Task 2.4

Task Title

Environmental impacts of future hydropower operating conditions

Research Partners

Swiss Federal Institute of Aquatic Science and Technology (EAWAG), Applied Hydroeconomics and Alpine Environmental Dynamics (AHEAD) at EPFL, Chair of Hydrology and Water Resources Management (HWRM) at ETH Zurich, Laboratory of Hydraulics, Hydrology and Glaciology (VAW) at ETH Zurich, Institute of Earth Surface Dynamics (Idyst) at University of Lausanne

Current Projects (presented on the following pages)

Optimizing environmental flow releases under future hydropower operation (HydroEnv)
C. Gabbud, R. Pellicanò, A. Niayifar, P. Chanut

Ecohydrology of Macroinvertebrate Metacommunity Assembly in a Regulated Floodplain
P. Chanut, C. Robinson, P. Molnar

Trade-offs Between Electricity Production from Small Hydropower Plants and Ecosystem Services in Alpine River Networks
P. Meier, K. Lange, R. Schwemmle, D. Viviroli

Sustainable Floodplain Management and Hydropower
S. Stähly, A. J. Schleiss, M. Schaepman, M. Döring, C. Robinson

---

Trading-off among multiple objectives: energy production from small hydropower plants, biodiversity and ecosystem services
K. Lange, P. Meier, C. Trautwein, U. Kobler, M. Schmid, C. Robinson, C. Weber, J. Brodersen

---

Local-scale impacts of small hydropower plants on ecosystem functioning
K. Lange, S. Di Michelangeli, Y. Kahlert, J. Hellmann, C. Trautwein, C. Weber, J. Brodersen

---

Effect of a pumped-storage operation on hydrodynamics and water quality of the two linked lakes
U. Kobler

Improving the global efficiency of small hydropower
S. Tron, L. Gorla, P. Razurel, A. Niayifar, P. Perona

Task Objectives

In view of climate change and energy market dynamics, this task addresses the response of aquatic ecosystems to future streamflow alterations resulting from

- modified hydropower operating conditions and improved flexibility
- the increasing development of small hydropower plants (SHPPs), by means of which the Energy Strategy 2050 aims at an additional power generation of 1 to 2 $TWh \cdot yr^{-1}$.

A better understanding of the ecological effects following operational and infrastructural measures will allow to develop improved environmental impact strategies for a given power production. In particular, this will be achieved by

- optimizing the spatial distribution of power production in a network of HPPs and SHPPs at the catchment scale
- developing new criteria for environmental flows, which minimize negative environmental impacts by mimicking natural flow dynamics, while maintaining or increasing hydropower production.

Interaction Between the Partners – Synthesis

The five research institutes involved in this project jointly developed the NRP70 project proposal HydroEnv (Gabbud et al.).

Highlights 2015

- It has been theoretically shown that the current minimum environmental flow regulations are not optimal for both hydropower production and the environment at the same time (Tron et al.).
- A new research project has been initiated to further evaluate possibilities to optimize environmental flow releases (Gabbud et al.).
- A literature review has shown that the environmental impacts of small hydropower plants (SHPPs) are poorly known, especially the effects of multiple SHPPs on ecological and evolutionary processes at the network scale, and that there is a need to develop new management tools to consider these network-scale impacts (Lange et al.).
- Preliminary simulations indicate that the optimal positioning of SHPPs in a river network may be different if the network perspective is considered in the assessment (Meier et al.).
- Preliminary results from a reach-scale field study indicate that fish are affected by SHPP through changes in their respective food resources (Lange et al.).
- A new project has been started, which aims at evaluating the status of floodplains affected by hydropower operations and the development of suitable management actions and restoration measures at the floodplain scale (Schleiss et al.).

SCCER SoE
SWISS COMPETENCE CENTER for ENERGY RESEARCH
SUPPLY of ELECTRICITY

Swiss Competence Center on Supply for Electricity
Annual Conference 2015

In cooperation with the CTI
Energy
Swiss Competence Centers for Energy Research
Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra
Swiss Confederation
Commission for Technology and Innovation CTI
Energy Turnaround
National Research Programme NRP 70

Optimizing environmental flow releases under future hydropower operation (HydroEnv)

Gabbud C, Pellicanò R, Niayifar A and Chanut P ---- *Under the supervision of Prof. Burlando P (ETHZ) and respectively Lane SN (UNIL), Molnar P (ETHZ), Perona P (EPFL) and Robinson C (EAWAG)*

1. Introduction

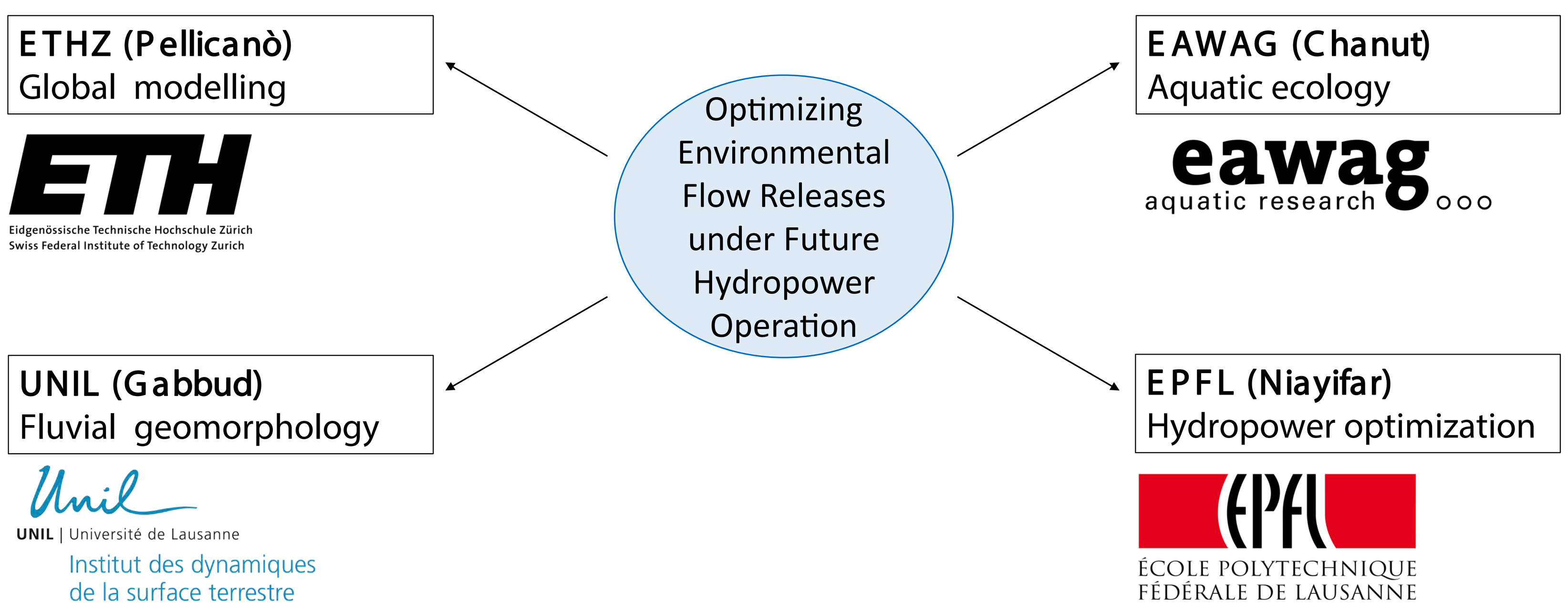
This project is part of the **NRP 70 Program** – Energy Turnaround: Scientific and technological aspects.

The global aim is to provide new and advanced methods for the analysis of medium- to long-term **tradeoffs between hydropower production and eco-hydrological dynamics** in Alpine catchments under current and projected future climate.

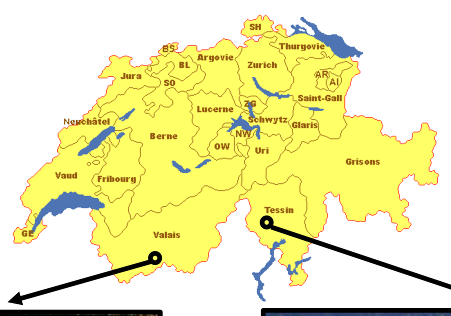
We expect the results to provide a basis for **guidelines** to hydropower producers and legislators regarding, as much as possible, this overall aim.

Four institutes are involved (ETHZ, UNIL, EPFL, EAWAG).

In addition to interactions with SCCER-SoE tasks, we have the opportunity to interact with **national leaders** in hydropower production (OFIMA – Ticino; HYDRO Exploitation SA, Alpiq – Valais) and with different **environmental associations** (WWF, Pro Natura, aso).



2. Study sites



Borgne d'Arolla (VS)

- Water intake
- Irregular flushing flows
- Sediment trapping and flushing

Sediment deposition processes
Sediment wave propagation
No aquatic habitat

Maggia River (TI)

- Reduction of flows
- Floods maintained
- Small sediment disruption

Riparian vegetation processes
Decrease in aquatic habitat
Water stress in riparian zone

3. Methods

- Hydrology, watershed and hydraulic modelling
- Fluvial geomorphology and river processes
- Remote sensing (LiDAR, drone and airplane aerial imagery)
- Aquatic ecology
- Habitat studies and modelling
- Riparian vegetation dynamics modelling
- Strategies of dynamic environmental flows (DEFs)

4. Four orientations, a lot of interactions

ETHZ
- Hydrology of the systems
- riparian water stress
- climate change effect

EAWAG
- Aquatic ecology of the systems
- Monitoring
- Indicators

UNIL
- Sediment disruption and fluxes
- River morphology
- Climate change

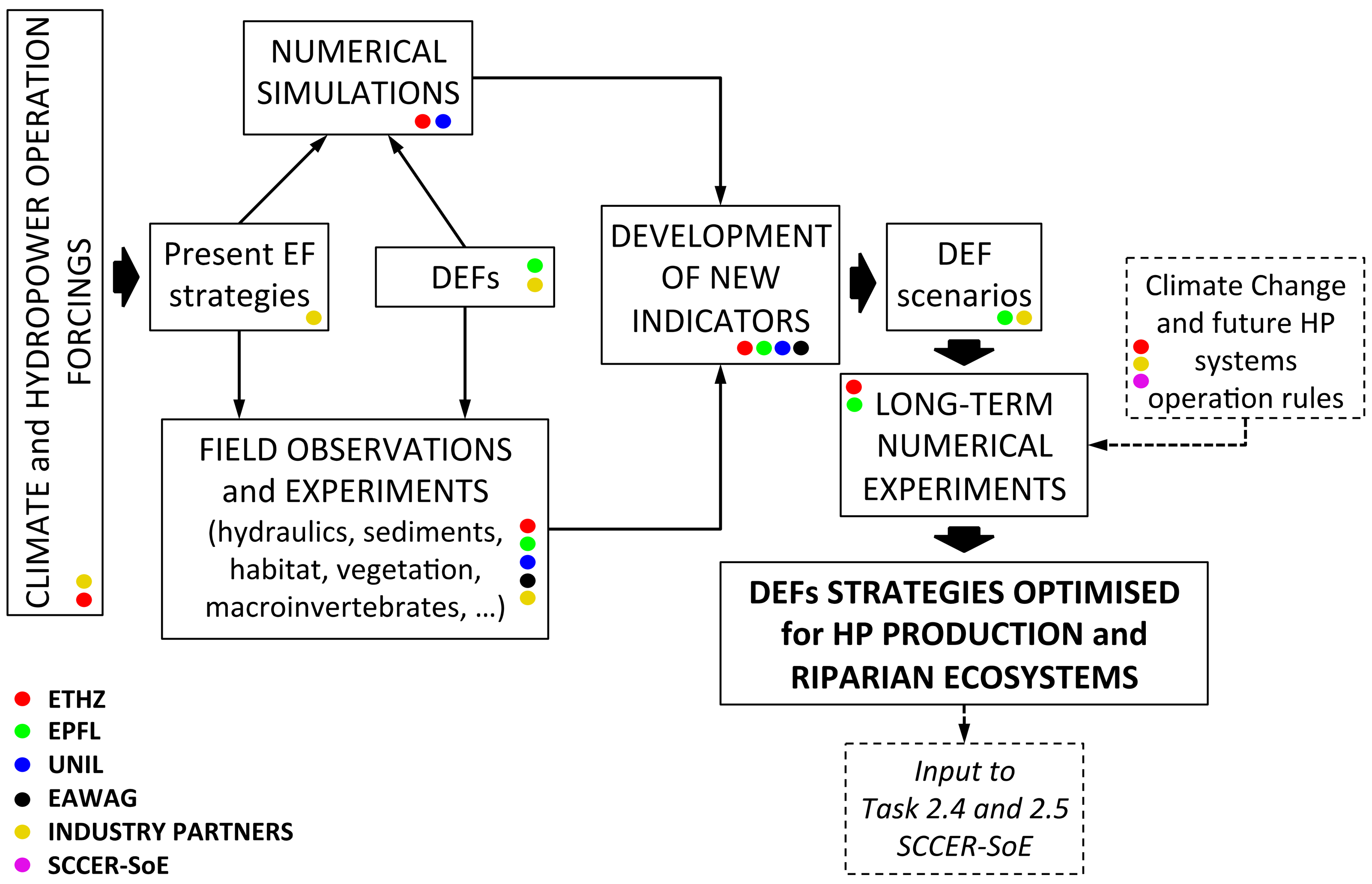
EPFL
- DEF modelling
- Hydropower optimization
- Riparian benefits

Hydropower Production system (operation and release rules)

Abiotic river environment (sediment, morphology)

River ecosystem (macroinv., fish, riparian vegetation)

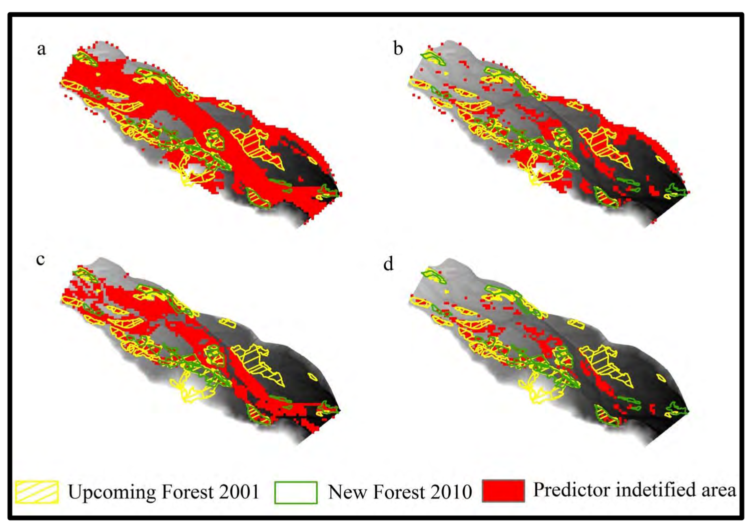
Dynamic Environmental Flows (DEFs)



5. Perspectives

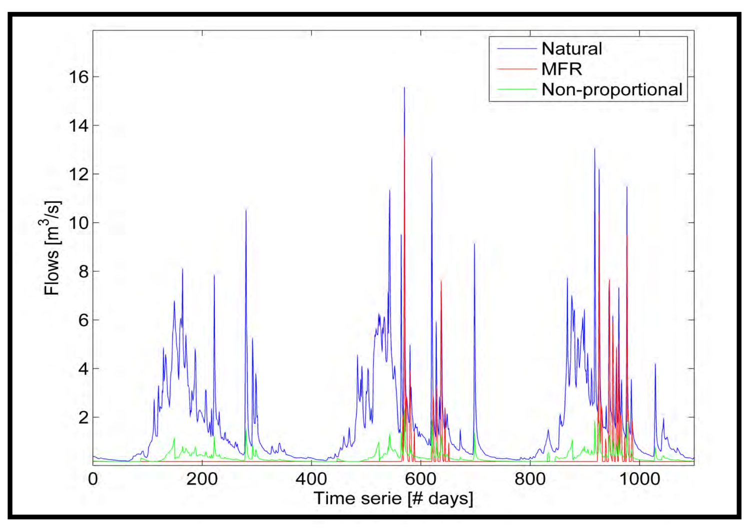
- Three year project, started in spring 2015
- Data generation and analysis (from summer field work)
- Emphasis upon remote sensing of historical impacts and **effects of trials** undertaken as part of project; as well as ecosystem sampling
- Integrating **numerical models** to be developed as forecasting tools

Improve current models of a river reach (from Shaad and Burlando 2015)



Drone-based ortho-images (resolution < 10 cm)

Determination of possible eco-sustainable flow releases for dam-regulated and water offtake systems



Ecological monitoring (e.g. macroinvertebrate sampling and determination)

SCCER SoE
SWISS COMPETENCE CENTER for ENERGY RESEARCH
SUPPLY of ELECTRICITY

Swiss Competence Center on Supply for Electricity
Annual Conference 2015

In cooperation with the CTI
Energy
Swiss Competence Centers for Energy Research
Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra
Swiss Confederation
Commission for Technology and Innovation CTI

Ecohydrology of Macroinvertebrate Metacommunity Assembly in a Regulated Floodplain

Pierre Chanut[1], Christopher T. Robinson[1], Peter Molnar[2]
[1]*EAWAG, Dübendorf, Switzerland. Email: pierre.chanut@eawag.ch*
[2]*ETH, IfU*

Abstract

Flow reduction for hydropower production is expected to have significant effects on aquatic ecosystems in the Maggia River (Canton Ticino). Within this floodplain ecosystem, the ecological effects of flow regulation are likely to be mediated by aquatic habitat fragmentation and change in local environmental conditions (temperature, chemistry, oxygen levels, habitat size…).
By studying macroinvertebrate community assembly and food web structure at sites linked by varying degrees of hydrological connectivity, we will quantify the effects of habitat fragmentation on aquatic ecosystems.
More generally, this study will contribute to the Energy Strategy 2050 by providing robust knowledge on processes linking flow regulation and downstream ecological effects.

1. Introduction

The Maggia River is maintained at low flow during prolonged periods for hydropower production. This flow reduction creates a mosaic of habitat patches with varying degrees of hydrological connectivity, ranging from fully connected flowing channels to isolated ponds. Local environmental conditions are expected to be substantially different between these habitat patches due to differing hydrological regimes.

In order to quantify the effects of flow reduction on the ecosystem in this fragmented floodplain habitat, we will study macroinvertebrate metacommunity assembly as inter-patch connectivity decreases after a flow event.

2. Methods

Two sampling designs: a tri-monthly sampling campaign will reveal seasonal variation in macroinvertebrate metacommunity structure, and an intensive sampling campaign following a flood will identify processes driving metacommunity assembly.

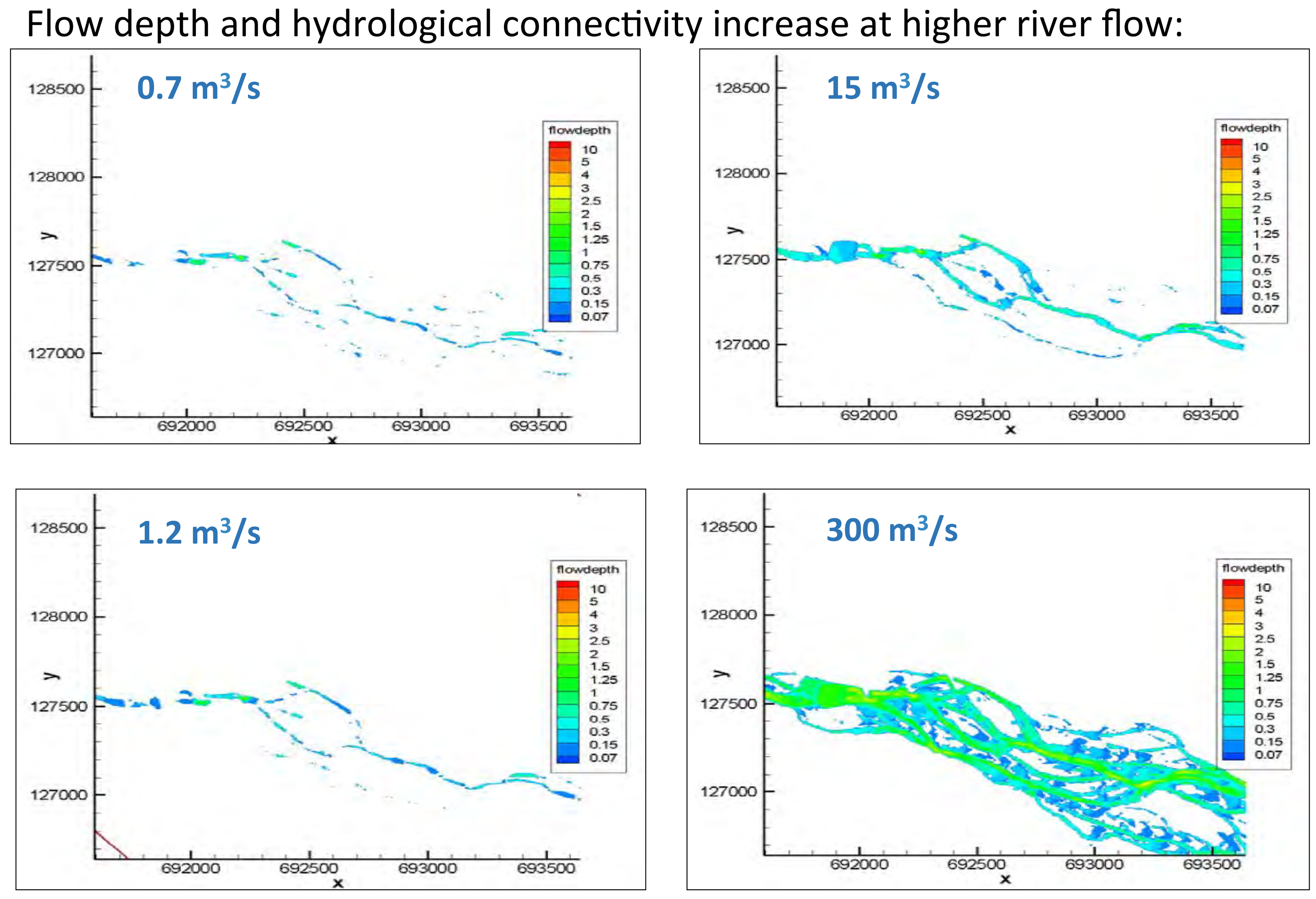
❑ Habitat characterization for each site:
- 2D hydrodynamic model to derive hydrological regime for each site
- Deployment of temperature data loggers
- Drone imagery to derive habitat size fluctuations
- Field-based habitat characterization: substrate-size distribution, water physicochemistry, habitat size, primary productivity (periphyton cover)

❑ Characterization of spatial distances and connectivity among sites:
- Drone imagery in combination with flow gauging to identify fluctuations of hydrological connectivity between habitats
- Drone imagery to derive Euclidian distances between sites and friction maps

❑ Analysis of macroinvertebrate community composition and food web structure
- Characterization of macroinvertebrate community composition and biological traits from field samples
- Analysis of stable isotopic ratios from macroinvertebrates, fish, and periphyton to derive food web structure
- Combination of quantitative sampling and stable isotopic analysis to calculate energy flow through the food web

Habitat heterogeneity in the Maggia floodplain:

Flow depth and hydrological connectivity increase at higher river flow:



Source: Wolfgang Ruf et al. "Modelling the interaction between groundwater and river flow in an active alpine floodplain ecosystem". International Symposium: Floodplains. Goerlitz 2005

3. Conclusions

This study of the effects of flow regulation on macroinvertebrate community assembly will provide key knowledge on ecological effects of flow regulation on downstream floodplain ecosystems. The combination of structural and functional ecological metrics will enable to not only identify patterns but also understand ecological processes linking flow regulation, habitat fragmentation and ecosystem health (in terms of resistance and resilience).

Swiss Competence Center for Energy Research – Supply of Electricity
Annual Conference 2015

SCCER SoE
SWISS COMPETENCE CENTER for ENERGY RESEARCH
SUPPLY of ELECTRICITY

In cooperation with the CTI
Energy
Swiss Competence Centers for Energy Research
Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra
Swiss Confederation
Commission for Technology and Innovation CTI

Trade-offs Between Small Hydropower Plants and Ecosystem Services in an Alpine River Network

Philipp Meier[1], Katharina Lange[2], Robin Schwemmle[1], and Daniel Viviroli[3]

[1]Eawag, Department of Surface Waters – Research and Management, Kastanienbaum; [2]Eawag, Department of Fish Ecology and Evolution, Kastanienbaum; [3]Hydrology and Climate Unit, Department of Geography, University of Zurich

Introduction

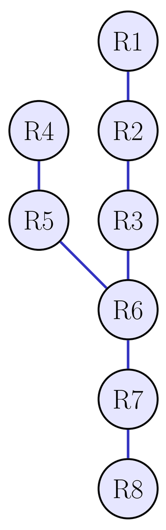
Being considered a relatively environment-friendly electricity source, investment in small run-of-the-river hydropower plants (SHP) is promoted through subsidies. However, SHP can have a significant impact on riverine ecosystems, especially in the Alpine region where residual flow reaches tend to be long. An increase in hydropower exploitation will therefore increase pressure on ecosystems.

In order to avoid the most severe ecological effects, the following questions need to be answered during the planning process:

- **Where** should small hydropower plants be built?
- **What costs and benefits** can be expected?

Optimal positioning of SHP

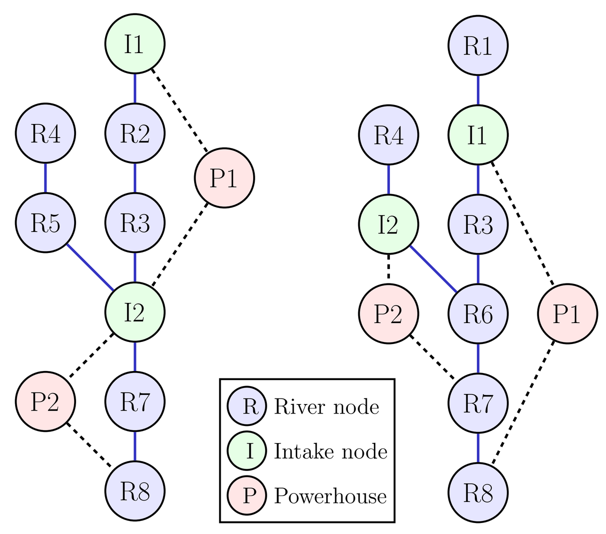
SHP need to be added to the system while respecting multiple objectives, such as power production, investment cost and ecological impacts. Therefore a **multi-objective optimisation** strategy is deployed using evolutionary algorithms.



For this purpose the whole river basin is divided uniformly into river segments. For each segment the natural discharge regime and incremental discharge ($\frac{dQ}{dx}$) is derived from a hydrological model.

The position of water intake and outlet and the design capacity of SHP are used as decision variables.

The optimisation algorithm evaluates different configurations of SHP within the river basin and selects a set of Pareto-optimal configurations based on different objectives.



Objective functions

Lumped objectives

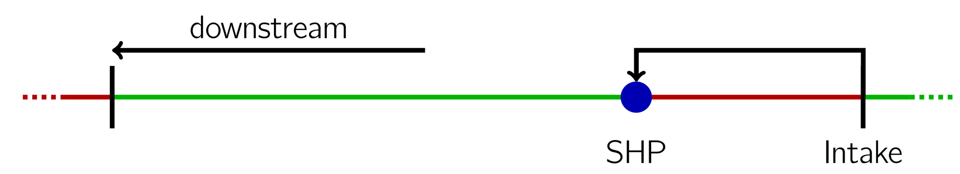
Lumped objectives are local impacts, summed up over all power plants n or over each river segment i.

Total electricity production (PP)	$\sum_n \sum_t \varepsilon_i(P_n, Q_{n,t})\rho g \Delta h_n Q_{n,t}$
Investment cost (Inv)	$\sum_n f(P_n) + f(L_n)$
Fraction of residual flow reaches (Resi)	$\sum_n L_n \;/\; \sum_i \Delta x_i$
High-flows deficit (HD)	$\sum_i \frac{Q_{i,7d,nat} - Q_{i,7d}}{Q_{i,mean}}$

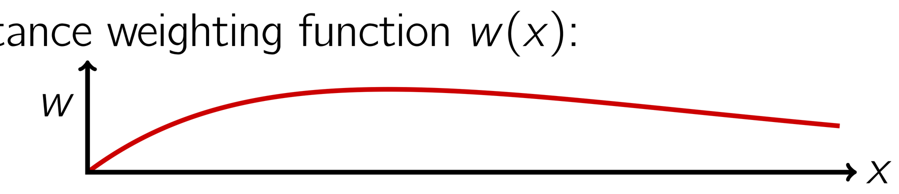
Network based objective

Maximum migration capacity (Mig)

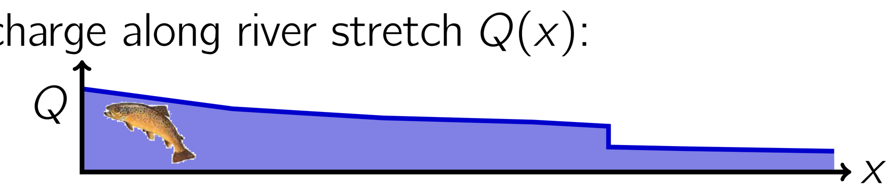
Even small dams at water intakes block migration paths for many aquatic organisms. The maximum migration capacity within the river network is defined as follows:



Distance weighting function $w(x)$:



Discharge along river stretch $Q(x)$:

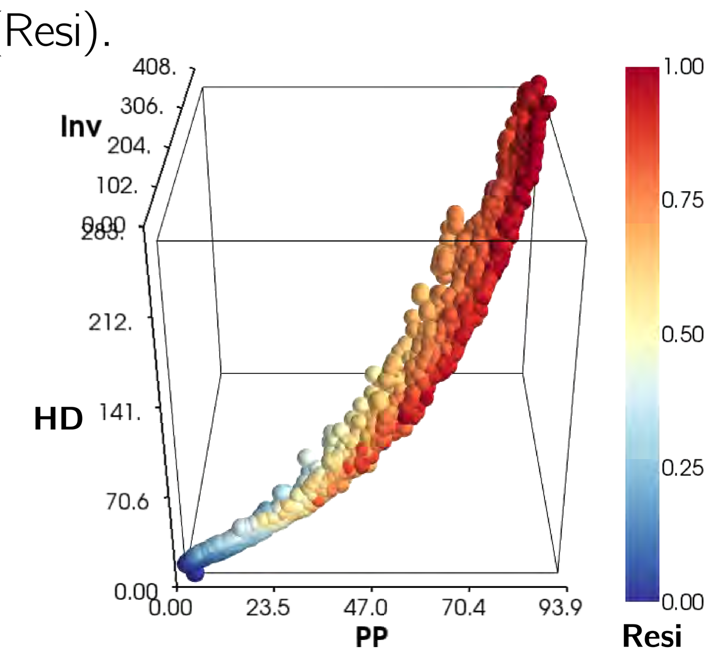


$$\textbf{Mig} = \max_n \int_x wQdx$$

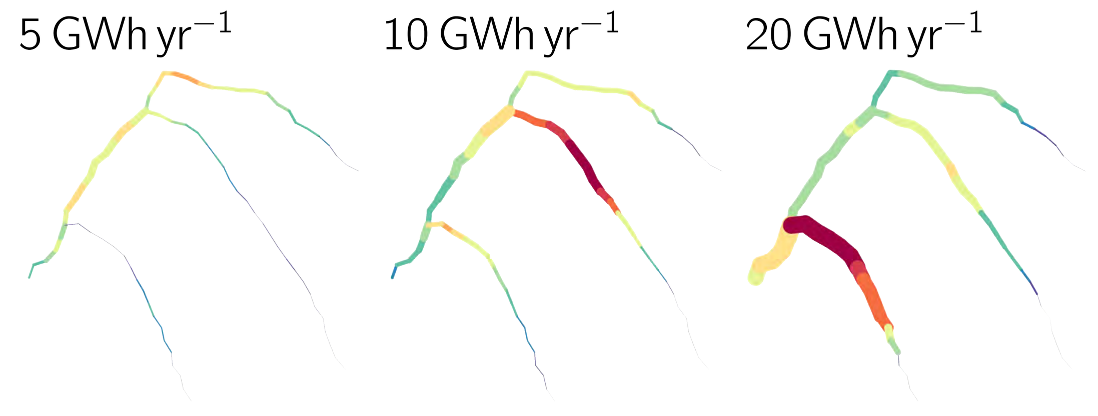
Results from case study Albula River

Using lumped objectives only

Pareto-optimal solutions with respect to four objectives: total electricity production (PP), investment cost (Inv), high-flows deficit (HD) and fraction of residual flow reaches (Resi).

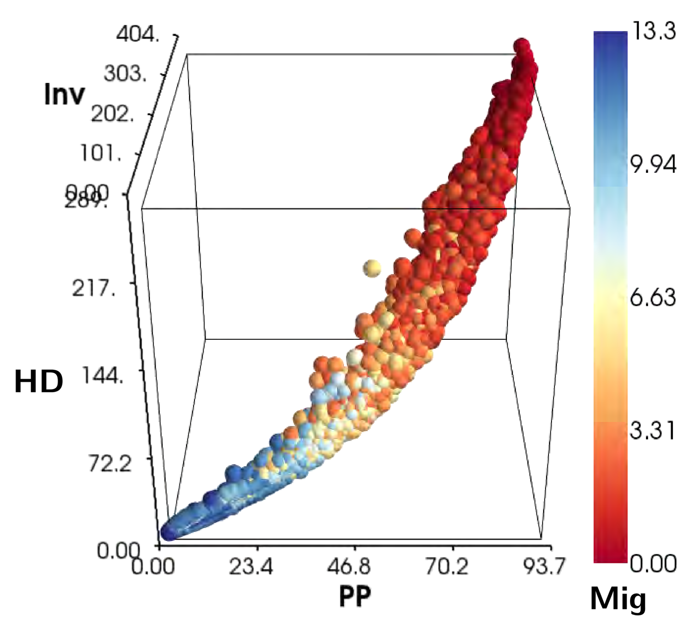


SHP positions are mainly driven by mean discharge and slope, independent of yearly power production.

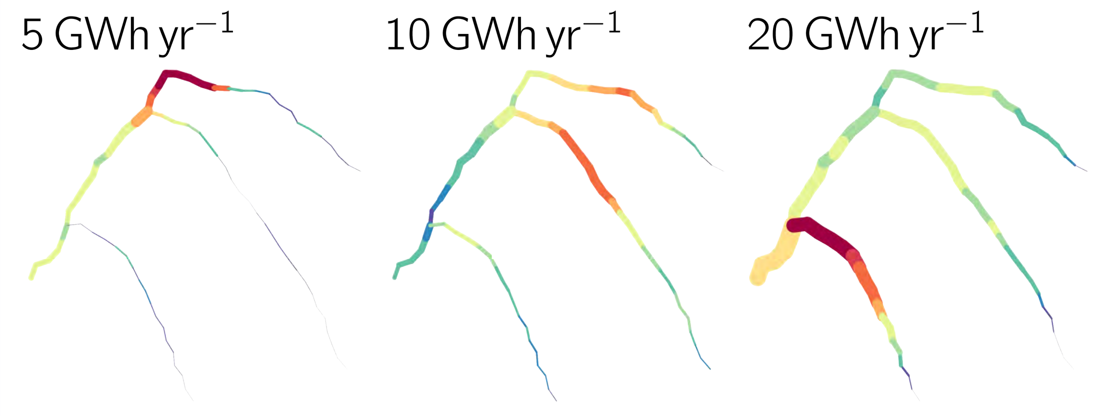


Using network-based objectives

Pareto-optimal solutions including the maximum migration capacity (Mig) for aquatic organisms as additional objective.



Position of SHP driven by network based objective as long as power production is small. For higher electricity production the network based objective loses its significance.



Hydrological impact (low – high)
Probability of SHP being built along river stretch: low, high

Evolutionary Algorithms

A class of optimisation algorithms inspired by biological evolution.

Reproduction of parameter sets

Parents: 1 1 0 | 0 1   0 1 1 | 1 0

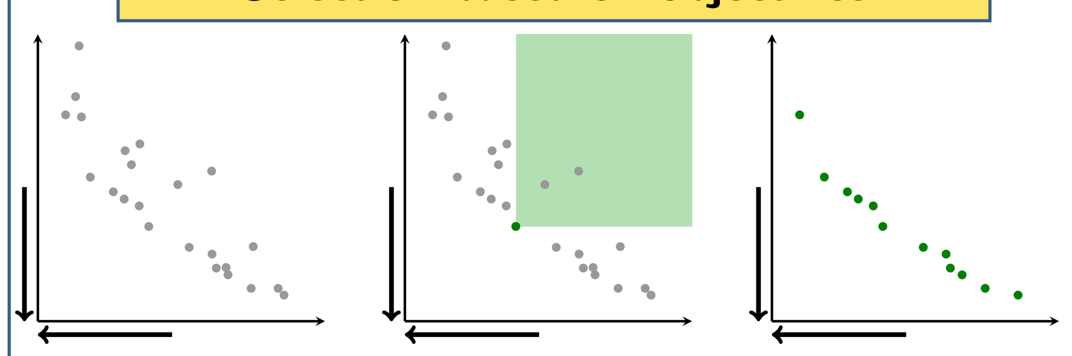
Children: 1 1 0 1 0   0 1 1 0 1

Mutation of parameter sets

1 1 0 1 0 ⟶ 1 0 0 1 0

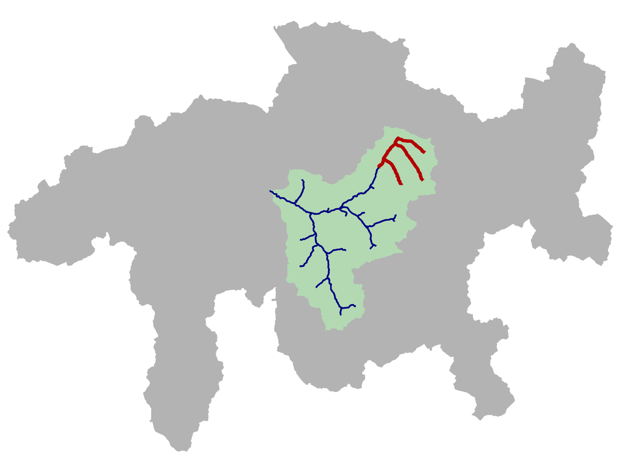
Random change

Selection based on objectives



1. Calculate objectives for each parameter set
2. Select non-dominated solutions
3. Non-dominated solutions are parents for next generation

Study site: Albula River



- Area of 529 km^2
- Mean discharge of 15.5 m^3 s^{-1}
- River divided into segments of 500 m
- Natural discharge from hydrological model PREVAH

Conclusions

- A framework for Pareto-optimal positioning of small hydropower plants is presented.
- The selection of objectives drives the optimal locations for constructing new power plants.
- With increased planned power production network based objectives become less dominant.
- Objectives need to be refined to represent ecological needs.

Download poster

http://bit.ly/1X4Lc0O

Swiss Competence Center on Supply of Electricity
Annual Conference 2015

SCCER SoE
SWISS COMPETENCE CENTER for ENERGY RESEARCH
SUPPLY of ELECTRICITY

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

LCH LABORATOIRE DE CONSTRUCTIONS HYDRAULIQUES

In cooperation with the CTI
Energy
Swiss Competence Centers for Energy Research
Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra
Swiss Confederation
Commission for Technology and Innovation CTI
Energy Turnaround
National Research Programme NRP 70

Sustainable Floodplain Management and Hydropower

Severin Stähly[1], Anton J. Schleiss[1], Michael Schaepman[2], Michael Döring[3], Christopher Robinson[4]
[1]LCH-EPFL, [2]RST-UZH, [3]Ecohydrology - ZHAW, [4]Aquatic Ecology-EAWAG

1. Abstract

Conducting river ecological analysis in combination with hydraulic measurements and modeling shall allow the connection between of biologic with hydraulic indicators (i.e. Hydromorphological Index of diversity, HMID).
This will result in tools for a sustainable development of hydropower production while optimizing and evaluating ecological floodplain goods and services, and sustaining effective decision-making processes. Different floodplains showing different hydropower and morphological impacts like hydropeaking, residual flow, damming, bedload deficit are subject of this study.

2. Introduction

In Switzerland, around 55% of the electricity is produced by hydropower plants. Hydropower facilities directly influence the natural flow regime, the main driver of environmental complexity in river floodplains (e.g. hydropeaking, water abstraction and sediment retention).

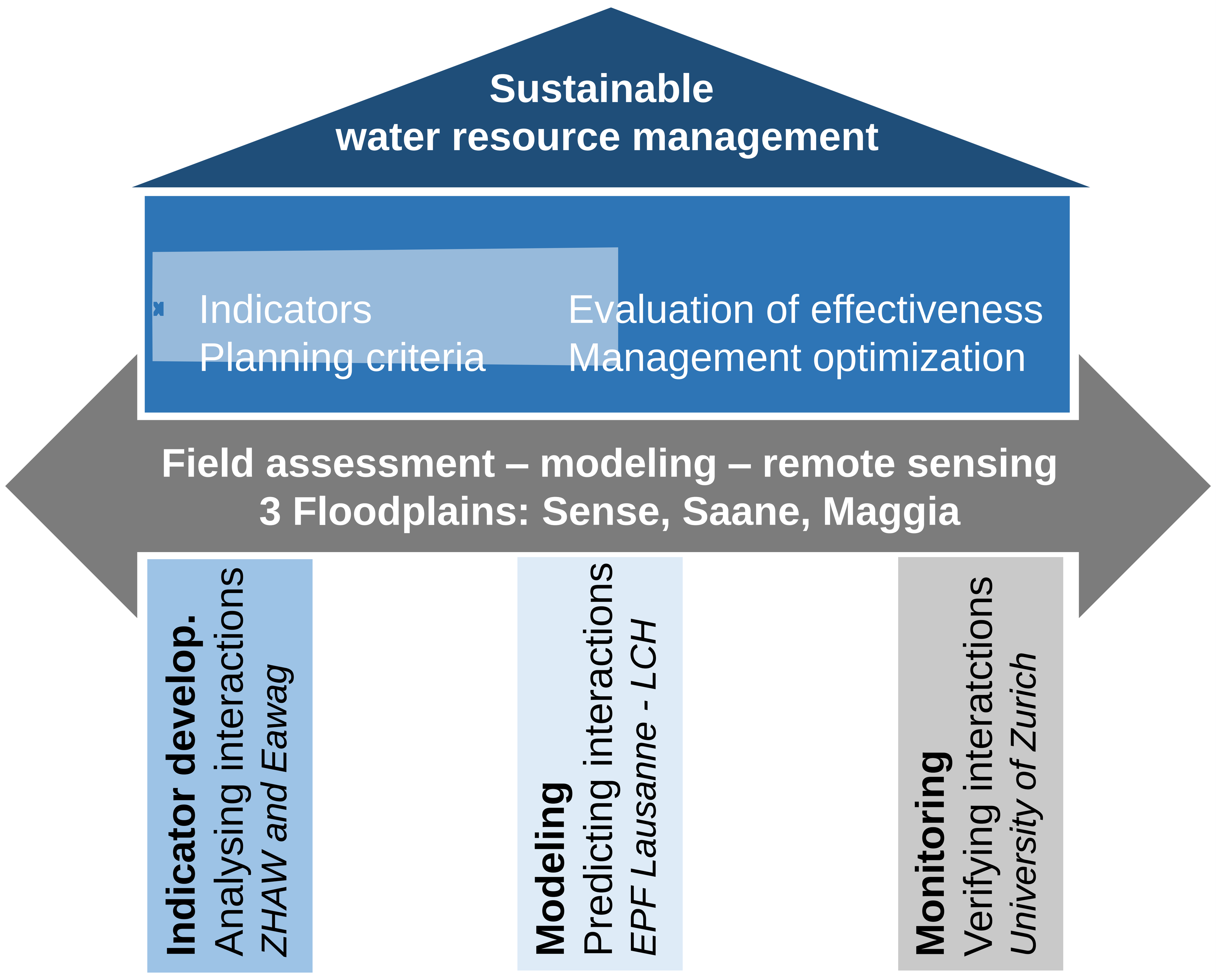
Floodplains cover only 0.26% of Switzerland`s territory. However, 10% of the fauna species found in Switzerland live exclusively, 40% regularly and 80% occasionally in floodplains what reflects their importance for Switzerland's biodiversity

3. Methods & Concept

Indicator development
Integrating structural (e.g. hydromorphology, fauna) and functional (e.g. respiration) floodplain properties
<u>Main goals</u>
Extend existing sets of mainly structural indicators
Ecological evaluation of (managed) floodplain

Modeling
Predicting changes in structural and funtional floodplain properties
<u>Main goals</u>
Extending ecological significance of structural hydraulic indicators and models
Evaluation of the ecological potential and impacts of (managed) floodplains at the landscape scale

Monitoring
Verifying changes in structural and functional floodplain properties
<u>Main goals</u>
Effective assessment at the landscape scale
Model calibration and spatial explicit quantification of inticators



4. Partners & Collaborators

Partners: KWO AG, BAFU, Auenberatungsstelle Abteilung Naturförderung kt BE;

Integration: BAFU-program "Wasserbau&Ökologie", SCCER, "Handbook for evaluating rehabilitation projects in rivers and streams";

Follow-up group: M. Nietsche (BAFU), C. Weber (EAWAG), W. Gostner (Patscheider & Partner AG), C. Jörin, (Kt. FR);

Collaboration: ETH Zurich, University of Montana, University of Poland, University of Waterloo

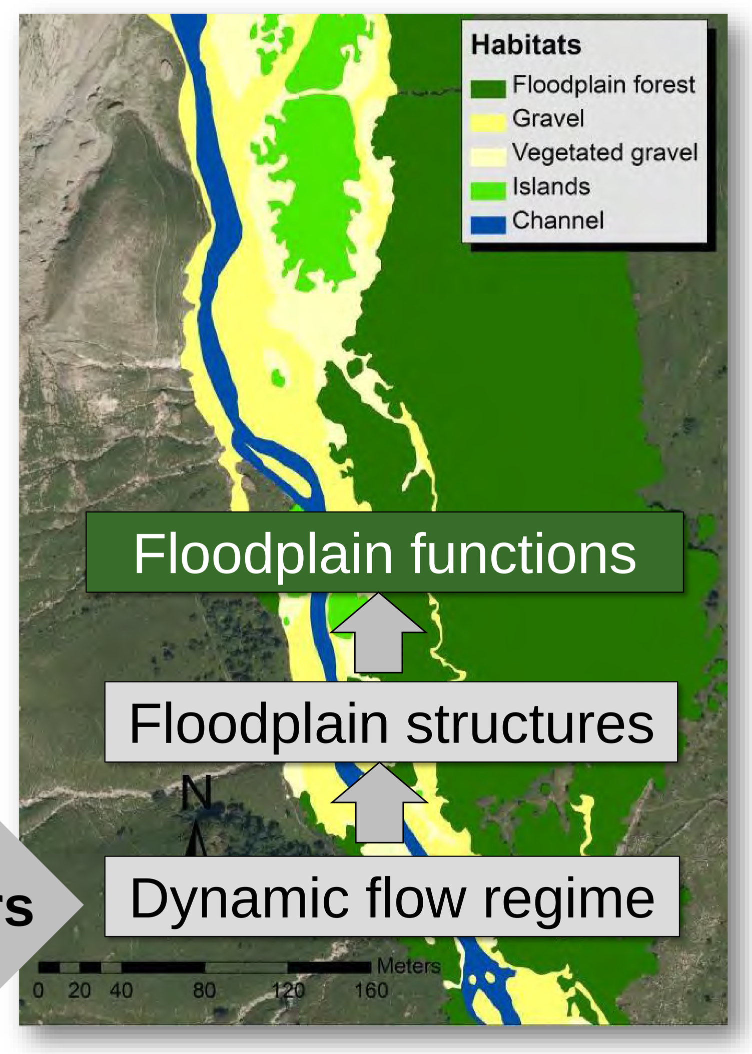
5. Conclusions

With increased knowledge of floodplain ecosystem needs and stressor specific indicators, economically feasible managing possibilities of hydropower plants to minimize negative impacts on floodplain shall be developed.

This will improve the environmental sustainability of hydropower plants and increase the acceptance of existing and planned plants within society and politics.

Hydropower
Hydropeaking, water abstraction, sediment retention

Stressors



6. Contacts

PROJECT LEADER
Prof. Dr. A. J. Schleiss
LCH – EPF Lausanne
T +41 21 693 23 82
E anton.schleiss@epfl.ch

PROJECT COORDINATOR
Dr. Diego Tonolla
ZHAW Wädenswil
T +41 58 934 52 41
E diego.tonolla@zhaw.ch

HYDRAULIC MODELING
Mr. Severin Stähly (PhD student)
LCH – EPF Lausanne
T +41 21 693 28 51
E severin.staehly@epfl.ch

REMOTE SENSING
Mr. Gillian Milani (PhD student)
UZH, Irchel
T +41 44 6355103
E Gillian.milani@geo.uzh.ch

SCCER SoE

SWISS COMPETENCE CENTER for ENERGY RESEARCH
SUPPLY of ELECTRICITY

eawag aquatic research

Swiss Competence Center for Energy Research – Supply of Electricity
Annual Conference 2015

In cooperation with the CTI

Energy
Swiss Competence Centers for Energy Research

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Confederation

Commission for Technology and Innovation CTI

Trading-off among multiple objectives: energy production from small hydropower plants, biodiversity and ecosystem services

Katharina Lange[1], Philipp Meier[2], Clemens Trautwein[1], Ulrike Kobler[2], Martin Schmid[2], Christopher Robinson[3], Christine Weber[2], and Jakob Brodersen[1]

[1]Eawag, Department of Fish Ecology & Evolution, Kastanienbaum; [2]Eawag, Department of Surface Waters, Kastanienbaum; [3]Eawag, Department of Ecology, Dübendorf

Why focus on small hydropower plants?

Global surge in producing more energy from renewable sources is pushing the construction of small hydropower plants (SHP, < 10MW). These are often operated as run-of-river power plants that do not require large storage volumes and may create residual flow reaches below water intakes.

a. Already numerous and many more will be constructed in the next decade
b. Considered to have low ecological impact due to small size
c. Lack of knowledge on ecological impacts at large scales
d. Construction of SHP often subsidized by governmental funding

Aims of our interdisciplinary review

- Enhancing collaboration between engineers and ecologists to effectively trade-off economic gain and long-term environmental impacts of small hydropower plants.
- Overview of existing management tools for SHP construction and operation (where to build? how to run?).
- Identification of five challenges for ecological and evolutionary research to provide lacking information for management tools.

Overview of existing management tools

Hydropower management considers two decisions:
1. **where** to build a new hydropower plant, and
2. **how** to operate it.

Most management tools were developed for the operation of large hydropower plants typically regulated through reservoirs. SHPs are usually not operated actively. Ecological flow requirements for SHPs must be considered at the design stage; e.g. implementation of proportional flow release structures.

So far, optimisation of hydropower operation has been based mainly on single ecological objectives. Tools considering multiple objectives to assess optimum locations within a river network are rare (e.g. see Ziv et al. 2012, *Proc. B.*).

What are the next steps?

Predictive modelling allows for the inclusion of more parameters than in the past, as computational costs decreased in recent years.

The long-term goal for SHP management is to **optimise the location and the operation** of planned hydropower plants **based on multiple objectives**. These objectives should consider the challenges for ecological and evolutionary research at larger spatial scales.

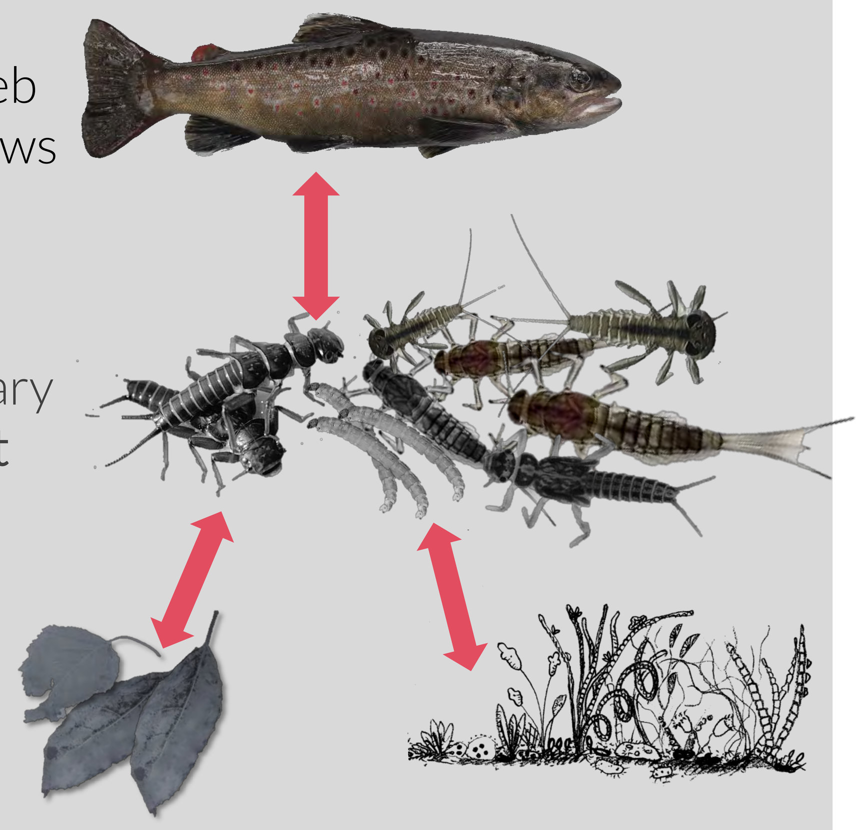
It is important to select key organisms and functions for the development of metrics for biodiversity and ecosystem functioning that can be used for predictive modelling (see Poster by P. Meier) as well as for field assessments (see Poster by K. Lange).

Five challenges for ecological research

At the reach scale:

1 Understanding of SHP impacts on food-web composition as well as matter & energy flows

>> Reduced flows, sediment dynamics and organic matter retention have impacts on community composition, fish fitness, primary production and ecosystem metabolism **but causal relationships are not known**
(also see by Poster K. Lange)



At the catchment scale:

2 Implications of multiple barriers for organism movement

3 Importance of spatial arrangement and connectivity of river reaches for habitat size and diversity

4 Isolation of river reaches and reduced habitat size and diversity as drivers of evolutionary processes

>> No genetic exchange in upstream direction
>> Loss of large, long-distance migratory fishes
>> Reduced population size, **loss of genetic diversity and locally-adapted individuals**

5 Interaction among multiple anthropogenic stressors: synergisms and antagonisms in combination with agricultural land-use and climate change

SCCER SoE
SWISS COMPETENCE CENTER for ENERGY RESEARCH
SUPPLY of ELECTRICITY
eawag
aquatic research

Swiss Competence Center for Energy Research – Supply of Electricity
Annual Conference 2015

In cooperation with the CTI
Energy
Swiss Competence Centers for Energy Research
Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra
Swiss Confederation
Commission for Technology and Innovation CTI

Local-scale impacts of small hydropower plants on ecosystem functioning

Katharina Lange, Sergio Di Michelangeli, Yvonne Kahlert, Johannes Hellmann, Clemens Trautwein, Christine Weber, and Jakob Brodersen

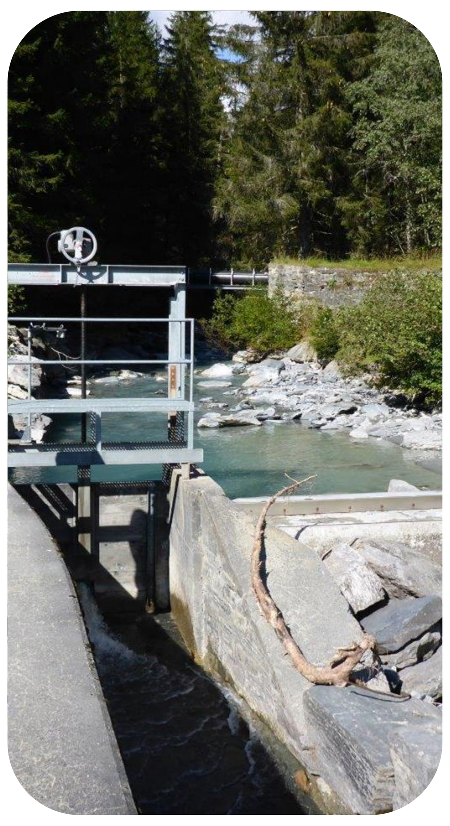
Eawag, Center for Ecology, Evolution and Biogeochemitry, River Fish Ecology and River Restoration Groups, Kastanienbaum

Background

To gain a better **process-based understanding** of the potential negative effects of small hydropower plants (SHPs) on stream ecosystem structure and functioning, we study organisms and processes at multiple trophic levels:

- Trout density and somatic condition
- Trout stomach contents
- Invertebrate food supply
- Algal biomass
- Organic matter retention

Study design



We investigated six small run-of-river hydropower plants (< 3MW) located in alpine regions Cantons: Graubünden, Bern

3 sampling locations at each power plant:

1 **Upstream** water intake

2 **Residual** reach below intake

3 **Downstream** power plant

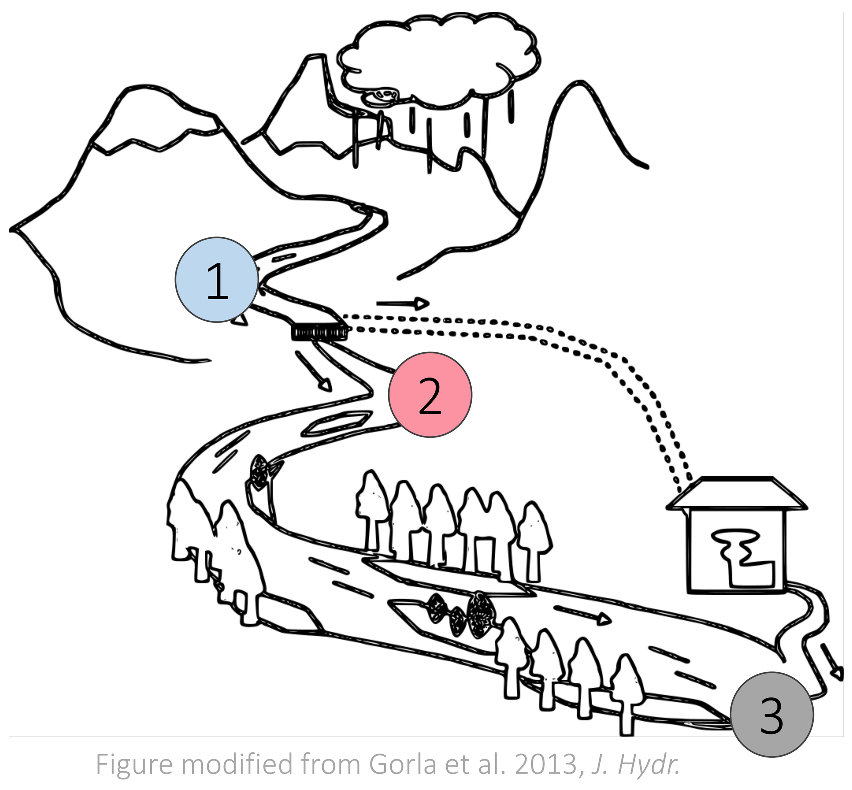


Figure modified from Gorla et al. 2013, *J. Hydr.*

Data collection. Using synergies with the Progetto Fiumi team working on the assessment of Swiss River Fish Biodiversity

In the field:

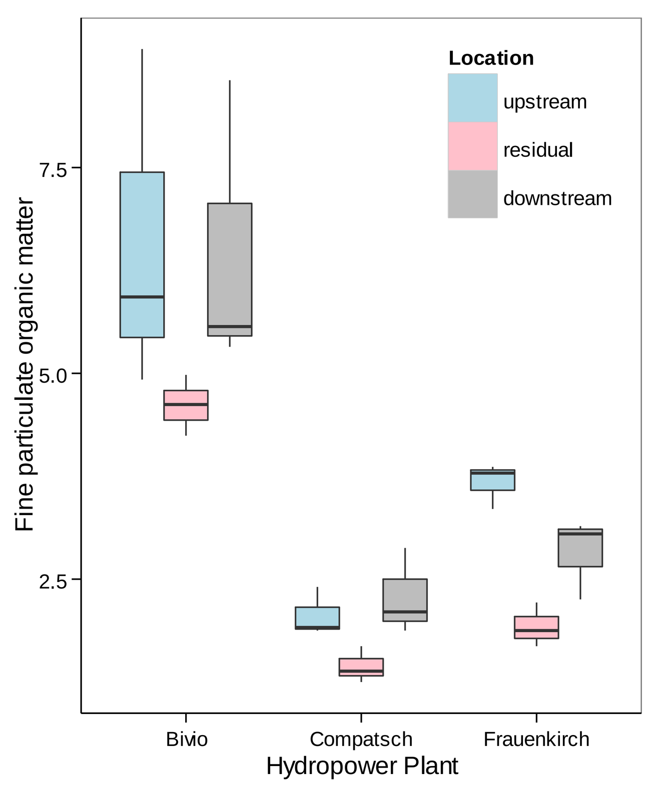
- Electrofishing, measuring, and preserving fish
- Sampling invertebrates, benthic algae and leaf material
- Assessment of channel stability, substrate and organic matter

In the laboratory:

- Analysing fish stomach contents
- Analysing benthic invertebrate community structure
- Processing algal biomass and stream sediments

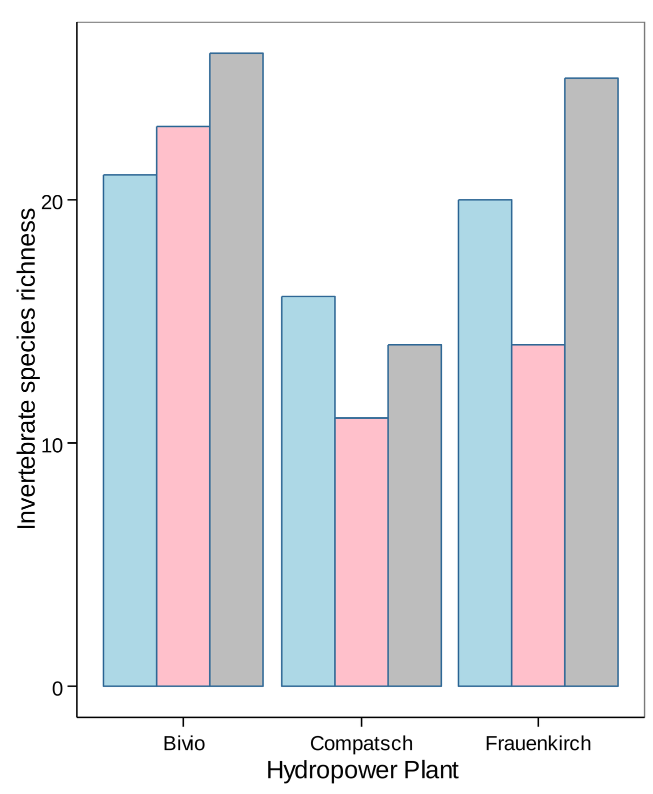
Preliminary results from 3 SHPs

Site characteristics



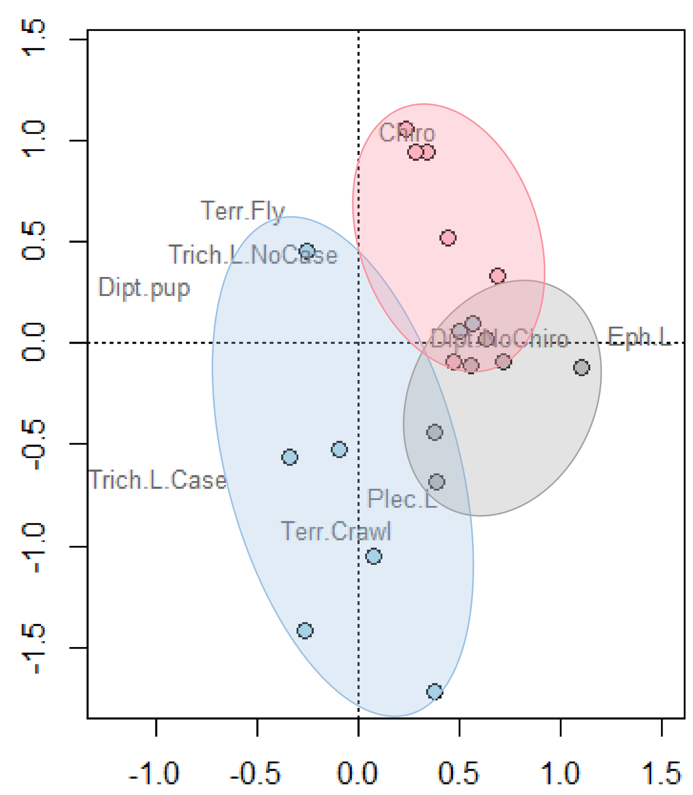
The sediment organic matter content was significantly lower in the residual flow reaches ($p < 0.05$).

Invertebrate community structure



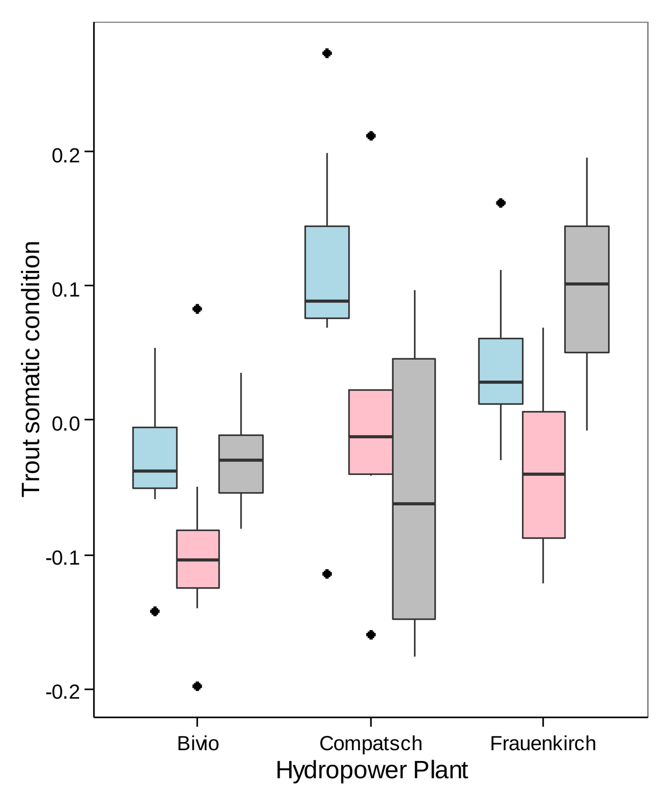
Invertebrate species richness was significantly lower in the residual flow reaches than the downstream reaches ($p<0.1$).

Shift in trout stomach contents



PCA of stomach content composition for the powerplant Compatsch shows a shift in trout food sources for the three sampling locations.

Trout somatic condition



Trout somatic condition (based on weight and length) was lower in the residual flow reaches than the downstream reaches ($p < 0.01$).

First conclusions

Invertebrate species richness was reduced in the residual flow reaches and fish showed shifts in resource use along a river corridor impacted by a SHP.

Fish somatic condition was reduced in the residual flow reaches, potentially due to alterations in invertebrate food supply.

Outlook

Stable isotopes will be used to study changes in food-web dynamics, e.g. shifts in basal ressource use of lower trophic levels, **food-chain length and carbon-transfer efficicency**.

Assessment of **ecosystem functioning** using invertebrate traits which can serve as indirect functional indicators, e.g. signalling changes in flow, sediment and disturbance regimes and also shifts in resource use.

Further, we should be able to single out the key organisms and processes affected by small hydropower plants in alpine streams which will inform the development of ecological metrics. These **metrics** can then be used for predictive modelling and, hence, **for efficienct ecosystem management to sustain biodiversity and ecosystem services.**

SCCER SoE
SWISS COMPETENCE CENTER for ENERGY RESEARCH
SUPPLY of ELECTRICITY
eawag aquatic research
SBB CFF FFS

Swiss Competence Center for Energy Research – Supply of Electricity
Annual Conference 2015

In cooperation with the CTI
Energy
Swiss Competence Centers for Energy Research
Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra
Swiss Confederation
Commission for Technology and Innovation CTI

Effect of a pumped-storage operation on hydrodynamics & water quality of the two linked lakes

Ulrike Gabriele Kobler

Eawag, Department of Surface Waters – Research and Management, Kastanienbaum, Switzerland (ulrike.kobler@eawag.ch)

Introduction

Sihlsee and Upper Lake Zurich are linked by a pumped-storage (PS) hydropower plant, operated by the Swiss Federal Railways. In 2017, a concession renewal is due. Therefore, this thesis deals in three stages with the impact assessment based on different pumped-storage scenarios.

Possible Impacts (e.g. Bonalumi et al. (2011)) . . .

. . . on both upper reservoir and lower lake

- Sediment resuspension due to water level fluctuations
- Entrainment of organisms
- Changes in turbidity, light availability, water temperature, stratification and nutrient fluxes

. . . on the upper reservoir

- Modification of ice-on, ice-off and the thickness of the lake ice cover

Research Questions

Stage 1: Assessing PS-Impacts

- How will the hydrodynamics and water quality be affected?
- Is the additional complexity of 3D-modelling necessary to assess the impacts due to PS operation?

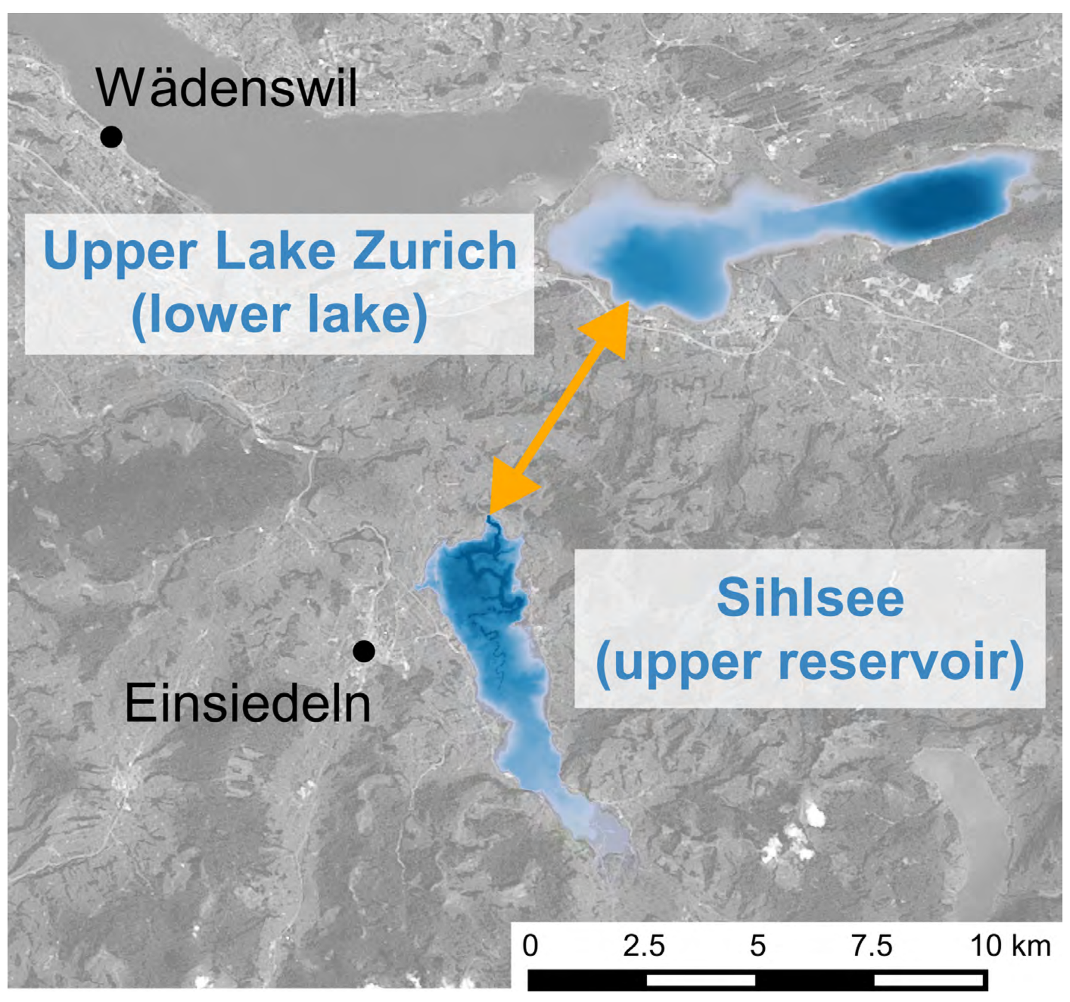
Stage 2: Ice Modelling

- What are the dominant processes determining lake ice formation and decay?
- How can these be observed at Sihlsee?
- Are tools available to increase ice module accuracy?
- What is still lacking regarding concepts of lake ice modelling, particularly to assess impacts of PS operations?

Stage 3: Assessment of Climate Change Effects

- How are the impacts of PS modified by climate change?

Study Sites



Acknowledgments

I would like to thank Martin Schmid and Alfred Johny Wüest for their supervision, the Swiss Federal Railways for funding this thesis as well as the following institutions for providing data - MeteoSwiss, SC Sihlsee, FOEN, cantonal agencies (St.Gallen, Schwyz), WSL and WVZ.

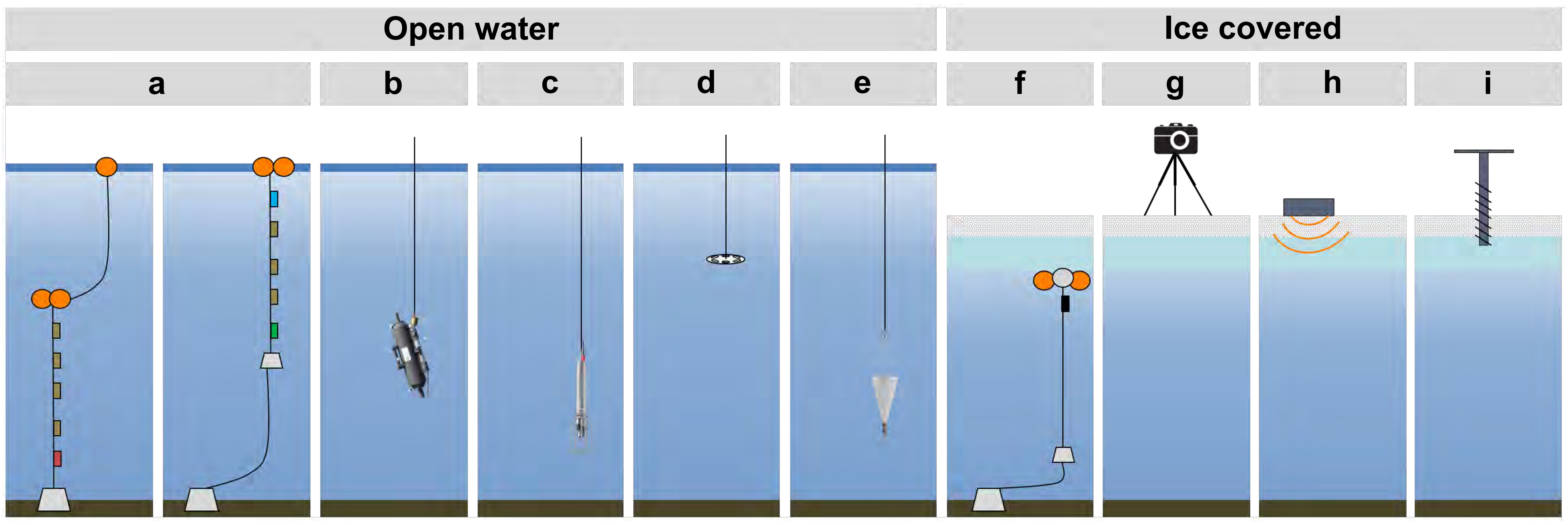
Methodology

Modelling Procedure

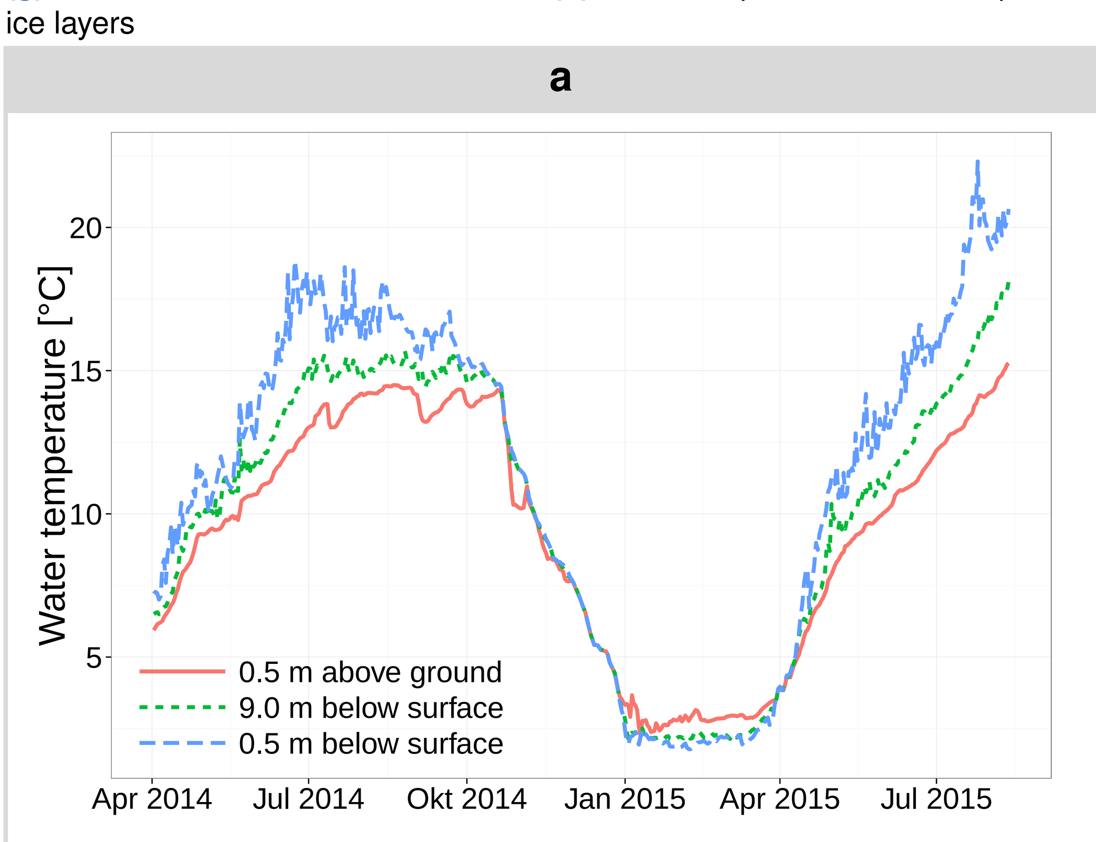
Research Questions (RQ) → Model Selection → Model Setup → Simulation → Outcomes → RQ

- Research Questions (RQ): Stage 1 - 3
- Model Selection: Stage 1 - 3
  - Stage 1: 2D-Model: CE-QUAL-W2; 3D-Model: Delft3D
  - Stage 2: Adaption Ice Module
- Model Setup: Stage 1 - 3
  - Input Preparation
  - PS-Scenario Preparation
  - Sensitivity Analysis using PEST
  - Parameter Estimation with PEST
  - Stage 2: Additional Input Ice Module
  - Stage 3: Climate Change Scenarios based on CH2011
- Simulation: Stage 1 - 3
- Outcomes: Stage 1 - 3

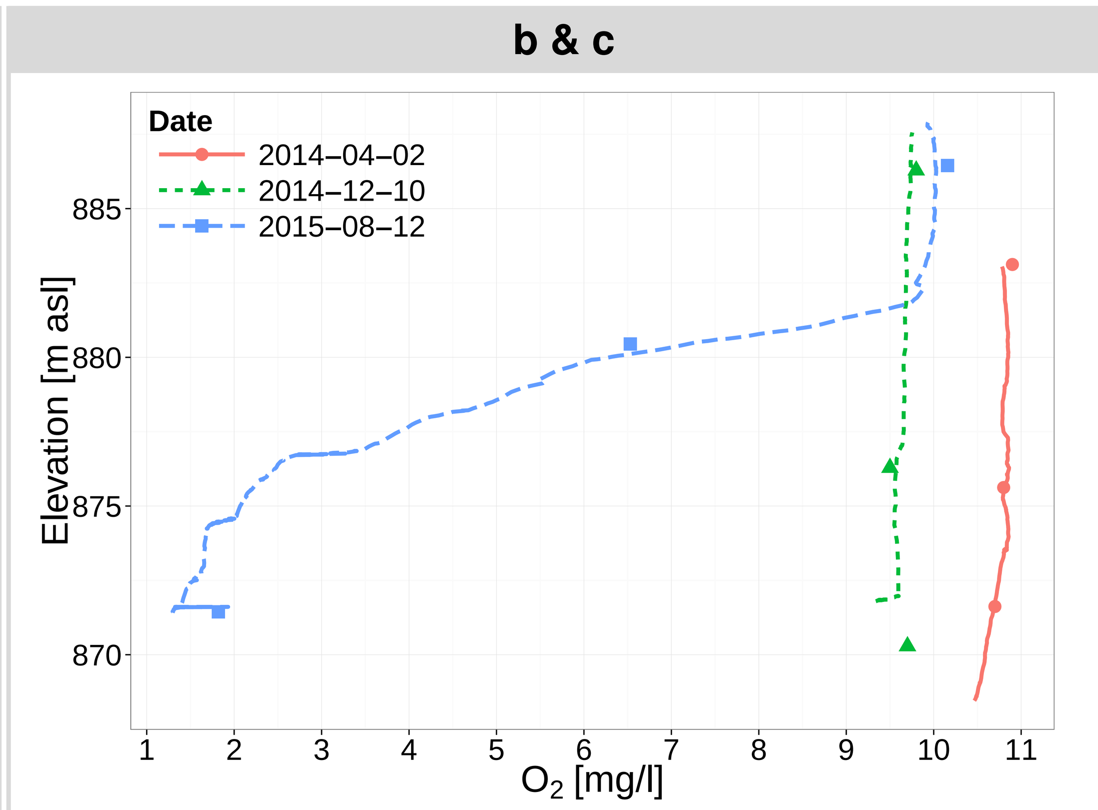
Fieldwork at Sihlsee (upper reservoir)



(a) Thermistors attached to moorings to record temperature and depth; (b) Niskin bottle to take water samples for chemical analysis (oxygen, phosphorus, nitrogen, particles, chlorophyll a); (c) CTD probe to record profiles of conductivity, temperature, depth, oxygen & pH; (d) Secchi disk to determine light extinction; (e) Plankton nets to sample zoo- and phytoplankton; (f) PAR sensor to determine the photosynthetically available radiation under ice; (g) cameras to observe lake ice extent; (h) Georadar probe to observe spatial distribution of lake ice layers; (i) Ice core sampling for punctual information of lake ice layers



Water temperature [°C]: measured using thermistors



Oxygen Concentrations [mg/l]: observed with CTD probe (lines) and determined by chemical analysis (Winkler-Method) (points)

Expected Outcomes

Stage 1: Assessing PS-Impacts

- Quantification of the impacts on hydrodynamics and water quality and their ecological compatibility
- Enhanced understanding of the required model complexity for investigating impacts due to PS operations
- Determination of the individual role of each model parameter using sensitivity analysis as well as objective parameter estimation

Stage 2: Ice Modelling

- Foster knowledge of dominant processes through field observations
- Determining the reliability of adapted lake ice modules in comparison to field observations
- Quantification of the impacts on the ice cover at Sihlsee

Stage 3: Assessment of Climate Change Effects

- Evaluation of the coupled effect of PS operation and climate change and of the necessity of additional management strategies

References

Bonalumi, M., Anselmetti, F., Kaegi, R., and Wüest, A. (2011). Particle dynamics in high-Alpine proglacial reservoirs modified by pumped-storage operation. *Water Resources Research*, 47, W09523.

Cole, T. M. and Wells, S. A. (2013). *CE-QUAL-W2: A Two-Dimensional, Laterally Averaged, Hydrodynamic and Water Quality Model, Version 3.71. User Manual.* Department of Civil and Environmental Engineering, Portland State University.

Deltares (2014a). *Delft3D-FLOW–Simulation of multi-dimension hydrodynamic flows and transport phenomena, including sediments. User Manual. Hydro-Morphodynamics. Version 3.15.* Deltares.

Deltares (2014b). *D-Water Quality–Versatile water quality modelling in 1D, 2D or 3D systems including physical, (bio)chemical and biological processes. User Manual. D-Water Quality. Version 4.99.* Deltares.

PEST (2010). *PEST–Model-Independent Parameter Estimation. User Manual: 5th Edition.* Watermark Numerical Computing.

Swiss Competence Center on Supply of Electricity
Annual Conference 2015

SWISS COMPETENCE CENTER for ENERGY RESEARCH
SUPPLY of ELECTRICITY

In cooperation with the CTI

Energy
Swiss Competence Centers for Energy Research

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Confederation

Commission for Technology and Innovation CTI

Improving the global efficiency of small hydropower

S. Tron, L. Gorla, P. Razurel, A. Niayifar and P. Perona – Gr. AHEAD, EPFL ENAC, Lausanne, CH

Abstract

River intakes are used to divert water from the main course in both small and traditional hydropower systems. We show that **the global (i.e., economical and ecological) efficiency** of water diversions for energy production in small hydropower plants (SHPP) **can be improved towards sustainability by engineering non-proportional dynamic flow-redistribution rules**. The theoretical background is presented and applied to **three case studies** in order to **test the global performance** of such policies. Out of numerical simulations, a Pareto frontier emerges **in the economic vs environmental efficiency plot**, which shows that non-proportional distribution policies improve both efficiencies with respect to those obtained from some traditional MFR and proportional policies. We conclude that **preserving natural river reaches requires to abandon inappropriate static release policies** in favor of non-proportional ones, particularly **under long term climatic scenarios affecting water availability and the natural flow regime.**

1. Introduction

Releasing constant environmental flows Q_2 (one or more thresholds) has been proven to be ecologically inefficient.

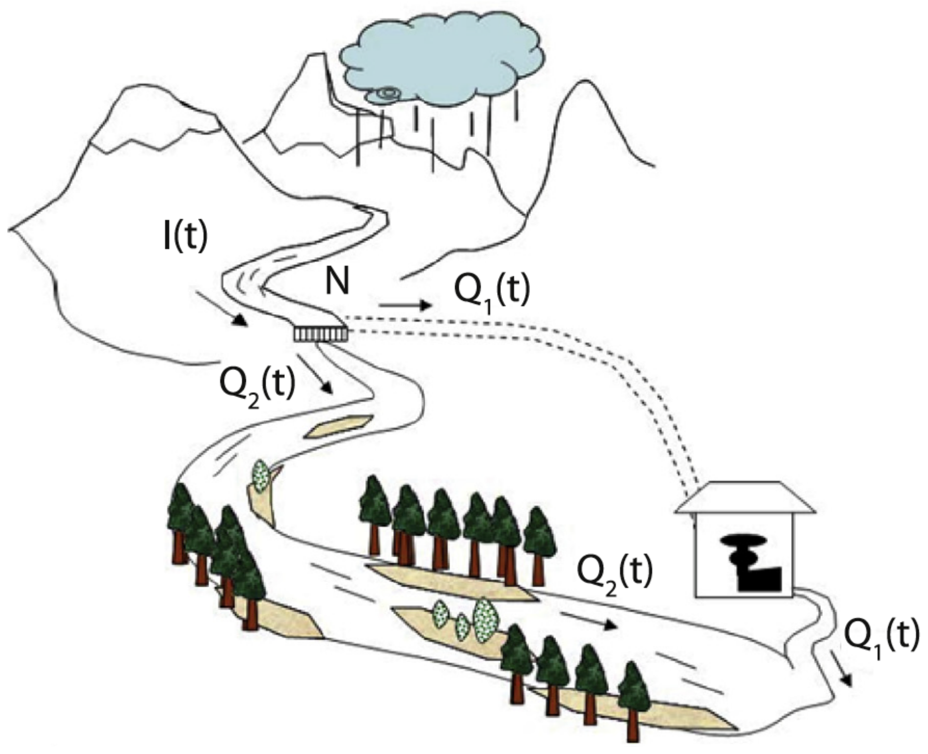
New rules are sought in order to protect the biodiversity of riverine ecosystems (Perona et al., 2013).

Gorla and Perona (2013) introduced the concept of non-proportional redistribution for SHPP (Figure).

Razurel et al. (in revision) have generalized the methodology to a class of nonlinear functions.

Gorla et al. (submitted) have used such functions to compute the Pareto frontier in real SHPP.

In this work, we show advances of such researches.



Schematics of SHPP; water is distributed at the node N following a given rule

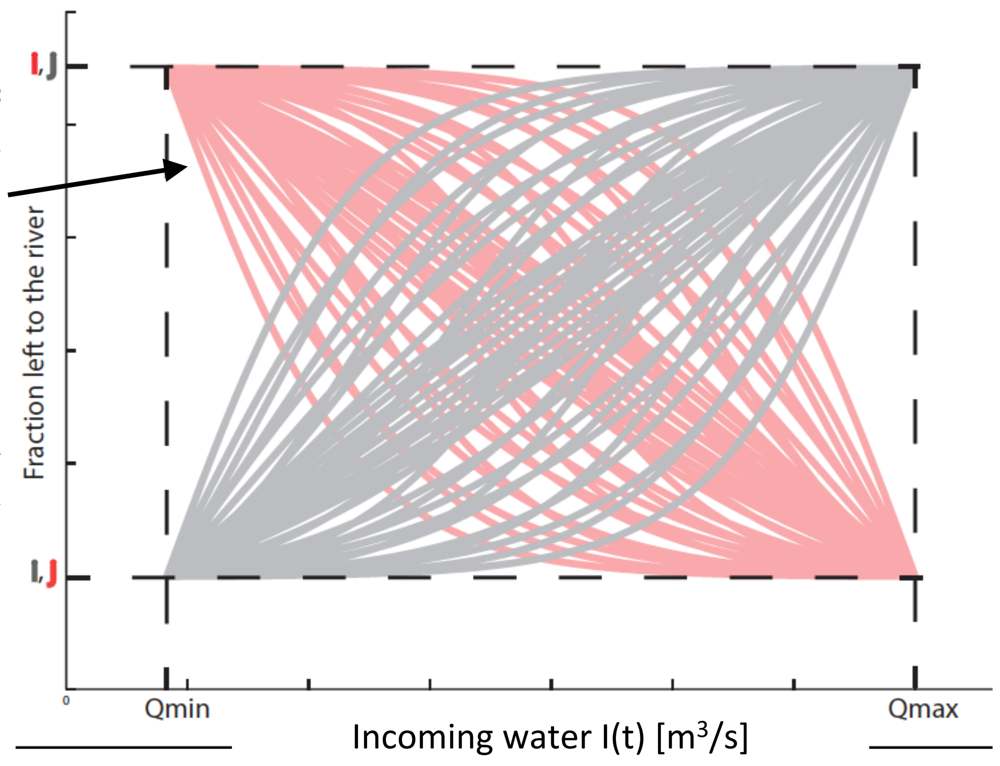
2. Methods

Redistribution rules

We describe the fraction of water that is left to the river by means of a family of nonlinear functions

We use a set of $2{\cdot}10^5$ such functions to computer simulate SHPP production and flow releases using 30 ys of daily flow data.

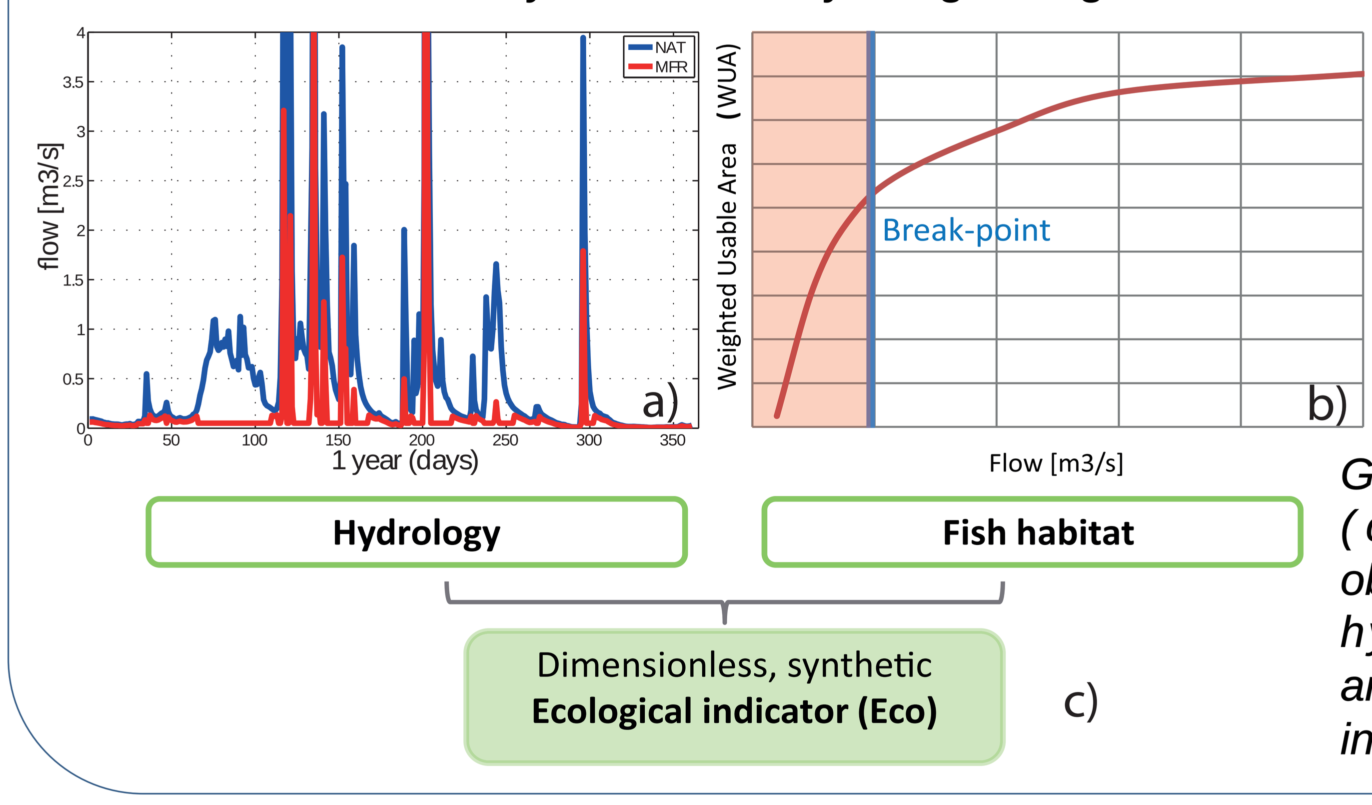
We compare the results of using such policies against MFR and proportional ones.



Non-proportional redistribution rules in the form of Fermi-Dirac distributions.

Global ecological efficiency.

A global ecological indicator is built by joining normalized hydrological and habitat suitability indicators by weighted geometric average

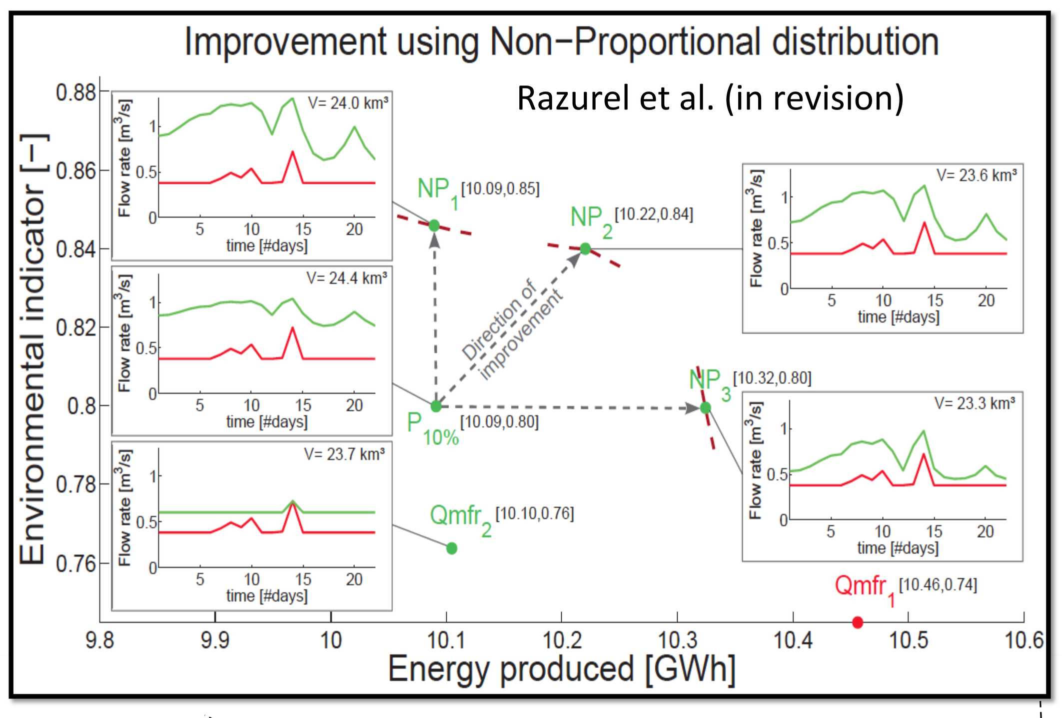


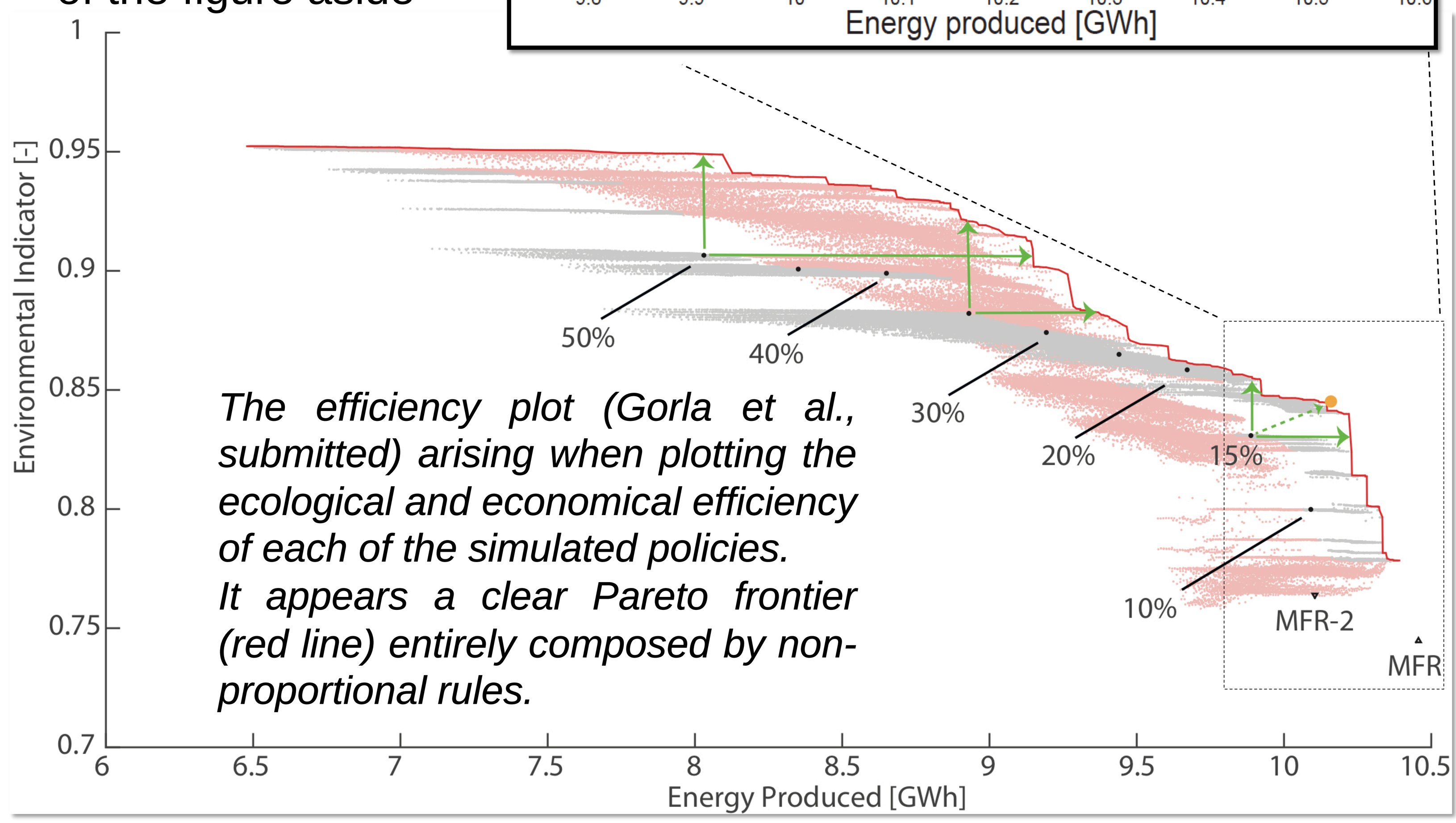
Global ecological (c) indicator obtained by joining hydrological (a) and fish habitat (b) indicators

3a. Results: the Pareto frontier in the efficiency plot

For Buseno SHPP we show the shape of the Pareto frontier (below), which is only formed by non-proportional rules.

The resulting flow variability can be seen in the panels of the figure aside

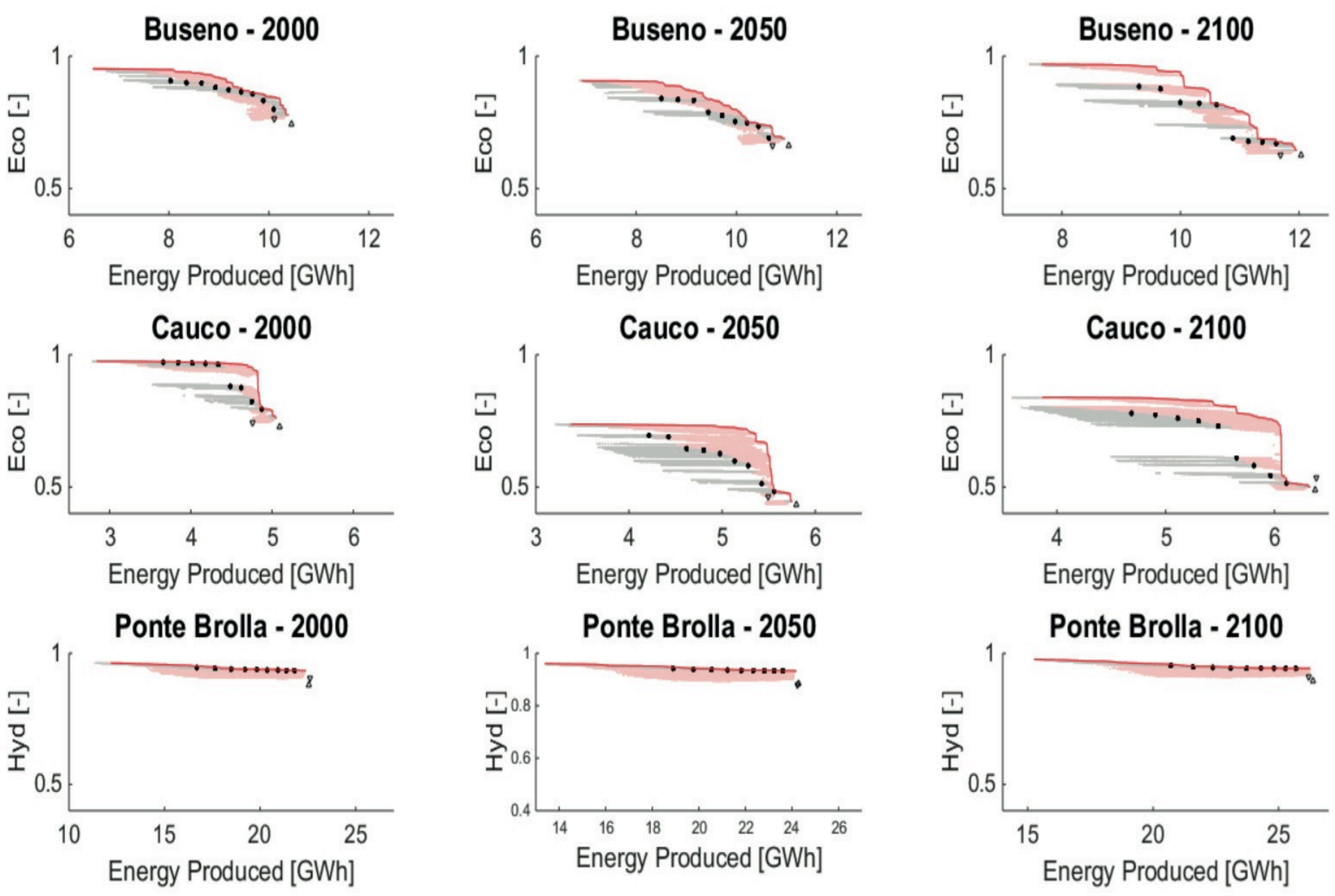




The efficiency plot (Gorla et al., submitted) arising when plotting the ecological and economical efficiency of each of the simulated policies. It appears a clear Pareto frontier (red line) entirely composed by non-proportional rules.

3b. Results: changing scenario of water availability

Water availability changes at medium- and long-term modifies the Pareto frontier and shifts the efficiency point toward other non-proportional rules. Concessions should be revisited before renewal!



The effect of water availability at medium (2050) and long (2090) term compared to present scenarios for three real case study (Gorla et al., submitted).

6. Conclusions

Constant minimal flow policies (particularly two or more thresholds) are often not efficient and can be improved with dynamic ones that ensure natural-like variability of flow releases

Depending on basin and power plant characteristics, non-proportional rules can be a better choice to protect the environment when exploitation is close to water resource saturation and availability

A Graphical User Interface (GUI) that allows to obtain the efficiency plot for SHHP is being developed and released

Bibliography

Perona, P. , D. Dürrenmatt, G. Characklis (2013). Obtaining natural like flow releases in diverted river reaches from simple riparian benefit economic models. *J. of Environmental Management* 118: 161-169
Gorla, L. and P. Perona (2013). On quantifying ecologically sustainable flow releases in a diverted river reach. *J. of Hydrology* 489: 98-107
Razurel, P., Gorla, L., Crouzy, B. and P. Perona (in revision). Non-proportional flow repartition rules for flow diversions. *Water Rsources Management*
Gorla, L., Razurel, P., Crouzy, B., and P. Perona (submitted). Non-proportional flow redistribution improves energy production and protects the environment.