Task 2.3

Title

Environmental impacts of future operating conditions

Projects (presented on the following pages)

Hydro-economic Consequences of Hydro-peaking Removal
Alternative: Work Package 5
L. E. Adams, P. Meier, J. Lund

Disentangling the effects of hydrology and predation on macroinvertebrate community assembly: a field experiment
P. Chanut, F. J. Burdon, T. Datry, C. T. Robinson

Evolution of a gravel-bed river subject to SBT operations
M. Facchini, A. Siviglia, R. M. Boes

Streams impacted by hydropower production through water intakes: do we need sediment flows more than minimum flows?
C. Gabbud, C. Robinson, S. Lane

Impacts of altered pumped-storage operation on water quality
U. G. Kobler, M. Schmid

Trading off energy production from small hydropower with biodiversity conservation
K. Lange, P. Meier, C. Trautwein, M. Schmid, C. T. Robinson, C. Weber, J. Brodersen

System modelling for hydro-peaking mitigation
P. Meier, M. Bieri, P. Manso, F. Zeimetz, C. Gerber, A. Mark, S. Schweizer, A. Fankhauser, B. Schwegler

Modeling macroroughness contribution to riverine ecosystem
A. Niayifar, P. Perona, J. Oldroyd, S. N. Lance, T. J. Battin

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Hydro-economic Consequences of Hydro-peaking Removal

L.E. Adams[1,2*] P. Meier[2] J. Lund[1]

[1]University of California- Davis, Department of Civil and Environmental Engineering, [2]Eawag, Swiss Federal Institute of Aquatic Science and Technology

1. Introduction

- The Swiss Water Protection Act requires that Swiss hydropower plants must mitigate any serious environmental harms of hydro-electricity by 2030 (e.g., remove hydro-peaking, or sub-daily discharge variability from peak electricity production).
- Building an after-bay or re-operating the hydropower plant system are primary options for attenuating hydro-peaking.
- Our goal is to develop a method for comparing the financial and ecological tradeoffs and required operational changes for choosing different after-bay sizes for removing hydro-peaking.

2. Methods

Two-stage linear programming **maximizes system flexibility for each of several planned after-bay sizes** and **maximizes operational benefits** for the operational changes required to compensate for any hydro-peaking not managed by the after-bay.

$$\min_{x}(\mathbf{z}) =$$

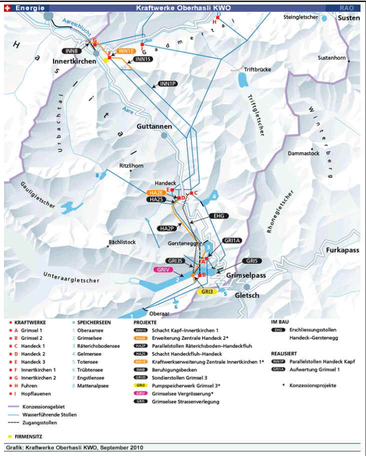
$$\sum_{n}\sum_{T}\sum_{t}\left(\frac{x_T - V_T^{target}}{V_T^{max}}\right)^2 + f^{-}(\mathrm{J},\mathrm{t})f^{lowflow}(\mathrm{J},\mathrm{t}) + f^{+}(\mathrm{J},\mathrm{t})$$

$$- B_n(C, e_x, h)$$

n = release points (e.g., each facility and river inflow)
x = outflow to river from each n (m^3/s);
t = operational time step (e.g., 15 min)
T = planning time step (e.g., 30 or 45 min)
V = water volume in after-bay (m^3);
J = ramping rate (positive and negative) (m^3/min);
target = time required between $\int_{t\_empty}^{t\_full} V\ (min)$;
B = benefits (€ / ($kNm/\ min$))
C = turbine flow capacity ($kN\ m\ /\ min$)
h = hydraulic head (m)
e = possible energy production (min)

3. Case Study

The Kraftwerke Oberhasli hydropower system releases to the Aare River in Canton Bern after generating electricity along a cascade of reservoirs and power plants from Innertkirchen 1, the most downstream power house, and Innertkirchen 2, the last of several run-of-river power plants. For KWO and others, **the goal of hydropeaking is to smooth ramping rates at least cost.**



Grafik: Kraftwerke Oberhasli KWO, September 2010

3. Operational Benefits

Operational benefits minimize revenue losses.

$$\underset{(n,T,t)}{\mathbf{B}} = E\sum_{t}^{T}\overline{P(e_x)_t} =$$

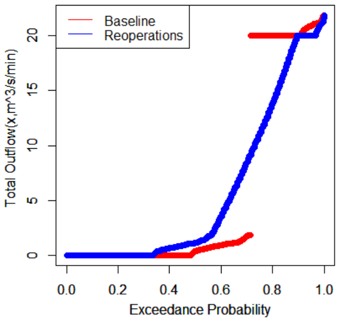
$$\gamma\,(\varepsilon\, h)_n N_{n,T}\frac{\|(Q-V)_{n,T}\|}{C_n}\Delta t\sum_{t}^{T}P_{t,T}\left(\frac{(Q/C)_n}{\Delta T} * 100\right)_t$$

E = electricity production (kN); P = electricity price (€$/min$);
Q = inflow (m^3/min); ɣ= specific weight of water (kN/m^3);
ε = generation efficiency (%); N = time at full capacity (min)

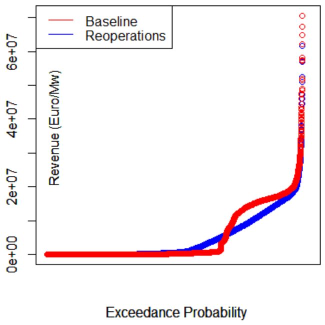
Model Formulation references: Pereira and Pinto (1985), Olivares (2008), and Loucks (1983)

4. Preliminary Results

Releases and revenue losses from hydropower re-operation with no after-bay (baseline conditions).



Left: Frequency of Operational Changes to Mitigate Hydro-peaking

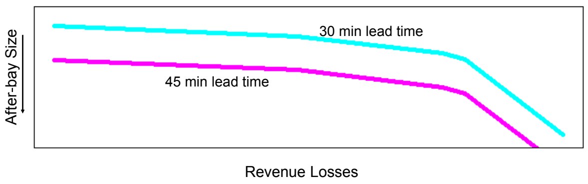


Right: Revenue Gains and Losses from Re-operations to avoid hydro-peaking

Operational changes require production during off-peak hours, which on net results in revenue losses equivalent to about 10.6% of average winter revenues, the season in which hydro-peaking is most notable.

5. Future Work

Future work will compare revenue losses from meeting hydro-peaking requirements for different size after-bays with 30- and 40- minute lead time for operations decisions made at 15-minute intervals. Expected final results will form a Pareto Front like this:



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*For more information, contact L.E. Adams at leadams@ucdavis.edu

Disentangling the effects of hydrology and predation on macroinvertebrate community assembly: a field experiment

Pierre Chanut[1], Francis John Burdon[1], Thibault Datry[2], Christopher T. Robinson[1]

[1]EAWAG, Dübendorf, Switzerland. Email: pierre.chanut@eawag.ch

[2] IRSTEA, Villeurbanne, France

1. Objectives

- Assessing the effect of floodplain hydrology (connectivity) on aquatic habitat characteristics
- Jointly quantifying the relative effects of floodplain hydrology (connectivity) and fish predation on macroinvertebrate community composition
- Identifying the key ecological processes at play
- Assessing how community assembly rules vary with hydrology (connectivity) and fish predation

2. Experimental setup and analyses

We excavated 24 ponds (~ 9 m^3) in a gravel bar, with homogeneous substrate and distributed them in 8 spatial blocks along a hydrological gradient

Within each block, we assigned a juvenile brown trout treatment: 0 or 2 or 6 fish

We sampled every 15 days for 2 months (invertebrates, periphyton, phys-chem)

Analyses:

- Effects on Community composition: **forward selection & dbRDA**
- Effects on biological traits (Tachet): **RLQ + Fourth-corner analysis**
- Investigation of assembly rules: **Functional diversity (Null model deviation)**

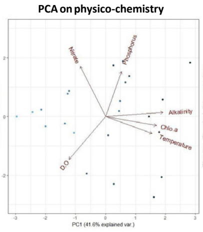
3. Results

3.1 Hydrological gradient

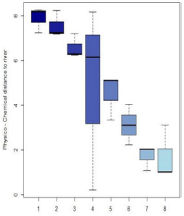
PC1 is structured by alkalinity, conductivity, chlorophyll a and water temperature.

High alkalinity and conductivity results from high concentration of dissolved cations, reflecting longer interaction time between water and rock.

PC 1 is interpreted as the gradient of **connectivity**, used in the rest of the study.



PCA on physico-chemistry



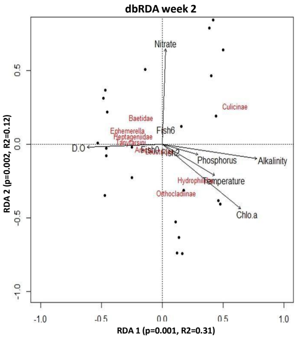
Physico-chemical distance to main channel water

3.2 Community composition

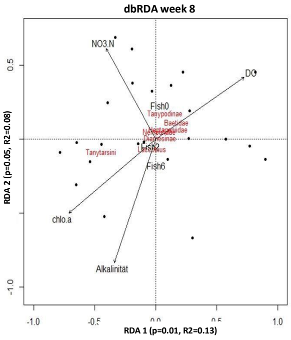
At week 2 The gradient of connectivity constrains community composition

At week 8 The gradient of connectivity remains the main environmental constraint on community composition but the effect of primary productivity has increased.

No effect of fish density on community composition were found



dbRDA week 2



dbRDA week 8

3.3 Trait selection

Traits :

Dispersal :Aquatic / Aerial

Respiration: Aerial / with gills

Locomotion: surface swimmer / open water swimmer / crawler

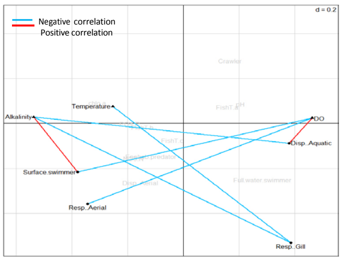
Feeding habit: Predator

At week 2, *aerial respiration* and *surface swimming* are advantageous traits in the less connected sites. More connected sites are colonized primarily by *aquatic dispersers* and species using *gills* to breathe. A similar pattern is found at week 8

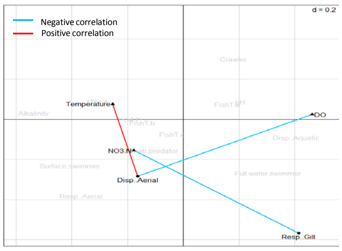
The fish treatment was not found to have significant effect on the traits we investigated.

Dispersal mode affects colonization patterns with active aerial dispersers better able to colonize isolated sites. And the difference in DO among connected and less connected sites appears to be the most important factor constraining community assembly.

Trait selection at week 2



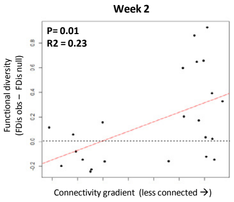
Trait selection at week 8



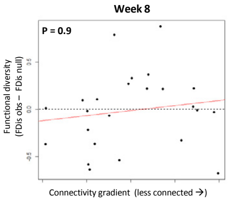
3.4 Assembly rules

At week 2, the less connected sites are functionally over-dispersed compared to the null expectation. This suggests that increased competition in the less connected sites limits niche similarity within each community.

At week 8, functional diversity is no different from the random expectation. No effect of fish density on functional diversity was found.



Week 2



Week 8

4. Conclusion

- Hydrological connectivity affects primary productivity and constrains invertebrate community assembly through indirect biotic processes (functional over-dispersion).
- Fish density was not found to have a significant effect on community composition neither functional diversity (in a separate analysis, fish presence was found to homogenize community compositions across environmental gradients).
- Based on these results, preserving habitats with various levels of hydrological connectivity is key to conserving biodiversity and ecosystem resilience.
- Both the flooding regime and the low flow conditions have to be adapted to preserve habitat diversity and hydrological connectivity at the floodplain scale.

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eawag aquatic research

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Evolution of a gravel-bed river subject to SBT operations

Facchini, M.[1], Siviglia, A., Boes, R.M. – VAW, ETHZ
[1] facchini@vaw.baug.ethz.ch

Introduction

Sediment Bypass Tunnels (SBTs) (Fig. 1(a)) have been proven to been an effective countermeasure to reservoir sedimentation (Sumi et al., 2004), but their morphological effects on the downstream reach are still poorly investigated. During flood events, they divert sediment from upstream to downstream around or through the dam (Fig. 1(b)). Therefore, the downstream reach is subject to repeated releases of water and sediment in form of hydrographs (Q_w) and sedimentographs (Q_b) (Fig.1(c)). The overarching goal of this work is to quantify the morphological changes in terms of riverbed slope and grain size distribution (GSD) induced by realistic SBT operations.

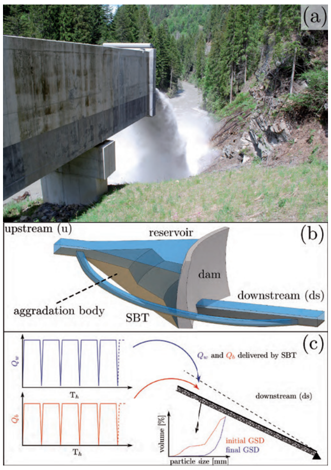

Fig. 1: (a) Solis SBT(Canton Grisons, Switzerland) in operation, (b) sketch of SBT-dam system, (c) 1D numerical study setup.

Conceptual framework for SBT-release scenarios

To properly work, a SBT must have a higher sediment transport capacity than the river flowing in the reservoir. Therefore, given the slope and the GSD of the upstream river reach, the relationship between the water Q_w and the bedload discharge Q_b (bedload rating curve, BRC) can be calculated for the upstream river reach (BRC_u) and the SBT (BRC_{SBT}) (solid red and blue lines in Fig. 2). SBTs are usually designed according to a given water discharge value $Q_{w,d,SBT}$. Then, we identify four possible SBT release scenarios (see Fig. 2):

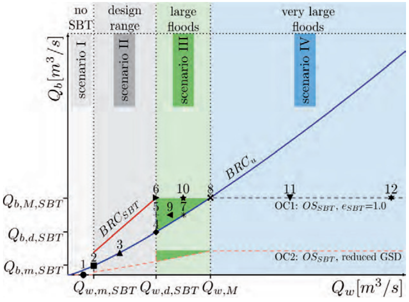

Fig. 2: SBT release scenarios with Bedload Rating Curves (BRC), Operational Conditions (OC), and numbers of numerical runs.

- scenario I (no SBT operation): the SBT is not operated, sediments are stored in the reservoir and water might be conveyed through the dam;
- scenario II (design range): sediment coming from upstream is diverted downstream by the SBT;
- scenario III (large floods): Q_w flowing through the SBT is $Q_{w,d,SBT}$ and the surplus (Q_w>$Q_{w,d,SBT}$) can be either stored in the reservoir or conveyed through dam outlets; Q_b is smaller or equal to maximum $Q_{b,M,SBT}$ that can be carried by the SBT releases;
- scenario IV (very large floods): Q_b = $Q_{b,M,SBT}$ and extra water (Q_w>$Q_{w,M}$, where $Q_{w,M}$ is the Q_w needed for carrying $Q_{b,M,SBT}$ in the upstream reach) is released from the dam.

OC1 and OC2 refer to two different Operational Conditions, namely:

- OC1: the bypassing efficiency of the SBT e_{SBT} = 1.0, i.e. all sediments from the upstream reach enter the SBT and are conveyed downstream;
- OC2: the coarsest part (i.e. coarser than fine pebbles) of the sediments from upstream is mined before entering the SBT.

Methods

To quantify the downstream changes in riverbed slope and GSD, we run 1D numerical simulations with BASEMENT (www.basement.ethz.ch). The model describe the hydro-dynamics by the Saint-Venant equations. Friction exerted by flow over a cohesionless bottom composed of mixed sediment induces sediment transport, which is assumed to occur only as bedload. The GSD of the riverbed surface and the development of size stratification are described by using the active-layer approach of Hirano (Hirano 1971, 1972).

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Numerical model setup

The specific quantification of the inputs to the numerical runs takes as a reference the reach of the Albula River downstream of the Solis Dam and the Solis SBT (Canton Grisons, Switzerland). The cross-sectional geometry has been simplified to a rectangular channel with a length of 10 km and a constant width of 15 m. We discretize the channel with 100 cross-sections, 100 m apart from one another. Q_w and Q_b are fed at the upstream end of the domain in form of repeated trapezoidal hydrographs and sedimentographs varying sympathetically in time as represented in Fig. 1(c). Each release lasts 12 hours and Q_w and Q_b reach the peak after one hour from the beginning. A quantification of the peak-magnitudes under both OCs is given in Table 1 (values relative to OC1 refer to numbered symbols of Fig. 2).

	run	1	2	3	4	5	6	7	8	9	10	11	12
Q_w [m³/s]		30	50	100	170	170	170	223	275	197	222	428	623
Q_b [m³/s]	OC1	0	0.23	0.55	1.06	1.49	1.92	1.49	1.92	1.49	1.92	1.92	1.92
	OC2	0	0.07	0.17	0.33	0.46	0.6	0.46	0.6	0.46	0.6	0.6	0.6

Table 1: Summary of input Q_w and Q_b for numerical simulations under different OCs.

Results

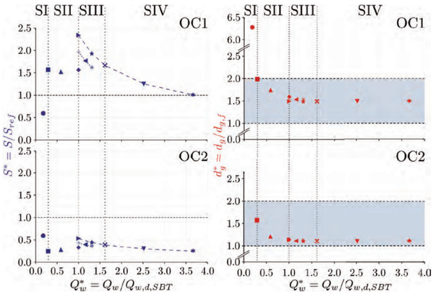

Fig. 3: Results at mobile-bed equilibrium.

Results at mobile-bed equilibrium (after thousands of SBTs operations) are given in Fig. 3 and are presented in terms of a non-dimensional riverbed slope *S** and mean geometric size *dg**. The reference values S_{ref} and $d_{g,f}$ are relative to the upstream reach and to the feeding, respectively. We chose these references to evaluate the effectiveness of SBTs as a mean for river restoration, i.e. their efficacy in restoring almost natural water and sediment fluxes. Results at mobile-bed equilibrium show that:

1) For a given Q_b, the more water is released the lower the resulting equilibrium slope will be (dashed blue lines in Fig.3);
2) if the feeding is deprived of its coarsest part then $S<S_{ref}$;
3) the riverbed tends to unarmored conditions, i.e. $d_g^*< 2$ under almost all circumstances.

On a shorter time-scale, i.e. after 50 SBT-operations, results show that:

1) the riverbed GSD is already close to the equilibrium after a few SBT operations under OC1;
2) under OC2, the rework of the riverbed takes more time since the initial conditions are more apart from the equilibrium than under OC1;
3) both under OC1 and OC2 the riverbed level approaches the equilibrium configuration at the same pace, which is much slower than the one relative to the riverbed GSD.

Conclusions

SBTs operated with e_{SBT} = 1 are able to increase the downstream riverbed slope and reduce the armoring degree of the riverbed surface, while they are causing erosion in the domain if they transport only fines. However, the equilibrium GSDs under OC2 for each run are the one of a sand-bed river, since the feeding is composed mostly by sand. On a shorter time-scale (i.e. tens of events), the GSD converges to the equilibrium faster than the riverbed level. By re-establishing sediment and water fluxes at dams, SBTs might have the power to increase the riverbed slope and break riverbed armoring.

References

Sumi, T., M. Okano, and Y. Takata (2004), Reservoir sedimentation management with bypass tunnels in Japan, *in Ninth International Symposium on River Sedimentation*, pp. 1036–1043.

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Streams impacted by hydropower production through water intakes: do we need sediment flows more than minimum flows?

Part of the NRP70 HydroEnv project

Gabbud Chrystelle[1], Robinson Christopher[2] and Lane Stuart[1]

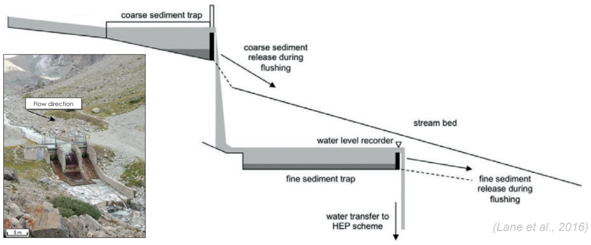
[1]Institute of Earth Surface Dynamics (IDYST), University of Lausanne / [2]Department of Aquatic Ecology, EAWAG, Dübendorf

1. Context - Alpine water intakes

While ecosystem impacts downstream of dams can be managed by a properly designed compensation release like environmental flows or e-flows, they could be insufficient to insure the viability of aquatic life in **the case of water intakes**.

Indeed, the latter are much smaller than dams. **Sediment is trapped in one or two basins before water is abstracted for transfer to storage or at altitude for eventual electricity production** (Fig. 1).

Given their small storage capacity, **these basins have to be flushed/purged of sediment regularly**, through short duration floods with exceptionally high sediment loads. Thus, these intakes do not eliminate sediment connectivity from upstream to downstream (as in dams) but maintain it, whilst potential downstream sediment transport capacity is substantially reduced.



(Lane et al., 2016)

Figure 1: Water intake (here – Bertol Inférieur) and its typical scheme of sediment management through basins

Figure 2: a) High altitude glacial catchment with water intake; b) Channel before and during a (small) purge

The question of sediment in river management is rarely considered. However, in the context of high altitude water abstraction, the **proximity of plants with glaciers induces a high sediment delivery rate to intakes** (Fig. 2a) meaning that flushing can be frequent. Frequent **flushing** (Fig. 2b) may induce deposition and erosion downstream that drastically modifies the geomorphological conditions that determine stream habitat, which can **impact plant and animal communities**.

The aim of this study is to address the management of sediment in intake-controlled Alpine streams and to define **whether we need sediment flows as well as, even instead of, minimum flows**.

2. Study site and Methods

Borgne d'Arolla (Hérens, VS)

- stream fed by a series of both glacial and nival tributaries (Fig. 3)
- regulated by a series of water intakes part of the Grande Dixence scheme
- Sediment trapping and purging

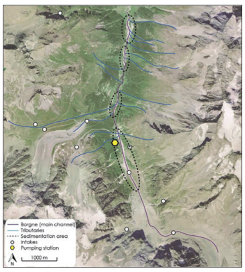
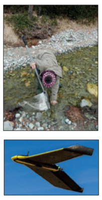


Figure 3: Borgne d'Arolla catchment



Main methods are (Fig. 4):

- Fluvial geomorphology, river processes, habitat studies
- Drone imagery and DEM production, hydraulic modelling
- Macroinvertebrate sampling

Figure 4: a) Macroinvertebrates ampling; b) Ebee drone

3. Results - Purge modify river morphology and prevent fauna to establish

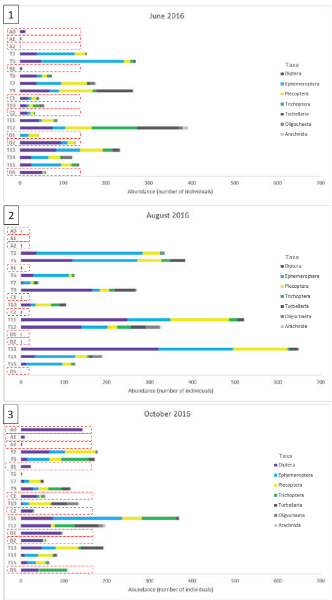
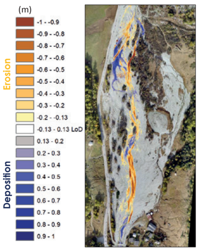


Figure 5: Vertically, measuring station in both the Borgne [red dotted line] and in the tributaries (T); horizontally, macroinvertebrate abundance (length) and taxa (colours)

1. In June, no purges, macroinvertebrate appear and are numerous and diverse, in both the tributaries and the Borgne
2. In **August, the Borgne is almost void of life**; channel morphology changes daily, no organic matter; sediment load passes from **100mg/l to 6500mg/l during a purge** (Gurnell, 1983); purges occur several times a day in summer
3. In October, they are less purges, pioneers are able to quickly recolonise the Borgne.

→ The tributaries can feed the Borgne (Fig. 5) with macro-invertebrates, but:

- As the tributary habitats are extremely different (OM, temperature, turbidity, etc.), it **is very difficult for the fauna to colonise**
- The constant instability of the channel - **purges - modifies the habitat and drift and kills** the prospective animals.



4.5 km downstream from the water intake, sediment **deposition / erosion can be up to 1 m in 4 months** (June – October) (Fig. 6).

Figure 6: Digital Elevation Model of difference between June 2016 and October 2016 to see erosion and deposition areas and amount

Water intakes strongly impact aquatic ecosystems and destroy macroinvertebrate populations during periods of frequent purges.

4. Discussion and perspectives

In this system, the problem is less the water abstraction. Groundwater recharge rapidly leads to minimum flows greater that the Q_{347} defined at the intakes. The problem is sediment purges which induce short duration floods with exceptionally high sediment loads, causing substantial erosion and deposition downstream.

Thus introducing a **minimum flow will not be sufficient and perhaps not even needed**. It is now necessary to identify a suitable sediment management regime as an integral part of designing ecologically sustainable flows in abstraction systems.

This is why not only flow manipulation but also sediment management have to be considered.

One suggestion would be to **stock sediments upstream** the water intake in order to decrease the purges frequency (landscape issues).

Policies should **distinguish between dams and water intakes in the water law** in order to find a win-win solution instead of the **current likely lose-lose solution**, as minimum flows in this kind of system will reduce water available for hydropower production and ecology will not be improved as long as sediment load is not considered.

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Publication

Gabbud C and Lane SN (2016). Ecosystem impacts of Alpine water intakes for hydropower: the challenge of sediment management. *WIREs Water,* 3(1), 41-61.

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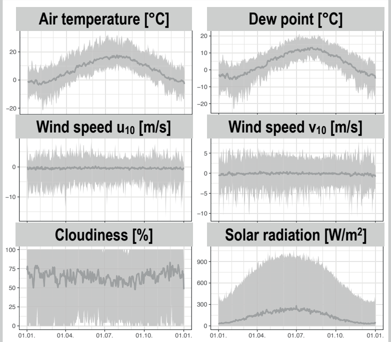
Impacts of altered pumped-storage operation on water quality

Ulrike Kobler, Martin Schmid
Eawag, Department of Surface Waters - Research and Management, Kastanienbaum, Switzerland
ulrike.kobler@eawag.ch

FORCING SIHLSEE (1998-2015)



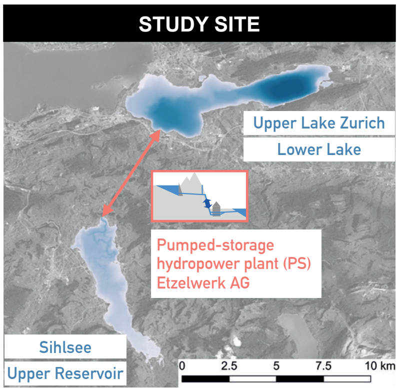
Meteorological Forcing

INTRODUCTION

PS operations are an efficient technology for storing electric energy. This storage capacity addresses main drawbacks of intensified "new renewable" electricity production resulting from changing energy policies. These drawbacks include highly variable production and network load stability problems. However, these PS operations affect physical, biogeochemical as well as ecological properties of the linked water bodies. Especially the impacts on natural lakes need to be limited to keep lake ecology intact.

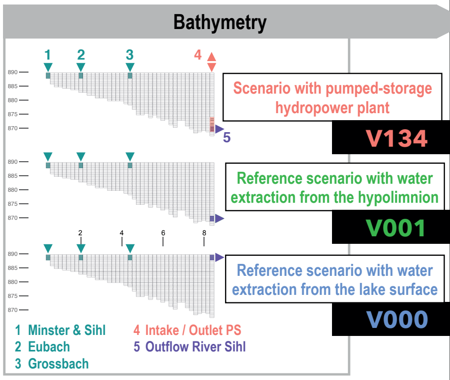
In this study, we use a two-dimensional model to project the impacts of a PS hydro-power plant between Sihlsee and Upper Lake Zurich on temperature, stratification, oxygen concentrations as well as suspended solid dynamics for 1998-2015. Three different scenarios are discussed in detail for Sihlsee: V134, representing the current situation with the existing PS and two reference scenarios, where a *quasi*-natural outflow is feed into River Sihl either from the lake surface (V000) or from the current intake of the hydropower plant (V001).

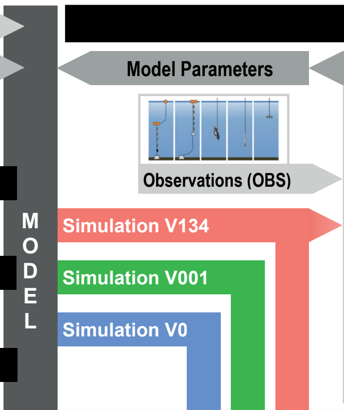
STUDY SITE



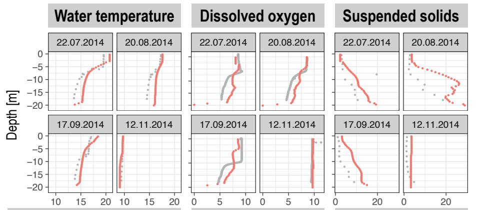
METHODOLOGY

Bathymetry



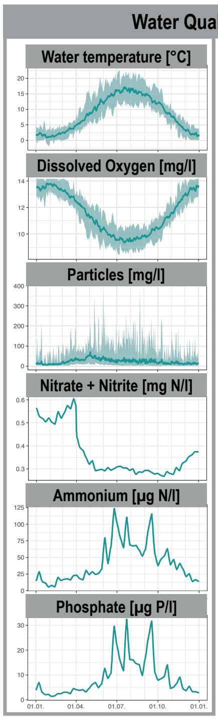


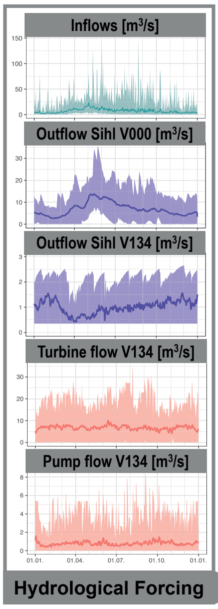
Model Calibration



	RMSE [°C]	RMSE [mg/l]	RMSE [mg/l]
Total:	1.15	1.19	4.80
Epilimnion:	1.12	1.08	1.46
Hypolimnion:	1.23	1.44	6.03
Bruce et al. (2017):	**1.37**		

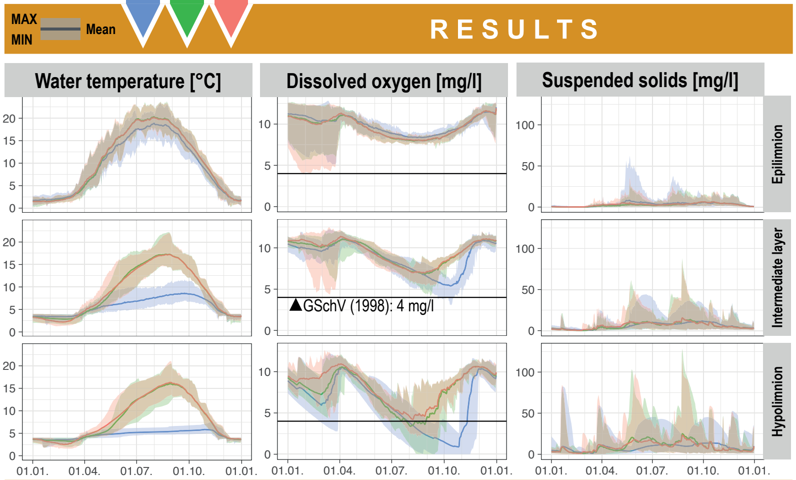
Water Quality Forcing





Hydrological Forcing

RESULTS



CONCLUSIONS

Water temperature
Sihlsee experiences a warming of its hypolimnion, when water is extracted at the current intake of the hydropower plant (scenarios V134 and V001). As a result summer stratification is weakened and mixing occurs one or two months earlier than for the reference scenario V000.

Dissolved oxygen
For the scenarios V001 and V134 (water extracted from the hypolimnion) the shorter and weakened stratification results in less and shorter oxygen depletion in the hypolimnion of Sihlsee. However, all scenarios show DO concentrations less than the legally required 4 mg/l (GSchV, 1998), which is most likely due to unfavourable bathymetry.

Suspended solids
The impacts on stratification also affect the dynamics of suspended solids in Sihlsee. For the reference scenario V000 the suspended solids are likely to remain closer to the lake surface, which also explains the lower concentrations in the hypolimnion. Yet, limited forcing information must be kept in mind.

References

Bruce, L. et al. (2017). *A multi-lake comparative analysis of the General Lake Model: Stress-testing across a global observatory network*. Environmental Modelling & Software (submitted).
GSchV (1998). *Gewässerschutzverordnung* (SR 814.201).

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Trading off energy production from small hydropower with biodiversity conservation

Katharina Lange, Philipp Meier, Clemens Trautwein, Martin Schmid, Christopher Robinson, Christine Weber & Jakob Brodersen*
**katharina.lange@eawag.ch; Eawag, Department of Surface Waters, Kastanienbaum, Switzerland*

Hydropower boom threatenes unique freshwater biodiversity

The construction of small hydropower plants is booming. This exacerbates ongoing habitat fragmentation and degradation, further fueling biodiversity loss. A systematic approach for selecting hydropower sites within river networks may help minimize detrimental effects on biodiversity. Key for designing planning tools is knowledge on reach-scale and basin-scale impacts.


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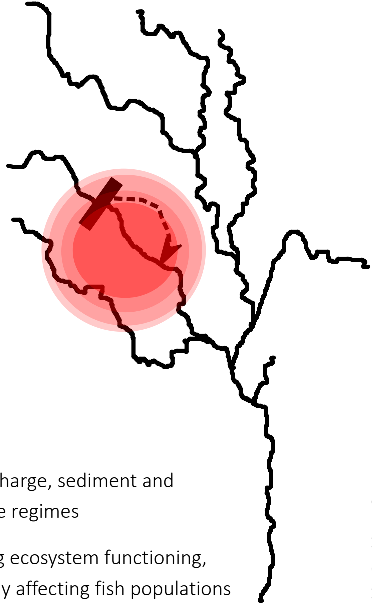
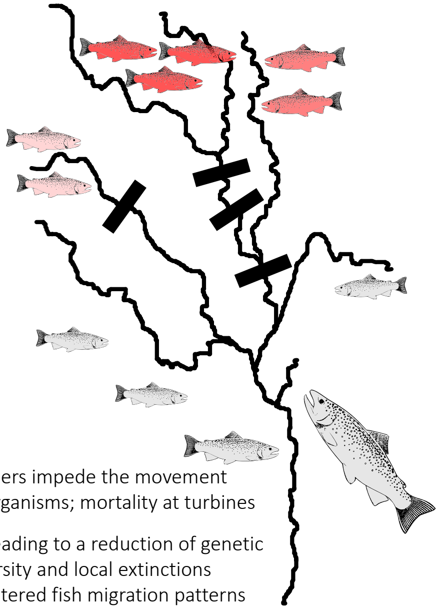
Reach-scale



Altered discharge, sediment and temperature regimes

>> impairing ecosystem functioning,
>> negatively affecting fish populations

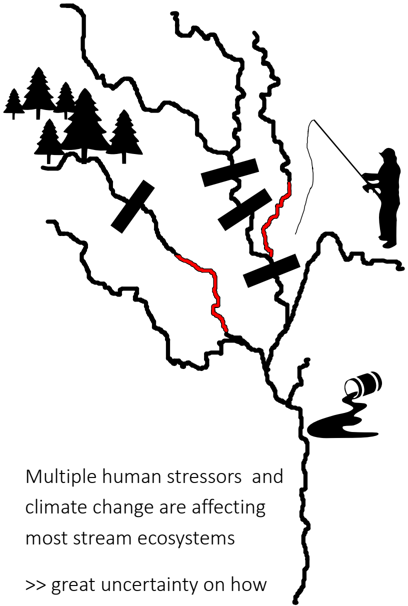
Basin-scale



Barriers impede the movement of organisms; mortality at turbines

>> leading to a reduction of genetic diversity and local extinctions
>> altered fish migration patterns

Multiple stressors



Multiple human stressors and climate change are affecting most stream ecosystems

>> great uncertainty on how stressors will interact (synergisms/ antagonisms)

What we need to know

Downstream propagation of effects – important for cumulative effects of multiple hydropower plants?

Impacts on algal and invertebrate communities which are important for provisioning of ecosystem services ?

Loss of locally adapted genotypes which would lead to a reduction intraspecific biodiversity?

How do river fragment size and the position of dams within the river network drive genetic diversity and the persistance of species within river networks?

How important are cumulative effects of multiple dams for genetic diversity and the persistance of species within river networks?

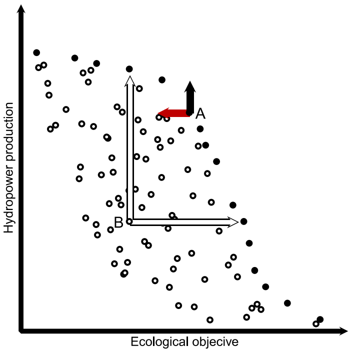
Do different fish species respond in similar ways?

How will hydropower production and other anthropogenic stressors interact in affecting habitat availability, organisms and ecosystem functions?

Climate change, causing alterations of discharge and temperature regimes, may further affect organism life-histories and ecosystem functioning.

Spatial planning tools

The position of each hydropower plant within the river basin should therefore be compared with alternative sites based on multiple objectives, such as economic gains and low ecological impacts. In multi-objective optimization, the solutions form the so-called Pareto-optimal set where the improvement of one objective can only be achieved at the expense of one or other multiple objectives



Conclusions

Multiple drivers of biodiversity need to be considered and expressed as indicators, e.g.

- % of unique habitats/populations
- Species-specific habitat-size requirements
- Importance of specific river reaches for spawning/rearing

> Interactions with other stressors may modify the habitat template

➔ Invaluable for policy makers and resource managers
➔ Assist stakeholders and decision makers to develop a shared view and negotiate policies

Manuscript under review with *Frontiers in Ecology and the Environment*

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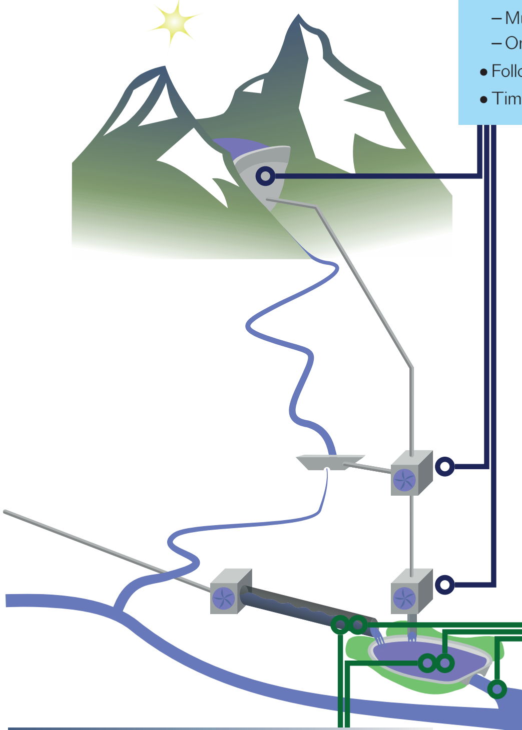
System modelling for hydro-peaking mitigation

Philipp Meier[1], Martin Bieri[2], Pedro Manso[2], Fränz Zeimetz[2], Christoph Gerber[1],
Angela Mark[2], Steffen Schweizer[3], Andres Fankhauser[3], and Benno Schwegler[3]

[1]Eawag, Department of Surface Waters – Research and Management, Kastanienbaum; [2] EPFL, Laboratory of Hydraulic Constructions (EPFL-LCH), Lausanne; [3] Kraftwerke Oberhasli AG (KWO), Innertkirchen

Introduction

Designing efficient measures to mitigate hydro-peaking is a task many hydropower operators in Switzerland face. Constructing a retention basinwhich allows to sufficiently attenuate up- and down-surges in the river, while maintaining the operational flexibility of the powerplant. Such a retention basin needs to be designed carefully by including the entire hydropower system into a detailed analysis.

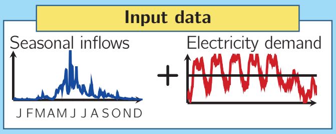


Scenario generator for future hydropower operation

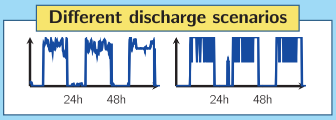
For complex hydropower systems it is not desirable to model the whole system. Therefore, a simple **scenario generator** is developed to reproduce potential future turbine **discharge variability**.

- System defined as network
  - Multiple inflows (water intakes)
  - One reservoir and one power plant
- Follows seasonal cycle
- Time step of 15 minutes

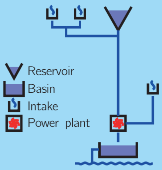
Input data



Different discharge scenarios



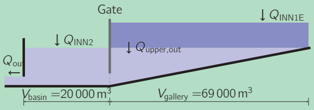
An arbitrary network can be specified:



Optimal operation of the retention basin

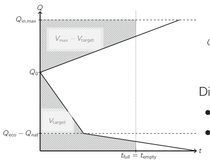
The performance of a compensation basin is be assessed using a simulation-optimisation model. The model operates at a rolling horizon. This means that only limited information about future inflows is available, inflows are only known for the next 30 minutes. An optimisation algorithm is used to find the best possible operation of the retention volume.

For the KWO case, the two volumes, the gallery and the open-air basin, are included explicitly.



Basin operation model

At each time step a target volume is defined that maximises future operational flexibility.

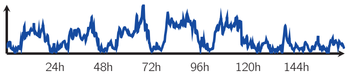


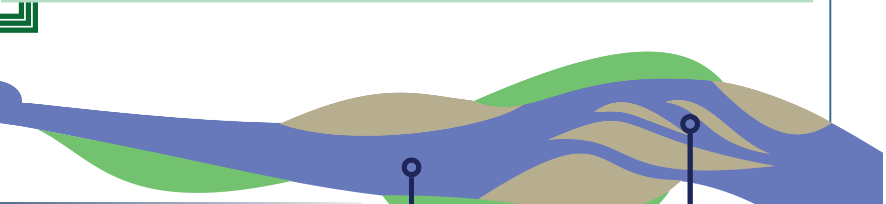
$$\min_{Q_{\mathrm{out}}(t)} \left(\frac{V_{\mathrm{lower}}(t_{\mathrm{end}}) + V_{\mathrm{upper}}(t_{\mathrm{end}}) - V_{\mathrm{target}}}{V_{\mathrm{lower,max}} + V_{\mathrm{upper,max}}}\right)^2 + \sum_t \left(f_{\mathrm{neg}}(J,Q,t) + f_{\mathrm{pos}}(J,t)\right)$$

Discharge **gradient** restrictions

- $\frac{dQ}{dt} < 0.7\,\mathrm{m^3\,s^{-1}\,min^{-1}}$
- if $3\,\mathrm{m^3\,s^{-1}} < Q < 8\,\mathrm{m^3\,s^{-1}}$: $\frac{dQ}{dt} > -0.14\,\mathrm{m^3\,s^{-1}\,min^{-1}}$

Reduced discharge gradients

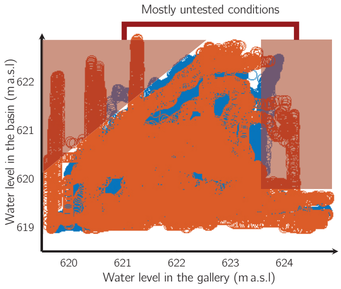




Hydraulic stability of retention basin operation

The operation of the retention volume can be compromised by hydraulic instabilities. Based on extensive data from commissioning tests, the interdependency between water levels, gate openings and power plant discharge is analysed.

Results from commissioning tests

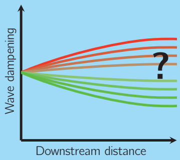


➜ Need to quantify risk of critical combinations

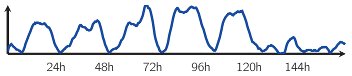
Influence of morphology on hydro-peaking mitigation

The local morphology of the river plays a complimentary role in attenuating hydro-peaking. Morphology not only impacts the propagation of waves, but also the extent of disturbance of fish and macroinvertebrate populations during hydro-peaking events.

Characterising the contribution of river bank morphology to surge gradient attenuation.



Attenuation from river morphology



Conclusions

System extensions and upgrades, as well as an increased availability of new renewable energy sources, will significantly impact the operation of hydropower plants. Hydro-peaking might affect the aquatic ecosystem of many rivers.

Using models of relevant infrastructure elements and processes, the most effective mitigation measures can be selected and implemented. The tools developed within this case study will help to design and plan mitigation measures for hydro-peaking in other hydropower schemes and river systems.

LaTeX TikZposter

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Unil Lane
eawag Robinson
EPFL Battin/Perona

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Modeling macroroughness contribution to riverine ecosystem

Amin Niayifar[1] (amin.niayifar@epfl.ch), Paolo Perona[2], Holly J. Oldroyd[3], Stuart N. Lane[4] and Tom J. Battin[1]

Motivation

Changing the natural flow regime, e.g., due to anthropic uses or climate change, causes an environmental degradation in alpine streams

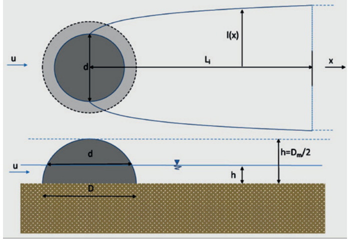
Good understanding of this environmental degradation is of vital importance to minimize such effects

Defining environmental indicators based on macroroughness contribution to riverine ecosystem:

- Creating a wake region where the incoming flow velocity decreases. Fishes minimize energy expenditure by resting in these refuge zones and can easily move to adjacent patches for foraging
- Enhancement of the level of turbulence intensity that results in the increase of reach-scale oxygenation rate

Methodology

A straight river reach of width, w, slope, s, and general bed roughness given by a Manning coefficient, n is considered. The following shows the scheme of the wake and related variables:



Using the Manning-Strickler relationship and also the streamwise and spanwise length scales of the wake proposed by Negretti et al. (2006), the wake area behind a macroroughness can be calculated as:

$$A_w = \int_0^L l(x)dx = \sqrt{\frac{D\sqrt{1-\frac{4\left(\frac{nQ}{\sqrt{S}w}\right)^{\frac{5}{6}}}{D^2}}\left(\frac{nQ}{\sqrt{S}w}\right)^{\frac{12}{5}}}{4g^3n^6}B}$$

Supposing macroroughnesses with a size density distribution, $p_s(D)$, the density function of the wakes areas can be calculated using the derived distribution approach as follows:

$$p_w(A_w,Q) = p_s(D(A_w,Q))\left\|\frac{dD(A_w,Q)}{dA_w}\right\|$$

The usable area provided by stones for a given flow rate is thus:

$$UA(Q) = \int_{A_{w1}(Q)}^{A_{w2}(Q)} w_w p_w(w_w,Q)dw_w$$

where this equation can be plotted for varying flowrate conditions to build up the usable area curve.

The **environmental threshold** can be defined as the stream flow rate where the derivative of the usable area curve becomes zero

In a case where all the stones have the same diameter:

$$Q_{threshold} = \frac{s^{0.5}wD^{0.33}}{n}$$

Results

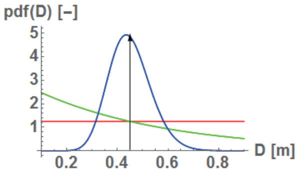
Four case studies with different stones diameter are considered:

Delta distribution

Uniform distribution

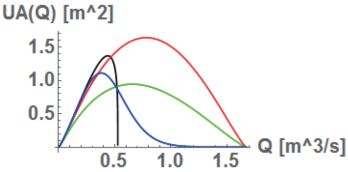
Truncated exponential distribution

Truncated gamma distribution



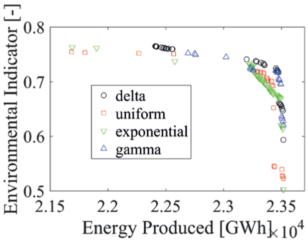
Large stones have a substantial contribution in creating the total wake area in the streams

Environmental threshold at the peak as the usable area decreases significantly



Application of the new model in optimization of a reservoir flow release policies

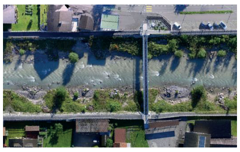
A simple and robust way of evaluating the environmental friendliness of flow release policies



Ongoing Work

Application to a case study (Aare river in the center of Switzerland)

- Characterizing the statistical distribution of stones diameter by taking orthorectified aerial photographs with drones and analysing them with image processing techniques



Measuring the gas exchange coefficient as a function of the stream blockage ratio

- Using the gas (Argon) tracer technique; releasing a gas into a reach and measuring its loss downstream

References

Niayifar, A., & Perona, P. (2017). Dynamic water allocation policies improve the global efficiency of storage systems. *Advances in Water Resources*, *104*, 55-64.

Negretti, M. E., Vignoli, G., Tubino, M., & Brocchini, M. (2006). On shallow-water wakes: an analytical study. *Journal of Fluid Mechanics*, *567*, 457-475.

Appendix

$$B = -2\left(1-\frac{1}{e}\right)^{0.5} + \mathrm{Ln}\left[1+\left(1-\frac{1}{e}\right)^{0.5}\right] - \mathrm{Ln}[1-\left(1-\frac{1}{e}\right)^{0.5}]$$