Optimization of reservoir operation

Although the technique for optimization for hydropower projects is standard practice, the optimization including sediment-management operations has not been presented for dams anywhere. This part of the study demonstrates that with advanced optimization tools it is possible to apply a state-of-the-art approach that successfully optimizes power and sediment management for Funagira HPP.

An optimization of the operation of Funagira Dam (as an example) was set up as a standalone model with the software RTC-Tools 2. RTC-Tools is an open-source Python toolbox for optimization of control in water systems (reservoir outflow, weir crest level position, pump operations, water extractions, hydropower production management) developed and maintained by Deltares.

Model Predictive Control (MPC) for Hydropower

An optimal operational strategy for the current situation can be derived with the help of Model Predictive Control (MPC, Garcia et al., 1989; Schwanenberg, Becker et al., 2015). Instead of introducing rules, operational goals and constraints are formulated as a mathematical optimization problem together with a model of the water system. The water system model computes the system response to an operating strategy under the given boundary conditions.

Within the optimization procedure the system state is evaluated against the operational goals and constraints, smartly adjusting control parameters until the best matching operational strategy is found. Compared to rule-based operations, the added value of MPC is in the operators' capability to take control actions now or in the near future to anticipate on future events (Uysal et al., 2016).

RTC-Tools software package

RTC-Tools 2 has been developed to run under operational decision support systems as a model predictive control component and for standalone-use for planning studies. RTC-Tools is an open source software available under Lesser GPL license conditions. By delivering RTC-Tools as a Python package, maximum flexibility is given to the modeler to handle very complex water system models and operational goals.

RTC-Tools offers two approaches to the handling of competing goals and objectives: the weighting method and lexicographic goal programming (priorities). RTC-Tools supports the use of ensemble forecasts to generate robust solutions under forecasting uncertainty. RTC-Tools can be tightly integrated with Delft-FEWS.

Website: https://www.deltares.nl/en/software/rtc-tools/

Website: https://rtc-tools.readthedocs.io/en/latest/

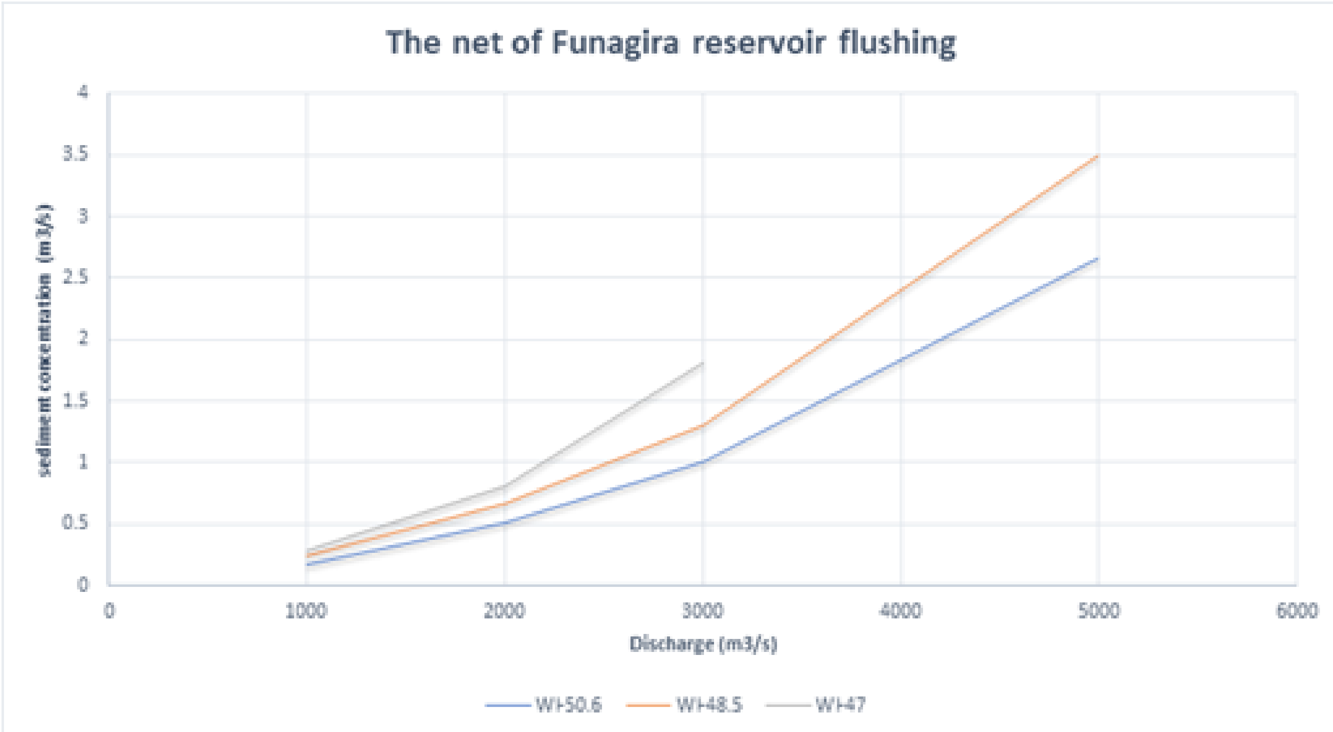
Sedimentation Flow (SQ):

An important objective for the creation of the Funagira optimization model is to be able to take sedimentation flow into account. The actual dynamics of flushing are very complex, so we will have to make some assumptions on how to model this based on the available data and balance the complexity of the modelling.

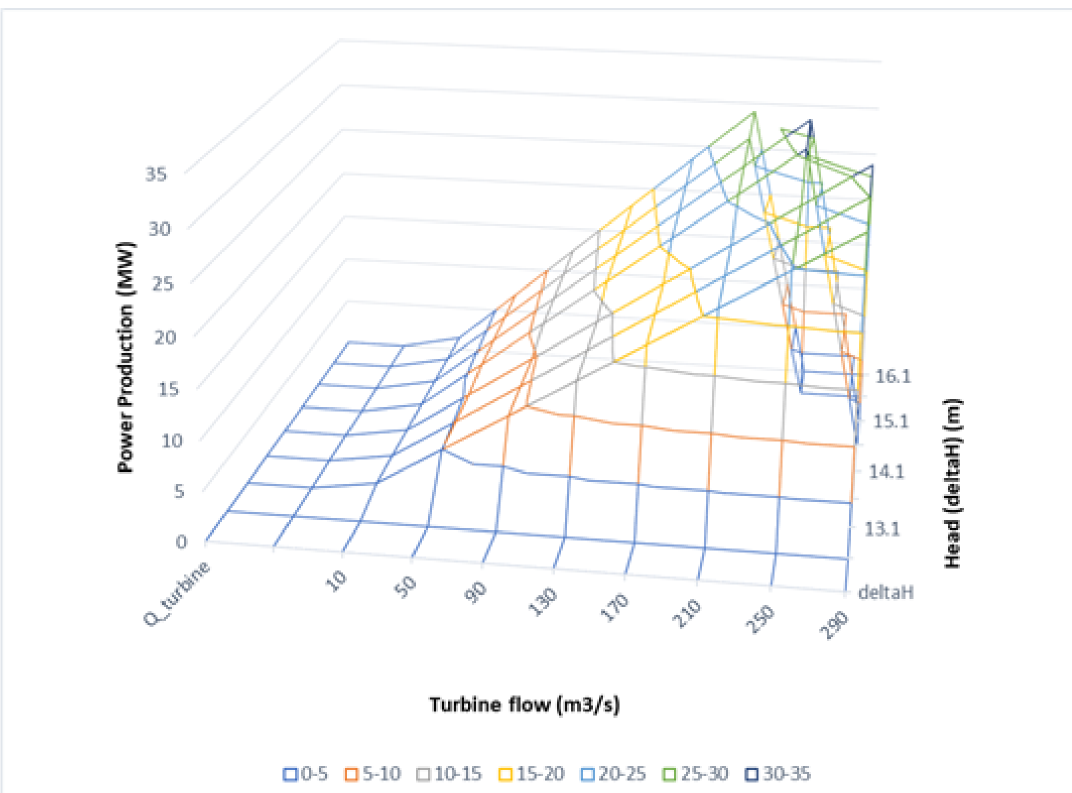
The graph below shows the net erosion rate from the Funagira reservoir (m^3/s) for steady-state simulations (simulation time of 56 hours).

Some points of attention:

- It is expected to achieve this volume if the discharge >1000 m^3/s
- Following this data, sedimentation is only expected at water levels lower than 50.6m
- The net flushing (sedimentation flow) of the reservoir is here expressed as a relation of total outflow *Q_out* and the Funagira reservoir level. This is a proxy as the actual relation is not that straight forward.
- As these flushing values are a result of a steady-state simulation, sedimentation flow values will also be different when *Q_out* will be fluctuating.



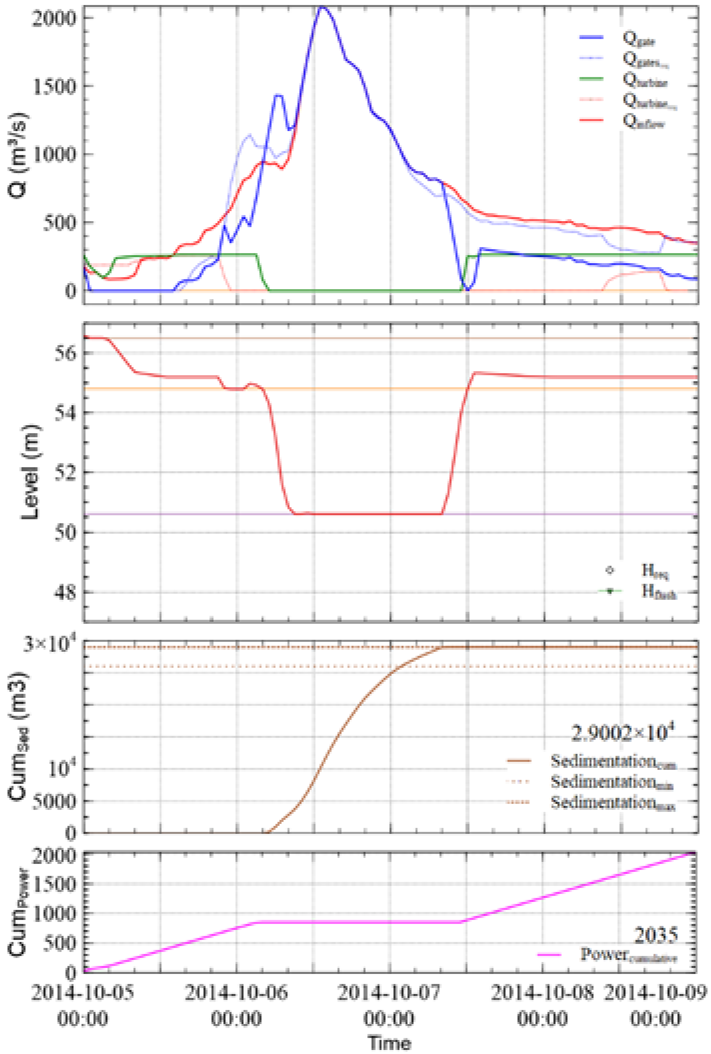
The net of Funagira reservoir flushing (discharge- sediment volume relation)



The relation between power production, the head and turbine flow

Plotting results of the optimization experiments

For this project, we have devised a standard output graph that aims at providing a visual overview of the (optimization) experiment and its quantitative results. An example output graph is presented below.



An example output graph of optimization result

Below a description is given of the elements in this graph that can be interpreted after an experiment.

In the top graph we can see:

- the reservoir inflow in red
- the modelled turbine flow in green (dashed green for the target (real-life) turbine flow)
- the modelled gates flow in blue (dashed blue for the target (real-life) gates flow)

In the second graph we can see

- the target (real-life) water levels as diamond markers
- the modelled reservoir water level in red
- some (static) lines depict specific reservoir levels, like maximum min/max water level of the operational range (typically 54.8m and 56.5m) and the default low water level during flooding situation (50.6m)

The modelled cumulative sedimentation flow (m3) is depicted in the third graph. The value of the final volume (m3) is also printed in the lower-right corner. Any minimum/maximum target sedimentation flows (optional) are also visualized with dashed lines.

The modelled cumulative hydropower generation (MW) is depicted in the final, fourth graph. The value of the final volume is also printed in the lower-right corner. The value of the total power production (MW) is also printed in the lower-right corner.

References:

- Schwanenberg, D., Becker, B. P. J., & Xu, M. (2015). The open real-time control (RTC)-Tools software framework for modeling RTC in water resources sytems. *Journal of Hydroinformatics*, *17*(1), 130-148.
- Garcia, C. E., Prett, D. M., & Morari, M. (1989). Model predictive control: Theory and practice—A survey. *Automatica*, *25*(3), 335-348.
- Uysal, G., Akkol, B., Topcu, M. I., Sensoy, A., & Schwanenberg, D. (2016). Comparison of different reservoir models for short term operation of flood management. *Procedia Engineering*, *154*, 1385-1392.