A synthesis of low flow prediction at ungauged basins – PUB report and beyond

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Outline of presentation

A synthesis of low flow prediction at ungauged basins:

- PUB report…
  - Low flow and drought characteristics
  - Processes & Similarity
  - Low flow regionalisation methods
  - Benchmark assessment
  - Lessons to be learned
- … and beyond
  - FRIEND-Water
  - COST-Action: Low flows and droughts in a changing climate

PUB report … Setting the scene

- The PUB-community
  … is compiling a Benchmark Assessment Report for Predictions in Ungauged Catchments (PUB, 2007).
- Its purposes are:
  - to assess the state of hydrological predictions in the absence of data,
  - to identify future challenges for prediction,
  - to serve as a reference benchmark for future achievements,
  - and to quantify predictive uncertainty in clearly specified contexts.
- Chapters … runoff parameters
  (…extreme and average runoff conditions at different time scales)
- The Chapter on low flows
  - jointly compiled by EURO-FRIEND Low Flow and Drought Group and experts from the PUB initiative
  - aims at a synthesis from benchmark studies from all over the world

Low flows and droughts – definition and indices

- Definition
  - Low flows … low stream flows during dry periods
  - Streamflow drought … lack of water for specific purpose
- Characterised by
  - Low flow indices
    - Flow quantiles (Qx)
    - Mean annual minimum flows (MAMd)
    - Flows of a given return period ($Q_{d,T}$),
  - Streamflow drought indices
    - **Duration indices:** Maximum duration (MaxD) and average duration (MeanD) of dry spells.
    - **Volume indices:** Maximum volume (MaxV) and sum of volumes (SumV) of dry spells.

Low flows and droughts – definition and indices

– Streamflow drought indices
- **Duration indices**
- **Volume indices**

- Sum / max Duration
- Sum / max Volume

Threshold -> e.g. Q70

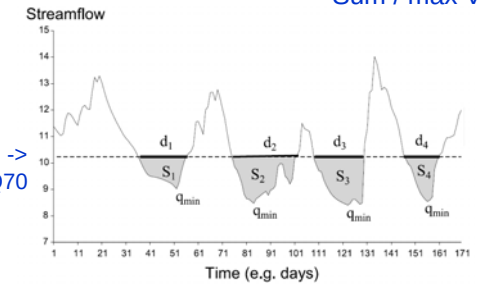


Figure: Definition of streamflow deficit duration d_i and volume S_i of dry spells. From Engeland et al. (2004).

Processes

- A flow in a river is the result of the complex natural processes, which operate on a catchment scale
- Main processes / drivers of low flows?
- What makes two catchments similar?

… catchemnt similarity = the basic principle of regionalisation

Low flow generating processes

- Climate forcing
  - Two types of low flows
    - Summer low flows
    - Winter low flows

Figure: Summer and winter low flows. Left: Baker River, Chile; right: River Inn, Austria.

Low flow generating processes

- Catchment processes
  - **Land surface processes**
    - determine water for infiltration
      - surface, topo, soil, vegetation, climate
  - **Soil processes**
    - determine how quick water flows vertically to recharge groundwater
      - Soil moisture capacity and drainability
  - **Aquifer processes**
    - groundwater discharge to the stream
      - storage and release properties
  - **Lakes**
    - additional storage to maintain low flows
    - lake evaporation losses (semi-arid)

Figure: Upper: Danube at Immendingen, Germany; lower: Karst system of Plitvice Lakes, Croatia.

Low flow generating processes

- Human influences
  - abstractions from / discharges into rivers, reservoir storage, land use change
  - reservoirs have a major effect on fluctuation:

Between-day Within-day fluctuations

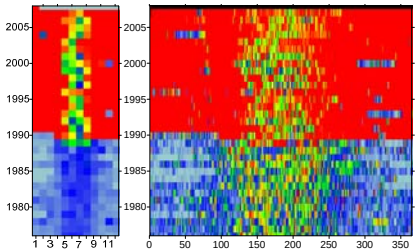


Figure: Impact of reservoir operation (startup in April 1990) on the amplitude of discharge fluctuations. River Salzach at Wald im Pinzgau. **Left panel:** monthly average fluctuations of daily discharges, **right panel:** daily average fluctuations of hourly discharges.

What makes two catchments similar?

- Seasonality
  - Linked to climate

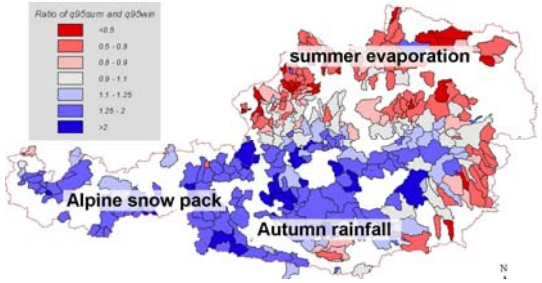


Figure: Seasonality ratio - ratio of summer and winter low flow discharges for 325 sub-catchments in Austria. From Laaha & Blöschl (2006b).

Similarity

- Response time and flashiness
  - Linked to catchment processes

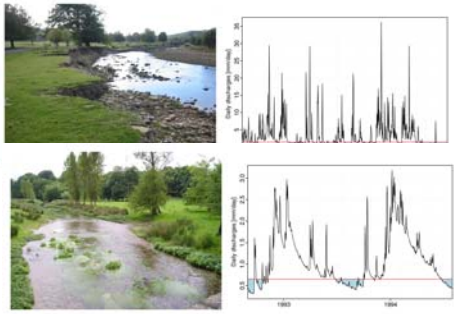


Figure: Hydrographs of a flashy (South Tyne at Featherstone, UK, upper panel, mooreland, LIMESTONE) and a slowly responding catchment (Kennet at Theale, UK, lower panel, CHALK).

Similarity

- Base flow and recession behavior
  - Linked to flows from stored sources

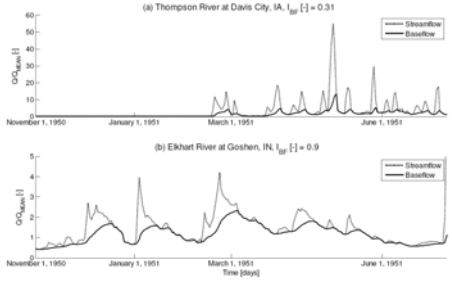


Figure: Sawicz et al., 2011, HESS

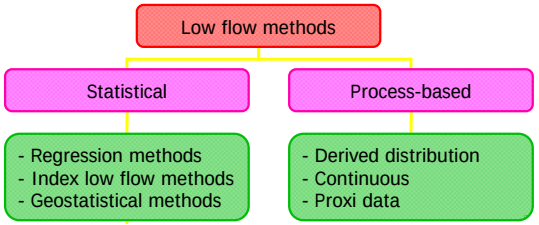
Similarity

Indicators of similarity

- Discharge characteristics
  - Base flow index BFI, recession constant Rec
- Climate characteristics
  - Temperature, Precipitation, Evapotranspiration
- Catchment characteristics
  - **Morphometric** and **topographic** properties
  - **Hydrogeological information** (physical properties - porosity, storativity and transmissivity). Hydrogeological and soil classes
  - **Land use**
- Spatial proximity
  - Close-by catchments are likely to be similar (climate, geology, …)

=> Used in regionalisation methods

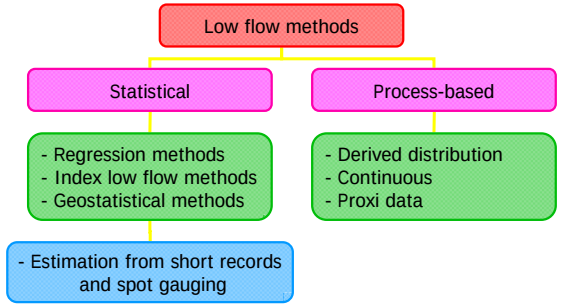
Methods for low flow regionalization



Methods for low flow regionalization

- Statistical methods
  … some kind of correlation of low flows
  - Regression methods … with catchment characteristics
  - Geostatistical methods … spatial autocorrelation
  - Index low flow methods … pooling of similar catchments
- Process-based methods
  … representation of important low flow processes
  - Derived distribution approaches
  - Continuous models (rainfall-runoff models)
  - Proxi data (site visits, distribution of springs)

Methods for low flow regionalization



Benchmark assessment

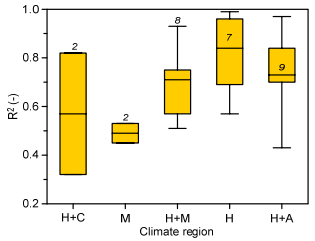
Assessment Method

Comparison of performance measures from existing studies

- Level 1: Studies where overall performance measures were available
  - 28 individual assessments in 15 studies
- Level 2 : Detailed studies where performance for individual catchments were available
  - 8 individual assessments in 6 studies

Assessment - Level 1

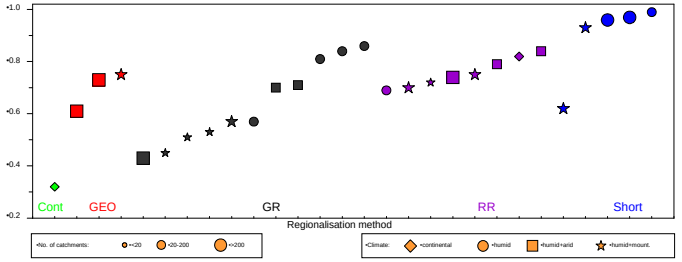
- Performance (R^2) by climate



→ Uncertainty depends on geo-climatic region

Assessment - Level 1

- Performance (R^2) by regionalisation method



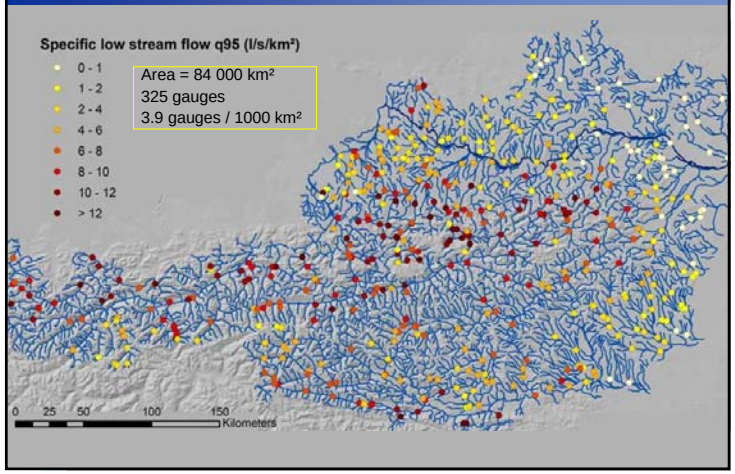
→ Differences between methods,
but unclear if/how they depend on specific setting

Assessment - Level 1 – benchmark studies

- Subset: benchmark studies (more than one method)
  -> assessment by relative ranks

  – Austria (Laaha & Blöschl, 2005, 2006ab, 2007, in prep.)
  – France (Plasse & Sauquet, 2010)
  – Norway (Engeland and Hisdal, 2009)
  – USA (Kroll et al., *in prep*)

Example Austria - Data



Example Austria – overview

Tested Models

- Global Regression (GR)
- Regional Regression (RR)
  – various groupings (Sea, Tree, Res, Clus)
- Regression adjusted to obs. (SAR – Sea)
- Geostatistical Top-kriging (Geo)
- Spot gauging (Spot)
- Short records with climate adjustment (Short)

Results – Austria, all models

	GR	RR-Sea	RR-Tree	RR-Res	RR-Clus	SAR-Sea	Geo	Spot	Short
R^2 (-)	0.57	0.70	0.64	0.63	0.59	0.75	0.75	0.62	0.93
rmse ($ls^{-1}km^{-2}$)	2.62	2.22	2.40	2.43	2.56	2.00*	2.03*	2.48*	1.27*
rrmse (-)	0.41	0.35	0.38	0.38	0.40	0.31*	0.32*	0.39*	0.20*
Rank	9	4	5	6	8	2	3	7	1

Benchmarking according to error measures (cv)

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- Adjusted Regression better than unadjusted

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- Regional regression better than global regression
- Seasonality based grouping better than others
- Adjusted Regression better than unadjusted
- Geostatistical Top-kriging better than regressions
- Short records > 1-5 ys. outperforms regionalization

Assessment - Level 2 – detailed studies

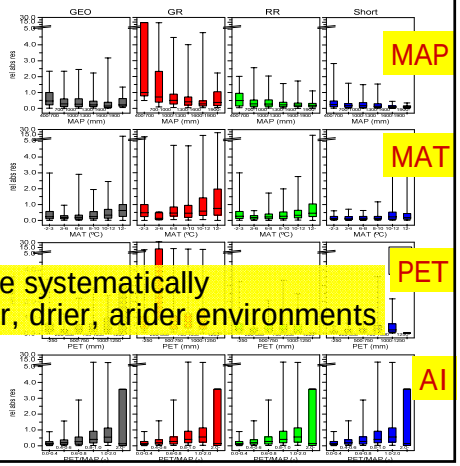
- List of studies with more detailed information

Study	Region	No. of catch.	Method	Area (km^2)	ELEV (m)	MAP (mm)	PET (mm)	MAT (°C)
Eng et al. (2011)	United States (east)	516	Short	+	+	+	+	+
Eng et al. (2011)	United States (central)	125	Short	+	+	+	+	+
Eng et al. (2011)	United States (west)	422	Short	+	+	+	+	+
Engeland & Hisdal (2009)	Norway (southwest)	51	RR	+	+	+		+
Laaha & Blöschl (2005)	Austria	131	Short	+	+	+	+	+
Laaha & Blöschl (2006a)	Austria	325	RR	+	+	+	+	+
Laaha et al. (2007)	Austria	300	GEO	+	+	+	+	+
Plasse & Sauquet (2010)	France	585	GR, RR, GEO	+	+	+	+	+

Assessment - Level 2 – detailed studies

- Climate

Overall, relative errors
(-) with MAP,
(+) with MAT,
(+) with PET,
(+) with aridity index PET/MAP



=> rel. errors are systematically higher for warmer, drier, arider environments

… putting it all together

Lessons to be learned

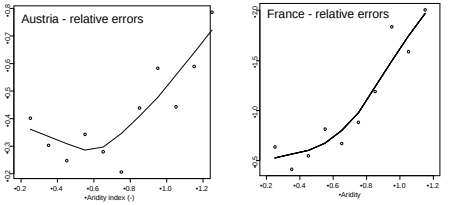
What is the best regionalization model?

- Statistical models outperform process based models
  … insufficiently adapted for low flow situation
  … calibration at ungauged catchments?
- Performances of statistical - depend on the situation
  – setting of the study area
  – available data
- Larger catchments, main rivers, high gauging density
  … **Geostatistical models** (for stream networks!)
- Headwater catchments
  … **Regression** - information transfer (similar catch.)

Opportunities for progress

What are the main sources of uncertainty?

- Hydrological complexity
  … mountainous , karsts, catchment boundaries
- Data availability
  … geostatistical -> gauging density
  … regression -> catchment characteristics
- Climate (aridity)



Opportunities for progress

How can predictive uncertainty be reduced?

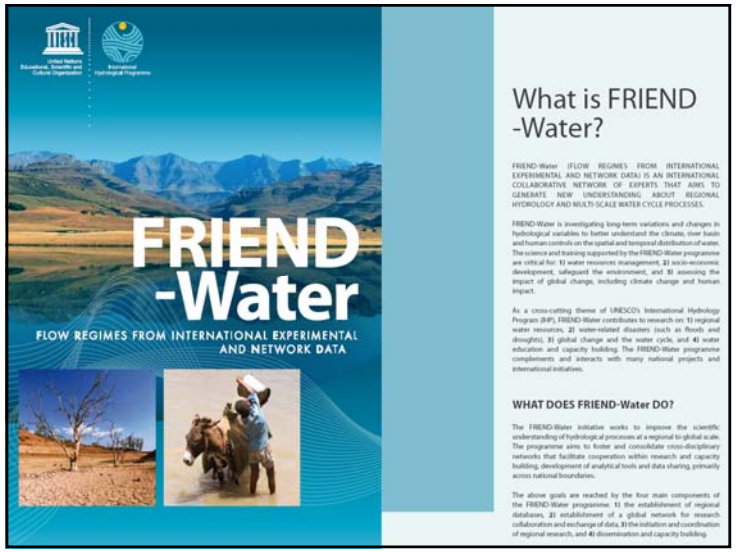
- Choice of the model
  … synthesis report can help !
  … cross-validation can help, too!
- Using additional streamflow information
  … short records !
  – 1 year of continuous low flow data can outperform even highly sophisticated regionalisation models when climate adjustment is used (Austria)
  – 6 temporally independent streamflow measurements applied within the baseflow correlation method were sufficient to outperform global regression (USA)

Research gaps

Assess and develop methods

- for data scarce situations
- for different climates
- process-based models

... and what about low flows under climate change???



COST-Action (Proposal)

COST-Hearing: 2 March 2012, Brussels

FRIEND-Water: Low flows and droughts in a changing climate

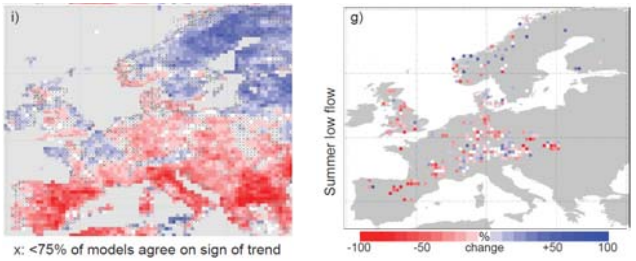
Presenter: Kerstin Stahl (Freiburg)
Proposer: Gregor Laaha (BOKU)

&

David Hannah, Henny van Lanen,
Christel Prudhomme, Lena Tallaksen

State of Knowledge: Recent Trends and Future Projections

- Coupled climate-land surface hydrology models: Ensemble
- Do models represent reality?



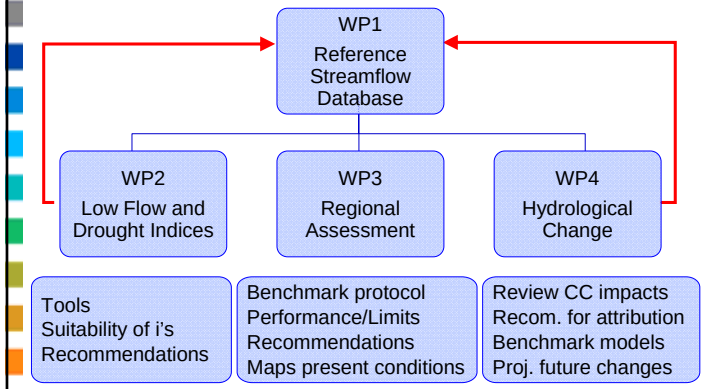
→ Summer low flows have decreased
→ Strong geographic patterns
→ Differences in strength
→ high local variability

Source: Stahl, Tallaksen, Hannaford and van Lanen, 2012, Hydrol. Earth Syst. Sci. Disc.

Main Objective of the Proposed Action

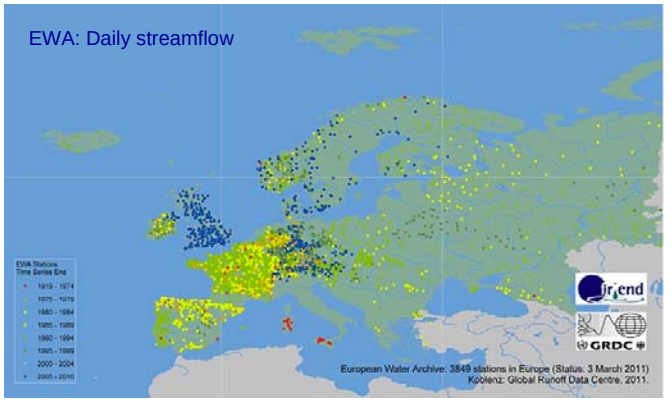
- to derive and integrate a set of common indices and tools applicable for past, present and future analyses of low flow and drought across a range of hydroclimatological regimes in Europe.
- This will allow a robust, comprehensive and consistent analysis and assessment of recent changes in water resources at the pan-European scale

Four Working Groups and their Scientific Work Programme



Four Working Groups and their Scientific Work Programme

- WG1: Reference Streamflow Database „iEWA“



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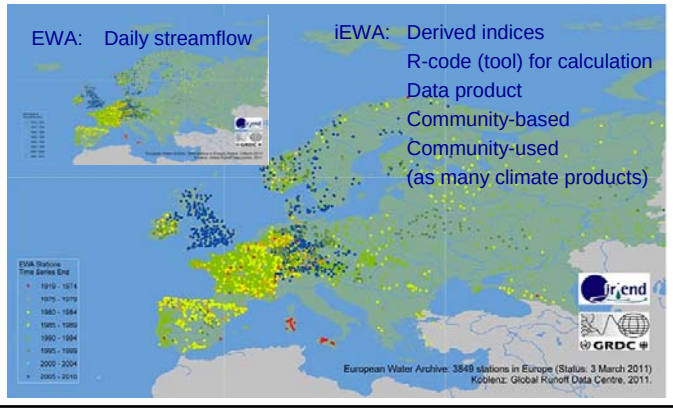

EURO FRIEND-Water – Low flow and drought group

http://www.euro-friend.de/