Task 2.3

Title

Environmental impacts of future operating conditions

Projects (presented on the following pages)

Ecological Impacts of Small-Flexible Hydropower:Macroinvertebrate Resilience to Varying Frequency Hydropeaking
Claire Aksamit, Davide Vanzo, Mauro Carolli, Nathalie Friese, Kate Mathers, Christine Weber, Martin Schmid

Sediment Flushing Downstream Dams a Study on the Clogging by Fine Sediments
Romain Dubuis, Giovanni De Cesare, Christophe Ancey

Optimizing of Coanda screen for Swiss bodies of water
Imad Lifa, Max Witek, Barbara Krummenacher, Seraina Braun

Integrated Sediment Management of Alpine Rivers
Christian Mörtl, Giovanni de Cesare

Hydropower thermal effects on the early life stages of brown trout
Kunio Takatsu, Martin Schmid, Davide Vanzo, Jakob Brodersen

Numerical modelling of river thermal heterogeneity under hydropeaking conditions
Davide Vanzo, Martin Schmid

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Ecological Impacts of Small-Flexible Hydropower:

Macroinvertebrate Resilience to Varying Frequency Hydropeaking

Claire Aksamit[1], Davide Vanzo[1], Mauro Carolli[2], Nathalie Friese[1], Kate Mathers[1], Christine Weber[1], and Martin Schmid[1]

1. Eawag: Swiss Federal Institute of Aquatic Science and Technology, Surface Waters – Research and Management 2. IGB: Leibniz-Institute of Freshwater Ecology and Inland Fisheries

Introduction

- Hydropower plants play an important role in providing a stable power network
- Switzerland is phasing out nuclear energy
- Small hydropower plants are expected to aid in compensation of this power loss, including flexible (intermittent) production from run-of-the-river schemes

Motivation

- Understand ecological impacts of a flexible hydropower schedule
  - Producing power in winter months and/or when energy demand is high (i.e., mornings and evenings)
  - Use of settling basin as water storage
  - More frequent fluctuations of water flow (hydropeaking)
  - Run as run-of-the river in summer months
- Abrupt changes from hydropeaking can negatively impact aquatic habitats, organisms, and river ecosystem processes (e.g., Tonolla et al. 2017)

Context

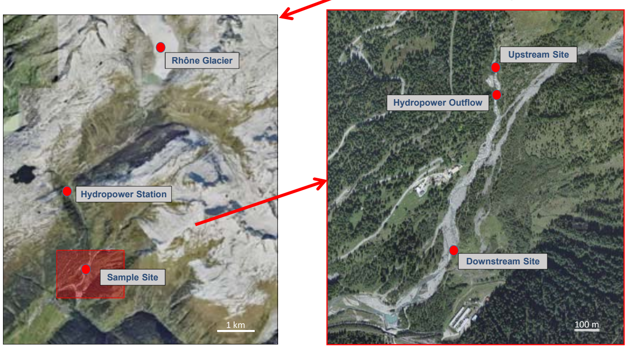
- Impacts of small run-of-the-river schemes on **natural flow regimes** are **poorly understood**
- **Drift** is a key aspect of macroinvertebrate population dynamics in rivers
- **Macroinvertebrate drift is** commonly used for assessing hydropeaking impacts
- Field measurements were performed in an alpine stream at a **small hydropower plant without previous hydropeaking**
- Study is part of the **SmallFLEX** project

Research Question

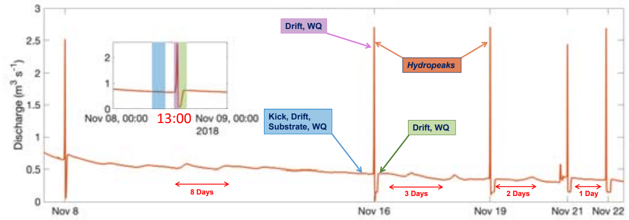
How does a varying hydropeak frequency affect drifting macroinvertebrates in a small alpine river in winter?

Experiment Site

- Canton of Valais
- Upper Rhône River (1377 m a.s.l)
- Unregulated until 2018



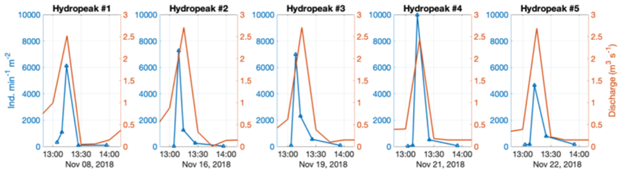
Methods

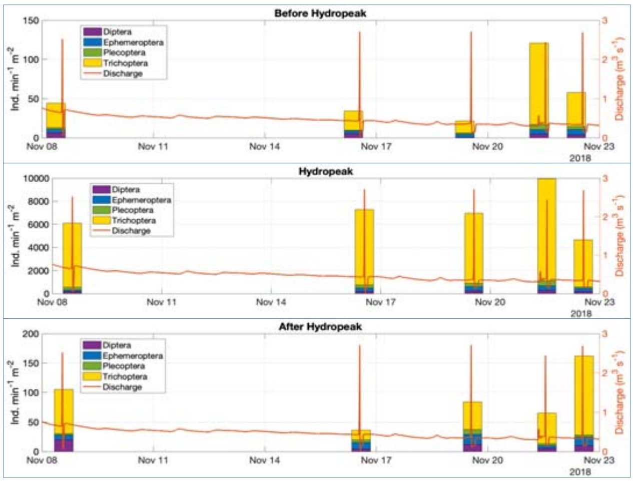


- Five hydropeaks with decreasing recovery intervals in between
- Sampling locations upstream and downstream of the outflow
- Two habitats (riffle and pool) with three drift nets per habitat
- Measured: Invertebrate drift, benthos (kick sample), temperature, water quality (WQ), substrate composition, and velocity

Preliminary Results

Riffle Habitat – Net 3, Density of drifting invertebrates





Outlook & Status

Initial Findings: In a realworld setting, **hydropeak frequency, duration,** and **environmental variables** are all important drivers of macroinvertebrates drift.

Other Initial Findings
Composition of drifting communities was different during hydropeaks compared to before and after hydropeaks

To Be Completed
Contrast of riffle and pool habitats
Validate and confirm factors driving different behaviour on Nov 21 and Nov 22

Future Contributions
Help inform hydropower strategies for the Swiss Energy Strategy 2050 that minimize ecological damage while still meeting societal energy demand

References

Tonolla D, Bruder A, Schweizer S. 2017. Evaluation of mitigation measures to reduce hydropeaking impacts on river ecosystems – a case study from the Swiss Alps. Science of The Total Environment **574**: 594-604.
Site Maps: Federal Office of Topography swisstopo: map.geo.admin.ch

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eawag aquatic research

SEDIMENT **FLUSHING** DOWNSTREAM DAMS
A STUDY ON THE **CLOGGING** BY **FINE SEDIMENTS**

A sub-project of : Wasserbau & Ökologie
hydraulic engineering & ecology

Romain Dubuis, Dr. Giovanni De Cesare, Prof. Christophe Ancey
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Plateforme de construction hydraulique, EPFL

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Uffizi federal d'ambient UFAM

PLATEFORME DE CONSTRUCTIONS HYDRAULIQUES

Introduction

Water reservoirs used to produce electricity have an impact on the environment and durability by :
- stopping the natural sediment flux
- changing the flow regime downstream of the reservoirs
- storing (fine) sediments that reduce the storage volume

Those 3 issues have been leading to the development of strategies in order to improve the equilibrium of the ecosystem downstream such structures, with solution such as sediment flushing and simple water flushing reproducing flood events.

Those operations produce excessive sediment inflow on certain river sections, which can lead to the clogging of the gravel bed. River construction work, soil erosion, emergency actions and natural river bank erosion can also bring similar problematic.

For example, a dramatic event happened in 2013 on the Spöl River in Eastern Switzerland. Due to some operations on a Punt dal Gall dam, important amounts

Fig. 1 : Clogged bed of the Spöl river after the release of fine sediments, from De Cesare, G et al. 2015 (1)

Fig. 2 : River-bed at the same location as fig. 1 after the clean water flushing, from De Cesare, G et al. 2015 (1)

of fine sediments were flushed downstream the reservoir and resulted in significant damages to the river ecosystem[1]. A strong clogging of the river bed was noted (see fig. 1). A clean water flushing a few months later led to a cleaning of the clogged areas (fig 2.).

Clogging and hyporheic layer

The hyporheic layer represent the interface between groundwater and surface flow, and play an important role in the vertical connectivity of rivers. It is also a decisive zone for the life and reproduction of aquatic fauna. Many studies[2] concluded on the impact of clogging by fine sediments on the development of fish spawns and benthos. In order to understand the clogging of rivers, numerous on-field, flume and numerical experiments were undertaken in the last 50 years[3].

However, the influence of factors such as up- and downwelling (exchange with the groundwater) and the self-cleaning process remain hard to quantify and poorly documented. A better understanding of the physical processes and influences of the different parameters is needed in order to assess new solutions to prevent the damaging of river bed ecosystems.

Thesis research goals

Degree of clogging of benthic habitats and fish spawns depending on:
- bed composition
- size and distribution of suspended fine sediments
- flow conditions (surficial and interstitial)

Capacity of the surface flow to reduce the fine sediment suspension under the various conditions

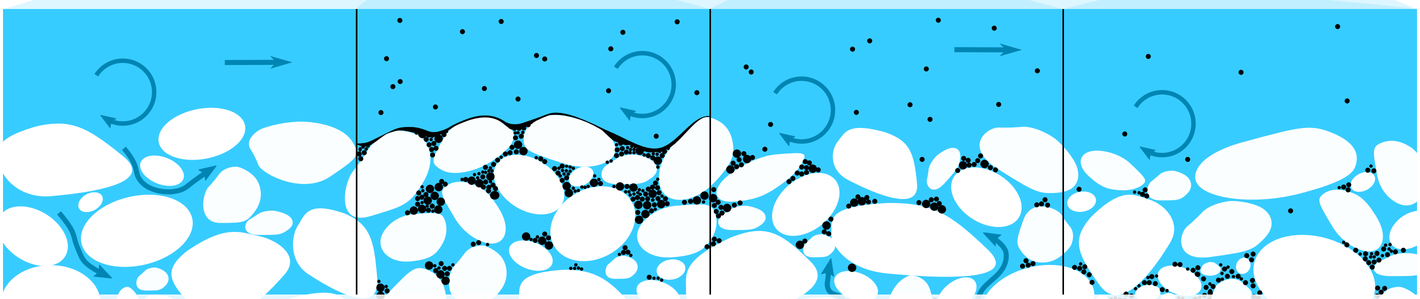
Consequence of clogging on the river-bed and flood plain permeability, considering case studies.

Flume experiments with gravel composition based on river-bed size distributions

Analysis of vertical flux using PIV-RIMS technology and spatial development of clogging

Influence of **upwelling** and **downwelling** on the clogging, induced by the gradient between surface flow and groundwater. Main concern regarding the transport of:
- oxygen
- nutrients
- water temperature
- removal of metabolic wastes

Conditions needed for a **self-cleaning** of clogged fine sediment under different flow conditions - effectiveness of the process (depth of cleaning)



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2. For example : Boulton, A., Findlay, S., Marmonier, P., Stanley, E., Valett, M., (1998) The functional significance of the hyporheic zone in streams and rivers. Annu Rev Ecol Syst 1998, 29:59–81.
3. A good summary of the general state of the research can be found in : Wharton, G., Mohajeri, S. H., & Righetti, M. (2017). The pernicious problem of streambed colmation: A multi-disciplinary reflection on the mechanisms, causes, impacts, and management challenges. Wiley Interdisciplinary Reviews: Water, 4, e1231.

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Optimizing of Coanda screen for Swiss bodies of water

Imad Lifa, Max Witek, Barbara Krummenacher, Seraina Braun (HTW Chur, Switzerland)

Motivation

Coanda screens help to clean mountain water for turbines in hydropower plants. There are problems with the abrasion of their sharp-edged profiles, so that the screens often have to be replaced, or have limited swallowing ability. Isolated scientific studies on Coanda screens can be found in the literature. However, comprehensive hydraulic investigations under natural boundary conditions do not exist.

Methods

We constructed a 1:1 scale model at the VAW (Versuchsanstalt für Wasserbau, Hydrologie und Glaziologie, ETH Zurich), where we were able to run different flow rates from 50 l/s – 300 l/s with or without debris.

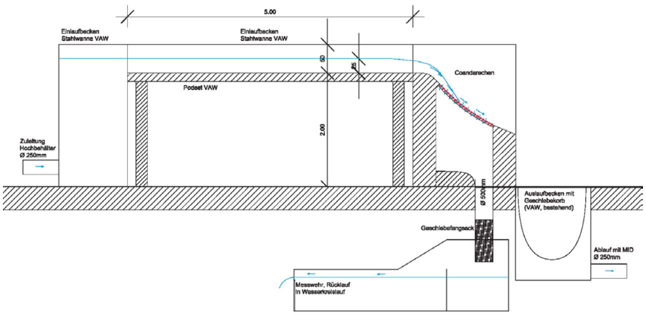

Fig. 1: longitudinal section of the model

We used in total seven screens whereas six screens were constructed by Wild Metal, Italy. They showed a gap width of 0.4 mm, 0.6 mm, 1.0 mm, 1.5 mm, 2.0 mm and 3.0 mm, respectively. The seventh screen was constructed by Höhenergie, Switzerland, and showed a gap width of 1.05mm.
In a first step, we performed clear water tests to analyse the intake capacity of each screen. In a second step, we inserted defined debris at different flow rates, both, broken material and grounded gravel. We then examined the material passing through the screen in weight and granulometry.

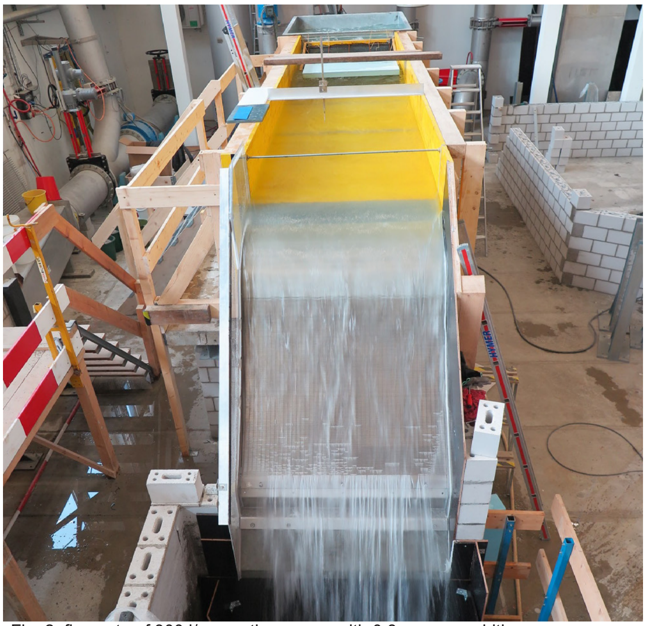

Fig. 2: flow rate of 300 l/s over the screen with 0.8 mm gap width

Results

Intake capacity
The intake capacity is high for all the tested screens. Even the maximum of 300 l/s could be swallowed by all the screens. Only the two screens with the widest gaps of 2 mm resp. 3 mm showed 1 – 2 % of overflow. Figure 3 ist showing the gravel sticking in the gaps as seen in every screen tested so far. This leads as well to lower intake capacity over time.

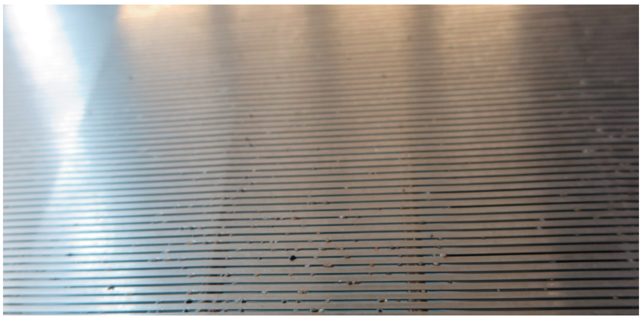

Fig. 3: screen with sticking gravel in the gaps

Rejection rate

Following the manufacturer specifications, 90 % of the debris with a size of at most 50 % of the gap width should be rejected. Our investigations showed, that only a few screens reached this aim. These are shown in the following tables 1a and 1b.

ROUNDED GRAVEL 0 - 8 MM	
gap width	rejection rate
1.5 mm	90 %
2.0 mm	97 %
3.0 mm	98 %

BROKEN MATERIAL 0 – 4 MM	
gap width	rejection rate
2.0 mm	88 %
3.0 mm	93 %

Tab. 1a and 1b: screens following the manufacturer specifications

Discussion

Following the unexpected results, we discuss the shape of the screen in general as well as the different possibilities to form the gaps between the single metal rods.
We also sealed part of the screen with tape to simulate growth of moss or glaciation.
Furthermore, we narrowed the channel above the screen to simulate flow rates above 300 l/s.

Outlook

Hydropower plants are in general competing against natural wildlife, particularly fish downstream migration. We are therefore interested in proofing or denying the fish friendliness of the Coanda screen. Therefore, we are currently working on further investigations to gain more information about the behaviour of fishes. We focus on their probable loss of scales and the mortality rate.

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Integrated Sediment Management of Alpine Rivers

Christian Mörtl, Giovanni de Cesare
Ecole Polytechnique Fédérale de Lausanne, Plateforme de Constructions Hydrauliques

Motivation

Sediment management of alpine rivers is crucial to ensure sustainable hydropower production.

Dams inhibit not only biological consistency but also drastically restrain natural sediment dynamics.
Upstream of the dam, coarse material is accumulated, leading to a progressive *sedimentation* of the reservoir. This causes a reduction in the effective water head and can even lead to the blockage of lower-lying operation organs.
Downstream of the dam, reduced flow velocities promote the settling of suspended sediments, causing the *clogging* of open pore spaces in the bed material that naturally serve as fish spawning ground. The lack of coarse sediment also provokes extended *streambank erosion* and the *channeling* of the river, leading to a less altered river morphology and reduced living space for a large biodiversity.

An integrated sediment management helps to optimize ecological, economical and social effects linked to hydropower.

State of Science

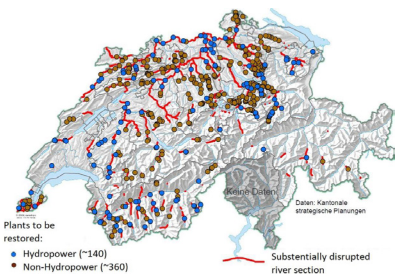
Understanding sediment dynamics of alpine rivers and its sequential effects is subject to ongoing interdisciplinary research.

Field studies quantify the effects of *reservoir flushing* combined with *sediment replenishment* on short-term morphologic [1] and ecologic changes [2].
Laboratory experiments provide insights on optimization potential for *replenishment techniques* [3] as well as reference for *sediment transport theories* [4].
Computational Models deliver *predictions of altered sediment dynamics* based on high-level numerical [5], morphodynamical [6] or statistical modelling [7].

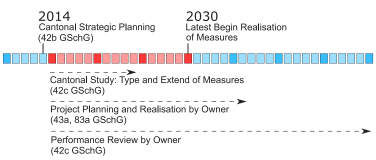
Due to the complexity and variability of alpine rivers, research is generally performed based on specific study conditions.

Practical Application in Switzerland

In Switzerland, about 140 hydropower and 360 non-hydropower plants have been identified to require remediation.



The procedure and responsibilities are regulated by the Swiss Water Protection Law (GSchG).



This project is part of a PhD Thesis on the **Eco-Morphological Assessment of Sediment Replenishment** (E.ASSERT).

It is conducted in the framework of the research program **Hydraulic Engineering and Ecology** from a joint initiative of the Swiss Federal Office for the Environment (BAFU) and four research institutions:

- Swiss Federal Institute of Aquatic Science and Technology (Eawag)
- Swiss Federal Institute of Forest, Snow and Landscape (WSL)
- Platform of Hydraulic Constructions (PL-LCH) of the EPFL
- Laboratory of Hydraulics, Hydrology and Glaciology (VAW) of the ETH

The objectives are to outline the state of science and practical applications of **Integrated Sediment Management of Alpine Rivers** in Switzerland and to identify key research questions for future investigation.

The approach is based on comprehensive literature research, contact of officials and the analysis of the latest national statics.

A comprised source of information on integrated sediment management will outline its importance for sustainable hydropower production. It can deliver key aspects for strategic decision making in the framework of the **Energy Strategy 2050.**

Research Gaps

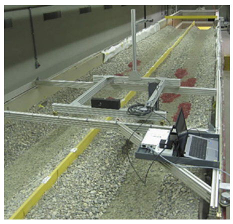
The following research questions are addressed:

- Influence of hydrographs and duration of artificial floods on alternating gravel banks
- Durability of gravel banks with regard to natural flood events
- River morphological structures formed by debris from different water morphologies
- Influence of bedload cover on sole stability in channel widenings
- Characterization of the ecological value of the resulting habitat structures

Artificial Flooding at the Sarine underneath the Rossens Dam [8]

Ongoing Field-Work at the Sarine River

Scheduled Laboratory Work at the EPFL PL-LCH



Experimental channel with sediment replenishment in the PL-LCH [3]

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Hydropower thermal effects on the early life stages of brown trout

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† Contacts: Kunio Takatsu (kunio.takatsu@eawag.ch)

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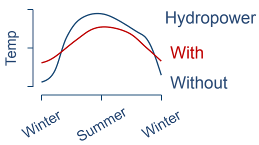
1. Research background

Hydropower induced temperature change

In general, hydropower plants cause water temperatures to decrease during summer and increase during winter.

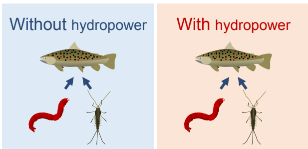
Wüest (2010) *Downstream Relevance of Reservoir Management. In: Bundi (eds) Alpine water*



Riverine organism; ectotherms

e.g., Fish, aquatic invertebrate…

Riverine ecosystem is probably sensitive to the hydropower thermal alterations



2. Motivation

Energy strategy 2050 of Swiss government: Increase hydropower production

Our knowledge of how hydropower plants may thermally affect river communities is still limited

3. Objective

Study organism: **brown trout**…

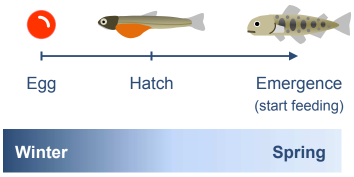
- ecologically and commercially important species

To examine how hydropower thermal alterations affect the early life stages of brown trout

Early life stages

- Most vulnerable life stage
- Play a key role in shaping population dynamics

Einum et al. (2000) *Evolution*
Skoglund et al. (2012) *Funct Ecol*



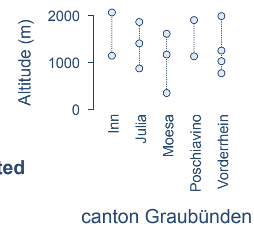
- Hydropower increases temperature during early life stages

4. Methods

- **Egg collection**

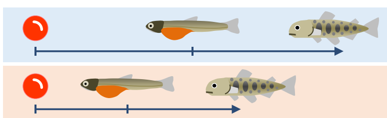
We collected eggs from 14 sites from 5 drainages (altitude 343 – 2073 m)

Each local population might be adapted to each local environment



- **Laboratory experiment**

Eggs were divided between two temperature treatments and many traits were measured throughout the early life stage



5. Results

Statistical analysis 1

To examine how early life history traits are affected by
1. rearing temperature (thermal effects in ecological time scale)
2. altitudinal origin (thermal effects in evolutionary time scale)
3. drainage

Linear mixed model

Traits = Altitude + Treatment + Drainage
"Altitude x Treatment" + "Altitude x Drainage"
"Treatment x Drainage" + "Altitude x Treatment x Drainage"
+ Random effects (Family, Incubator)

Trait	A	T	D	A*T	A*D	T*D	A*T*D
Hatch timing		-	*			*	*
Metabolic rate	+	+					
Size at hatching	-	-				*	
Yolk sac volume	-				*		
Yolk absorption timing	-	-			*		
Size at yolk absorption	-				*		

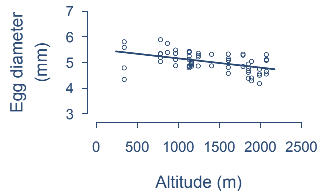
- **Increase in rearing temperature enhanced embryonic development** (probably due to increased metabolic rates)
- **Trout from high altitude (i.e., cold environment) developed faster than that from low altitude (i.e., warm environment)** (faster development might be achieved by higher metabolic rate)
- **Embryonic traits differed among drainage**

Ecological and evolutionary effects of hydropower thermal alterations could differ in direction

Statistical analysis 2

- Egg size reduced with altitude
- Egg size is a well known factor affecting early life history traits

Hutchings. (1991) *Evolution*;
Einum et al. (1999) *Proc R Soc B*



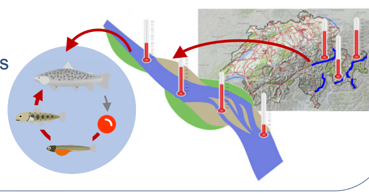
We considered egg size as explanatory variable

- Significant effects of egg size were found in almost all traits
- Except yolk sac volume, effects of altitude were no longer significant

The observed altitude effects on life history traits can be explained by the altitude-dependent egg size

6. Future research

Develop mathematical models to predict how hydropower thermal alterations affect each local population



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Numerical modelling of river thermal heterogeneity under hydropeaking conditions

Davide Vanzo[1] and Martin Schmid[1]

1. Eawag, Swiss Federal Institute of Aquatic Science and Technology, Surface Waters - Research and Management, Kastanienbaum, Switzerland

Introduction

- River water temperature is a fundamental physical property of flowing waters.
- **Alterations** of the natural thermal regime can adversely affect the river biota (e.g. Caissie 2006).
- Artificial **reservoirs** and **hydropower plants** cause thermal alterations on a broad spectrum of temporal and spatial scales (e.g. Vanzo *et al.* 2016a).
- The **modelling** and **quantification** of local thermal heterogeneity alterations is still a challenge (Carrivick *et al.* 2012).

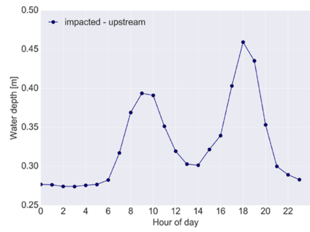
Motivation

- Further **exploitation** of hydropower (HPP) sector (Swiss Energy Strategy 2050).
- Need for scenario-based **predicting tools** of future climate-change and anthropogenic effects on river hydro- thermodynamics.

Research questions

- How is river **thermal heterogeneity** affected by hydropower production?
- Does **river morphology** play a relevant role in the thermal dynamics of hydropeaking rivers?
- Which are the **dominant heat fluxes** at different seasons under **hydropeaking** conditions?

Fig. 1 – Average water depth per hour of the day recorded at the beginning of the study reach (Moe_10_w). Hydropeaking events are concentrated in the morning (7 to 11) and in the late afternoon (16-20) .



Challenges

A tool to simulate river thermal heterogeneity under hydropeaking conditions requires several features:

- **two dimensional, unstructured** grid: to properly describe morphological feature in shallow rivers, as for Alpine and headwater streams;
- **shock-capturing** methods (e.g. Toro 2001): to ensure the proper simulation of hydro-thermal waves that propagate in the investigated reach;
- robust **wet-and-dry** and **advection-diffusion** strategy (Vanzo *et al.* 2016b): to simulate the wetting and drying and dispersion processes during hydropeaking rising and falling limbs;
- computational **efficiency** and **parallelization** strategies: to allow high-resolution thermodynamic simulations on standard workstations.

Modelling workflow

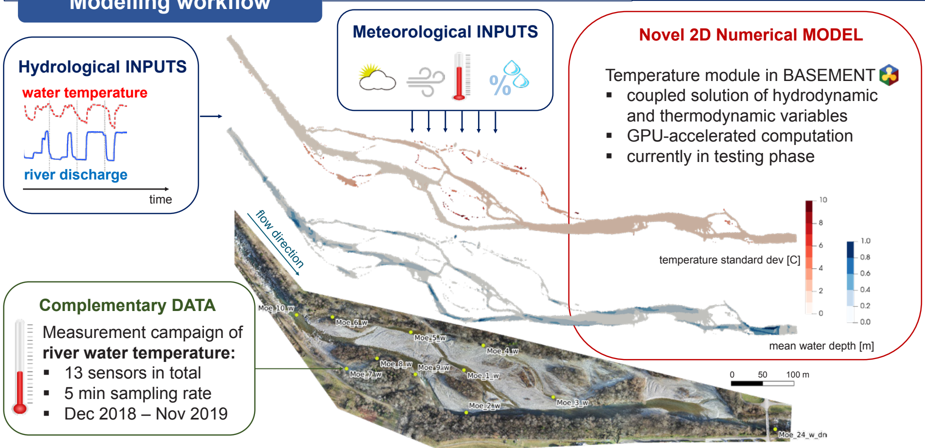
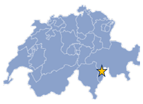


Fig. 2 – Study site in Moesa River with location of the thermal sensors.

Study case



Moesa River at Lostallo, Graubünden (CH) (Fig. 2)

- **Sharp hydraulic alterations** at sub-daily scale due to HP production (Fig. 1).
- Winter records (Dec-Jan-Feb) show differences of about 3 °C compare to unaltered water temperature, with a variability of about 0.5 °C within the floodplain (Fig. 3).
- **Magnitude** of sub-daily thermal variation (TP1, Fig. 4) lies outside the range of natural variability.

Outlook

- The full measurement campaign will allow the comparison of thermal dynamics among different seasons.
- Remote-sensing (UAV) surveys will be used to further test and calibrate the numerical model.
- Preliminary tests suggest the model is robust and can well reproduce hydro-thermopeaking events.
- After the testing phase, scenario-based simulations will be conducted.

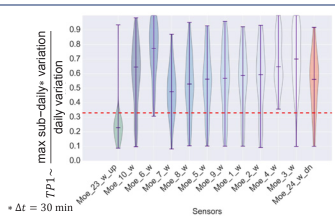
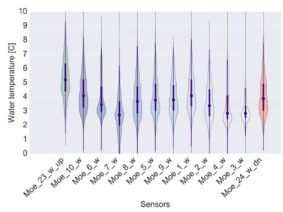


Fig. 4 – Magnitude of sub-daily* thermal alterations (TP1, Vanzo *et al.* 2016a); the red dashed line is the threshold between natural (below) and altered (above) thermal fluctuation. First and last violin represent the most upstream (before HP release) and most downstream sensor, respectively (see Fig. 2).

Fig. 3 – Winter (Dec-Jan-Feb) water temperature: first and last violin represent the most upstream (before HP release) and most downstream sensor, respectively (see Fig. 2).



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