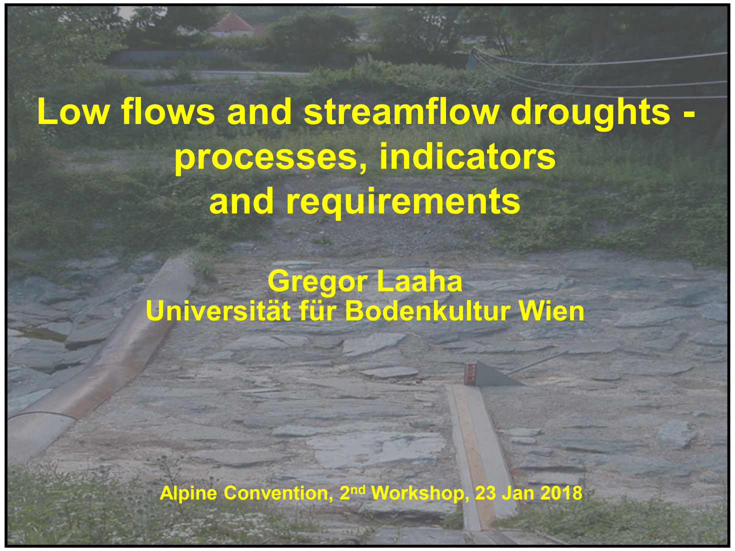


Low flows and streamflow droughts - processes, indicators and requirements

Gregor Laaha
Universität für Bodenkultur Wien

Alpine Convention, 2nd Workshop, 23 Jan 2018

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?

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

Generation of low flows

Cause: lack of precipitation
→ that propagates through the water cycle

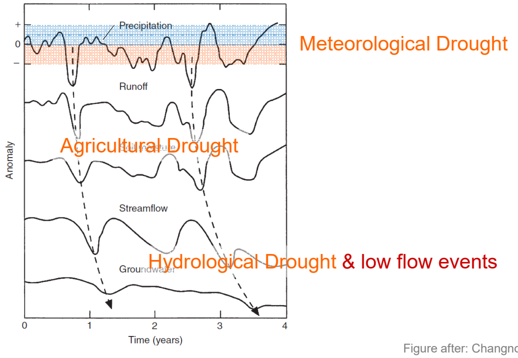
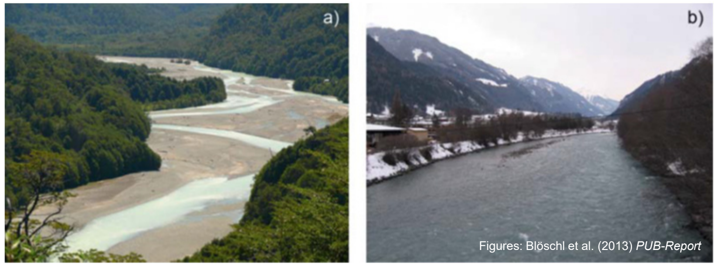


Figure after: Changnon (1987)

Summer and winter low flows

Both are caused by water deficit, but triggered by different processes
a) summer: precipitation deficit
b) winter: freezing

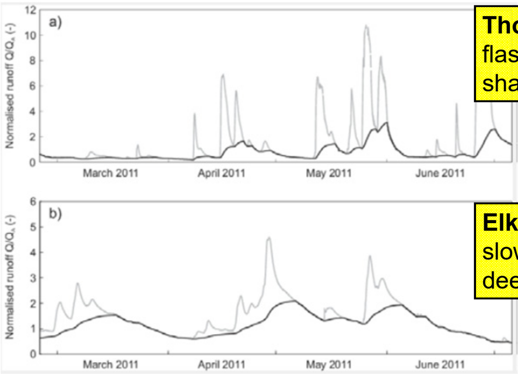


Figures: Blöschl et al. (2013) *PUB-Report*

→ seasonality of events determines processes and impacts

Catchment processes

Store and release of water
→ dampening, redistribution in time



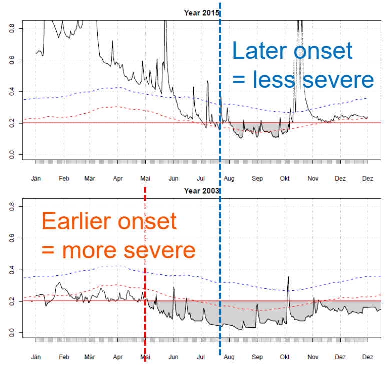
Thompson river:
flashy (BFI = 0.3)
shallow aquifer

Elkhart river:
slowly (BFI = 0.9)
deep aquifer

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

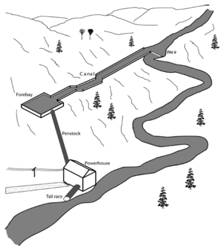
Figure from: Laaha et al. (2017, *HESS*)

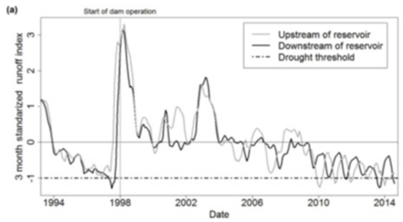
Artificial influences

- 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 Manual*), b) Loon et al. (2016, *HESS*)

Questions

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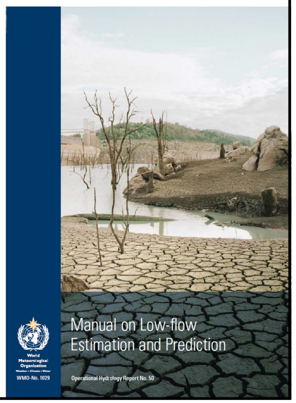
Low flow characteristics

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:

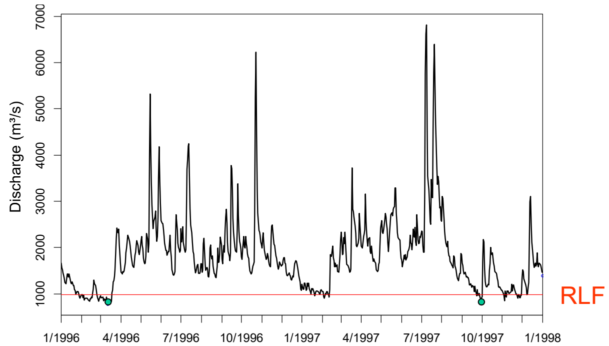
- How much is RLF discharge?
- How often is shipping limited by low flows, and to what extend?
- How long do limitations last in wet and dry years?

➔ different low flow related questions
… that require different characteristics

Example: Gauge Wildungsmauer @ Danube

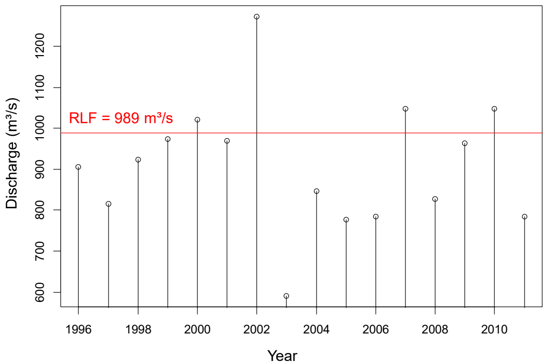
Low flow discharge

➢ **Flow quantiles (Qx) or mean annual minimum (MAM)**
… RLF = Q94 = 989 m³/s (Rhine: GlW ≈ Q95: <20 d/yr)



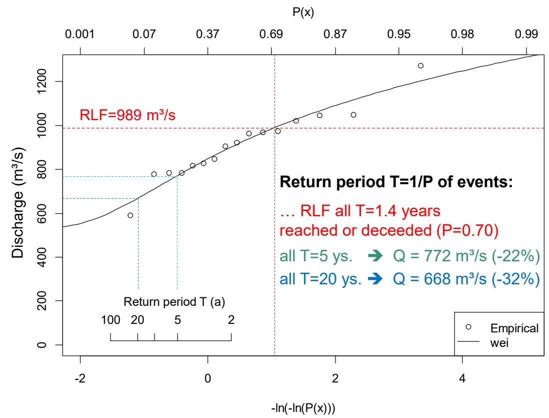
How often ?

➢ **Annual Minima (AM)**
… 12 of 16 years had discharges < RLF



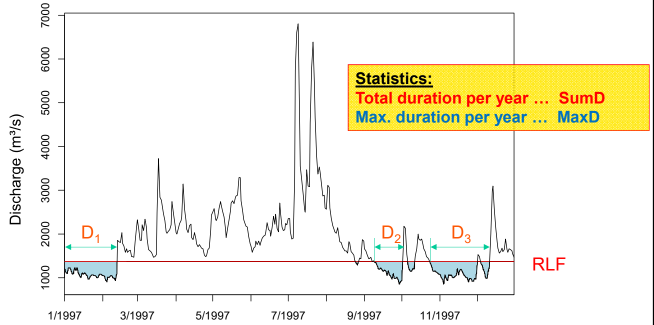
To what extend in individual years?

➢ **Extreme value statistics of annual minima**



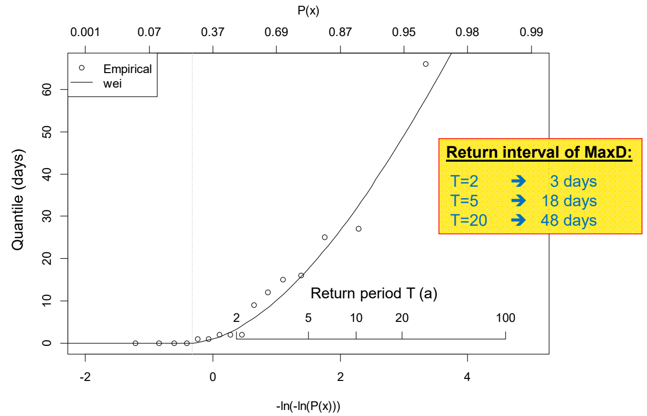
How long?

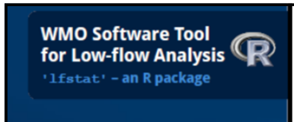
➢ Duration (D_i) of dry spells (“under threshold”)



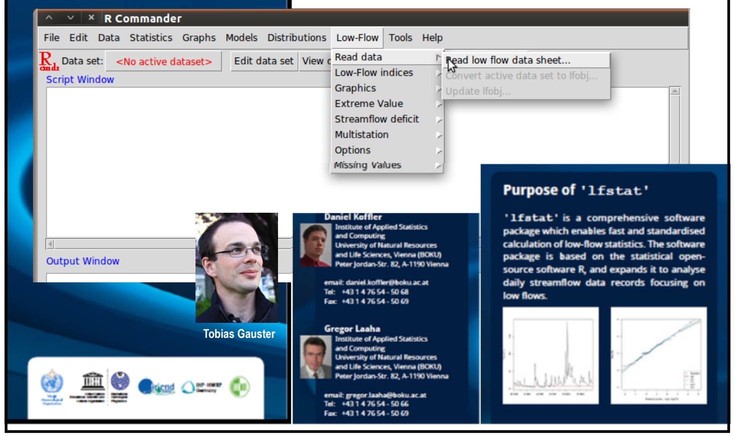
Maximum duration per year

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





Free R-Software: lfstat



Meteorological drought indices

➢ **Standardized indices SPI, SPEI, Palmer PDSI**

All in common:

- *Anomalies of aggregated precipitation*
- *For specific month or season*

➔ *“Relatively wet or dry”, but not absolute indicator of drought*

(Note that this is also valid for streamflow indices based on monthly or seasonal varying thresholds, such as SSI)

Consider:

Precipitation is not a water resource, cannot manage

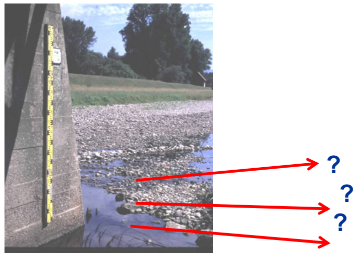
For impacts, hydrological indicators needed

Van Lanen et mult. (2016): Hydrology needed to manage droughts: the 2015 European case. Hydrological Processes 30, 3097–3104.

Which indices are used in different countries?

Type
- flow quantiles
- mean annual min. flow
- flows of given return period

Country
- **AT / CH**: Q95 / Q_{347}
- **DE / AT**: MAM7
- **F**: $Q_{7,30}$



Picture: Gustard and Demuth (2008, *WMO Manual*)

Questions

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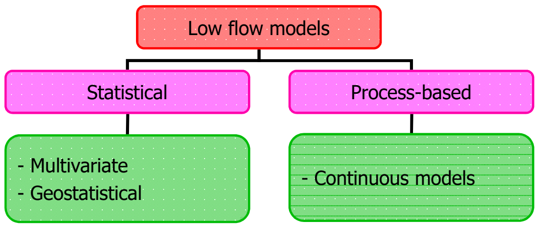
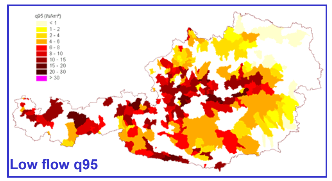
How to model and predict

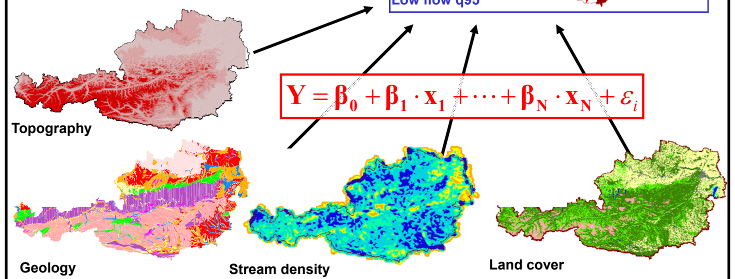


e.g. Regression methods

Relationship b/w LF and CC

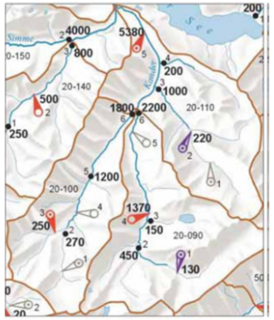
Data: N>30 catchments (better more)





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*)

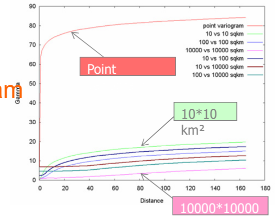
Discharge at river location
= integral of point runoff over catch.

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

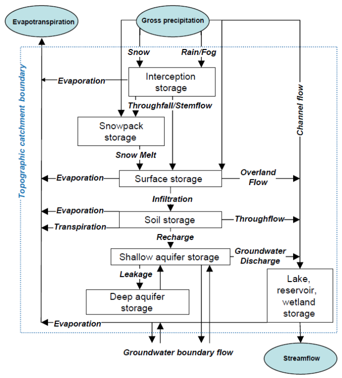
Support = Catchment area (A_i)

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)

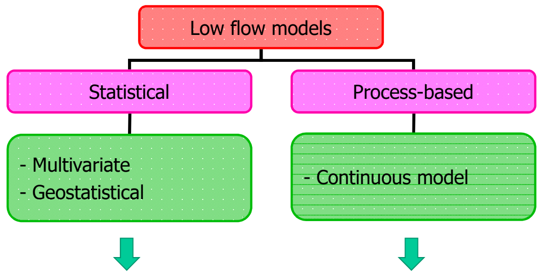
Also temporal stability (calibration period)

→ 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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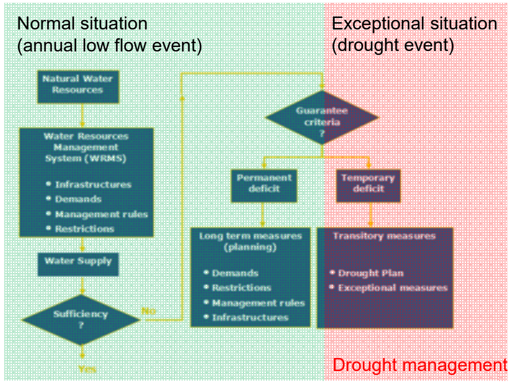
EU-Water Framework Directive (WFD)

WFD: Good status and sustainable water use
→ River basin management plan (RBMP)



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

Drought Management Plan (DMP)

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

Overall aim: From crises management to preparedness

Components (general framework):

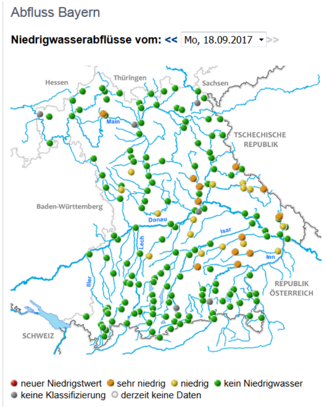
- Monitoring system (indicators and thresholds)
  … water quantity, quality, impact indicators
- Measures to be taken in each drought phase
- Organizational framework

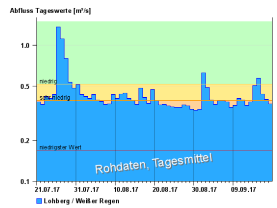
Indicator status:

- 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…





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)

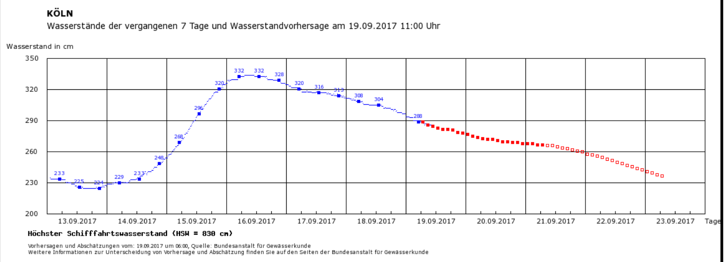


Figure: https://www.elwis.de

Forecasting

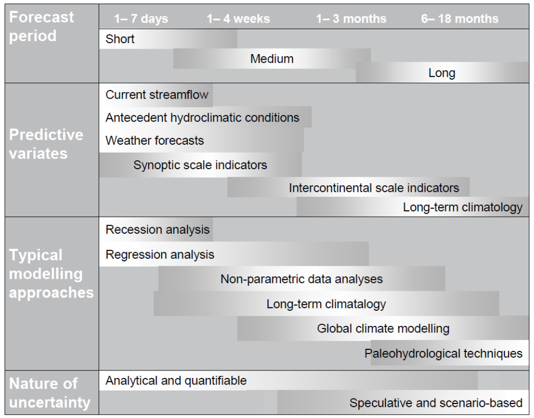


Table: Gustard & Demuth (2008) *WMO Manual*

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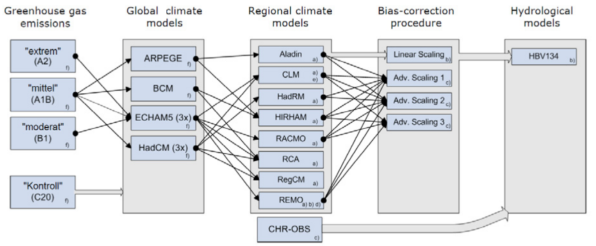
Climate change

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%*

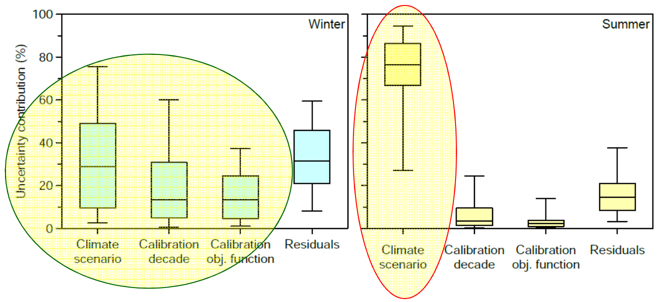
Less summer-precipitation

Higher winter-temperature

Need to consider uncertainty

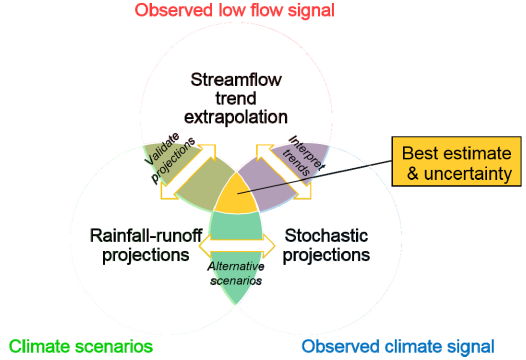
Model cascades – cascades of uncertainty
Study: Uncertainty contributions to low flow projections (Austria)

Ensemble uncertainty (% of true value):
Winter-regime: up to 60% **Summer-regime: up to 20%**



Parajka et al. (2016, *HESS*)

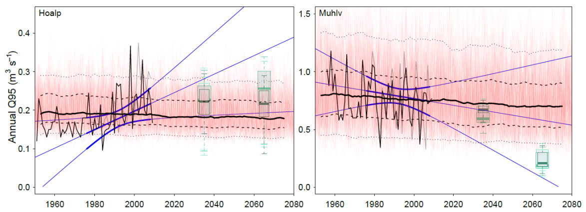
Using different pillars of information



Laaha et al. (2016, *HESS*)

Example: 3-pillar approach

- Synoptic view of data, model outputs and process reasoning
- (In)consistency of pillars → indicator of (un)certainty



Green: climate projections
Blue: Low flow trend
Red: Stochastic projections

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

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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

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