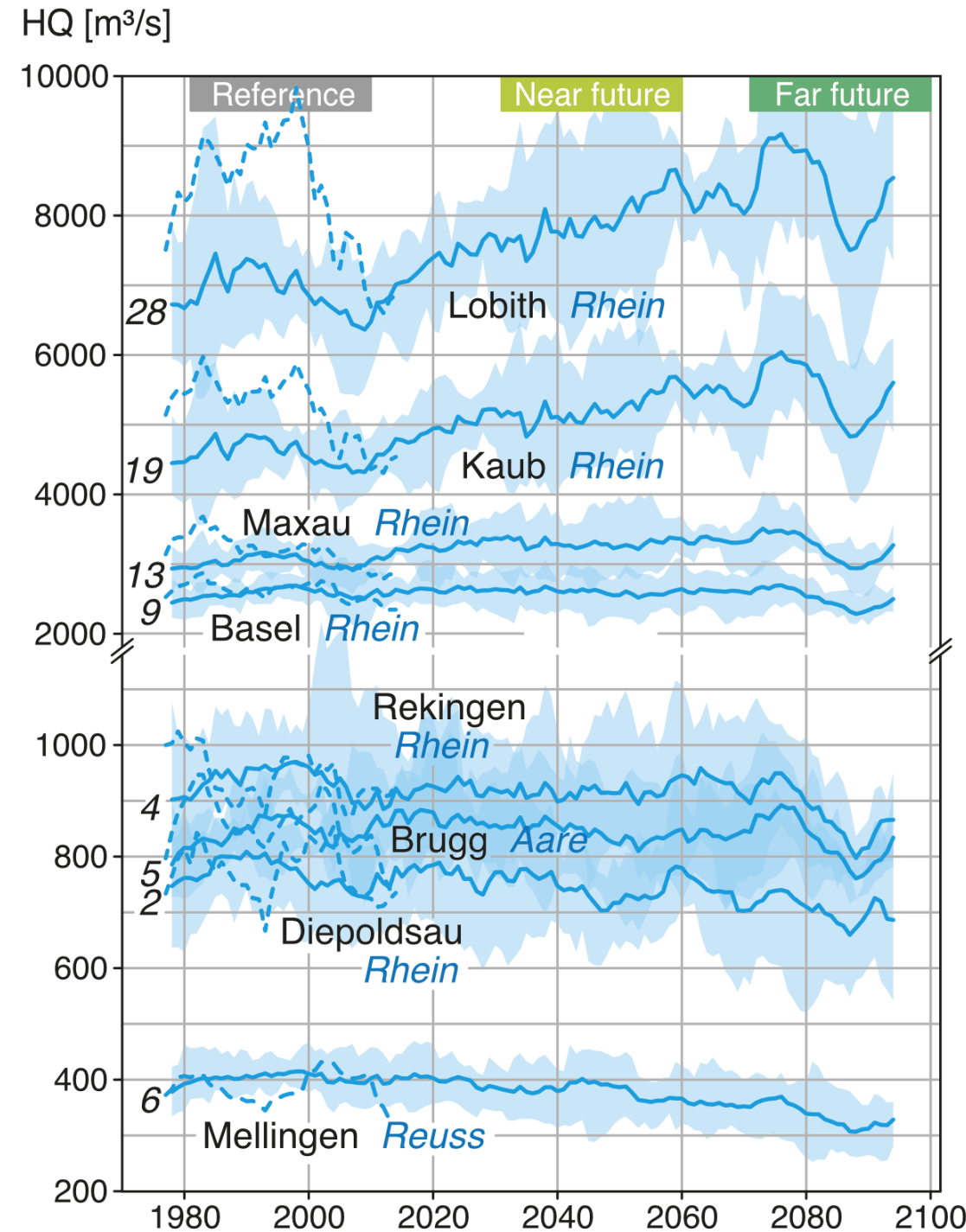
Ensemble mean modeled annual summer low flows (April–Oct) and corresponding streamflow components

# Annual maxima, HQ

- Similar than mean flow
- Increasing downstream Basel
- Decreasing upstream Basel



Rhine Basin & Gauges

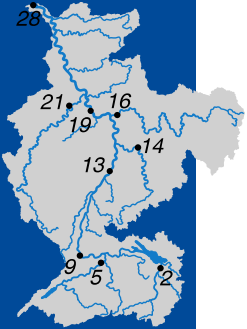




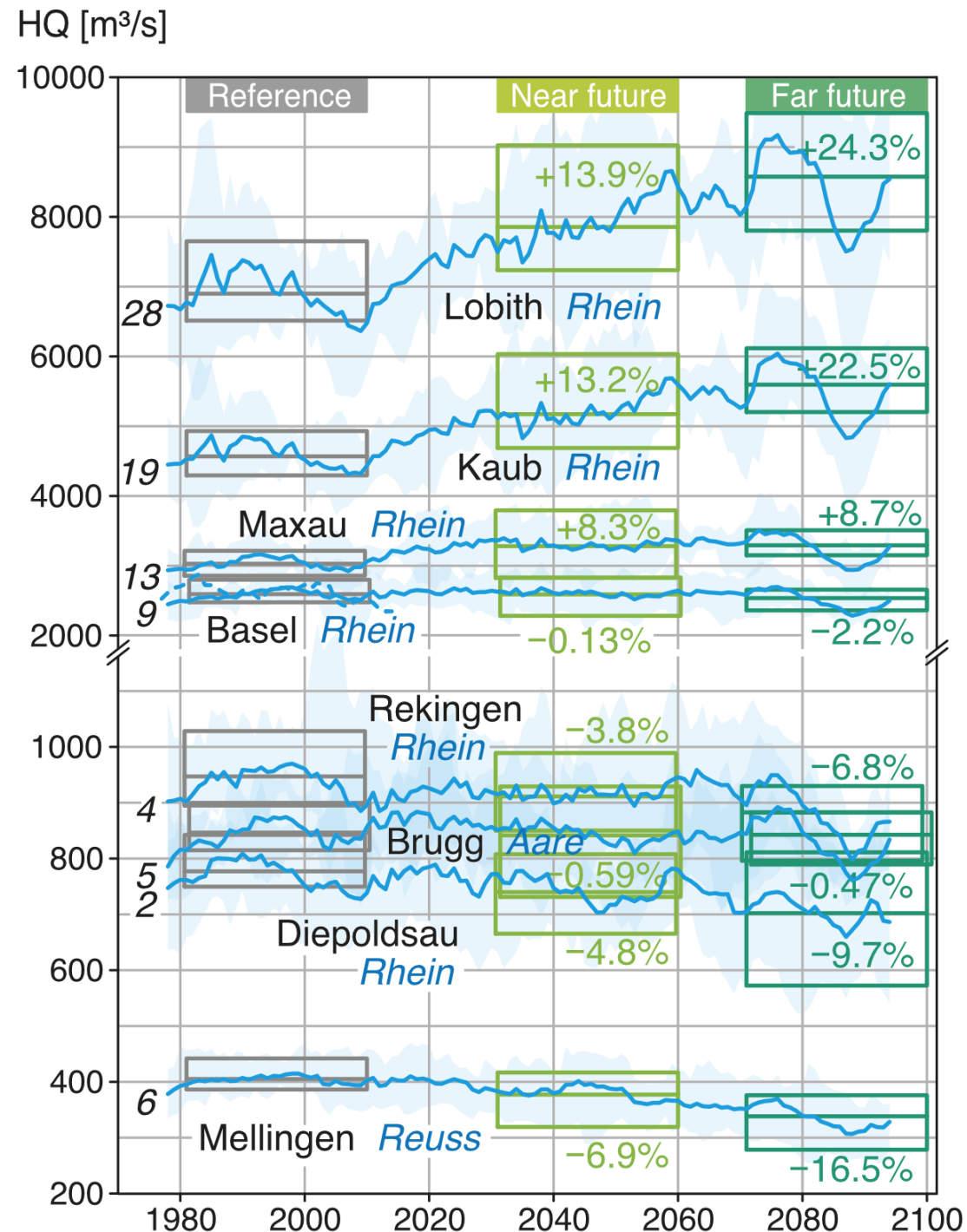
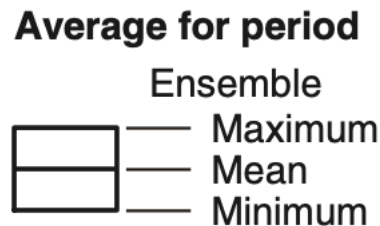
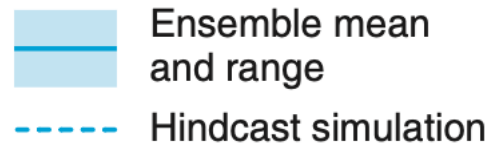
# Annual maxima, HQ

## Downstream Basel

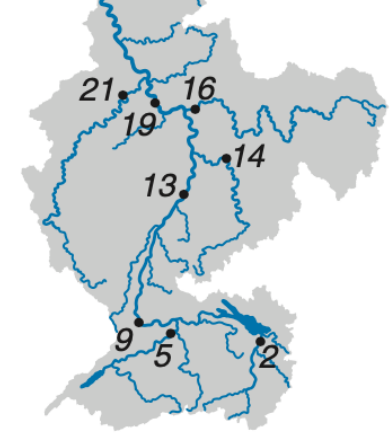
- Near Future: plus 8-14%
- Far Future: plus 8-24%
  
- Improving upstream Basel
- Increasing problematic from Basel to river mouth



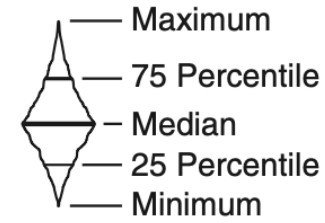
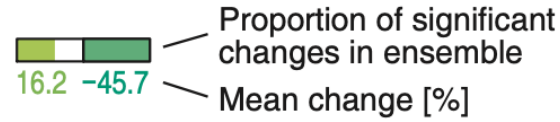
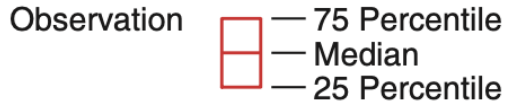
Rhine Basin & Gauges



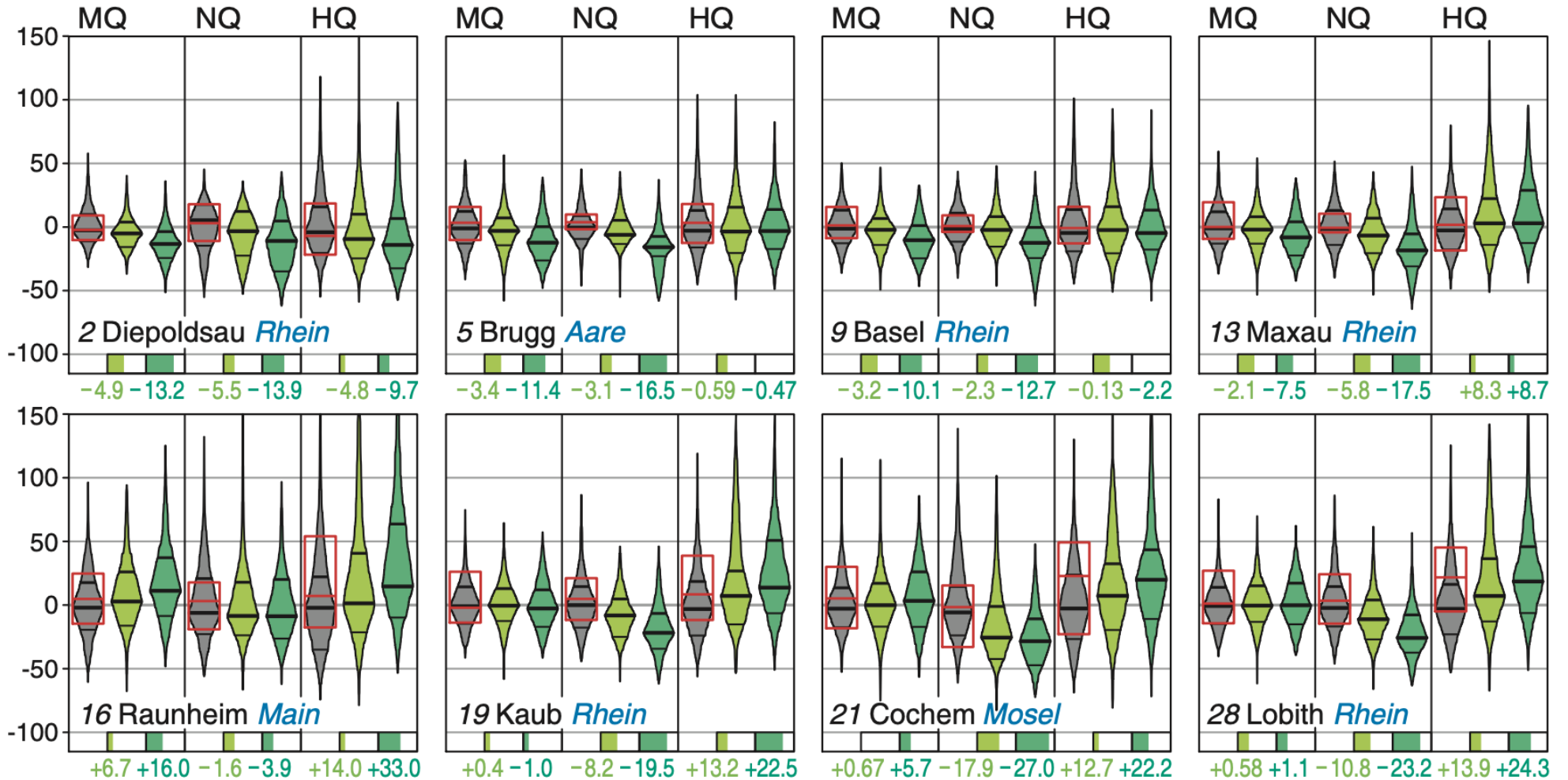
# Changes and Variability



**Observation** - Reference - **Near Future** - **Far Future**

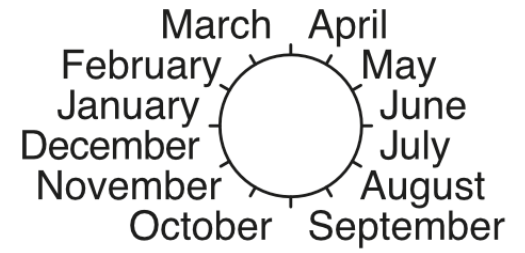


Q [%]

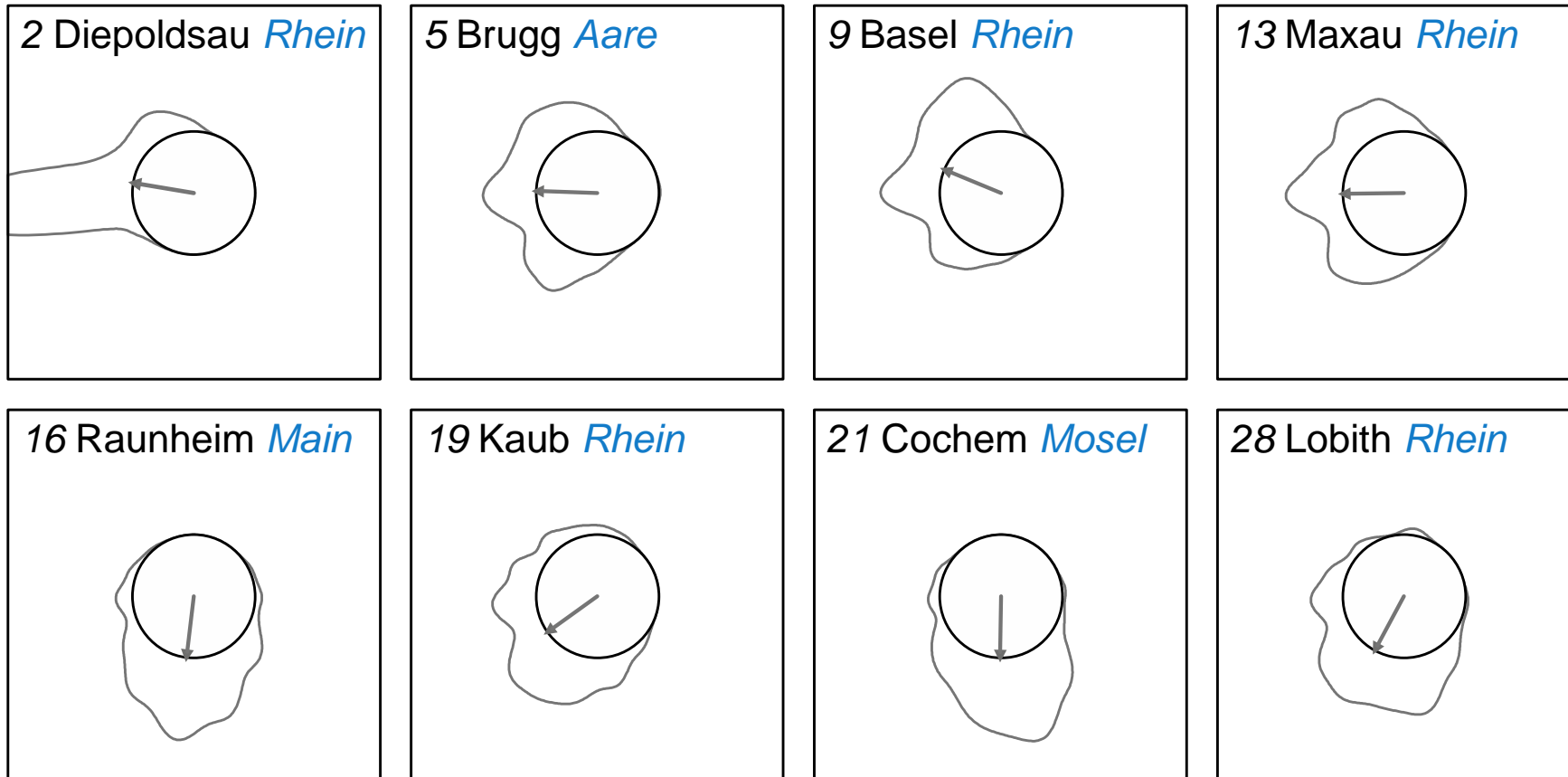




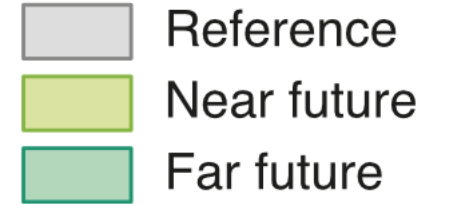
# Seasonality: Low flows (NQ)



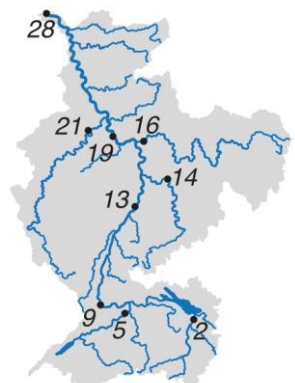
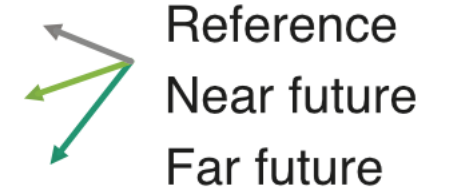
NQ



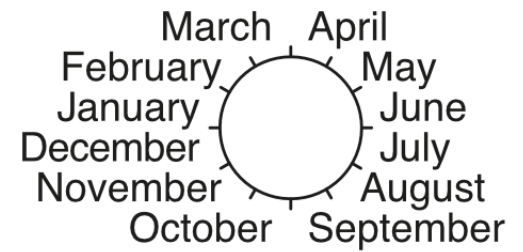
Probability density



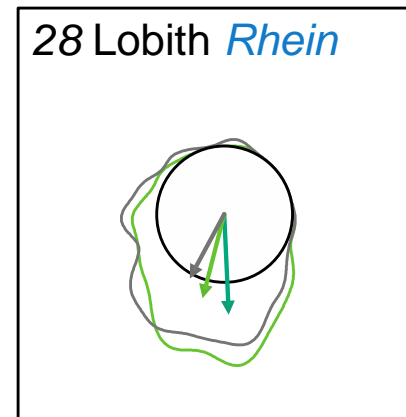
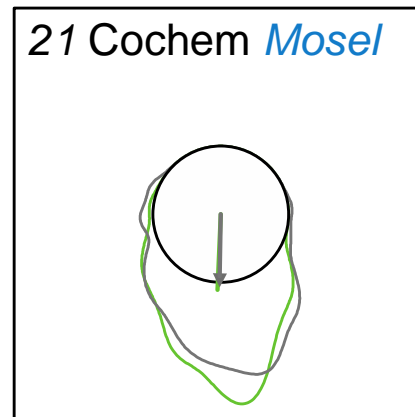
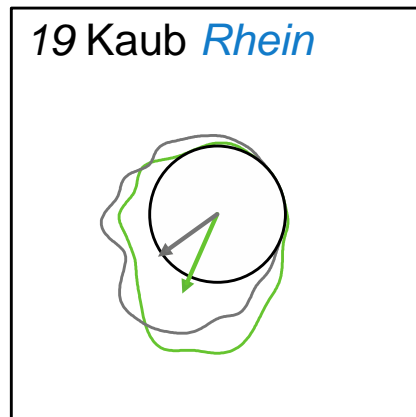
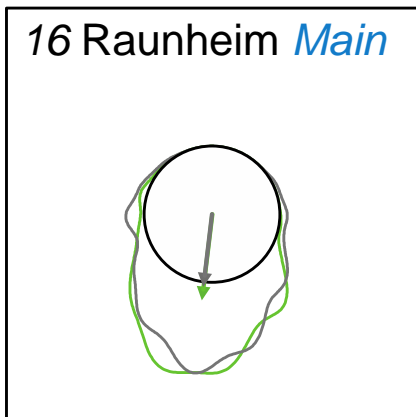
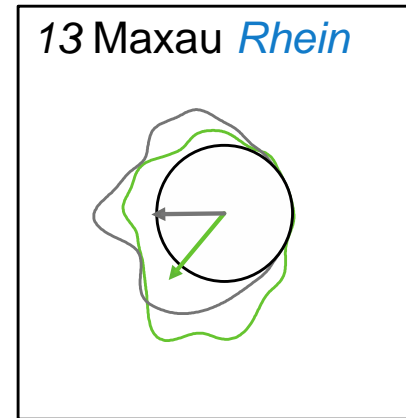
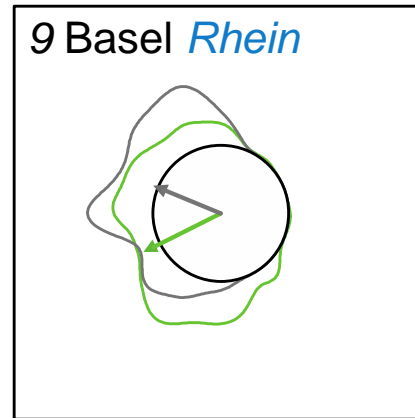
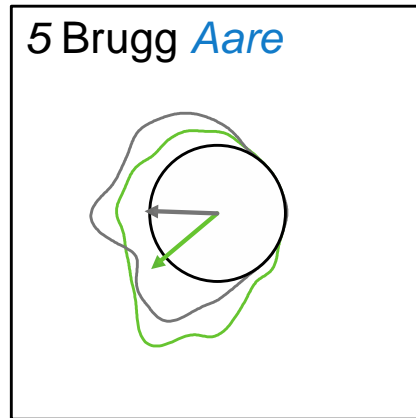
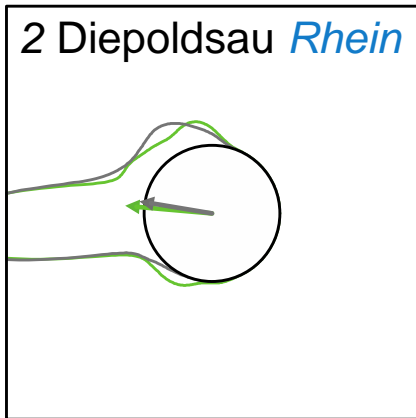
Average occurrence



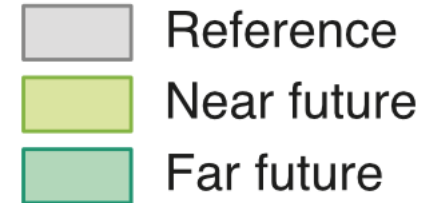
# Seasonality: Low flows (NQ)



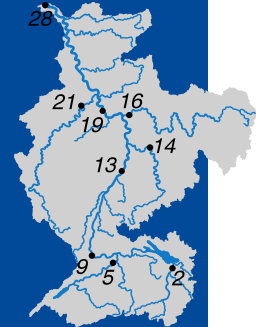
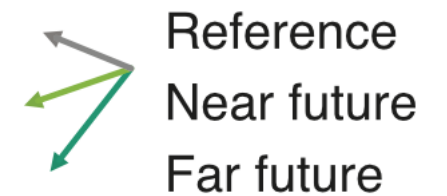
NQ



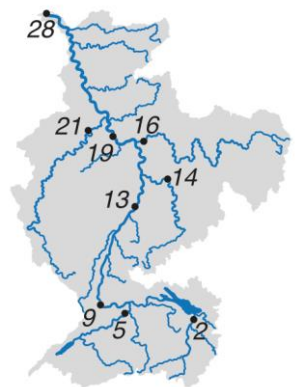
Probability density



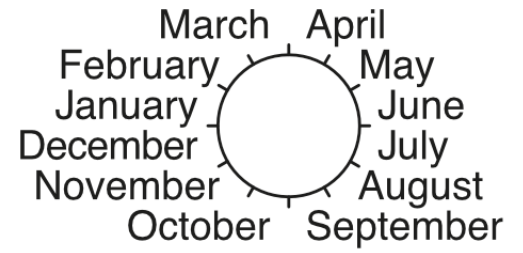
Average occurrence



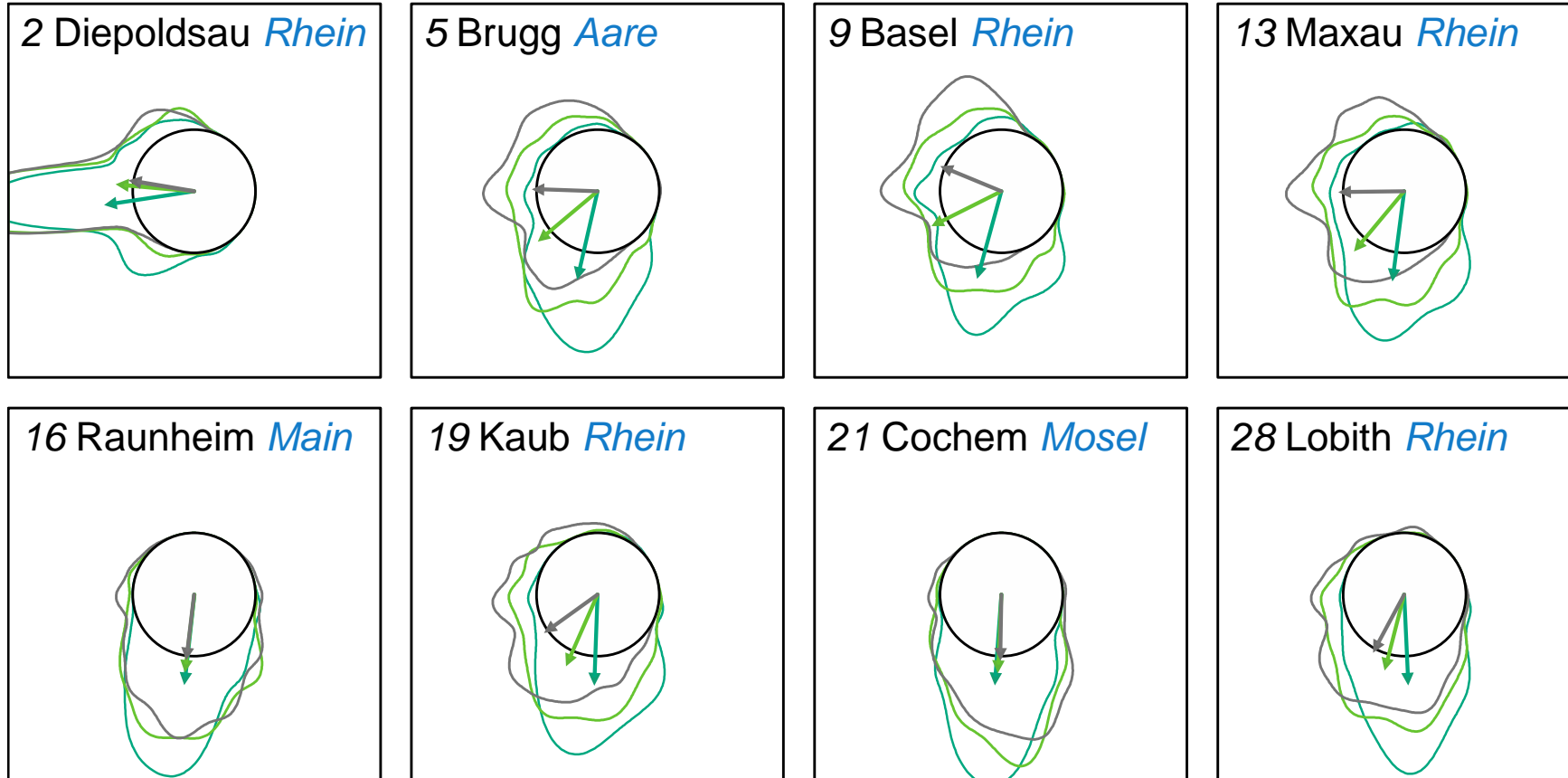
Rhine Basin & Gauges



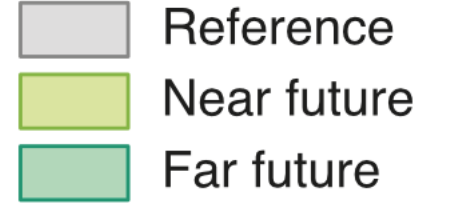
# Seasonality: Low flows (NQ)



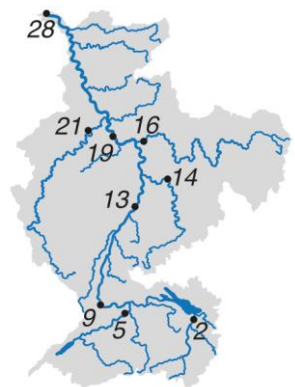
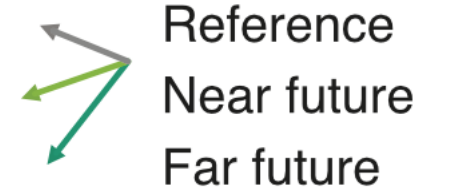
NQ



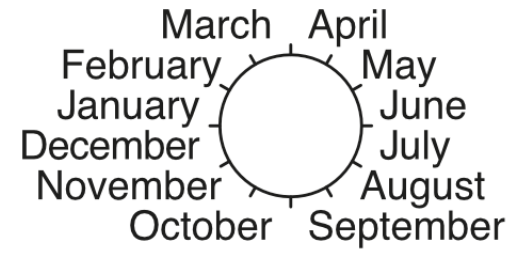
Probability density



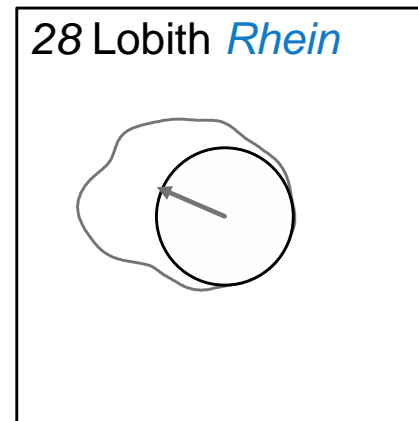
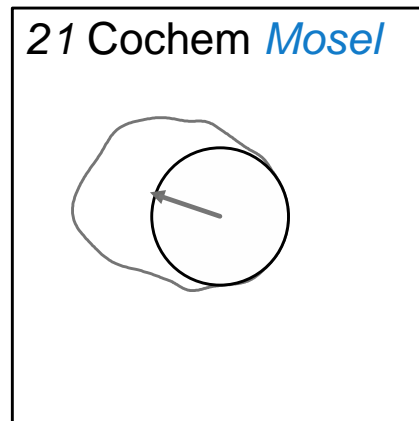
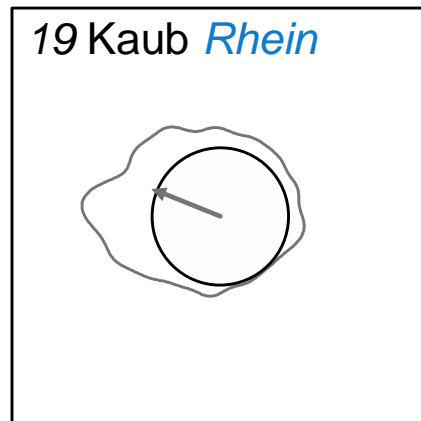
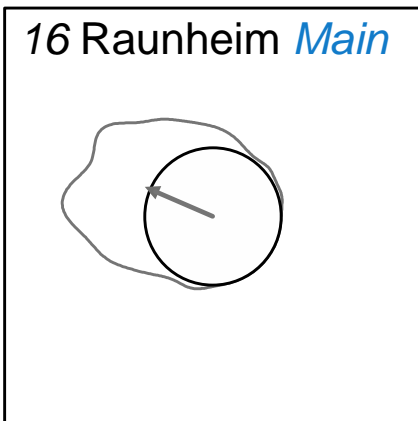
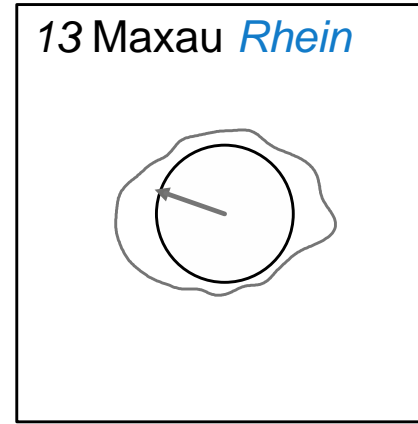
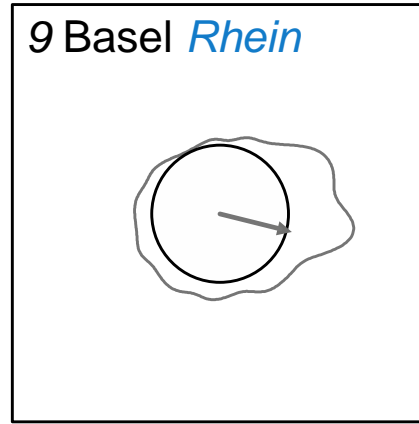
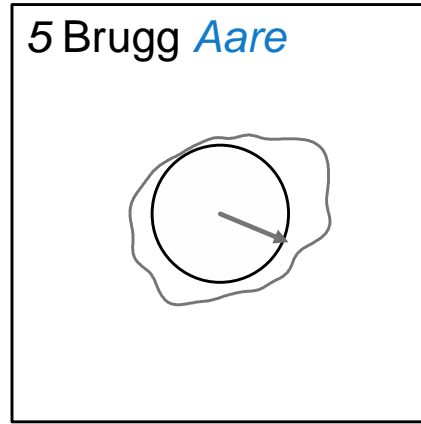
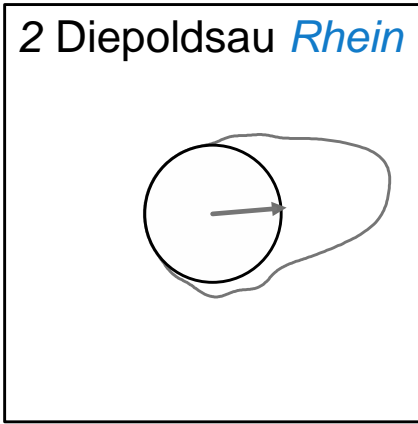
Average occurrence



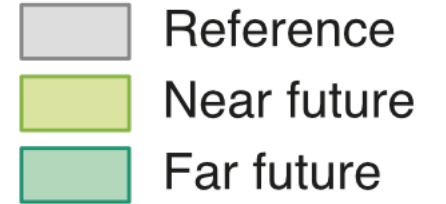
# Seasonality: High flows (HQ)



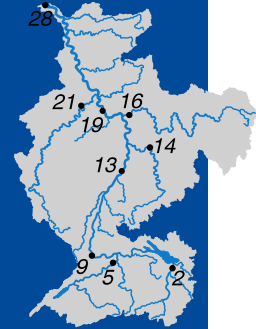
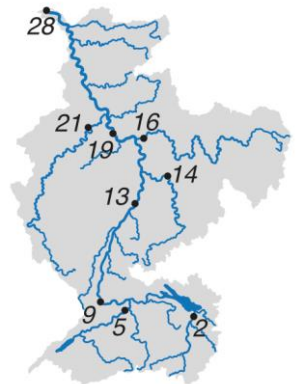
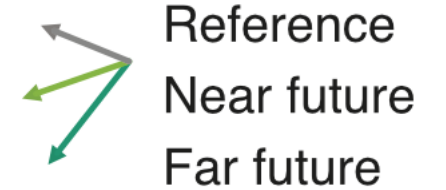
HQ



Probability density



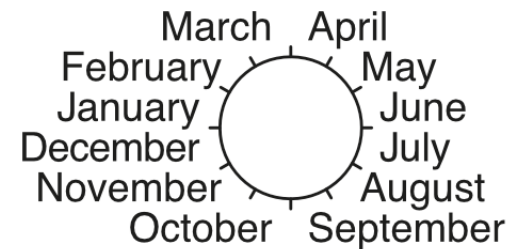
Average occurrence



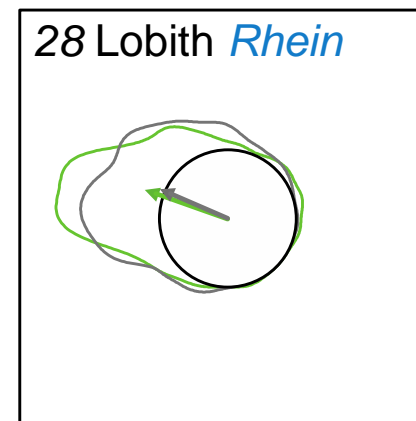
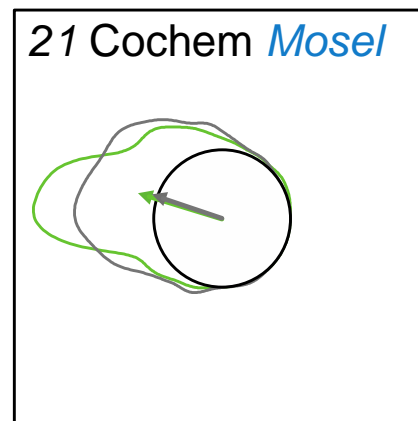
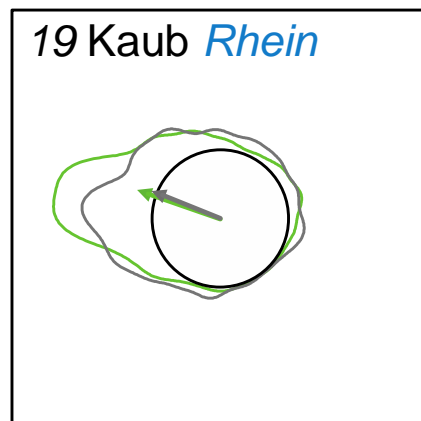
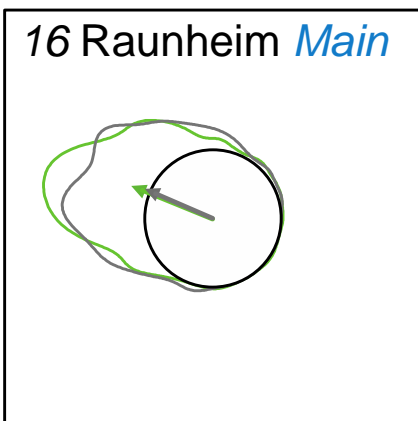
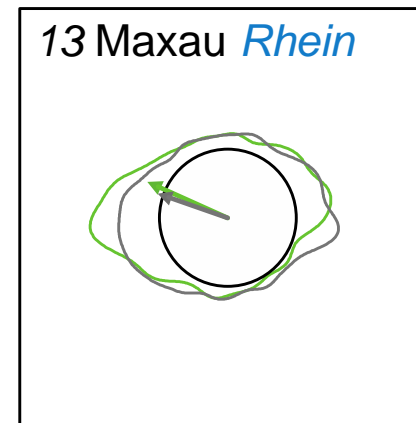
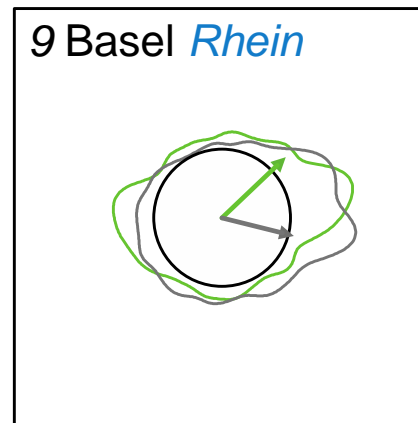
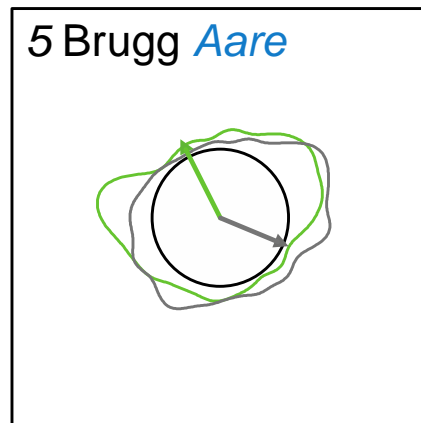
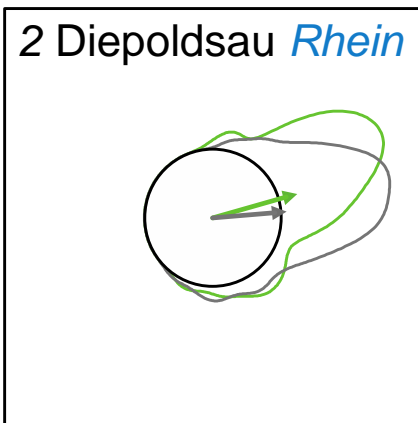
Rhine Basin & Gauges



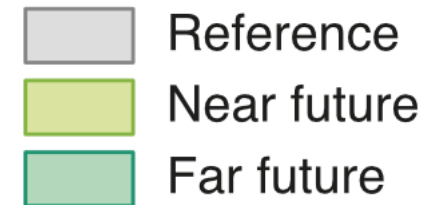
# Seasonality: High flows (HQ)



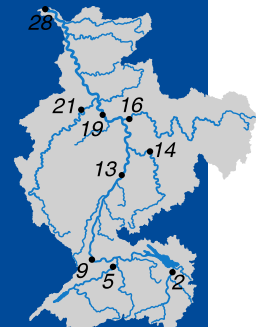
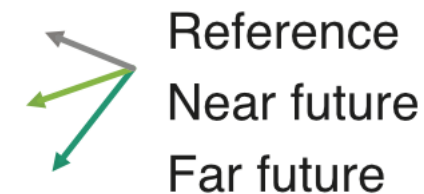
HQ



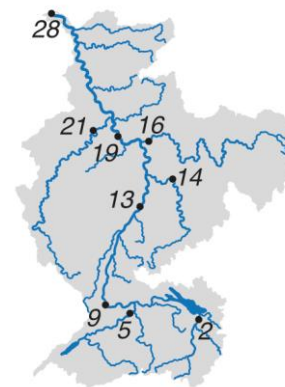
Probability density



Average occurrence

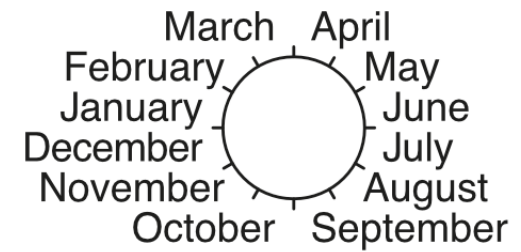


Rhine Basin & Gauges

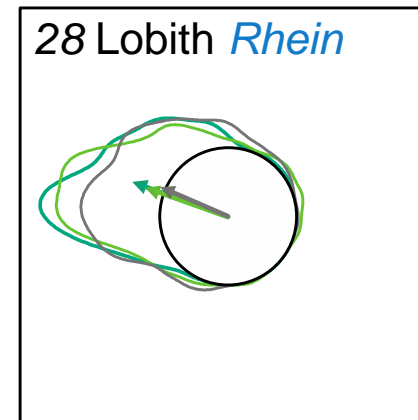
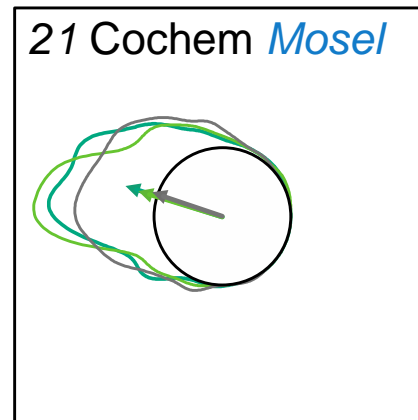
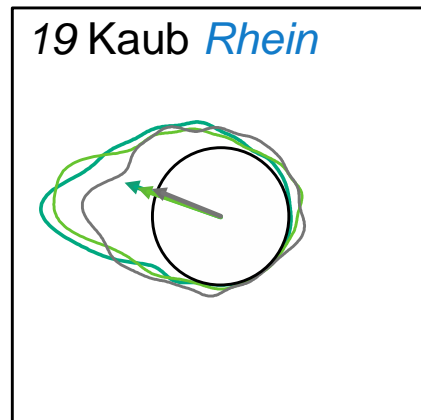
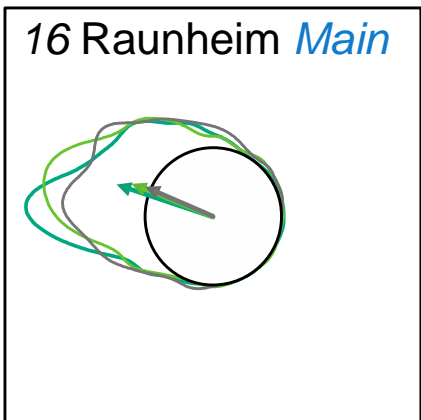
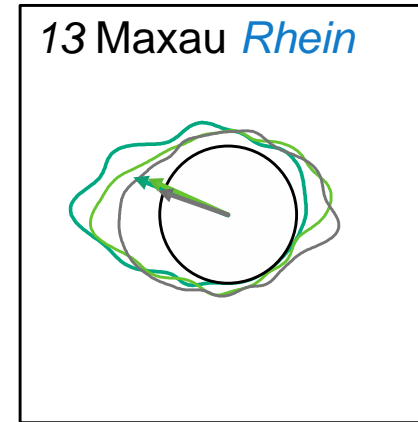
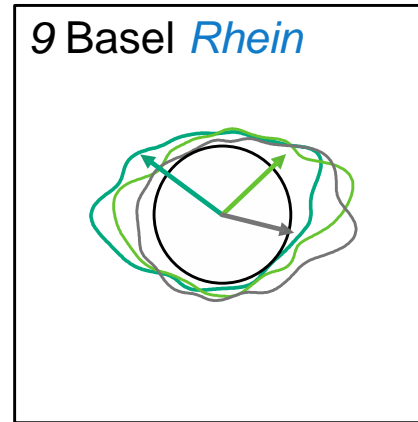
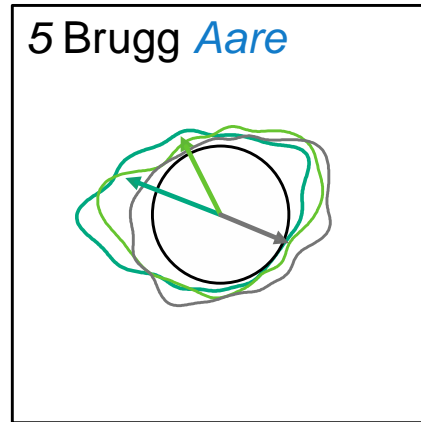
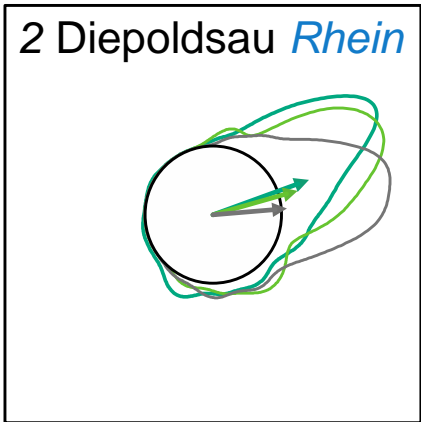




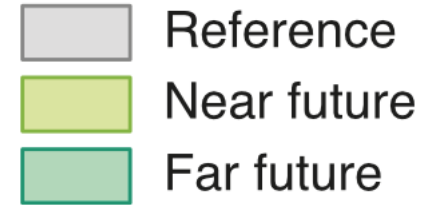
# Seasonality: High flows (HQ)



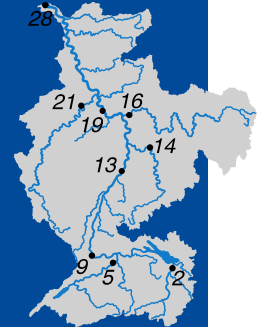
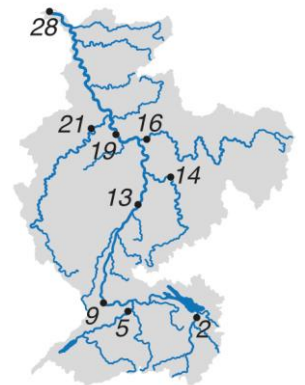
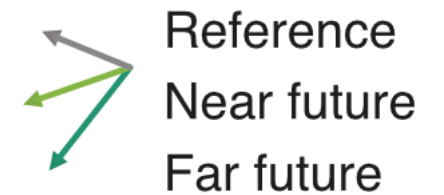
HQ



Probability density



Average occurrence



Rhine Basin & Gauges



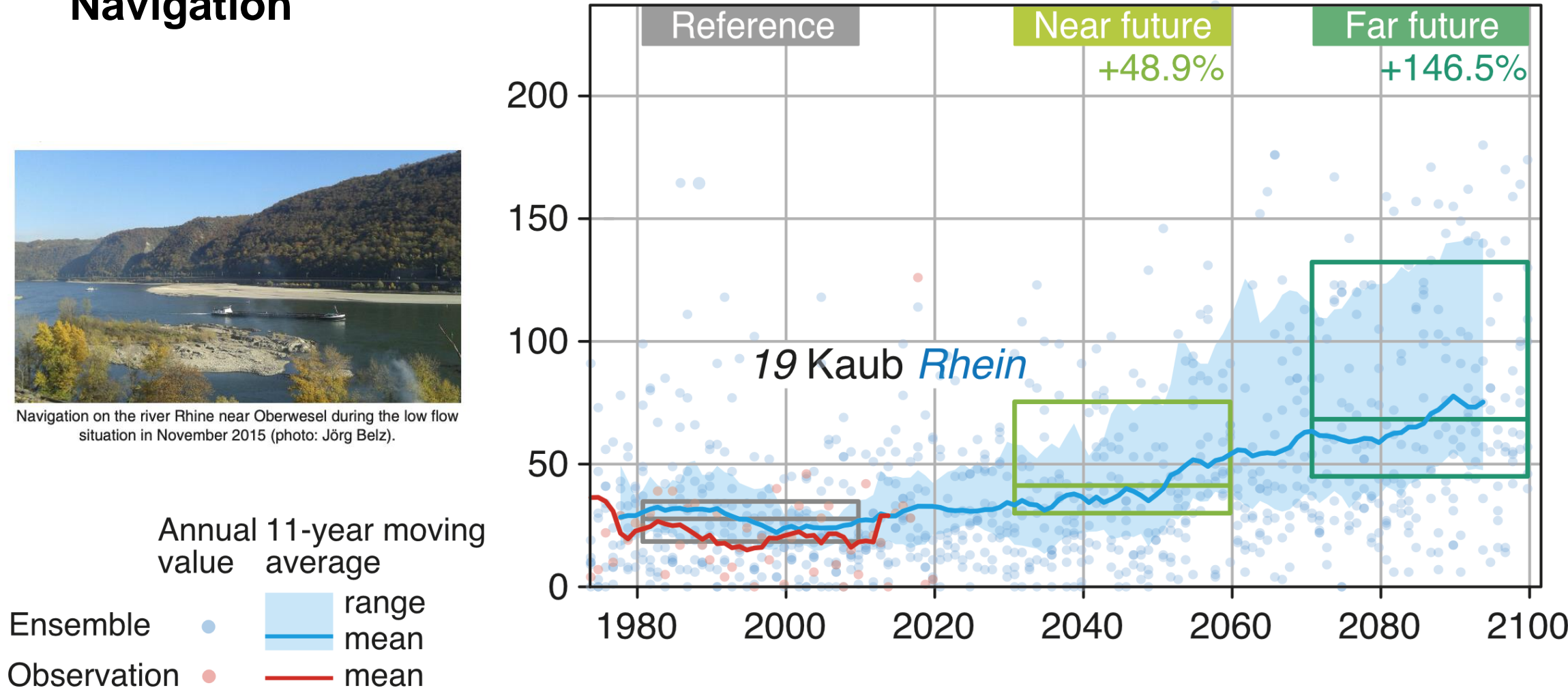
# Implications for operational Q-thresholds

## Navigation



Navigation on the river Rhine near Oberwesel during the low flow situation in November 2015 (photo: Jörg Belz).

## Duration of impaired navigation periods [days per year]



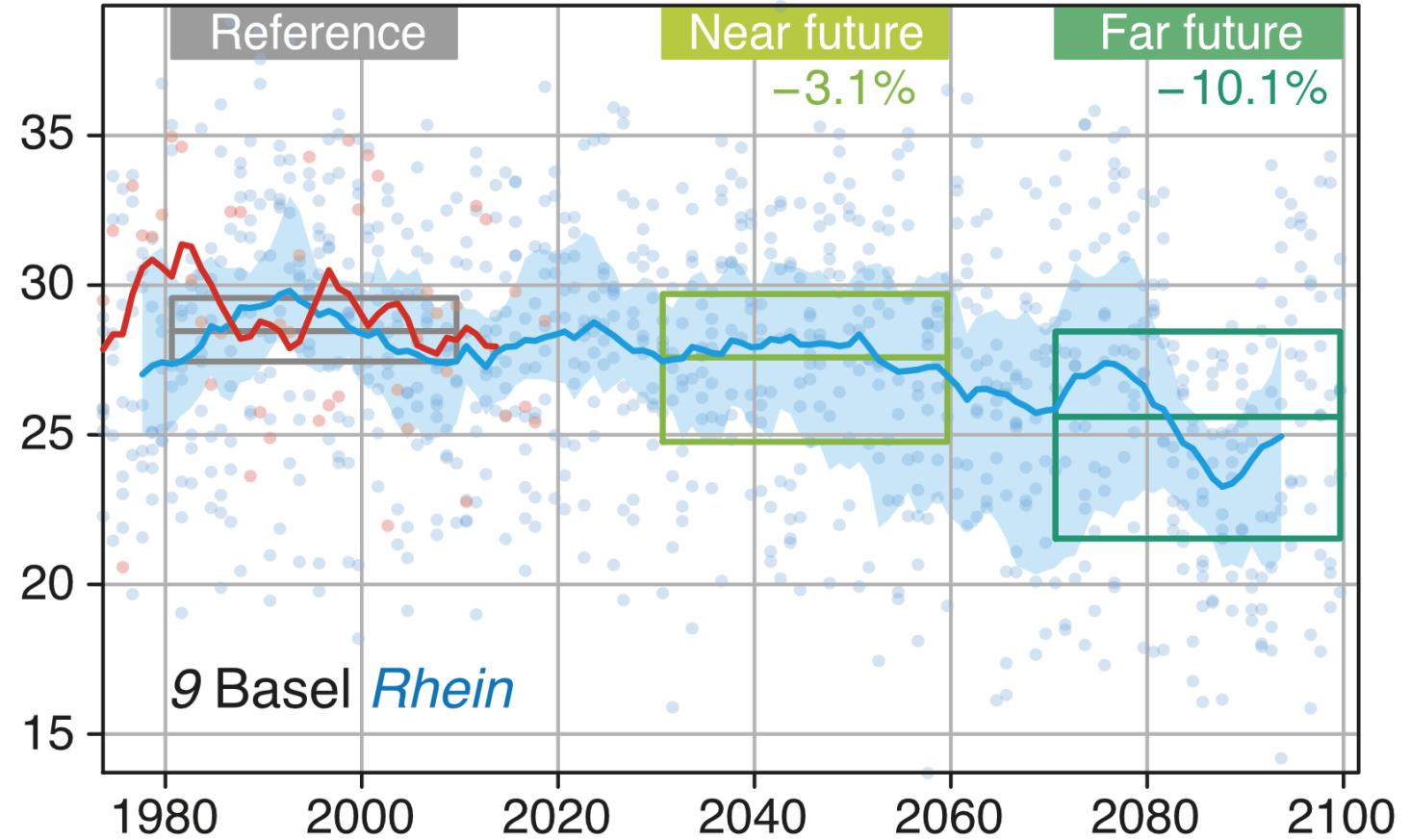
# Implications for operational Q-thresholds

## Hydropower



Weir Märkt at the hydro power plant Kembs (photo: Thomas Berwing; ©: <https://creativecommons.org/licenses/by-sa/4.0/>).

Water available for hydropower production [km<sup>3</sup> per year]



Annual 11-year moving value average

- Ensemble ●  range
- mean
- Observation ● — mean

# Implications for operational Q-thresholds

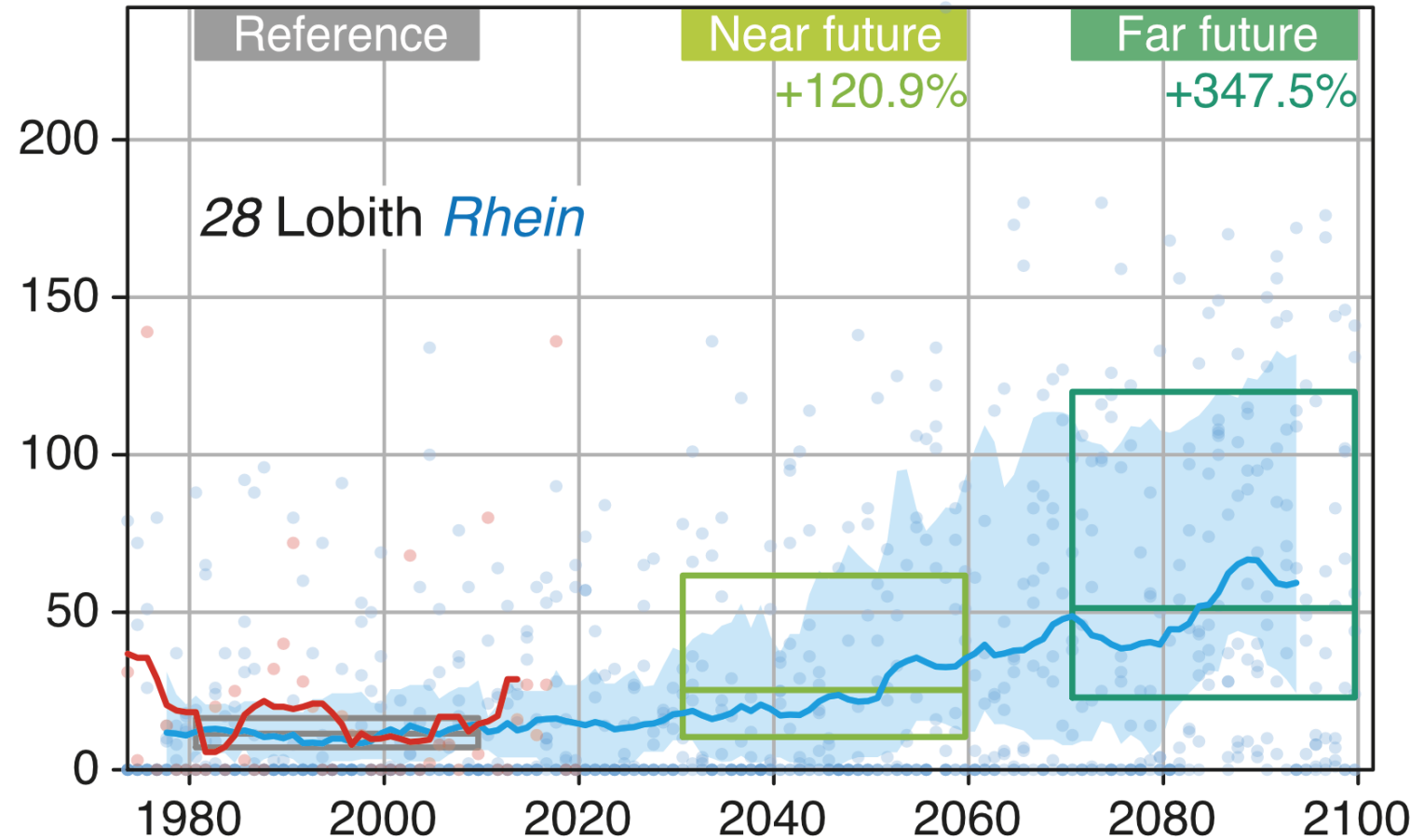
Annual 11-year moving value average

Ensemble ●  range  
 mean  
 Observation ●  mean

## Drought Alert



Duration below Dutch alert level [days per year]





# Implications for Q-thresholds

## River Ecology

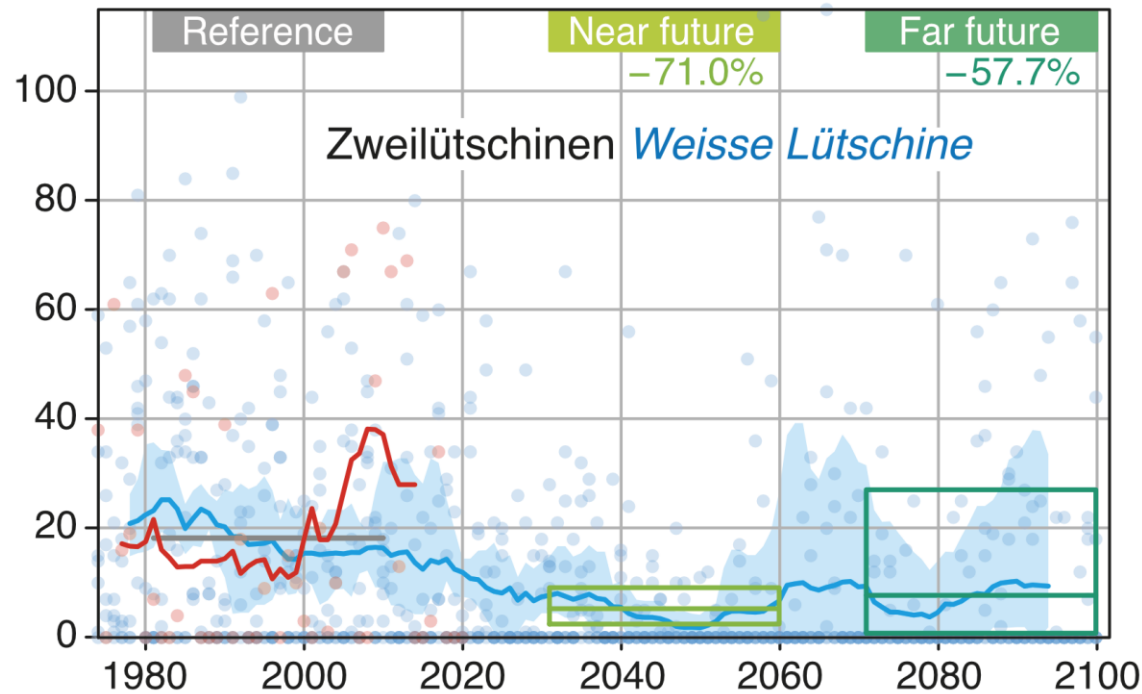


Lake run brown trout (Seeforelle) in the stream Urbachwasser (photo: Matthias Meyer, 2014).

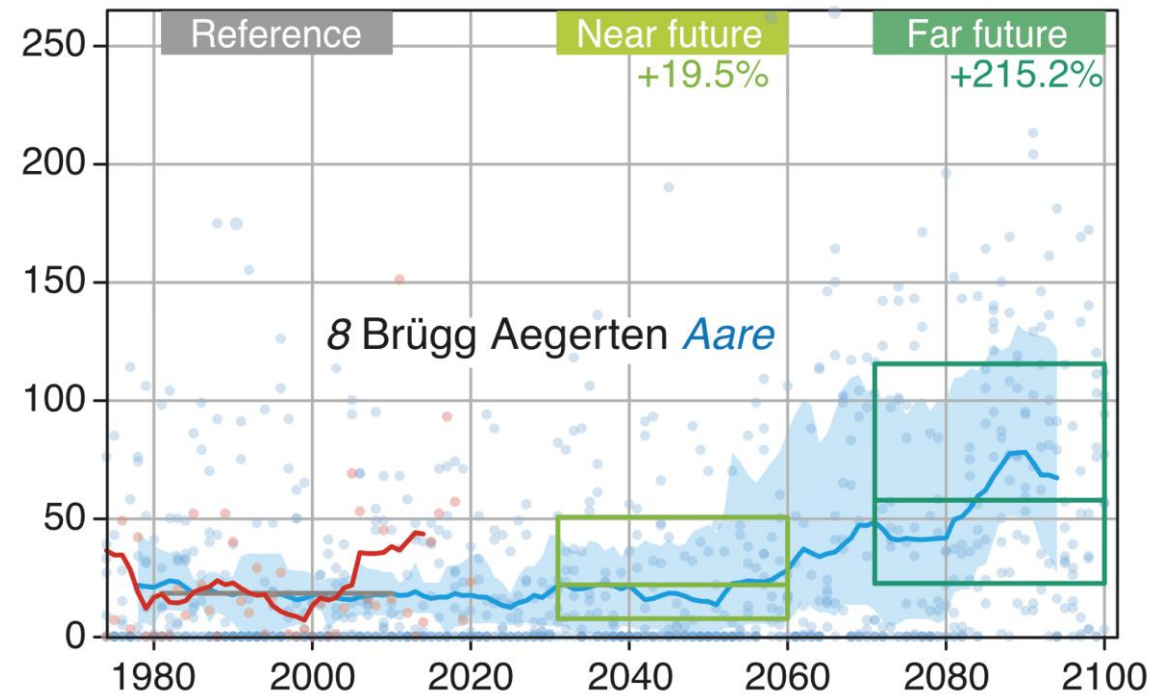
Annual 11-year moving value average

- Ensemble ●  range
- mean
- Observation ●  mean

Flow below Q347 [days/year]



Flow below Q347 [days/year]

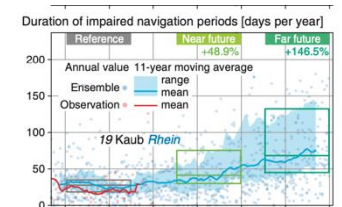
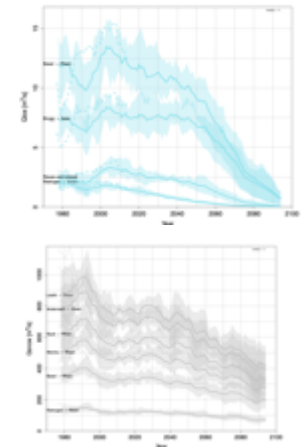




# Conclusion

Impacts and changes are divided into Rhine upstream and downstream of Basel for:

- Low flows
  - Low flow seasonality
  - Seasonality of Floods
- 
- Annual energy production declines
  - Summer use restrictions will strongly exacerbate



# Evapotranspiration

