Task 2.1

Title

Morpho-climatic controls

Projects (presented on the following pages)

Predictability of Droughts using Monthly Forecasts
K. Bogner, M. Zappa

Glacier inventory for ice volumes from ice penetrating radar and glaciological modeling
Melchior Grab, Lisbeth Langhammer, Sebastian Hellmann, Gregory Church, Hendrik Pormes, Lino Schmid, Lasse Rabenstein, Andreas Bauder, Hansruedi Maurer

Climate change effects on reservoir inflows (Maggia valley, OFIMA)
Sebastian Moraga, Nadav Peleg, Daniela Anghileri, Simone Fatichi, Paolo Burlando

Calibrated Glacier Modelling – Correcting by Collecting
Hendrik Pormes, Lisbeth Langhammer, Melchior Grab, Andreas Bauder, Hansruedi Maurer

Change in Run-of-River Power Production Calculated with the New Climate Change Scenarios CH2018
Tobias Wechsler, Massimiliano Zappa, Manfred Stähli

SCCER SoE
SWISS COMPETENCE CENTER for ENERGY RESEARCH
SUPPLY of ELECTRICITY

SCCER-SoE Annual Conference 2019

Supported by:
Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Confederation

Innosuisse – Swiss Innovation Agency

Predictability of Droughts using Monthly Forecasts

K. Bogner and M. Zappa

70 NRP Energy Turnaround
National Research Programme

Motivation

Main questions:
Is it worth the effort to use monthly forecasts as an early indicator for upcoming dry periods?
Do they have skill, resp. are they reliable at all? When and where did they show the 2018 drought?

Data

In order to answer these questions tercile forecast have been produced for different variables indicating the likelihood of the forecast to be below, close to or above the long-term averages

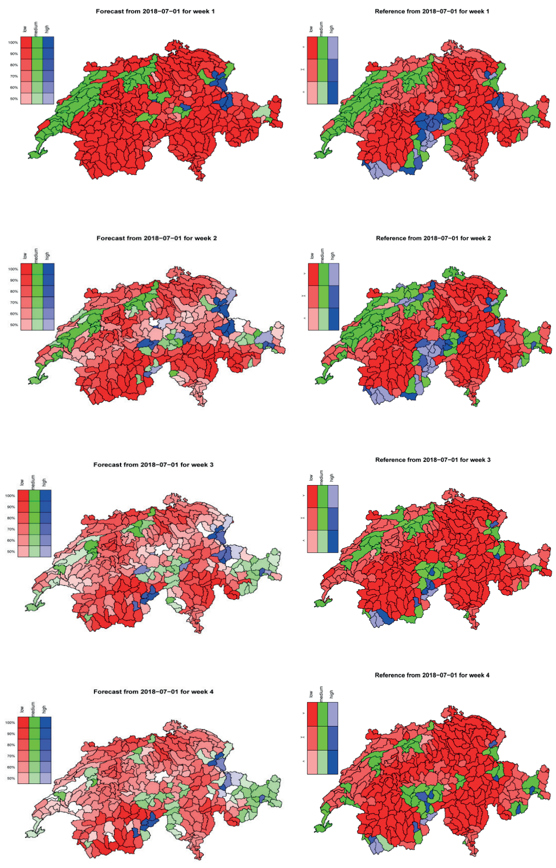


Figure 1: Example of a tercile forecasts end of June 2018 for the upcoming four weeks on the left. The right side shows the reference model simulation with measured meteorological input for the corresponding weeks.

Verification

Quality of the forecast expressed as Ranked Probability Score (RPS), with a perfect forecast shown in dark red (see below). The lighter red, the lower the skill in comparison to a climatological forecast. On the left side the results of the surface runoff are shown for the Summer 2018, on the right side the results for the baseflow R2) are shown after applying post-processing (quantile mapping) for the year 2018

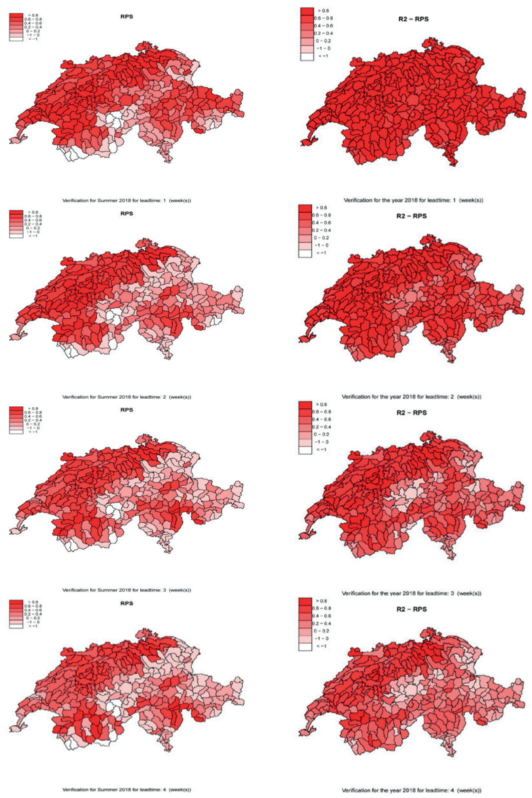


Figure 2: Results of the Ranked Probability Score (RPS) for the Summer period 2018 for the surface runoff (left) and the post-processed baseflow (right)

Results

The skill of the monthly forecasts shows some spatial variability. Especially catchments with glaciers are more difficult to predict.
Variables with short reaction times (surface runoff) are predictable for 1-2 weeks in advance, which can be enhanced using post-processing methods
For slower reacting variables (baseflow) the skill of the forecast lasts for up to 4 weeks
The skill of the Summer 2018 period was higher compared to the long-term predictability (with very stable atmospheric conditions)
Monthly forecasts are gainful! Already end of June the forecasts show some possibilities of dryness for the coming weeks (however site and variable dependent) and post-processing increase the forecast skill!

References

S. Monhart, M. Zappa, C. Spirig, C. Schär, and K. Bogner. Subseasonal hydrometeorologicalensemble predictions in small-and medium-size mountainous catchments: Benefits of the NWP approach. *Hydrology and Earth System Sciences*, (23):493–513, 2019.
K. Bogner, K. Liechti, L. Bernhard, S. Monhart, and M. Zappa. Skill of Hydrological Extended Range Forecasts for Water Resources Management in Switzerland. *Water Resources Management*, 2017.

Acknowledgment:
The authors would like to thank the WSL-Initiative: Drought for supporting this study

SCCER SoE
SWISS COMPETENCE CENTER for ENERGY RESEARCH
SUPPLY of ELECTRICITY

SCCER-SoE Annual Conference 2019

Supported by:
Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra
Swiss Confederation
Innosuisse – Swiss Innovation Agency

Glacier inventory for ice volumes from ice penetrating radar and glaciological modeling

Melchior Grab, Lisbeth Langhammer, Sebastian Hellmann, Gregory Church, Hendrik Pormes, Lino Schmid, Lasse Rabenstein, Andreas Bauder, Hansruedi Maurer

Introduction:
The ongoing melting of glaciers causes a large loss of ice volumes in the Alps: E.g. 75±22 km^3 of ice have been estimated for the year 1973 and 65±20 km^3 for 1999 (Linsbauer et al., 2012). This has consequences for the supply of electricity, for tourism, or with regard to natural hazards. Detailed knowledge of the bed topography is key for developing strategies to deal with risks and new opportunities arising from the glacier melt.

During the past years we have developed AIR-ETH (Airborne Ice Radar ETH Zurich), a helicopter-borne ground penetrating radar (GPR), and the data processing software package GPRglaz for surveying the ice thickness of Alpine glaciers. The acquired data is fed into the recently developed GlaTE algorithm to obtain maps of the ice thickness distribution and bedrock topography. The resulting map-data together with the GPR-data will be made accessible on public data base platforms.

Helicopter-borne Ice Penetrating Radar

- ~1500 km of older radar profiles from various data bases.
- ~1100 km of new radar profiles acquired in the frame-work of SCCER-SoE.
- Additional datasets, e.g. from seismics or boreholes.

Geographic input data

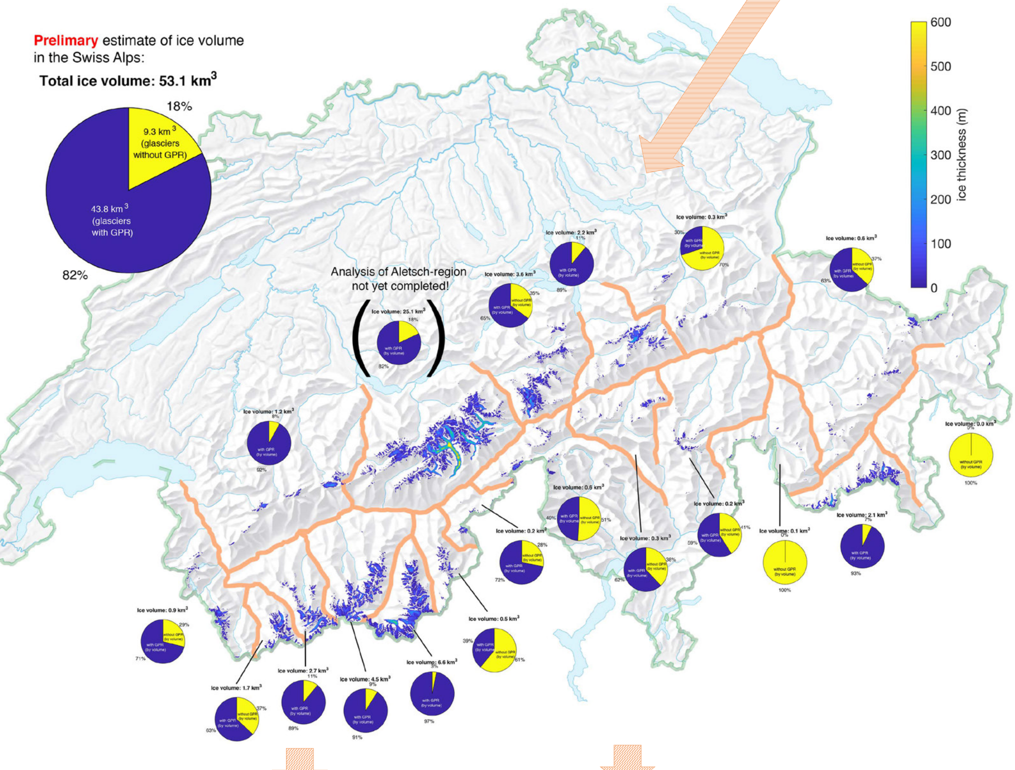
- Digital elevation model from SwissTopo (currently 2008-2016)
- Glacier outline polygons (swissTLM3D, 2019-update in process)
- Manual picking of outlines across Swiss borders (for non-zero ice thickness models at the border)

Glacier Thickness Estimation (GlaTE)

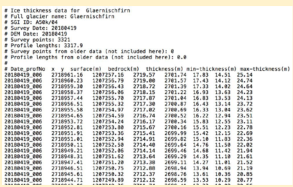
- Glaciological modeling (Clarke at al., 2013)
- Optimized accounting for GPR-ice thickness using GlaTE inversion (Langhammer et al., 2019)

$$\begin{pmatrix}\lambda_1 \mathbf{G}\\ \lambda_2 \mathbf{L}\\ \lambda_3 \mathbf{B}\\ \lambda_4 \mathbf{S}\end{pmatrix}\mathbf{h}^{est} = \begin{pmatrix}\lambda_1 \mathbf{h}^{GPR}\\ \lambda_2 \nabla \mathbf{h}^{glac}\\ 0\\ 0\end{pmatrix} \xrightarrow{\text{invert for } \mathbf{h}^{est}\text{, until}} \left\|\mathbf{G}\mathbf{h}^{est} - \mathbf{h}^{GPR}\right\| < \varepsilon^{GPR}$$

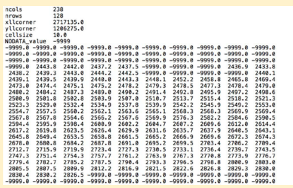
- Calibrated glacier modeling for glaciers without GPR profiles (see poster of H. Pormes)



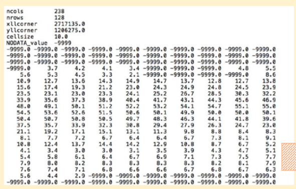
Dataset 1:
Surface elevation and ice thickness from new GPR profiles



Dataset 2:
ESRI grid file with bedrock topography from GlaTE modeling



Dataset 3:
ESRI grid file with ice thickness distribution from GlaTE modeling



Final Steps:
1. Quality control of older GPR-input data (ice surface altitudes)
2. Optimizing weighting factors of the GlaTE inversion
3. Updating GlaTE inversion with the newest outlines and DEM's.
4. Uncertainty estimates
5. Publishing data on databases such as WGMS and/or GLAMOS

Acknowledgments:

We thank for the fruitful collaboration with P. Lathion, P. Schaer, K. Délèze (GEOSAT), B. Rinderknecht (BRTechnik), C. Bärlocher (ETH Zurich), AIR Glacier and Heli Bernina. Financial support was provided by ETH Zurich, the Swiss Geophysical Commission, and SCCER-SoE/Innosuisse.

References:

Clarke, G. K., Anslow, F. S., Jarosch, A. H., Radić, V., Menounos, B., Bolch, T., & Berthier, E, Ice volume and subglacial topography for western Canadian glaciers from mass balance fields, thinning rates, and a bed stress model. Journal of Climate, 26(12), 4282-4303, 2013.

Langhammer, L., M. Grab, A. Bauder, & H. Maurer, Glacier thickness estimations of alpine glaciers using data and modeling constraints. *The Cryosphere*, *13*(8), 2189-2202, 2019

Linsbauer, A., F. Paul, & W. Haeberli, W, Modeling glacier thickness distribution and bed topography over entire mountain ranges with GlabTop: Application of a fast and robust approach. Journal of Geophysical Research: Earth Surface, 117(F3), 2012.

SCCER SoE
SWISS COMPETENCE CENTER for ENERGY RESEARCH
SUPPLY of ELECTRICITY

SCCER-SoE Annual Conference 2019

Supported by:
Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Confederation

Innosuisse – Swiss Innovation Agency

Climate change effects on reservoir inflows (Maggia valley, OFIMA)

Sebastian Moraga, Nadav Peleg, Daniela Anghileri, Simone Fatichi, Paolo Burlando

Motivation

Climate change is expected to affect the hydrological system (e.g. modifying river flows, snow accumulation and melt), with consequences for the inflows to hydropower reservoirs and therefore their operation policies.

In the context of Task 2.4, we studied the effects of climate change on the three largest reservoir systems of the OFIMA hydropower system in the Maggia valley, Robiei-Zott, Cavgnoli-Naret, and Sambuco.

Objectives

- To estimate local climate change effects (precipitation and temperature) over the Maggia region for mid of the century and for a severe emission scenario (RCP8.5).
- To estimate the changes of the future inflows to the three reservoir systems.
- To provide inflows scenarios to Task 2.4 for the investigation of new hydropower operational policies, which account for uncertainties of changes in climate and hydrology.

Methods

- Changes in precipitation and temperature are estimated using 9 climate models that were post-proccessed in the official CH2018 climate change scenarios initiative.
- The AWE-GEN-2d stochastic weather generator model is used to produce local climate variables needed for the hydrological projections (present and future) at high-resolution of 2-km and 1-h.
- The Topkapi-ETH distributed hydrological model is used to simulate the basin hydrology and estimate the inflows to the reservoirs.

Climate change

- Temperatures in the Maggia valley are projected to increase during all seasons. The changes in precipitation are less pronounced, with most months showing small changes that are within the range of the natural variability (Fig. 1).

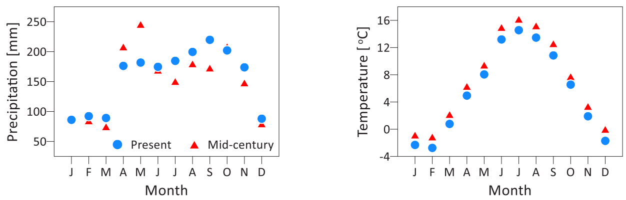


Fig 1. Example of changes in precipitation (left) and temperature (right) averaged over the Maggia valley, downscaled from the ECEARTH_CLMCOM-CCLM4 model using AWE-GEN-2d for the period 2030-2059.

- While the increase in temperature is projected to be relatively homogenous in space, precipitation is projected to change more in the central and southern areas than the northeast and southwest areas (Fig. 2).

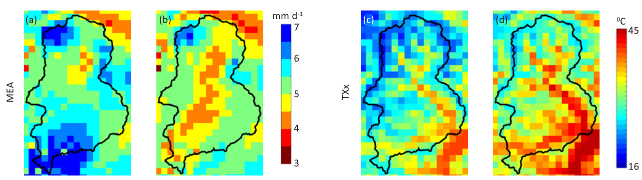


Fig 2. Comparison between present and future mean daily rainfall (left) and hottest day of the year (right) over the Maggia valley. Climate indices were computed from downscaled simulations driven by the IPSL_SMHI-RCA model.

Present inflows to the reservoirs

- Inflow data for the three reservoirs were obtained from OFIMA for the period of 2005-2015.
- Outputs (100 simulations, daily runs) from a preliminary set-up of the Topkapi-ETH model accounting only for the main diversions and intakes were compared with the observed data (Fig. 3).
- The seasonality and flow dynamics are reasonably reproduced by the model, while the absolute inflow values are either underestimated (for the peak season, Sambuco and Robiei-Zott) or overestimated (all seasons, Cavagnoli-Naret), due to the preliminary set-up.

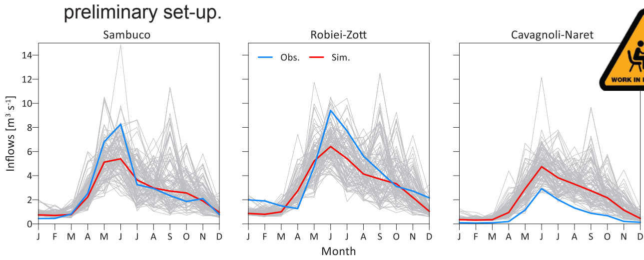
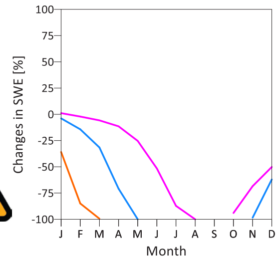


Fig 3. Comparison between the observed (blue lines) and 100 simulations (gray lines) of inflows to the three reservoirs. Red lines represent the median of the stochastic simulations.

Future inflows to the reservoirs

- 200 simulations were conducted to analyze the impacts of climate change on the hydrology for the mid of the century.
- The hydrological system is sensitive to the changes in climate, particularly with respect to the contribution of snow water equivalent, which declines significantly in all reservoirs in the future simulations (Fig. 4).
- Results point at a reduction in the total inflows into the reservoirs, with a clear seasonal pattern (increase during April-May and decrease between June and October, Fig. 5).

Fig 4. Relative change in snow water equivalent contributing to the flow between future and present climate.



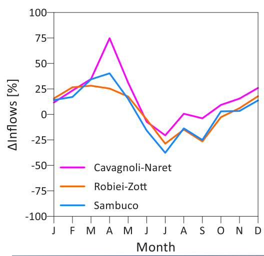


Fig 5. Relative change in inflows to the reservoirs between future and present climate.

Future work

This poster presents preliminary results from the project. For the next year, the following steps are planned:

- Finalizing the setup of the model – adding the missing contributions (e.g. Gries reservoir and Altstafel tunnel and Sfundau reservoir).
- Switching from daily simulations to hourly, in order to simulate sub-daily hydrological processes (e.g., radiation variability) and flow dynamics.
- Update the model parameterization to account for the new HP scheme and to improve the model performance.
- Providing the final set of inflow scenarios to be used for the investigation of future hydropower operation policies in Task 2.4.

SCCER SoE
SWISS COMPETENCE CENTER for ENERGY RESEARCH
SUPPLY of ELECTRICITY

SCCER-SoE Annual Conference 2019

Supported by:
Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra
Swiss Confederation
Innosuisse – Swiss Innovation Agency

Calibrated Glacier Modelling – *Correcting by Collecting*

Hendrik Pormes, Lisbeth Langhammer, Melchior Grab, Andreas Bauder, Hansruedi Maurer

1. How much ice is there left on the glaciers?

- The ice-thicknesses of glaciers can be estimated from surface measurements, such as *Ground Penetrating Radar* (GPR), in combination with glaciological modelling by using our **GlaTE** algorithm *(Langhammer et al.,2019)*
- For glaciers where no GPR data exists, glaciological modelling can be used *(Clarke et al., 2013).* The inputs then are:
  - The glacier boundary
  - The surface topography
- The glaciological model takes the conservation of mass and the physics of ice-flow into account, but there are still some **uncertainties**.
- These uncertainties cause the ice thickness estimations to be over- or under-estimated
- However, we can correct these uncertainties using the **Glacier Factor** $\boldsymbol{\alpha_{GPR}}$, obtain[illegible]e GPR data exists

$$\mathbf{h}^{glac} = \alpha_{GPR}\hat{\mathbf{h}}^{glac}$$

- If the glacier-factor is >1, the ice-thickness is **under-estimated**
- If the glacier-factor is <1, the ice-thickness is **over-estimated**

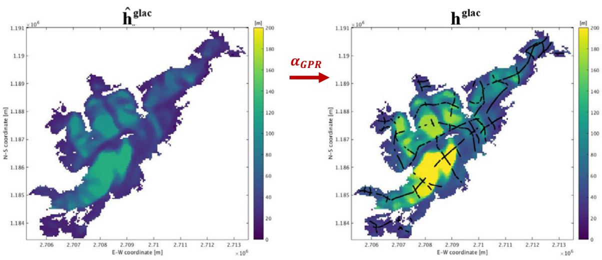
Now the question is..

- *On wat does the value of this Glacier-Factor depend?*
  - Area? Altitude? Exposition? Slope?

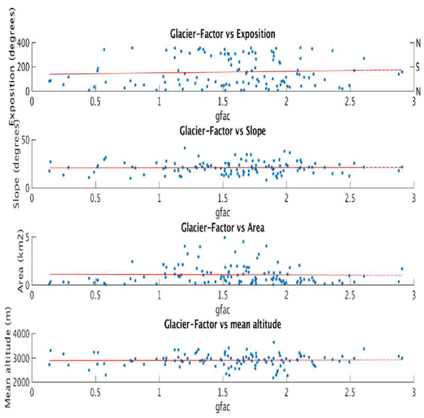
2. Dataset Example

- To illustrate what the GlaTE model does, we take the one glacier, namely the **Huefifirn/Claridenfirn,** as an example:

- The black lines on the h^{glac} model indicate several GPR profiles, which eventually are used for the calibration of the glacier-model
- When we compare the $\hat{h}^{glac}$ and the h^{glac} model, we see that there is a **discrepancy**, which indicates that we need the **Glacier-Factor** $\boldsymbol{\alpha_{GPR}}$, in order to obtain the right results
- Using the Glacier-Factor the difference in what we model and what we measure gets smaller



3. Testing the Glacier-Factor for multiple glaciers



4. Turns out the Glacier-Factor …

- Does ***not*** have a strong correlation with any of the parameters
- Is often completely random

However …

- The Glacier-Factor is almost always above 1!
- Which means most glaciers are **under-estimated**
- The average Glacier-Factor lies around **1.6** with a standard deviation of around 0.3
- This all means that for glaciers without GPR-data the calibration can be done with a Glacier-Factor *higher than 1* in order to minimize the discrepancy

References: - Langhammer, L., Grab, M., Bauder, A., and Maurer, H.: Glacier thickness estimations of alpine glaciers using data and modeling constraints, The Cryosphere, 13, 2189–2202, https://doi.org/10.5194/tc-13-2189-2019, 2019.,
- Clarke, G. K., Anslow, F. S., Jarosch, A. H., Radić, V., Menounos, B., Bolch, T., & Berthier, E, Ice volume and subglacial topography for western Canadian glaciers from mass balance fields, thinning rates, and a bed stress model. Journal of Climate, 26(12), 4282-4303, 2013

SCCER-SoE Annual Conference 2019

SCCER SoE

SWISS COMPETENCE CENTER for ENERGY RESEARCH
SUPPLY of ELECTRICITY

Supported by:
Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra
Swiss Confederation
Innosuisse – Swiss Innovation Agency

Change in Run-of-River Power Production Calculated with the New Climate Change Scenarios CH2018

Tobias Wechsler, Massimiliano Zappa, Manfred Stähli – Swiss Federal Research Institute WSL, Birmensdorf

Research question

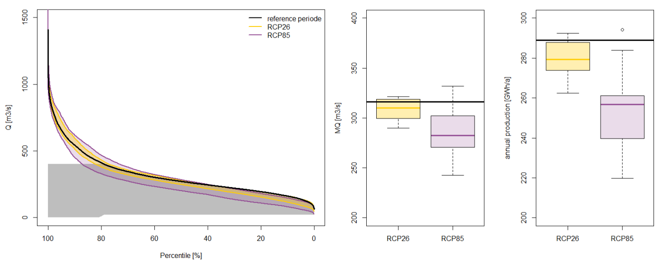
How will run-of-river power production in Switzerland change with climate change?
This depends on the change in the **usable** water volume, which is controlled by the capacity/dimensions of the power plant and the residual flow regulations.

Method

We used the most recent climate change scenarios (CH2018) to calculate the change in water discharge of Swiss rivers (using PREVAH, a state-of-the-art hydrological model) for mid-century (2060) and the end of the century (2085).
Then, we determined for eleven selected RoR power plants the corresponding Flow-Duration Curve (FDC). In a FDC, all daily runoff values are ordered by size and frequency distribution, resulting in a concave shape. The shaded area represents the volume that can be used for power production and is limited by two parameters: 1) the maximum discharge that the power plant can use; 2) the volume that cannot be used for hydropower (HP) because the minimum turbine height is not reached or because discharge is used for residual flow or other purposes. FDCs can be used to estimate the yearly (or half-yearly) power production of a RoR power plant.

Example Wildegg/Brugg – Aare (a typical river of the Swiss plateau)

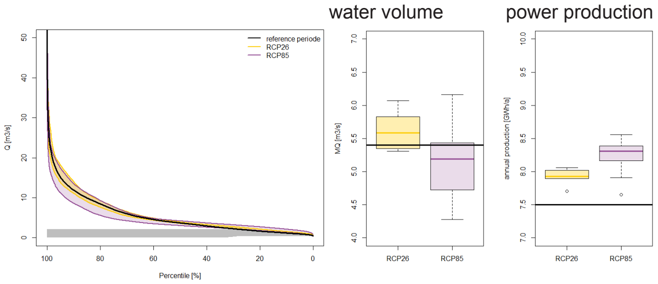
Flow-Duration Curve | Change in available water volume | Change in annual power production



The water volume usable for HP production (shaded area) depends mainly on low and medium water ranges. For the RoR power plant Wildegg-Brugg, the hydrological predictions indicate that both the average water supply and the annual production will decrease in the future.

Example Davos Glaris - Landwasser (a typical alpine river)

Flow-Duration Curve | Change in available water volume | Change in annual power production

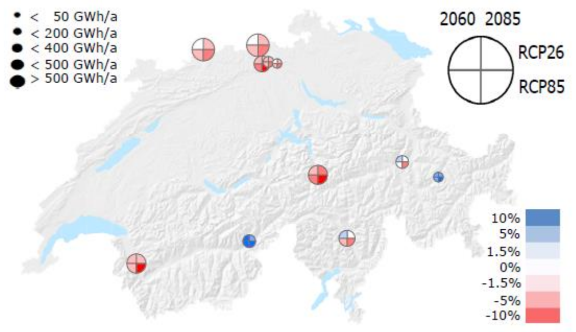


For the RoR power plant Davos Glaris, which is heavily influenced by snow, the total water supply will decline by the end of the century; still, HP production is likely to increase.

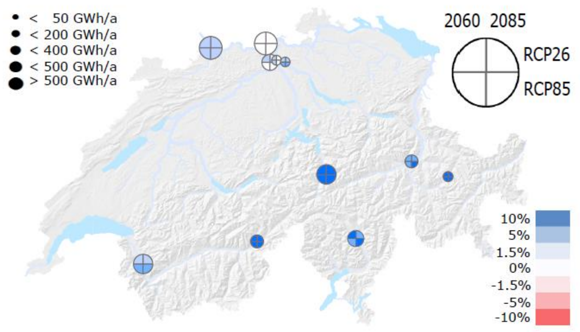
Change in mean annual production:

for eleven selected RoR power plants

for mid-century (2060) and the end of the century (2085) and for two different emission scenarios (RCP2.6 – with the assumption of concerted mitigation efforts; RCP8.5 – with the assumption of no climate change mitigation)



Change in mean winter production (Oct – Mar):



Overall projection for RoR power production in Switzerland

By mid-century (2045-2074):

- **Annual production** will remain roughly the same with concerted mitigation efforts (RCP2.6) as during the reference period. Production will slightly decrease (about -3%) without climate change mitigation (RCP8.5). Exceptions are those power plants that are influenced by strong melting processes.
- **Winter production** will increase at almost every RoR power plant considered in this study by mid-century, on average about +5%.

By the end of the century (2070-2099):

- **Annual production** will decline slightly (-1.5%), even with concerted mitigation efforts (RCP2.6). Without climate change mitigation (RCP8.5), production will even decrease by up to -7%.
- **Winter production** will increase at virtually all of the RoR power plants of this study. Depending on the emission scenarios, the average increases will be between +5% (RCP2.6) and +10% (RCP8.5). However, the increase in winter production will not be able to keep annual production at the same level.