WP 5 Projects

Title

Pilot & Demonstration projects

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*Alba Zappone, Melchior Grab, Anne C. Obermann, Claudio Madonna, Christophe Nussbaum, Antonio P. Rinaldi, Clément Roques, Quinn C. Wenning, Stefan Wiemer*
Motivation
One objective of the SmallFlex project is to increase the flexibility of the management of the Small Hydropower Plant (SHP) by coupling the high resolution now-cast system INCA-CH and COSMO-1 forecasts to predict the inflow for the next hours to days. This combined forecast system is implemented now at WSL and runs operationally since March 2018.

Results
At first the Nash-Sutcliffe Efficiency has been estimated for June and July 2019 (see below). All post-processing methods show some significant improvements; the best results were achieved with NGR.

Conclusions
The application of the INCA-CH system to such a small mountainous catchments reveals the sensibility of small shifts in the temporal and spatial evolution of thunder storms reflected by large errors. Thus it will be necessary to work with ensembles of such high resolution forecasts and to apply post-processing methods. First results of testing machine learning based error correction methods are shown highlighting the potential of such methods for improving the inflow forecasts.

References
In-situ stress and rock mass characterisation via mini-frac tests at the Bedretto Underground Laboratory

Kai Bröker1,2, Xiaodong Ma1,2 and the Bedretto Lab Team

1 Swiss Competence Center for Energy Research – Supply of Electricity (SCCER-SoE)
2 Geothermal Energy and Geofluids Group (EGG)

INTRODUCTION AND MOTIVATION
- Investigation of in-situ stress state (principal stress directions & magnitudes) and its variation around the Bedretto Underground Laboratory for Geoenegies (BULG)
- Located inside Bedretto tunnel, Canton Ticino
- Stress field determines hydraulic fracture initiation pressure & propagation direction
- Knowledge of stress state important for future creation of geothermal reservoir via hydraulic stimulation, especially for reactivation of pre-existing fractures linked to induced seismicity
- Experiments carried out in crystalline rock (Rotondo granite), overburden ≥ 1 km

METHODS
1. Mini-frac tests: performed in four 30 m-long vertical + two 40 m-long inclined boreholes
   -> estimation of formation breakdown (\(P_b\)) and fracture closure pressure (\(P_c\)), which is
     minimum horizontal stress (\(S_{Hmin}\)) on different diagnostic plots (e.g. G-function plots)
2. Extended shut-in times (20 min, 1 hr, to 12 -14 hr): estimation of local pore pressure
   (\(P_p\)), when pressure derivative approaches zero
3. Dry packer reopening test: calculation of rock mass stiffness and evaluation of fracture
   reopening pressure (\(P_r\)) without interfering fluid flow effects due to residual aperture of fracture

RESULTS
- Fracture compliance method by McClure et al. (2014, 2016) is applicable to crystalline rock mass to pick \(P_r\) as estimate for \(S_{Hmin}\)
- G-function plots show comparable pressure transients between intervals, often two peaks visible in Bourdet derivative.
- Intra- and inter-borehole variations of pressure values and stress magnitudes are identified.
- Proximity to natural fractured zones (identified using borehole logs) influences stress state.
- Dry reopening tests give higher \(P_r\) values than mini-fract tests.
- \(P_r\) between 2.4 - 5.3 MPa (below hydrostatic) indicates tunnel drainage effects.

OUTLOOK
- Calculate matrix permeability from overnight shut-in pressure transients
- Estimate stiffness from wet- and dry- packer reopening tests
- Calibration of equipment needed
- Analyze remaining boreholes and intervals to characterize larger scale spatial variations (stress heterogeneity)

References

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Heightening of very high gravity dams: the case study of the Grande Dixence

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Motivation

Dam heightening can provide large incremental positive impacts on storage with minimum incremental negative impacts, but requires deep knowledge of the structure and its foundation. Very high gravity dams are usually well studied and documented due to their importance and complexity. Such profound knowledge of the dam-reservoir-foundation system considerably reduces the uncertainty about site conditions already at an early stage of design. Furthermore, the availability of monitoring data and safety assessment tools (FE models, predictive behaviour models) strongly reduce the preparation time to reach feasible design solutions. The Grande Dixence dam, located in the Canton of Valais, creates the largest reservoir in Switzerland, providing 10% of the country’s storage energy. If heighten this dam could be used to transfer a larger share of the summer inflows to produce electricity in winter.

Methods

The methodology consists of two main steps. The first step evaluates the feasibility state of the studied hydropower scheme to identify major constraints, while the second step consists of analysing and generating heightening solutions. The analysis of the results obtained during both prior stages should allow an assessment of the developed variants to determine the optimal solution.

Results

Screening of heightening concepts

Several heightening solutions were considered, but constraints were quickly acknowledged [1]. The plan shape of the dam crest strongly limits the integration of an arch and the presence of joints every 16 m is a strong constraint to any solution of buttress or multiple-arch heightening concepts. Considering building artificial abutments and/or using post-stressed anchors was also investigated. However, the use of 300 m long anchors is technically unheard of and challenging and has been discarded. In summary, due to its easier implementation and higher flexibility in regards to the geometry of the actual dam, a similar structural concept was preferred from inception when considering joint behaviour of the original and heightened structures. This concept lead to retaining four alternative solutions for comparison, all with a new crest width of 5 m. Investigations cover height increase limits the integration of an arch and the presence of joints every 16 m is a strong constraint to any solution of buttress or multiple-arch heightening concepts. To determine the optimal solution.

Verification results analysis

The verification analysis shows satisfactory results as all variants meet the design criteria.

Major constraints

As seen on the simplified diagram above, the height increase solutions would submerge the main conveyance tunnel outlet and the backwater effects modify pumping and aeration conditions farther upstream. Moreover, the water pressure increases on the waterways leading to both powerplants downstream: although Bieudron’s surge tank can withstand the increase, Fionnay’s cannot without adaptation measures.

Economic analysis

A preliminary analysis of the Levelized Cost of Electricity (LCOE) indicates a remarkably low cost price and point out that a height increase within 10 to 15 m would likely be optimal.

References

Hydro-structural investigation of a 100 MW Francis turbine based on experimental tests and numerical simulations


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4 PL-LCH / 5 LMH, EPFL, Lausanne, Switzerland

Motivation

- Pumped-storage power plants: key components in a successful integration of renewable energies
- Hydraulic turbines and pump-turbines:
  - Operation in a wide range to offer power regulation flexibility;
  - Undergo frequent start-up and/or stand-by operating regimes;
  - Facing to harsh structural loadings with impact on their lifetime.

Objectives

- Achievement of a hydrodynamic instability level hill-chart of the machine;
- Investigation of the harmful conditions using experimental and numerical resources;
- 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 redraw hydrodynamic instability level hill-charts on different hydropower units using only a simplified instrumentation set.

Hydrodynamic instability hill-chart

- Puts in evidence the high level of strain fluctuations observed on the runner blades at the Speed No-Load (SNL) operating condition characterized by a small opening angle of the guide vanes.

Investigation of harmful conditions

- Combining the experimental data with CFD and FEM simulations as well as the theoretical works, an origin for the high level of strain fluctuations has been proposed:
  - At the SNL operating condition, an Eigen mode of the runner is excited by an external source;
  - After several years of operation, the fatigue limit of the material is reached and cracks are observed at the trailing edge of the runner close to the hub.

Alternative start-up path

- Three alternative slower start-up procedures have been tested:
  - No beneficial effect noticed since the synchronization process remains unchanged.
  - Synchronization procedure with the pump filled seems to be safe for the turbine.

Diagnosis protocol with a simplified instrumentation set

Main achievements

- Investigation of harmful conditions
  - Combining experimental data with CFD and FEM simulations as well as the theoretical works, an origin for the high level of strain fluctuations has been proposed:
    - At the SNL operating condition, an Eigen mode of the runner is excited by an external source;
    - After several years of operation, the fatigue limit of the material is reached and cracks are observed at the trailing edge of the runner close to the hub.

References


Acknowledgements

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[FlexSTOR] [HES-SO//VALAIS-WALLIS] [YKWO] [PPA] [EPA]

Swiss InnoSwiss – Swiss Innovation Agency
Control of sediment transport on an alpine catchment basin for the safe application of smart storage operations on an run-off-river HPP

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Objectives
Smart storage operations (SSO) have been implemented on an alpine run-off-river HPP (case study: KW Gletsch-Oberest HPP) in order to enhance the flexibility of the power plant (ref poster SmallFlex). SSO operations consist on the use of available space underground, such as the settling basin, in order to store the water, particularly in periods of the year with low inflow, which can afterward be used for energy production when the demand and the remuneration tariffs are higher and at a discharge close to the optimum of the turbines to have the best efficiencies.

The aim of efficiently implementing the SSO operations on the setting basin requires sediment management in order to assure a safe use of this part of the system whose function is temporarily changed. In order to understand the amount of sediment inflow into the setting basin, the following actions were undertaken:
- Determine the amount of potential mobilized sediments at the catchment scale with the use of Bayére-Portner (1998) and Gavrilović (1990) formulas;
- Determine the maximum sediment transport capacity of the river Rhone upstream the intake with the use of Bayére-Portner (1998) formula.

This will allow to verify in which periods of the year the sediment basin can be used for water storage with no risk related with sediment conveyance into the waterways and therefore at the turbines.

Study Area
Gletsch catchment:
- Surface area: 40.34 km²
- Average altitude: 2691 m a.s.l.
- River principal watercourse length: 3450 m
- River discharge: 2.93 m³/s
- River secondary watercourse length: 3870 m
- Average altitude: 2691 m a.s.l.
- Average slope along the course: 13.7%
- Surface area: 40.34 km²
- Average slope along the course: 13.7%
- River discharge: 2.93 m³/s

Procedure
Soil coverage analysis
The map was created to display the land use of the case study. The values produced for calculating the erosion models and sediment transport model:

Land use:
- Vegetation: 5.1 km²
- Open spaces with little or no vegetation: 15.9 km²
- Lakes and rivers: 0.2 km²
- Glaciers and perennial snow: 18.6 km²
- Artificial surfaces: 0.3 km²
- Erodible soils: 15.5 km²

Pebble count
Collect the data for a chosen exposed substrate area

Within Pebble Count Method

Results
Grain size distribution
The analysis of the measurements following the Pebble count method resulted in the compilation of the following grain size distribution:

Erosion Model Calculations
Bayer-Portner formula

Gavrilović method

Sediment Transport Model Calculations
Smart and Jaeggi formula

Discussion
A detailed analysis of the catchment characteristics, in terms of soil coverage and grain size, has allowed to investigate the potential sediment input to the KWRO hydropower plant. It has been found that the sediments volume available at the catchment scale is limiting the effective sediment inflow i.e. the sediments transport capacity is reduced by the sediments availability.

The sediment transport formula has been used to calculate the sediment discharge as a function of the water discharge and linearly distributing estimated sediment availability. The hourly sediment volume at the intake can therefore be calculated as:

Pebble count

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1. First insights on the production flexibility of the KWGO Power Plant, Smallflex Project, SCCER-SoE Annual Conference 2019
Monitoring of small hydropower plants with a digital clone

Matthieu Dreyer, Christophe Nicolet, Anthony Gaspoz, Steve Crettenand, Cécile Münch-Alligné

SmallFlex motivation
• To show how small hydropower plants (SHP) can provide winter peak energy and ancillary services, whilst remaining eco-compatible.

Overarching research question
• What are the consequences of enlarging the operational range of the Pelton turbines in case of large head variations?

Hydro-Clone® contributions
• Monitoring of the power plant
• Estimation of the available power/energy for ancillary services

Digital clone implementation

Hydro-Clone® real-time simulation
• Real-Time numerical “cloning” using the complete 1D-model of the power plant
• Boundary conditions measured in-situ and fed to the model in real-time
• Data processing and diagnosis of the power plant health

Live monitoring and data archiving
• Monitoring of non-measurable quantities
• Detection of abnormal pressure transients prior to reach admissible limit
• Detection of Hydraulic/Electrical anomalies
• Anticipation of power plant damages

Benefits and outcomes from real-time simulation monitoring

1. Commissioning follow-up
• Comparison of the measured and simulated pressure at the penstock bottom during an emergency shutdown

2. Monitoring of the power plant during hydropeaking
• Recording of the time evolution of the sandtrap water level and discharge during hydropeaking operating mode

3. Available power/energy assessment for ancillary services
• Calibrated numerical model used to explore the behavior of the power plant
  ➔ assessment of the primary control potential

Contributors

Acknowledgments
This work is funded by SFOE, Swiss Federal Office of Energy (grant funding SI/501636-01), within the framework of the project «Demonstrator for flexible Small Hydropower Plant»
First insights on the production flexibility at the KWGO Power Plant


Context
The aim of the SMALLFLEX project is to investigate how small-hydropower plants (SHP) can provide winter peak energy and ancillary services, whilst remaining eco-compatible. The 15 MW Gletsch-Oberwald Power Plant, owned by FMV and commissioned at the end of 2017, has been selected as pilot site.

Available storage for the first campaign
For the first campaign of this project, the settling basin and the forebay tank, connected by two gates, have been used providing a storage volume of 3'700 m$^3$. This part of the identified storage allows to maintain a minimum available net head of 282 m required for a comfortable operation of the Pelton turbines.

First campaign objectives & method
In November 2018, during three weeks, the competences of the research team have been gathered to explore experimentally the flexibility of KWGO. The first two weeks have been dedicated to induce 5 hydro-peaking events to monitor the impact in the downstream alluvial area. The last week was devoted to generate several production peaks taking into account the energy demand and the available storage.

According to the discharge forecast and the available storage, a schedule for each day of test has been systematically prepared by the research team and sent to FMV.

Monitoring in the power plant during the tests
Since the acceptance tests of the turbines in July 2018, the HydroClone developed by PVE, partner of the project, is installed in the power plant. This monitoring system records all operating parameters of the power plant and provides access, from numerical simulation, to non-measured quantities. In parallel, a turbidimeter to monitor the sediments in the settling basin, a camera to supervise the free surface level in the forebay tank and several sensors on the turbine casing have been installed by HES-SO and EPFL PL-LCH.

Analysis
During the five days, the planned and effective productions show a minimum difference of around 1%. Through the use of the storage, the energy production has been increased of more than 40% for the five days considered.

Conclusion and perspective
This first campaign demonstrated the possibility to use the settling basin and the forebay tank as a storage during periods of low discharge to maximize the energy production and the income adjusting the peak according to the SPOT price. A second campaign is planned in 2020, doubling the available storage using part of the headrace tunnel of the power plant.

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Contributors
HES-SO, EPFL PL-LCH, Power Vision Engineering, FMV
HEATSTORE SWITZERLAND: New Opportunities for District Heating Network Sustainable Growth by High Temperature Aquifer Thermal Energy (HT-ATES) Storage


Motivation
- Industry uses about 92% of their total energy requirement for generating process heat
- 50% of the total energy consumed in Switzerland is used to supply heat
- 86% of the required heat is generated by the burning of fossil fuel
- Households and services use about 92% of their total energy needs for heating applications
- Waste heat generated is continuously discharged into the environment

Let’s convert waste heat into a resource

HEATSTORE aims at developing subsurface storage techniques to reduce wasting heat. A key technology is High Temperature (~25°C to ~90°C) Underground Thermal Energy Storage (HT-UTES). HEATSTORE is a European GEOTHERMICA ERA-NET co-funded project, with 24 contributing partners from 9 countries, composing a mix of scientific research institutes and private companies.

THE SWISS CONTRIBUTION
- 2 Industrial partners
- 4 Research institutions
- 2 HT-ATES study sites

Geneva
- Seasonal storage of waste heat from the Cheneviers incinerator
- Two potential reservoirs at depths between 500m and 1100m
- Heatstore contribution: subsurface characterization constrained by drilling and testing at two different locations (GEo-01 and GEo-02); Energy system integration modelling, which will be coupled to economical, regulatory, and social constraints, to potentially lead to a commercial implementation of the system in a following stage.

Bern:
- Seasonal storage of waste heat from the Bern-Forsthaus power plant.
- Three wells will be drilled to a depth of <500 m deep, into sandstone layers of the Lower Freshwater Molasse (USM)
- Assess the feasibility of an HT-ATES system and, if the results are encouraging, more wells will be drilled after the HEATSTORE project, to realize a fully functional heat storage system
Introduction

L’aménagement hydroélectrique de Ritom se situe dans le canton du Tessin. Actuellement, l’aménagement turbine les eaux du lac de Ritom (CFF) et du bassin d’Airolo (AET) essentiellement pour l’approvisionnement électrique du réseau électrique CFF et AET. Dans le cadre du renouvellement de l’aménagement hydroélectrique de Ritom, la construction d’un bassin de démodulation d’un volume de 100'000 m³ est prévue à l’aval des centrales de Ritom (CFF) et de Stalvedro (AET) avec pour objectif l’atténuation des éclusées. Le projet comprend l’augmentation de la production à 60 MW impliquant un débit turbiné maximal de 29.3 m³/s.

Méthodes

Divers variantes ont été testées. La solution retenue consiste en la création d’une zone tampon sous forme de plaine alluviale par l’élargissement du cours d’eau aval. Cette zone tampon est délimitée du cours d’eau par une marche de 35 cm et a une rugosité plus élevée que le cours d’eau naturel.

Conclusion

Les résultats montrent que la solution proposée est relativement efficace pour les faibles débits (c.f. Figure 4). En effet, on observe une atténuation du débit de pointe à la zone aval ainsi qu’une atténuation des gradients pour les débits inférieurs à 15 m³/s. Pour les débits supérieurs (c.f. Figure 5), on n’observe aucune atténuation de l’hydrogramme. En effet, l’espace de stockage limité représente moins de 1% du volume à atténuer pour des débits importants. Une solution possible consisterait à activer l’espace de stockage avec une section critique contrôlée située à la fin de la plaine alluviale.

Références

Introduction

Many rock types behave anisotropic in their elastic and inelastic properties due to their complex micro-structure. Gischig et al. (2018) has recently demonstrated that rock anisotropy plays a critical role in the in-situ stimulation and circulation experiments in the deep underground laboratory at the Grimsel test site in Switzerland. It was concluded that the anisotropy of the mechanical properties such as elasticity, strength and fracture toughness must be taken into account to accurately predict the rock mass deformation and failure in those experiments (Dutler et al., 2018, Dambly et al., 2019). In this research, we present the experimental results on the directional-dependency of Mode I fracture toughness in Grimsel Granite.

Methodology

The stress intensity, or K-based approach, postulates that a crack extends when the stress, strain or a linear combination of the two, reaches a critical value in the region near the crack tip. Fracture growth criteria, such as maximum tangential stress and maximum tangential strain are based on the value of $K_I$ to predict the crack growth under Mixed-Mode I/II conditions. The two energy-based fracture growth criteria, maximum energy release rate and minimum strain energy density, predict the onset of the crack growth using the critical values of the energy release rate ($G_{cr}$) and the critical strain energy density ($S_{cr}$). $G_{cr}$ and $S_{cr}$ are related to $K_{Ic}$, through the elastic constants.

We point out that the measurement of $K_{Ic}$ requires crack extension in a self-similar manner. While this typically happens in isotropic solids, it is likely that a Mode I crack in an anisotropic solid kinks towards the direction in which crack extension requires less fracture energy. This normally happens when $K_{Ic}$ exhibits a strong directional dependency.

We recently modified the semi-circular bend (SCB) test to incorporate the elasticity anisotropy in the determination of the fracture toughness (Nejati et al., 2019a). The schematic of this test is shown in Figure 1a. This new test scheme allows to determine the fracture toughness at any orientation with respect to the principal directions (see Figure 1b).

In order to prepare the SCB samples, the original rock core, with the diameter of 120mm, was sub-cored in the direction normal to its axis in such a way that the foliation plane is parallel to the axis of the core. A meter of the original core produced eight sub-cores with a diameter of 95 mm, each being cut to yield four SCB samples that have identical angles between the SCB base and the foliation. The SCB specimens from each sub-core were then notched with a thin cutting blade, so that all have the same angle, $\beta$, between the crack plane and the foliation. In total, a set of 29 samples with seven different angles, $\beta = 0º; 15º; 30º; 45º; 60º; 75º$ and $90º$, were prepared. Once the peak load is measured for each experiment, the fracture toughness, $K_{Ic}$, is obtained by correcting the apparent fracture toughness for the kink angle. The solid lines in $K_{Ic}$ results represent the least-squares fit to the shown sinusoidal fit. It can be seen that the experimental data are fitted well using this sinusoidal variation. This gives supporting evidence for that yields a suitable type of variation of the critical SIF in an anisotropy plane. One can therefore use the two principal values of fracture toughness, measured along the two principal material directions, to determine the fracture toughness in any other direction.

Results and Discussion

Figure 2 illustrates the variations of the different measures of fracture toughness, $K_{Ic}$, $G_{cr}$, and $S_{cr}$, versus the angle $\beta$. The $K_{Ic}$ data are obtained by correcting the apparent fracture toughness for the kink angle. The solid lines in $K_{Ic}$ results represent the least-squares fit to the shown sinusoidal fit. It can be seen that the experimental data are fitted well using this sinusoidal variation. This gives supporting evidence for that yields a suitable type of variation of the critical SIF in an anisotropy plane. One can therefore use the two principal values of fracture toughness, measured along the two principal material directions, to determine the fracture toughness in any other direction.

<table>
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<th>Figure 1.</th>
<th>Figure 2.</th>
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<td>a) Schematics of the modified SCB test with asymmetric loading.</td>
<td>Variations of different measures of Mode I fracture toughness against $\beta$ for a set of experiments on Grimsel Granite samples.</td>
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<tr>
<td>b) Modified SCB test of Grimsel Granite with $S_{cr}$/R=0.6.</td>
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References


Computational Modelling of Fine Sediment Release Using SEDMIX Device with Thrusters

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Introduction

- **Problem:** Reservoir sedimentation occurs in dams worldwide, reducing the live storage available in the reservoirs.
- **Possible solution:** Jenzer-Althaus (2011) tested a water stirring device (called SEDMIX) that keeps sediments in suspension, enhancing its release through the power intakes of the dam reporting a high efficiency.
- **Background studies:** Numerical simulations for a prototype for the Trift reservoir have been carried out in the past by Amini et al. (2017) and Chraibi et al. (2018), obtaining good results for sediment evacuation and determining the optimal location and dimensions of the device.
- **Objective of the current work:** Numerically test the performance of SEDMIX at the Trift reservoir implementing thrusters instead of the previous configuration with water jets using ANSYS 2019 R1 software.

Methodology

1. Compare the flow patterns in a regular tank obtained through numerical modelling (figure 1) with the experimental ones obtained by Jenzer-Althaus (2011).
2. Determine the sediment release at Trift reservoir and compare it with the one obtained with jets.
3. The geometrical dimensions and location of the device were the same obtained with jets.
4. Considering various bottom clearances and a single phase flow, the jets were modelled as inner sources and the thrusters as a combination of inner sinks and sources to avoid refining elements.
5. The jets were calibrated to a higher velocity, a similar flow pattern and Chraibi et al. (2018), obtaining good results for sediment release and determining the optimal location and dimensions of the device.
6. The flow patterns obtained through numerical simulation of SEDMIX with water jets (figure 3a) are similar to the ones obtained by Jenzer-Althaus (2011) (figure 3b).
7. The thrusters were calibrated to a higher velocity, a similar flow pattern and Chraibi et al. (2018) (figure 3c).
8. The experimental study of the device using thrusters is highly advised and the hydrodynamic behaviour in the reservoir should be further studied.

Results And Analysis

- The flow patterns obtained through numerical simulation of SEDMIX with water jets (figure 3a) are similar to the ones obtained by Jenzer-Althaus (2011) (figure 3b).
- With thrusters maintaining the same induced flow as the one considered for the jets, the flow velocity provided by them is too small to reproduce the flow patterns expected (figure 3c).
- Adjusting the thrusters to a higher velocity, a similar flow pattern was obtained (figure 3d).

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Conclusion

- The numerical simulations showed similar patterns when using jets and thrusters, however, a higher induced flow is needed by the thrusters to be able to replicate the recirculation flow generated by the jets.
- For the Trift reservoir, the optimal thruster had a diameter of 0.42 m with a induced flow of 3.2 m³/s.
- Since the use of thrusters means no dealing with head losses, the power requirements could be less and the operational costs could be lower compared to the use of water jets.
- The experimental study of the device using thrusters is highly advised and the hydrodynamic behaviour in the reservoir should be further studied.
Assessment of a turbine model to predict cost effectively the far wake of a hydrokinetic farm

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Context
- To maximize the energy harvest from rivers, several hydrokinetic turbines [1,2] are assembled to form a farm, which requires to investigate the influence of the machines between each other and their influences on the local flow.
- To study these influences, numerical simulations are used. However, it requires to compute the free surface flow and all the interfaces between the stationary and rotating parts, which is time and computational expensive.

Objective
- To implement a simplified hydrokinetic model to save computational resources.

Hydrokinetic Turbine Model
The hydrokinetic turbine model (similar to the actuator disk) mimics the pressure drops experienced by the fluid from the runner [3]. The model requires a loss coefficient as parameter, which is obtained numerically using steady state simulations with a simplified computational domain.

Numerical setup
Two different computational domains were designed using ANSYS ICEM CFD. The first one (case 1) uses a rectangular domain and was used to define the turbine model by steady and single phase simulations. The second one uses a trapezoidal domain and was used to simulate the flow field through a farm using once the full geometry of the machine (case 2 ) and once the turbine model (case 3). These simulations were unsteady and multiphase.

Computed performance and loss coefficient
To establish the performance characteristic and the model parameter of the hydrokinetic turbine, several combination of the tip speed ration \( \lambda \) were computed using ANSYS CFX R17.2. The Best Efficiency Point is reached for a \( \lambda=2.54 \) [-] and a \( \lambda=2.84 \) [-]. Based on these simulations, the coefficient of resistance \( K \) can be computed and corresponds to 0.71 [-] at BEP [4].

Results
- Case 3 required approximately 15 time less CPU hours and mesh resources compared to case 2.
- Case 2 shows a qualitative faster wake recovery, which might be attributed to the difference of mesh type and the lack of flow rotation in case 3.
- However, the quantitative comparison between case 2 and 3 shows that the difference in the horizontal velocity profile at \( x/D=99.0 \) is only of -13%.

Conclusions
- A methodology was proposed to investigate faster the flow field passing through a hydrokinetic turbine farm.
- The comparison between the high resolution simulation (case 2) with the simplified one (case 3) showed acceptable discrepancies but a significant gain in mesh size and computation time.
- This methodology is well suited for an initial investigation on where to place hydrokinetic turbines in a river to get the maximum power output.

References
**LARGE-SCALE FIELD TESTS ON IMPULSE WAVES**

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**Motivation**

Impulse waves, generated by avalanches, ice- or rockfalls, may seriously impair the reservoir of a hydropower plant. In some cases they even overtop or damage the dam and trigger hazardous flood waves (Fig. 1). Examining their potential impact is therefore an inevitable part of a comprehensive hazard assessment for hydropower reservoirs in alpine areas.

**Results**

Due to the high sledge impact velocity in the field tests, a large splash is created, reaching up to 3/4 of the basin length. The maximum wave height occurs when a maximum of the sledge’s energy has been transferred to the water body and the wave has propagated a certain distance from the impact location. The first and second waves are very steep and therefore start to break shortly after generation such that they finally propagate as long waves with reduced wave height.

**Field and laboratory tests**

Within the CTI project FlexSTOR, both laboratory tests at VAW and prototype field tests at a gravel pit in Bülach were carried out to investigate the impulse wave generation and propagation. A test site was established in a 30 m deep gravel pit. The artificial reservoir was 15 m wide, 55 m long and had a still water depth of 1.5 m. A 40 m long steel ramp along the pit slope (37°) provided a sliding surface. The sliding mass was represented by a steel sledge (3 to 7 tons). The sledge could be released from different ramp positions to vary the impact velocity between 6 and 17 m/s. The resulting wave heights along the wave propagation path and the wave run-up were visually determined using gauge poles. A total of 13 tests were carried out in both field and model scale.

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Motivation

The role of WSL and SLF within the SCCER-SoE is to develop and provide state-of-the-art snow cover and hydrological models suitable to predict inflow at the intake of hydropower plants as a basis for sediment management and for a flexible power production scheme. A high-resolution energy-balance-type snow model is applied enabling a realistic representation of small-scale processes in alpine terrain. Accounting for spatial variability is key to accurately assess changes in the distribution and frequency of runoff in small mountain catchments.

Methods

We used the state-of-the-art snowcover model JIM to describe the spatially variable water input at the soil surface. We recently refined the model to allow applications at very high spatial resolution by specifically accounting for small-scale processes relevant in mountainous environments. This model upgrade integrates developments such as a dynamically downscaling of radiation input delivered by Numerical Weather Prediction (NWP) models from 1 km to 250 m resolution and a subgrid-parametrization of snow covered fraction. Measured snow and air temperature data were assimilated in the model in order to initialize realistic start conditions for forecast values. Modelled surface water input was provided to the hydrological model PREVAH to simulate the intake to a hydropower plant. This model setup was applied to the demonstrator project “SmallFlex” (Task 5.1) in Gletsch, VS.

Results and Discussion

Shortwave radiation (SWR) was dynamically downscaled from coarser NWP models and include shading from the terrain.

Figure 1: Modelled shortwave radiation for a clear day in June 2019 at 10 am (a) and 1 pm (b), respectively.

The resulting surface water input reacts on the spatial difference in shortwave radiation, but is also dependent on other factors as the current states of snow amount, snow covered fraction and snow wetness (next block) as well as other energy fluxes (Discussion).

Figure 2: Modelled surface water input for one hour on a clear day in June 2019 starting at 10 am (a) and 1 pm (b), respectively.

Snow covered fraction (SCF) is dependent on modelled snow depth and terrain variables to account for snow depth variability. It is an important state variable since it strongly influences modelled surface water input (SWI). SWI is also dependent on the ability of snow to retain melt or rain water.

Snow free       Snow covered

Figure 3: Modelled snow covered fraction for a day in June 2019 (a) and an example of the effect of SCF and snow retention capacity on surface water input (SWI) (b).

Surface water input (SWI) is provided to the hydrological model PREVAH, a high resolution semi-distributed model. This model chain is able to forecast the intake of the small hydropower plant of up to five days. A first analysis of the quality shows that the largest uncertainty is due to the input data. For example, the model receives too little precipitation at June 10. Ensemble of precipitation input may improve the forecast value significantly, especially for small alpine catchments where the localisation of high intensity precipitation is difficult to forecast correctly.

Figure 4: Intake of the small hydropower plant, in blue are observations, in green hindcast intake and in red forecast intake.

Figure 5: Accumulated precipitation this catchment for June 9 and 10. Observation in red, deterministic forecast in black, and ensemble forecast in blue (median in bold and innerquartile range shaded).

Discussion

Snow melt depends only indirectly on air temperature, while shortwave radiation is known to be the main driver for most situations. However, in most hydrological models snow melt is calibrated based on air temperature. This works fine for most situations, however, snow melt during rain-on-snow events can hardly be modelled correctly. Also for extreme situations, which are not well represented in the calibration data set, the less calibration-based energy balance model approach has a strong advantage. This is also true for future climate scenarios, for which the empirical relation between air temperature and runoff may change substantially.
Multipurpose water reservoirs: a necessity for future irrigation?

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Switzerland, considered as the water tower of Europe, will not escape the problems related to water in the next years. Several causes indicate that such as fluctuating water supplies, local water shortages and also local geopolitical conflicts between the resources users.

Climate variations will change the hydrological regimes of alpine regions in the next years (2050-2100). The glaciers will slowly disappear inducing changes in the water regime by moving the peak earlier in the year [1]. So it is necessary to be able to store the water when we do not need to reuse it later in the year.

The challenges are the storage of winter water for the summer and that all users of the region are equitably supplied with water [2]. The multipurpose reservoir are part of the solution.

Multipurpose reservoirs:
- Significant contribution to having enough water available in the future
- Can compensate for the disappearance of glaciers
- Coordinate the multiple users of water
- Available for flood protection

Objective and Method

The project is divided into 4 distinct parts. The project aims to define the future hydrological regime of the region, to monitoring a part of the current network to make a numerical model that will allow to set up a master plan by the municipality of Val de Bagnes.

- Know the needs and future water resources in Val de Bagnes (VS)
- Develop a decision support for the management of water reservoirs
- Develop a general planning of the irrigation network

Perspectives and illustrative simulation

- Identify critical section of the network according to future scenario simulations
- Connecting the two numerical models
- Develop a holistic approach to water use in these watersheds
- Participate in the development of the master plan (connection - new reservoirs)

Water Network Modelling

- The numerical model is initially divided into two part. On the one hand the water addition network (open channel flow (A)) and on the other hand the irrigation network distribution (pipe flow (B)).

References


Set-up and configuration of an ensemble Kalman filter for an operational flood forecasting system

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INTRODUCTION:
To forecast riverine floods, short-range forecasts are normally provided. In such cases, the initial hydrological conditions highly influence the predictability of a flood event. The study evaluates the potential of an ensemble Kalman filter (EnKF) for the operational flood forecasting system in the Upper Rhone River basin (Fig 1). Observed discharge data is used to update the initial conditions of the hydrological model. Past flood events in the Reckingen subbasin (Fig. 1) are modelled to assess the robustness of the methodology and the quality of flood predictions.

RESULTS:
Figure 3 shows the streamflow prediction of the EnKF in comparison with the Control and VBU simulation as well as the observed discharge during an event in Reckingen in 2012. Figure 4 shows the KGE of the different simulation methods for four flood events in the Reckingen subbasin.

METHODOLOGY:
- Simulations are computed with the semi-distributed hydrological model RS MINERVE (CREALP, 2019).
- Three different discharge predictions are computed and compared:
  - Control simulation: Open-loop scenario where discharge observations are not used to correct model initial conditions.
  - Volume based update (VBU) simulation: Iterative approach correcting the initial soil saturation in order to generate the modelled water volume which has been observed over the 24 h before the forecast.
  - EnKF simulation: Data assimilation (DA) method where the initial conditions of the model are updated based on the covariance matrices of the discharge observations and the model prediction (Fig. 2) (Evensen 1994).
- Forecast quality is evaluated based on the Kling-Gupta-efficiency (KGE) calculated for different lead times (Gupta et al., 2009):
  \[
  \text{KGE} = 1 - \sqrt{(r - 1)^2 + (\alpha - 1)^2 + (\beta - 1)^2}
  \]
  where \(r\) is the correlation coefficient, \(\alpha\) is a measure of variability and \(\beta\) is a measure of bias.

DISCUSSION AND CONCLUSION:
- For short lead times, the EnKF simulation outperforms the other two simulations. With an increased lead time the results depend on the event and the model calibration.
- To achieve good results with the EnKF, an appropriate model calibration and high-quality input data is needed.
- A DA method which specifically accounts for the time lag needed for streamflow routing could increase the robustness of the framework.

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GPR imaging of fractures in the Bedretto Lab
Alexis Shakas and Peter-Lasse Giertzuch

Motivation
The Bedretto Tunnel is located in Bedretto Valley (Ticino). Within the tunnel, at 2 km length (from a total of 5.2 km) there exists the Bedretto Underground Laboratory for Geosciences (BULG) - a research facility where the ETH Zurich and external partners are conducting experiments that focus on the safe and efficient extraction of geothermal heat from engineered geothermal systems within crystalline rock reservoirs.

Fracture Detection using Ground Penetrating Radar (GPR)
Various geophysical techniques are used in the BULG to characterize the granitic rock mass and the presence of fractures along with their spatial properties. These properties, including the fracture density, aperture, length scale and orientation allow us to characterize processes such as fluid flow, heat dissipation and rock mechanical aspects such as hydraulic shearing and fracturing. One of the most promising methodologies for remote sensing of fractures (and associated processes) is ground penetrating radar, a technique that uses high-frequency (100 to 250 MHz) electromagnetic wave propagation and scattering.

Forward Modeling of GPR reflections

Discussion and Outlook
The Bedretto Underground Lab for Geosciences has been developing since 2017. Geophysical characterization of the granitic rock mass that surrounds the underground laboratory is of primary importance, prior, during and after any stimulation experiments, which can alter the natural state of the fracture network. Geophysical tools such as GPR offer a promising technology to delineate geometrical properties of fractures. This can be done in boreholes, as is presented here, but also along the tunnel wall.

Additionally, several geophysical imaging techniques can be combined in order to reduce the uncertainty in the measured properties by providing complementary information. For example, GPR uses electromagnetic waves to detect fracture aperture using the dielectric properties of the host rock and water (for water filled fractures). Additionally, active seismic methods will be used in a similar geometry to detect fracture aperture, while being sensitive to the density and elastic properties of the host rock and water. Such information can then be used in a joint modeling and inversion framework to constrain fracture permeability and assess permeability enhancement as a result of stimulation experiments.

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The work presented here is part of the Bedretto project for Geo-energies (http://www.bedrettolab.ethz.ch). The Bedretto team is to thank for all their individual contributions and effort in the project.

References
1. Aims of the Experiment:

- Understanding how exposure to CO2-rich water affects sealing integrity of faults in caprock (permeability changes; mechanical changes; induced seismicity);
- Imaging fluid migration along a fault and its interaction with the surrounding environment;
- Testing instrumentation and methods for monitoring fluid transport;
- Validate Thermo - Hydro - Mechanical - Chemical (THMC) simulations.

2. CS-D Experiment

The CS-D experiment is located in a niche in the shaly facies of the clay. We inject CO2-saturated water into the fault and monitor changes in pressure, pH and electrical conductivity in nearby wells. The portable mass spectrometer Minirued (cooperation with EAWAG) is used to monitor the chemical composition in the monitoring well. Seismic sensors in boreholes and along the walls of the niche will detect microseismicity, if any. Strain is measured through FO and SMIFIB (cooperation with LBNB).

3. Injection tests

Several injection tests were performed to understand the system response to pressurization. The test shown in Fig. 3 is a prolonged step test in interval Q4. The pressure was increased by steps of 300 kPa, up to 4800 kPa. Each step was about 28-30 hours long. Analysis of pressure decay (3 days) with the Neuzil model provides an estimate of transmissivity in the order of $10^{-12}$ m$^2$/s.

4. Geophysical monitoring

The experiment is monitored using active and passive seismic methods. Two sets of sensors consisting of piezoelectric transducers and grouted geophones were installed for this purpose (Fig. 2). During the pumping tests, no induced seismicity was detected. Further analysis of data, including also recordings during gallery excavation activities (Fig. 5), is ongoing.

Active seismic measurements have been performed with hammer sources in the gallery and a P- and S-wave sparker sources in the boreholes. During the injection test and the long-term injection, these measurements are repeated. In Fig. 6, an example trace is shown, which has been recorded during injection tests. Variations in arrival times were detected which are larger than the variability within repeated shots (Fig. 6, left). The data is currently processed for tomographic travel time imaging.

5. Start of the long term injection of CO2 saturated water

Mid June 2019, the long-term injection of CO2 saturated water was started, together with repeated active seismic and ERT measurements. Since then, the injection takes place under constant pressures of 4500 kPa. The injection rates are small (~0.1 ml/min) and up to now slightly decreasing with time.

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