# What is the problem of low flow in the Rhine catchment?

# Setting the scene

**Gregor Laaha**
**Universität für Bodenkultur Wien**

**CHR-Symposium „Low flows in the Rhine catchment“,**
**Basel, Switzerland, 20-21 September 2017**

# Low Flows and Streamflow Droughts
# – a hazard across Europe!


**Environmental Impacts**
- Water quality → ecological status of Europ. water bodies

**Socio-economic Impacts**
- Navigation, power production
- Water supply, incl. for irrigation

➢ Concerns of increasing drought risk in Europe due to climate change

Picture Sources: Environment Agencies of Rheinland-Pfalz and Bayern, …

## From river to basin:

# Low flows - one signature of drought

Examples of impacts of the 2003 summer drought in Europe
Figure by A.J. Teuling, Wageningen, from Van Loon (2015, WIREs)

# Low flow and drought hydrology - Questions

1. How are low flows generated?
2. How to quantify low flow events?
3. How to model and predict?
4. How to manage drought events?
5. How dry will it be in a future climate?

# Generation of low flows

Cause: lack of precipitation

→ that propagates through the water cycle

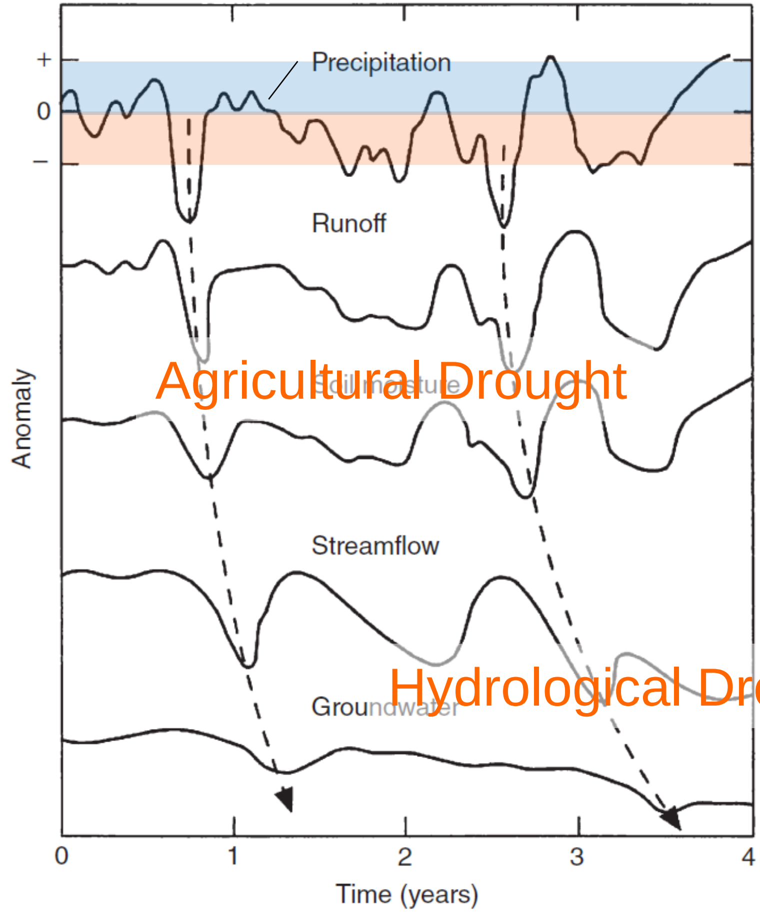


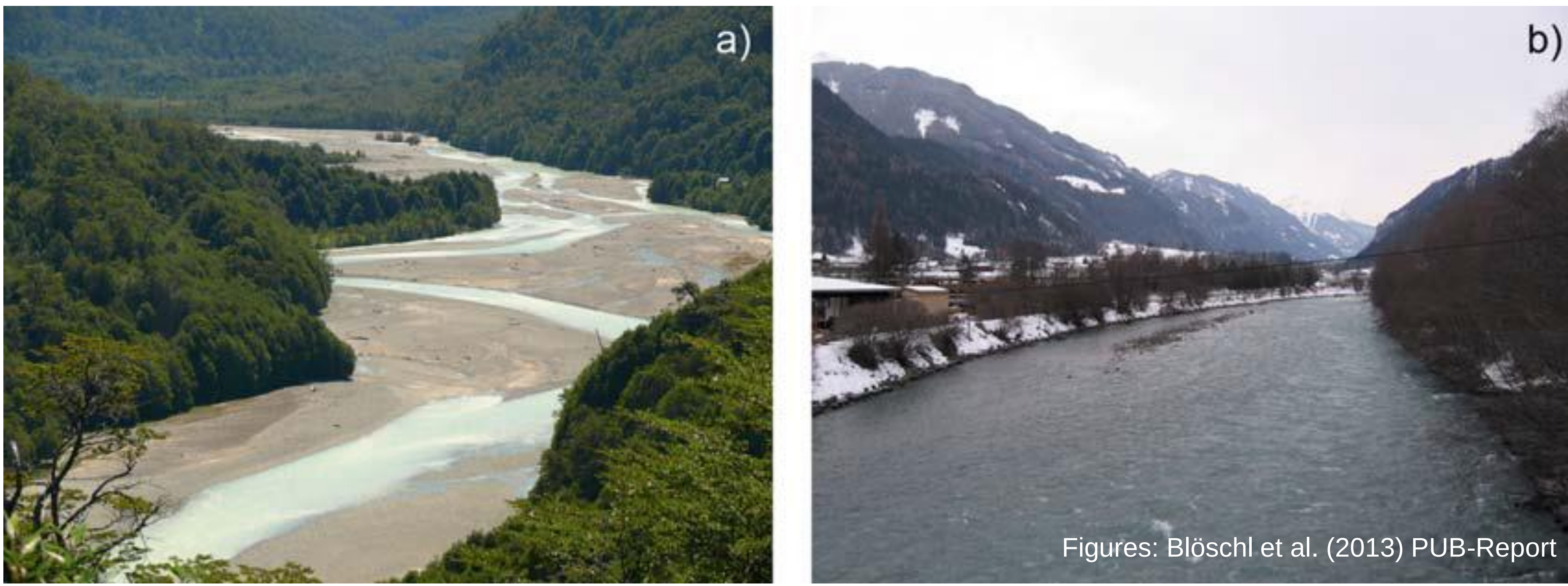

Figure after: Changnon (1987)

# Summer and winter low flows

Both are caused by water deficit, but triggered by different processes

a) summer: precipitation deficit

b) winter: freezing

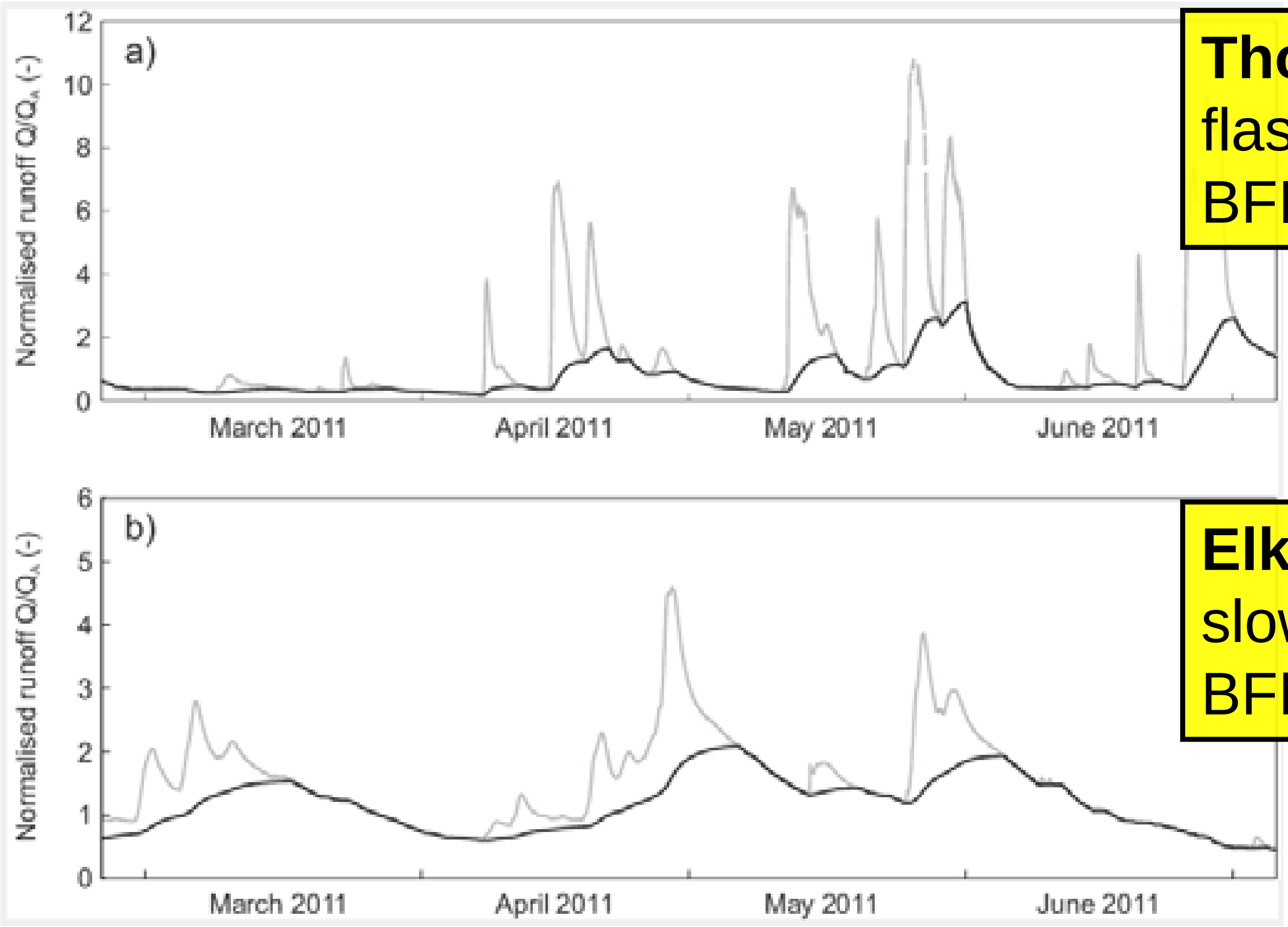


Figures: Blöschl et al. (2013) PUB-Report

→ seasonality of events determines processes and impacts

# Catchment processes

Store and release water
→ dampening, redistribution in time



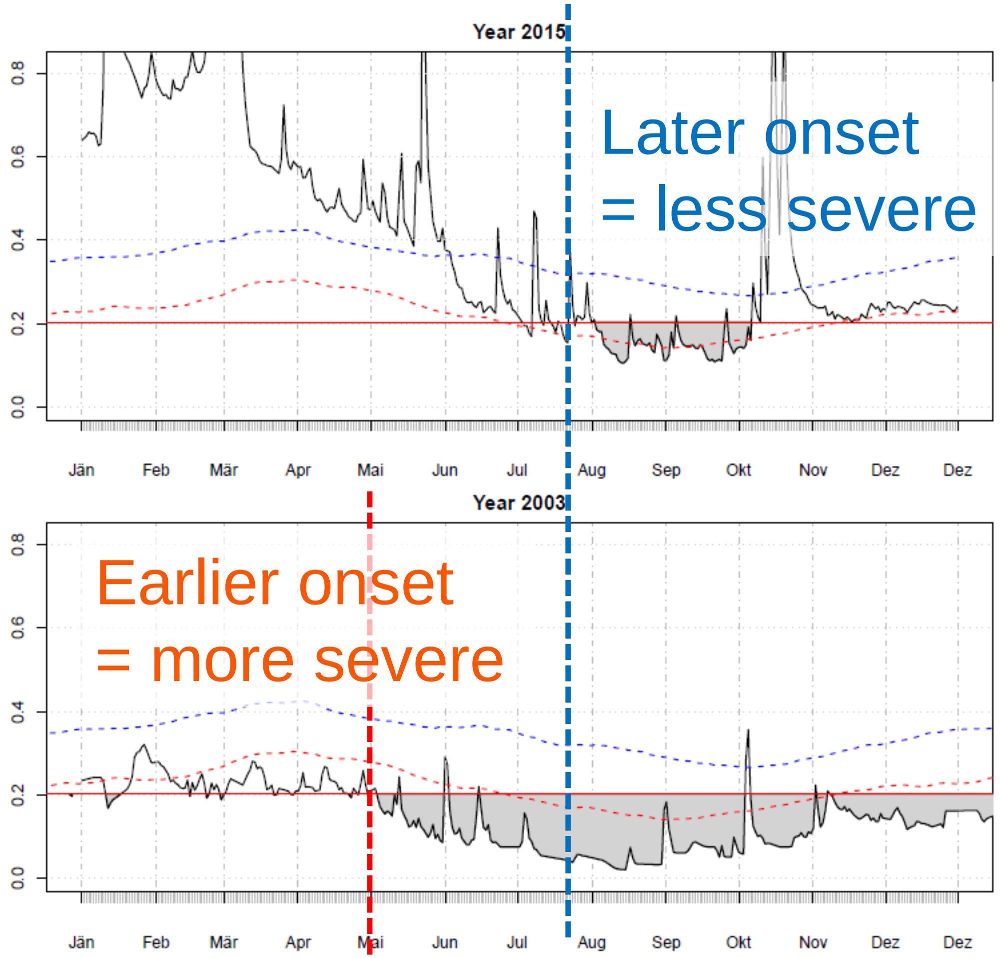

**Thompson river:**
flashy = shallow
BFI = 0.3

**Elkhart river:**
slowly = deep
BFI = 0.9

Figure from: Sawicz et al. (2011, *HESS)*

# Effect of preconditions

Example: Tauchenbach, Austria: 2015 and 2003 events (similar summer precipitation in both years)




**2015:**
**Wet preconditions**

**2003:**
**Dry preconditions**

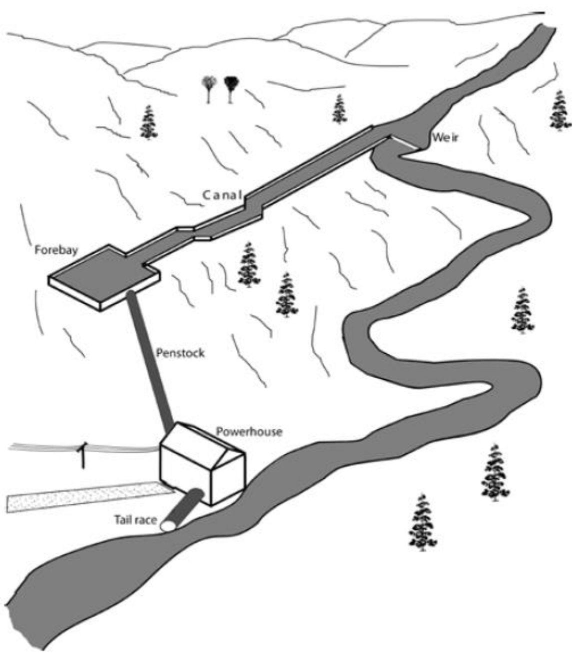
Figure from: Laaha et al. (2017, HESS)

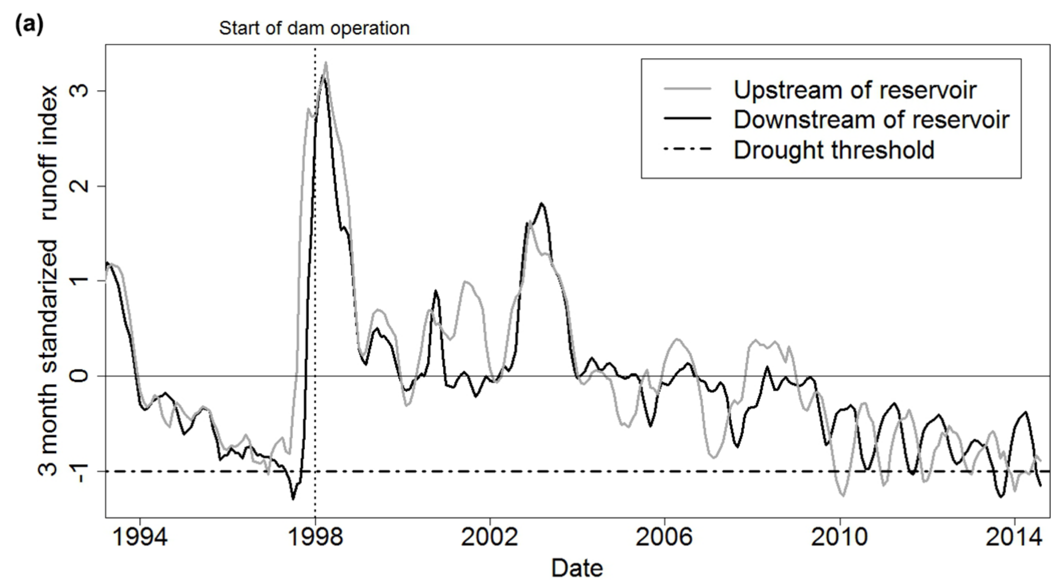
# Artificial influences

- Abstractions / discharges into rivers
- Abstractions from groundwater
- Reservoir storage
- Land-use change

Redistribution of water in space and time

→ Change low flow regime




Pictures: a) Gustard and Demuth (2008, *WMO Man*ual), b) Loon et al. (2016, *HESS*)

# Questions

1. How are low flows generated?
2. **How to quantify low flow events?**
3. How to model and predict?
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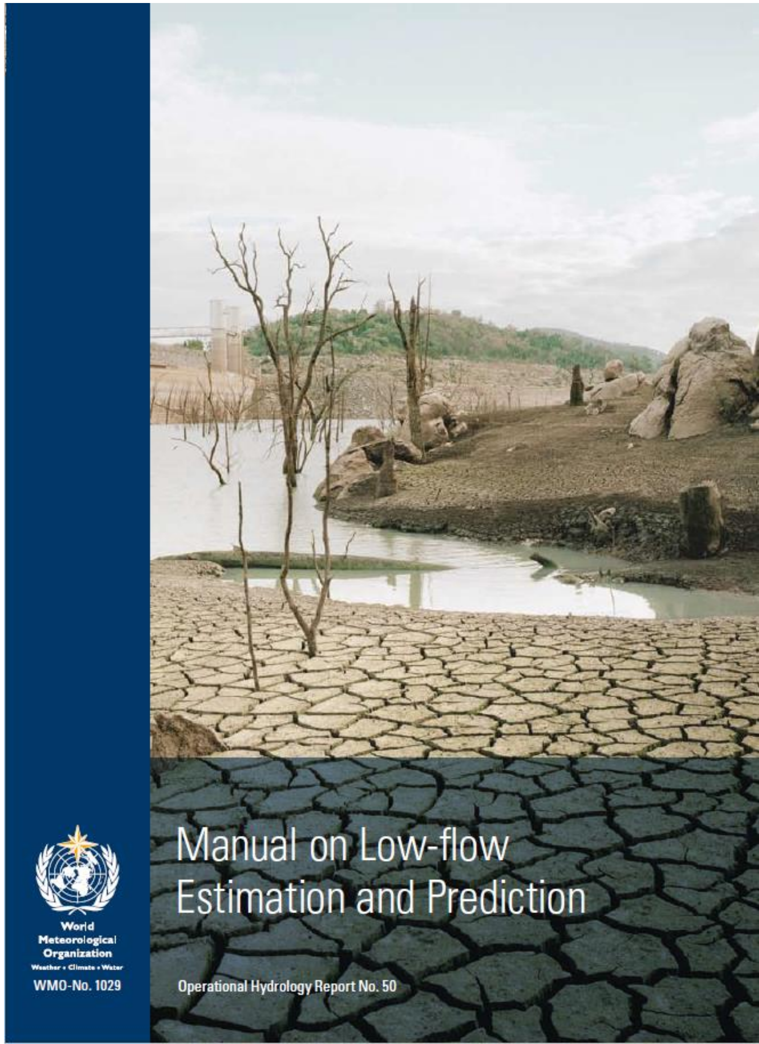
5. How dry will it be in a future climate?

# Low flow characteristics

**As opposed to floods, different characteristics are used:**

- Flow characteristics (MAM, quantiles Q95)
- Duration and deficit volumes of dry spells
- Extreme value statistics ($Q_{7,10}$)
- BFI, recession gradient

… see WMO Manual
(Gustard and Demuth, 2008)



# Example: Navigation at Rhine

Navigation is limited during low flow periods

Critical: Discharge Q < RLF (regulation low flow)

# Evaluation of navigability

## Questions:


- <u>How much</u> is RLF discharge?
- <u>How often</u> is shipping limited by low flows,
  and <u>to what extend</u>?
- <u>How long</u> do limitations last in wet and dry years?

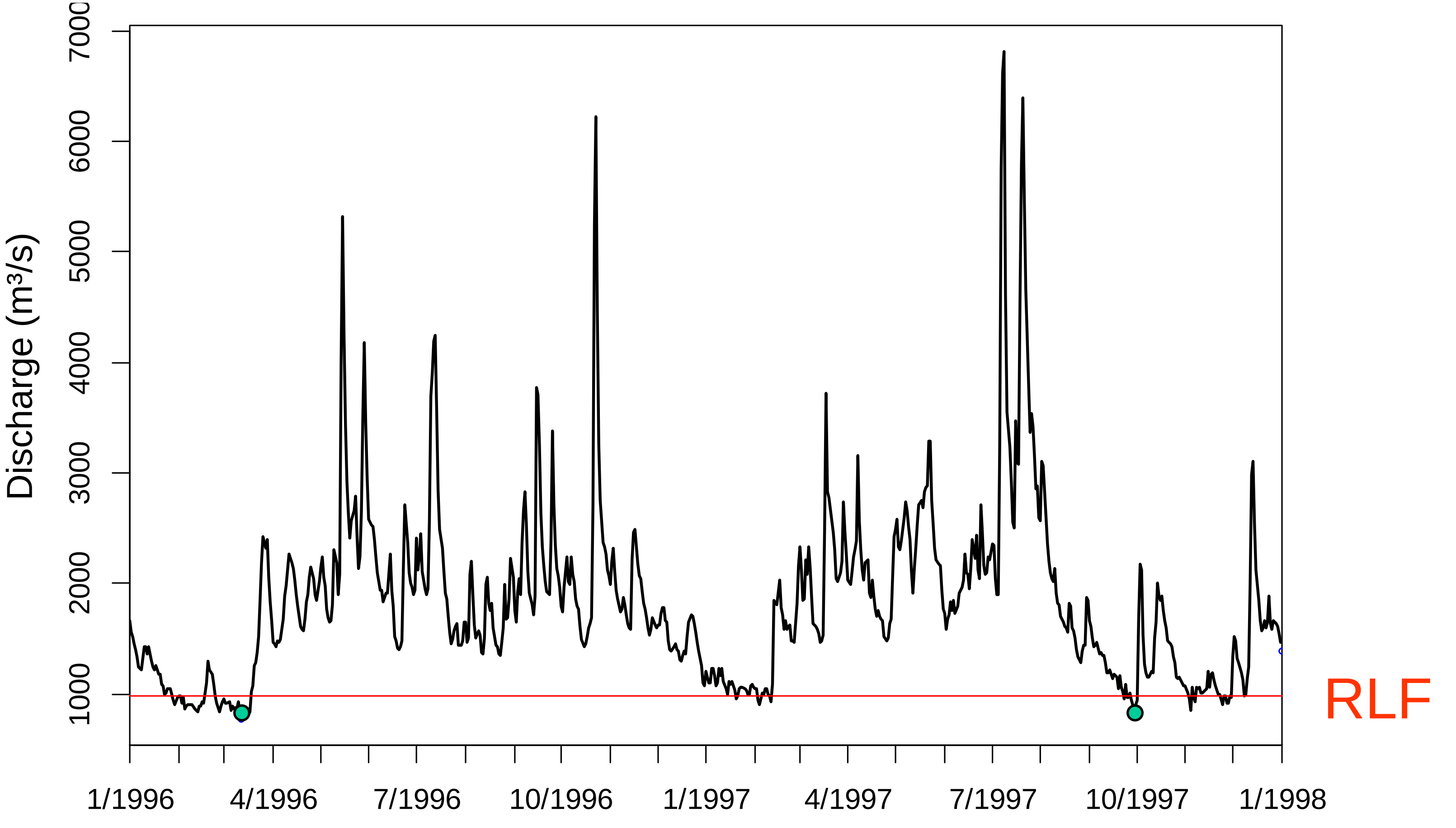
➔ different low flow related questions
… that require different characteristics

<u>Example:</u> Gauge Wildungsmauer @ Danube

# Low flow discharge

➢ **Flow quantiles (Qx) or mean annual minimum (MAM)**

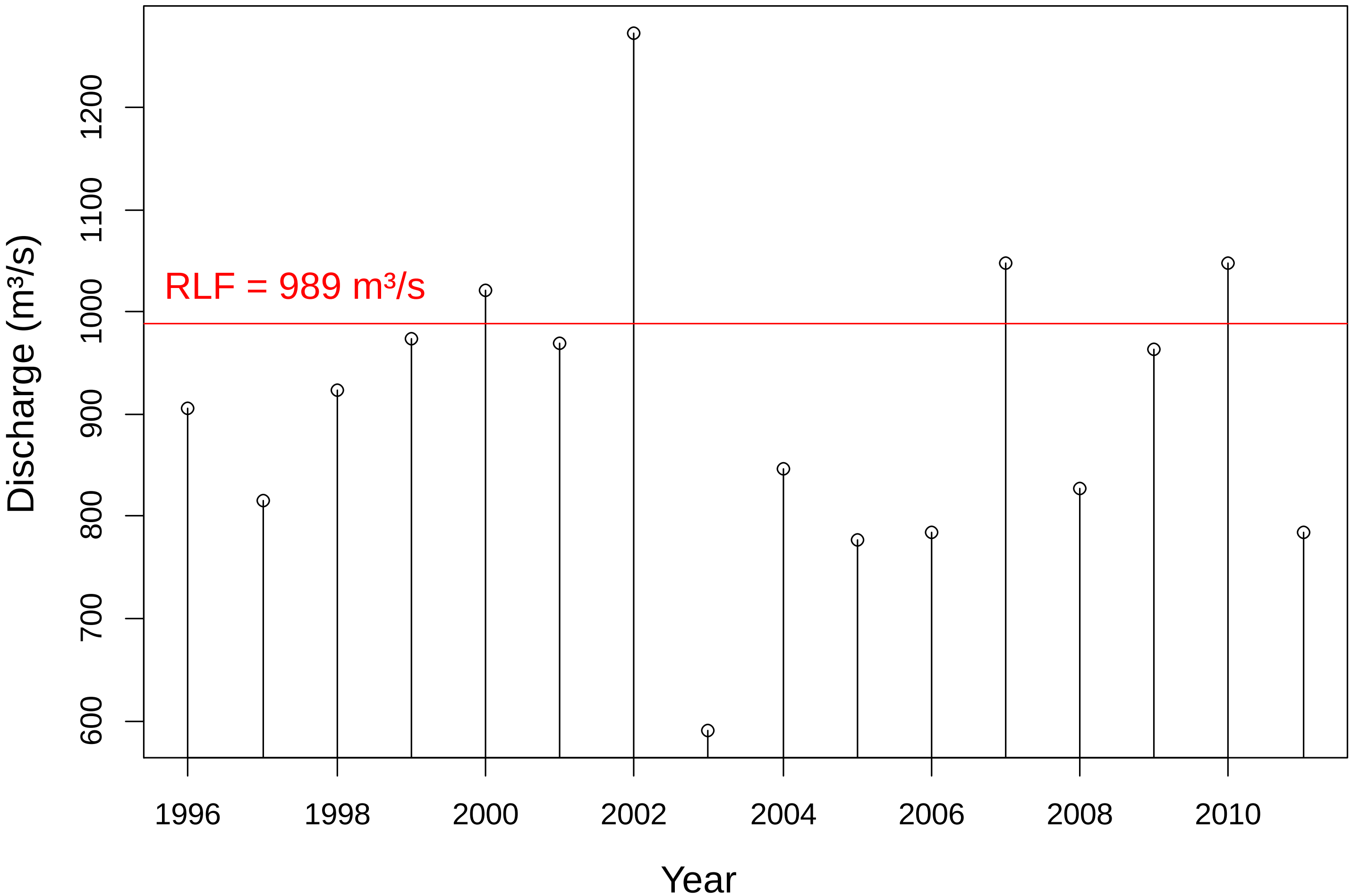
… RLF = Q94 = 989 m³/s (Rhine: RLF ≈ Q95: <20 d/yr)



# How often ?

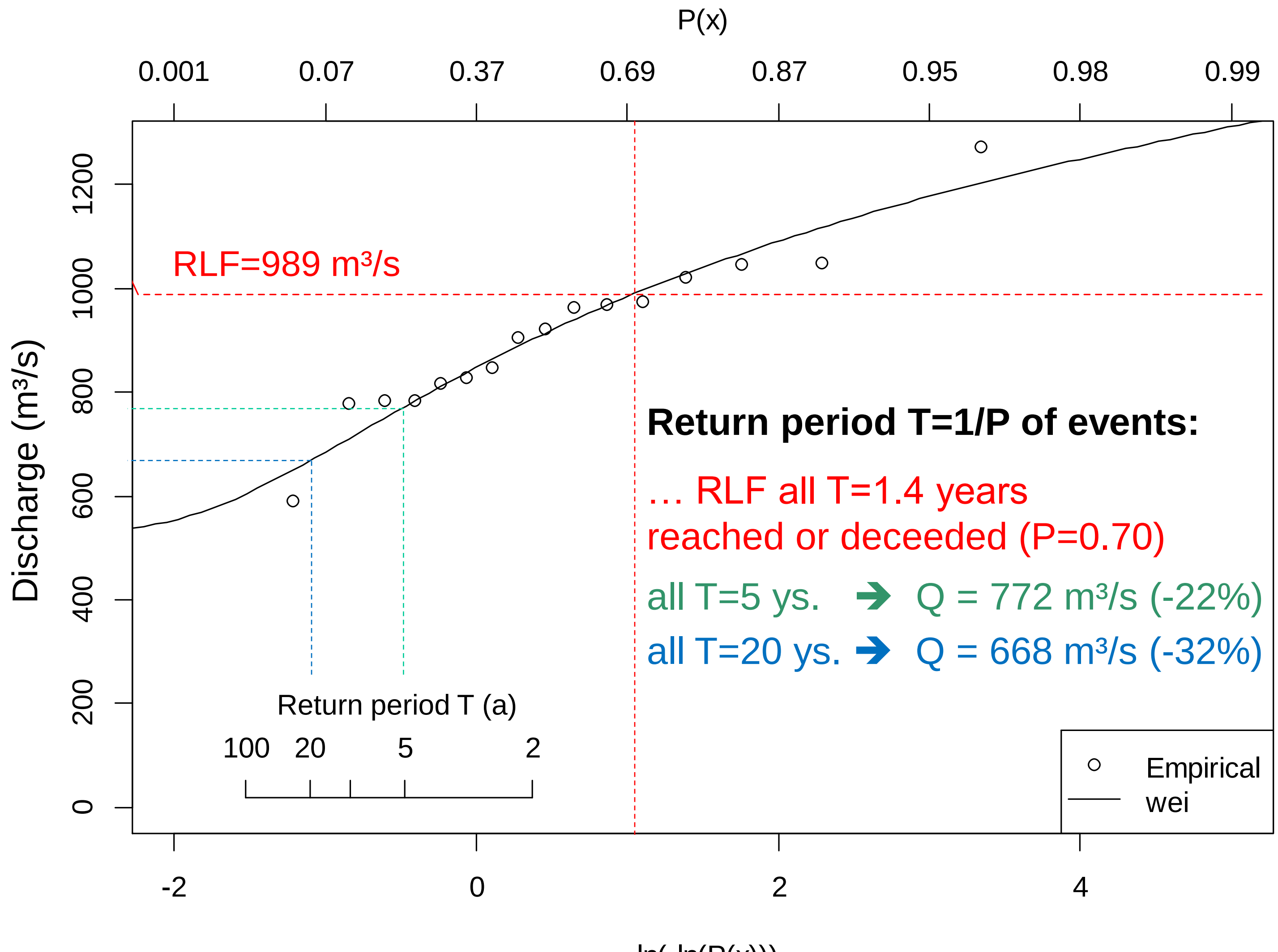
- **Annual Minima (AM)**

*… 12 of 16 years had discharges < RLF*



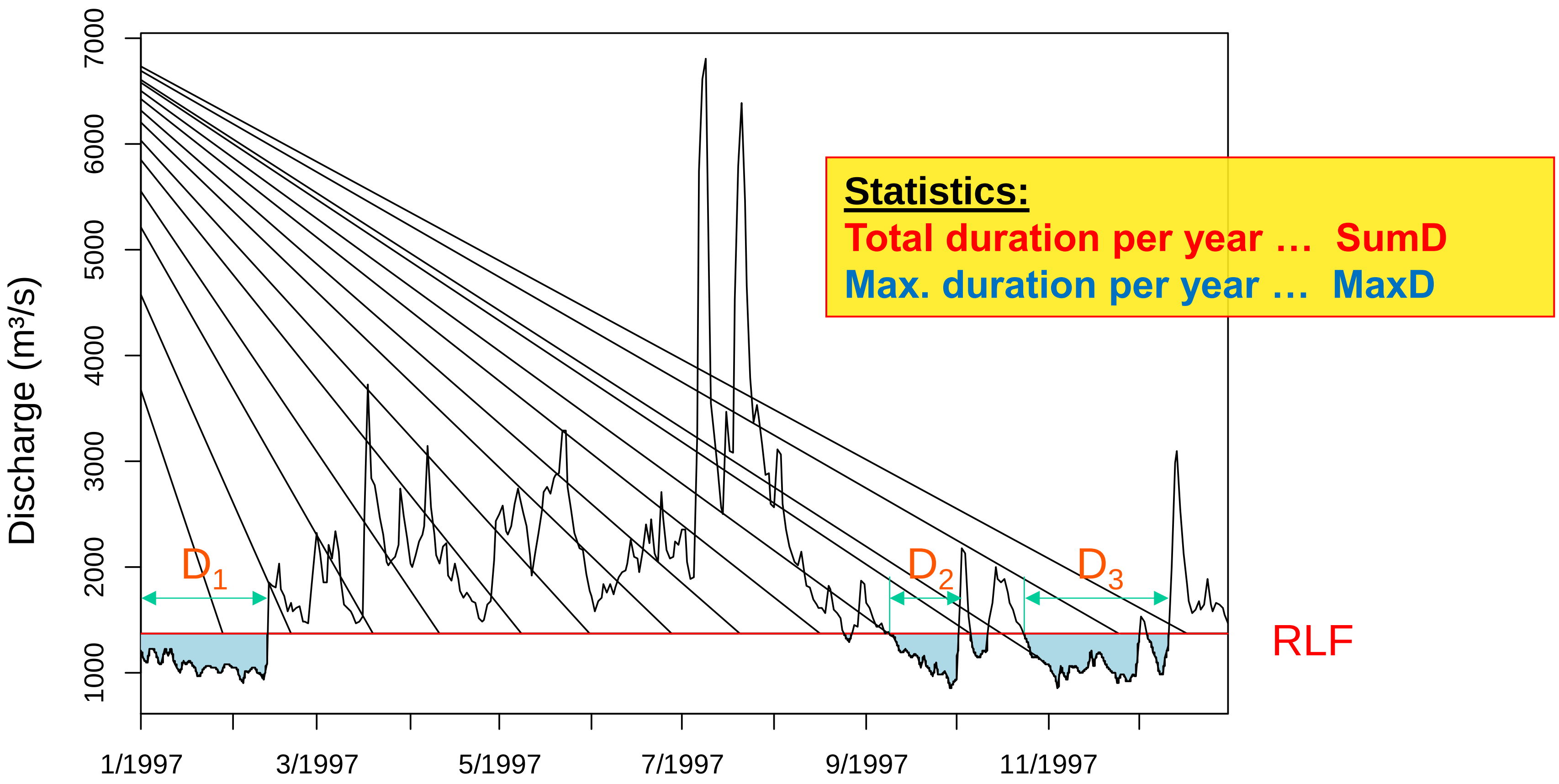
# To what extend in individual years?

- **Extreme value statistics of annual minima**



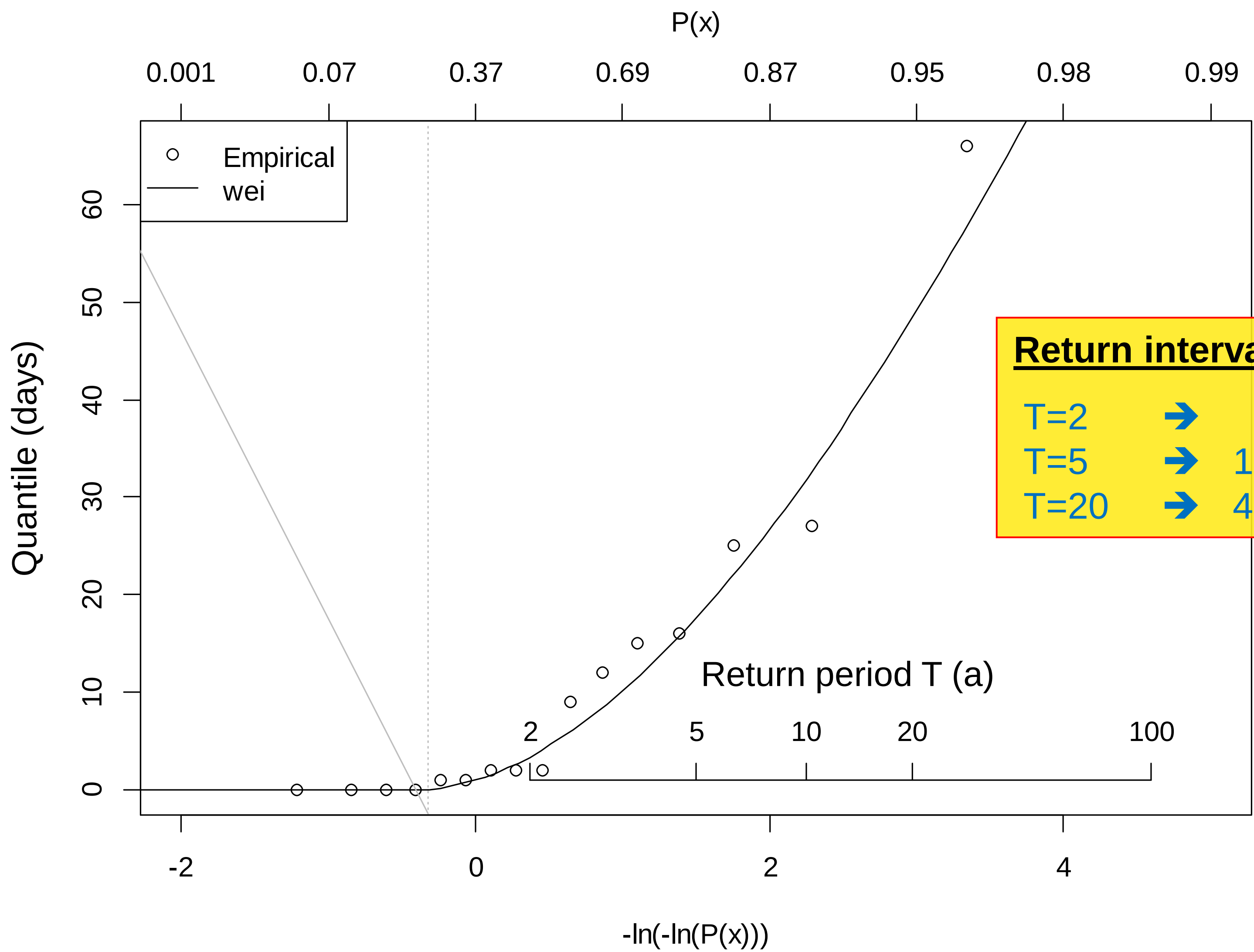
# How long?

➢ **Duration ($D_i$) of dry spells ("under threshold")**



# Maximum duration per year

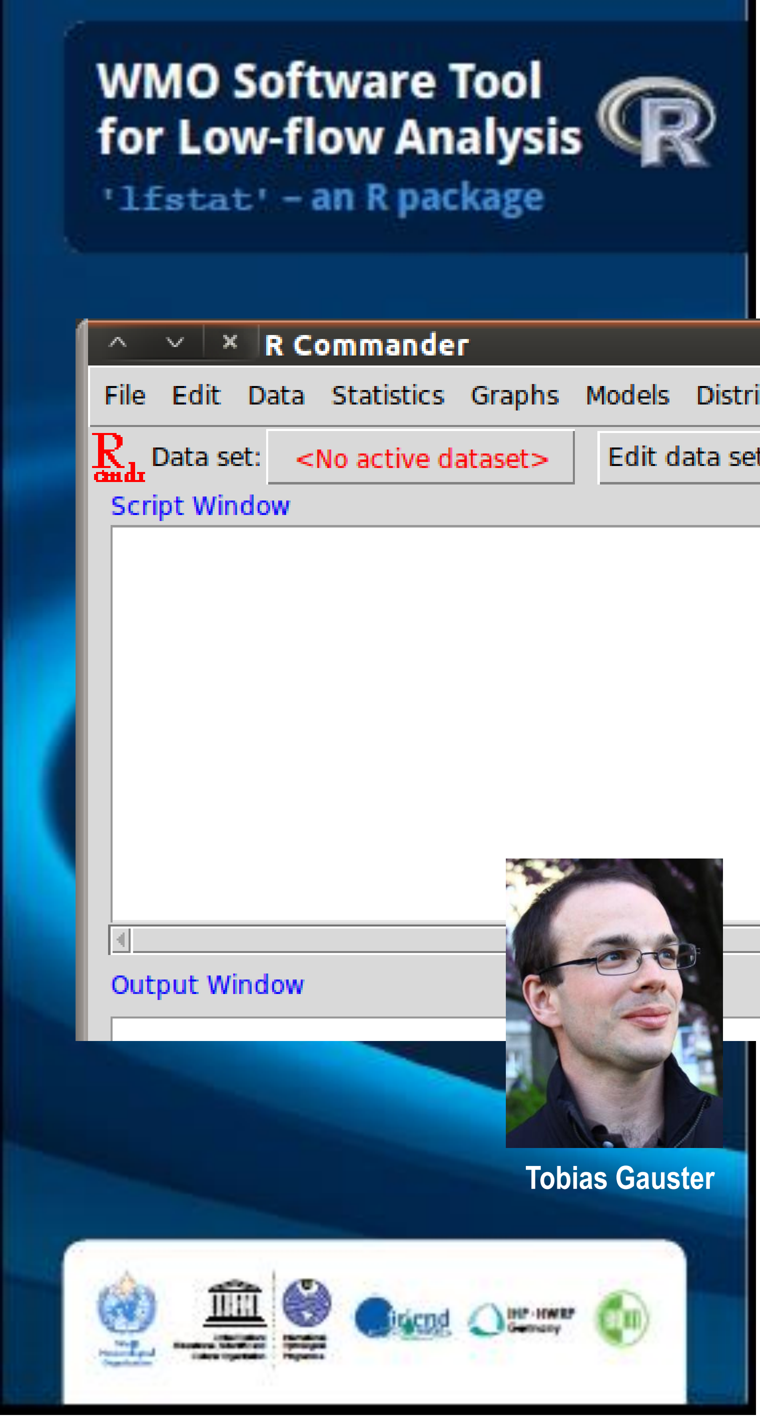
- **Extreme value statistics of MaxD (after IC-Pooling)**

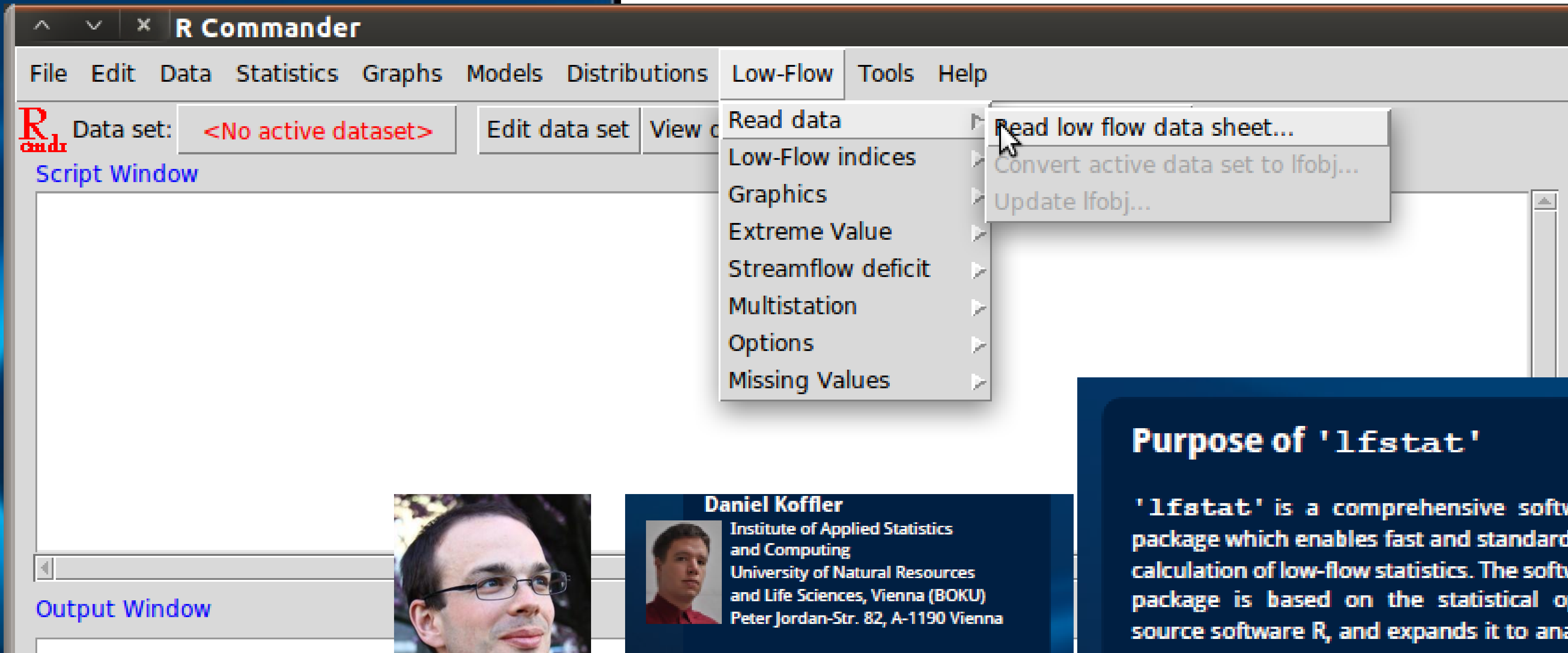



**Return interval of MaxD:**

T=2 ➔ 3 days
T=5 ➔ 18 days
T=20 ➔ 48 days

# Free R-Software: lfstat





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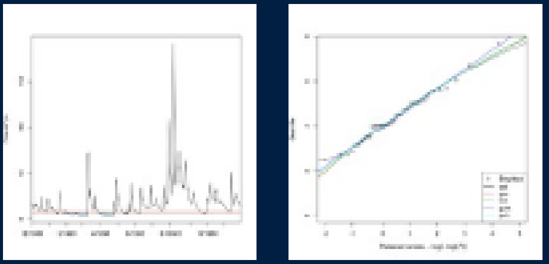
## Purpose of 'lfstat'

'lfstat' is a comprehensive software package which enables fast and standardised calculation of low-flow statistics. The software package is based on the statistical open-source software R, and expands it to analyse daily streamflow data records focusing on low flows.



# Questions

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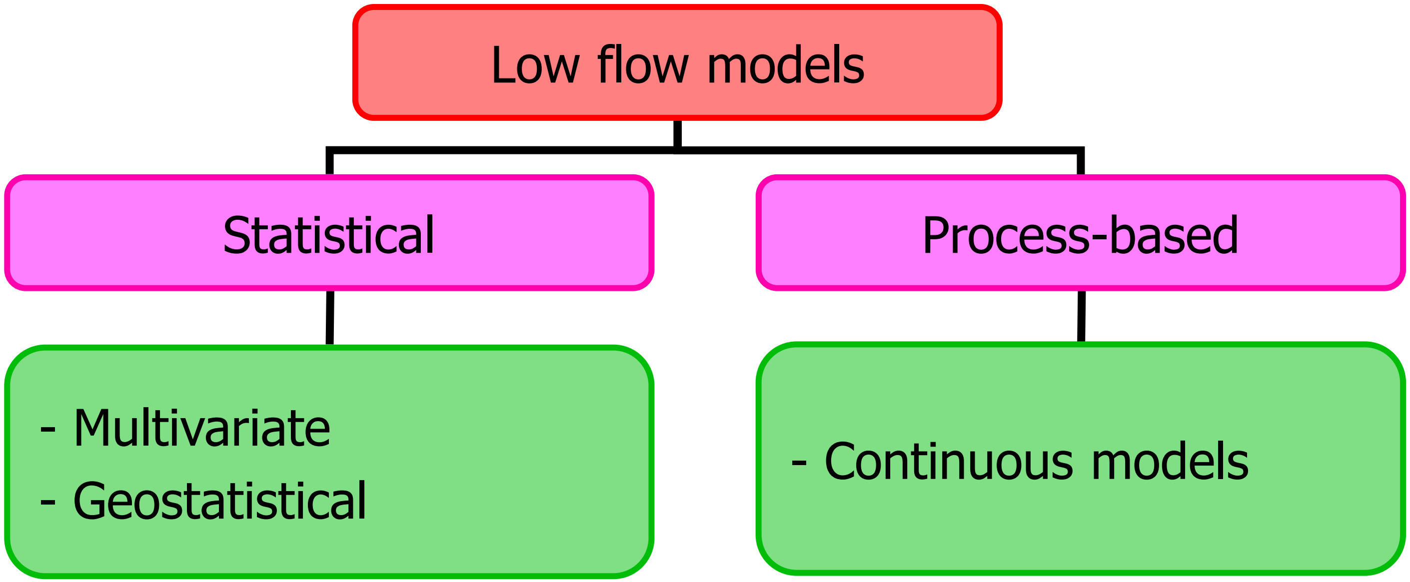
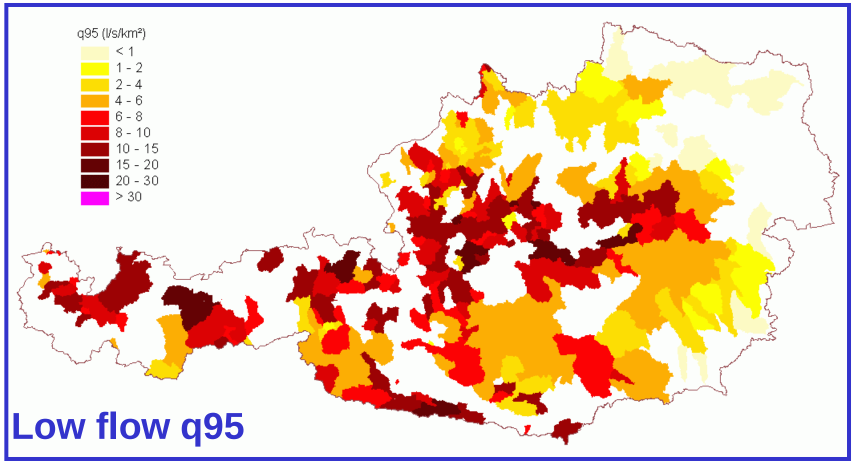
# How to model and predict



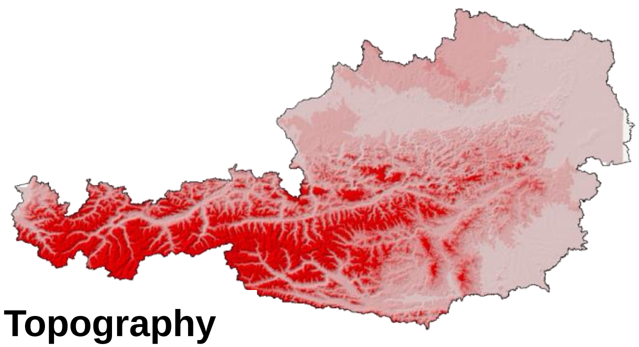
# e.g. Regression methods

**Relationship b/w LF and CC**

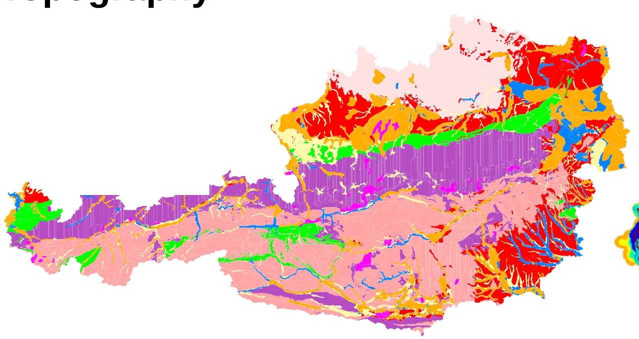
Data: N>30 catchments (better <u>more</u>)



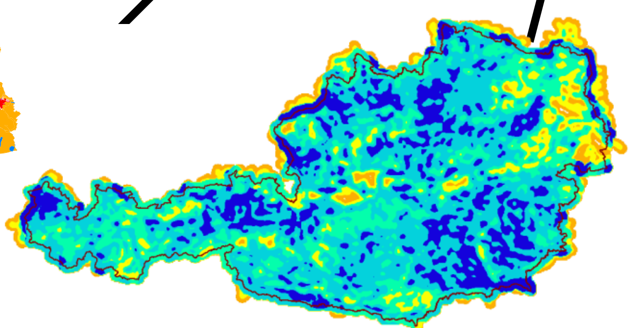

$$Y = \beta_0 + \beta_1 \cdot x_1 + \cdots + \beta_N \cdot x_N + \varepsilon_i$$



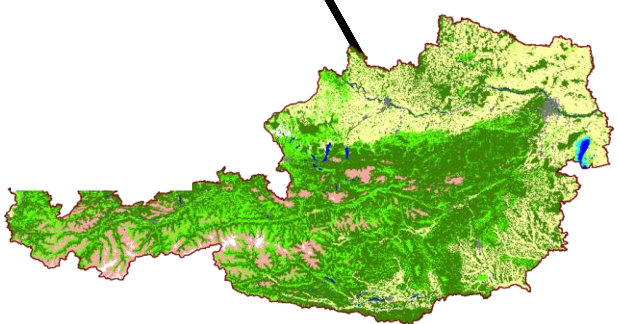
Topography



Geology



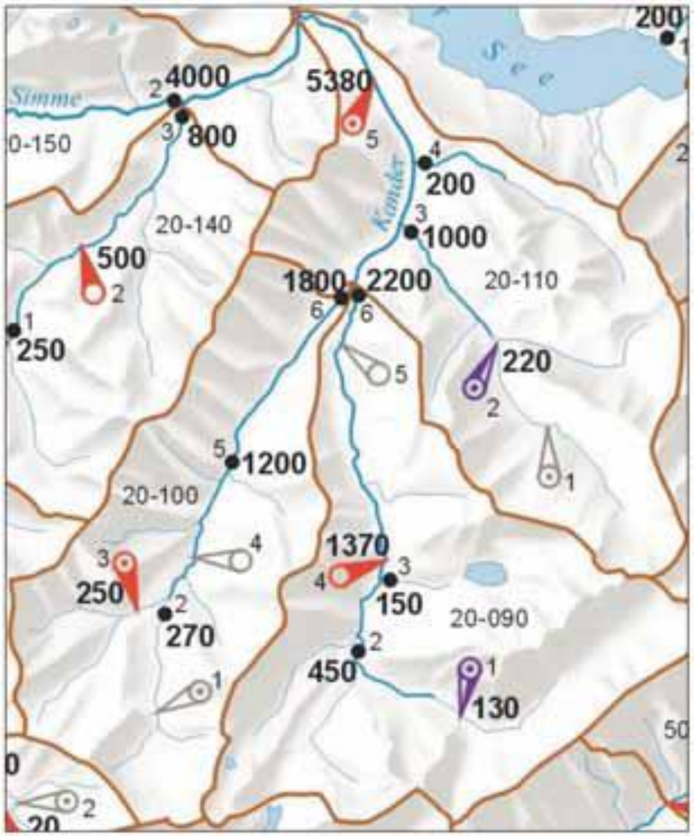
Stream density



Land cover

# Regional Regression

… Study area subdivided into homogeneous regions




Example:
Low flow map Q95 in the Hydrolog. Atlas of Switzerland (HAS)

6 regions
Independent reg-models

Requires grouping

Aschwanden & Kan (1999) *Hydrologische Mitteilungen* 27

# Geostatistical interpolation

… Weighted average of spatial neighbours

→ Need to take river network structure into account

Example: Top-Kriging (Skøien et al. 2006 *HESS*)

Discharge at river location

= integral of point runoff over catch.

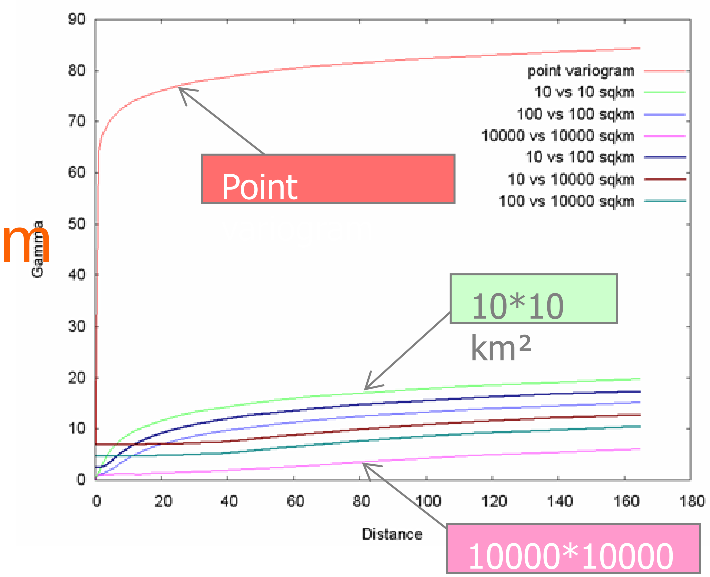
$$z(A_i) = \frac{1}{|A_i|} \int_{A_i} z(\mathbf{x})\, d\mathbf{x}$$

Support = Catchment area ($A_i$)

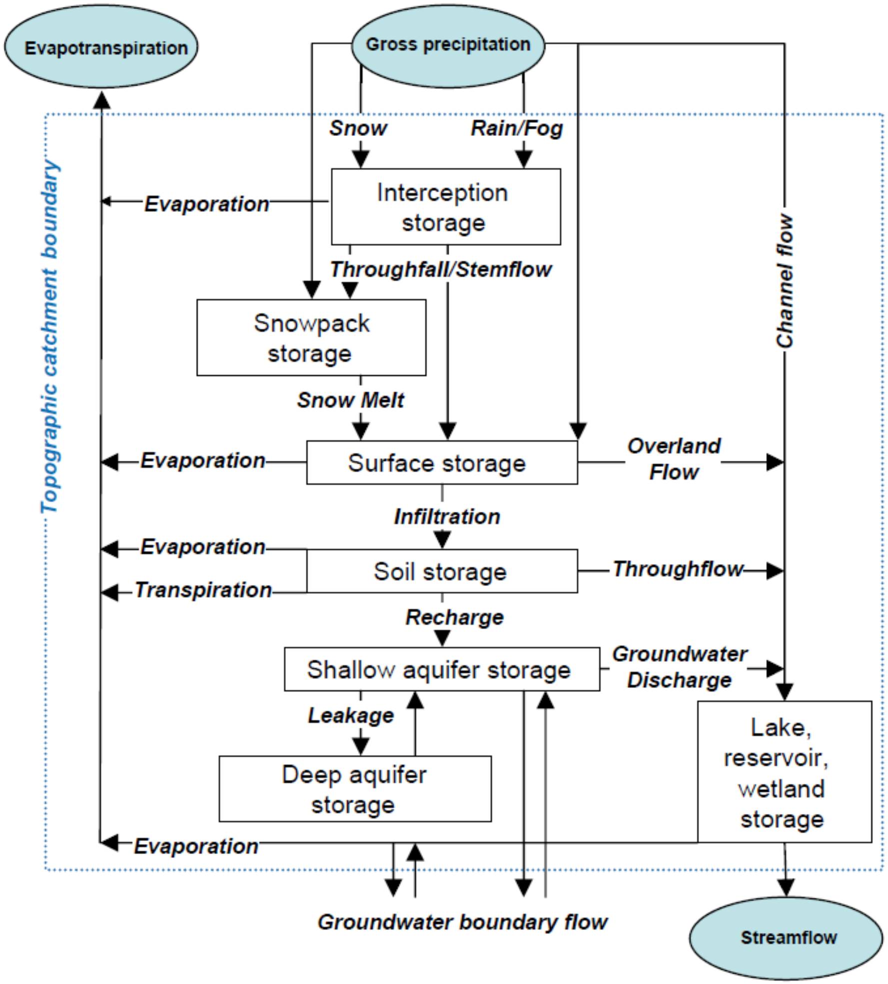
Estimator = Block-kriging

Weights from regularised variogram

… Variogram as a function of distance (h) and area ($A_1$,$A_2$)



# Continuous rainfall-runoff model




## Challenges:

Models designed for floods

- Structural errors (storage components)
- Calibration errors (objective function)

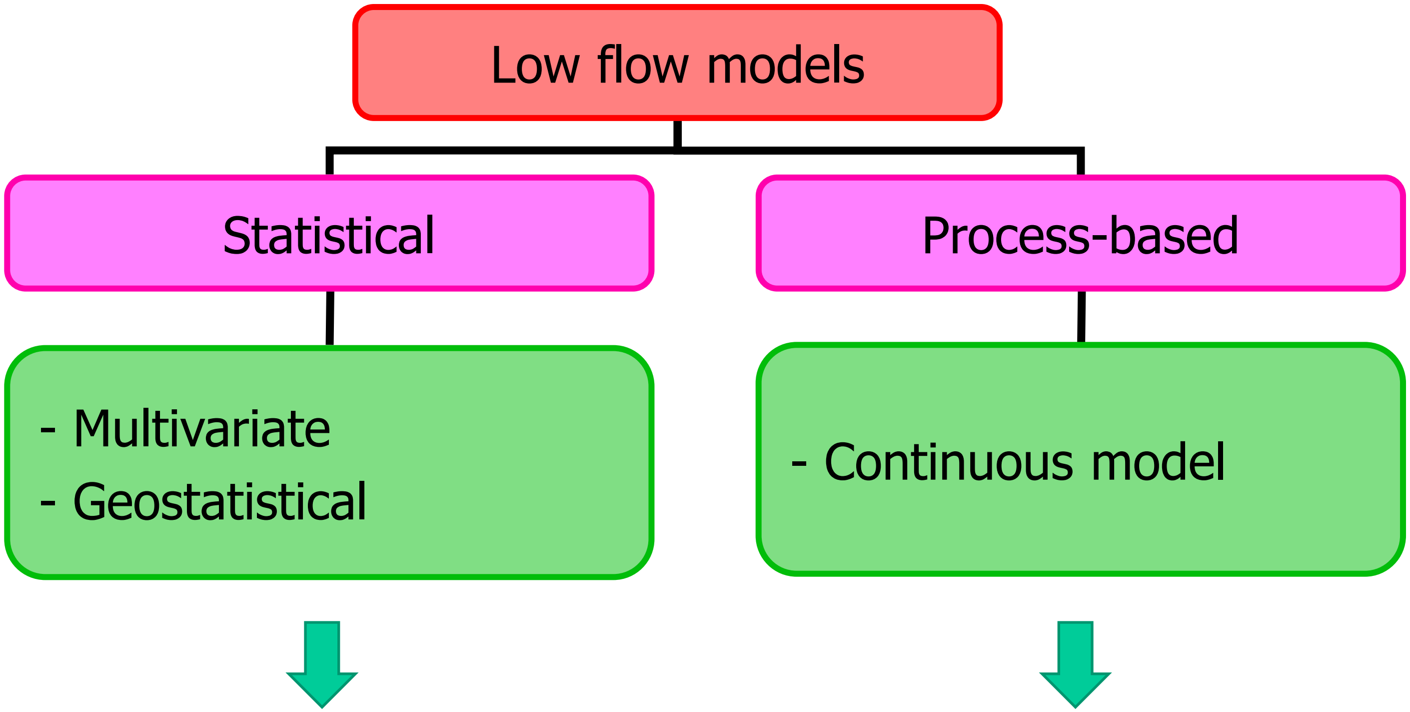
Also temporal stability (calibration period)

→ Hydrological drought more uncertain than atmospheric drought

→ Attempts to improve models for drought

Figure: Example of HBV-Type model, Tallaksen & Van Lanen (2004) *Hydrological Drought*, 580p

# How to model and predict




(rather) **Spatial models**

… but also possible to link to dynamic variables
→ Space-time models

(rather) **Temporal models**

… but also regional transfer of parameters possible
→ Time & space

**Challenge:** parameter validity for different spatial / temporal situation

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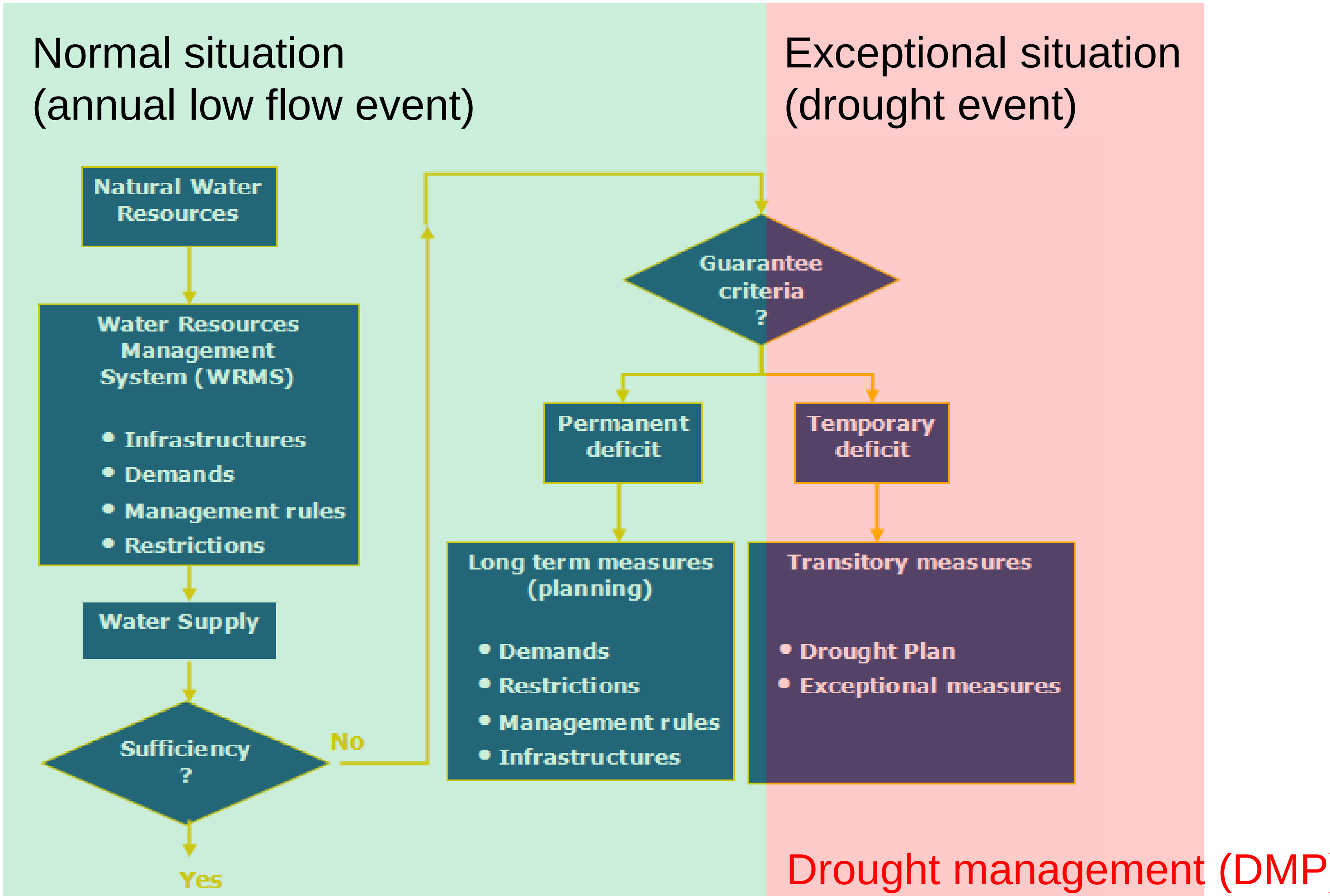
# EU-Water Framework Directive (WFD)

**WFD: Good status and sustainable water use**

→ River basin management plan (RBMP)



# Drought Management Plan (DMP)

Source: Water Scarcity and Droughts Expert Network (2007) *Technical Report*

**Overall aim:** From crises management to preparedness

**Components (general framework):**

- Monitoring system (indicators and thresholds)
  … water quantity, quality, impact indicators
- Measures to be taken in each drought phase
- Organizational framework

**Indicator status:**

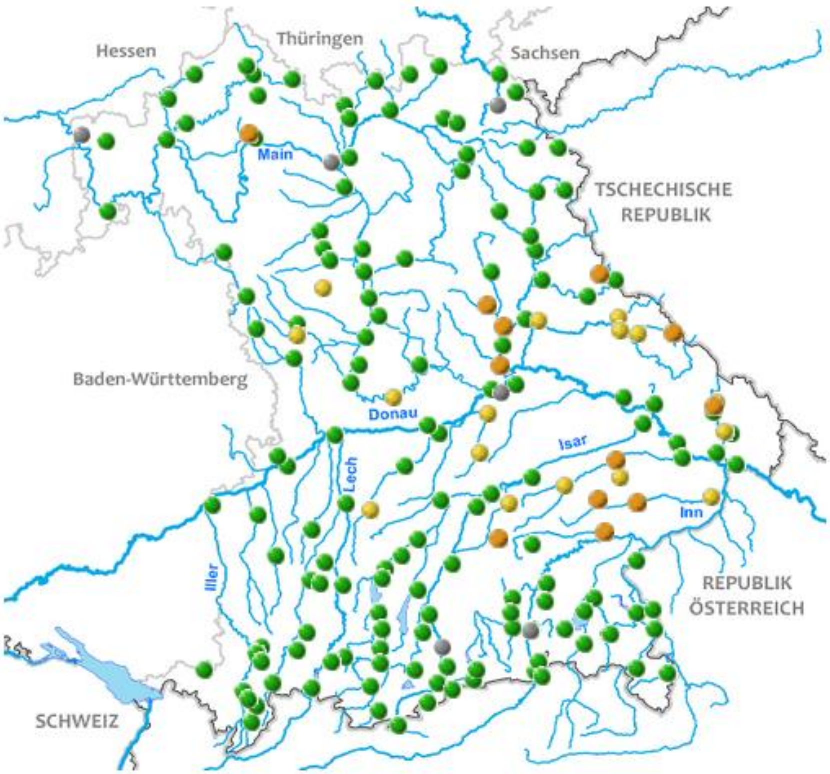
- Normal status: …hydrological planning status
- Pre-alert: …information and control measures
- Alert: …focus on saving water, demand restrictions applied
- Emergency status: … essential water uses not sustained

# Monitoring

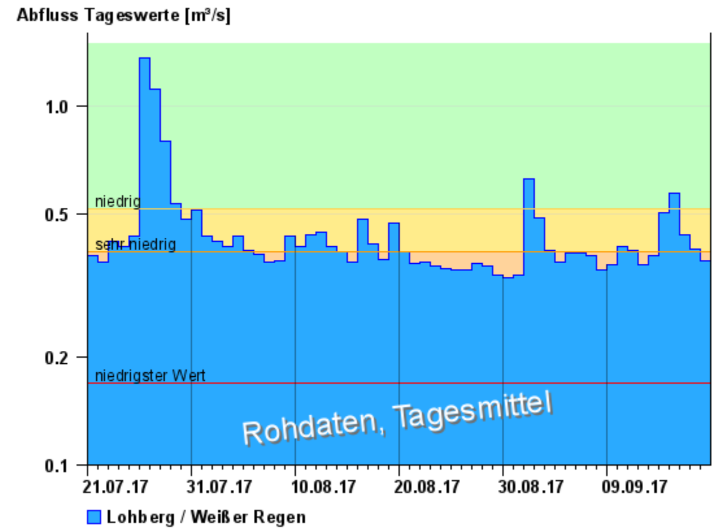
Discharge - relative to thresholds…

Abfluss Bayern

**Niedrigwasserabflüsse vom: <<** Mo, 18.09.2017 >>




● neuer Niedrigstwert ● sehr niedrig ● niedrig ● kein Niedrigwasser
● keine Klassifizierung ○ derzeit keine Daten




Source: http://nid.bayern.de/abfluss

# Forecasting

**Monitoring needs to be complemented by future prognosis…**

→ Deterministic and probabilistic forecasts (using rainfall ensemble)

Time horizons:

- Short-term (7 days): current flow, pre-conditions, weather-forecast
- Medium-term (seasonal): weather-patterns, sea-surface temperature, atmospheric modes
- Long-term (up to yrs.): historical climatology, analogues

→ Relevance of preconditions reduces with length of forecast period

Challenge: Much longer forecasting periods needed than for floods
e.g., for agriculture: What is the risk of having a summer drought given the pre-conditions in spring…

Source: Gustard & Demuth (2008) *WMO Manual*

# Example: Rhine water level forecast (short-term)

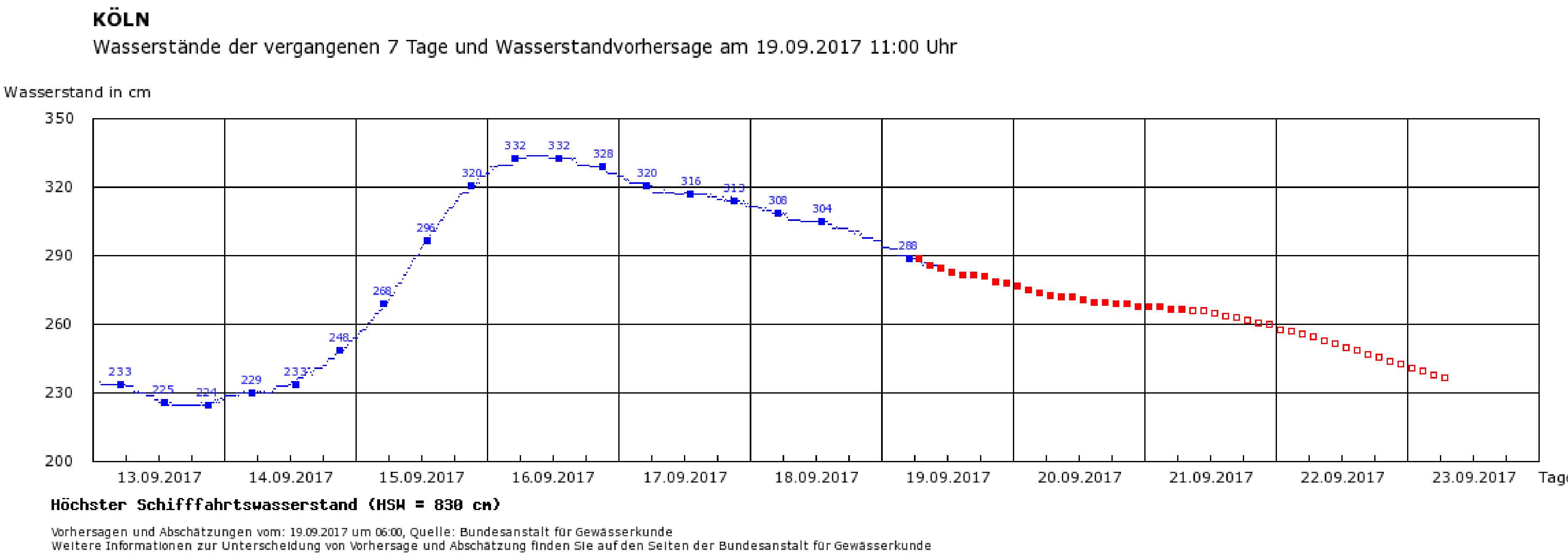



Figure: https://www.elwis.de

# Questions

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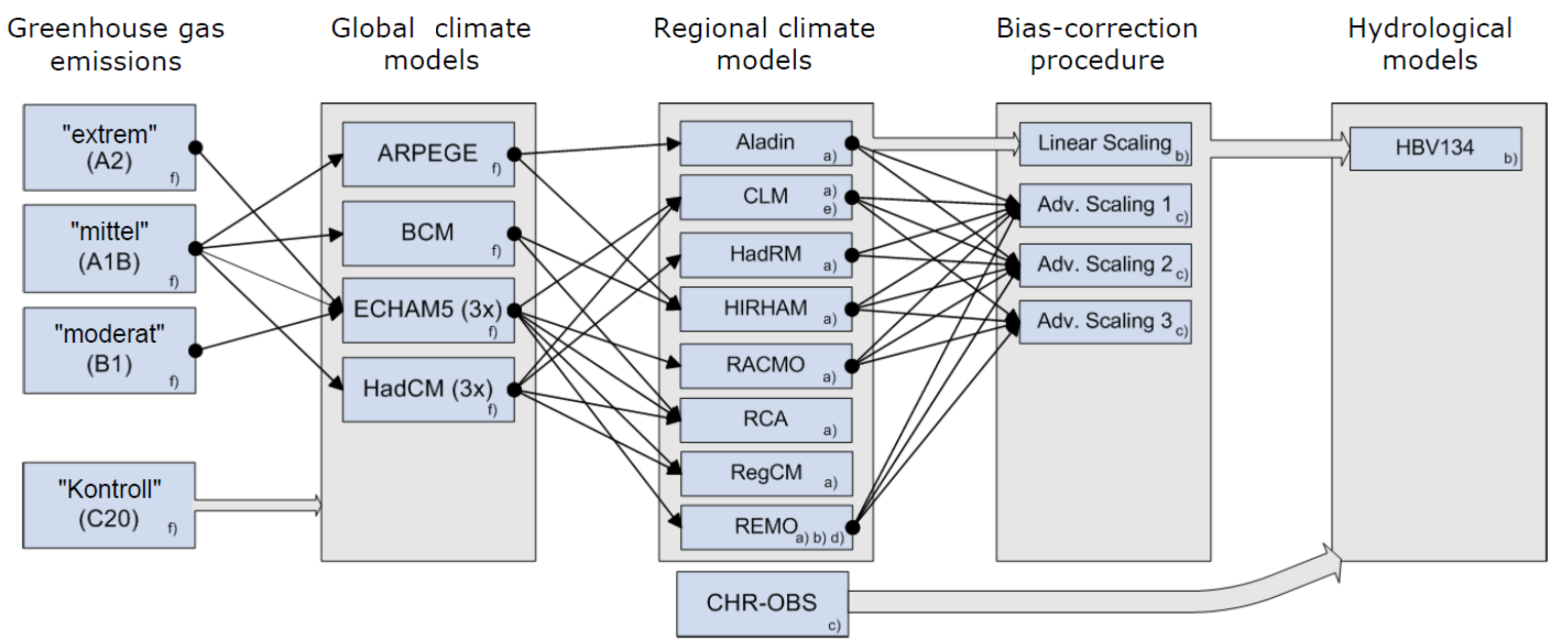
# Climate change

**Model chains:**

...rainfall-runoff model driven by downscaled GCM scenarios

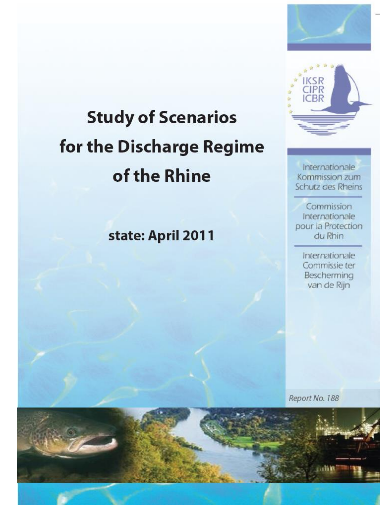
Example: Scenarios for the Rhine, IKSR Report No. 188





→ Ensembles - more robust, more information

# Low flows at Rhine - projected changes




| | | 2050 | 2100 |
|---|---|---|---|
| NM7Q Hydrological summer half year (May-Oct) | Basel | -10% to +10% | *-20% to -10%* |
| | Maxau | -10% to +10% | *-20% to -10%* |
| | Worms | -10% to +10% | *-25% to -10%* |
| | Kaub | -10% to +10% | *-25% to -10%* |
| | Cologne | -10% to +10% | *-30% to -10%* |
| | Lobith | -10% to +10% | *-30% to -10%* |
| | *Raunheim (Main)* | 0% to +20% | *-20% to 0%* |
| | *Trier (Moselle)* | -20% to +20% | *-50% to -20%* |
| NM7Q Hydrological winter half year (Nov-Apr) | Basel | +5% to +15% | *0% to +15%* |
| | Maxau | 0% to +10% | *-5% to +15%* |
| | Worms | +5% to +15% | *-5% to +15%* |
| | Kaub | 0% to +15% | *-5% to +15%* |
| | Cologne | 0% to +15% | *0% to +20%* |
| | Lobith | 0% to +15% | *-5% to +15%* |
| | *Raunheim (Main)* | +5% to +15% | *0% to +20%* |
| | *Trier (Moselle)* | -15% to +15% | *0% to +20%* |

Less summer-precipitation

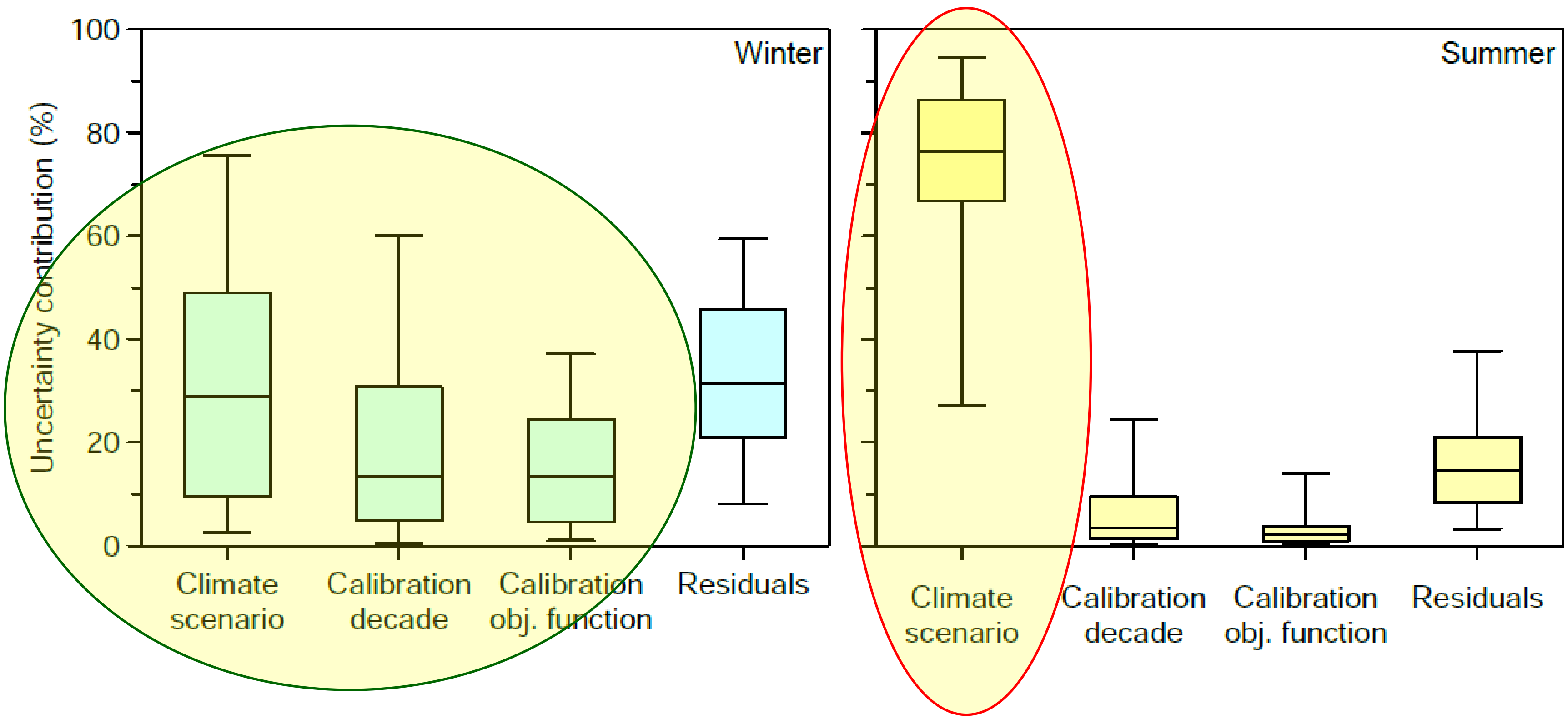
Higher winter-temperature

# Need to consider uncertainty

Model cascades – cascades of uncertainty
Study: Uncertainty contributions to low flow projections (Austria)

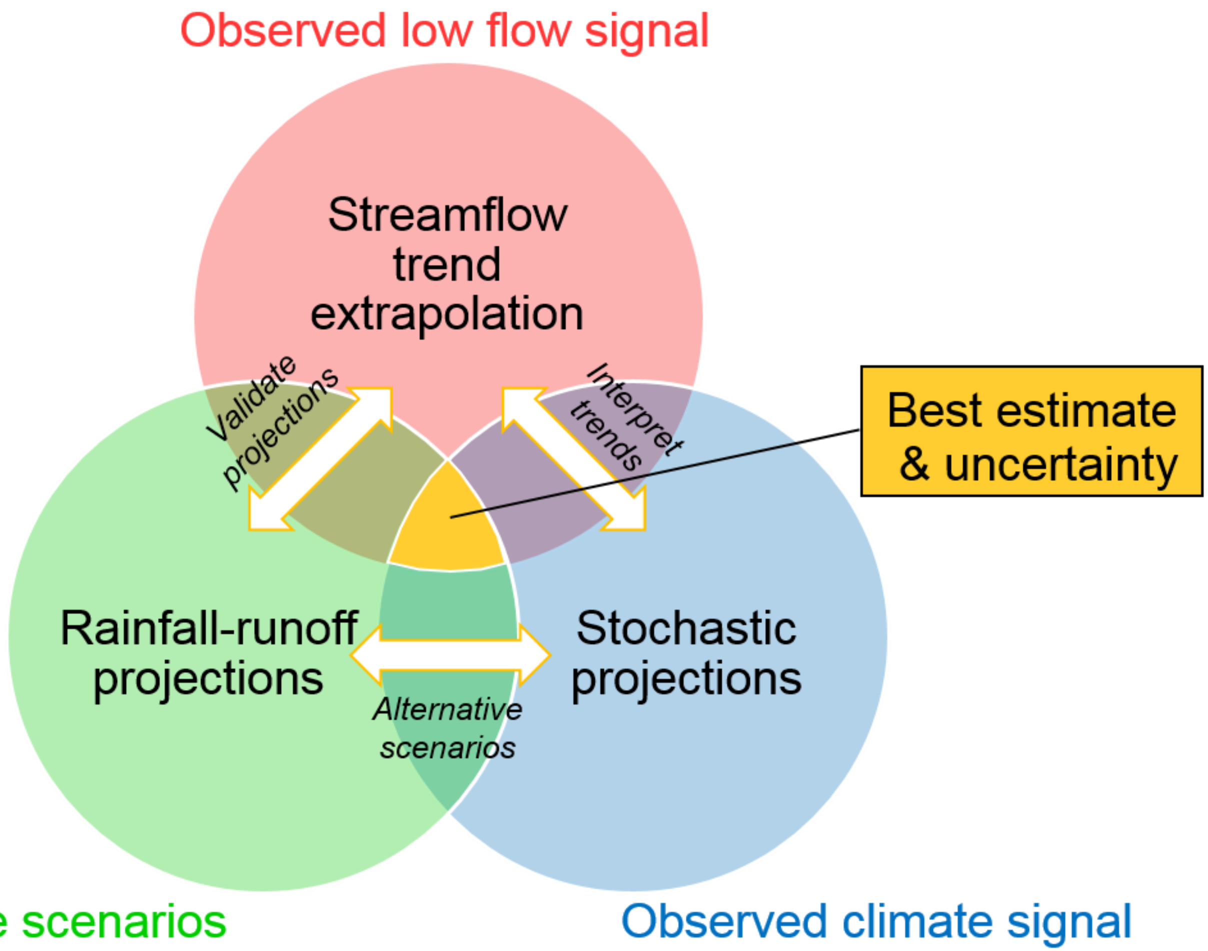
**Ensemble uncertainty** (% of true value):

**Winter-regime: up to 60%** **Summer-regime: up to 20%**




Parajka et al. (2016, HESS)

# Using different pillars of information




Laaha et al. (2016, HESS)

# Conclusions & future requirements

1. How are low flows generated?

→ Drought is a complex beast. Better understanding needed to model, predict and manage water resources

2. How to quantify low flow events?

→ Range of streamflow and other drought indices. Make use of the best suited one (impact)

3. How to model and predict?

→ Challenge to predict changes over space and time

# Conclusions & future requirements (cont.)

4. How to manage drought events?

→ DMP beneficial to rise preparedness and mitigate adverse effects of severe droughts

→ Monitoring, forecasting and impact information needed

5. How dry will it be in a future climate?

→ Seasonal shifts, but magnitude of change uncertain

→ independent information beneficial

# Low flows in the Rhine catchment

Have a great conference !