Work Package 5: Pilot & Demonstration Projects

The key objective of the SCCER-SoE in Phase II is the initiation and in some case completion of pilot & demonstration (P&D) projects, which will be executed in close collaboration with industrial partners. The new WP5 combines the integrated approaches developed for geo-energies (WP1), hydropower (WP2), and the innovative technologies of WP3 in a series of seven P&D projects. The successful completion of these projects is a key milestone to deliver in 2025 a portfolio of tested solutions, which shall enable Switzerland to reach the targets of the Energy Strategy 2050. Status and highlights are summarized below.

The seven demonstrator projects are:
Demo-1: Flagship stimulation experiment in the Deep UnderGround Laboratory
Demo-2: Reservoir engineering for heat exchange in Haute Sorne
Demo-3: Geneva basin-scale hydrothermal play for heat extraction and storage
Demo-4: CO_2 geological storage pilot
Demo-5: Small Hydro-Power Plant
Demo-6: Controlled fine sediment release from a reservoir by a hydrodynamic mixing device
Demo-7: Complex large hydropower scheme

Demo-1: Flagship stimulation experiment in the Deep UnderGround Laboratory

The project aims at a better understanding of the hydroseismo-mechanical coupled processes that are associated with high pressure fluid injections in a crystalline rock mass. Experiments are carried out at various scales ranging from centimeters to hundreds of meters. Intermediate experiments at ten-meter scale are carried out at the Grimsel Test Site, Switzerland. All stimulation activities have been completed in May 2017 and the circulation phase will be performed in Oct-Dec 2017. Subsequently, all personnel and funding will move to the DUGLab Bedretto Pilot Project in 2018 which will demonstrate hydraulic stimulation at hundred-meter scale.

Demo-2: Reservoir engineering for heat exchange in Haute Sorne

GeoEnergie Suisse AG is developing a pilot and demonstration project for deep petrothermal electricity generation in the village of Haute-Sorne (Jura). The system aims at depths of 4000 – 5000 m and is projected to deliver up to 5 MW electricity and/or heat for industrial processes as well as district heating. For the first time, the project will implement the so-called multi-fracture system in a granitic environment. Enabling the success of the Haute-Sorne project is one of the highest priorities within the SCCER-SoE. Many activities will be targeted towards enabling the technology but also in using the data from Haute-Sorne for calibration, upscaling and validation of methods and results, such as strategies for adaptive traffic light seismic monitoring systems, underground heat exchanger design, construction, and optimization, as well as research on optimal fluid circulation and associated heat extraction strategies.

Demo-3: Geneva basin-scale hydrothermal play for heat exchange and storage

This demonstration project will be implemented as part of the “Geothermie 2020” program of the Canton of Geneva. A step-wise approach including drilling wells (production and storage) at progressively increasing depths (650-1500m) will be performed by SIG during Phase II (Q4 2017-2018). This will provide the opportunity to test and validate the effectiveness of exploration concepts and models developed within WP1 as well as proof the feasibility of direct heat production and subsurface storage potential in sedimentary basins at relatively shallow depths. The project is already approved and in advanced stage of realization.

Demo-4: CO_2 Geological Storage Pilot

According to IEA, IPCC and COP21, (Carbon Capture & Storage) CCS has to be implemented to keep global warming within 2°C. ELEGANCY, an SFOE funded P&D project, embedded in a larger European framework, has the mission to provide clean hydrogen for heat and mobility based on steam-methane-reforming. CCS is an essential part of this concept. Underground experiments at the Mt Terri Lab will study the potential CO_2 migration through a fault in the caprock and the effects of fault activation. This is complemented by lab experiments on rock samples, modelling of injection and CO_2 migration, and the identification of regions in the Swiss sedimentary basin that are suitable for a future CO_2-storage pilot site.

Demo-5: Small Hydro-Power Plant

Research performed by SCCER-SoE partners will be implemented in a new small HP plant to be installed/ built in the coming 2 to 3 years. This demonstrator will show the ability produce clean, sustainable and renewable energy while producing ancillary services. Several topics will be addressed such as: the now-casting and seasonal forecasts of discharge to the water intake as a basis for sediment management and for a flexible power production scheme; a critical review of the implemented operation practice, in view of efficiency improvements considering multi-sectorial objectives; a technical optimization of the hydro electrical equipment operating conditions allowing a flexible control and set up of a predictive maintenance; an investigation of the ecosystem (metabolism, food web), fish migration and biodiversity; an assessment of the new regulation for small hydropower plant and the possible financial models.

Demo-6: Controlled fine sediment release from a reservoir by a hydrodynamic mixing device

Following the preliminary implementation carried out in the Mauvoisin reservoir in Valais, we will implement a project with HP industry with the goal of demonstrating the effectiveness of technologies to artificially stir the water stored in a dam reservoir to prevent sediment from settling and allow for the sediment to be conveyed downstream at acceptable rates through the turbines. The mobile mixing device will be tested at a few dams to show its efficiency in different conditions. The expected outcome is (i) to validate the flushing efficiency as compared to laboratory development conditions; (ii) to characterize the dependence from local conditions; (iii) to identify practical difficulties and shortcomings of field implementation; (iv) to control the modifications to the sediment regime in the river downstream of the powerhouse as well as in the residual flow strength, and the resulting environmental impacts. We will seek funding for industry and SFOE to initiate the demonstrator in 2017.

Demo-7: Complex large hydropower scheme

FLEXSTOR will test a set of innovative tools for flexible operation of storage hydropower plants in changing environment and market conditions at a complex hydropower scheme. This demostrator is motivated by the main hydropower challenge in Switzerland, namely the need for flexible operation targeting premium remuneration hours, for which comprehensive methodologies for hydropower upgrading projects are still missing. Specific goals of FLEXSTOR are to demonstrate how to: concentrate production in less hours, while mitigating negative impacts (e.g. river up/down surges); manage reservoir sedimentation to expand storage capacity while complying with the Waters Protection Act; address mountain slope instability risks in periglacial zone, avoiding non-optimal “preventive reservoir lowering”; identify the changing demand structure and the required adaptation of the storage management; extend the operating range of hydraulic machinery, whilst avoiding instabilities; optimally manage a compensation basin in order to minimize the ecological impacts of hydropeaking in the downstream river reach. All these developments, which are at the core of the WP2 efforts, will be validated in the complex system of KWO Oberhasli, which allows later replication to other hydropwer schemes in Switzerland.

Projects (presented on the following pages)

Hydro-economic Consequences of Hydro-peaking Removal
Poster see task 2.3
L. E. Adams, P. Meier, J. Lund

Demonstrator 6: SEDMIX Fine sediment evacuationthroughthe power intakes at Trift reservoir
A. Amini, N. Lindsay, P. Manso, A. Schleiss

Fine sediment settling under pumped-storage operations in Räterichsboden
A. Baldin, S. Guillén Ludeña, P. Manso, A. J. Schleiss

Development of a real-time nowcasting and short range forecasting system of inflows to a small alpine hydropower plant
K. Bogner, M. Buzzi, M. Schirmer, M. Zappa

Cross-borehole characterization of permeability enhancement & heat transport in stimulated fractured media: preliminary results from the ISC experiment at the Grimsel Test Site
Poster see task 1.2
B. Brixel, M. Klepikova, M. Jalali, F. Amman, S. Loew

Influence of the angle of the jet-inflow on sediment settling in Räterichsboden»
M. Carbonne, S. Guillén Ludeña, P. Manso, A. J. Schleiss

Impacts of Future Market Conditions on Hydropower Storage Operations
Poster see task 2.2
L. Chambovey, J. P. Matos, P. Manso, A. J. Schleiss, H. Weigt, I. Schlecht, F. Jordan

CFD investigation of a Francis turbine to help the experimental measurements and the definition of start-up procedures
J. Decaix, V. Hasmatuchi, M. Titzschkau, F. Avellan, C. Münch-Alligné

Injection Protocol and First Results of Hydraulic Fracturing Experiments at the Grimsel Test Site
Poster see task 1.2
N. Dutler, B. Valley, L. Villiger, H. Krietsch, M. Jalali, V. Gischig, J. Doetsch, F. Amann

A comparison of the seismo-hydro-mechanical observations during two hydraulic stimulations at the Grimsel Test Site
Poster see task 1.2
V. Gischig, J. Doetsch, M. Jalali, F. Amann, H. Krietsch, L. Villiger, N. Dutler, B. Valley

Sediment balance of a system of alpine reservoirs in cascade
S. Guillén Ludeña, P. Manso, A. J. Schleiss

Challenging onboard measurements in a 100 MW high-head Francis turbine prototype
V. Hasmatuchi, M. Titzschkau, J. Decaix, F. Avellan, C. Münch-Alligné

Permeability Changes Induced by Hydraulic Stimulation at the Grimsel Test Site
Poster see task 1.2
M. Jalali, V. Gischig, J. Doetsch, H. Krietsch, L. Villiger, N. Dutler, B. Valley, K. F. Evans, F. Amann

Tracer based characterization of the connected fracture volume in the DUG Lab at the Grimsel Test Site
Poster see task 1.2
A. Kittilä, K. Evans, M. Jalali, M. Willmann, M. O. Saar

Geological characterization and in-situ stress state of the ISC experimental volume
Poster see task 1.2
H. Krietsch, V. Gischig, F. Amann, J. Doetsch, M. Jalali, B. Valley

Deformation and tilt measurements during the ISC experiment at the Grimsel Test Site
Poster see task 1.2
H. Krietsch, V. Gischig, B. Valley, F. Amann

Hydropeaking attenuation: how can revitalized rivers contribute?
A. Mark, P. Manso, S. Stähly, A. J. Schleiss, P. Meier

Operation changes of a complex hydropower system over decades
Poster see task 2.2
J. P. Matos, P. Manso, B. Schaefli, A. Schleiss

Augmentation de la flexibilité d'exploitation d'aménagements hydroélectriques de haute-chute au fil de l'leau en Valais
G. Morand, N. Adam, P. Manso, A. J. Schleiss

SmallFlex: Demonstrator for flexible Small Hydropower Plant
C. Münch, P. Manso, M. Staehli, M. Schmid, C. Nicolet, F. Avellan, A. Schleiss, J. Derivaz

Demonstration of new solutions for an upcoming small alpine HP plant (Adont, Surses)
M. Stähli, K. Bogner, M. Schirmer, A. Amini, M. Klauenbösch

Pico-seismicity during hydraulic stimulation experiments at the Grimsel Test Site
Poster see task 1.2
L. Villiger, V. Gischig, J. Doetsch, H. Krietsch, M. Jalali, N. Dutler, B. Valley, K. Evans, F. Amann, S. Wiemer

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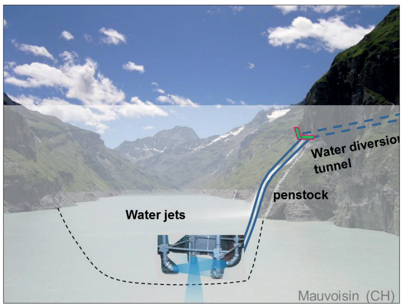
Demonstrator 6 : SEDMIX

Fine sediment evacuation through the power intakes at Trift reservoir

Azin Amini, Nicole Lindsay, Pedro Manso, Anton Schleiss
Ecole Polytechnique Fédérale de Lausanne, Corresponding author: azin.amini@epfl.ch

Introduction

Taking advantage of the withdrawal of some glaciers, several new dams will eventually be constructed in Switzerland in the coming years as a part of the 2050 energy strategy. The Trift dam, is one of these new projects. However, sedimentation is a key issue for reservoir sustainability as it results in a loss of capacity storage thus also affecting the hydropower production capacity [1].
A recent study by Jenzer-Althaus (2011) shed light on an innovative system, (called SEDMIX) allowing to keep in suspension or resuspend the fine particles near the outlets and the dam thanks to specific water jet arrangements and to avoid reservoir silting. The SEDMIX demonstrator aims to identify the possibility of controlled sediment release through power waterways.

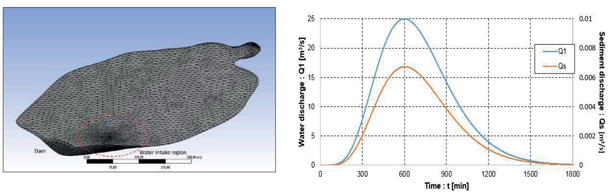


Concept of SEDMIX device implemented in Mauvoisin reservoir [2]

The project of a new dam reservoir in the Trift Valley currently being developed by *Kraftwerke Oberhasli SA (KWO)* is an opportunity to implement the SEDMIX device for the first time in a real case.

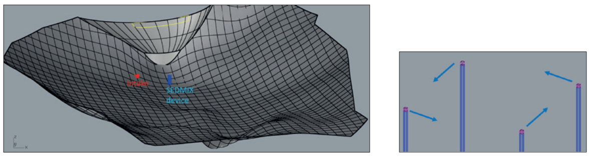
Numerical model

The current study aims at creating a three dimensional numerical model of the Trift reservoir and evaluating the effect of SEDMIX device on mitigation on the reservoir sedimentation. For this purpose The ANSYS-CFD three-dimensional finite volume model for multiphase flows is used.
The key physical parameters that will be tested are the geometry and mass inertia of the reservoir (which vary with the water level as function of the seasonal inflows and hydropower operation), the position, orientation and discharge of the SEDMIX jets, as well as the characteristics of the suspended sediments such as initial concentration and grain size.



Numerical model mesh (left) and the inflow hydrograph and solidograph (right)

To design the device in the case of the Trift reservoir, the optimal values found empirically by Jenzer-Althaus (2011) are upscaled in order to define the dimension of jet nuzzles, the distance between jets, as well as the jet's discharge. The upscaling relies on Froude similarity. As such, jets with a distance of 20 m and a total discharge of 1 m^3/s are considered.

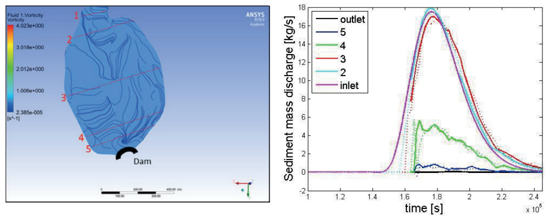


Water intake and SEDMIX jets location in the Trift reservoir [2] (left) details of SEDMIX jets (right)

In a preliminary phase, many simulations have been done with/without sediments both in steady state and transient flow conditions. Once the model parameters have been adjusted, the SEDMIX device is implemented into the model. It is placed close to the dam in a distance of about 100m from the water intake. The results are then compared to the reference case, i.e. simulation without jets.

Results

The numerical model highlights the influence of SEDMIX device in producing rotational flow in the reservoir, that can eventually keep fine sediments in suspension.



Flow pattern in the reservoir due to jet effect (left) sediment discharge at sections 1 to 5 (right)

The evacuated sediment ratio, the ratio between the total evacuated sediment weight and the initially supplied sediment weight [3], is equal to 14% for the reference case without SEDMIX jets. However, the presence of SEDMIX device increase the evacuation rate up to about 70%. This results brings out the efficiency of SEDMIX device in increasing the sediment release to downstream.

Conclusions

Moreover, at the current stage and with a preliminary choice of the jets position, this study shows high contribution of jets in keeping fine sediments in suspension and evacuation through the water intakes during normal operation of the hydropower plant. Numerical simulations have been successfully launched. However, due to the complex morphology of the reservoir, the hydrodynamic behavior needs further investigations.

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[3] J. Jenzer-Althaus, G. De Cesare & A.J.Schleiss. Sediment evacuation from reservoirs through intakes by jet-induced flow. Journal of Hydraulic Engineering, 141 (2).2014
[4] A. Amini, P. A. Manso, S. Venuleo, N. Lindsay, C. Leupi, A.J. Schleiss "Computational hydraulic modelling of fine sediment stirring and evacuation through the power waterways at the Trift reservoir", Conf. Hydro 2017, Seville.

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Fine sediment settling under pumped-storage operations in Räterichsboden

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

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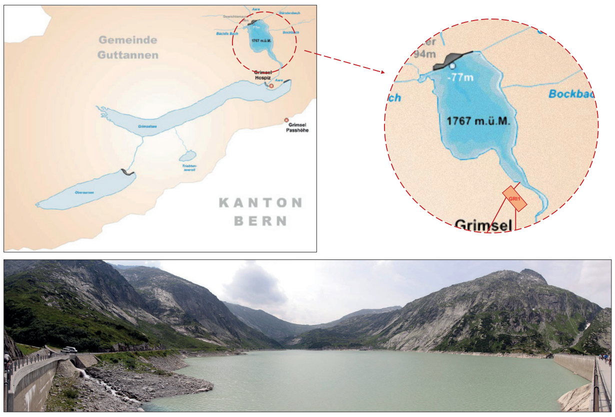
LABORATOIRE DE CONSTRUCTIONS HYDRAULIQUES

Framework

Reservoir sedimentation is, at present, one of the main concerns in the operational management of dams. The reduction of the reservoir capacity due to sedimentation has negative impacts on the hydropower production, flood protection and availability of water for irrigation and human consumption. The most efficient and sustainable measure to cope with reservoir sedimentation consists in guaranteeing the sediment balance between upstream and downstream of the reservoir.
The main purpose of this poster is to describe the study of the interaction between pumped-storage operations (PSO) and the sedimentation process in the Räterichsboden reservoir.

The goals can be summarized as listed below:
- Characterize the hydrodynamics of the reservoir under PSO;
- Analyze the influence of the PSO on the reservoir sedimentation process;
- Determine the region of in- and out-flow sequences.

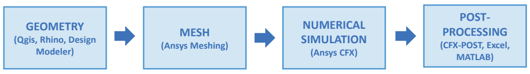


Figg. 1 – Plant of Raterichsboden reservoir and view of the lake from the dam (source of pictures: Wikimedia)

Methods

This study is based on a 3D numerical modelling using ANSYS CFX. However, in order to complete it, different programs were used as reported below:

Tab. 1 – Software used for the analysis of Räterichsboden reservoir



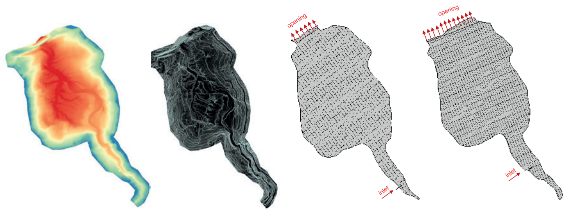


Fig. 2 – From the left to the right: Qgis DEM, countour lines, Rhino geometry 1753 m a.s.l. and 1767 m a.s.l.

Different parameters were taken into account and were varied for checking how they influence the hydrodynamic and the sedimentation process inside the reservoir.

Tab. 2 – Parameters taken into account for this study

Water level	Maximum supply level (1767 m a.s.l.)		Operating level (1753 m a.s.l.)
Volume	Minimum volume	Mean volume	Maximum volume
In- and outflow rates	Constant hydrograph		Oscillating hydrograph
Sediment concentration at the inlet	0 mg/L (inflow of water)		75 mg/L (75% of the initial concentration of the reservoir)

Tab. 3 – Mesh statistics for the two models

Mesh statistics	Model Min Operating Level	Model Max Supply Level
Total Number of Nodes	69445	87962
Total number of Elements	209849	271142

Sand particles (density equal to 2600 kg/m^3) with a diameter of 4.37 μm were chosen for all the simulations.
For a better understanding of the influence of the different models (in terms of mass-momentum and turbulence transfer between the two phases) inside ANSYS CFX, a large number of tests was carried out with a simply geometry (a cylinder).
Finally, an analysis of the results let us choose the best models for this study.

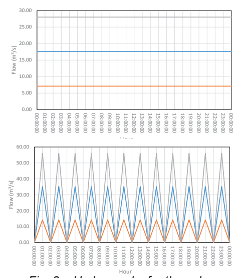


Fig. 3 – Hydrographs for the volumes

In the end, the simulations which were launched and completed for this study were 26.

Tab. 4 – Table summarizing the experiment schedule

TRANSIENT	Water level	Volume	In- and outflow rates	Sediment concentration at the inlet	TOTAL
Hydrodynamics	2	3	2		12
Sediment	2	2	1	2	8

STEADY STATE	Water level	Volume	In- and outflow rates	Sediment concentration at the inlet	TOTAL
Hydrodynamics	2	3	1		6

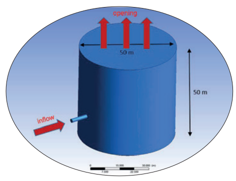


Fig. 4 – Cylinder used for the tests

Results

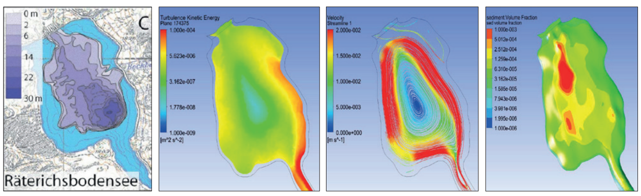


Fig. 5 – From the left: sediment isopach[1], main parameters for hydrodynamic and sediment studies

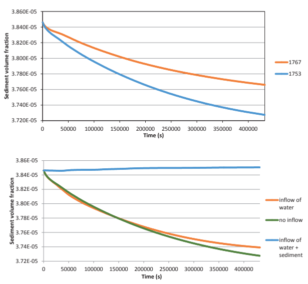


Fig. 6 – From the top: sediment volume fraction vs time (no inflow) and sediment volume fraction vs time for the different conditions (minimum operational level)

By analysing the results from the simulations, it was possible to conclude that:

- Low water TKE and velocities areas correspond to areas with thicker sediments (delta).
- The graphs show the results expected: by increasing the inflow (and consequently the velocity of the fluid) or the concentration of sediment in the inlet, the particles require more time to settle down.

Conclusion

- Numerical simulations provide predictive information about the behaviour of the flood inside the reservoir. These results must be validated by physical experiments. However, if we compare the influence zones from previous studies and from the analysis following the simulations, it' s clear how there are several similarities.
- From CFD simulations it was possible to characterize the hydrodynamics of the reservoir, the influence of PSO on the sedimentation process and to determine the region of in- and outflow sequence.

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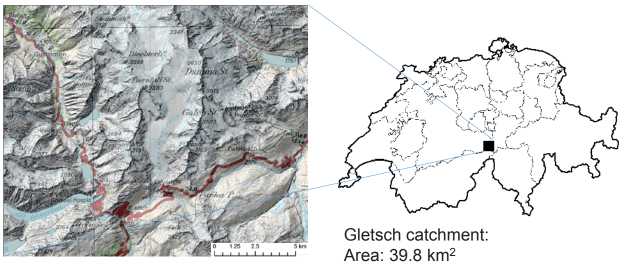
Development of a real-time nowcasting and short range forecasting system of inflows to a small alpine hydropower plant

K. Bogner[1], M. Buzzi[2], M. Schirmer[3], M. Zappa[1]
[1] WSL, [2] MeteoSwiss, [3] SLF

Motivation

In order to highlight the possibilities of increasing the flexibility in managing Small Hydropower Plants (SHP) with very limited storage capacities high resolution forecasts will be adapted to the small alpine catchment at Gletsch. Up to now the COSMO-E meteorological forecasts with a spatial resolution of ~ 2.2 km have been implemented in an operational hydrological forecast chain, which produce hourly inflow forecasts for the next 5 days. For the first six hours the INCA-CH nowcast system will be implemented at next with a resolution of ~ 1 km. All produced inflow forecasts will be post-processed in order to minimize modelling errors and to improve the reliability in real-time by the use of novel statistical methodologies, like machine learning methods.

Study area

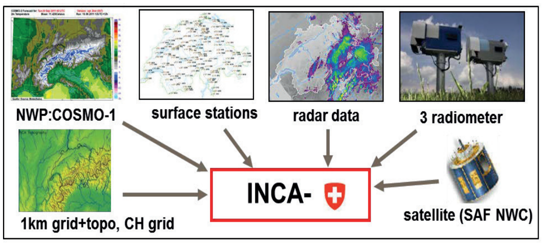


Gletsch catchment:
Area: 39.8 km²
Glaciation: 52%
Mean elevation: 2719 m a.s.l.

Methods

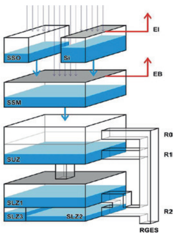
The forecast chain under development consists of :

- Meteorological forecasts
  → **Seamless forecast chain:** 0-6h INCA-CH, 6-24h COSMO-1, 24-120h COSMO-E

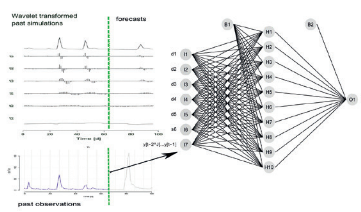


INCA-CH model set up

- Hydrological model PREVAH + Post-Processing of the inflow forecasts



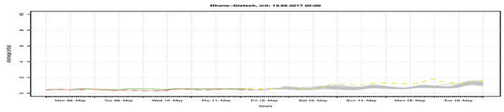
PREVAH model scheme



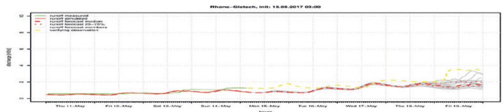
Novel statistical error correction methods

Preliminary results

- The hydrological model PREVAH has been calibrated for the Gletsch catchment and the COSMO forecasts have been set up for producing inflow forecasts to the Gletsch Small Hydropower Plant (SHP), which is under construction. The runoff from the Gletch catchment is heavily influenced by glacier melt. During the winter period the runoff is very low (close to zero), only at the late Spring time, when the temperature increases, the runoff starts to react. This will be one of the crucial periods to forecast. Below you can see the forecasts one day ahead and one day after the melting period starts.

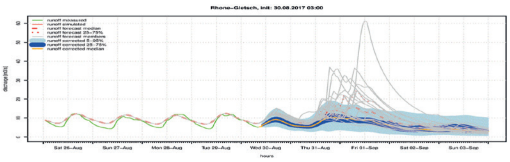


Forecast example one day before the glacier melt starts (mid of May)



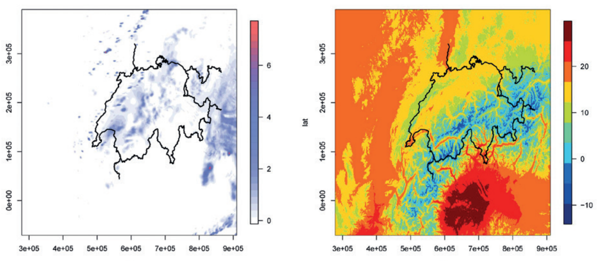
One day after the start of the melting season

- Post-processing methods have been adapted to the operational forecasts



Post-processed forecast applying the Quantile Regression Neural Network (QRNN) method

- INCA-CH forecasts are retrieved every 10 min with forecasts for the next 6 hours with 10 min resolution. These high-resolution forecasts will be incorporated into the forecast chain at next. An ensemble nowcast system, which is under development at MeteoSwiss, will be included in the next year in order to derive the total predictive uncertainty.



Example of INCA precipitation and temperature forecast from the 12th of September 2017

Outlook

Besides the development of a seamless forecast chain and the derivation of the predictive uncertainty including the hydrological and the meteorological uncertainty, possible improvements in the forecast quality will analysed by integrating novel snow hydrology models developed at SLF.

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Influence of the jet-inflow angle on sediment settling in Räterichsbodensee

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Framework

Reservoir sedimentation is, at present, one of the main concerns in the operational management of dams. The reduction of the reservoir capacity due to sedimentation has negative impacts on the hydropower production, flood protection and availability of water for irrigation and human consumption. The most efficient and sustainable measure to cope with reservoir sedimentation consists in guaranteeing the sediment balance between upstream and downstream of the reservoir.
The main purpose of this poster is to describe the study of the interaction between pumped-storage operations (PSO) and the sedimentation process in the Räterichsboden reservoir.

The aims of the study can be summarized as listed below:

- Characterize the hydrodynamics of the reservoir under PSO under different jet-inflow angles
- Analyze the influence of the PSO on the reservoir sedimentation process

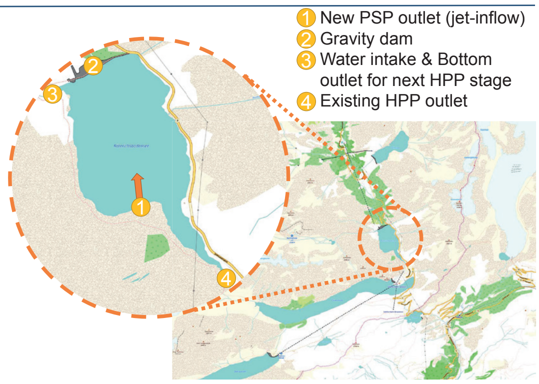

Figure 1: Location plan of Räterichsbodensee

Methods

The study was carried out with 3D numerical modelling using Ansys CFX as well as some other software to prepare the geometry.
There were several parameters in this study : water level, jet angle (**alpha**), discharge (**Q**), initial sediment concentration in the lake, **concentration ratio** (ratio between inflow concentration and initial sediment concentration in the lake).

Geometry
- A custom software was used to create the basic geometry from the terrain elevation data
- Rhino 3D was used to simplified the geometry
- Design Modeler

Mesh
- Ansys Meshing
- Inflation layers at the bottom

Numerical Simulation
- Ansys CFX
- Outlet at the water surface near the dam

Results post-processing
- Ansys CFD-Post
- Libreoffice Calc
- Custom coding (python, matplotlib)

Figure 2: 3D model obtained from terrain elevation data

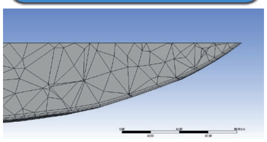

Figure 3: cutaway of the mesh, we can see inflation layers

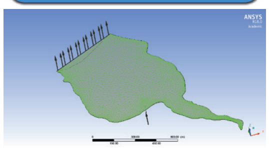

Figure 4: overview of the model, once set up

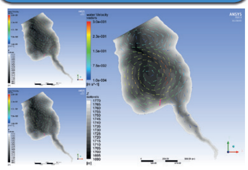

Figure 5: velocity field for different angles (clockwise from top left : +30°, 0°, -30°)

Results

The first main result is obviously the change in the velocity field. On Figure 5, the velocity field in the reservoir is plotted for different jet-inflow angles (the tunnel is drawn in pink). The number of vortexes also depends on the inflow angle. But our concern is the sediment settling, and I had to find a link between velocity field and sedimentation. In order to find a correlation between sediment settling and the velocity field (and thus the jet angle) I proposed several indicators to quantify the different phenomena :

agitationta : volume average of time-averaged velocity in the whole reservoir

sed : volume average of sediment volume fraction in the whole reservoir

depta : area average of time-averaged sediment volume fraction on the bottom surface of the reservoir

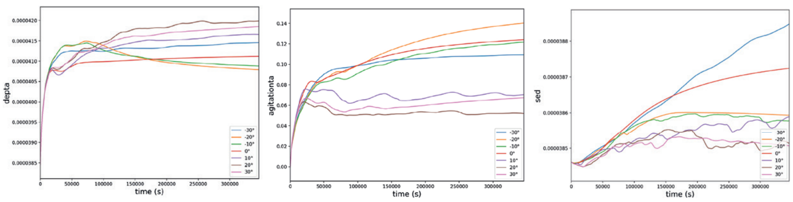

Figure 6: jet-inflow angle influence on main indicators
*Evolution of **depta**, **agitationta** and **sed** in time for Q = 90 m³/s, water level at 1767 m.a.s.l, and alpha = -30° to +30° (from left to right)*

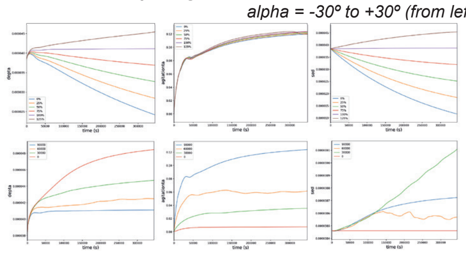

*Figure 7: influence of discharge level (Q) and concentration ratio : Evolution of **depta**, **agitationta** and **sed** in time for*
- *Q = 90 m³/s, water level at 1767 m.a.s.l and concentration ratio = 0% to 125% (first line)*
- *Q = 0 m³/s to 90 m³/s, water level at 1767 m.a.s.l and concentration ratio = 100% (second line)*

Conclusion

With this study, I tried to show the influence of the jet-inflow angle. I can conclude that for alpha lower than -20°, the inflow impacts on the sediment bar located near the inlet. This impact is associated with a local energy dissipation and thus, favors the sediment settling within the reservoir. It also seems that a good range is between -20° and -10°. Nevertheless, a finer study in this range would be appreciated. In fact, due to lack of time and computational resources, we decided to limit the number of simulations. Finally, results should be taken with caution : this study is mainly based on global indicators and is aimed to study the global trend. I recommend further studies and taking in account erosion.

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CFD investigation of a Francis turbine to help the experimental measurements and the definition of start-up procedures

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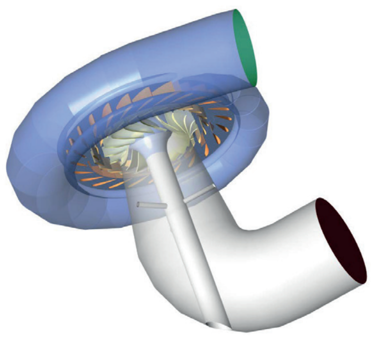
Motivation

Due to the development and the integration of renewable energies, the electrical grid undergoes instabilities [1]. Hydraulic turbines and pump-turbines are a key technology to stabilize the grid. However to reach this objective, the hydraulic machines have to extend their operating range. Such an extension requires to deal with start-up and stand-by operation, which often leads to a reduction of the lifespan of the machines [2].
Nowadays, numerical simulations reached a robustness allowing to investigate unstable operating points such as rotor/stator interaction, low head operating condition and start-up [3].
By coupling numerical and measurements investigations, several features can be drawn and solutions can be found to extend the operating range of the machine whilst the lifespan is weakly affected.

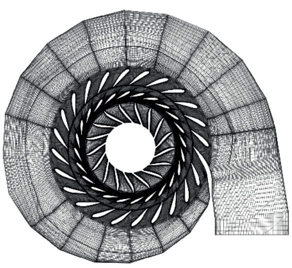
Test Case

The machines of hydropower plant Grimsel 2 is equipped with horizontal ternary units with a complete motor-generator coupled with a Francis turbine on one hand and a single stage radial pump on another hand.
The Francis turbine undergoes cracks at the junction between the trailing edge of the blades and the shroud. The cracks appeared after the operating conditions of the turbine changes from few stop and start per day to a large number of stop and start per day.
The origin of the cracks is however not yet understood.
The phenomenon responsible for the development of the cracks is investigated using numerical simulations to complete the experimental approach.



Numerical Set Up

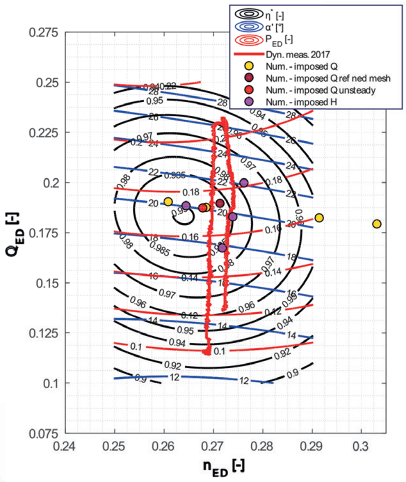
The computational domain takes into account the spiral case, the distributor, the runner and the draft tube. The tripod inside the draft tube is also considered.
An hexahedral mesh is generated for each part of the turbine and then put together.
Reynolds-Averaged Navier-Stokes simulations are performed using the SST k-ω model.
The operating points investigated are clustered around the best efficiency point. Both inlet flow rate or inlet total pressure boundary conditions have been considered.

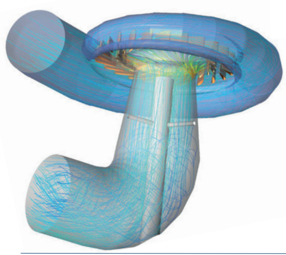


Results

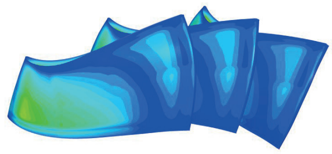
The performance of the turbine predicted by the simulations are plotted on the hillchart of the Francis turbine. The agreement between the simulations and the measurements is good, whatever the operating points considered.

Pressure field





Blades Pressure field



Conclusions & Perspectives

The numerical simulations are able to predict the performance of the turbine for different operation points clustering the best efficiency point with a good agreement compared to the measurements.
Therefore, the confidence in the simulations will allow the investigation of unstable operating points mainly those corresponding to the start-up procedure of the turbine in order to determine the phenomenon responsible of the blade cracks.

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Acknowledgements

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Sediment balance of a system of alpine reservoirs in cascade

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Scope of work

Reservoir sedimentation is, at present, one of the main concerns in the operational management of dams. The reduction of the reservoir capacity due to sedimentation has negative impacts on the hydropower production, flood protection, and availability of water for irrigation and human consumption.

This study aims firstly at determining the sediment balance of a system of reservoirs in cascade. Secondly, this study aims at determining the percentage of fine sediments (d_m < 10 μm) contained in the overall volume of sediment deposited annually in each reservoir.

For those purposes, this study analyzes the system formed by the reservoirs of Oberaar, Grimsel, and Räterichsboden in the Swiss Alps (Figure 1).

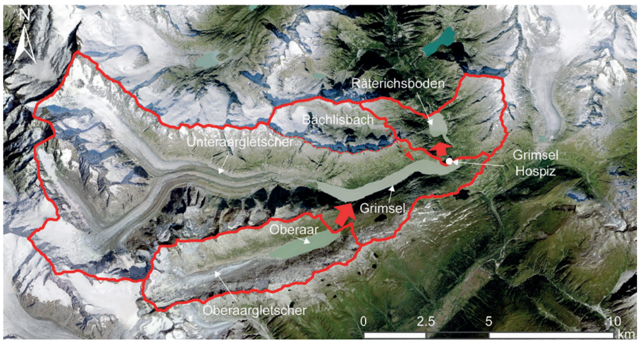

Figure.1 Aerial view of the system formed by the reservoirs of Oberaar, Grimsel, and Räterrichsboden

Methods

The methodology followed in this study to determine the sediment balance of the system of reservoirs in cascade consists in quantifying the in- and outfluxes of sediments for each reservoir. These fluxes are:

- V_A: Annual sediment yield produced by the catchment computed by the formula of Beyer-Portner et al. (1998):
  $$V_A = 93 \cdot 10^{-15} \cdot H^{0.052} \cdot SE^{0.091} \cdot SV^{8.108} \cdot \Delta LG^{0.082} + 274$$
  where *H* stands for the average precipitation in mm registered from June to September, *SE* is the percentage of erodible soil (not including the glacier), *SV* is the percentage of surface non covered by vegetation (including the glacier), and *ΔGL* is the annual variation of the glacier length in percentage.
- *PSE*: Volume of sediments exchanged between reservoirs as a results of pump-storage operations. These fluxes are computed as the product of the volume of water exchanged annually and the suspended sediment concentration of the reservoirs.
- *SR:* Annual sedimentation rate estimated from periodic bathymetric surveys and compared to those estimated by Anselmetti et al (2007).

The formula proposed by Bonalumi et al (2011) was used to compute the annual volume of fine sediments deposited annually:

$$SRF = \frac{1}{t_2 - t_1}\int_{t_1}^{t_2} w_s \cdot SSC(t) \cdot A(t) \cdot dt$$

where w_s is the settling velocity of the suspended particles (0.5 m/day), *SSC* is the suspended sediment concentration for each reservoir (Figure 2d), and A(t) is the evolution of the surface of the reservoirs.

Data

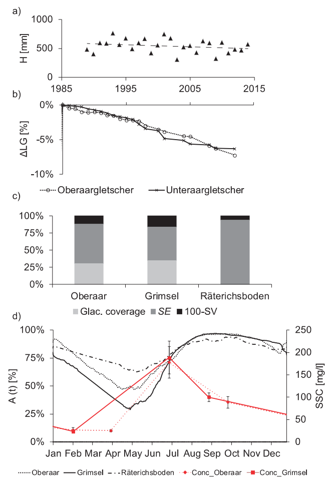

Figure.2 a) Annual average precipitation measured at Grimsel-Hospiz. b) Accumulated variation of the glacier s' length. c) Percentage of glacier coverage, erodible soil (SE), and vegetated surface (100-SV) for each catchment. d) Daily average evolution of the surface of the reservoir and the suspended sediment concentration within the reservoirs

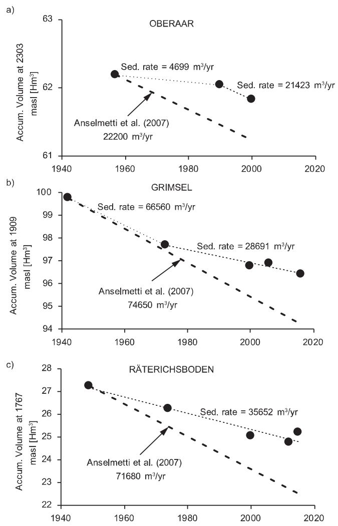

Figure.3 Annual sedimentation rates estimated by means of bathymetric surveys, and those reported by Anselmetti et al (2007) for: a) Oberaar, b) Grimsel, and c) Räterichsboden

Results

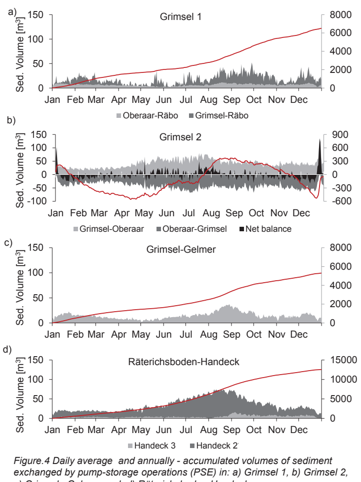

Figure.4 Daily average and annually - accumulated volumes of sediment exchanged by pump-storage operations (PSE) in: a) Grimsel 1, b) Grimsel 2, c) Grimsel –Gelmer, and d) Räterichsboden-Handeck

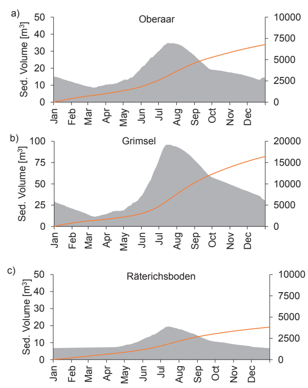

Figure.5 Daily average and annually - accumulated volumes of fine sediments deposited in: a) Oberaar, b) Grimsel , and c) Räterichsboden

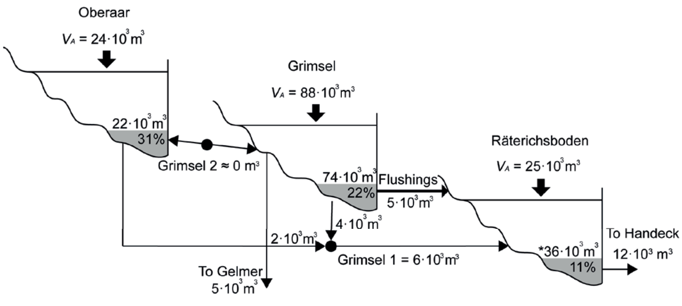

*Figure.6 Sediment balance of the system of reservoirs in cascade. The percentage indicate the portion of fine sediments deposited with respect to the total sedimentation rate (SR). * The sedimentation rate of Räterichsboden might be affected by periodic flushing operations in Grimsel.*

Conclusion

The sediment balance of the system of reservoirs in cascade formed by Oberaar, Grimsel, and Räterichsboden was determined by quantifying the in and outfluxes of sediments of each reservoir. The sedimentation rate estimated for fine sediments is not negligible with respect to the total sedimentation rate, since it may reach up to 30% of the total sedimentation rate of Oberaar.

References

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Challenging onboard measurements in a 100 MW high-head Francis turbine prototype

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Motivation

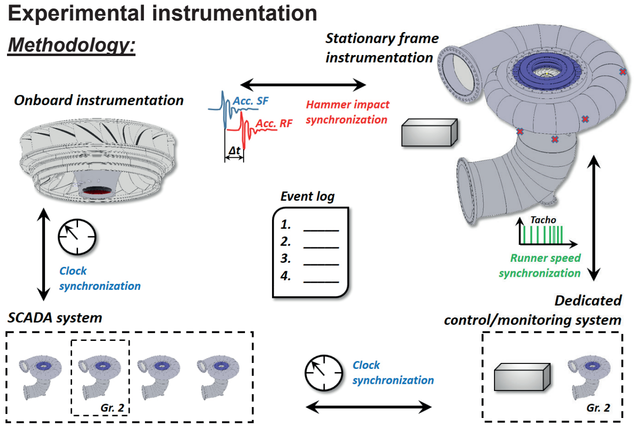
- Pumped-storage power plants: key components of a successful integration of renewable energy sources into electrical grid.
- Hydraulic turbines and pump-turbines:
  - operation in a wide range to offer power regulation flexibility
  - subject to frequent start-up and/or stand-by operating regimes
  - facing harsh structural loadings with impact on their lifetime.

Objectives:

- Establishment of a hydrodynamic instability level hill-chart of the machine based on several experimental monitoring parameters;
- Proposal of an alternative less-harmful start-up path and stand-by position with direct effect on the long-term maintenance costs;
- Elaboration of a diagnosis protocol to draw hydrodynamic instability level hill-charts on different hydropower units, using only a simplified instrumentation set.

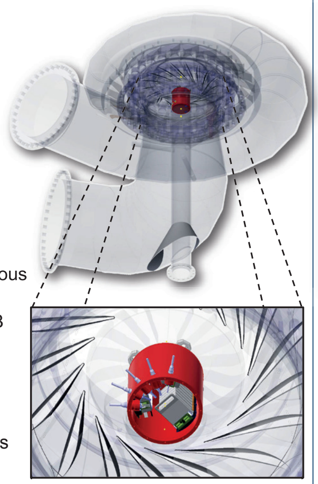
Experimental instrumentation

Methodology:



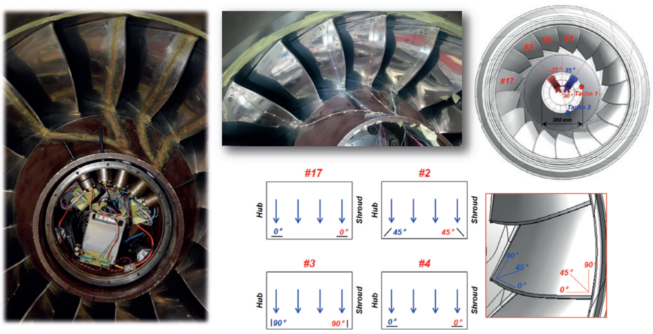
Onboard instrumentation:

1x Gantner Q.brixx acquisition system
2x 21 Ah, 22.2 VDC LiPo batteries
1x power supply protection electronics
8x quarter bridge strain gauges
2x single-axis IEPE accelerometers
2x inductive tachometers



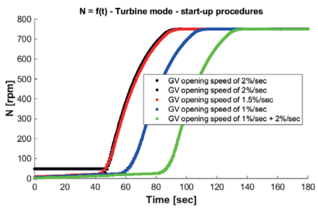
Main features:

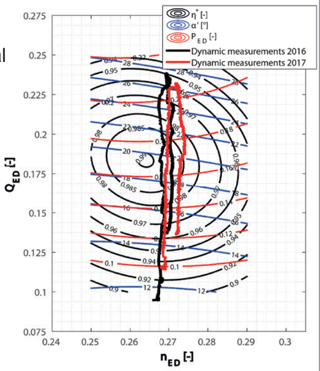
- Autonomous multichannel synchronous 10 kHz continuous acquisition
- Data storage capacity: 2xUSB 16GB
- Autonomy of power supply : > 20h
- Protection relay against deep discharge of the batteries
- Possibility of data downloading, fast controlled recharging of batteries and system power switch on/off



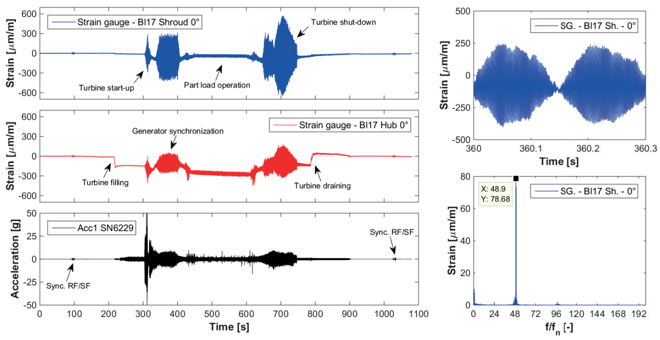
Preliminary results

- Conducted tests focused on normal turbine operation, deep part-load, turbine normal start-up, modified slower turbine start-up and pump start-up





- Evidence of harmful structural loading of the turbine runner blades during the normal start-up and shut down procedures – signals recorded with the onboard instrumentation



Conclusions & Perspectives

- Two experimental campaigns conducted in a 100 MW high-head Francis turbine prototype
- Onboard measurements successful, post-processing ongoing

- Seek for a feasible simple technical solution to reduce the turbine head for the start-up and shut down procedures
- Setup of a 3rd experimental campaign using only simplified instrumentation to test the new proposed start-up method(s)
- Driving the 3rd experimental campaign and analysis of results
- Establishment of a diagnosis protocol based on a simplified instrumentation set to identify harsh operating conditions on a different hydropower unit.

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Acknowledgements

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FlexSTOR

Partners of the FLEXSTOR - WP6 project (CTI no. 17902.3 PFEN-IW-FLEXSTOR)

Hes·so VALAIS WALLIS — EPFL ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE — KWO GRIMSELSTROM

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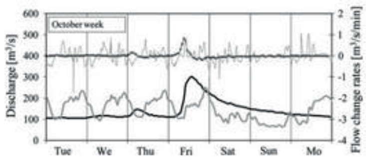
FlexSTOR

Hydropeaking attenuation: how can revitalized rivers contribute?

Mark[1] A., Manso[1] P. A., Stähly[1] S., Schleiss[1] A.J. and Meier[2] P.
1) EPFL-LCH; 2) Eawag

Motivation



Hydropeaking, the sudden starting and stopping of turbines, lead to highly unsteady flow regimes in the river downstream of the restitution points of hydropower plants. Powerplants mainly operate during peak hours, when the selling price is at it's highest due to an important energy demand. Therefore a restrictive turbine mode, which would efficiently reduce the hydropeaking effect, would not be an economically nor and energy efficient or sustainable option for the operating company. The strict restrictions in these up and down surges (hydropeaking) can be controlled either with construction measures before the water is released, either by morphological features in the river itself or combining both. This work aims at assessing the contribution of different geomorphic river features in attenuating the hydropeaking effects. The Hasliaare, river in the Canton of Bern, operated by KWO, is analysed and used as a benchmark for other Alpine rivers. It's morphology is varied and therefore adequate for this analysis.

Method

Our *scientific hypothesis* is that varied river morphology is more prone to attenuate hydropeaking up-/down-ramps, in particular if it provides for lateral inundation, water storage and therefore somewhat delayed wave routing. Testing this hypothesis is done through the following methodology:

1. Establish a 2D river model (Figure 1)
2. Through field measurements, calibrate the model and then let hydrographs pass through the model to obtain the variation in the hydrograph, assessing the contribution of different geomorphic features.
3. Compare the present attenuation factors (lumped factors per each section, see below) with observed attenuation for variable discharges.

Following first field tests carried out in 2008/09 [2] between Innertkirchen and the Lake of Brienz, *lumped attenuation factors* (one value per river cross section for all discharges) have been obtained with the methodology presented below (applies to all three places if not mentioned otherwise).

- Input hydrographs (modified for Meiringen, probably due to an unstable section)
- Adjusting baseflow to the estimated values
- Adjusting high discharges in respect to sub catchment areas
- Imposing a maximal up-ramping rate
- Imposing a minimal down-ramping rate
- Calculate mean up- and down-ramping rates

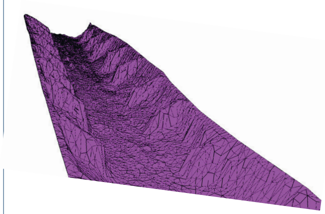


Figure 1: Resulting mesh from groin field with a DTM recording with a vertical exaggeration factor of 3; 3D mesh representation done with Basement (dry bed).

Figure 2: Aerial photo of the river reach of figure 1 (Flow rate estimated at 17 m³/s).

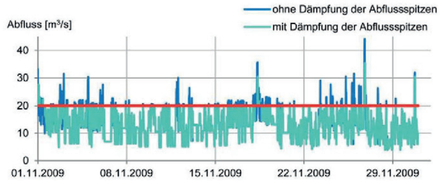
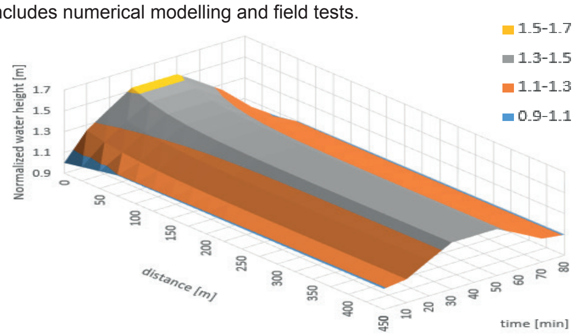


Figure 3: Attenuation due to the compensation basin (Limnex, 2009).

Results

A preliminary attempt to assess wave attenuation in the groin field reach is done using Meile's attenuation parameter for macro-roughness elements in a prismatic channel [1]. This method can only be applied to real size channels with certain restrictions, such as geometric ratios of the macro-roughness elements and the flow regime; It applies when groins are not submerged. Applying such methodology to the Innertkirchen groin field reach (figure 4) indicates that attenuations of up to 40% of the wave height can be obtained in the main channel within 400 m, and up to 20% in few dozen meters at the upstream side of the river reach, as shown in the graph 1 below. This results set a (state-of-the-art) reference for future analysis, which includes numerical modelling and field tests.



Graph 1: Hydrograph going through a groin field in a prismatic channel, without taking into account the time the wave takes to travel the distance. (Normalized water height: water height of the wave divided by the normal water height)

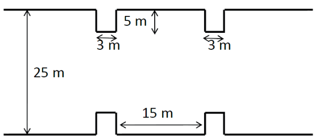


Figure 4: Idealized geometry of the river reach used to obtain the results from graph 1.

Outlook

The output of the work is to develop a methodology and a tool to characterise the spatial variation of hydropeaking mitigation as a function of the travelling distance and of a riverbank configuration.
Furthermore, we aim at adapting the current attenuation assessment methods expressed in terms of discharge variation into water levels variations instead.

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We acknowledge KWO team, for the great help with the work and the very usefull documents.

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Augmentation de la flexibilité d'exploitation d'aménagements hydroélectriques de haute-chute au fil de l'eau en Valais

LCH LABORATOIRE DE CONSTRUCTIONS HYDRAULIQUES

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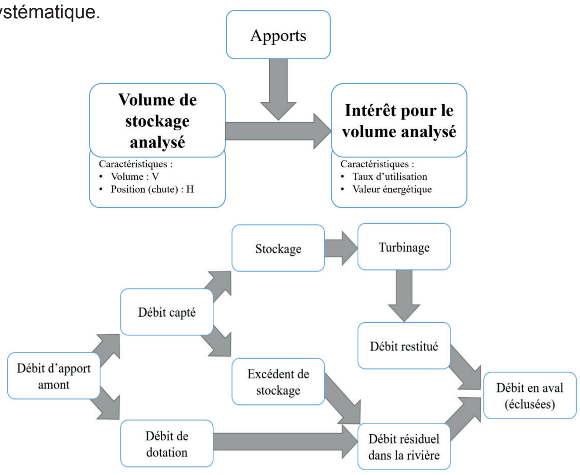
EPFL ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Introduction

En Suisse et ailleurs dans les Alpes, plusieurs aménagements hydroélectriques de haute chute fonctionnent sans retenue amont. Cela oblige à turbiner les apports captés au fil de l'eau par manque de capacité de stockage. Il n'est donc pas possible d'adapter la production hydroélectrique selon la demande. En hiver, les débits d'apport des rivières alpines sont largement inférieurs au débit équipé. Il arrive parfois même qu'il ne soit plus possible de turbiner tant les débits sont faibles. Le but de ce projet est donc de trouver des solutions innovatrices permettant d'exploiter ces aménagements en hiver.

Méthodologie

L'augmentation de la flexibilité d'exploitation passe par l'utilisation de volumes de stockage intra-journalier (dessableur, galerie en charge, galerie d'accès). La recherche de ces volumes se fait de manière systématique.

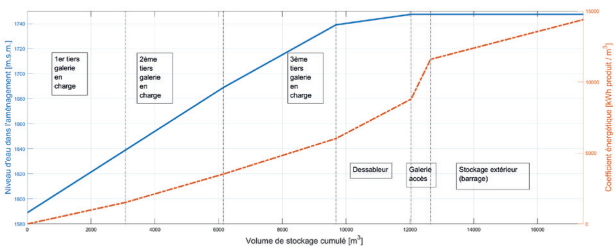


Résultats

Six modules de stockage ont été identifiés. On les combine de manière progressive en ajoutant aux modules déjà utilisés un nouveau module.

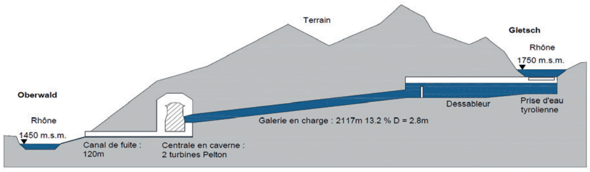
Modules	Volume [m^3]	Volume cumulé [m^3]
Galerie en charge 1/3	3075	3075
Galerie en charge 2/3	3075	6150
Galerie en charge 3/3	3075	9225
Dessableur	2355	11580
Galerie d'accès	609	12189
Stockage extérieur (barrage-mobile)	4795	16984

Le graphe ci-dessous montre la hauteur de chute en fonction du volume ainsi que le coefficient énergétique de chaque combinaison de modules.

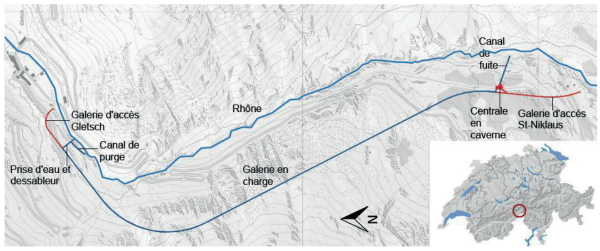


Cas d'étude : Kraftwerk Rhône-Oberwald (KWRO)

Cet aménagement hydroélectrique au fil de l'eau est situé sur le Rhône entre les villages de Gletsch et d'Oberwald en Valais.



- Chute brute 287.85 m
- Débit nominal 5.7 m^3/s
- Puissance installée 14.4 MW
- Puissance annuelle moyenne 4.6 MW (reçoit la RPC)
- Production annuelle prévue 39 GWh

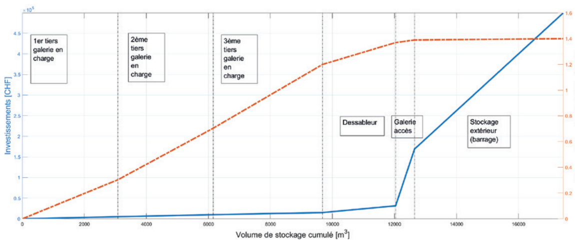


Discussions

D'après les résultats obtenus, les modules de stockage les plus intéressants d'un point de vue économique et flexibilité sont :

1. Dessableur : bon rendement économique de par sa hauteur de chute constante (grande valeur énergétique) et faibles investissements nécessaires.
2. Galerie en charge inclinée : valeur énergétique plus faible que celle de autres modules mais grand volume de stockage, ce qui rend l'exploitation plus flexible. Investissements faibles.

La galerie d'accès et le barrage mobile ont une grande valeur énergétique mais leur rentabilité économique est moins bonne.



Conclusion

La démarche entreprise peut également s'appliquer à d'autres aménagements de haute chute au fil de l'eau (en Suisse, 175 petites centrales de puissance entre 1 et 30 MW avec des débits inférieurs à 5 m^3/s) [WASTA, 2015]. Les modes d'exploitation flexible appliqués au cas d'étude permettent d'augmenter de 169% la production d'électricité hivernale de KWRO, ce qui équivaut à 2.8% de la production annuelle (gain de 1.09 GWh par an).

Enfin, ce type de projet s'inscrit parfaitement dans la stratégie énergétique suisse et dans le marché d'un futur proche sans RPC où l'énergie de pointe sera fortement valorisée. Ce type d'aménagement est aussi appelé à remplir de nouvelles fonctions comme la stabilisation du réseau.

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SmallFlex: Demonstrator for flexible Small Hydropower Plant

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Context

The current project is integrated in the activities of the SCCER-SoE, which include for the period 2017-2020 **a demonstrator on small hydropower schemes** (SHPs). Small hydropower plants are expected to provide a large share of the production increase planned in the 2050 energy transition strategy.

Summary

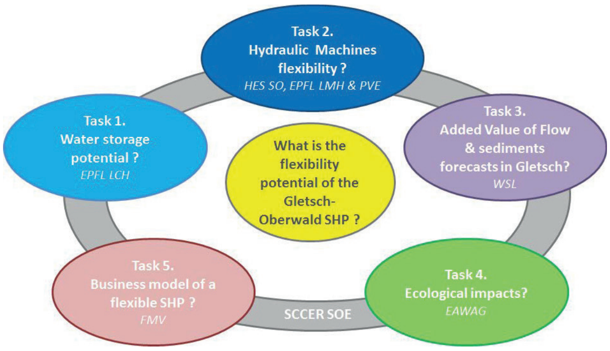
The aim of this project is to investigate how small-hydropower plants (SHP) can provide winter peak energy and ancillary services, whilst remaining eco-compatible.

The outcome of recent research by SCCER-SoE partners will be applied to a pilot facility provided by FMV with the goal of providing operational flexibility to the SHP owner and therefore harvest additional revenues.

The addition of flexibility will be done by testing infrastructure and equipment or operational adaptation measures, assessing their impact in terms of outflows, electricity output and revenues.

The lessons learned from this Demonstrator will be publically presented and used as a benchmark for the SHP sector.

Project activities & organisation

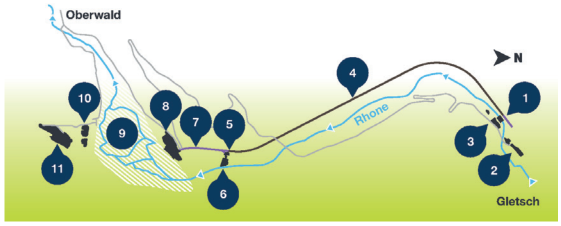


Overarching questions

- How can intra-day, intra-week or intra-monthly storage be added to a given run-of-the-river scheme, on the headrace side, on the tailrace side or both, in order to allow the scheme to generate peak energy and eventually contribute to grid regulation?
- What are the consequences of enlarging the operational range of the Pelton turbines in case of large head variations ?
- What's the added value of short and extended range inflow forecasts in Gletsch for the flexible operation of the new HP plant and for the management of sediments at the basins of decantation?
- What are the effects of short-term hydropeaks/ inter-dial fluctuations in discharge on the structure and function of alpine river ecosystems?
- What is the business model of the flexibility for small hydropower plants even in case of run-of-the-river plants with a priori small storage capacity?

Demonstrator site : The Gletsch-Oberwald SHP Project

With a installed discharge of 5.7 $m^3.s^{-1}$ and a net head of 288 m, this future SHP will produce 41 GWh with a mean gross capacity of 4.68 MW. The SHP is equipped with two Pelton turbines of 7 MW



1. **Zugangstollen Fassung** *Galerie d'accès à la prise d'eau*
2. **Installastionsplätze Gletsch** *Place de chantier de Gletsch*
3. **Wasserfassung** *Prise d'eau*
4. **Triebwasserstollen** *Centrale souterraine*
5. **Zentrale unterirdisch** *Centrale souterraine*
6. **Rückgabestollen** *Galerie en charge*
7. **Zugangsstollen Zentrale** *Galerie d'accès à la centrale*
8. **Installationsplatz St. Niklaus** *Place de chantier de St. Niklaus*
9. **Umweltmassnahmen** *Mesures de compensation environnementale*
10. **Materialaufbereitung Kieswerk** *Valorisation des matériaux à la gravière*
11. **Ablagerung Grie** *Dépôt des matériaux*

Pictures of demonstrator site

Expected results

The methods developed in this project may be applicable to affect positively **several hundred high-head plants** with no or little storage, resulting in an annual revenue increase of 5-10% from increased value of the winter production. A small increase in energy production (< 5%) is foreseen, due to an improved use of excess waters at high-altitude intakes above the residual discharge releases.

Research partners :

FMV, Hes·so, EPFL École Polytechnique Fédérale de Lausanne, WSL, eawag aquatic research, Power Vision Engineering

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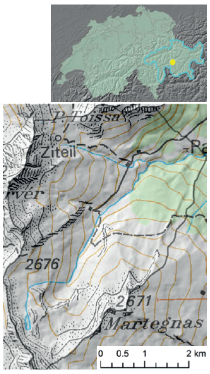
Demonstration of new solutions for an upcoming small alpine HP plant (Adont, Surses)

Manfred Stähli, Konrad Bogner, Michael Schirmer (WSL), Azin Amini (EPFL), Martin Klauenbösch (ewz)

Background

With the **aim** of testing new solutions for a productive and sustainable operation of new small HP plants (< 10 MW) *SCCER SoE* and *ewz* have started a joint research collaboration in central Grisons. Here, the implementation of a new diversion plant in the Adont-catchment (commune Surses) is in the planning stages. The case poses particular challenges as it is located in an inner-alpine area with relatively small amounts of precipitation and water demand for different purposes. In addition, the terrain is highly erosive requiring a smart sediment management.

Description of the planned small HP plant



- Hydropower plant type: Run-of-the-river SHP (~3 MW, 11 GWh/a)
- Location: in the Adont-catchment, commune Surses, Grisons
- Small alpine catchment of 17 km^2, 1'500 – 2'700 m asl.
- Planned turbine : Peltonen (6 nozzles)

Current state of project implementation by ewz

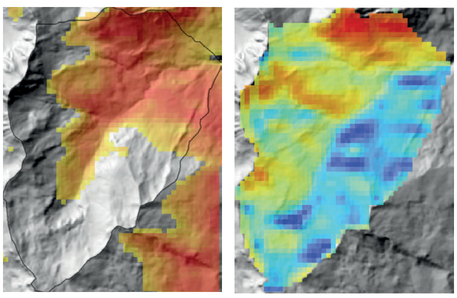
- Construction permit has been obtained from commune and canton
- Depending on available feed-in remuneation at cost, tenders for implementation will be invited soon.

Research questions

Researchers and representatives from *ewz* have discussed and identified the following key-questions:

- Availability of water with current and future climate (special focus on specific extreme events)
- Short-term (<24 hours) forecasts of snowmelt and runoff for intra-day operation
- Winter-time operation (winter turbine?)
- Implication of the large erosion in the channel for the sediment management
- Synergies with other water users (snow production, meadow irrigation)

High resolution modelling of snow melt processes



Modelled snowmelt and shortwave radiation for an ablation day in April

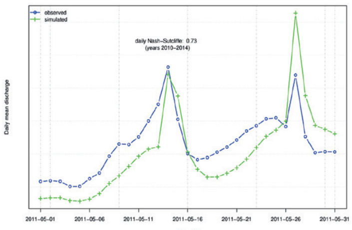
- Snow melt has a crucial role for the hydrology of this alpine catchment
- Resolving small-scale processes is mandatory to capture the spatial variability of snowmelt dynamics
- Allows for a realistic depiction of the amount and timing of runoff in small mountain catchments
- Outlook: Coupling with a weather generator (see related poster) and a gridded hydrological model for future runoff simulations

Flexible operation of a small HP plant with limited storage

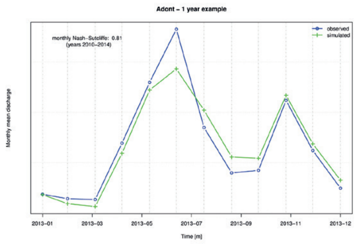
To optimize the benefit of a small HP plant – both for the consumers and the producer – it could be an option to store the water during some hours of the day with low electricity demand and turbine it during hours of peak demand. Such a flexible operation requires a) an operational hydrological forecast system that predicts the water inflow of the coming few hours at very high accuracy, and b) storage capacities.

Operational hydrological forecast system

A well-established hydrological model (PREVAH) has been set up for the Adont catchment. The model uses a digital terrain model at a resolution of 200 m to represent the alpine topography and hourly meteorological input fields to simulate within-day variability in runoff. The forecast system will be run in real-time to facilitate the intra-day management of the plant. In addition, it will be used for calculating the climate change impact on the water availability in this catchment.



Example of the results of the model calibration with daily resolution for one month and 200m spatial resolution



First results of the model calibration for one year of monthly aggregates and 200m spatial resolution

Storage capacities

Similar to many other small run-of-the river HP plants, no reservoir is available, and consequently the water cannot be retained easily. This issue can mainly lead to decrease of power generation during times when available flow is less than minimum design flow. From mid-November to the beginning of April the river discharge is very low and accordingly difficult to be turbined. However, by providing intra-day storage capacity, the water can be stocked, and HP operation can be launched once a certain volume of water is available.

To this end, the following possibilities can be considered:

1. Modification of hydraulic structures (e.g. penstock, sand trap, access gallery to the sand trap or headrace channel) and using them for water storage.
2. Building an external basin close to the water intake
3. Constructing a small dam at the intake place

Different storage/operation cycles will be simulated and compared in order to achieve the optimal solution.

However, providing the extra storage capacity is costly and needs extra investment. Furthermore, using the hydraulic structures to retain water may increase the risk of damage for such structures. The following points will therefore be considered thoroughly:

- Constructive modifications and investment increase;
- Eventual need for changing the concession;
- Risk of air entrainment into the penstock;
- Risk of sediment entrainment into the penstock;
- Operational range of the machines (variable head);
- Environmental impacts;

In view of the elevated altitude of the catchment special attention will be paid to the risk of water freezing in the penstock or other structures.

(Note: The consideration of a small dam at the intake location has not been put forward by ewz, and there are no plans for implementation.)