Task 2.3

Task Title

Hydropower infrastructure adaptation to requirements of future operating conditions

Research Partners

Laboratory of Hydraulic Constructions (LCH) at EPFL, Laboratory of Hydraulics, Hydrology and Glaciology (VAW) at ETH Zurich, Lucerne University of Applied Sciences and Arts (HSLU)

Current Projects (presented on the following pages)

The ongoing research projects have been presented as posters during the Annual Conference, as per the list hereafter. The link with the 10-years Hydropower roadmap is presented below in Figure 1 (see numbering after the title).

Design optimization of alpine desanding facilities (1)
C. Paschmann, J. N. S. Fernandes, D. Vetsch, R. Boes

HydroGIS, a tool for Swiss hydropower asset management and implementation of the Energy Strategy 2050 (2)
M. del Mar, O. Rodriguez, P. Manso, B. Schaefli, A. Schleiss, M. Balmer

Influence of geometrical imperfections and flaws in welds on the design of steel liners of pressure tunnels and shafts considering rock anisotropy (3)
A. J. Pachoud, P. Manso, A. J. Schleiss

Experimental analysis of fluid-structure interaction and pipe-wall rheological behavior during hydraulic transients (4)
D. Ferras, P. Manso, A. J. Schleiss, D. I.C. Covas

Hydroabrasive-resistant materials at sediment bypass tunnels (5)
M. Hagmann, I. Albayrak, R. Boes

Dam Break Analysis under Uncertainty (6)
S. J. Peter, R. M. Boes, A. Siviglia

Flood forecasting initialization enhancement (7)
K. Cros, G. Artigue, F. Jordan, A. Schleiss

Sustainable management of reservoirs through turbidity currents venting (8)
S. Chamoun, G. De Cesare, A. Schleiss

Overtopping of Impulse Waves (9)
J. Kobel

Kraftwerksausbau unter Berücksichtigung des Wasserfallbilds am Diesbach (10)
F. Arnold

Flow duration curves for water resources quantification in Alpine environments (11)
A. C. Santos, B. Schaefli, P. Manso, M. M. Portela, A. Rinaldo, A. Schleiss

Dam Break Analysis under Uncertainty (12)
S. Peter

Restoration of the natural morphological conditions downstream of dams by means of artificial sediment replenishment (13)
E. Battisacco, M. J. Franca, A. J. Schleiss

Evaluation du potentiel hydroélectrique des eaux usées en Suisse (14)
C. Bousquet, I. Samora, P. Manso, L. Rossi, P. Heller, A. Schleiss

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L'aménagement de Trift (15)
C. Frutiger, S. Terrier, P. Manso, A. Schleiss

Réaménagement Etzelwerk (CFF) - Concepts d'aménagement innovateurs du point de vue énergie et protection contre les crues (16)
G. Kayser, F. Zeimetz, P. Manso, A. Schleiss

Hydropower Design under Uncertainties (17)
F. Oberrauch, P. Manso, A. Schleiss

Characterisation of hydraulic behaviour of surge tanks orifices (18)
N. J. Adam, G. De Cesare, A, Schleiss

Numerical modelling of fine sediments stirring at the new Trift reservoir (1)
A. Amini, P. Manso, G. De Cesare, J. Jenzer-Althaus, A. J. Schleiss

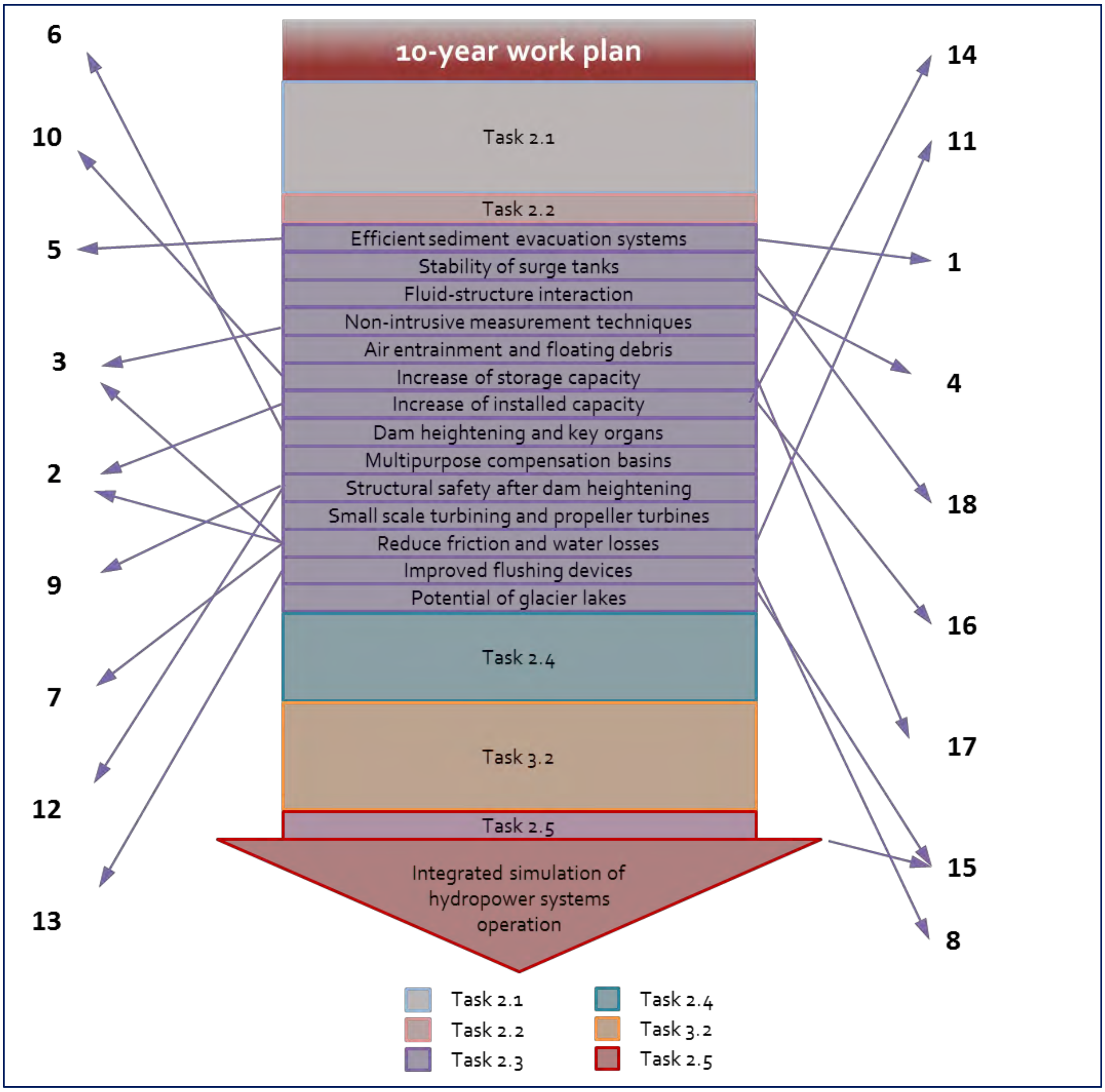

Figure 1: Link between the ongoing research projects and the SCCER-SoE Hydropower Roadmap

Task Objectives

This task focus on

- investigating the infrastructural adaptation of existing hydropower systems to cope with more flexible operation and with increased erosion and sediment transport and to maintain the required level of safety under harsher operational conditions or under storage increase
- identifying possible improvement margins through combined design of infrastructure, devices, and operation
- exploring the potential of lakes that can form following the retreat of glaciers

Interaction Between the Partners – Synthesis

The three research institutes involved in this task jointly participate in the CTI research proposal STODEV (see details below).

The ETHZ-VAW organized the first-ever Workshop on Sediment By-pass Tunnels, an original solution for sediment management on dam reservoirs, with the collaboration of EPFL-LCH in the international scientific and review committee.

Research activities lead by the three partners jointly or independently are, almost inherently, multidisciplinary and in connection with other SCCER-SoE tasks given the specific content of this task 2.3 on infrastructure, which make use of given resources (task 2.1), in a given economical context (task 2.2), within environmental restrictions (task 2.4) for operation (task 2.5) with given equipment solutions (task 3.2).

Highlights 2015

- A research funding proposal has been submitted to the CTI entitled "STODEV - Sustainable hydropower storage development in a changing environment: innovation as means to secure and expand operation and competitiveness of KWO's complex system." comprising research from six institutions (EPFL, ETHZ, HES-SO, EAWAG, WSL and HSLU) together with Kraftwerke Oberhasli.
- A cycle of conferences is being held at EPFL on hydropower related issues, consisting of twelve presentations in total, at a monthly frequency, with an average attendance of 50 participants per event, gathering private sector, public authorities and academia.
- A 3-day workshop was organized at EPFL on September 9-11, in collaboration with the Swiss Committee on Dams (CSB / STK), entitled 13th ICOLD Benchmark Workshop on the Numerical Analysis of Dams (http://icold2015bmw.epfl.ch/). The main focus was on dam safety against earthquakes considering recent directives. Over eighty participants follow two full days of sessions and one day field trip to two landmark dams which have recently undergone heightening or strengthening.

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Design optimization of alpine desanding facilities

C. Paschmann, J.N. Fernandes, D.F. Vetsch, R.M. Boes – VAW, ETH Zurich

Introduction

Operating high-head hydroelectric power plants under alpine conditions may expose facility components to hydro abrasion due to mineral suspended sediments in the water. Particularly, turbines can be affected by wear, leading to a considerable efficiency decline affiliated to power and financial losses. Therefore, high-head hydroelectric power plants are commonly equipped with desanding facilities (cf. Figure 1) to reduce the amount of suspended sediments.

Figure 1 Desanding facility Mörel (hydroelectric power plant Massaboden)

Nowadays, climate change causing glacier meltdown entails increasing sediment yield from glaciated catchment areas into alpine waters. Additionally, experiences show that the settling efficiency of existent desanding facilities often is below expectations, frequently due to shortcomings of the geometrical design. Thus, the geometric optimization of existing and proposed facilities is of major importance.

Objective

The aim is to development an enhanced guideline for the design of desanding facilities to improve the settling efficiency, putting an emphasis on the effects of various geometrical parameters as well as different headwork arrangements.

Methods

The optimization potential is systematically investigated by means of a hybrid approach, modeling flow and settling processes by numerical simulations based on precedent field experiments (Figure 2).

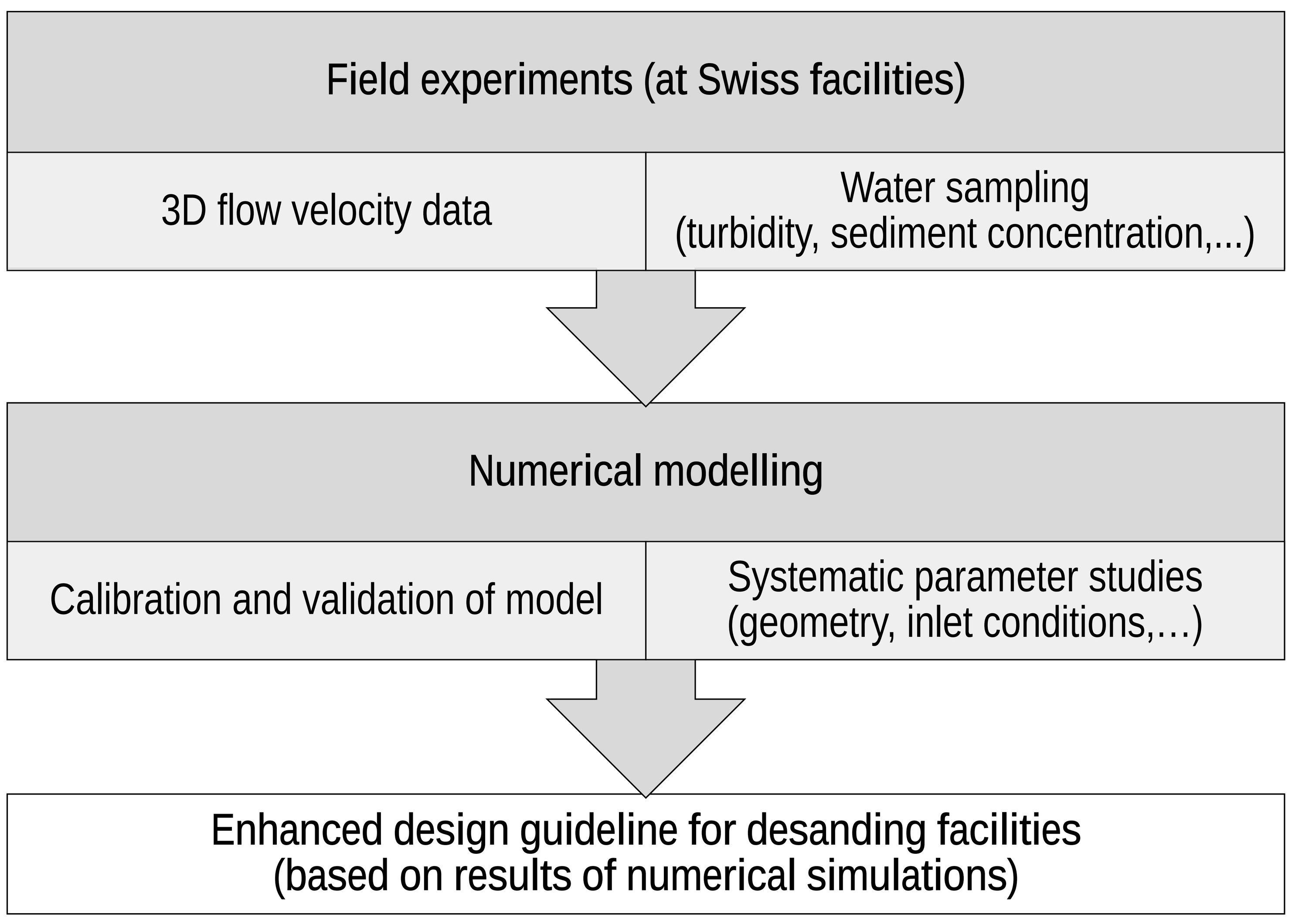


Figure 2 Flow chart of applied methods

Partners (to date)

The following operators provide their desanding facilities in the scope of the conducted field measurement campaign.

- Swiss Federal Railways (facility *Mörel*)
- EnAlpin (facility *Saas Balen*)
- Gommerkraftwerke AG (facility *Wysswasser*)

Highlights

Comprehensive spatial flow velocity measurements in inlet and chamber areas with acoustic Doppler velocimeters (Figure 3) at high sampling frequencies

Figure 3
Source: Nortek AS

In-line application of Coriolis flow and density meter (Figure 4), turbidity sensor and water sampling in dense measurement pattern

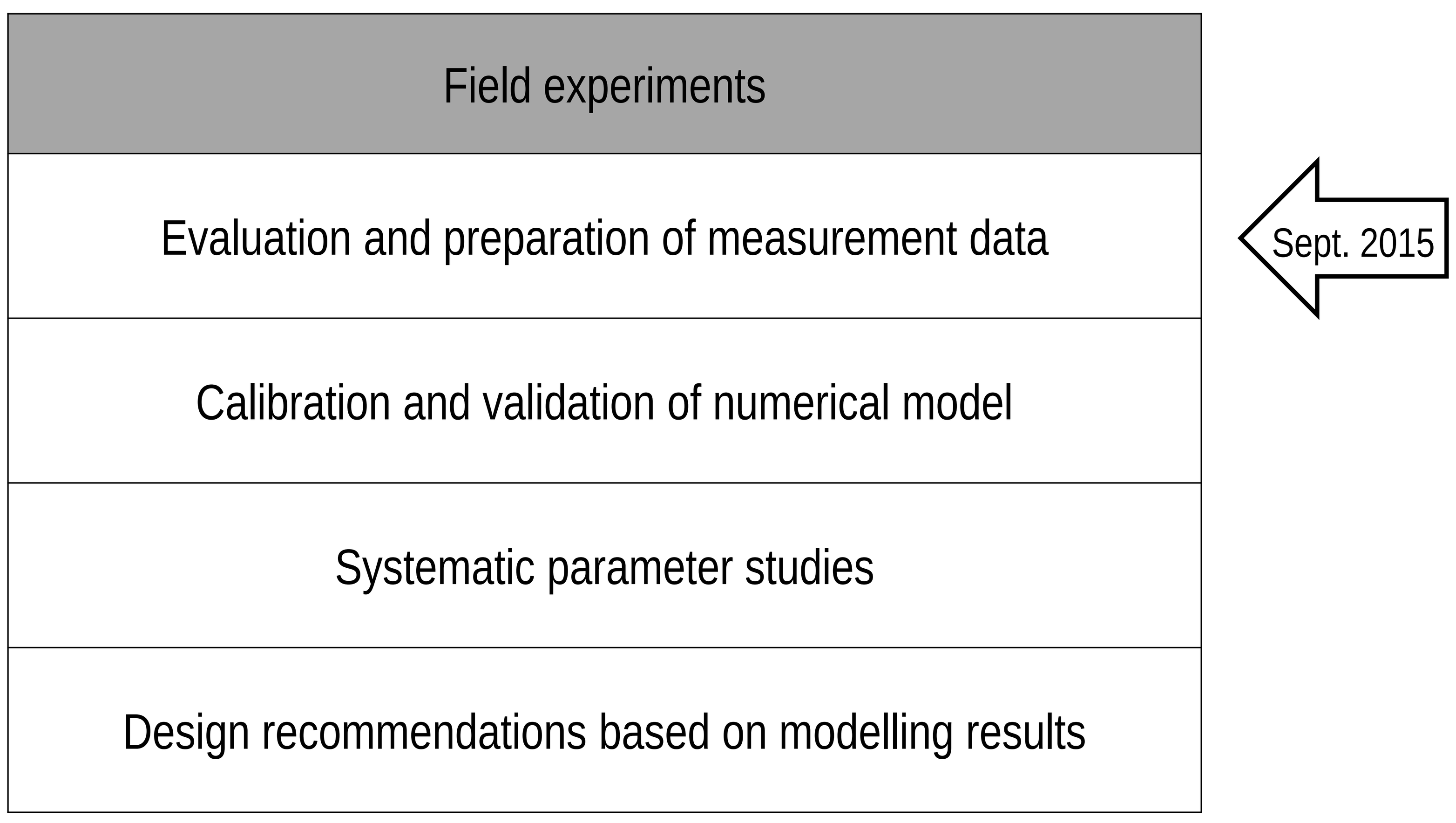
Figure 4
Source: Endress+Hauser

Added value regarding energy strategy 2050

Direct improvement of energy yield of existing and newly planned Alpine hydroelectric power plants due to enhanced efficiency of integrated desanding facilities and hence less downtime of power plant. In concrete terms:

- Geometry and thus flow field optimized for particle settling
- Increased trapping efficiency of particles with limit grain size
- Extended runtime between chamber flushing

Project status



Acknowledgement

This project is financially supported by the Swiss National Science Foundation (NRP70, No. 153861) and technically supported by the Swiss Federal Railways, EnAlpin and Gommerkraftwerke AG.

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HydroGIS, a tool for Swiss hydropower asset management and implementation of the Energy Strategy 2050

Maria del Mar Oliva Rodriguez[1], Pedro Manso[1], Bettina Schaefli[1,2], Anton Schleiss[1] & Markus Balmer[3]
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LCH LABORATOIRE DE CONSTRUCTIONS HYDRAULIQUES
EPFL ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

1. Approach: Swiss Energy Strategy 2050

The main goal of the S2050 is ceasing the use of nuclear plants, which implies **increasing renewable energy production**. It is intended that the authorities stop production of nuclear energy by 2050. Renewable energy production is supposed to increment overall by 22.6 TWh/a, of which 3.2 TWh/a correspond to **hydropower** (SFOE 2012). This aim is specially challenging since currently already 60% of the electricity production is provided by hydropower plants and most of the river systems are being used.

2. HydroGIS

HydroGIS is a **database** that collects both spatial and attribute data (Figure 1) of 285 of the largest Swiss hydropower plants with installed capacity above 300 kW, developed in the framework of by Dr. Markus Balmer PhD thesis presented at ETHZ in 2011.

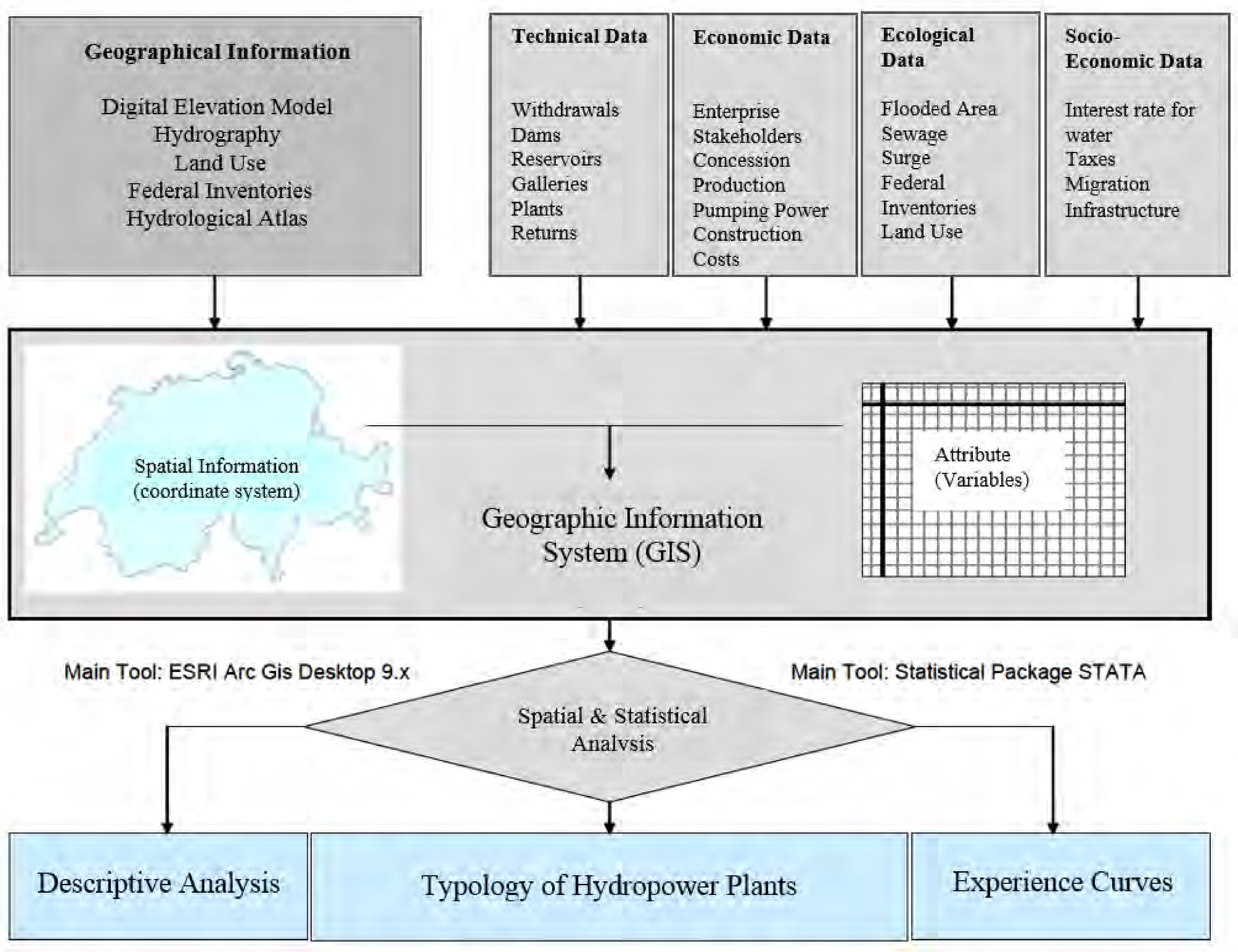

Fig.1: Scheme of Dr. Markus Balmer's PhD thesis content. Source: Balmer (2011).

The database includes information from several sources: WASTA, SWISSDAMS, GEOSTAT, GEWISS, INVENT, HADES, Tunnelstatistik, Swisstopo, organized in ten GIS layers. All elements are referred to using a power plant classification based on the company ID, derived from the WASTA number. Even if the database WASTA includes nowadays 664 hydropower plants, HydroGIS contents are more than enough to allow for comprehensive analysis to be carried out for the whole of Switzerland, as shown in Figure 2.

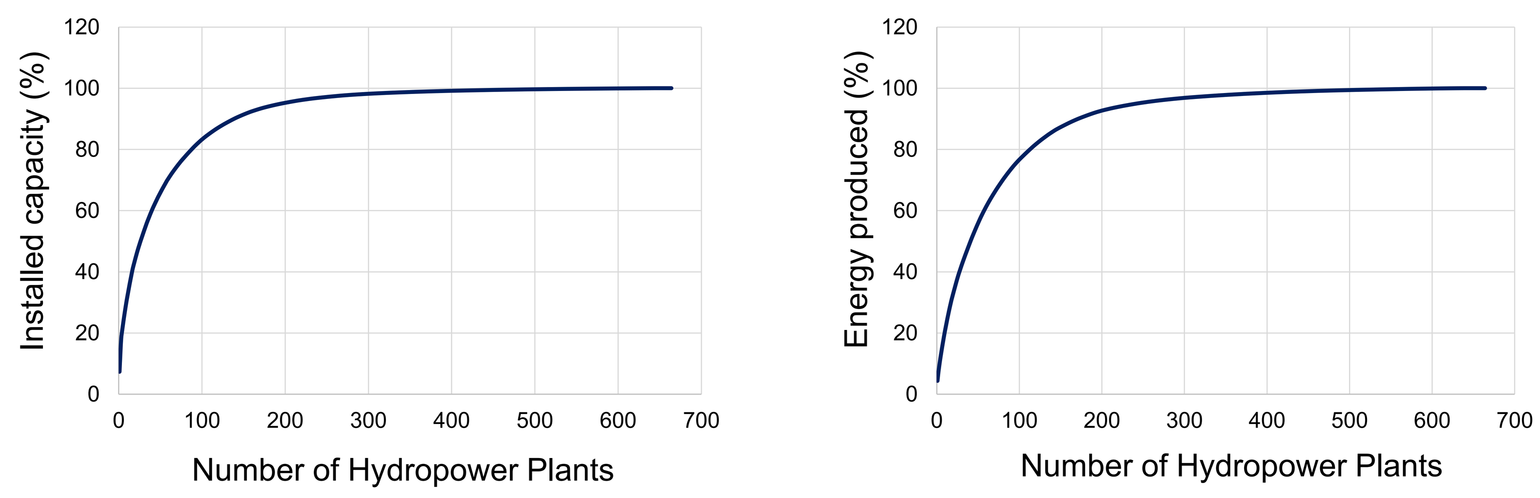

Fig. 2: Statistics of hydropower plants with capacity > 300 kW. Source: WASTA (2015).

3. Objectives

The present work aims at:
- Exploring the data base organization (Table 1).
- Suggesting new contents.
- Carrying out comprehensive analysis of Swiss hydro infrastructure based on HydroGIS data.

Issues presently been investigated:
- Hydraulic waterways.
- Glacier influence in catchments (see also the poster on **"Importance of glaciers for CH hydropower", Schaefli *et al.***).
- Powerplant & EHM units.

HydroGIS layers
Tunnels
Inputs
Outputs
Catchments
Residual Flow Reaches
Hydropeaking River Reaches
Backwater Reservoirs of
Run-of-river plants
Reservoirs
Dams
Watersheds

Table 1: HydroGIS structure. Source: Balmer (2011).

4. Waterways

The tunnel layer is one of the most relevant and provides information (e.g. diameter, length, slope and volume) about **tunnels, shafts and penstocks** of different configurations (Fig. 3). These data are the starting point for a comprehensive analysis of the friction losses in Swiss hydraulic tunnels, which may help defining priority measures to recover part of the lost energy, thus improving the efficiency of the hydropower network, in line with SES2050 targets.

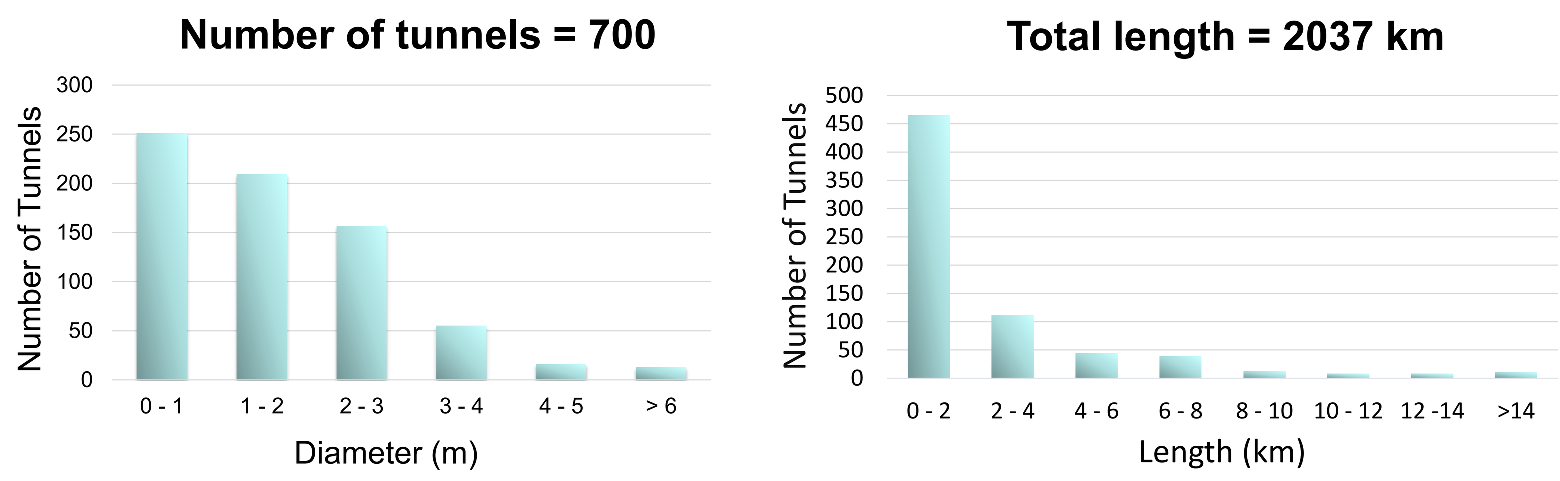

Fig.3: Tunnel diameter and length distribution (all data).

The waterways are currently divided in two groups: the supply waterways (leading to reservoirs) and the power waterways (leading to powerplants, presented in Figure 4).

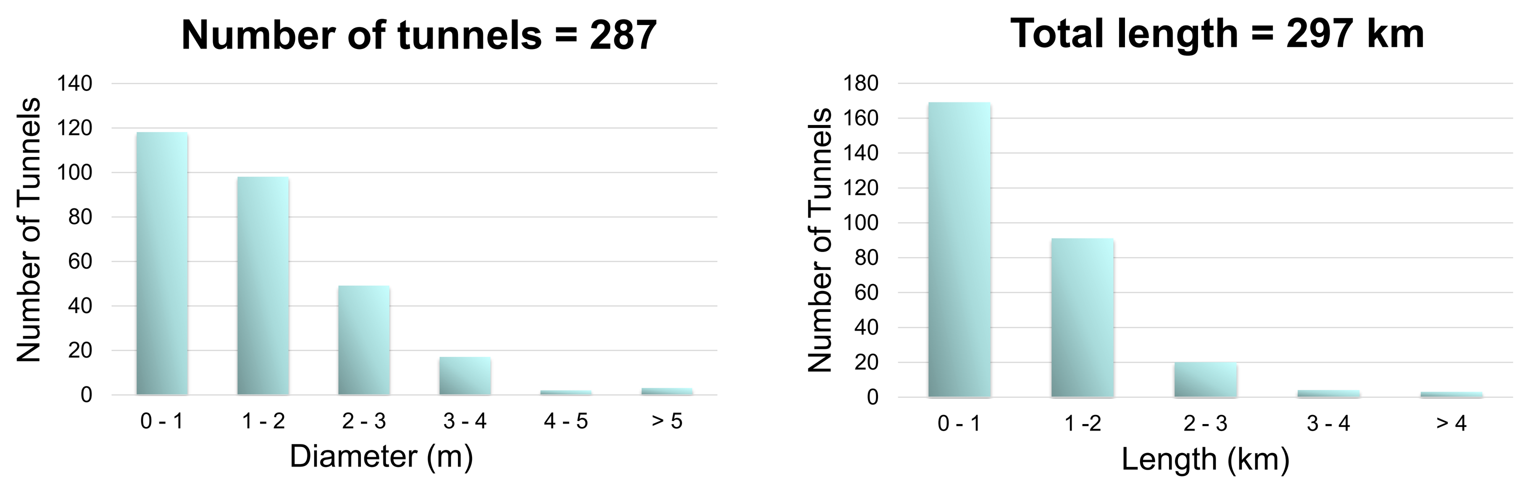

Fig.4: Power waterways, per diameter and length class.

The present works aims at dividing the power waterways in penstocks and pressure tunnels & shafts. The tunnel slope was computed, but the resulting slope distribution is rather broad (Figure 5) and not fully conclusive. A second criteria was flow velocity, deduced from discharge and section when available. Velocity is typically higher for penstocks than tunnels & shafts. Tunnels present flow velocities from 1 to 4 m/s for the total equipped rated discharge of the powerplant, whereas penstock design normally leads to higher velocities up to 10 m/s. A first analysis of the available sub-set of data (Fig. 6) indicates velocities mostly > 4 m/s for waterways with diameters below 3.20 m. These must be mostly penstock.

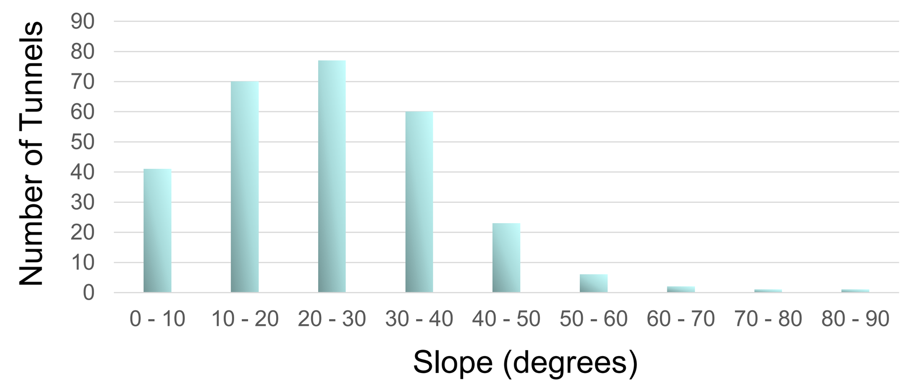

Fig.5: Slope distribution of power waterways.

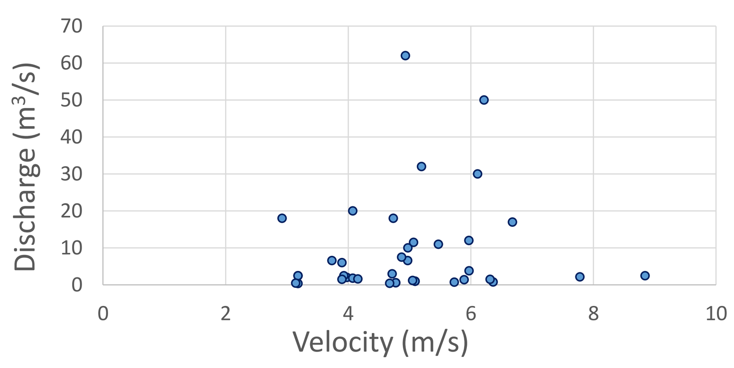

Fig.6: Velocity calculated from tunnel discharge to analyse 42 power waterways (diameters below 3.20 m).

5. Preliminary conclusions and outlook

- ✓ HydroGIS represents 97% of the Swiss hydropower facilities, in terms of installed capacity and energy generation.
- ✓ HydroGIS includes 700 tunnels, the majority shorter than 1 km.
- ✓ There are approximately 300 km of power waterways in Switzerland, the majority of which with diameters below 2 m. The sub-set of 42 tunnels better documented are penstocks with low velocities.
- ✓ Tunnel classification will be extended to all other power waterways.
- ✓ Establishing layer interconnections (e.g. tunnels with powerplants) is desirable for enhanced use of HydroGIS.

References:
Balmer, Markus (2011), "*Nachhaltigkeitsbezogene Typologisierung der Schweizerischen Wasserkraftanlagen. Gis-Basierte Clusteranalyse und Anwendung in einem Erfahrungskurvenmodell*".
SFOE, Swiss Federal Office of Energy. Geoinformation: http://www.bfe.admin.ch/geoinformation/05061/05249/index.html?lang=en#
WASTA: http://www.bfe.admin.ch/php/modules/publikationen/stream.php?extlang=fr&name=fr_743234287.zip&endung=Statistique

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Design of steel-lined pressure tunnels and shafts

Alexandre J. ***Pachoud****, Anton J.* ***Schleiss*** *& Pedro A.* ***Manso***
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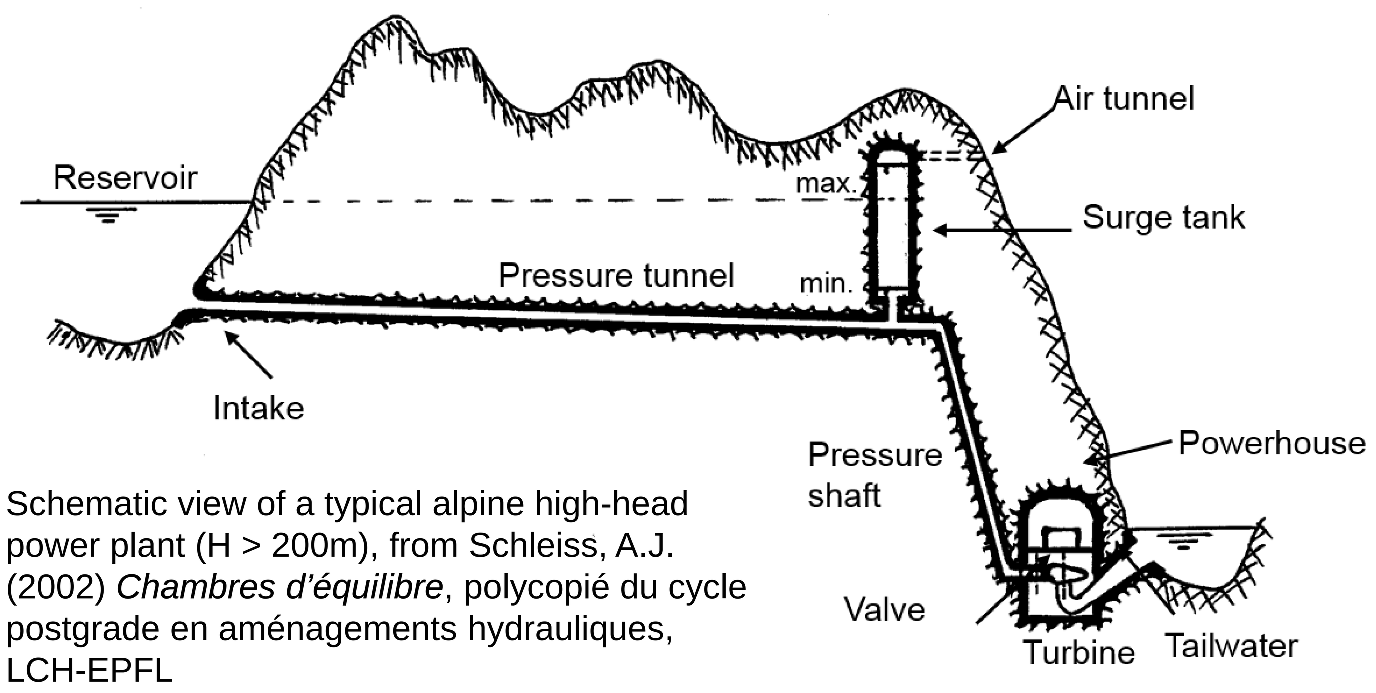
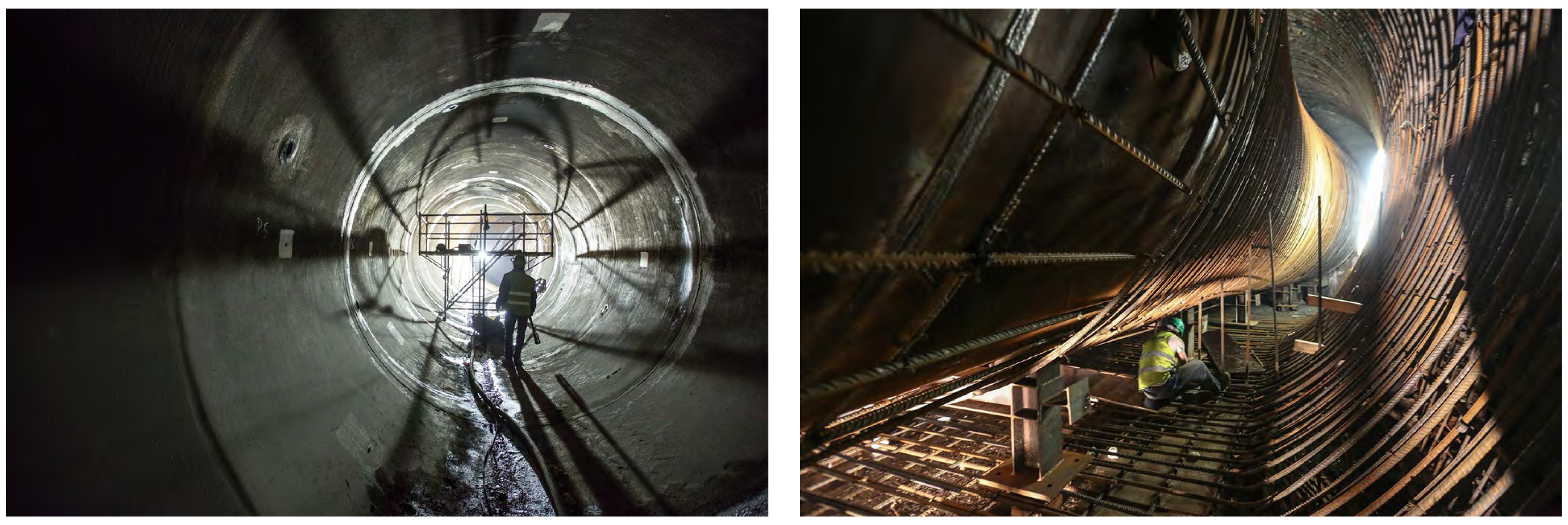
1. Introduction

Due to increasing integration of volatile new renewable energy in the European electric grid, storage hydroelectric power plants have to operate under harsh conditions in order to stabilize the electricity grid. As a result, pressure tunnels and shafts are subjected to more frequent pressure surges than before. High-strength steels (HSS) are being used to reduce costs of high-head hydropower schemes, which are normally equipped with Pelton turbines. The use of HSS limits the thickness of the steel liners but raises new challenges regarding the welding procedure and long-term resistance that are not yet satisfactorily solved. When the rock conditions are adequate, the design can consider load-sharing between the steel liner and the concrete-rock system. It is common practice to consider isotropic rock behavior for the computations of the stresses in the steel liners. In Europe, the C.E.C.T. (1980) recommendations are commonly used for the design, but are no longer adequate when using HSS. Various horizontal standards on reliability and failure assessment are also used for the qualifications of materials and for the design. There is still a lack of updated recommendations when using HSS in the specific case of steel-lined pressure shafts. This research project aims at addressing these issues by means of systematic numerical studies, with the finite element method. Several aspects are investigated, i.e., (1) the influence of anisotropic rock behavior; (2) the influence on the fatigue life of geometrical imperfections of the longitudinal welded joints (local notch stress approach); and (3) the probable presence of flaws in the seam welded longitudinal joints (Fracture Mechanics approach). This would provide new insights to prototype physical behavior as well as new recommendations for an integrated and probabilistic design approach for steel-lined pressure tunnels and shafts.

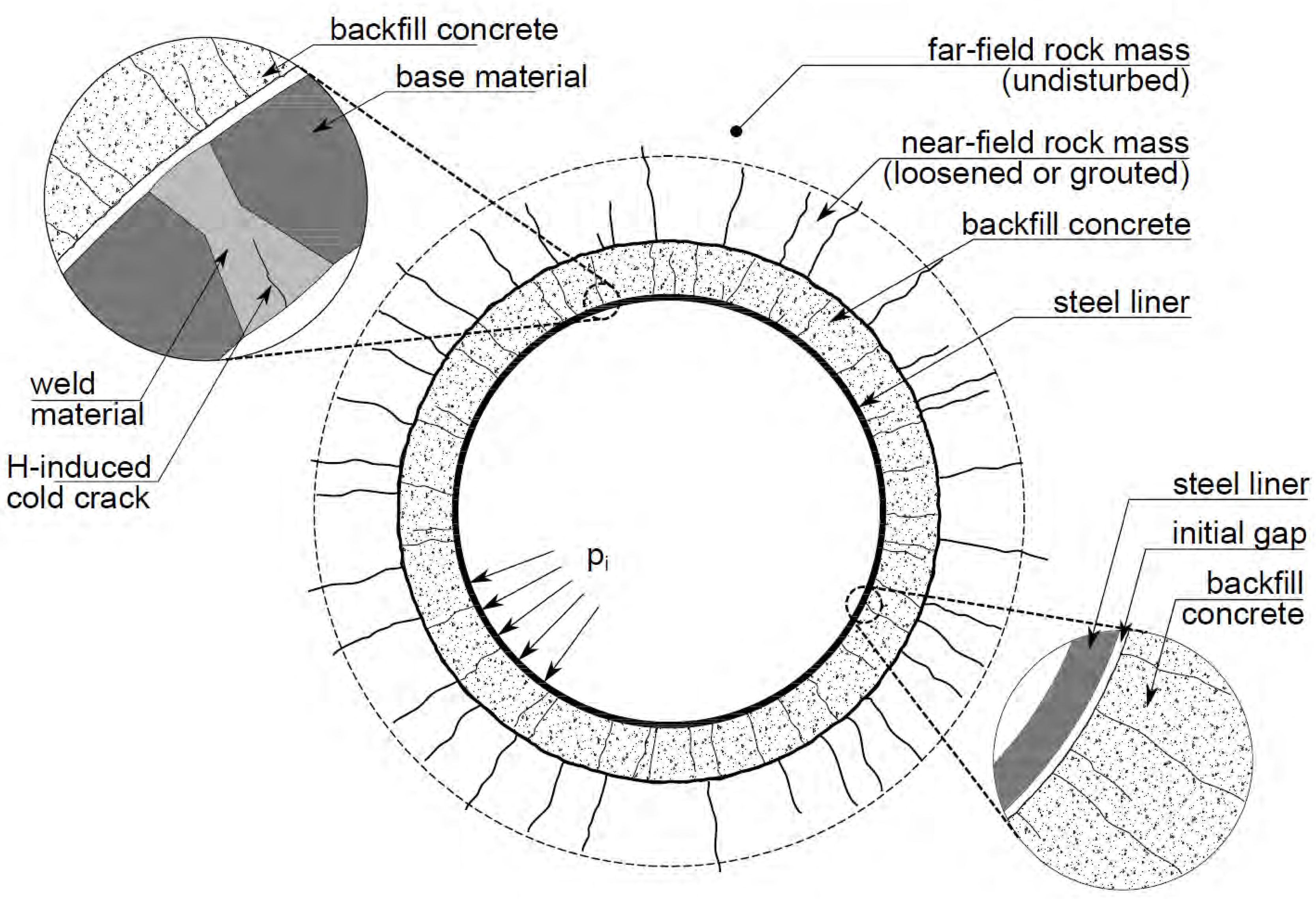


Schematic view of a typical alpine high-head power plant (H > 200m), from Schleiss, A.J. (2002) *Chambres d'équilibre*, polycopié du cycle postgrade en aménagements hydrauliques, LCH-EPFL



EDP (2015). Pumped-storage scheme Venda Nova 3, accessed 08 September 2015, http://www.a-nossa-energia.edp.pt/centros_produtores/fotos_videos.php?item_id=87&cp_type=he&section_type=fotos_videos

2. Definition sketch of the standard multilayer model



2. Influence of anisotropic rock behaviour

Based on numerical data, conceptual formulas were derived in order to estimate maximum stresses in the steel-lined pressure tunnels and shafts in anisotropic rock. Dimensionless correction factors were introduced in the expression of the stiffness of the concrete-rock system (that comes from the displacements compatibility between each interface), in order to correct the term related to the participation of the far-field rock [1]:

backfill concrete *near-field rock*

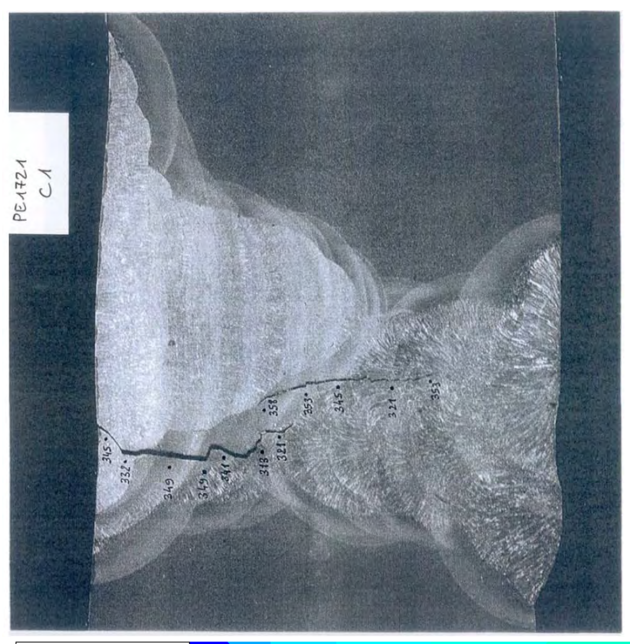
$$E_{eq,corr}^{-1} = \frac{1-\nu_c^2}{E_c}\ln\left(\frac{r_{crm}}{r_c}\right) + \frac{1-\nu_{crm}^2}{E_{crm}}\ln\left(\frac{r_{rm}}{r_{crm}}\right) + \left[\left(\frac{E}{E'}\right)^{-0.65}\left(\frac{G}{G'}\right)^{0.50}\left(\frac{1+\nu}{1+\nu'}\right)^{-0.56}\right]\frac{1+\nu}{E'}$$

correction factors with exponents optimized by means of Genetic Algorithm *far-field rock*

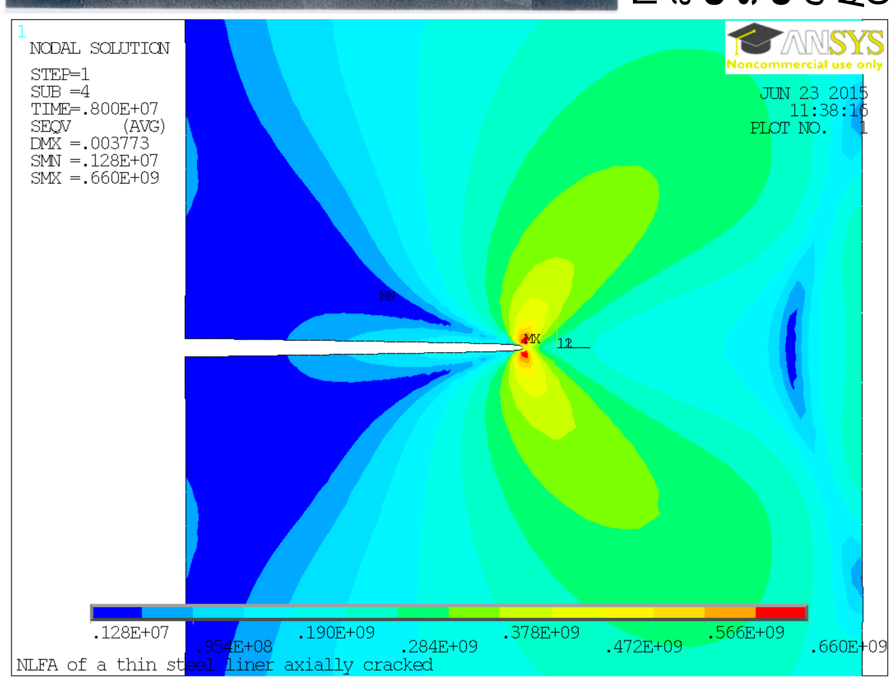
Inserted in the analytical developments to compute maximum major principal and equivalent stresses, it allows a rapid and accurate estimation of stresses in steel liners in anisotropic rock [1].

3. Ongoing and upcoming work

1. Fatigue assessment by notch stress analysis, considering geometrical imperfections (e.g. out-of-roundness, misalignment, etc.) and the contact with backfill concrete.
2. Fracture mechanics approach for the assessment of fatigue strength considering the initial presence of welding flaws.
3. Proposition of a new and innovative probabilistic approach for the design of steel-lined pressure tunnels and shafts.



Modified after Cerjak, H., Enzinger, N. and Pudar, M. (2013) **Development, experiences and qualifications of steel grades for hydro power conduits**. In: *Proc. of the conference on high strength steels for hydropower plants*. Graz University of Technology. Graz, Austria



4. Acknowledgements

This study is part of the consortium *HydroNet 2: Modern methodologies for design, manufacturing and operation of hydropower plants*, a research project funded by the Swiss Competence Energy and Mobility (CCEM-CH)

5. List of publications

[1] Pachoud, A. J., Schleiss, A. J. (2015) **Stresses and displacements in steel-lined pressure tunnels and shafts in anisotropic rock under quasi-static internal water pressure**. *Rock Mechanics and Rock Engineering* (accepted for publication)

[2] Mazzocchi, E., Pachoud, A. J., Farhat, M., Hachem, F. E., De Cesare, G., Schleiss, A. J. (2015) **Signal analysis of an actively generated cavitation bubble in pressurized pipes for detection of wall stiffness drops** (under review in the *Journal of Fluids and Structures*)

[3] Pachoud, A. J., Schleiss, A. J. (2014) **Steel-lined pressure tunnels and shafts in anisotropic rock**. In *Proceedings of the 3rd IAHR Europe Congress*, Porto, Portugal

[4] Pachoud, A. J., Schleiss, A. J. (2015) **Parametric study of steel-lined pressure shafts in anisotropic rock**. In *Proceedings of the ITA World Tunnel Congress 2015*, Dubrovnik, Croatia

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Fluid-structure interaction and pipe-wall non-elastic behavior in pressurized transient flows

David Ferras, Pedro A. Manso, Dídia I.C. Covas, Anton J. Schleiss

1. Introduction

Classical waterhammer theory is based on the simplification of pressure waves in pipes as a periodic flow dominated by fluid compressibility and pipe-wall distensibility and damped by steady friction. However, in real systems friction losses are not described by steady state formulae, the flow may cavitate, the pipe-wall may show hysteresis, the conduit may contain air, move, leak, or have blockages, *et cetera*; and classical theory is not accurate enough to describe such phenomena.

Literature in the field of waterhammer offers means to solve the aforementioned, though, the inclusion of these add-ons into classical theory is challenging, requiring the development of advanced mathematical models.

The aim of the present research is to give experimental and numerical insight on the distinction, identification and description of two strongly related phenomena that frequently affect in a similar manner the transient pressure wave: fluid-structure interaction and pipe-wall non-elastic rheological behavior.

2. Methodology

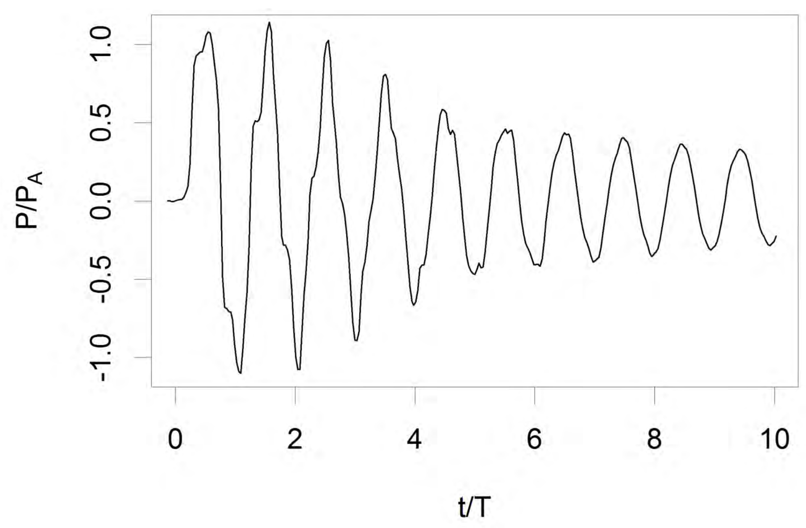
Experimental data collection:
- Copper straight pipe facility
- Copper coil pipe
- Polyethylene coil pipe

Numerical analysis:
- Fluid-structure interaction solver
- Viscoelastic model
- Unsteady friction model
- Integration of the three models

3. Experimental analysis

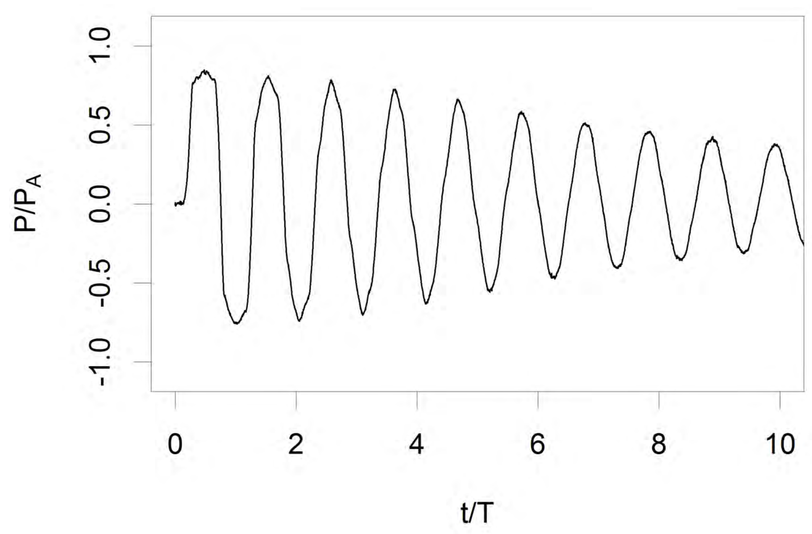
Copper straight pipe:

L = 15.49 m
D = 0.020 m
e = 0.001 m
E = 105 GPa
ν = 0.33
a = 1239 m/s



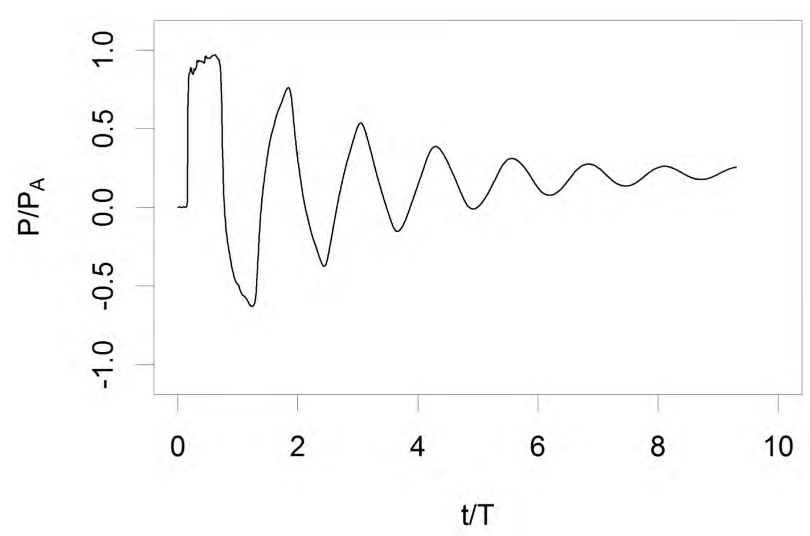
Copper coil pipe:

L = 105 m
D = 0.020 m
e = 0.001 m
E = 105 GPa
ν = 0.33
a = 1193 m/s



HDPE coil pipe:

L = 203 m
D = 0.043 m
e = 0.003 m
E = 1.42 GPa
ν = 0.43
a = 315 m/s



4. Numerical analysis

Fundamental FSI equations:

4-equation model

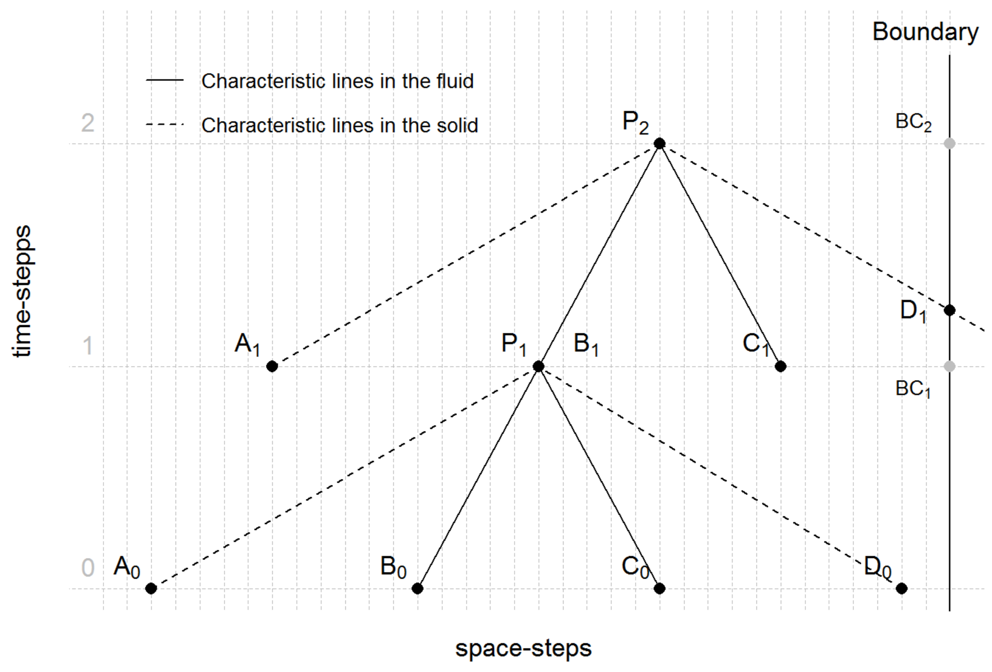
$$\frac{\partial V}{\partial t} + \frac{1}{\rho_f}\frac{\partial p}{\partial x} = -\frac{f}{4r}(V-U)|V-U|$$

$$\frac{\partial V}{\partial x} + \left(\frac{1}{K} + \frac{2r}{Ee}\right)\frac{\partial p}{\partial t} = \frac{2\nu}{E}\frac{\partial \sigma}{\partial t}$$

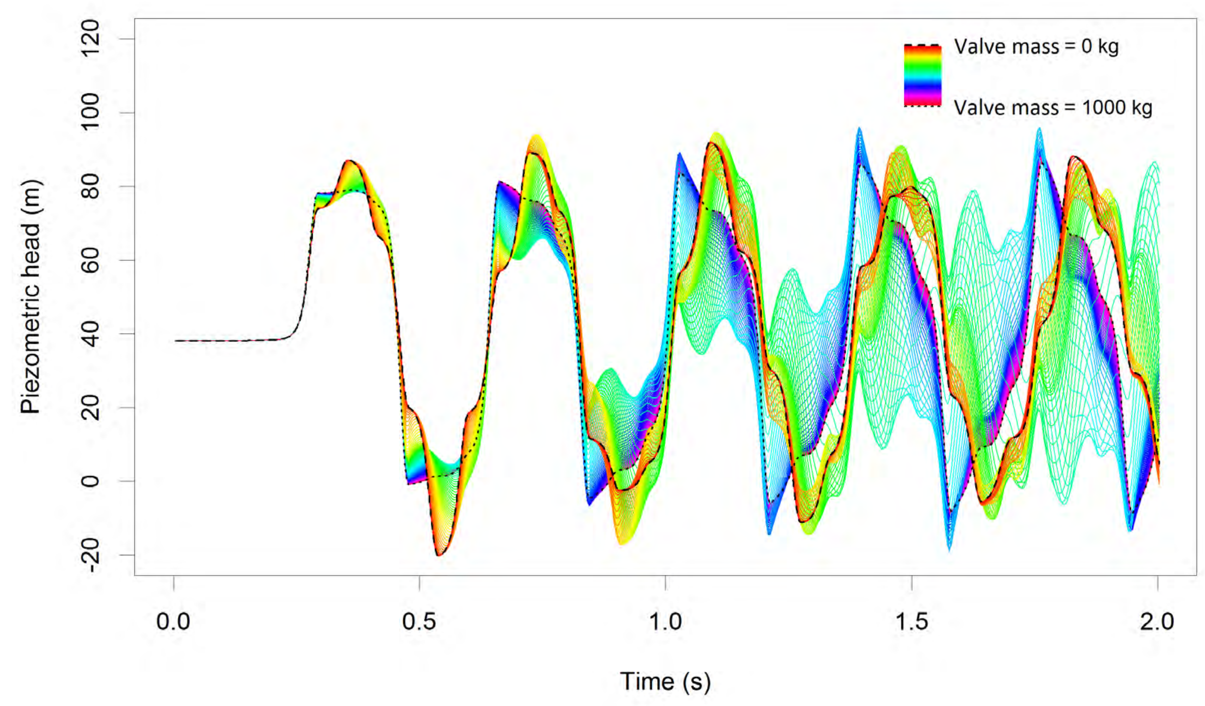
$$\frac{\partial U}{\partial t} - \frac{1}{\rho_s}\frac{\partial \sigma}{\partial x} = \frac{\rho_f}{\rho_s}\frac{A_f}{A_s}\frac{f}{4r}(V-U)|V-U|$$

$$\frac{\partial U}{\partial x} - \frac{1}{\rho_s {a_s}^2}\frac{\partial \sigma}{\partial t} = -\frac{r\nu}{eE}\frac{\partial p}{\partial t}$$

Numerical scheme:



Numerical output:



5. Conclusions

- The system response of a straight pipe is strongly influenced by the downstream anchoring conditions. FSI through junction coupling changes maximum pressure, wave shape and overall damping.
- A systematic pressure wave amplitude reduction is observed in coil pipes due to a "breathing effect" originated from the radial deformation of the coil rings.
- The viscoelasticity of the HDPE pipe-wall significantly affects the dissipation, shape and phase of the transient pressure wave due to the retarded response of the polyethylene material (hysteresis).
- Adequate modelling assumptions are crucial for the distinction of fluid-structure interaction and pipe-wall viscoelasticity effects, and the accurate description of pipe systems behavior during hydraulic transients.

6. PhD outputs

- Enhanced knowledge on hydraulic transients.
- Robust transient solvers for engineers and consultants.
- Designing and diagnosis guidelines for pressurised systems.
- Safer pressurised water systems

Journal and conference papers

D. Ferras, D. Covas, A.J. Schleiss. Stress-strain analysis of a coiled copper pipe for inner pressure loads. *Journal of Fluids and Structures*, 2014.
D. Ferras, D. Covas, A.J. Schleiss. Stress-strain analysis of a coiled copper pipe for inner pressure loads. *Proc. of 3rd IAHR Europe Congress: Water Engineering and Research*, number EPFL-CONF-198531, page 279.
D. Ferras. Fluid-structure interaction in pipe coils during hydraulic transients: numerical and experimental analysis. *Proc. of 36th IAHR World Congress*, 2015.
D. Ferras, D. Covas, A.J. Schleiss. Comparison of conceptual models for fluid-structure interaction in pipe coils during hydraulic transients. Submitted at *Journal of Hydraulic Research* (under revision), 2015.

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Hydroabrasive-resistant materials at sediment bypass tunnels

Background

Hydro-abrasive wear is a worldwide unsolved problem causing significant maintenance at hydraulic structures. Sediment Bypass Tunnels (SBT) as an efficient measure against reservoir sedimentation often face severe wear due to high flow velocities and massive sediment load (Fig. 1). Abrasion resistance of different invert materials and its relation to both sediment load and hydraulic operation conditions is investigated at two Swiss SBT.

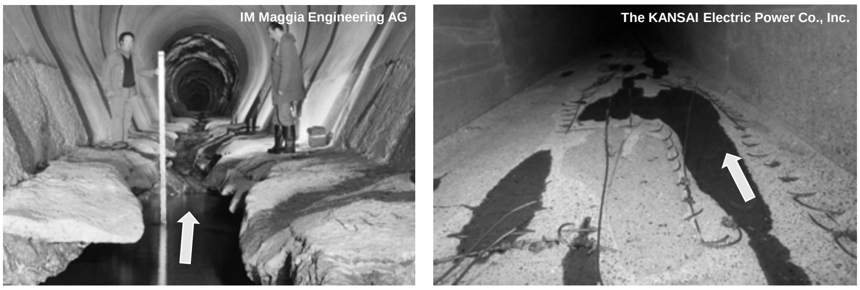

Fig. 1: Abrasion in (a) Palagnedra Bypass Tunnel, Ticino, Switzerland, (b) Asahi Bypass Tunnel, Japan

Field experiments at Solis Bypass Tunnel

Solis Dam was built in 1986. Currently, more than half of the initial reservoir volume is filled by sediment. To bypass sediment-laden discharges during flood events and to mitigate sedimentation, a SBT was constructed in 2012 (Fig. 2).

Six different test fields (four concretes, cast-basalt plates, and a steel armor) were installed along the tunnel invert (Fig. 3). The monitoring includes continuous measurements of both sediment transport rates and hydraulic conditions, and regular abrasion records of the tunnel invert.

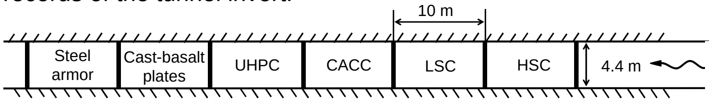

Fig. 3: Test fields at SBT Solis, Switzerland, with UHPC (Ultra-High Performance Concrete), CACC (Calcium Aluminate Cement Concrete), LSC (Low-Shrink Concrete with high modulus polymer fibers), HSC (High-Strength Concrete with steel fibers)

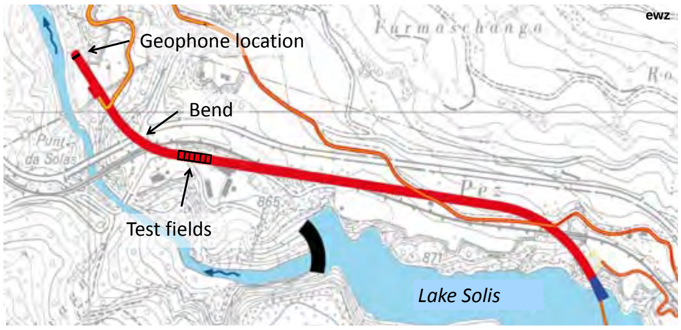

Fig. 2: Overview of Solis SBT, Switzerland

For a water discharge of 90 m^3/s, the concentration of bed-load transport on the orographic right tunnel side was recorded (Fig. 4). The bend 100 m upstream of the geophone location causes this effect. However, due to low bed-load transport, no abrasion occurred on the tunnel invert.

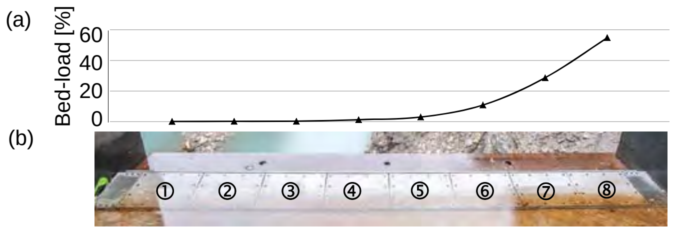

Fig. 4: Bed-load distribution across 4.4 m wide tunnel recorded with geophones ① to ⑧

Field experiments at Pfaffensprung Bypass Tunnel

The Pfaffensprung Reservoir and its bypass tunnel were built in 1922, diverting high discharges and sediment. Two granite and two concrete test fields were recently implemented (Fig. 5). The hydraulic conditions are continuously monitored, while abrasion is recorded yearly.

The abrasion patterns of the concrete fields after one and two years are similar but amplified with increasing operating duration (Fig. 6). The abrasion appears mainly at the orographic right tunnel side, confirming the expected bed-load distribution across the tunnel due to the tunnel bend.

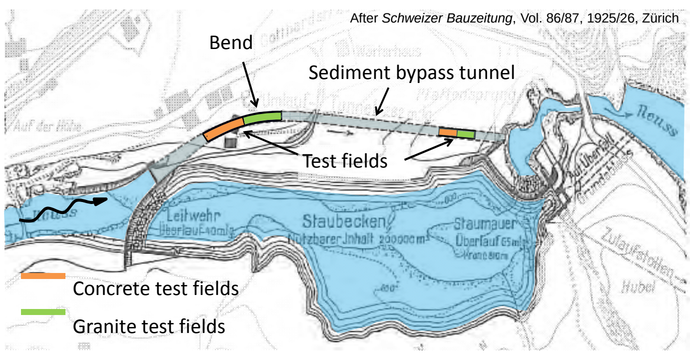

Fig. 5: Overview of Pfaffensprung Reservoir and SBT

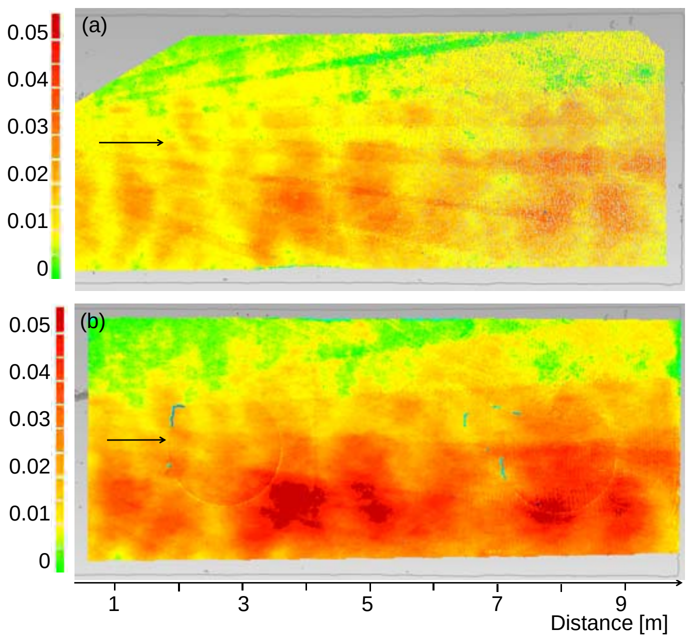

Fig. 6: Measured abrasion in [m] at concrete field after (a) first, (b) second year of operation in 2012/ 2013

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Dam Break Analysis under Uncertainty

1 Introduction

The current knowledge on processes of failing embankment dams is poor to predict the resulting outflow hydrograph. To account for its uncertainties, a probabilistic framework consisting of a strongly parametrized dam breach model was developed. The calibration of the probabilistic model is based on historical dam break data. To solve the computationally demanding uncertainty routing, the application of meta models is proposed, resulting in probabilistic flood maps (Fig. 1).

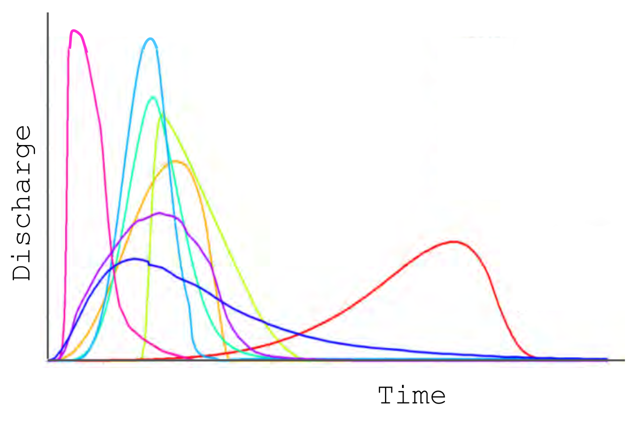

Figure 2 Hydrographs produced by dam break modeling experts using perfect information on dam properties (re-arranged from Benchmark Proc. Graz 2013)

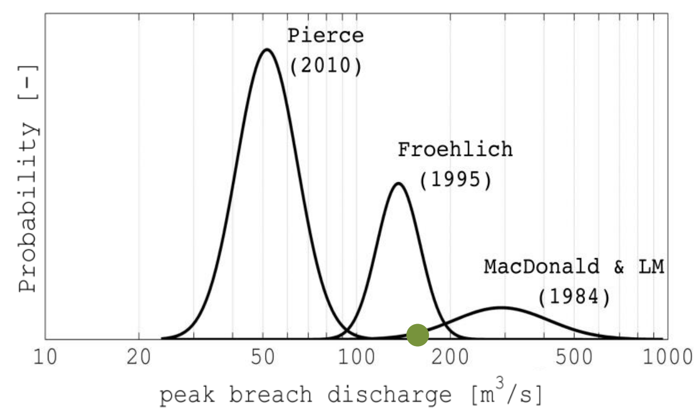

Figure 3 Peak discharge estimation for dam of 5 m height and 10^4 m^3 storage volume. 3 log-normal probability distributions based on empiricism, with (●) instantaneous dam failure (SFOE Guidelines)

3 *BASEbreach* Framework

The newly developed dam breach model framework focuses on quantification of indispensable uncertainties. Thus, probabilistic parameters should be: (1) Physically bounded, (2) small in their number, and (3) able to exclude a-priori model assumptions. The *BASEbreach* model setup for a given dam of height *H* and reservoir volume *V* reads

$$M^{BB} = \mathcal{M}(H, V, \boldsymbol{\chi}, f_s)$$

Here $\boldsymbol{\chi}$ is the vector of the uncertain but physical parameters, i.e. erosion and friction laws, breach shape, dam geometry, and initial conditions (Fig. 4). A scaling parameter f_s quantifies the erodibility of the dam and is used for calibration purposes. The model driving processes are: (1) Depletion of reservoir water level, and (2) erosion and transport of dam material (differential equations in Fig. 4).

The calibration process is based on data containing historical dam break events. The calibration process attempts that the modeled distribution of the peak discharges asymptotically converges to the distribution of historical peak discharges

$$\theta_{Q_p}{}^{data} = \theta_{Q_p}{}^{BB}(\chi, f_s)$$

Parameter f_s is such that the uncertainties in the input parameters χ resemble these in the collected dam break data.

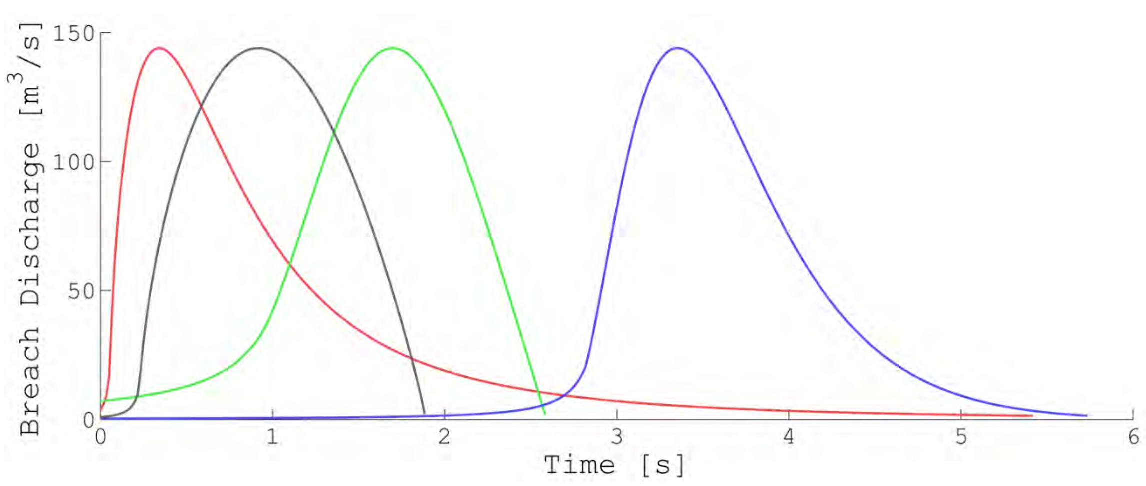

Figure 5 Possible failure hydrograph shapes (Fig. 3). Uncertain but physically bounded input parameters are responsible for visually obvious differences

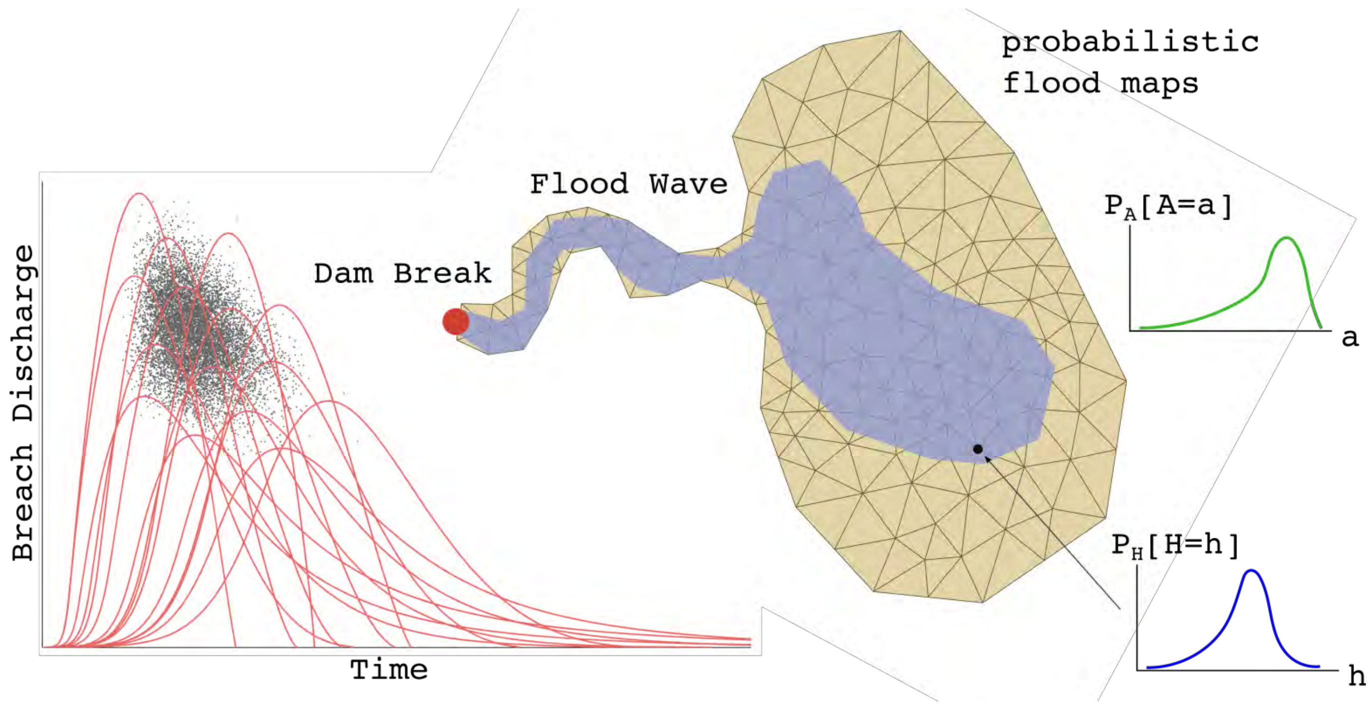

Figure 1 Visualization of research project and its components: Starting from uncertainties, transporting these downstream, and constructing probabilistic flood maps

2 Motivation and Goals

Progressive and highly dynamic mechanisms of gradually failing dams are unknown. During real dam breaks, data collection is challenging. The main issue remains to quantify the breach discharge and geometry. This lack of knowledge results in poor prediction tools (Figs. 2 and 3). Therefore, a tool is required that:

- Quantifies existing uncertainties in dam break models and their effect on flood waves for the subsequent risk assessment,
- Supports engineers and decision makers, and
- Is embeded in non-proprietary software (BASEMENT and QGIS)

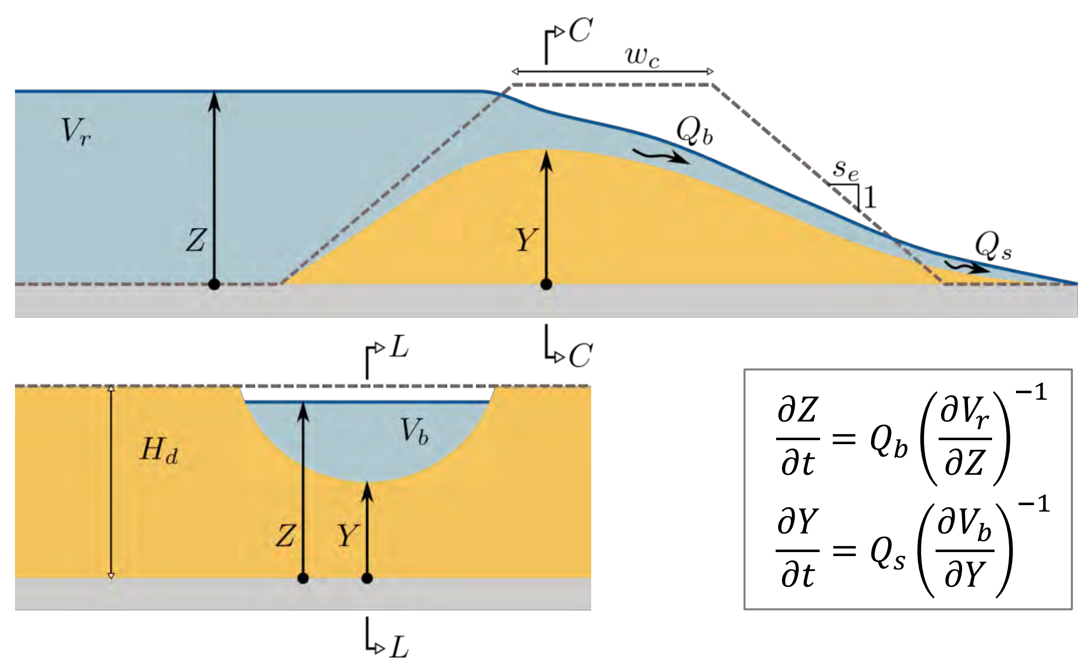

Figure 4 Failing embankment dam with dam height H_d, crest width w_c, and embankment slope s_e: Streamwise (top) and cross-sectional (bottom) sketches. Variables to describe the erosion process: reservoir level *Z*, breach level *Y*, breach discharge Q_b, sediment transport rate Q_s, breach volume V_b.

4 Flood Routing

Stochastic hydrographs resulting from *BASEbreach* (Fig. 5) define the upper boundary condition of the flood wave computation using BASEMENT. Accurately solving the shallow-water equations on complex topographies is computationally expensive. Thus, a crude Monte-Carlo approach is not applicable to quantify the uncertainties in the resulting flood variables.

The application of meta modeling is proposed, treating the hydraulic simulation as blackbox, and the output variables as a function of the uncertain dam break hydrograph. Advanced techniques provide additional features used for the interpretation of the stochastic flood maps. This approach takes a step toward decision making under uncertainty in engineering problems.

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Flood forecasting initialization enhancement

e-dric.ch au energie environnement ingénieurs conseils

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LCH LABORATOIRE DE CONSTRUCTIONS HYDRAULIQUES

Abstract

The Sarine in Rossinière basin has been chosen to assess the impact of updating initial conditions in real time on flood forecasting.
A qualitative analysis of the simulations done with the semi-distributed model RS Hydropower led to define the source of errors in the simulation of floods.
Limiting the real time update process showed a great reduction of the error sources related to initialization.

1. Introduction

The hydrometeorological chain used to forecast flows for hydropower production is presented on Fig. 1. A key component is the real-time update of the basin conditions that allows to use optimal initializations for forecasts.
This real time update is based on the past 24h flow observations. It changes the saturation of the soil iteratively until the volume difference between observed and simulated discharges is minimized. However, this efficient process can lead to correction excesses, especially before floods, that can be limited to avoid these side effects.

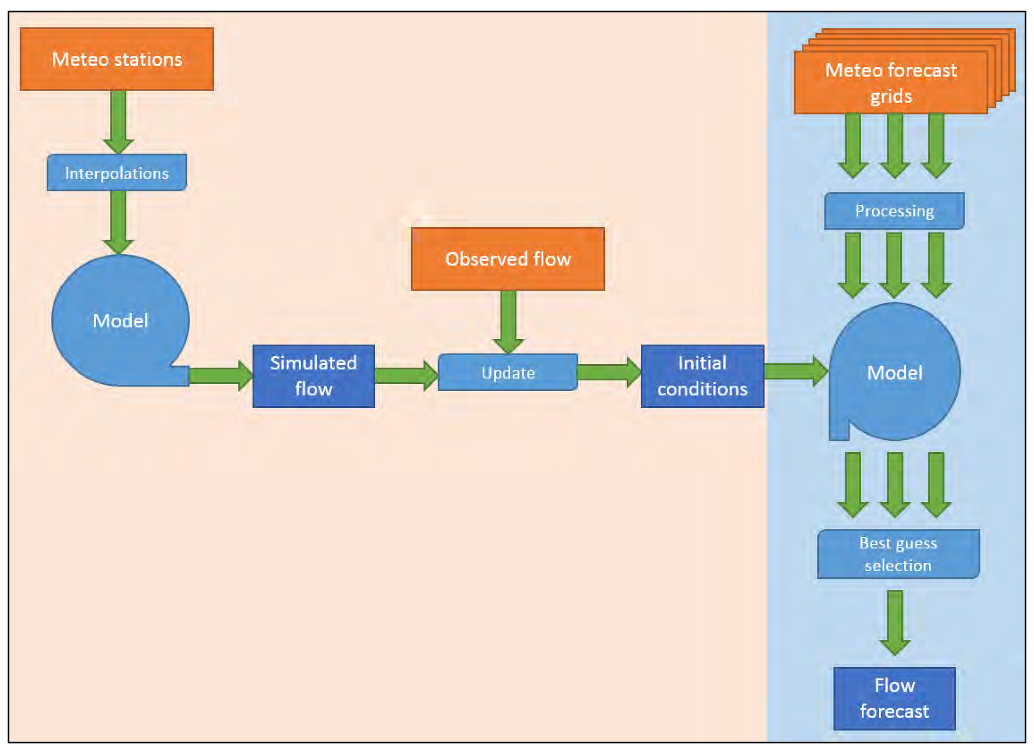

Fig. 1: schematic representation of the hydro-meteorological chain

2. Study area

The Sarine upper basin has been chosen because of its strong floods leading to safety issues for populations and hydropower (Groupe E). The basin is limited to Rossinière (390 sq. km) which is representative of the area where are generated most of the floods (Fig. 2).

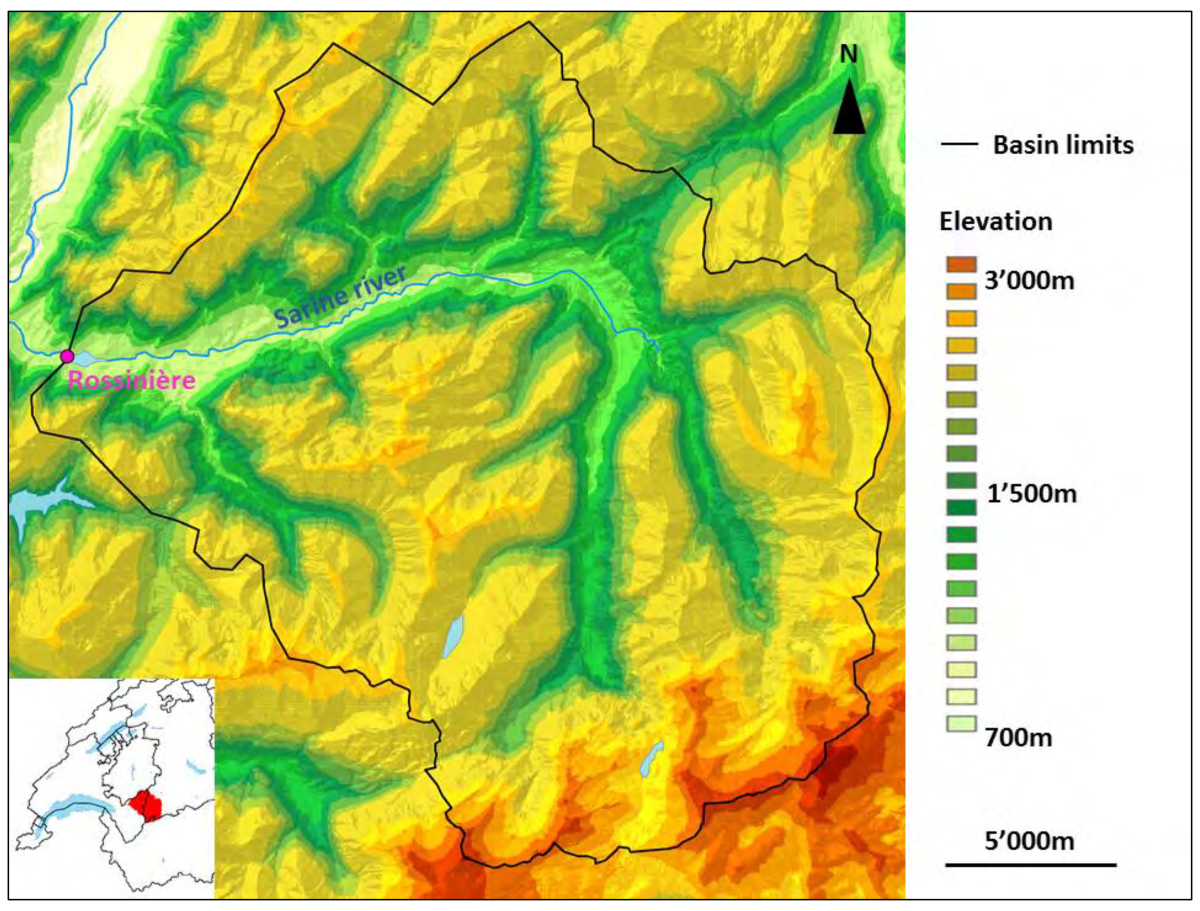

Fig. 2: physical map of the Sarine in Rossinière basin and location in western Switzerland. (elevation from ASTER GDEM, a product of METII and NASA).

The regime of the Sarine basin is pluvio-nival. Only four percent of the basin is covered by glacier which has a very low influence on discharges.

3. Hydrological modeling

The semi-distributed model RS Hydropower is used in operational conditions on more than 40 basins in the world by e-dric.ch. This model explicitly considers snow stock and glacier processes using elevation bands, as well as subsurface processes and runoff.
On the Sarine basin, the main processes used by the model are snow accumulation / melt, subsurface transfers and runoff.
The discharge data are provided by Groupe E and the meteorological data are provided by Groupe E for two gauges and MeteoSwiss (ANETZ network). Data are available from 2003 to 2013 which allows to include a various range of floods in the study.

About the OPT-HE project (CTI/KTI 16124.1 PFEN-IW)

The OPT-HE project aims at enhancing hydrological forecasts for hydropower production. It regroups industrial partners from hydropower sector (Alpiq, Groupe E, Romande Energie, SEFA, SIG), research partners (EPFL, ETHZ) and MeteoSwiss around e-dric.ch, an engineering company specialized in hydrological forecasting for hydropower production and floods.
The hydrological forecasts for hydropower production allow to anticipate water incomes in order to optimize the management of reservoirs, optimize the production quantity and timing and protect infrastructures from floods. They represent a great potential of power production increase without any new costly and disruptive for the environment infrastructures.
The main paths of inquiry are related to enhancing the consideration of observed and forecast meteorological data, the real-time update of the initialization of the forecasts, the enhancement of meteorological forecasts, the definition of an uncertainty margin for forecasts and, in general, every model process enhancement that could be beneficial to hydrological forecasting for hydropower production (short term to seasonal).

4. Limitation of the real-time update

To avoid taking into account the error from meteorological forecasts, the quality analysis of the flood forecast uses perfect forecasts (*id. Est*, use of observation data instead of meteorological forecasts). Therefore, this process can only be done *a posteriori*. The sources of error identified are snow melt, temperature, rainfall representativeness and initialization (*id. Est* , real-time update). Fig. 3 shows the sources of perfect forecasts error for 54 flood events. 28% of the total error comes from the initialization.

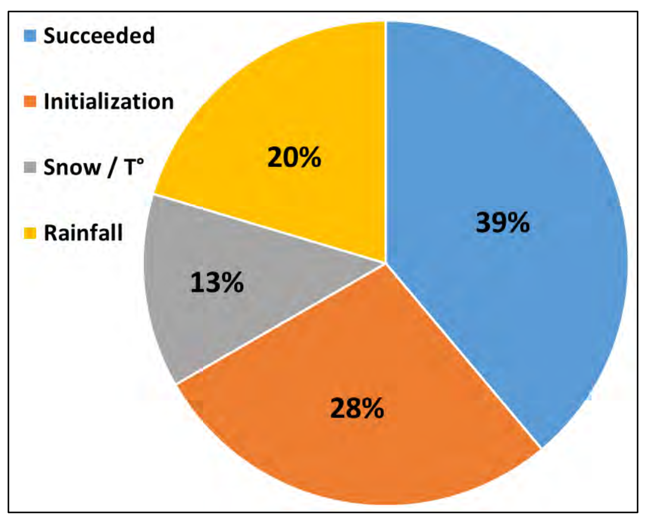

Fig. 3: repartition of error sources.

As mentioned in the introduction, the update process acts upon the soil saturation as a function of the difference of volume between observed and simulated discharge. Most of the time, we notice that this effect leads to an under- or over-saturation. The response of the model to a strong rainfall can thus lead to an under- or over-estimation of the peak discharge.

The soil saturation is changed based on a percentage of its own value. This percentage has to be adjusted as a function of the basin characteristics. For the Sarine basin, limiting the update to 10% gives better results (Fig. 4) and highlights the other sources of errors that have to be reduced. The benefit can also be emphasized by the HIT (% of forecasts reaching an observed discharge threshold) and FAR (% of forecasts missing an observed discharge threshold) criteria (Fig. 5).

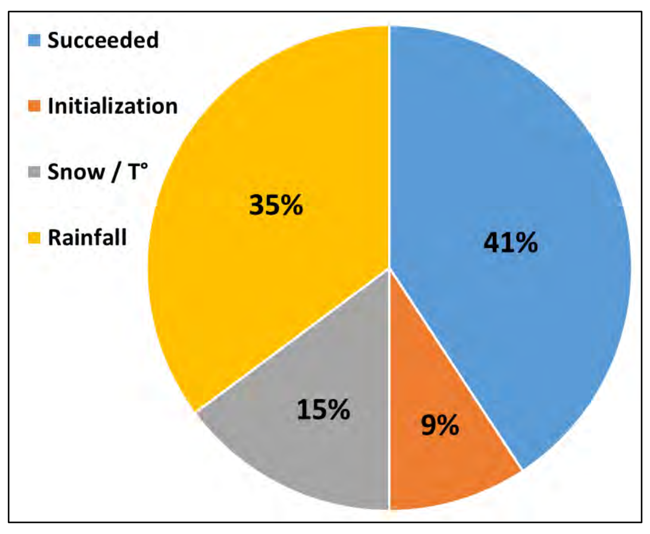

Fig. 4: repartition of error sources after limiting the real-time update

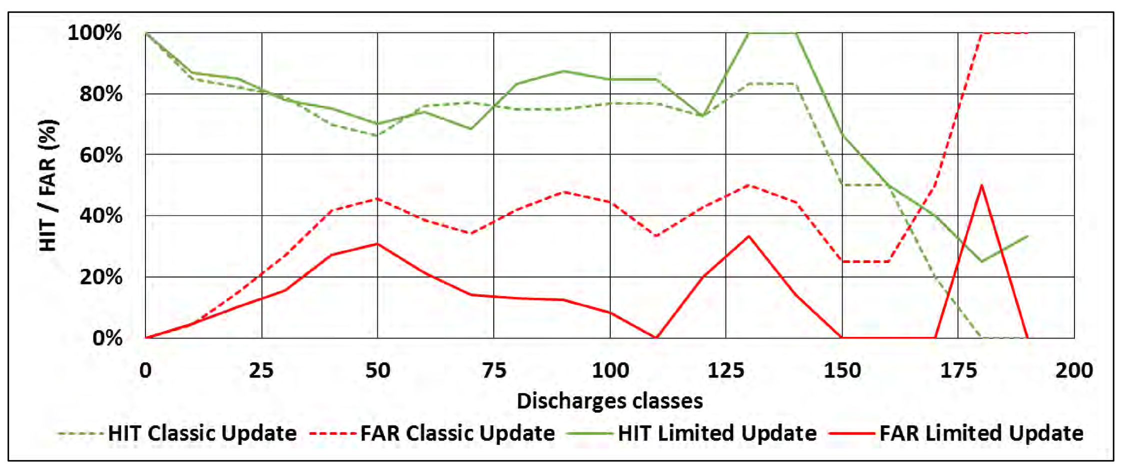

Fig. 5: HIT and FAR rates by threshold over the 2003-2013 period for the classic and limited updates.

5. Conclusions

The experiences conducted in this work show the relevance of real-time update but also highlight its limitations. By timely limiting the effect of this update, better results are obtained. Thus the future work can focus on the other sources of errors.

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Sustainable management of reservoirs through turbidity currents venting

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LABORATOIRE DE CONSTRUCTIONS HYDRAULIQUES

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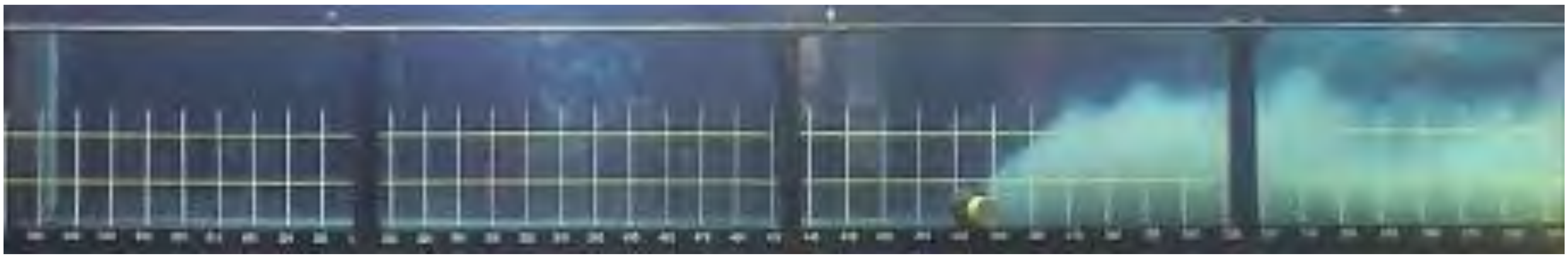

1. Introduction

Reservoir sedimentation is a worldwide problem reducing the lifetime of reservoirs due to the loss of storage capacity as well as the abrasion of hydraulic structures.
In the goal of reducing sediment amounts in concerned reservoirs, many sediment management techniques exist. Among the latter, venting of turbidity currents is one of the least investigated, particularly in terms of scientific research. Therefore, the present research aims to define venting of turbidity currents, to investigate its application worldwide, and to look into important parameters affecting its efficiency.
A deeper understanding of venting operations helps in optimizing the outlet design, leads to a better manipulation of outlets, and contributes to downstream replenishment. Additionally, the hydroelectricity sector finds great interest in such investigations as the water volume released from reservoirs is optimized and thus the reservoir's life is extended.

2. Methods

Based on an extended literature, the main venting parameters were chosen and are being tested experimentally. During the tests, a mixture of water and a polymer powder is prepared in a mixing tank with a specific concentration. This mixture is then sent to the head tank after which it is released into the main flume (Fig. 1) filled in advance with clear water. The turbidity current is created and advances towards a wall where the bottom outlet is placed and operates with a specific outflow discharge.

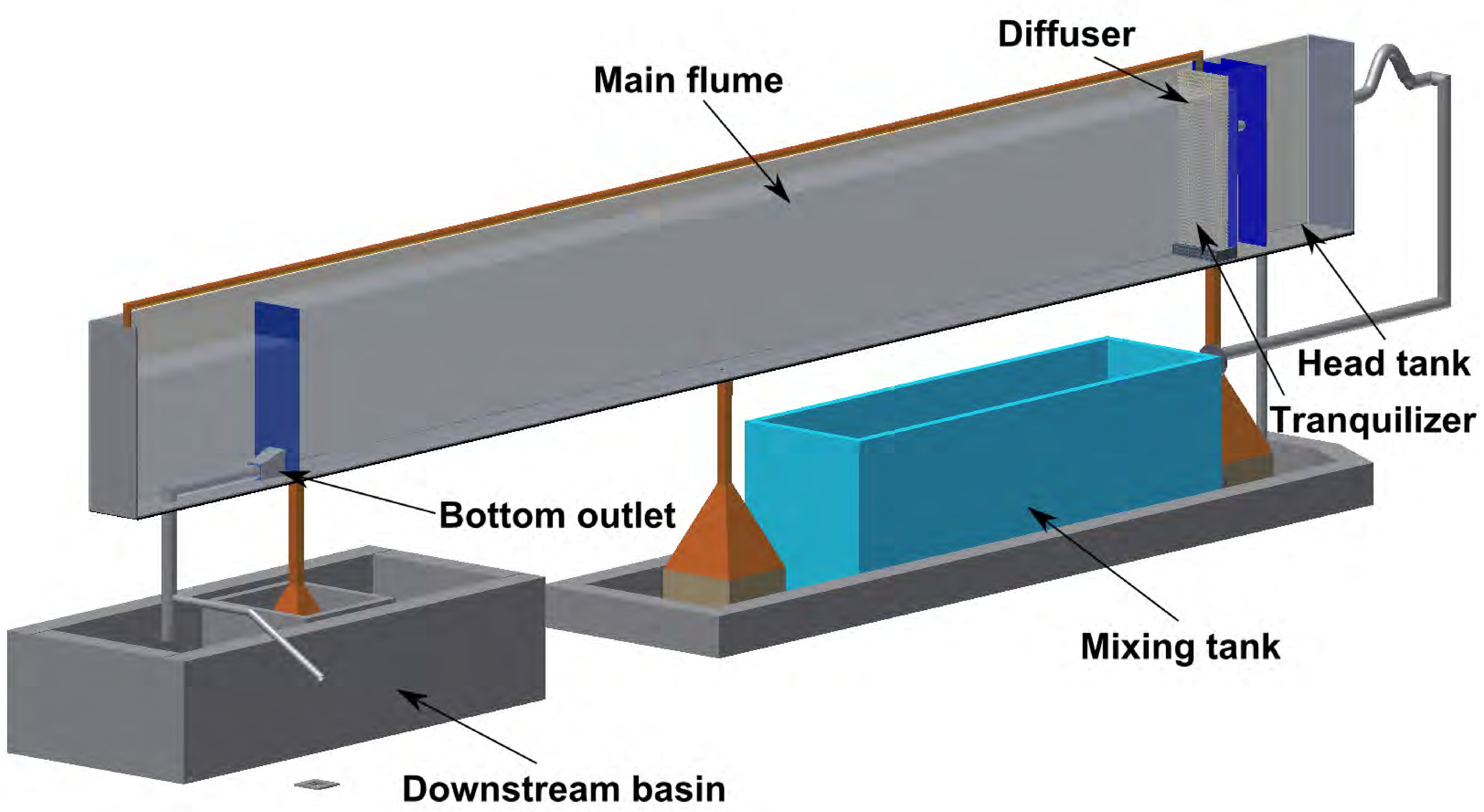

Fig.1 – Overview of the experimental set-up

Throughout the tests, several measurements are made:

- **Electromagnetic flowmeters** are used to measure inflowing and outflowing discharges
- **Water level probes** measure water levels upstream and downstream of the releasing gate
- **Ultrasonic Velocity Probes** (UVP) measure 2D velocity profiles of the advancing turbidity current
- A **depositometer** placed at the bottom of the flume measures deposition thicknesses of the current
- **Turbidity probes** provide concentration measurements upstream and downstream of the main flume.

Based on concentration and discharge measurement, venting efficiencies are calculated by dividing the total mass of outflowing sediments by the total mass of inflowing sediments.

3. Objectives

Objectives include the investigation of:

- The influence of **systematic outflow discharge** on venting efficiencies
- The effect of **opening timing** on venting efficiencies
- Differences between **venting subcritical** and **supercritical turbidity currents** using different bed slopes
- The influence of **outlet position and elevation** on the efficiency of venting operations.

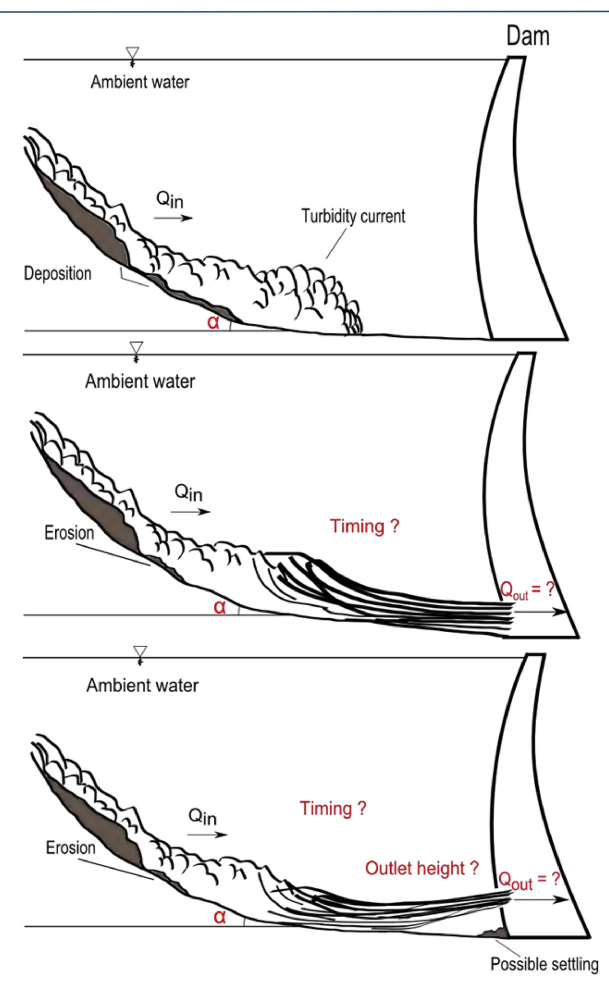

Fig.2 – Illustration of the investigated involved processes

4. Results

Results show a considerable effect of relative outflow discharges on venting efficiencies. The log shape of the efficiency relatively to the duration of venting can be directly linked to the dynamic structure of a turbidity current (i.e., a turbulent head and a steady body). When the relative outflow increases from 98% to 120%, the efficiency of venting increases more than three times the case where the relative outflow goes from 80% to 98% (Fig. 3). Thus, a certain threshold exists between efficiencies obtained when using outflows smaller than the turbidity current inflow discharge and the ones using higher outflows.

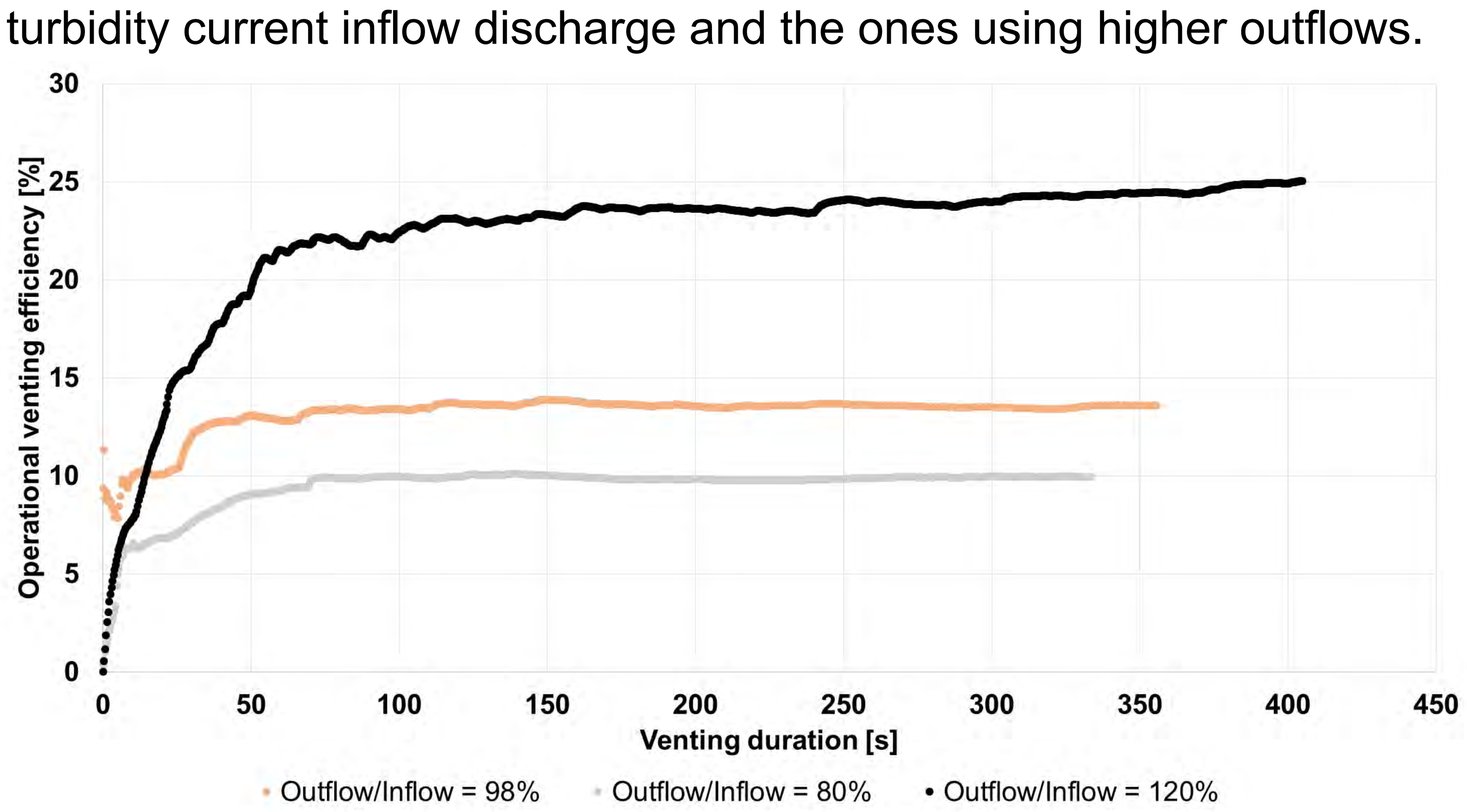

Fig.3 – Plot of venting efficiencies relatively to the duration of venting

5. Conclusions

In reservoirs where turbidity currents are the main reason behind sedimentation, venting is an interesting solution in terms of energy and downstream environment. It allows the reduction of the amount of sediments retained inside reservoirs without having to withdraw the water level. Research aiming to optimize venting operations provides an important tool for dam operator.

Acknowledgments

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Overtopping of Impulse Waves

Introduction

Large mass wasting into artificial reservoirs induce so called impulse waves. Their amplitudes can be much larger than these of typical tsunamis. Run-up occurs if these waves impact a dam. If its freeboard is insufficient overtopping results along with massive tailwater damage.

The wave overtopping phenomenon includes: (1) wave generation, (2) wave propagation and wave run-up, and (3) wave overtopping. This study deals with issue (3) concentrating on hydraulic features of wave overtopping (Fig. 1).

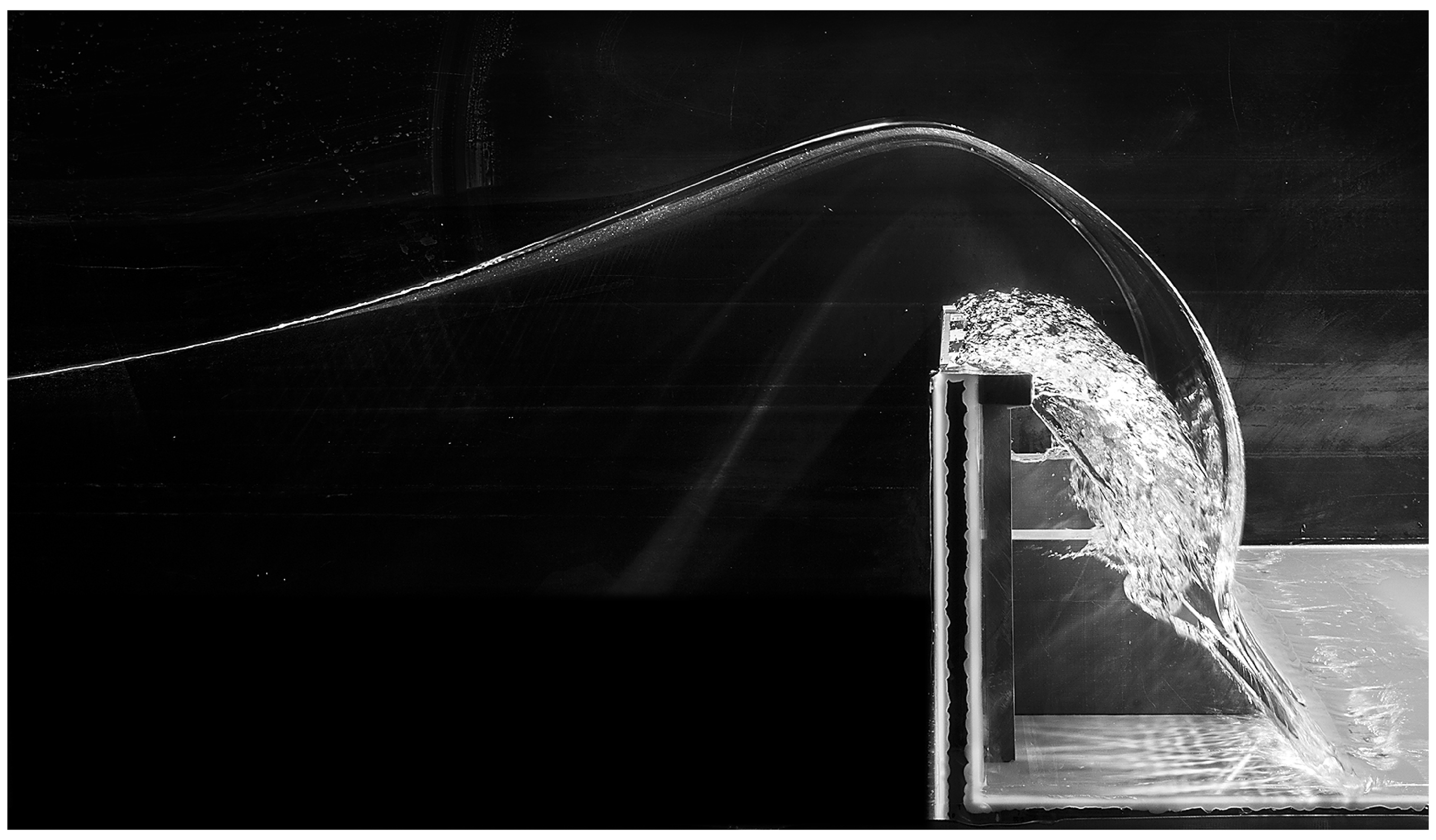

Figure 1: Photograph of model scale overtopping process

Method

To assess the overtopping process, as seen in Fig. 2, the fluid volume $\mathcal{V}$ and the maximum overtopping depth over the dam crest a_M allowed for the systematic study of the effects of still water depth h, wave amplitude a, dam crest width b_K, and dam inclination β.

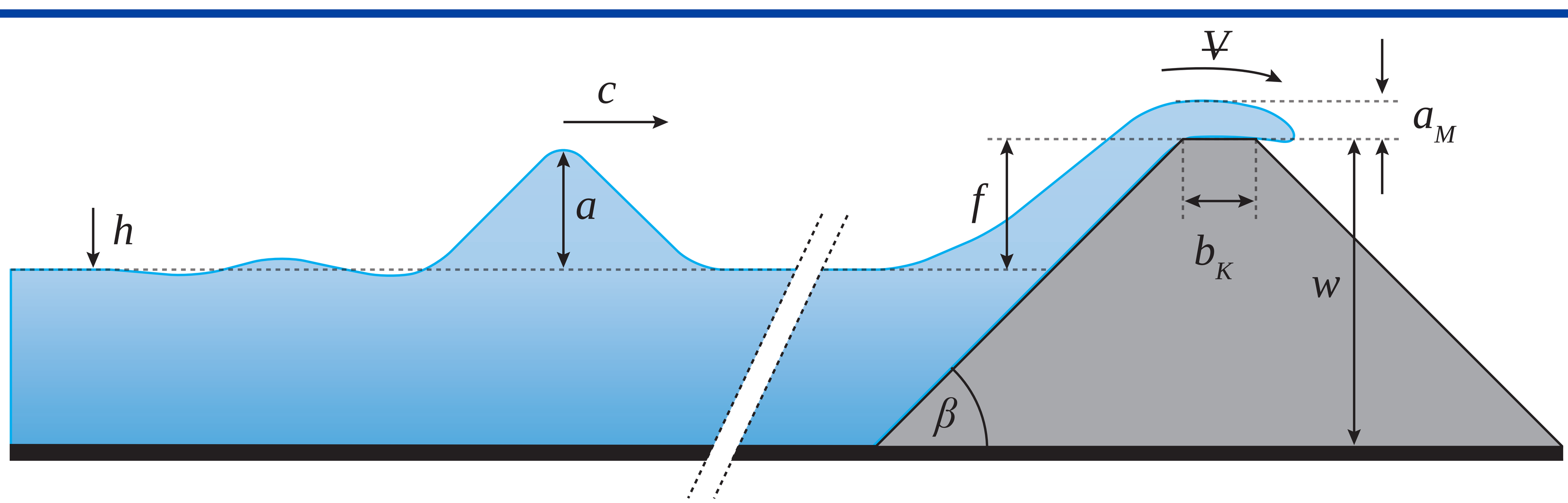

Figure 2: Definition sketch including relevant variables

The governing wave type was approximated with a solitary wave, involving a single crest but no wave trough. This wave was generated by a pneumatic piston type wave generator. The wave amplitude a and wave celerity c were checked by two vertical ultrasonic distance sensors. The overtopping volume $\mathcal{V}$ was weighed. The overtopping depth a_M was recorded with a highspeed camera operating at 80 Hz.

Results

Figure 3 shows the dimensionless overtopping volume (a), overtopping depth (b) and the respective fits.

$$\mathcal{V}/(bh^2) = [\varepsilon(h/w)^3(a_w/b_K)^{0.1}]^{0.8} = W^{0.8}, \quad R^2=0.96$$
$$a_M/w = \varepsilon(h/w)^{5/3}(\beta/90°)^{0.2} = E, \quad R^2=0.94$$

Both relationships strongly depend on the ratio h/w and moderately on the relative wave height $\varepsilon = a/h$. The effective wave height $a_w = a+h-w$ standardized by the crest width b_K has a slight effect, whereas the inclination β has no measurable effect on the overtopping volume. The relative dam inclination $\beta/90°$ has only a slight effect on the maximum overtopping depth. This analysis includes exclusively tests for which no scale effects apply.

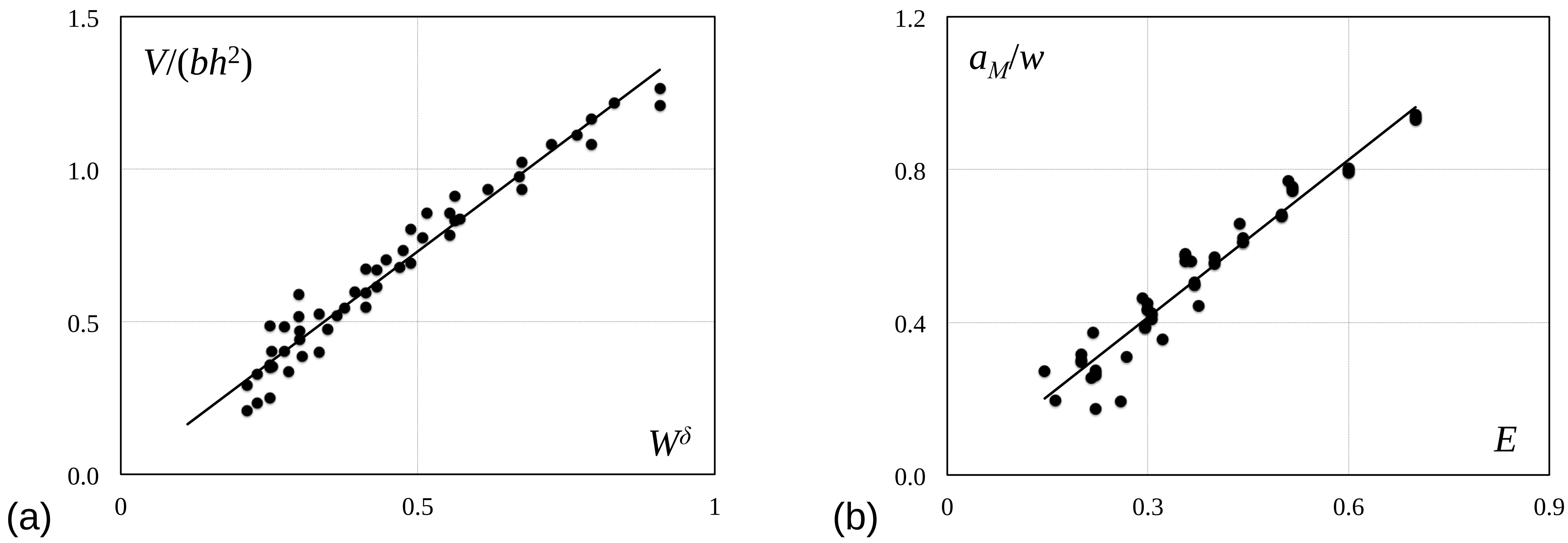

Figure 3: (a) Overtopping volume with $V/(bh^2)$ [W^δ] and (b) overtopping depth a_M/w [E]

Versuchsanstalt für Wasserbau,
Hydrologie und Glaziologie

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Kraftwerksausbau unter Berücksichtigung des Wasserfallbilds am Diesbach

Einleitung

Der Diesbachfall im Linthal gehört zu den mächtigsten Wasserfällen im Kanton Glarus. Aufgrund der grossen Fallhöhe über eine kurze horizontale Distanz eignet sich dieser jedoch auch für die Wasserkraftnutzung. Die Ermittlung einer Restwassermenge, welche das Wasserfallbild berücksichtigt sowie einen wirtschaftlichen Kraftwerksbau zulässt, ist somit von zentraler Bedeutung.

Vorgehen

Die Ermittlung der Restwassermenge basiert auf dem Prinzip eines Grenzabflusses. Nach dessen Überschreitung ändert sich das Wasserfallbild weniger stark. Für das Wasserfallbild wird die benetzte Fläche bestimmt und anschliessend mit dem Anteil der Farbe weiss des Wasser klassiert. Die **Ermittlung des Restwasserabflusse**s gliedert sich wie folgt:

1. Ermittlen von Grundlagedaten und Selektion der Fotografien
2. Ausscheidung und Klassierung der benetzten Flächen sowie die Bestimmung des Grenzabflusses
3. Quantifizierung der Einwirkung durch den Kraftwerkausbau
4. Bestimmung der Bedeutung des Wasserfalls
5. Gegenüberstellung von Einwirkungsintensität und Bedeutung

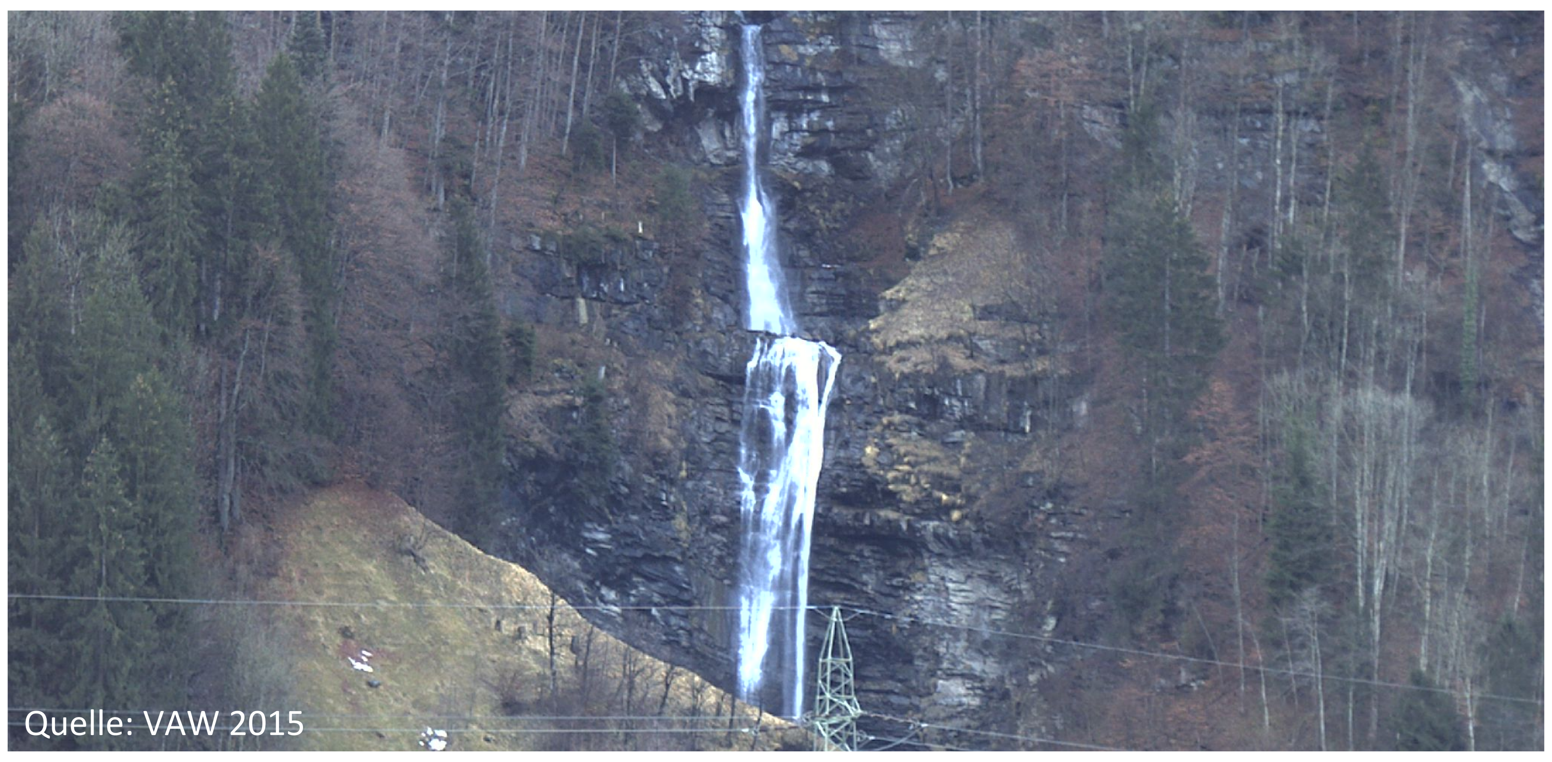

Abbildung 1: Diesbachfall bei geplantem Restwasserabfluss von 0.2 m^3/s

Resultate

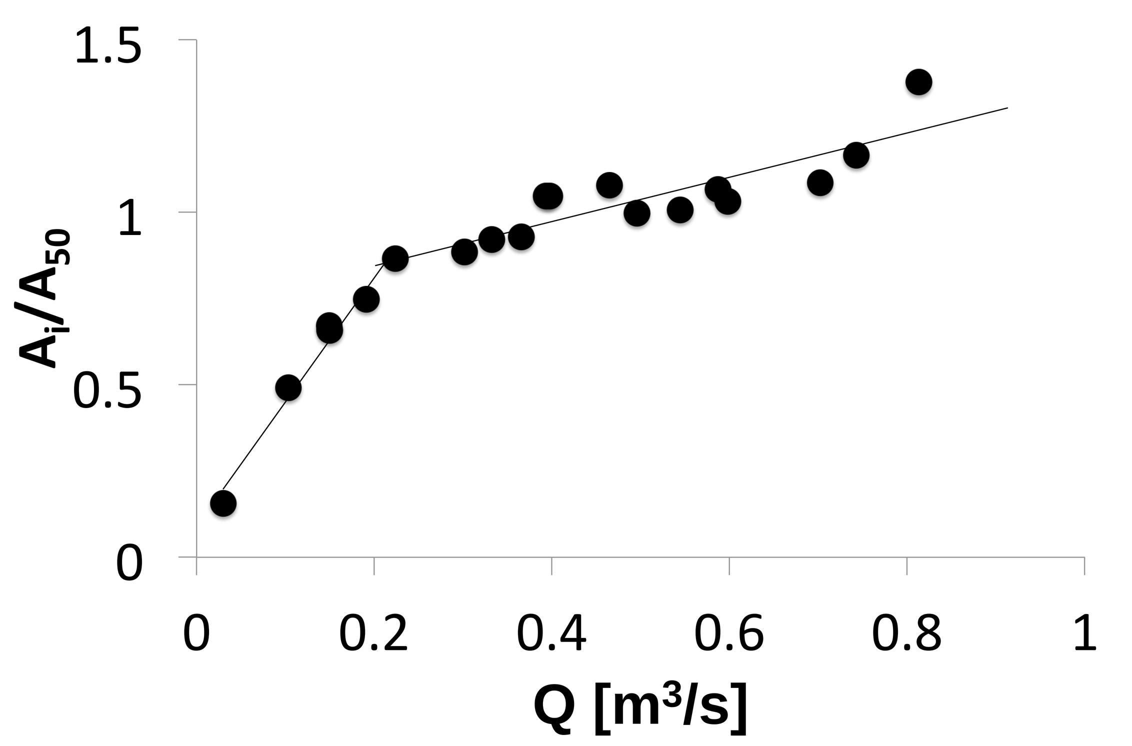

Abbildung 2: Darstellung der benetzten, klassierten Flächen A gegenüber den entsprechendes Abflüssen

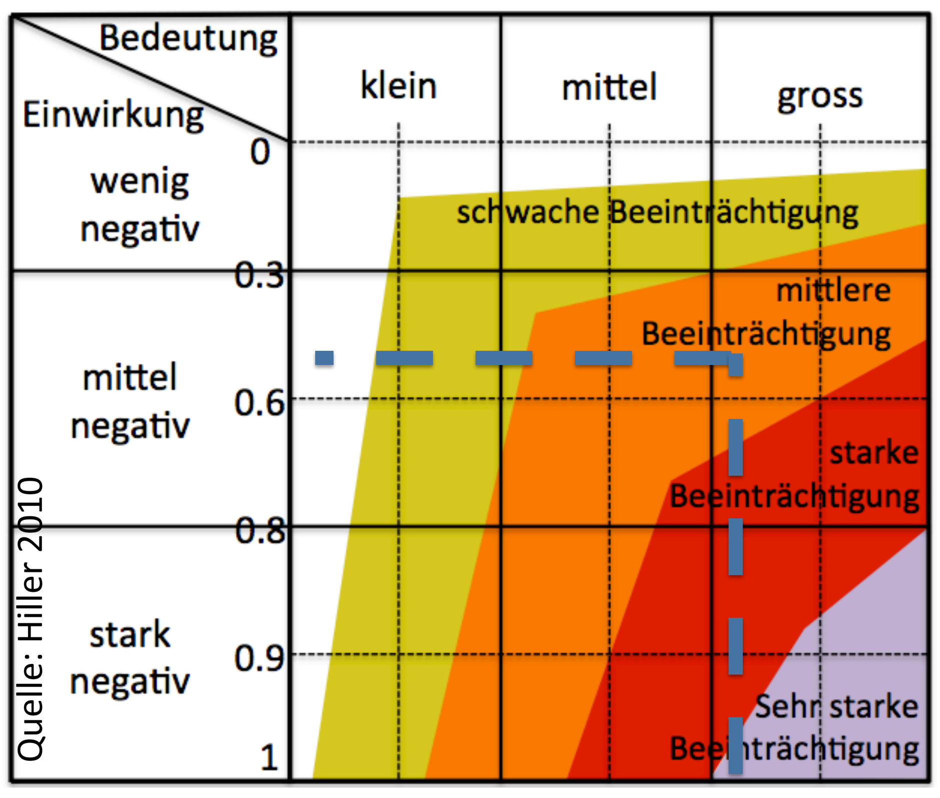

Abbildung 3: Gegenüberstellung von Einwirkung und Bedeutung (mittel bis gross) für Q_r = 0.2 m^3/s und Q_d = 1 m^3/s

Fazit Abbildung 2: Das Erscheinungsbild ändert unterhalb von **Q ≈ 0.2 m³/s** stärker. Die Restwassermenge sollte diesen Wert möglichst wenig unterschreiten. Abbildung 1 zeigt den Wasserfall bei Q = 0.2 m^3/s.

Fazit Abbildung 3: Mit einer Restwassermenge von Q_r = 0.2 m^3/s, einer Ausbauwassermenge von **Q_d = 1m³/s** und einer mittleren bis grossen Bedeutung der Diesbachfälle resultiert eine **mittlere Beeinträchtigung.**
Ein Übersichtsplan sowie einige Kenndaten eines solchen Kraftwerks sind in Abbildung 3 bzw. Tabelle 1 dargestellt.

Kraftwerksplanung

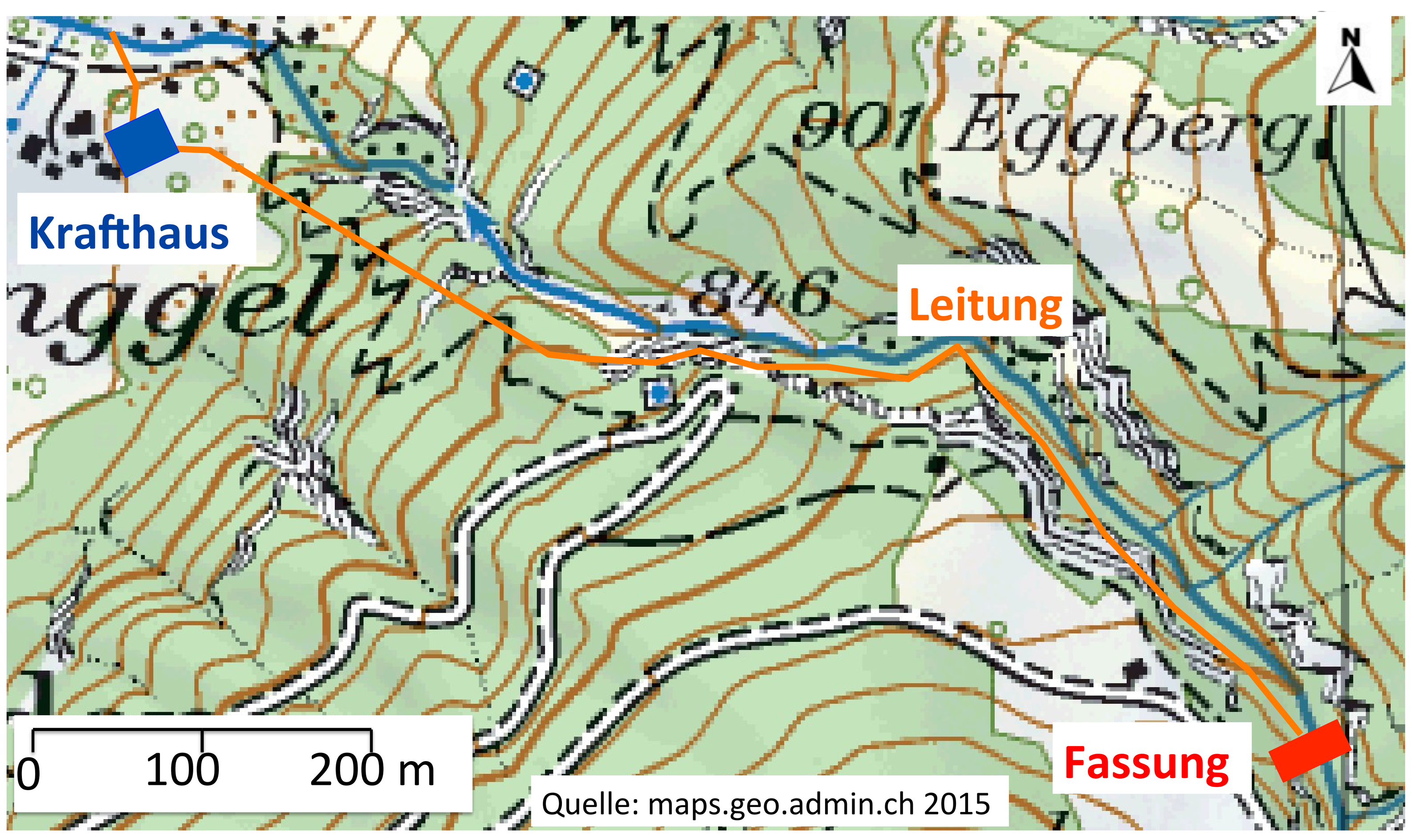

Abbildung 4: Übersichtsplan des geplanten Kraftwerks

Tabelle 1: Kenndaten des geplanten Kraftwerks

Bauwerk	Auführung
Bruttofallhöhe	Ca. 280 m
Fassungstyp	Fallrechenfassung mit Coandarechen
Leitungsmaterial	GFK und Stahl
Durchmesser Leitung	700 mm
Länge Leitung	Ca. 900 m
Turbinentyp	2-düsige Peltonturbine
Stromgestehungskosten	Ca. 10 Rp. / kWh

Fazit Kraftwerksplanung: Aus Tabelle 1 wird ersichtlich, dass der Bau eines Kraftwerks für eine mittlere Beeinträchtigung **wirtschaftlich interessant** wäre.

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Flow duration curves for water resources quantification in Alpine environments

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2 EPFL - ENAC, Laboratory of Ecohydrology (ECHO), 3: Instituto Superior Técnico, Civil Engineering Research and Innovation for Sustainability, Univ. Lisboa, Portugal,
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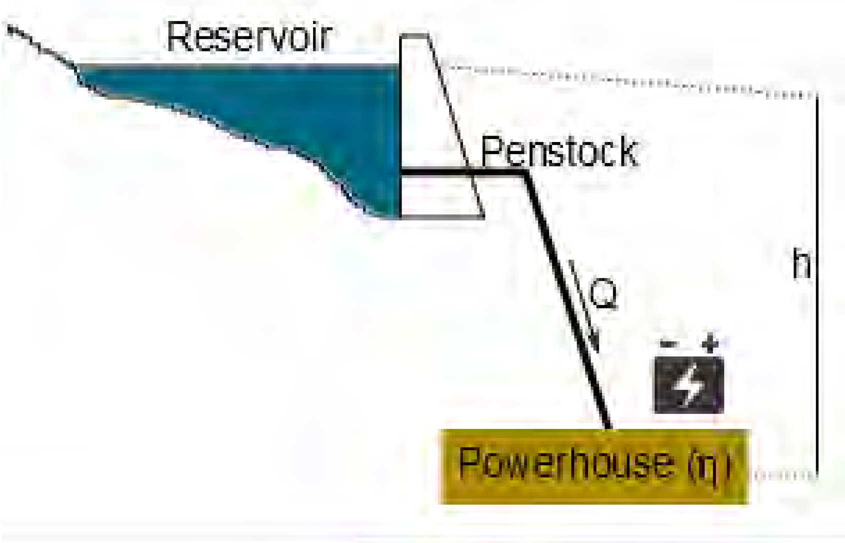
1. Introduction

Flow duration curves (FDCs) are very useful for hydropower design. Usually they are obtained from long series of discharge data, but those data are not always available and we should be able to predict the curves in those cases. This project aims to develop models to obtain FDCs for ungauged catchments in Switzerland considering uncertainties, beginning from a characterization of some Swiss FDCs. Here we have some results.

2. Method

- Discharge is a key factor for hydropower generation (Fig.1):



$$P = \gamma . Q . H . \eta$$

Where:
P: total power produced;
γ: specific weight of water;
Q: water discharge;
h: net height of fall;
η: overall efficiency of the power station.

Fig.1: Power generation in a hydropower plant

- Switzerland: 16 discharge regimes (Weingartner and Aschwanden, 1992) (Fig.2)

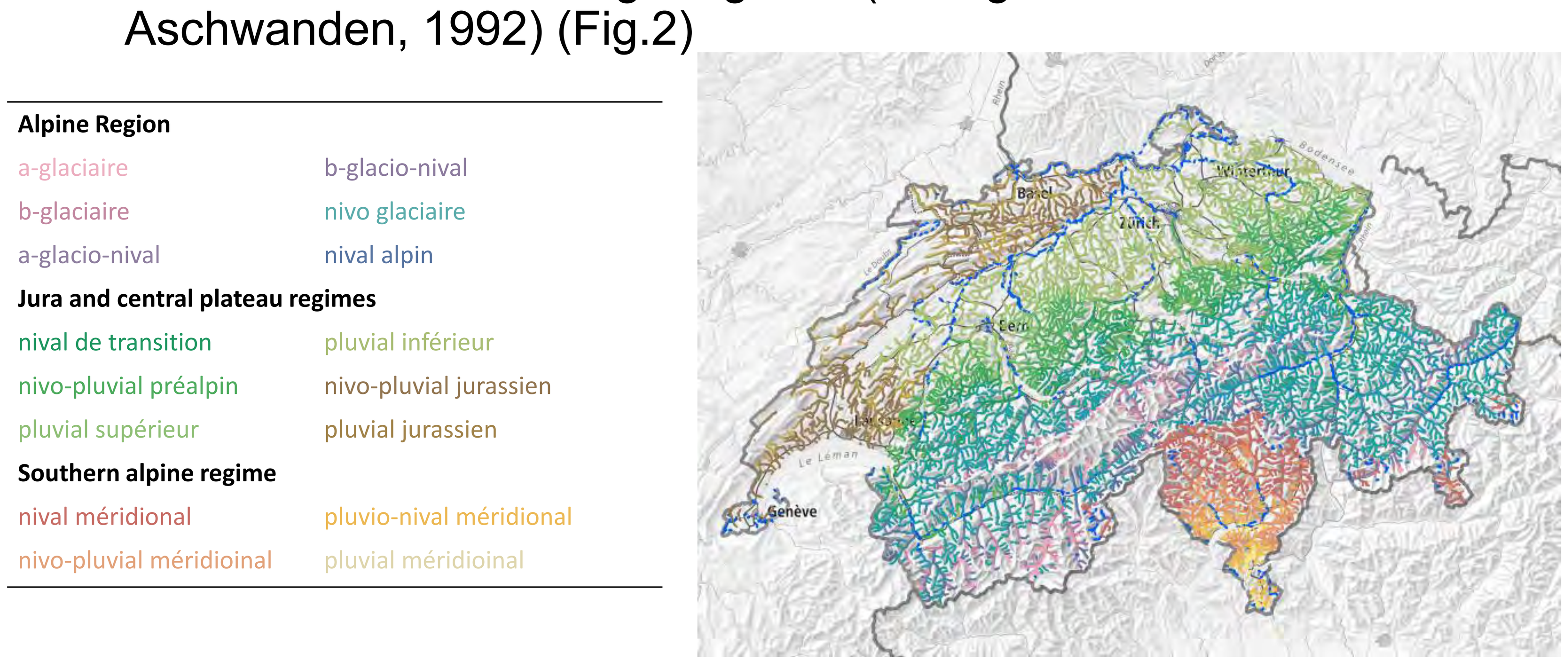


Fig.2: Schematic representation of the discharge regimes in Switzerland

Flow duration curve (FDC): represents the percentage of time, a discharge in a stream section is equalled or exceeded (Fig.3).

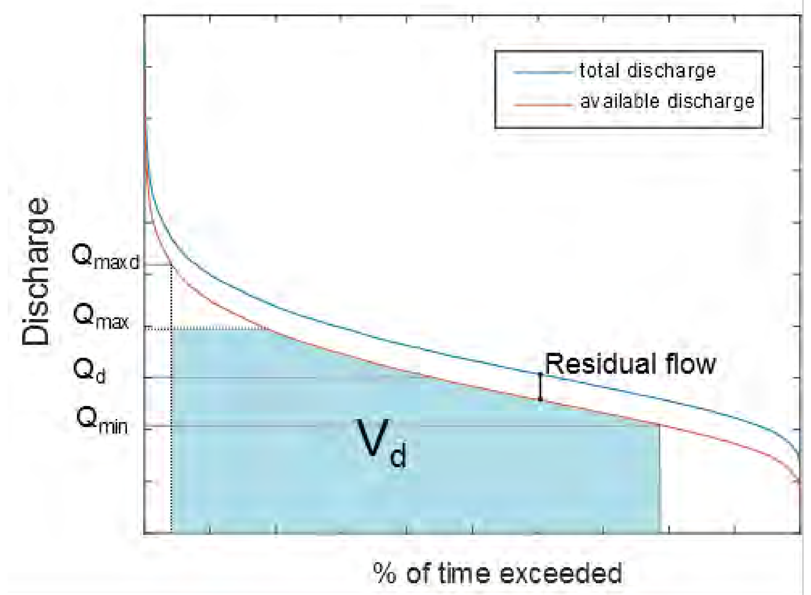
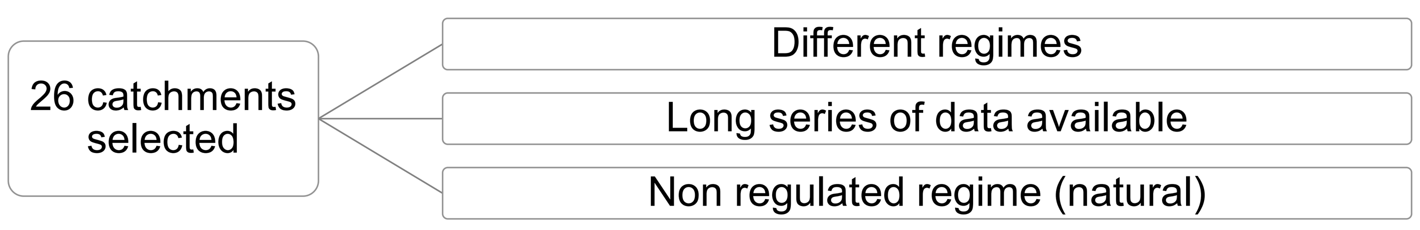


Fig.3: Design discharges and volume represented in a FDC.

- Q_{min}: minimum discharge that the plant needs to operate;
- Q_{max}: maximum discharge with which the plant can operate;
- Q_{maxd}: maximum discharge with which the plant can operate without being damaged;
- Q_d: design discharge (defined by optimization);
- V_d: design volume (volume available for production);

Construction of FDCs: discharge data, obtained from gauging stations for natural streamflow for selected catchments. There are still many streams that are not being measured (Fig.4).



(Hänggi and Weingartner, 2012).

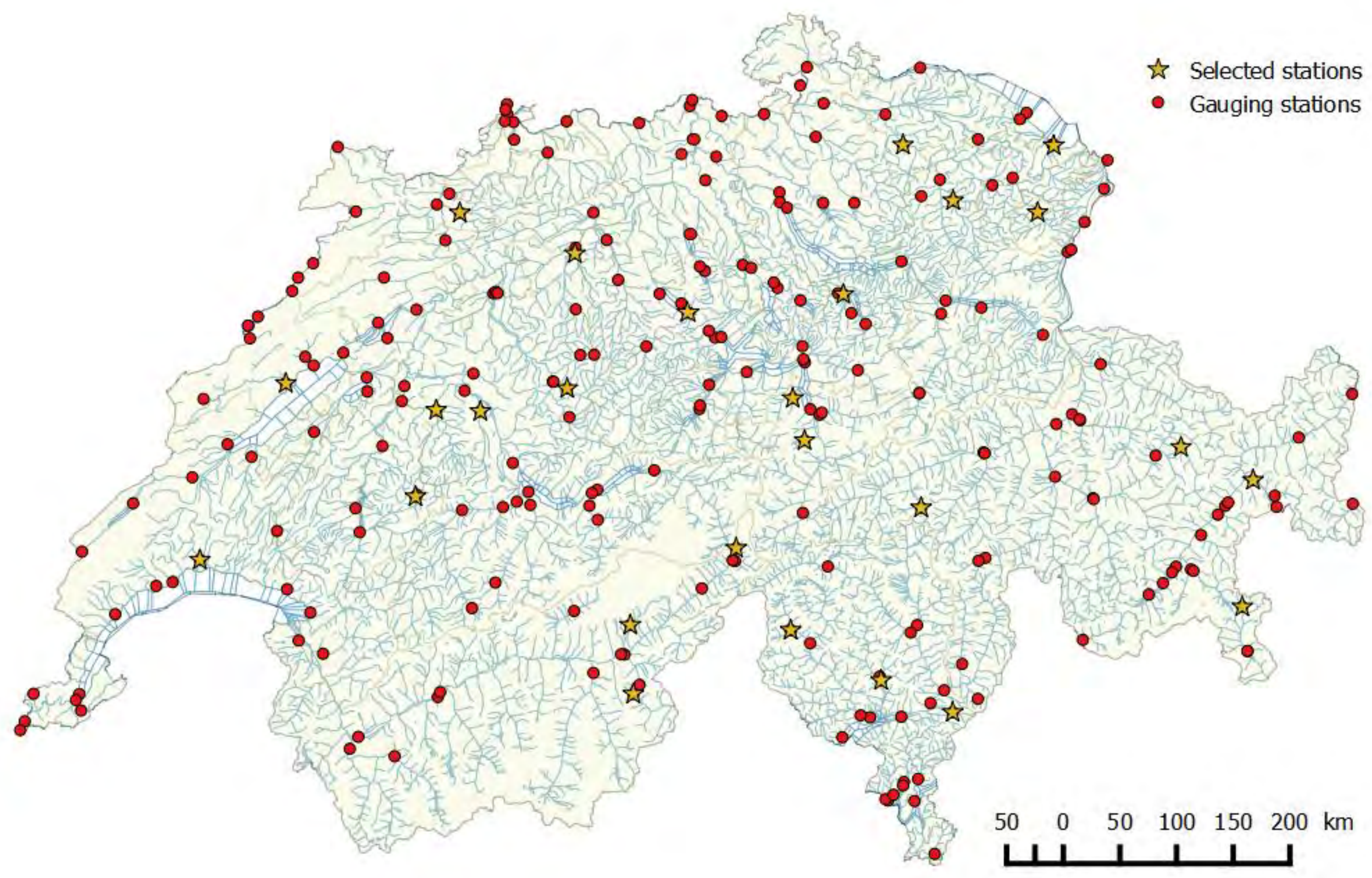


Fig. 4: Gauging stations in Switzerland with the selected study stations highlighted.

The FDCs obtained for the studied stations with different regimes are shown in the same graphic (Fig.5):

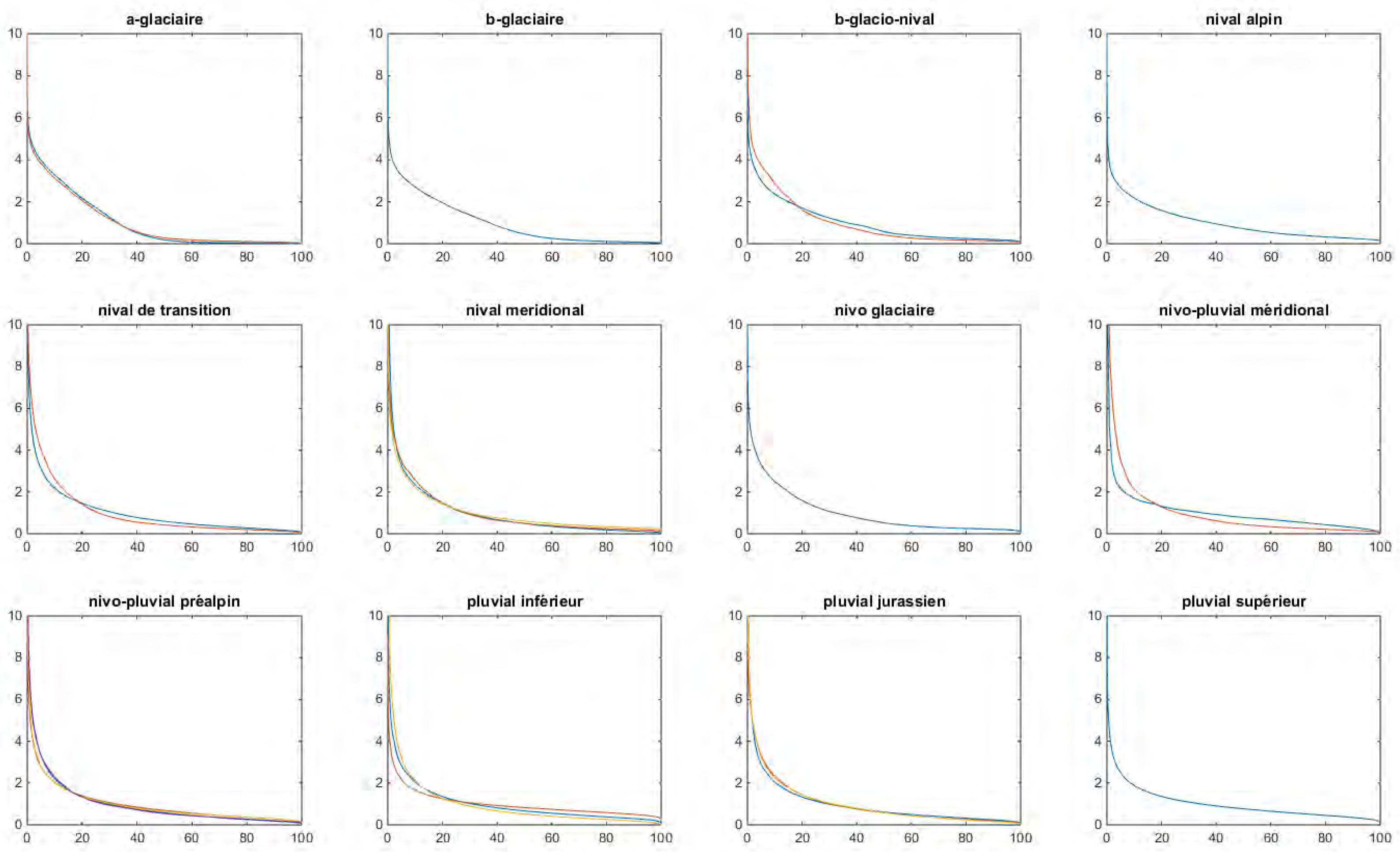


Fig.5: FDCs for some hydrological regimes in Switzerland (the axis *x* shows percentage of time and *y* shows the normalized discharges for selected catchments)

3. Conclusions / Perspectives

- The FDCs for each discharge regime have their own pattern. The project will follow the steps in Fig.6:

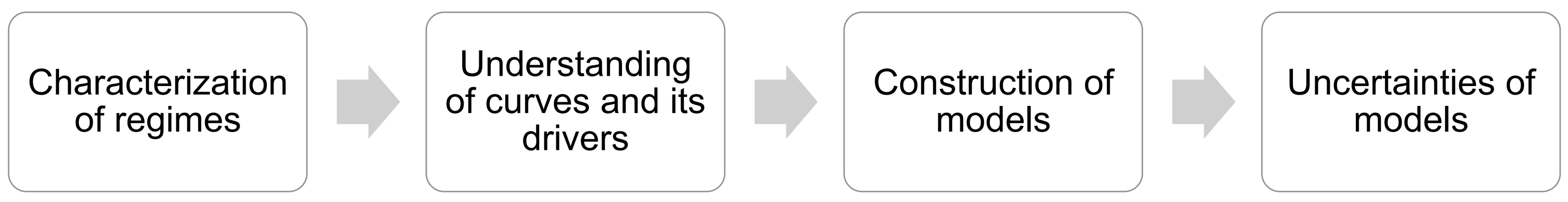


Fig.6: Next steps

- A reliable quantification of water resources, even in sites without data can lead to better design and operation of hydropower plants, increasing their production.

References:
Weingartner, R., Aschwanden, H., 1992. Discharge regime – the basis for the estimation of average flows. In: Hydrological Atlas of Switzerland, Plate 5.2. Swiss Federal Office for the Environment, Bern, CH.
Hänggi, P., Weingartner, R.,2012. Variations in discharge volumes for hydropower generation in Switzerland, Water Resources Management, 26, pp. 1231–1252

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Dam Break Analysis under Uncertainty

1 Introduction

The current knowledge on processes of failing embankment dams is poor to predict the resulting outflow hydrograph. To account for its uncertainties, a probabilistic framework consisting of a strongly parametrized dam breach model was developed. The calibration of the probabilistic model is based on historical dam break data. To solve the computationally demanding uncertainty routing, the application of meta models is proposed, resulting in probabilistic flood maps (Fig. 1).

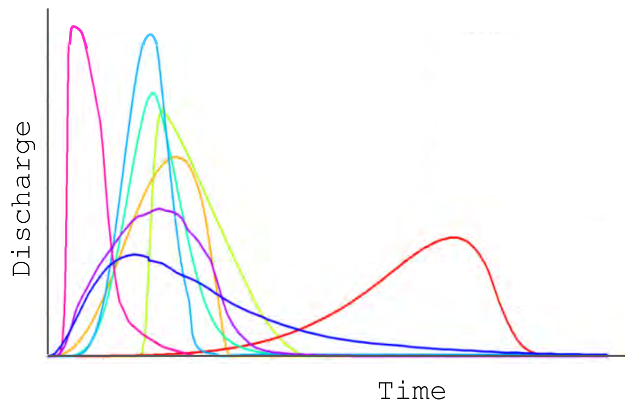

Figure 2 Hydrographs produced by dam break modeling experts using perfect information on dam properties (re-arranged from Benchmark Proc. Graz 2013)

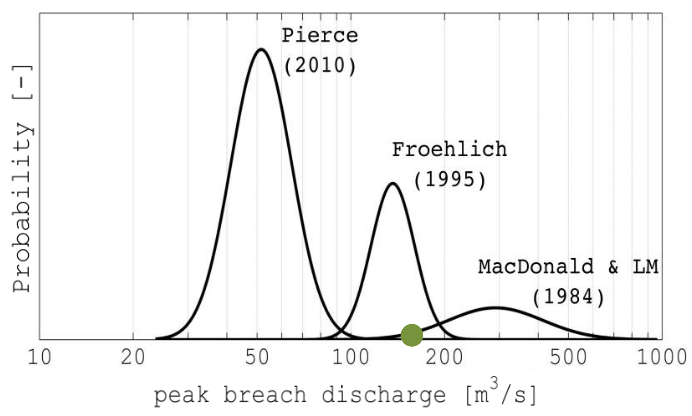

Figure 3 Peak discharge estimation for dam of 5 m height and 10^4 m^3 storage volume. 3 log-normal probability distributions based on empiricism, with (●) instantaneous dam failure (SFOE Guidelines)

3 *BASEbreach* Framework

The newly developed dam breach model framework focuses on quantification of indispensable uncertainties. Thus, probabilistic parameters should be: (1) Physically bounded, (2) small in their number, and (3) able to exclude a-priori model assumptions. The *BASEbreach* model setup for a given dam of height *H* and reservoir volume *V* reads

$$M^{BB} = \mathcal{M}(H, V, \boldsymbol{\chi}, f_s)$$

Here $\boldsymbol{\chi}$ is the vector of the uncertain but physical parameters, i.e. erosion and friction laws, breach shape, dam geometry, and initial conditions (Fig. 4). A scaling parameter f_s quantifies the erodibility of the dam and is used for calibration purposes. The model driving processes are: (1) Depletion of reservoir water level, and (2) erosion and transport of dam material (differential equations in Fig. 4).

The calibration process is based on data containing historical dam break events. The calibration process attempts that the modeled distribution of the peak discharges asymptotically converges to the distribution of historical peak discharges

$$\theta_{Q_p}{}^{data} = \theta_{Q_p}{}^{BB}(\chi, f_s)$$

Parameter f_s is such that the uncertainties in the input parameters χ resemble these in the collected dam break data.

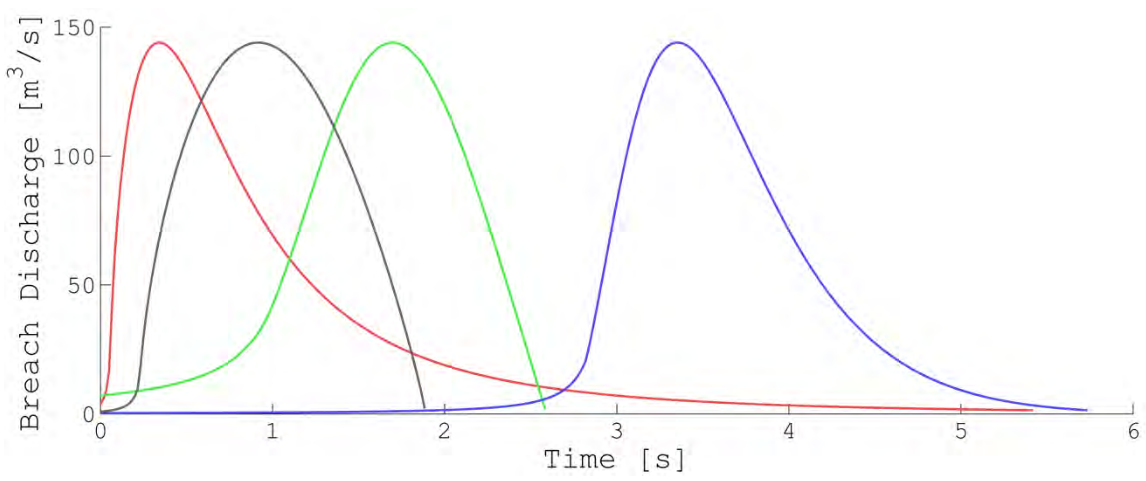

Figure 5 Possible failure hydrograph shapes (Fig. 3). Uncertain but physically bounded input parameters are responsible for visually obvious differences

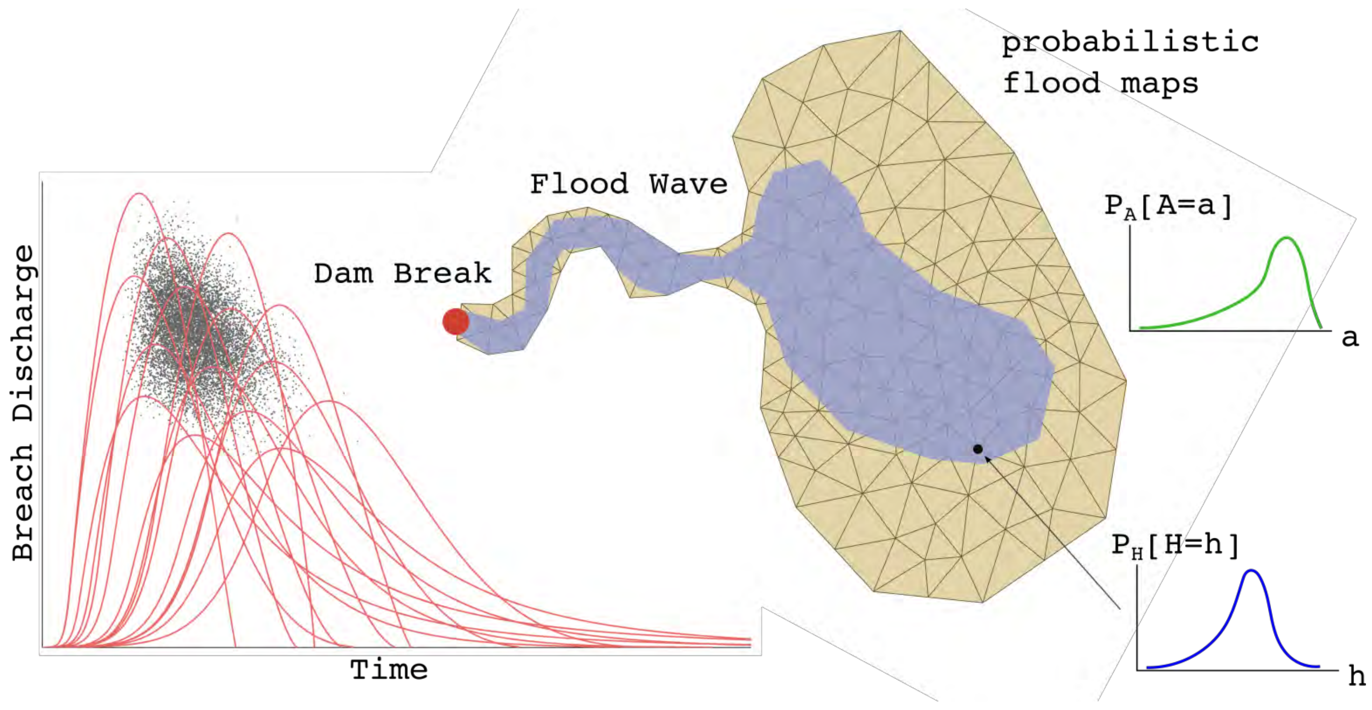

Figure 1 Visualization of research project and its components: Starting from uncertainties, transporting these downstream, and constructing probabilistic flood maps

2 Motivation and Goals

Progressive and highly dynamic mechanisms of gradually failing dams are unknown. During real dam breaks, data collection is challenging. The main issue remains to quantify the breach discharge and geometry. This lack of knowledge results in poor prediction tools (Figs. 2 and 3). Therefore, a tool is required that:

- Quantifies existing uncertainties in dam break models and their effect on flood waves for the subsequent risk assessment,
- Supports engineers and decision makers, and
- Is embeded in non-proprietary software (BASEMENT and QGIS)

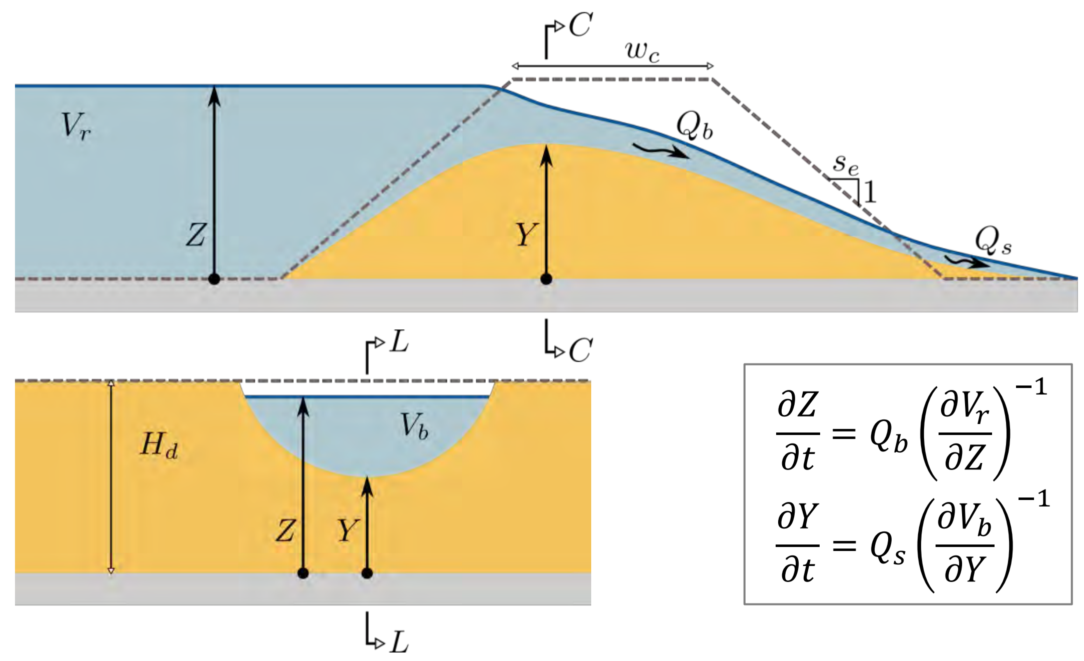

Figure 4 Failing embankment dam with dam height H_d, crest width w_c, and embankment slope s_e: Streamwise (top) and cross-sectional (bottom) sketches. Variables to describe the erosion process: reservoir level *Z*, breach level *Y*, breach discharge Q_b, sediment transport rate Q_s, breach volume V_b.

4 Flood Routing

Stochastic hydrographs resulting from *BASEbreach* (Fig. 5) define the upper boundary condition of the flood wave computation using BASEMENT. Accurately solving the shallow-water equations on complex topographies is computationally expensive. Thus, a crude Monte-Carlo approach is not applicable to quantify the uncertainties in the resulting flood variables.

The application of meta modeling is proposed, treating the hydraulic simulation as blackbox, and the output variables as a function of the uncertain dam break hydrograph. Advanced techniques provide additional features used for the interpretation of the stochastic flood maps. This approach takes a step toward decision making under uncertainty in engineering problems.

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Financial Support: Swiss Federal Office of Energy (SFOE))

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Artificial sediment replenishment to restore the natural morphological conditions downstream of dams

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LCH LABORATOIRE DE CONSTRUCTIONS HYDRAULIQUES

EPFL ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

1. Introduction

Dams are built worldwide for many purposes as to provide water for irrigation, electricity and drinking, representing one of the most severe human interventions in the hydrological cycle. Dams interrupt the sediment continuum along rivers as they store water and trap sediment in the reservoir. It is well know that the presence of a dam strongly modifies the river behavior in the downstream reach, in terms of morphology and hydrodynamics, with consequences on local ecology. The main observed effects, on what concerns the morphology of the rivers, are sediment deficit, bed armoring, river incision and bank instability, which in turn will affect negatively the aquatic habitats and the water quality (Figure 1).
In order to restore the sediment regime of such disturbed reaches downstream of dams, an increasingly common measure is the sediment replenishment. In this context, a series of laboratory experiments are run in order to assess the role of different geometrical configuration of replenishment on channel bed morphology.

Figure 1: river condition upstream and downstream the Echo Dam, Utah

2. Laboratory facility

The experimental channel at a scale of about 1:10 represents a straight alpine gravel channel with a slope of 1.5%, a length of 15 m, a width of 0.4 m and a trapezoidal cross section with a bank slope of 2:3 (V:H) (Figure 3 (right), Figure 2(1)). Two morphologically identical channels are created (Figure 2 (2)).

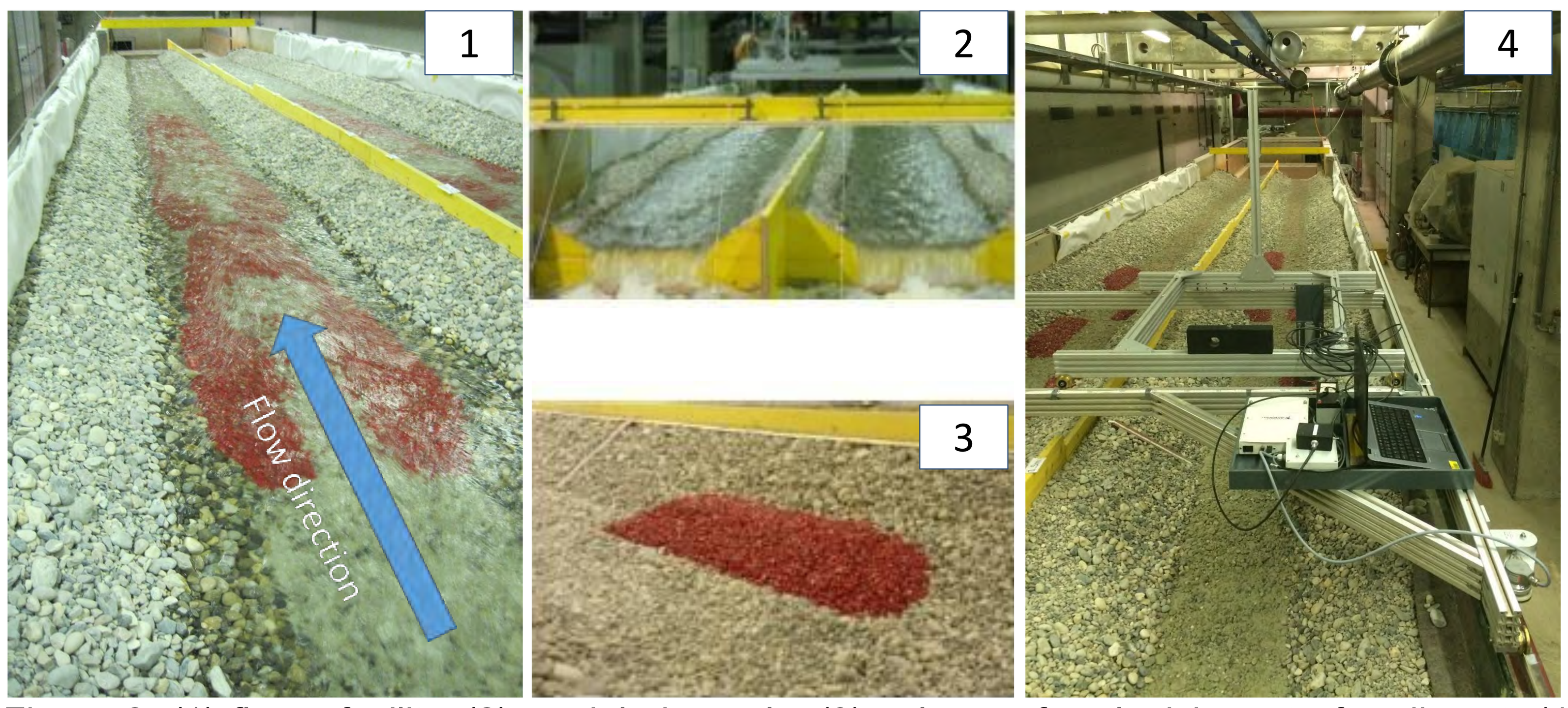

Figure 2: (1) flume facility, (2) model channels, (3) volume of replenishment of sediment, (4) installed instrumentations

- Replenishment volume has a constant height (h_{rep}= 0.07 m)
- Constant discharge during the entire test, indirectly determined by the submerged condition.
- Two submerged conditions: completely submerged (water depth= h_{rep}, 100%), over submerged (water depth > h_{rep}, 130%).
- Grain size distribution for the bed considers an average distribution of different Alpine Rivers (Figure 3 (left)).
- Fixed channel bed, accounting for bed armoring (D=11.5 mm).
- Grain size distribution for the replenishment considers: ecological needs for alpine fishes, sediment transport ensured for the replenishment volume (Figure 2 (3)).

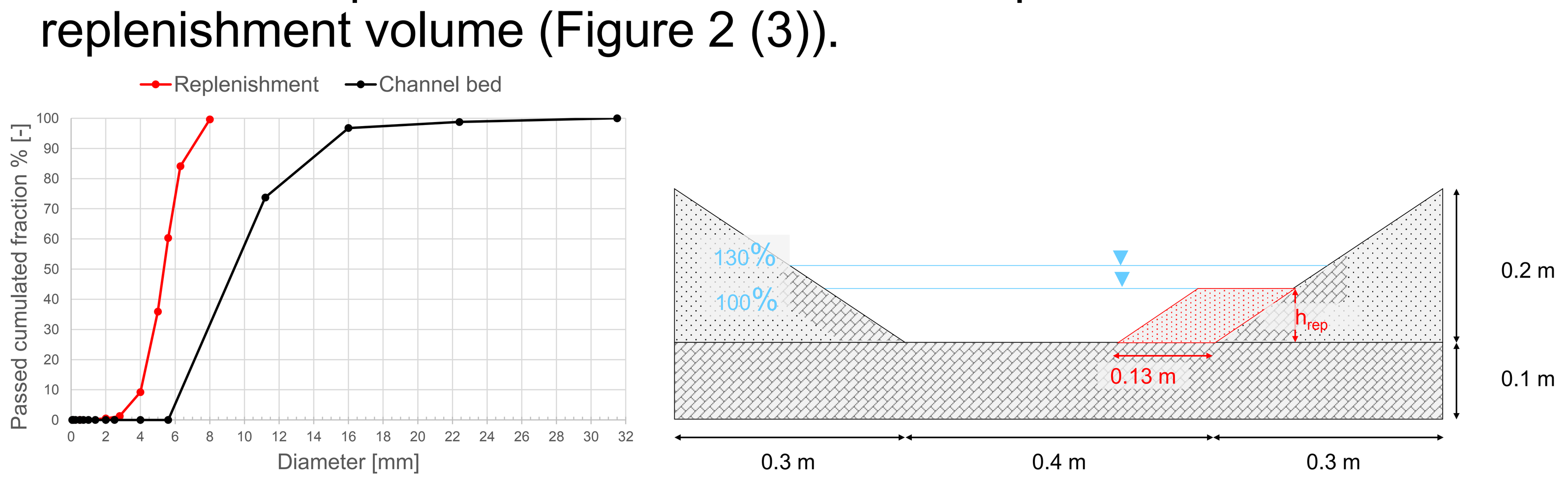

Figure 3: grain size distributions (left), cross section of the experimental model (right)

3. Methods

Four different geometrical configurations of replenishment volume are tested on the flume facility (Figure 4). The erosional process and the morphological changes occurring during the entire 3 hours of test are recorded by photo survey (1 photo each 0.5 m along both the channels). The bed morphology is measured at the beginning and the end of the test by a high definition laser installed on a moveable structure along the longitudinal and transversal directions (Figure 2(4)).

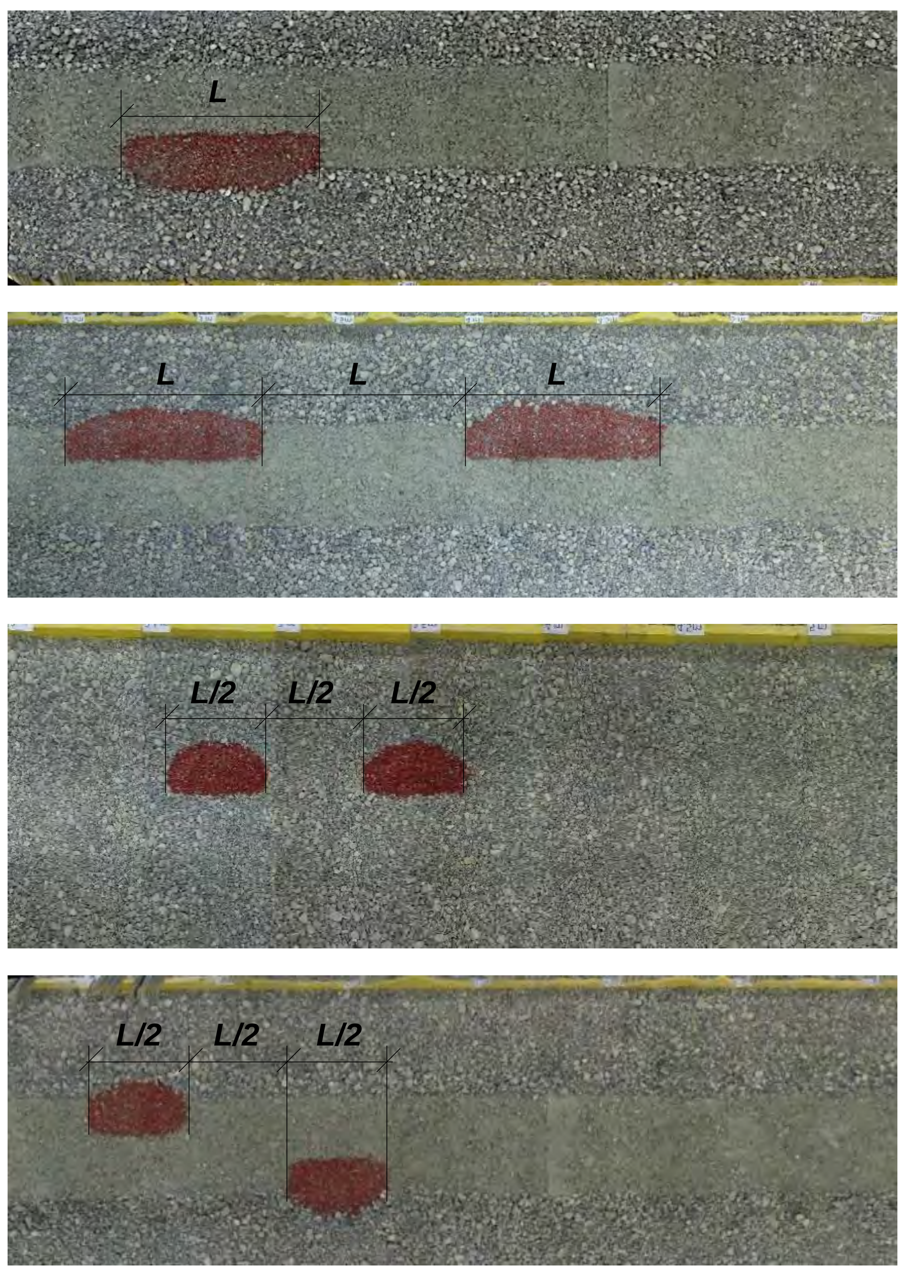

Figure 4: from the top: Single volume, double volume aligned, double half volume aligned and alternated

4. Results

Average distance: represents the distance travelled by sediments from the upper control section and the mobility of grains considering the time evolution (Figure 6).
Ratio perimeter-surface: considers the total sum of elements perimeter and total sum of elements surface. This parameter proposes a way to evaluate the maximum distance until which the replenishment can be considered efficient (Figure 7).

- Two half aligned volumes performs longer distance and the grains which are spread also along the channel width.
- Larger quantity of grains runs longer distance and it is faster eroded by water in case of aligned volumes.
- For double volumes, the upstream replenishment plays as an obstacle for the water flow, which accelerates the flow inducing erosion of the downstream volume in less time compare to a single volume.
- Higher submerge condition reduces the experimental time.
- 100% submerge condition is not enough for obtaining neither the same distance, nor the same rate of erosion performed by the 130% submergence condition.

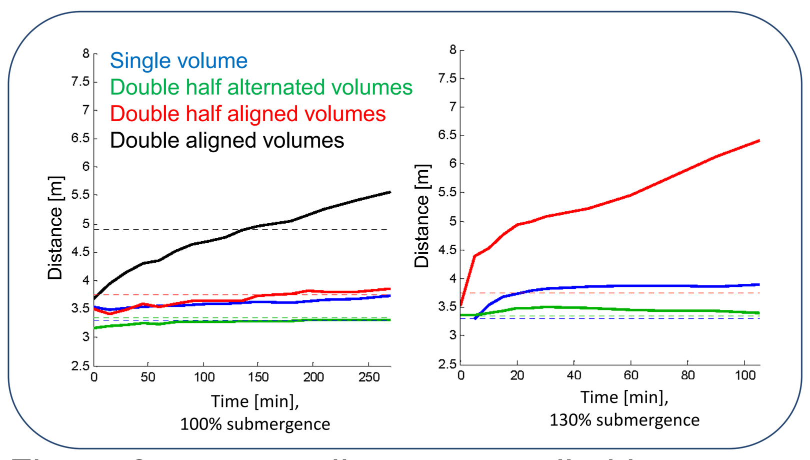

Figure 6: average distance travelled by sediment for submergence of 100% on left, 130% on right

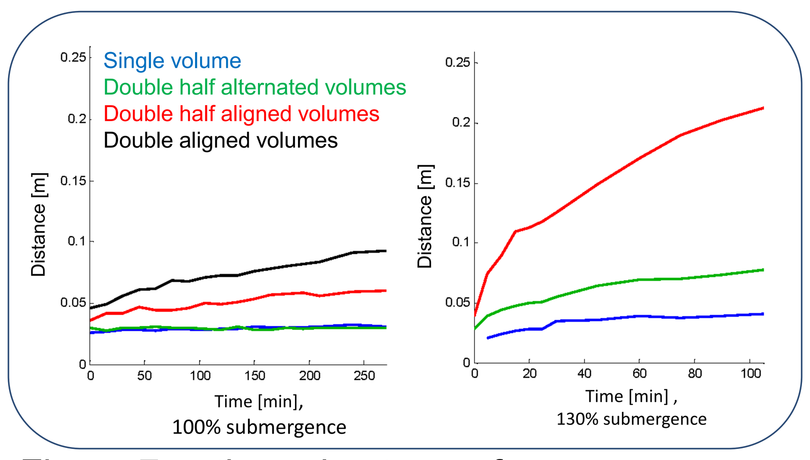

Figure 7: ratio perimeter-surface submergence 100% on left, 130% on right

5. Conclusions

This research aims at providing general recommendations for further applications of the method on the fields.

- The 100% submergence requires too long time to obtain a complete replenishment erosion.
- The flow behavior is influenced by the upstream bed narrowing, accelerating the replenishment volume place upstream
- The replenishment leads to a fining of the armored layer
- The replenished material is deposited along the downstream channel reach.
- Morphological bed forms start to develop in the downstream reach.

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Evaluation du potentiel hydroélectrique des eaux usées en Suisse

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1. Contexte et objectifs

La stratégie énergétique 2050 de la Suisse, qui prévoit de sortir du nucléaire, rend nécessaire le développement de nouvelles sources de production. Parmi les nouvelles sources, la petite hydraulique, en particulier celles sur les réseaux (exemple: les réseaux d'eaux usées) est très encouragée, notamment grâce à la rétribution à prix coûtant (RPC). Le but de l'étude est de déterminer s'il existe un potentiel non exploité pour l'hydroélectricité à partir des eaux usées en terme d'énergie disponible mais aussi en terme de rentabilité.

2. Définitions

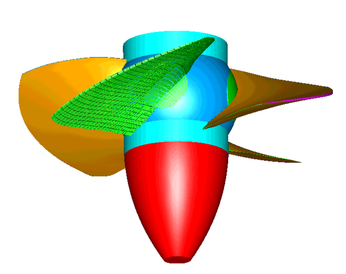
- Turbinage avant STEP: Turbinage des eaux usées brutes non traitées entre le point de collection principal et la station d'épuration (STEP). Nécessité d'installer un bassin de prétraitement.
- Turbinage après STEP: Turbinage des eaux traitées entre la station d'épuration et le point de rejet.

3. Méthodologie

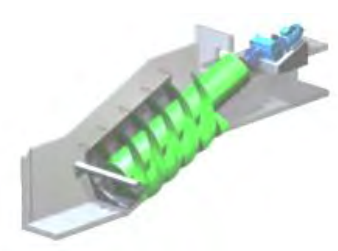
3.1. Potentiel énergétique

- Détermination du débit: utilisation de la base de données des STEPs de Suisse.
- Détermination de la chute: Etude SIG
  - Turbinage après STEP: calcul de la chute entre la STEP et le point de rejet (coordonnées disponibles)
  - Turbinage avant STEP: détermination du point de collection principal puis calcul de la chute entre ce point et la STEP

3.2. Turbines considérées


Turbine Kaplan

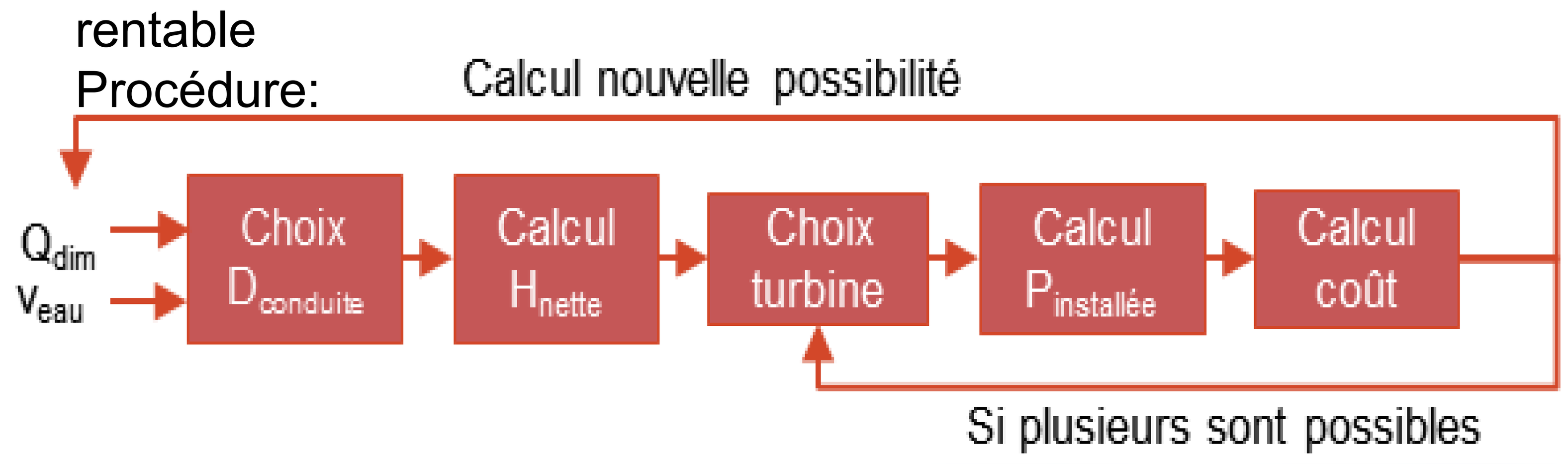

Pompe inversée


Vis hydrodynamique


Turbine Pelton

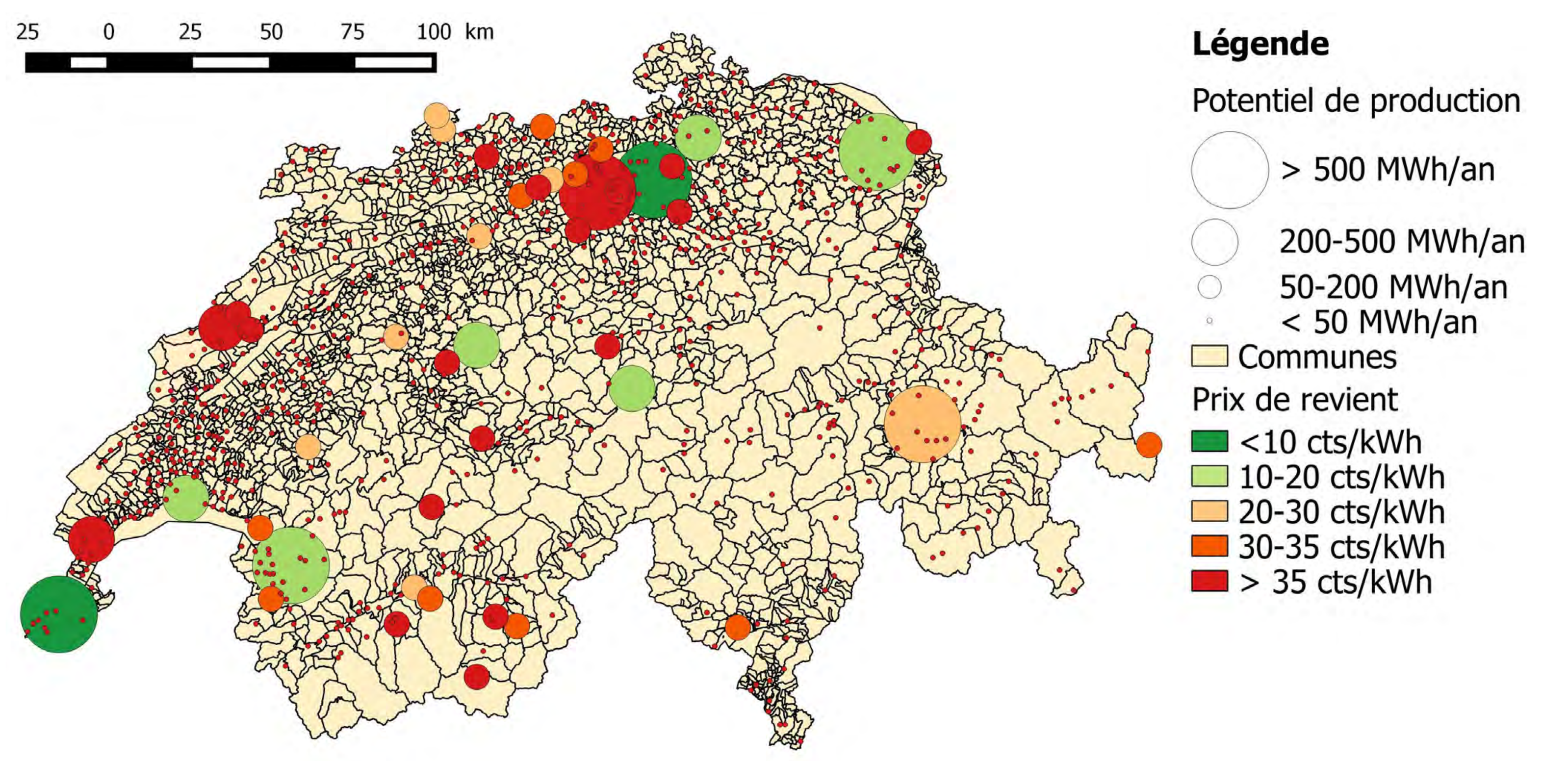
3.3. Rentabilité des sites

- Pour chaque site potentiel identifié, évaluation de tous les dimensionnements possibles en fonction de la vitesse de l'eau dans la conduite, du débit de dimensionnement et de la turbine
- Sélection du dimensionnement le plus rentable en terme de prix de revient (cts/kWh) pour une période d'amortissement de 25 ans
- Évaluation de la rentabilité en calculant la valeur actuelle nette (VAN) après 25 ans. Une VAN supérieure à 0 conclut à un site rentable
- Procédure:



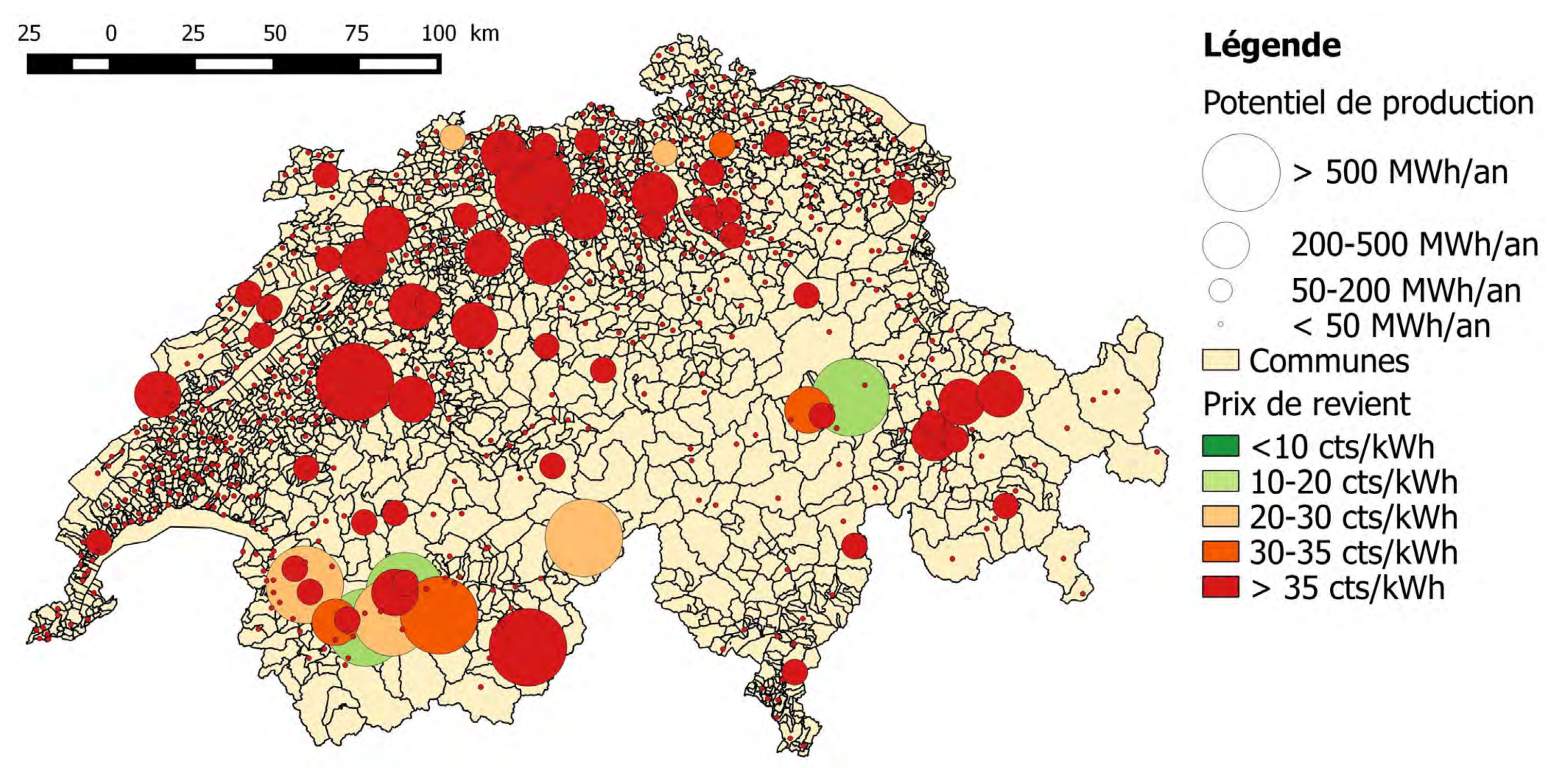
4. Résultats

4.1. Turbinage après STEP



- Potentiel de production: 9.6 GWh/an, 41 sites potentiels (production > 50'000 kWh/an).
- Rentabilité (selon VAN): 14 sites rentables, production de 4.64 GWh/an.
- Investissements nécessaires: 7 Millions CHF
- Revenus annuels attendus: 0.93 Millions CHF/an (avec RPC).

4.2. Turbinage avant STEP



- Potentiel de production: 21.7 GWh/an, 65 sites potentiels (production > 50'000 kWh/an).
- Rentabilité (selon VAN): 5 sites rentables, production de 4.63 GWh/an.
- Investissements nécessaires: 9 Millions CHF.
- Revenus annuels attendus: 0.91 Millions CHF/an (avec RPC).

5. Scénarios d'évolution du potentiel

- Centralisation de STEPs. Évaluation du potentiel hydroélectrique en regroupant les STEPs pour en créer des plus grandes.
  Augmentation du potentiel: 10.5 GWh/an, 44 sites potentiels
  Rentabilité: 31 sites rentables

- Changement du lieu de rejet. Recherche d'un nouveau point de rejet dans un périmètre de 1500 m autour de la STEP pour trouver une chute plus importante.
  Augmentation du potentiel: 16 GWh/an, 105 sites potentiels
  Rentabilité: 8 sites rentables

6. Conclusion

Potentiel total: 31.3 GWh/an soit l'équivalent de la consommation de 6000 foyers par an. Seule la production de 9.3 GWh/an serait rentable.
Les sites de turbinage après traitement sont plus rentables que les sites avant traitement. Le coût du bassin de prétraitement est un des principaux obstacles à la rentabilité pour l'hydroélectricité sur les eaux brutes.
L'étude des scénarios futurs a montré une augmentation importante du potentiel. Si la rentabilité de ces scénarios n'a pas toujours été prouvé, une prise en compte différente des coûts à l'avenir pourrait permettre de faire apparaître de nouveaux sites rentables.

Publications : Bousquet C., Samora I., Manso P., Rossi L., Heller P. , Schleiss A. J. (2015). "Turbinage des eaux usées : Quel potentiel pour la Suisse ? ". Revue Aqua & Gas (à paraître en Octobre).

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L'aménagement de Trift

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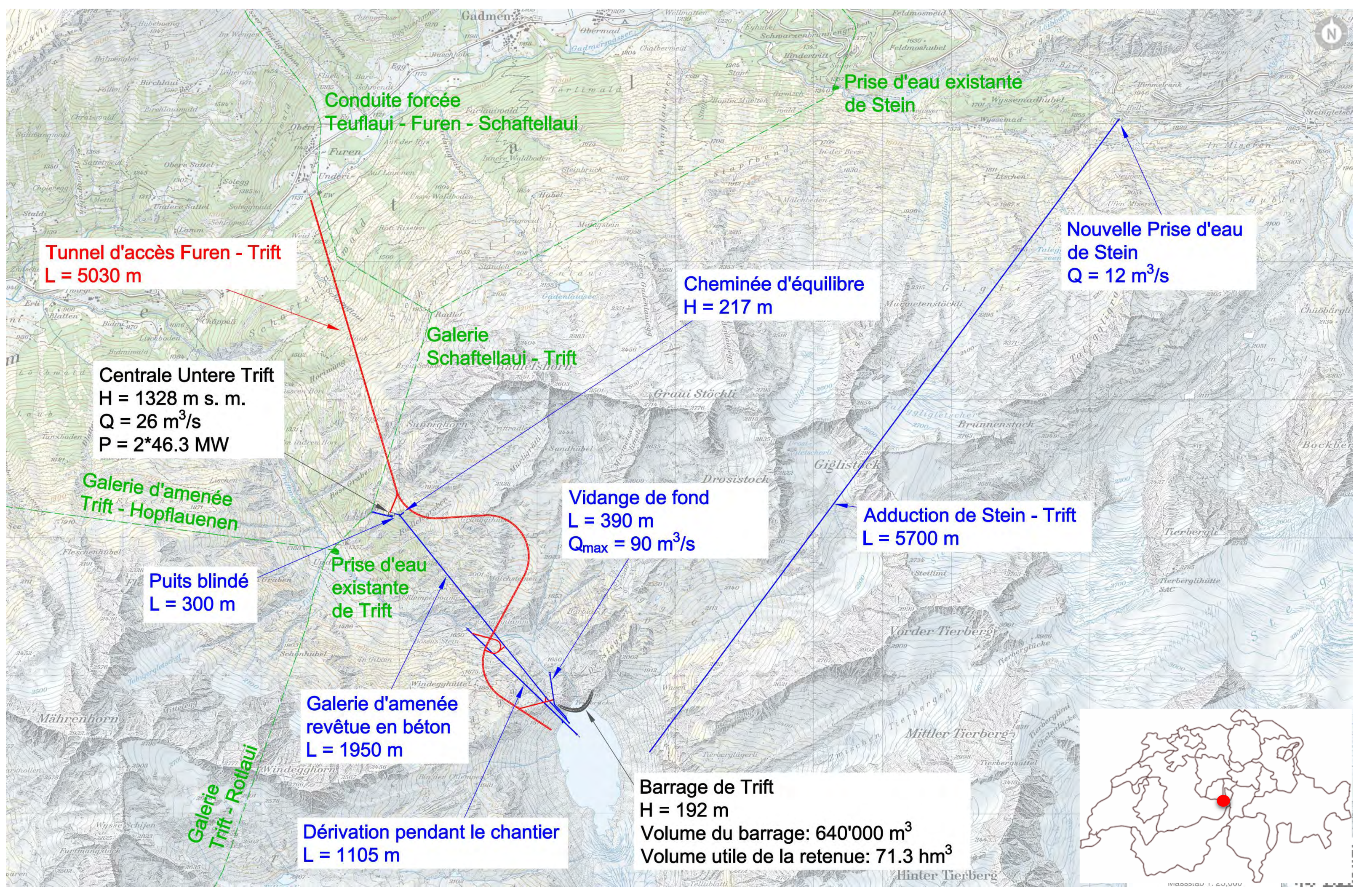
1. Objectifs

La vallée de Trift dans l'Oberland bernois présente un site intéressant pour la construction d'un nouvel aménagement de turbinage et de stockage saisonnier.
Avec la construction d'un barrage, il est possible de créer une retenue avec un volume de jusqu'à 130 hm^3.

2. Situation



Site de projet du nouvel aménagement de Trift.

3. Etude de variantes

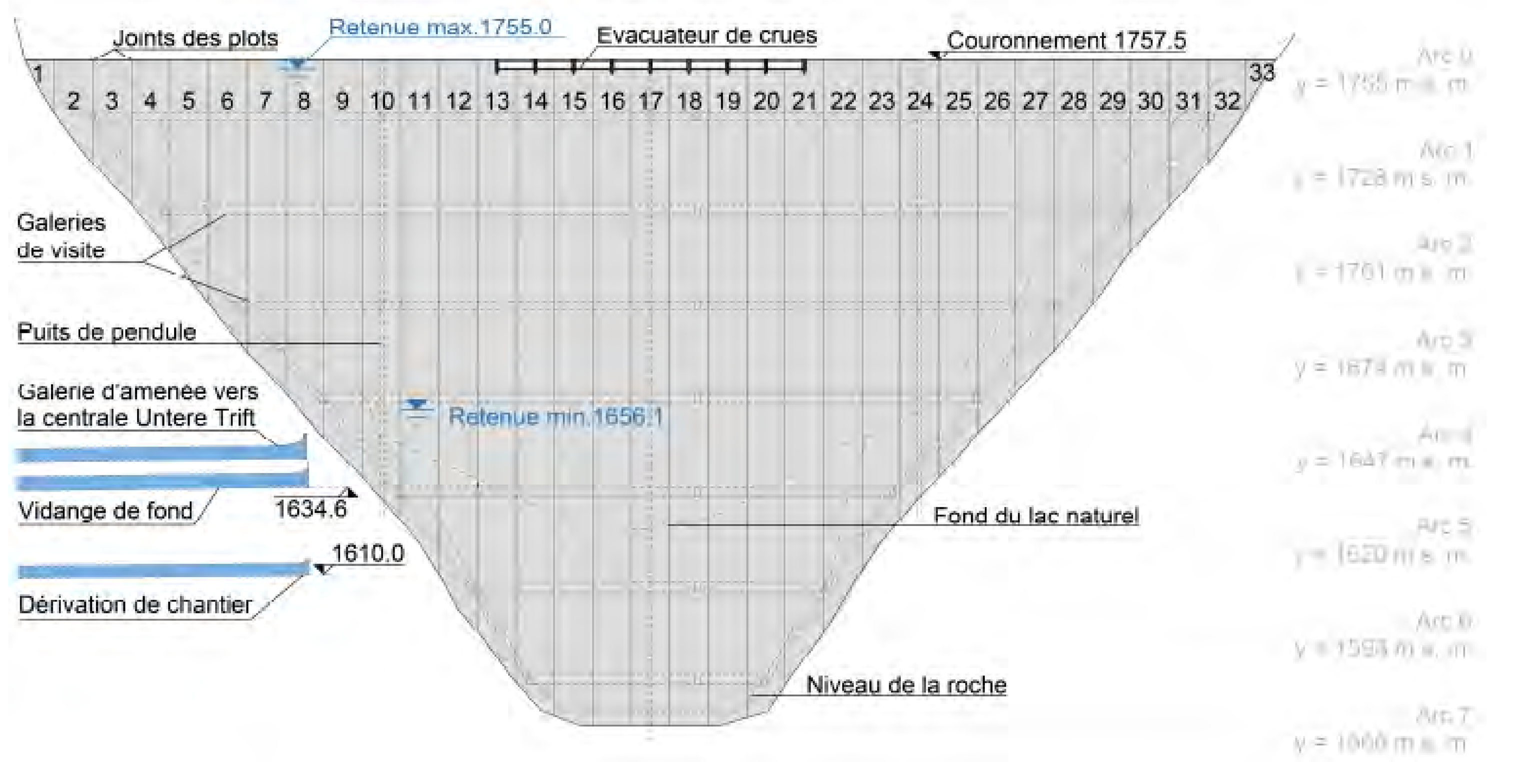
Pour l'étude de variantes, trois différents emplacement d'une nouvelle centrale, deux adductions, une connexion avec une autre retenue de KWO, ainsi que trois différentes hauteurs de barrage sont considérées.
Une combinaison de ces possibilités permet de comparer un total de 30 variantes d'un point de vue économique, écologique, technique et légal, afin de trouver la solution optimale.

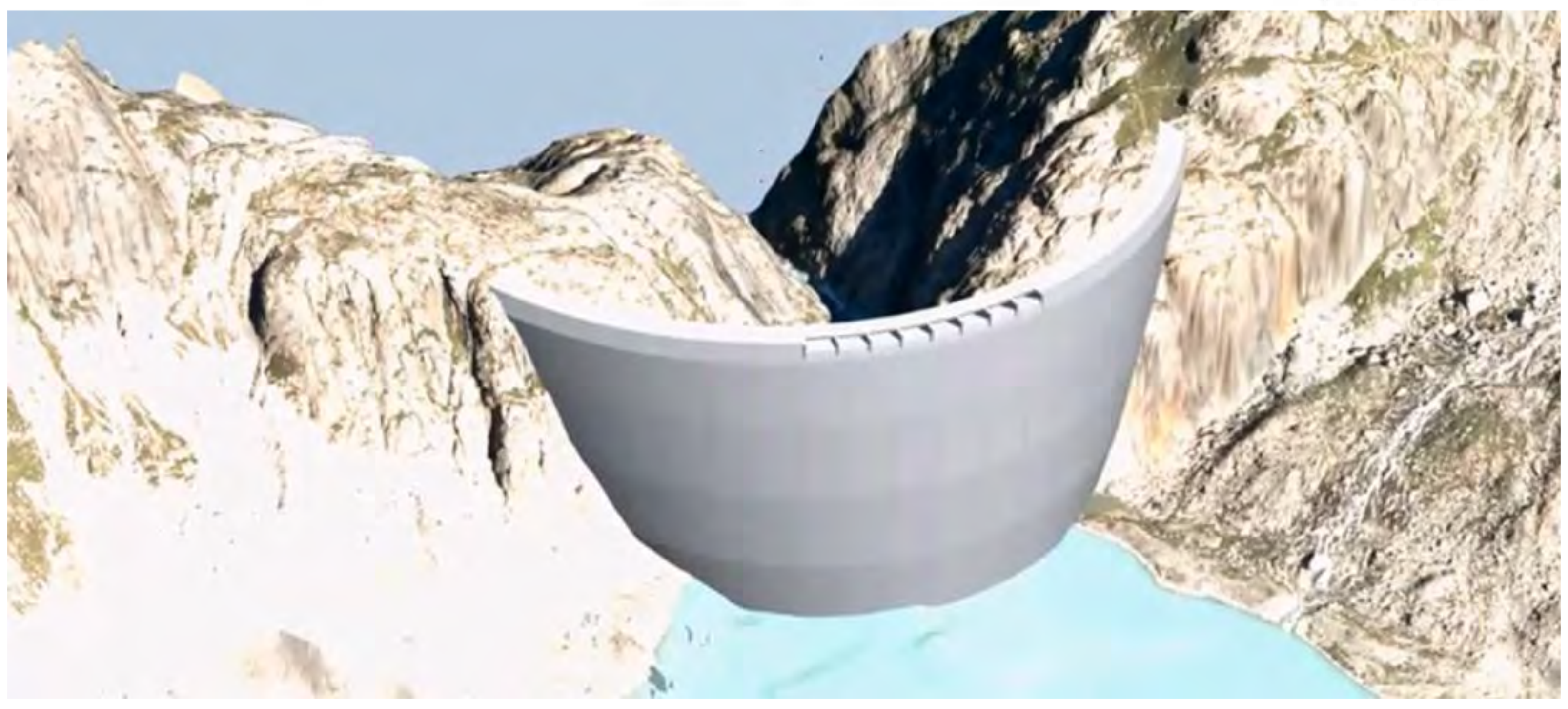
Emplacement de la centrale	Untere Trift	Hopf-lauenen	Innert-kirchen
Couronnement barrage [m s.m.]	1720	1720	1765
Volume utile [hm^3]	45.5	45.5	88.5
Puissance installée [MW]	69.2	193.4	274.5
Débit équipé [m^3/s]	21	23	29
Adduction Wenden	non	non	non
Connexion avec Räterichsboden	non	non	pas testée
Production [GWh/an]	109	249	324
Annuités du projet [MCHF/an]	16.62	27.43	43.09
Bénéfice annuel [MCHF]	4.83	5.16	5.73
Rapport B/C	1.29	1.19	1.13

Comparaison des meilleures variantes avec une centrale respectivement à Untere Trift, Hopflauenen et Innertkirchen.

4. Avant - projet

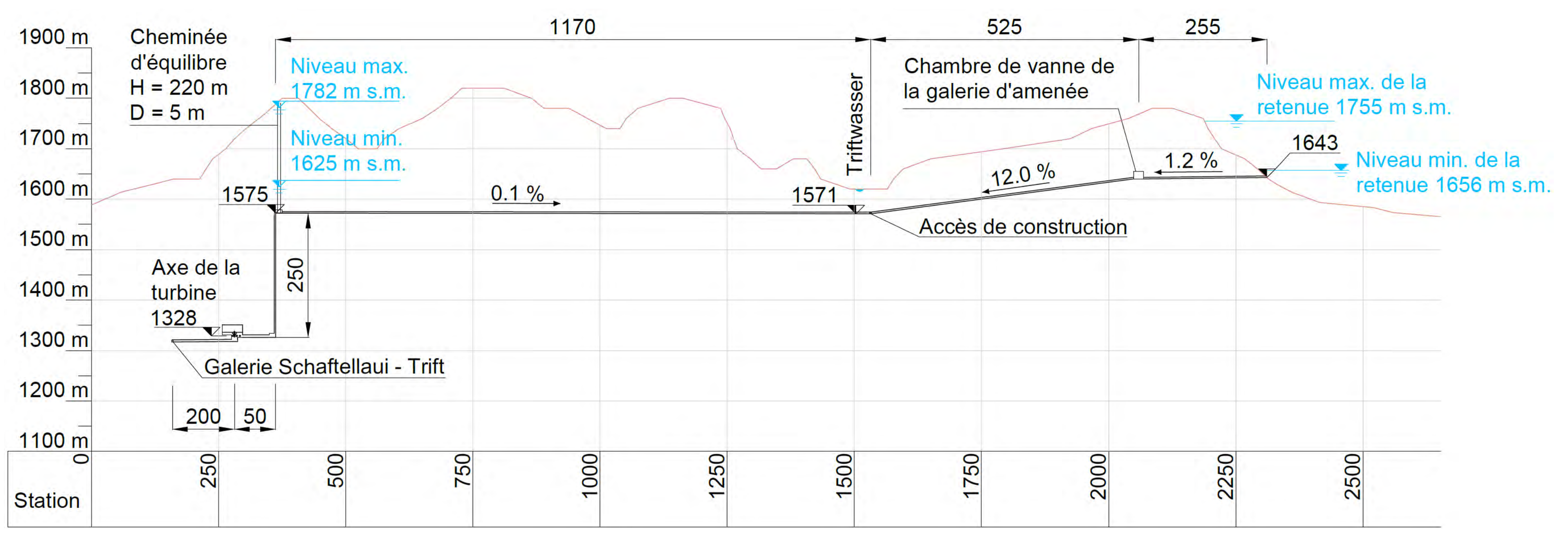
Variante retenue	
Hauteur du barrage	192 m
Volume utile de la retenue	71.3 hm^3
Eaux captées	Triftwasser (73 hm^3), Steinwasser (55 hm^3)





Vue amont et aérienne du barrage de Trift.

Centrale	
Hauteur de l'axe des turbines	1328 m s.m.
Puissance installée	93.6 MW
Débit équipé	26 m^3/s
Production annuelle	118 GWh



Coupe longitudinale de la galerie d'amenée et du puits blindé.

Economie	
Coûts de construction	330 MCHF
Durée de construction	9 ans
Gains annuels (amortissement linéaire)	5.7 MCHF/an
VAN à 50 ans (amortissement dégressif)	20 MCHF

5. Conclusion

Le projet de Trift permettrait de valoriser les ressources disponibles du Gadmertal et de contribuer de 8.6% aux objectifs de la Stratégie énergétique 2050. Grâce au fait que la majorité des constructions se font en souterrain, les effets néfastes restent justifiables vis-à-vis d'un projet rentable d'importance nationale. Le projet devrait donc se poursuivre.

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Réaménagement Etzelwerk (CFF)

Concepts d'aménagement innovateurs du point de vue énergie et protection contre les crues

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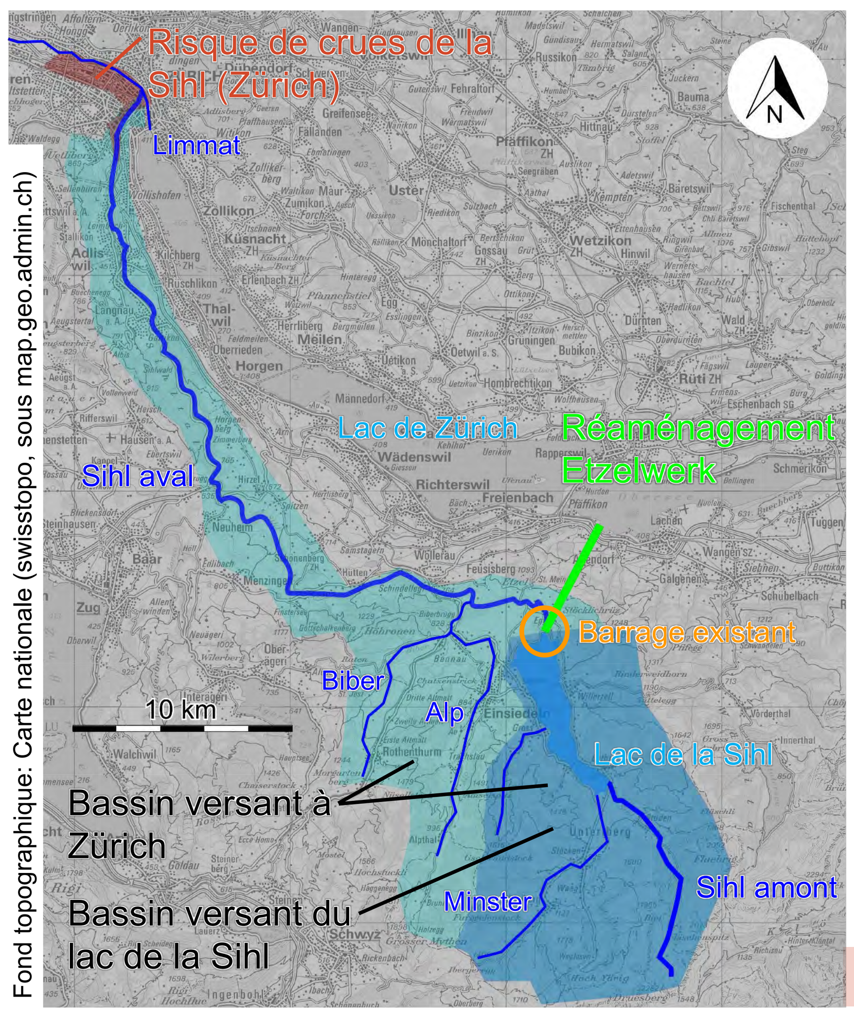


1. Objectifs

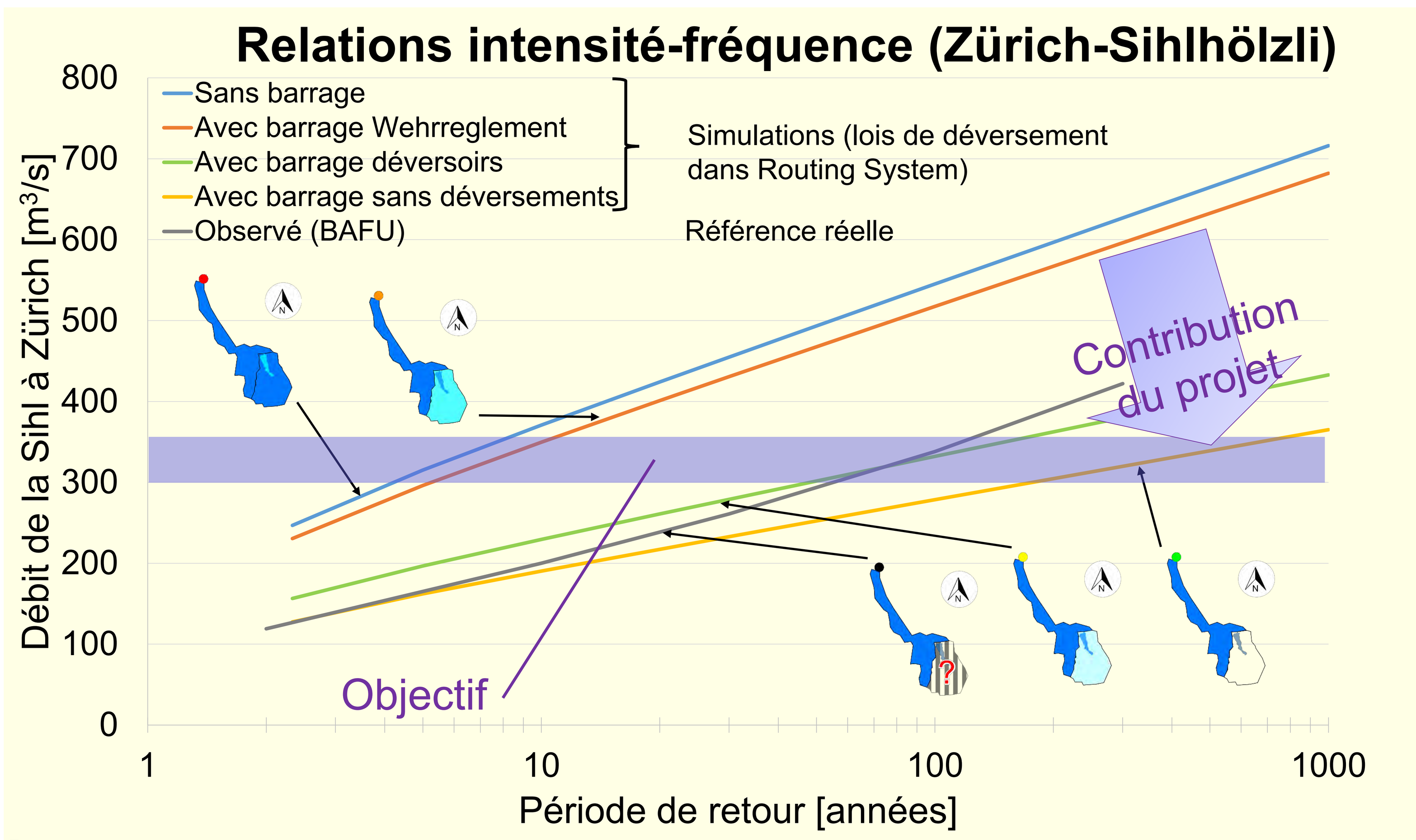
Dimensionnement au niveau avant-projet du réaménagement Etzelwerk (*Kombilösung Energie*), avec les objectifs suivants:

- ✓ Protection de la ville de Zürich contre les crues de la Sihl: réduction des débits à des valeurs comprises entre 300 et 360 m^3/s.
- ✓ Production d'électricité par pompage-turbinage (pour réseaux CFF et 50 Hz).

→ *Contexte du réaménagement Etzelwerk*

2. Étude hydrologique

Une étude hydrologique du bassin versant de la Sihl a été réalisée en partenariat avec le bureau e-dric.ch afin de déterminer le débit équipé du réaménagement Etzelwerk qui satisfait à la protection contre les crues de la ville de Zürich. Le logiciel de modélisation hydrologique-hydraulique Routing System a été utilisé.



↳ *Contribution du projet à la réduction des débits de crue à Zürich. L'intensité de couleur des cartes indique la contribution relative du bassin versant du lac de la Sihl au débit.*

3. Avant-projet

Pour le débit équipé de 147 m^3/s (puissance de 600 MW) retenu suite à l'étude hydrologique, le système hydraulique a été dimensionné en recherchant le diamètre économique sur la durée de service de l'ouvrage. Un système de by-pass permettrait d'assurer la dérivation des eaux vers le lac de Zürich même en cas de panne des lignes de transmission.

Au vu de la géologie de qualité moyenne à faible, l'avancement pour les galeries principales se fera au tunnelier, le revêtement définitif est réalisé par bétonnage à l'intérieur des voussoirs posés par le tunnelier.

Au final, un planning prévisionnel des travaux a été proposé et les coûts de construction ont été calculés.

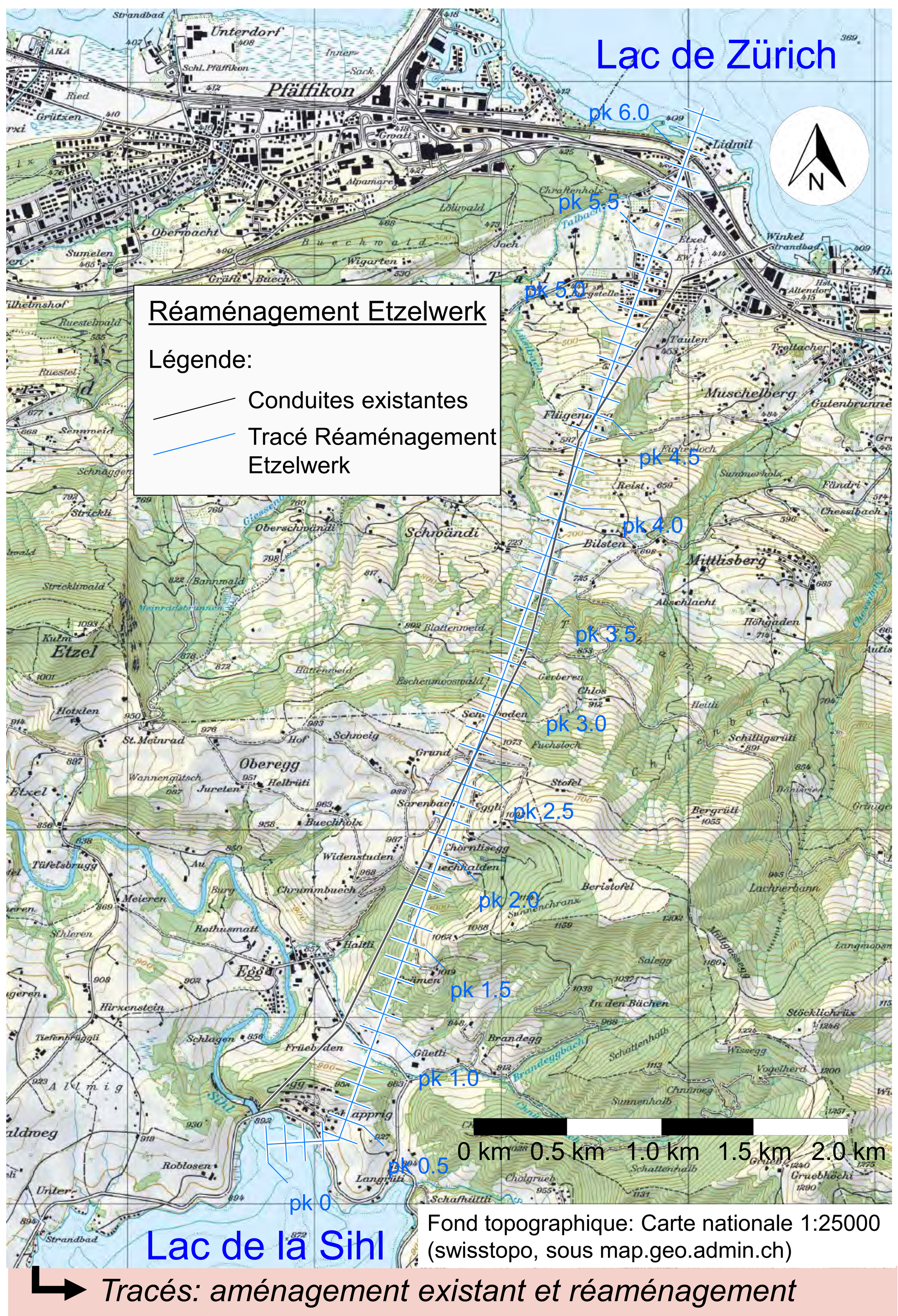
Une étude de sensibilité du marnage du lac de la Sihl en fonction du mode d'exploitation a également été menée.

↳ *Vue de la région avec le réaménagement proposé*

4. Analyse économique et conclusions

Les coûts ainsi que les revenus (production) et bienfaits (protection contre les crues) du projet ont été évalués et le calcul de rentabilité est effectué selon la méthode des flux monétaires actualisés (*discounted cash-flow analysis*). Le montant d'un projet concurrent de protection contre les crues à Zürich (galerie de dérivation à Langnau, *Entlastungsstollen Langnau*) a été considéré comme investissement possible dans le réaménagement Etzelwerk.

Les prix de l'électricité de 2012 ont été utilisés dans l'évaluation. Sous cette hypothèse, la rentabilité du réaménagement Etzelwerk à 600 MW proposé n'est pas acquise. Cependant, en considérant l'augmentation des prix de l'électricité lorsque les fortes subventions du solaire et de l'éolien en Europe seront réduites ainsi que la vente de puissance garantie (dont le prix est supérieur au prix du marché), le projet deviendrait sans doute rentable.



↳ *Tracés: aménagement existant et réaménagement proposé*

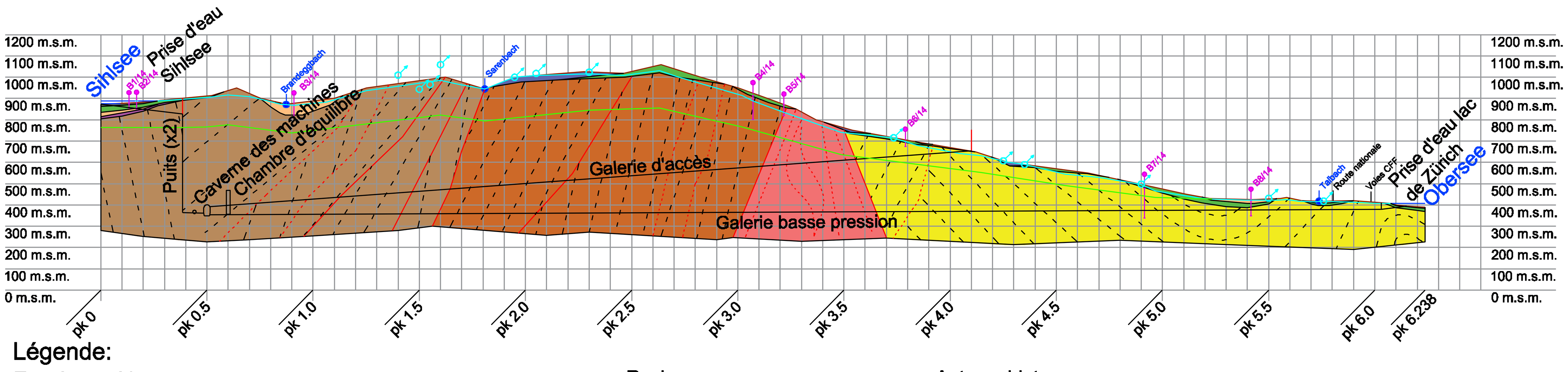
5. Caractéristiques techniques

Bassins versants et lac de la Sihl

- ✓ Bassin versant de la Sihl à Zürich (Sihlhölzli): 343 km^2 (100%)
- ✓ Bassin versant du lac de la Sihl: 157 km^2 (46%)
- ✓ Volume exploitable du lac de la Sihl: 21 millions de m^3 (1er juin au 30 octobre), 92 millions de m^3 (reste de l'année)
- ✓ Niveau normal du lac (max./min.): 889.34 m.s.m./ 876.74 m.s.m.

Réaménagement Etzelwerk proposé

- ✓ Débit équipé: 147 m^3/s (turbinage) / 123 m^3/s (pompage)
- ✓ Chute brute: 483 m
- ✓ Puissance installée: 4 x 150 MW (pompes-turbines Francis)
- ✓ Réduction de la crue Q_{500} à Zürich: de 630 m^3/s à 340 m^3/s
- ✓ Réduction du risque des crues à Zürich: de 16.5 millions (Oplatka, 2013) à 0.4 millions de francs par année.
- ✓ Production annuelle nette estimée: 261 GWh
- ✓ Coût de construction estimé: 570 millions de francs
- ✓ Durée des travaux estimée: 6 années



↳ *Profil en long du réaménagement proposé et géologie en place*

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Hydropower Design under Uncertainties

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1. Introduction

The design of hydropower plants is determined by long-term forecasts (on hydrology, on energy prices, on financial charges, a.s.o). These forecasts are highly uncertain and are one of the sources of major risk for hydropower projects. The traditional engineering task is to optimize the hydropower plant so that it meets the forecasted scenario. The engineering and economic approaches that underlie virtually all water planning **assume that the hydrological processes and market processes are stationary**, even if it is well known that these processes can change. None of these are static and a forecast is highly complex and contains many uncertainties. Additional uncertainties may also stem from interpretation of incomplete data. An aberration of the effective values from the forecasts can highly affect the success of a project.

Numerous hydropower projects exist where the forecasts were not matching the effective values and finally the plants did not reach the expected performance. Consequently, hydropower is strongly affected by risks and makes many developers sceptical against hydropower. It is a major reason why some hydropower projects are not constructed and cannot contribute to sustainable energy supply. Despite the high risks taking over on hydropower projects, surprisingly **little systematic knowledge exists about the incorporation of risk management into the design of hydropower plants**. Furthermore, the increasing proportion of private investors for hydropower projects reinforces the trend towards control or limitation of risks when making investment choices.

Our research project focus on both large and small hydropower plants, since they share similar sources of risk such as energy production and construction costs. In recent years **small hydropower has been identified as a major source of renewable energy in Switzerland and is expected to provide a significant contribution to achieving the targets of the Energy Strategy 2050**. Because of the undefined risk and high priority of small hydropower as renewable energy source, the risk of this projects are explicitly addressed in this research project.

2. Methods

Assessment of Uncertainties

In this work uncertainty refers to **upside and downside risks**. Consequently uncertainty can be also an opportunity to increase the project performance (upside risk). The focus of the research work is on uncertainties which are arising from long-term, highly uncertain forecasts, and which can significantly affect the performance of a hydropower plant. Two different approaches to assess and describe uncertainties are applied.

For a general, evidence-based risk analysis of hydropower plants the "**Outside View"** has been selected (Figure 1). Input for the economic model, namely energy production, electricity price and construction costs are analysed. A dataset of small hydropower projects with Feed-in Tariffs in Switzerland have been elaborated and the assessment of uncertainties have been carried out. In a next step the approach will be extended to large hydropower projects in Switzerland.

Another approach is to work through the entire model cascade from "**Bottom-up**" and finally to provide an estimation of the uncertainty of the performance parameters. This approach will be applied for selected case studies.

Probabilistic Evaluation

To evaluate the performance of a hydropower projects the criteria of Expected Net Present Value (ENPV), Value at Gain (VaG) and Value at Risk (VaR), instead of the Net Present Value applied (NPV) in the current practice of hydropower engineering, are applied.

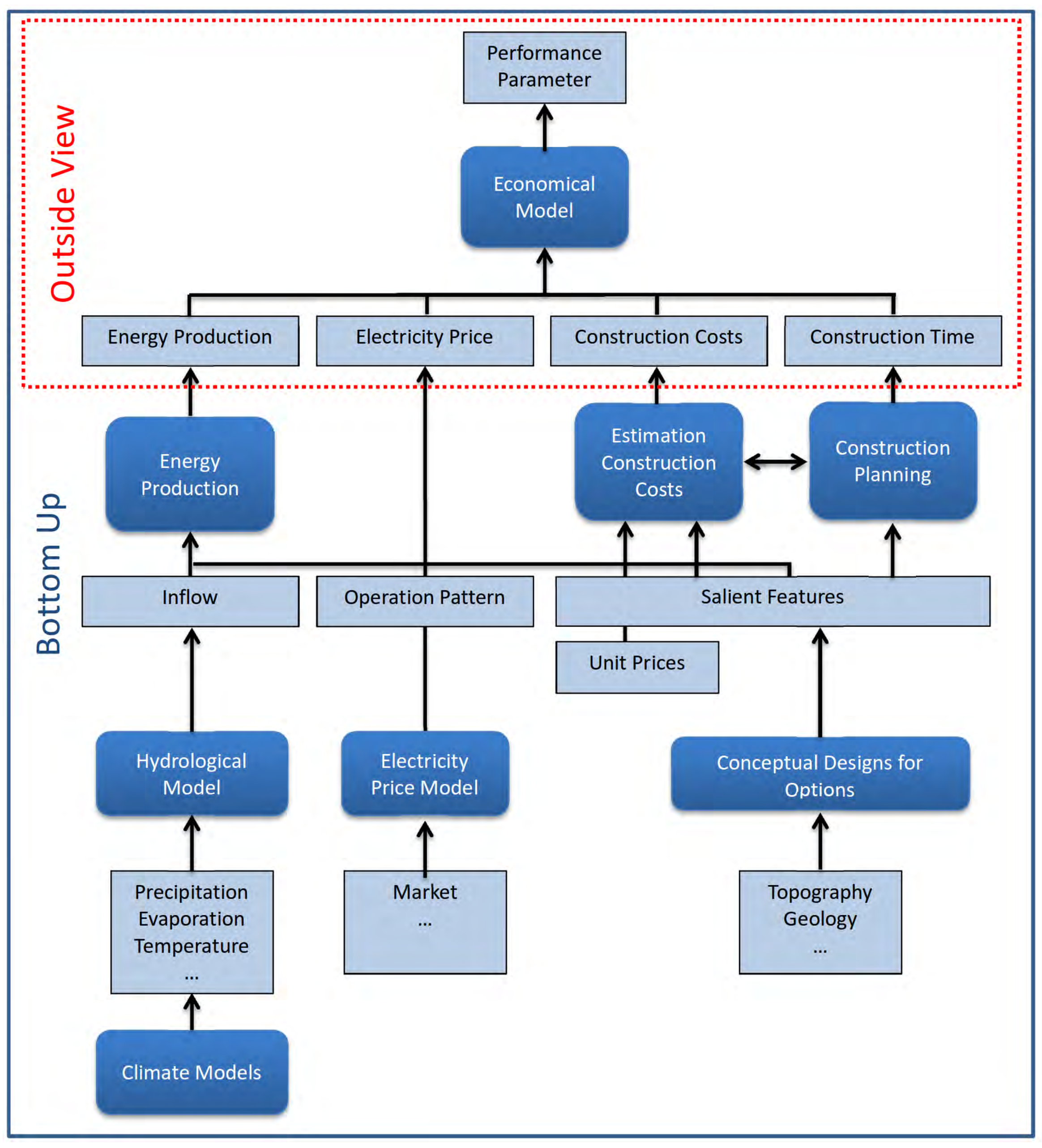

Figure 1 – Hydropower project design approaches

A three-step procedure to evaluate a design alternative is proposed:

1. Elaboration of probability functions for uncertain parameters based on historical data;
2. Monte Carlo Simulations to generate a set of input data for the economic model;
3. Evaluation under the criteria of ENPV, VaR and VaG. An example of the results of an analysed case is shown in Figure 2 below.

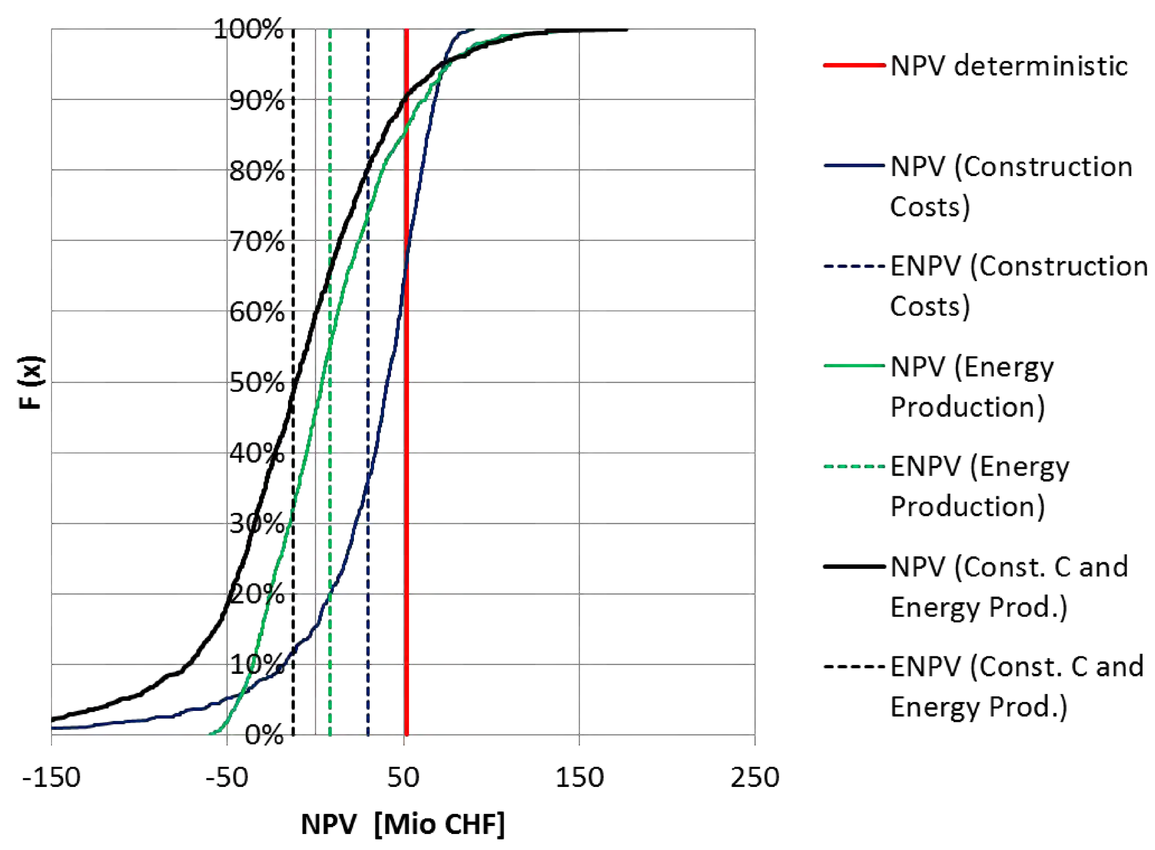

Figure 2 – Economical assessment using probabilistic evaluation as compared to a conventional deterministic approach

Design Methods

Real Option Analysis and Robust Design are incorporated into the engineering design process. The approaches will be adjusted for hydropower projects, analysed and compared to identify the best approach for specific uncertainties, conditions and design phases. The findings will be used to elaborate a planning framework which allows a preparation of a project specific strategy to manage uncertainties.

3. Conclusions and Outlook

- "Outside View" is a promising approach for a general evidence-based risk analysis of hydropower plants;
- Expected Net Present Value, Value at Gain and Value at Risk provide a more comprehensive picture about the pros and cons of design alternatives;
- Real Option Analysis and Robust Design can be applied to manage uncertainties of hydropower project.

With this research project we make important steps towards a better understanding of the application of innovative design approaches for management of uncertainty in the hydropower sector. We expect a substantial improvement of the traditional engineering approach for optimization and designing of new hydropower projects as well as for reconstruction projects.

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Characterisation of hydraulic behavior of surge tanks orifices

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1. Introduction

Hydroelectric plants have produced almost 60% of the total electricity production since 2000 in Switzerland. The Swiss storage power plants produced almost one third of the total production [SFOE, 2014]. Furthermore, this type of plants, and specifically high head power plants (Figure 1), are useful to follow cyclic peak demands (daily, weekly and seasonal) as they can provide large amount of electricity in a short lap of time. As new individual sources (solar and wind) have appeared, owners and producers may consider an increase of the peak generation of these plants.

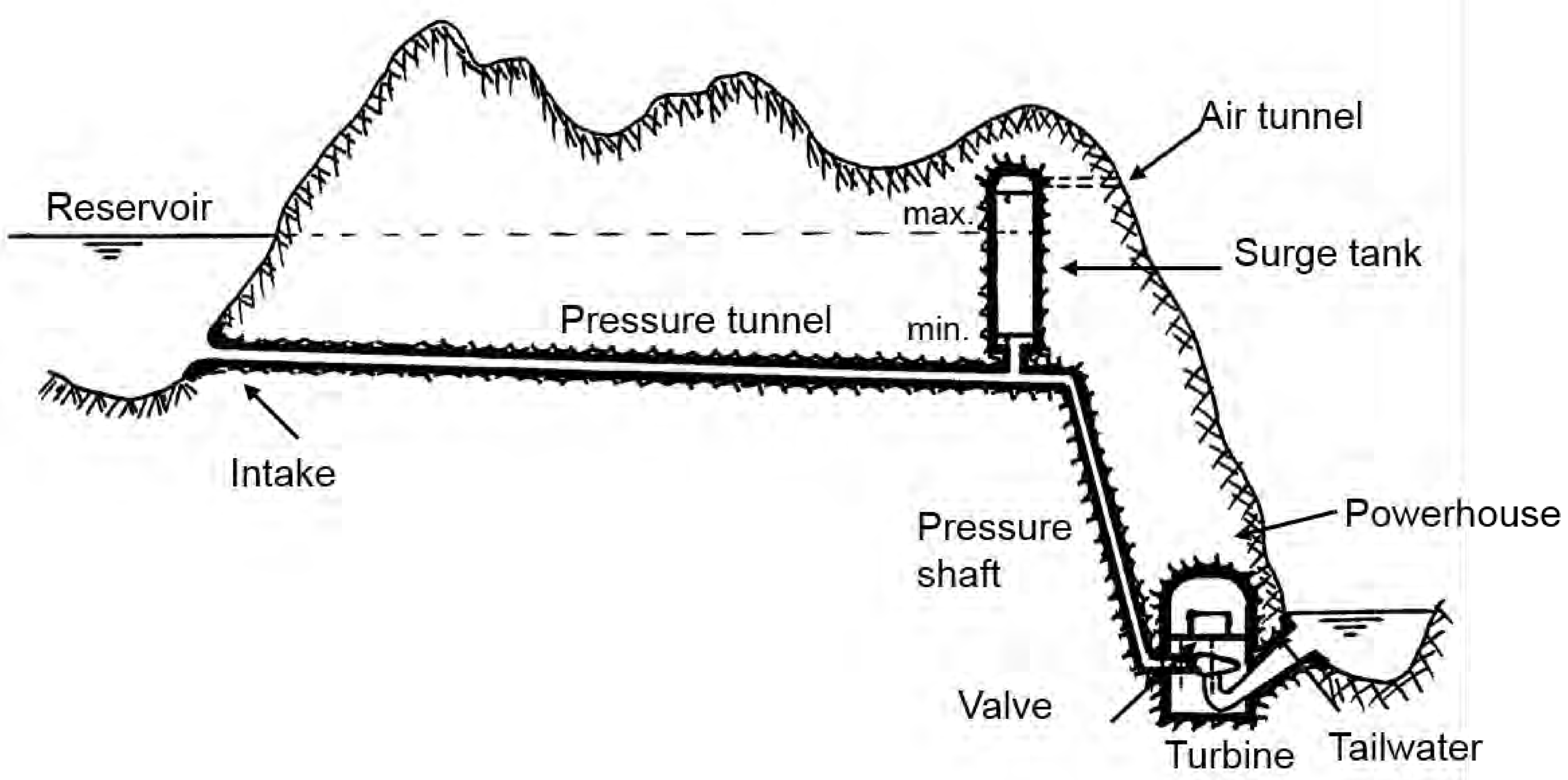

Figure 1 : Schematic view of a typical alpin high head power plant (H>200m) [Schleiss,2002]

Generally, an increasing of power capacity requires modifications to insure safe transient behaviors of the plant. Thus, the surge tank, which controls and damps discharge changes in the system, has to be modified. A simple and economical way to satisfy this safely behaviors is to place an orifice at the entrance of the surge tank. It ensures that pressures in the system remains acceptable when the time of closure or opening of downstream discharge controls is equivalent.

2. Objectives and methods

An orifice placement at the entrance of the surge tank needs usually iterative designs on physical scaled models in laboratory. The most challenging point is often the asymmetric head losses that orifices should produce. **This research aims to provides a catalogue of diaphragm head losses to decrease the number of iterations of physical studies by improving orifice draft designs**. For example, with target losses in both flow directions given by a first 1-D transient analysis, practical engineers should identify right orifice shape and geometry.

Both physical and numerical models are used to scan the largest possible head loss range in each directions. Two orifice shapes have been chosen to achieve this goal : the ASME (American Society of Mechanical Engineers) standard shape and an elliptical shape (Figure 2). Elliptical shape was found to be as close as possible to the relative ASME standard shape.
In this way, we are able to highlight the influence of the shape, orifice combinations on head loss coefficients and risk of cavitation to create the final catalogue.

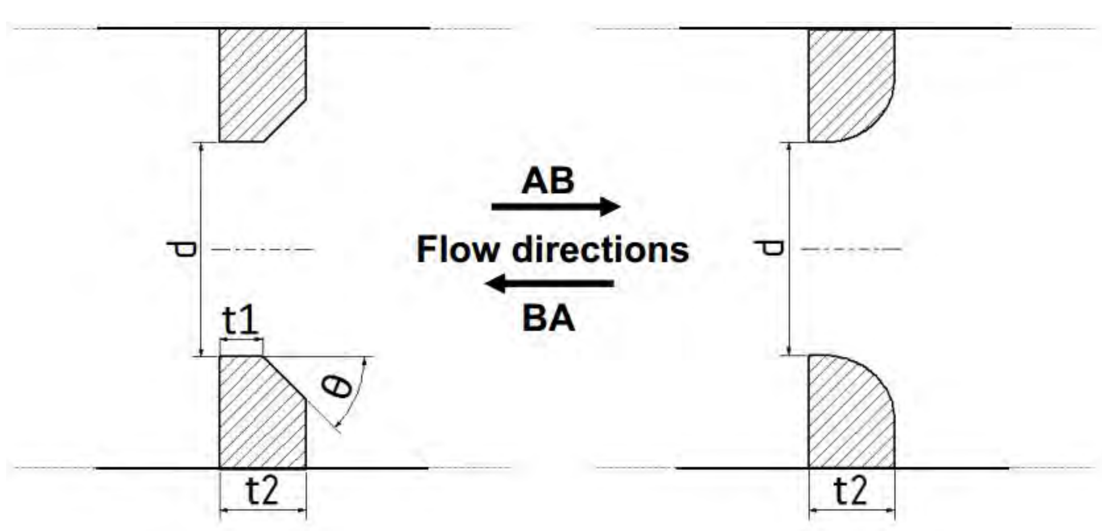

Figure 2 : Orifice cross-sections : ASME standard shape (left) and relative elliptical shape (right)

3. Experimental set-up

Both numerical and physical experiments have been undertaken at the LCH. The first tested set is the ASME-standard orifices. The experimental set-up is installed in the LCH laboratory in EPFL (Figure 3). The experimental set-up is equipped with 4-points pressure taps along the pipe to evaluate head losses and risk of cavitation and 1-point pressure taps along the pipe to evaluate natural frequency of the oscillating jet produced by the orifice (if it exists).

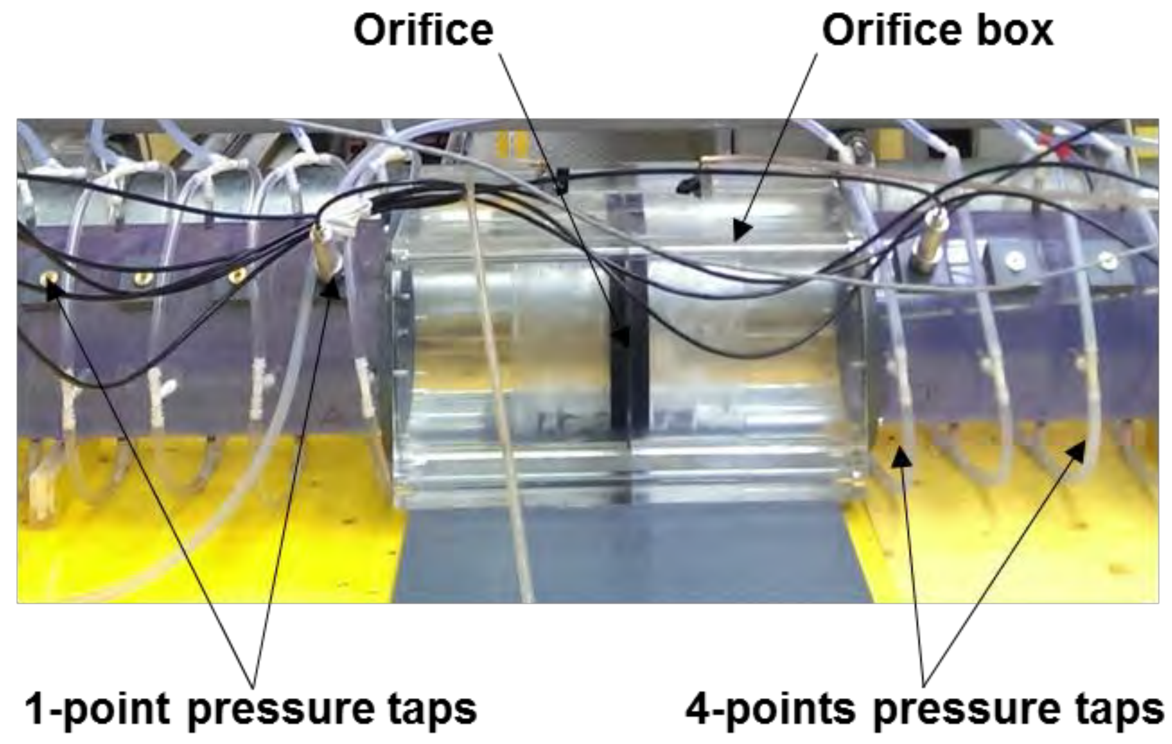

Figure 3 : View of the experimental set-up at LCH

4. Results

First numerical results investigated the influence of the θ-angle on the head loss coefficient (Figure 4, left). A comparison was carried out between the numerical and experimental results for the square-edged orifice.

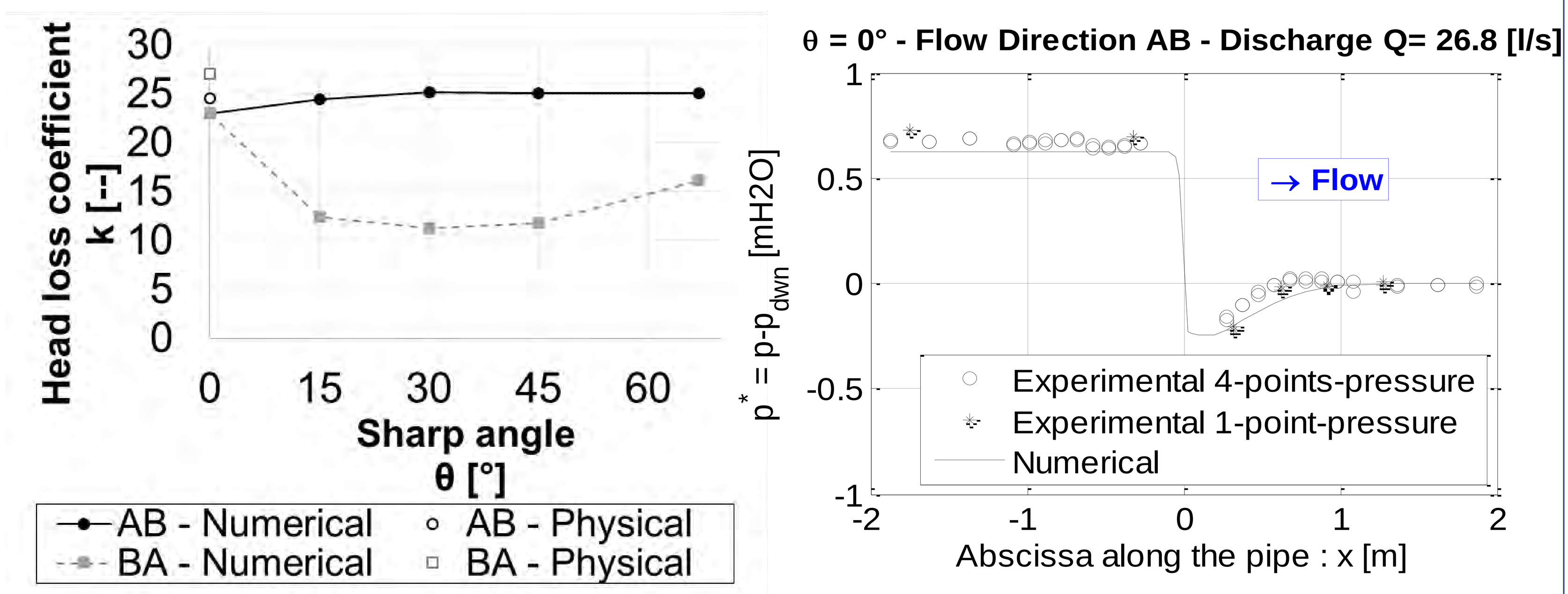

Figure 4 : Influence of the angle on the head loss coefficients (left) and a comparison between numerical and experimental results for square-edged orifice (right)

4. Conclusions and outlooks

This research focuses on the effect produced by an orifice placement and influencing parameters. Both numerical and experimental model are used to study these effects, i.e. head loss coefficient, risk of cavitation and oscillation frequencies.

Both numerical and physical experiments show that an angle placement in an orifice allows to have asymmetrical head losses with almost a 50-percent reduction with regard to flow direction. So far, there are still small differences between physical and numerical models which have to be studied.

Partners

The numerical models was built and performed in collaboration with the “Institut Systèmes Industriels (Hydroélectricité)” of the HES-SO Valais/Wallis.The first part of the research was financed by “The Ark: promoting innovation in Valais”.

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Numerical modelling of fine sediments stirring at the new Trift reservoir

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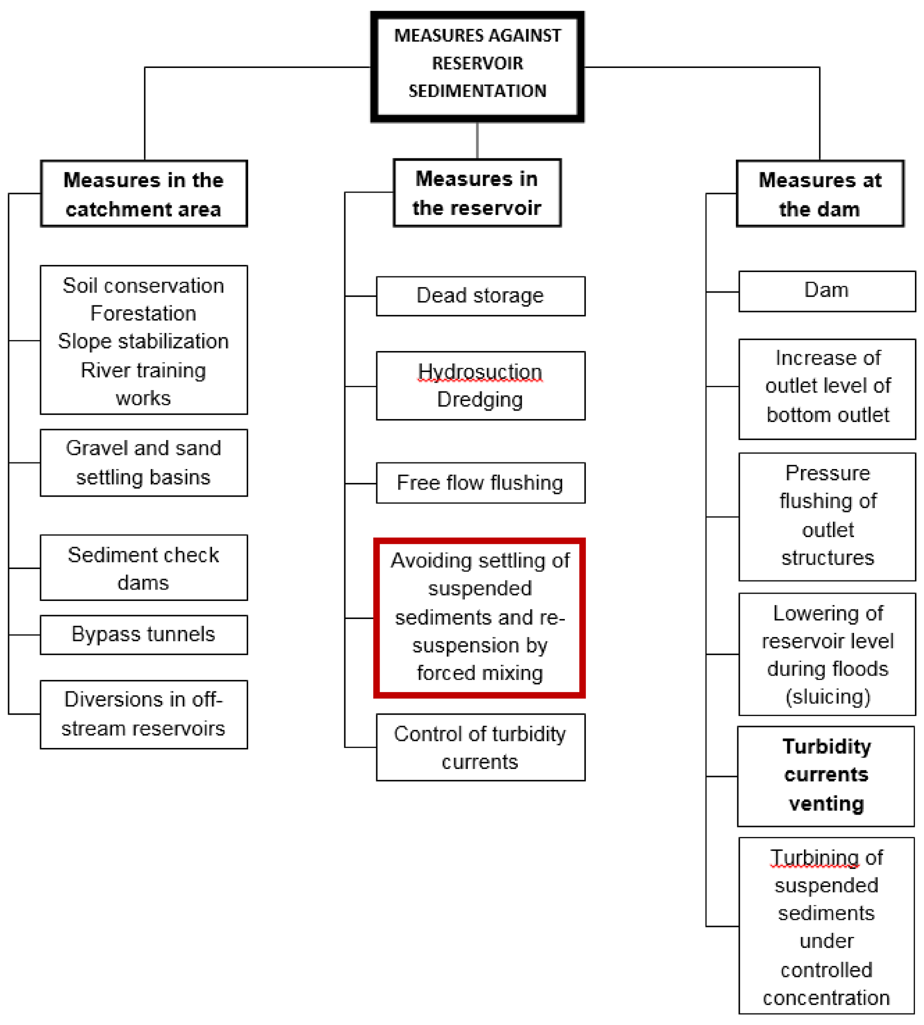
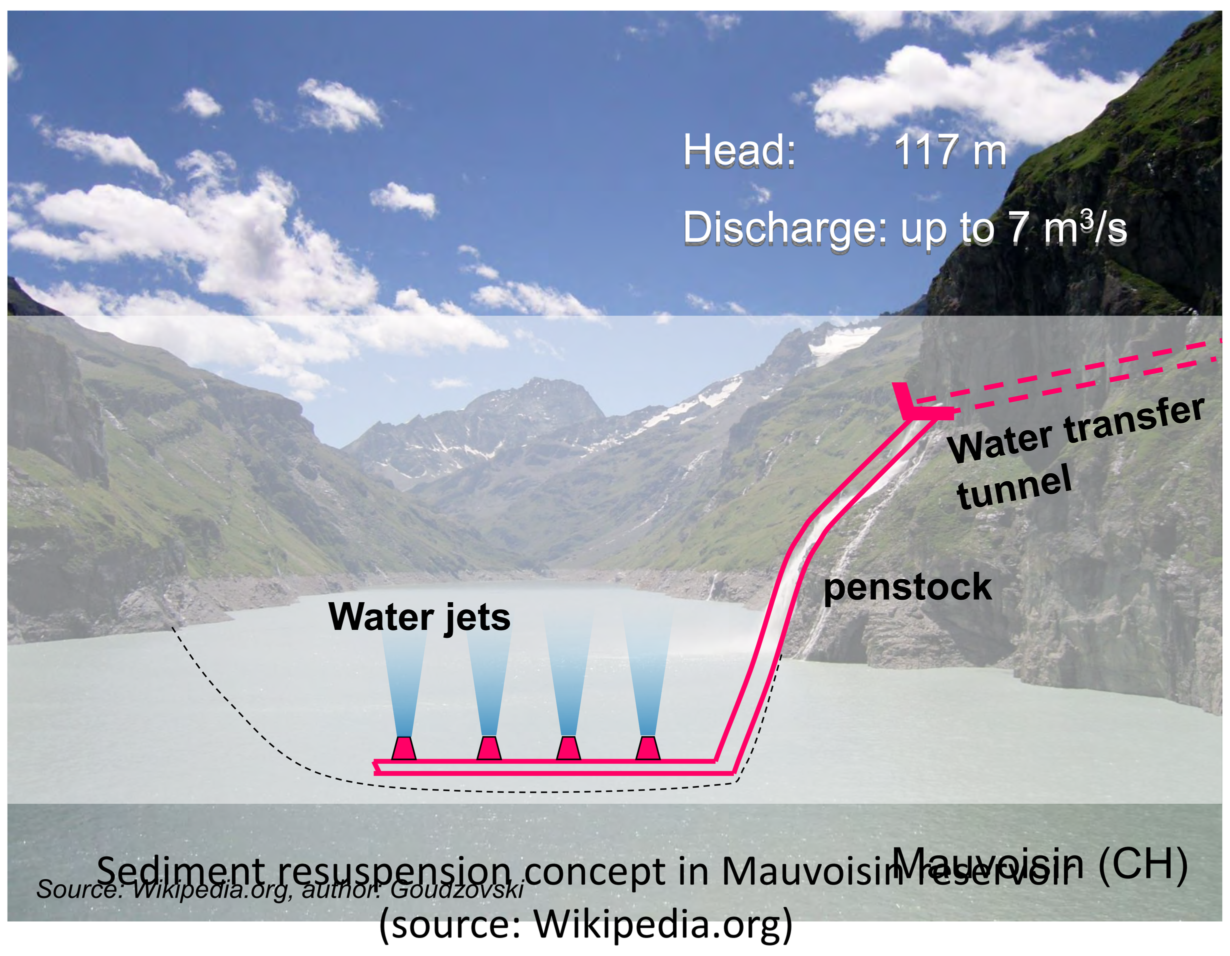
1. Introduction

As society seeks renewable energy sources with minimal environmental impact, hydropower is receiving increasing attention. 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. However, reservoir sedimentation is one of the main challenges for long-term sustainable operation of dam reservoirs [1]. Settling of suspended sediment may reduce reservoir live storage available for hydropower production. Jenzer-Althaus (2013) has experimentally tested a suspending system for sediment deposits that could be sent downstream through outlets. This innovative system can be potentially installed in several reservoirs in Switzerland and abroad to avoid the reservoir siltation.
The present project aims to implement this system in a hydraulic numerical model of the future retaining dam of Trift.



2. Innovative concept of resuspension of fine materials

The new concept promotes sediment transport to downstream by avoiding sediment settling in the reservoir. The upward movement created by rotational flow will maintain the fine sediments in suspension in front of the water intake and consequently enhances their transfer through headrace tunnel and turbines [2].



Sediment resuspension concept in Mauvoisin reservoir
(source: Wikipedia.org)

3. Experimental model set-up and results

This new idea was experimentally tested in a rectangular laboratory tank with the following dimensions: 2 m wide, 1.5 m high and 4 m long. Two jet configurations were systematically investigated: a configuration of four jets arranged in a circle on a horizontal plane and a linear jet configuration located parallel to the front wall. The influence of the jet characteristics (nozzle diameter d_j, jet velocity v_j, jet discharge Q_j, and jet angle θ) and the geometrical configuration parameters on the sediment release was investigated.

The efficiency of the jets was examined by comparing the sediment release obtained under different conditions: once when jets were employed, once without jets. Promising results were obtained for the experiments with jets. The linear jet arrangement was found to be much less favorable in view of sediment release. The results were in the same magnitude as for the experiments without jets. The circular jet arrangement is the most optimal configuration.

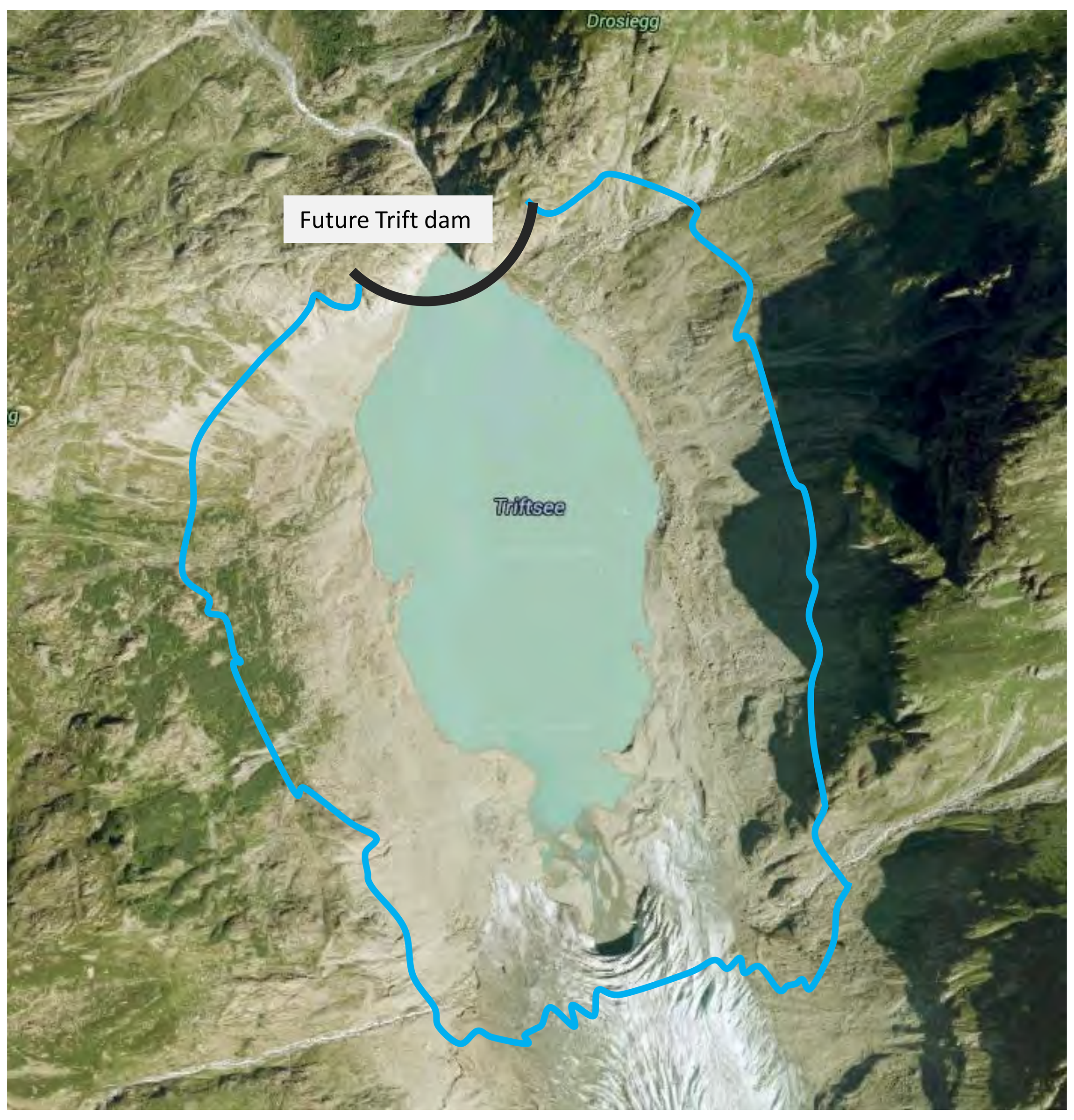
4. Numerical model of Trift reservoir

The sediment mobilization device is being implemented in a numerical model of the Trift reservoir, considering:

- Variable reservoir water levels, per season;
- Flood hydrographs with 2, 5, and 10-year return periods;
- Dam location as per present KWO project (March 2015)
- Bottom outlet and power intake location (March 2015)

The ANSY-CFX model is used for this purpose. ANSYS-CFX software is a high-performance, general purpose fluid dynamics program that has been applied to solve wide-ranging fluid flow problems for over 20 years [3].
Numerical modelling is being used to:

- ➢ Select appropriate locations for the sediment stirring device, with regards to reservoir morphology and outlets;
- ➢ Select the optimal device configuration (jet number, jet location, elevations, etc.) considering the hydrodynamic conditions in the reservoir in different operation scenarios.



Future Trift reservoir and dam

5. Outlook

Sediment stirring may allow keeping sediment in suspension in order to carry out venting manoeuvers at appropriate time slots, reducing water losses at premium hours.
Numerical modelling is being used to help selecting appropriate location and configuration for the sediment stirring device. The new Trift Dam [4] is used as a case study of new glacier lakes.

6. References

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