Task 2.4

Title

Integrated simulation of systems operation

Projects (presented on the following pages)

Improved alpine hydropower operation by forecast based optimization
Daniela Anghileri, Samuel Monhart, Andrea Castelletti, Massimiliano Zappa, Paolo Burlando

Multiobjective optimal operation of the Maggia hydropower systems: tradeoffs between environment conservation and hydropower
Daniela Anghileri, Andrea Castelletti, Enrico Weber, Nadav Peleg, Paolo Burlando

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Improved alpine hydropower operation by forecast based optimization

D. Anghileri[1], S. Monhart[2], Z. Chuanyun[1], K. Bogner[2], A. Castelletti[1], P. Burlando[1], and M. Zappa[2]

1) Institute of Environmental Engineering ETH Zurich; 2) Mountain Hydrology and Mass Movements, Swiss Federal Research Institute WSL

Motivation and objectives

Accurate and reliable forecasts are key to anticipate hydro-meteorological events which may inform hydropower operation over different time horizons from hourly operation, to weekly management, to monthly production planning.

The objectives of this work are:

- to analyze the quality of a set of streamflow forecasts on a retrospective dataset;
- to improve the real-time operations of hydropower system when informed by streamflow forecasts;
- to assess the advantage of pre-processing meteorological forcings when producing streamflow forecasts both in terms of forecasts reliability and improved hydropower performance.

Method and tools

We develop a real-time hydropower operation system (Figure 1), composed of:

Meteorological forecasting model
- ECMWF Integrated Forecasting System extended-range forecasts (CY40r1)
- Temporal resolution: daily
- Spatial resolution: 50 km x 50 km
- 32 days lead time and weekly frequency

Bias correction (pre-processing)
- Gridded observed data of precipitation, temperature
- Quantile Mapping approach: daily and lead-time dependent correction [1]

Hydrological forecasting model
- Hydrological model PREVAH Temporal resolution: daily
- Spatial resolution: 500 m x 500 m

Hydropower system optimization and simulation
- Model Predictive Control (MPC) scheme (rolling horizon: 32 days)
- Objective function: revenue computed using mean historical electricity wholesale price [2]
- Median of streamflow forecast ensemble members
- Temporal resolution: daily

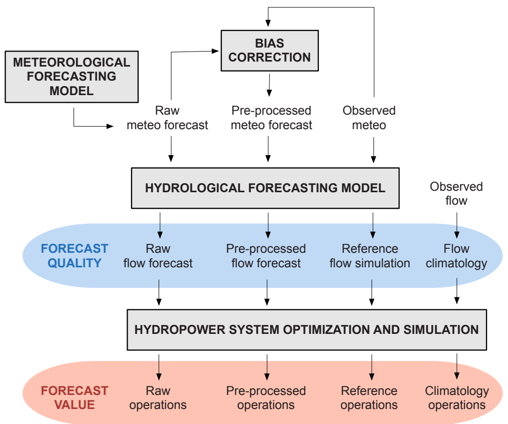

Figure 1: Forecast-based adaptive management scheme. The experimental setting consists of two benchmark (reference and climatology) which are compared with raw and pre-processed forecasts to determine forecast quality and value (see [3] for more details).

Experimental setting

The experimental setting consists of two benchmarks, i.e., climatology and perfect forecasts, which are used to assess the improvement of the forecasts we analyze, i.e., raw forecast and pre-processed forecast (Figure 1).

The **quality of the forecasts** is assessed in terms of Continuous Ranked Probability Score (CRPS) to assess the forecast reliability and sharpness; Mean Error (ME) to assess the forecast systematic bias.

The **value of the forecasts** is assessed in terms of avoided spill and gained revenue.

Study site

The forecast-based adaptive management scheme is applied to the Verzasca hydropower system (Figure 2):

- rain and snow dominated
- reservoir storage: $85 \cdot 10^6$ m^3
- installed power: 105 MW

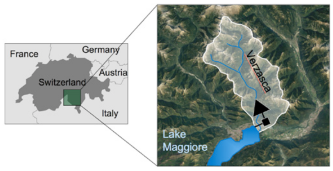

Figure 2: Study area in white and Verzasca hydropower system.

Results

Forecast quality

- Pre-processing allows for downscaling and systematic bias correction (Figure 3a).
- The pre-processing effect varies with lead time and season: spring and autumn shows the largest improvement, in contrast to summer and winter (Figure 3b, c).

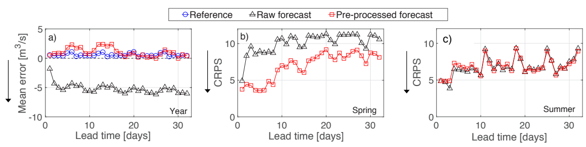

Figure 4: a) Mean annual error of streamflow reference, raw, and pre-processed forecasts, b-c) CRPS computed over spring and summer.

Forecast value

- Increase of 3% when using raw forecasts with respect to climatology (Fig. 5a).
- Increase of 12.5% when considering pre-processed forecasts with respect to climatology (Fig. 5a).
- The improvement is mostly given by the reduction of spill events which are a consequence of the systematic underestimation of reservoir inflows (Fig. 5b).

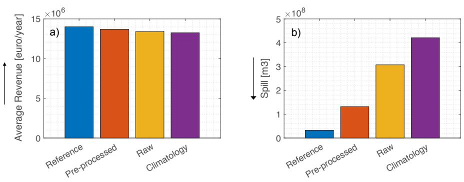

Figure 5: a) Mean annual revenue and b) total spilled volume of the raw and pre-processed forecasts and the two benchmarks.

References
[1] Monhart et al., submitted to JGR Atmoshperes
[2] EPEX SPOT (http://www.epexspot.com/en/)
[3] Anghileri et al. (2016), WRR, 52, doi:10.1002/ 2015WR017864.

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Multiobjective optimal operation of the Maggia hydropower systems: tradeoffs between environment conservation and hydropower

D. Anghileri[1], E. Weber[1], N. Peleg[1], A. Castelletti[1], and P. Burlando[1].

1) Institute of Environmental Engineering ETH Zurich;

Motivation and objectives

Volatile electricity prices and hydrological conditions might call for more flexible hydropower operations, which may expose downstream riverine ecosystems to increased threats.

The objectives of this work are:

- to analyze the well known conflict between hydropower generation and environment conservation;
- to balance the profitability of hydropower companies and environment conservation.

Research questions

- How much do environmental flows limit hydropower operating interests?
- How much will more flexible operations of hydropower reservoirs harm the environment?
- Do the trade-offs between hydropower interests and environment conservation change with increased energy price and water availability uncertainty?

Method and tools

To analyze the tradeoffs between hydropower interests and environment conservation, we use:

i) an hydrological model (Topkapi-ETH) [1]

- to simulate water availability to hydropower facilities;
- to simulate the effects of different hydropower operations on the downstream riverine ecosystem;

ii) a multi-objective optimization technique (evolutionary multi-objective direct policy search) [2]

- to simulate the effects of different environmental conditions on hydropower performance;
- to explore different trade-off operations that aim at balancing hydropower performance and ecosystem conditions.

[1] Fatichi et al. (2015), *JoH* 525, 362–382.
[2] Giuliani et al. (2016), *ERL* 11, 035009

Study site

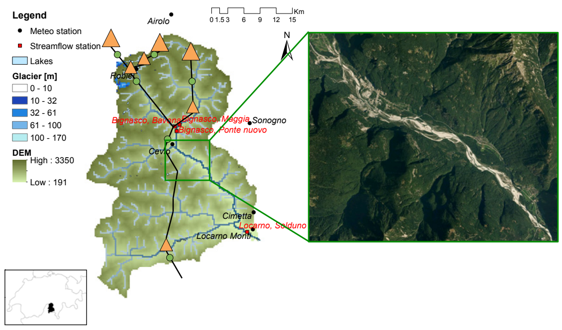

Figure 1: Left: Map of the Maggia river catchment and schematic of the hydropower system (reservoirs and plants are represented with triangles and circles respectively). The system is composed of 7 reservoirs with a total capacity of 600 MW, which produce annually 1265 GWh. Right: satellite image of the natural alluvial river which is regarded a floodplain of national interest.

Preliminary results

Hydrological modeling

We consider two different setups for simulating the pristine ecosystem during the pre-dam condition and the current situation during the post-dam condition.

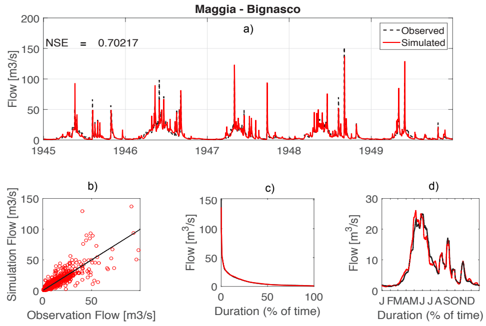

Figure 2: Performances of the Topkapi-ETH hydrological model during the pre-dam condition measured in terms of: a) time series, b) scatter plot, c) duration curve, and d) annual daily mean comparison between observed and simulated flow at Maggia-Bignasco.

Hydropower optimization model

We use multi-objective optimization to balance the following 3 interests:

- maximization of the **net electricity production** (production – pumping);
- maximization of the **net revenue** (production income – pumping cost);
- maximization of the **ecosystem quality** (we consider the pre-dam simulation as the reference target for the optimization).

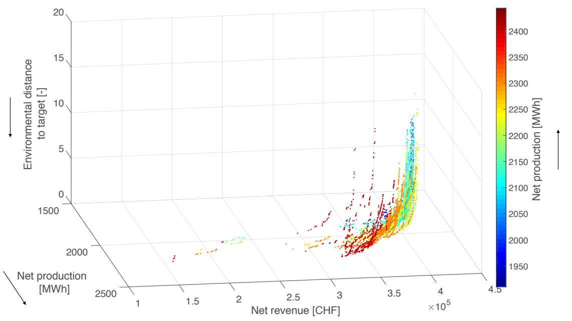

Figure 3: Performances of alternative hydropower systems operations designed using evolutionary multi-objective direct policy search. The different points represent Pareto optimal trade-offs between the above mentioned 3 objective functions.

Outlook

- Compare the optimized trade-offs with different strategies aiming at environment conservation, such as fixed and proportional environmental flows.
- Analyze the evolution of the Pareto optimal trade-offs under climate change and electricity price projections.
- Use a more sophisticated model of the alluvial floodplain to simulate the interaction between surface water and groundwater (in connection to the SNF NFP70 HydroEnv Project).