Stress test storylines for the quantification of streamflow drought sensitivity

Kerstin Stahl[1], Michael Stoelzle[1], Maria Staudinger[2], and Markus Weiler[3]

AGU 100 FALL MEETING Washington, D.C. | 10-14 Dec 2018

Stress testing

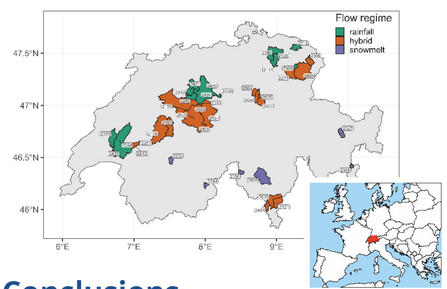
Low flows and streamflow droughts are the result of decreased recharge and a depleted outflow of water stored in the catchment. This response modifies climate and can vary strongly among catchments. By direct alteration of pre-drought recharge, rather than climate variables, two storyline-type model experiments test explicitly the sensitivity of streamflow drought in catchments with different storage and release characteristics.

The work aims to inform low flow management adaptation in Switzerland and Southern Germany and expands on earlier model experiments by Stoelzle et al. (2014, 2018) and Staudinger et al. (2015).

Staudinger et al., 2015, *Hydrol. Earth Syst. Sci.*
Stoelzle et al., 2014, *Geophys. Res. Lett.*
Stoelzle, M et al., 2018, *Proc. of the Int. Assoc. of Hydrol. Sci. (PIAHS)* (in review).

Data & Catchments

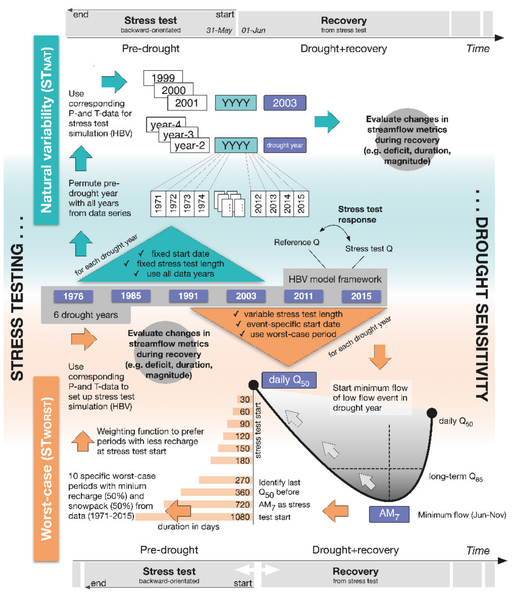
- 40 meso-scale (1-1000km^2) catchments grouped into rainfall-, hybrid- and snowmelt-dominated regimes.
- Daily data 1971-2015: precipitation and temperature (RHiresD and TabsD, MeteoSwiss) and observed streamflow (Swiss FOEN)



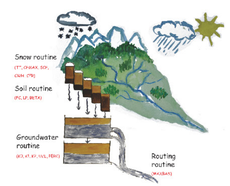
Stress testing model framework

Low flow indices of past drought years are assessed from model experiments with modified pre-drought recharge against the reference.
The stress test STNAT permutes pre-drought recharge based on the entire historical record.

The stress test STWORST subselects low pre-drought recharge periods to stress the hydrological systems. Their sensitivity is assessed by comparing drought indices of past drought years from stressed experiments against the unstressed reference model run.



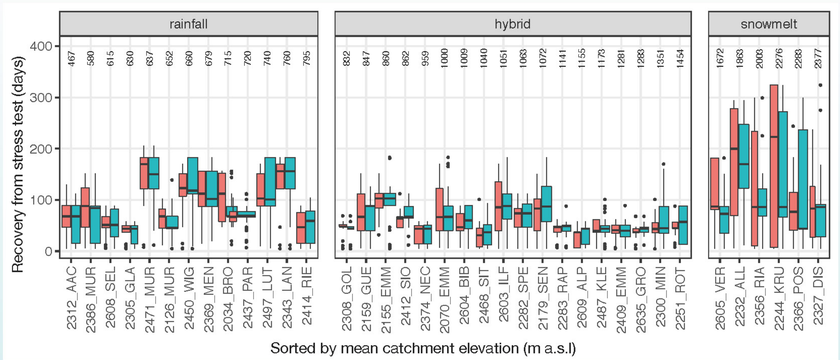
HBV model



Seibert and Vis (2012), *Hydrol. Earth Sys. Sci.*

- Hydrological bucket-type model
- Reference streamflow is simulated from an optimized parameter set (GAP calibration)

Natural historical variability: a story of the range of responses



Pre-drought recharge
higher
lower

Each boxplot pair consists of 39 drier but also wetter recharge stress x 6 drought test years = 234 stress tests. Single boxplots have between 60-170 stress test years.

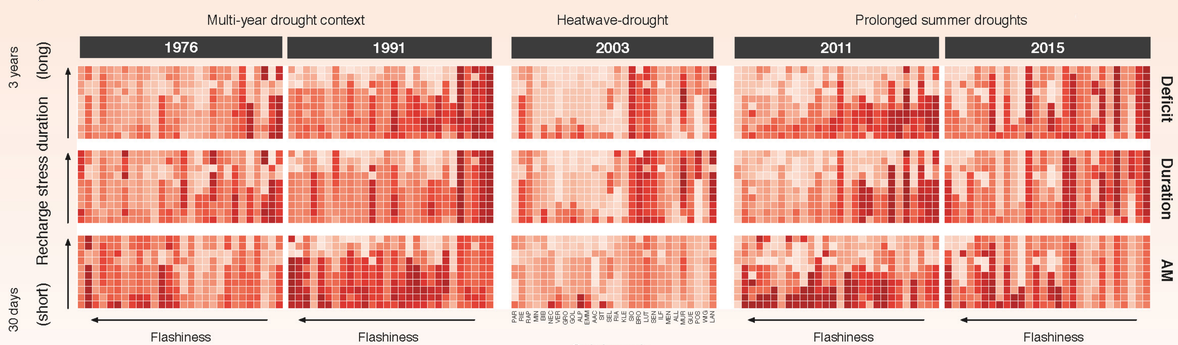
Storyline "Pre-drought year"

Permutation of natural recharge variability in the pre-drought year lead to drier as well as wetter pre-conditions and therefore not always to additional stress. The responses, measured by the recovery duration of the following summer drought (i.e. how long the system requires to approach the reference simulation) shows a considerable range of variability in individual catchments and among catchments.

Regime	Pre-drought	Recovery from stress test (days)
snowmelt	wetter	89 ± 74
	drier	87 ± 52
hybrid	wetter	63 ± 37
	drier	55 ± 35
rainfall	wetter	113 ± 88
	drier	127 ± 105

Only a few catchments with hybrid regime show prolonged drought recovery times for lower preceding recharge. Some rain-dominated regimes under decreased recharge stress show the longest mean recovery times of >100days; higher-elevation snow dominated regimes show the longest maximum recovery times but also the largest variability for all test years.

Worst-case pre-conditions: a story of intensification



Heatmap panels show ranked response intensities by recharge-stress duration (y-axis) and catchments organized by their flashiness (x-axis). Ranks were derived for each metric from the sample of all drought events, all recharge-stress durations and all catchments (n=5x10x40).

Storyline "Drought events"

Pre-drought recharge reductions most consistently intensify streamflow responses in a multi-year drought context. They exert less influence on heatwave droughts, which appear more event-controlled.

Storyline "Catchments"

Catchments' response intensifications to stress vary strongly, pointing to their uniqueness. Deficit and duration responses intensify more for generally less flashy, more baseflow dominated catchments.

Storyline "Deficit"

Pre-drought recharge reductions cause higher deficits in the (less flashy) groundwater- and snowmelt-dominated catchments. Deficit measures the intensification of the deficit below the seasonal Q85 for the Jun–Nov season compared to that of reference streamflow. Deficit is normalized by Q50-days.

Storyline "Recovery"

Recovery duration (in days) measures how long the system requires to approach the references simulation.
Catchments with stable regimes (less flashy) often respond with the longest recovery durations but longer recharge stress durations do not necessarily lead to longer recovery durations.

Storyline "Minimum Flow"

Annual minimum (AM) flow measures the low flow change in % for the Jun-Nov season.
Flashy catchments respond with more decreased minimum flows, especially for shorter duration recharge stress tests (<180 days). The response in this story contrasts those of the other metrics.

Conclusions

- Changing the recharge in the pre-drought year leads to drought intensification up 200-300 days.
- Groundwater- and snowmelt-dominated are often more sensitive to pre-drought changes.
- Catchments with more a stable flow regimes show larger drought deficits and longer recovery, catchments with a more flashy regime show drought intensification in terms of decreased minimum flows.
- No additional drought intensification is found for stress tests longer than 1 year.
- The concept of stress testing is complementary to climate change scenarios and was developed specifically to develop easy to communicate storylines that may inform adaptation and low flow management in a geographic region with rather unclear and contrasting seasonal climate change projections.

(1) Environmental Hydrological Systems, Faculty of Environment and Natural Resources, University of Freiburg, Germany (2) Department of Geography, University of Zurich, Switzerland
(3) Hydrology, Faculty of Environment and Natural Resources, University of Freiburg, Germany

Follow us on Twitter @UHydroFreiburg **Poster-Download:** researchgate.net/profile/Michael_Stoelzle **Data** Bundesamt für Meteorologie und Klimatologie MeteoSchweiz, Bundesamt für Umwelt BAFU, Office fédéral de l'environnement OFEV