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SWISS COMPETENCE CENTER for ENERGY RESEARCH
SUPPLY of ELECTRICITY

Multi-objective optimal operation of Alpine hydropower systems

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In cooperation with the CTI

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Goal of HWRM-ETHZ within SCCER-SoE

Define a *multi-objective model framework* to:

- evaluate different HP operation alternatives under *future climate, demand and market scenarios*
- assess which alternatives lead to maximization of production to *support the 2050 Energy Strategy*

Explore medium to long term strategies for:

- increasing production
- exploiting the pumping potential (especially in volatile and uncertain conditions)
- reducing negative effects on the riverine ecosystem
- exploring the role of technical adaptation of HP systems
- ...

Hydropower and riverine ecosystems nexus

Volatile electricity prices and hydrological conditions might call for more *flexible hydropower* operations.

These may expose downstream riverine ecosystems to increased threats, thus exacerbating the well known *conflict between hydropower generation and environment conservation*.

Environmental flows

The current Swiss legislation prescribes *water and aquatic ecosystems protection* e.g. through the practice of Environmental Flows releases (EFs)

Despite the expected aquatic ecosystem protection, EFs reduce significantly the quantity of water available to the ecosystem, thus reducing the habitat's size, and the variability of flow conditions, thus affecting habitat dynamics (e.g., Jager and Rose, 2003 Molnar et al., 2008).

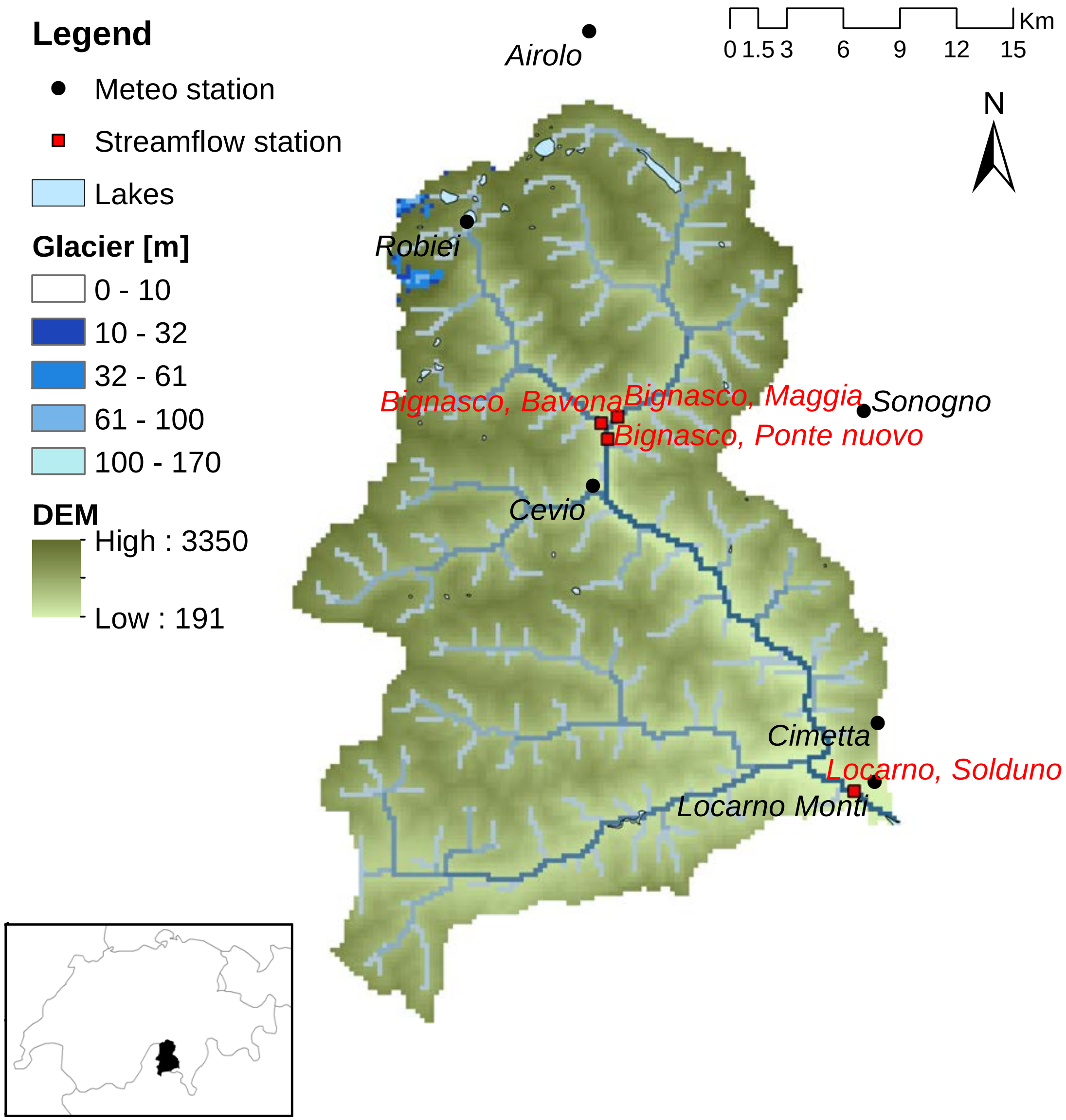
Present days EFs policies might *not* represent the best solution for environment conservation because they may be too simplistic (e.g. do not mitigate the HP induced dampening of the natural variability) and, thus, are not able to guarantee fundamental ecosystem processes (e.g., Baron et al., 2002, Jager and Smith, 2008).

Objective and research questions

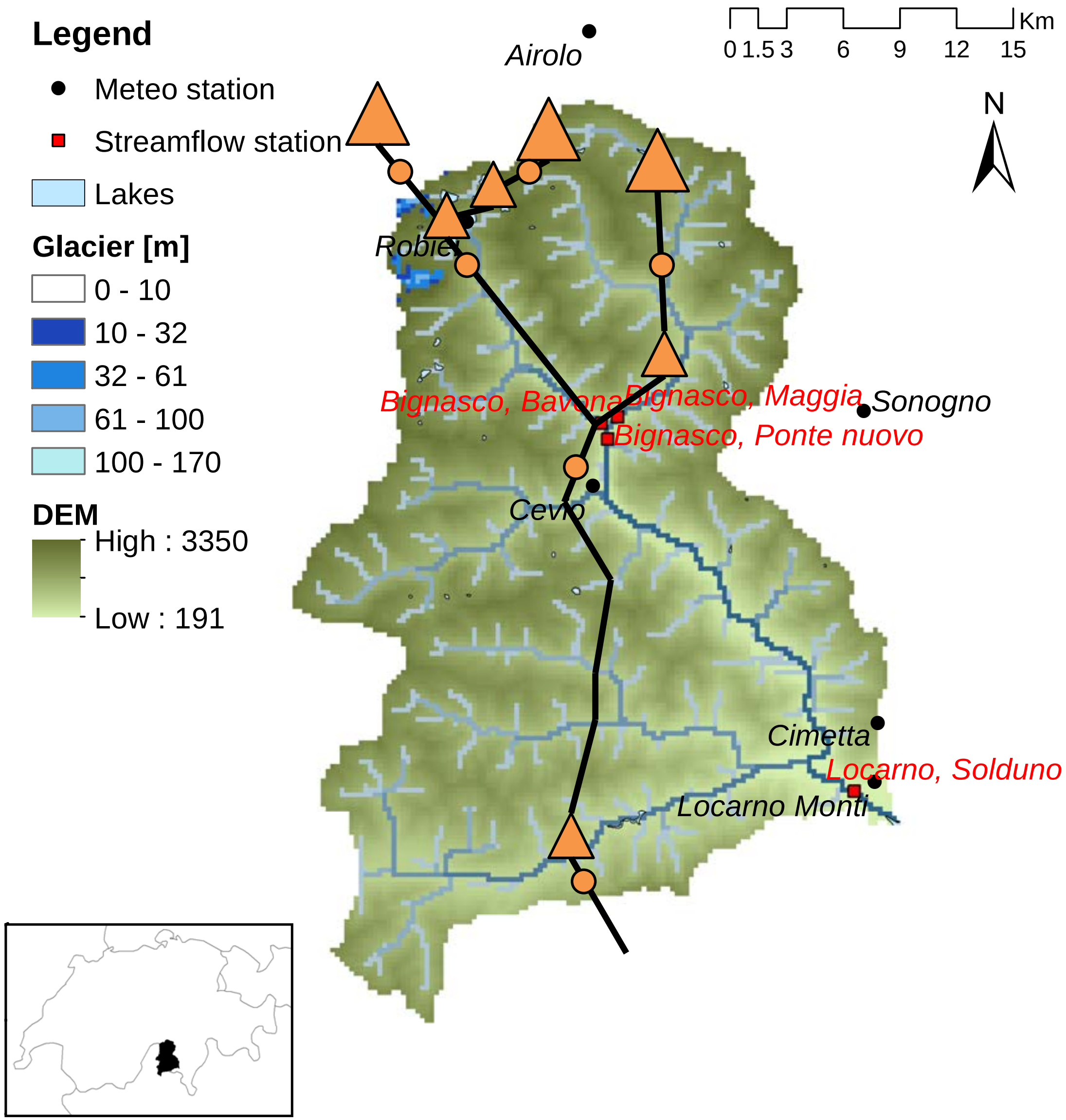
Balancing the profitability of hydropower companies and better conditions for the environment, under different forcing conditions (e.g. climate change and price volatility).

- How much do Environmental Flows limit hydropower operating interests?
- How much will more flexible operations of hydropower reservoirs harm the environment?
- Do the trade-offs between hydropower interests and environment conservation change with increased energy price and water availability uncertainty?

Case study: Maggia valley

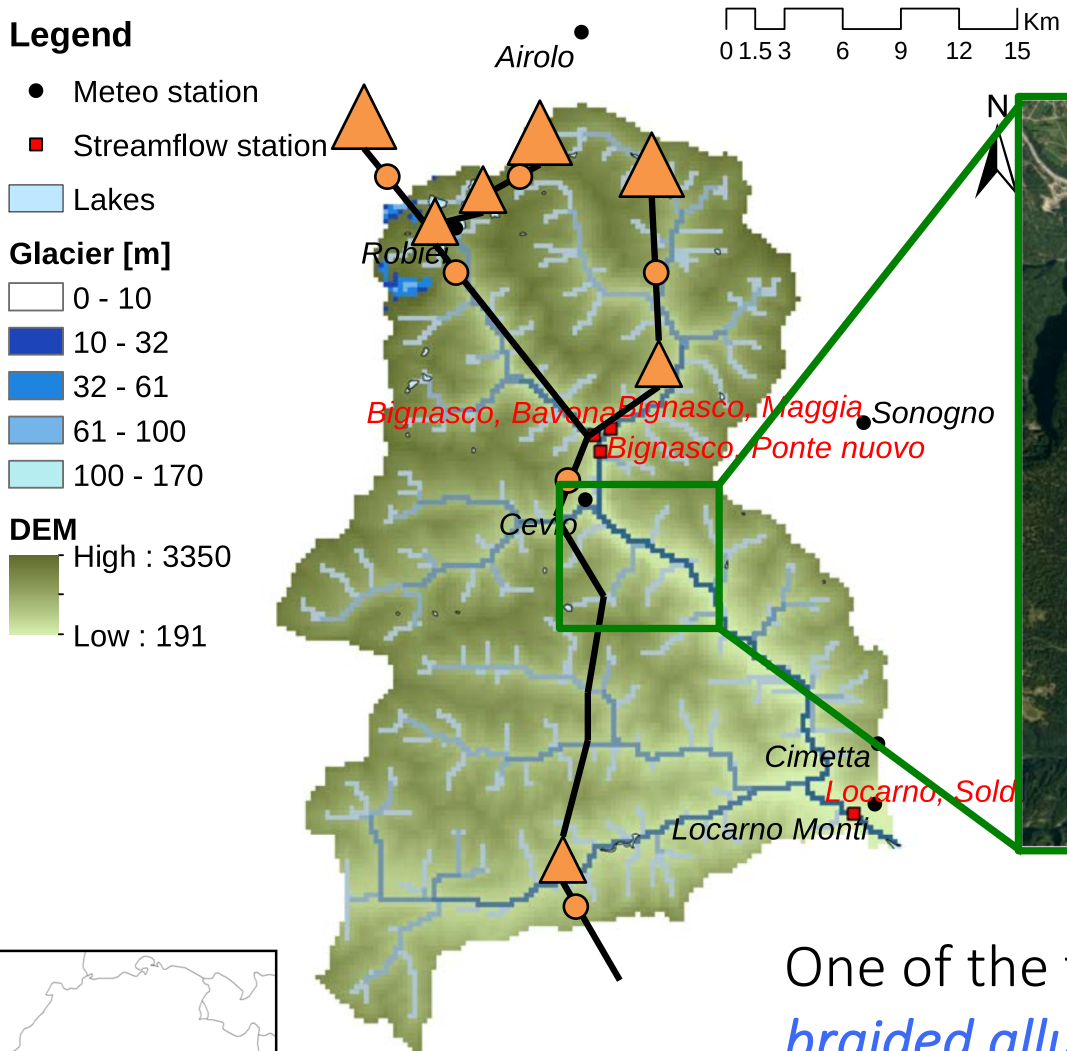


Case study: Maggia valley



7 reservoirs with a total capacity of 600 MW, which produce annually >1200 GWh

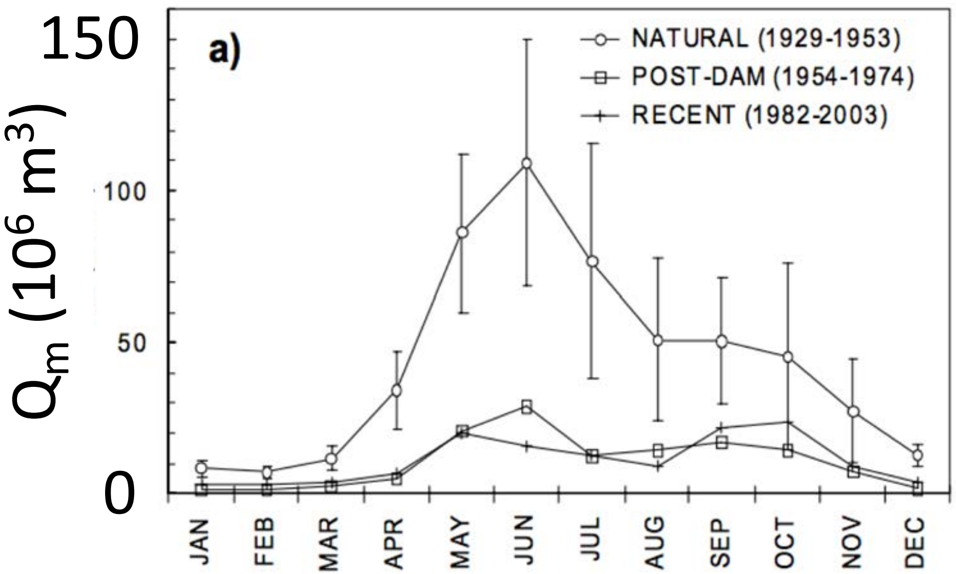
Case study: Maggia valley

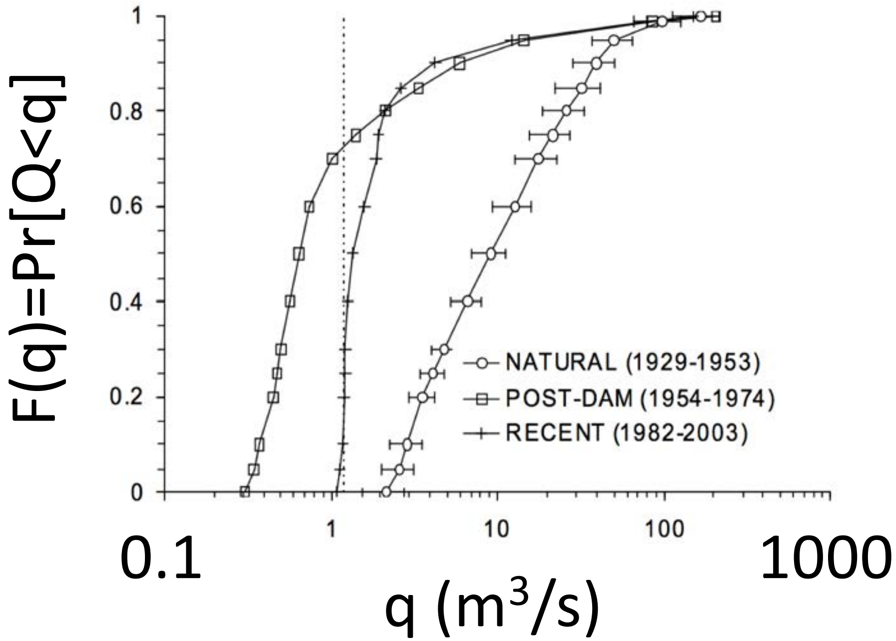


One of the few remaining natural and *braided alluvial floodplains* in Switzerland, declared of national interest.

Effects of hydropower operations on natural flow regime

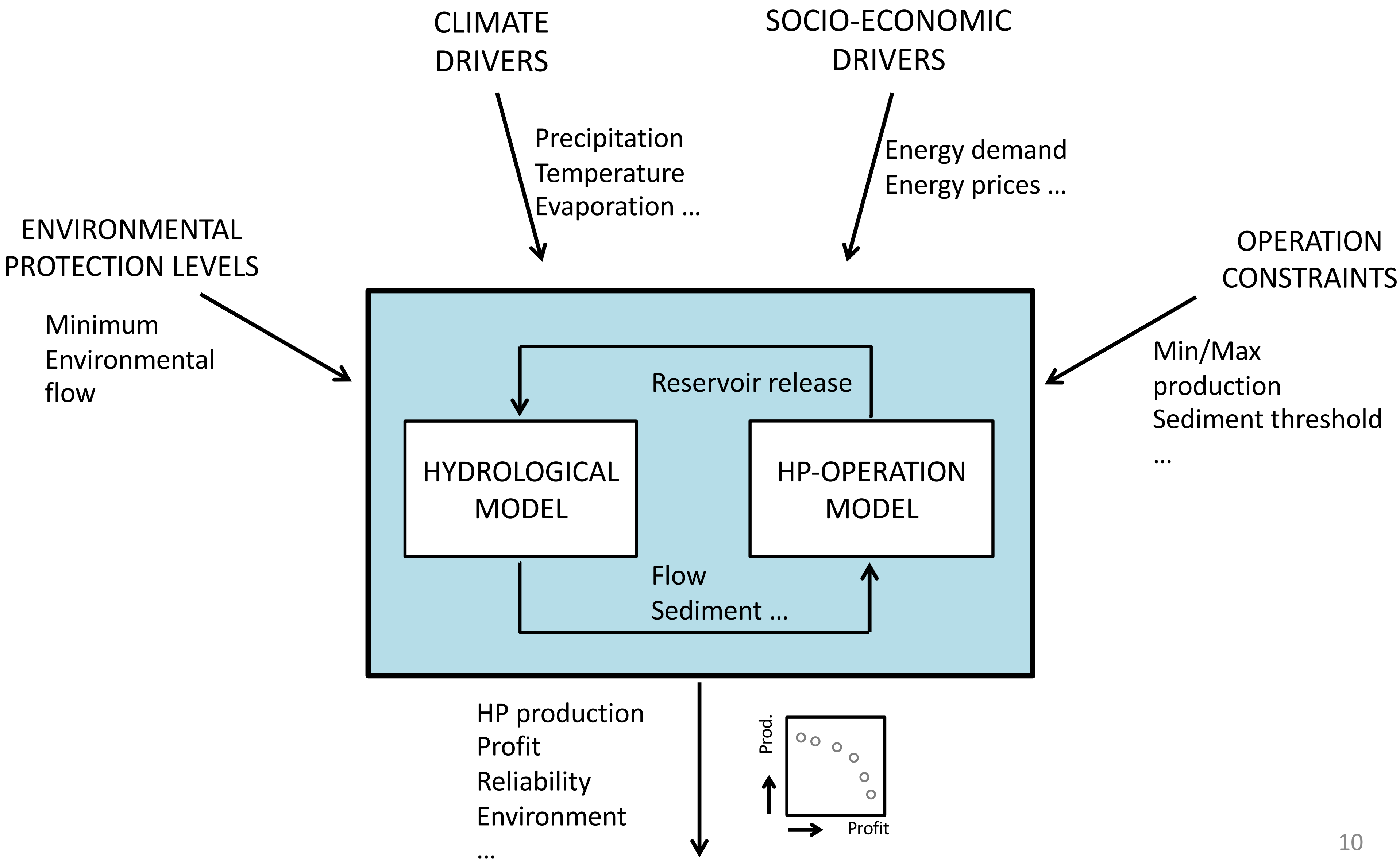
Changes in monthly flow at Bignasco (Molnar et al. 2008)





How do we approach the problem?

➡*Multi-objective modelling framework*

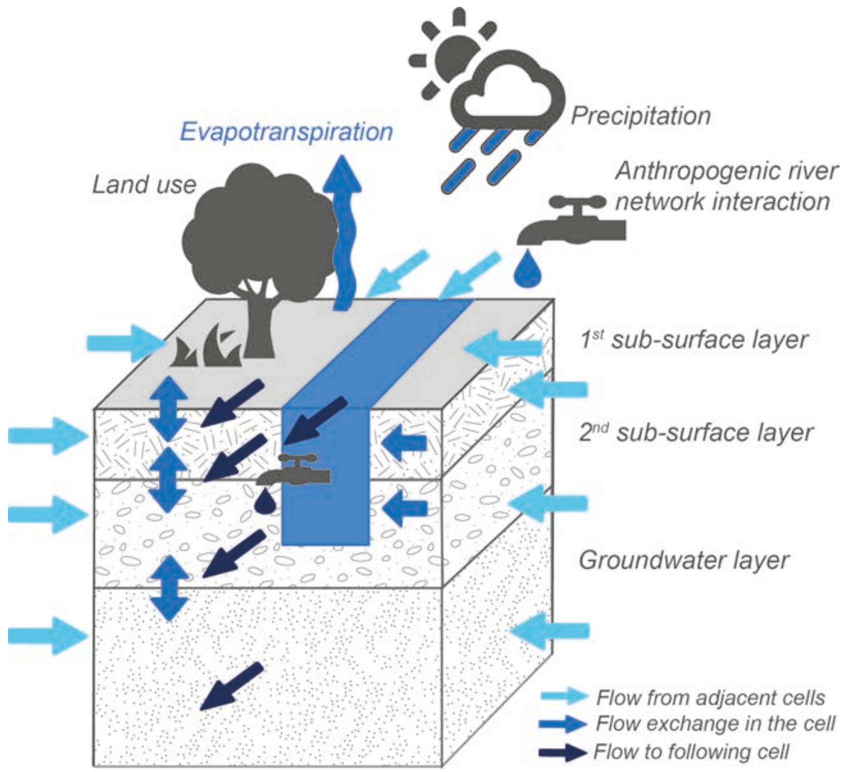


Hydrological modelling

Objective:
- simulate water availability to hydropower facilities
- simulate the effects of different hydropower operation on the downstream riverine ecosystems

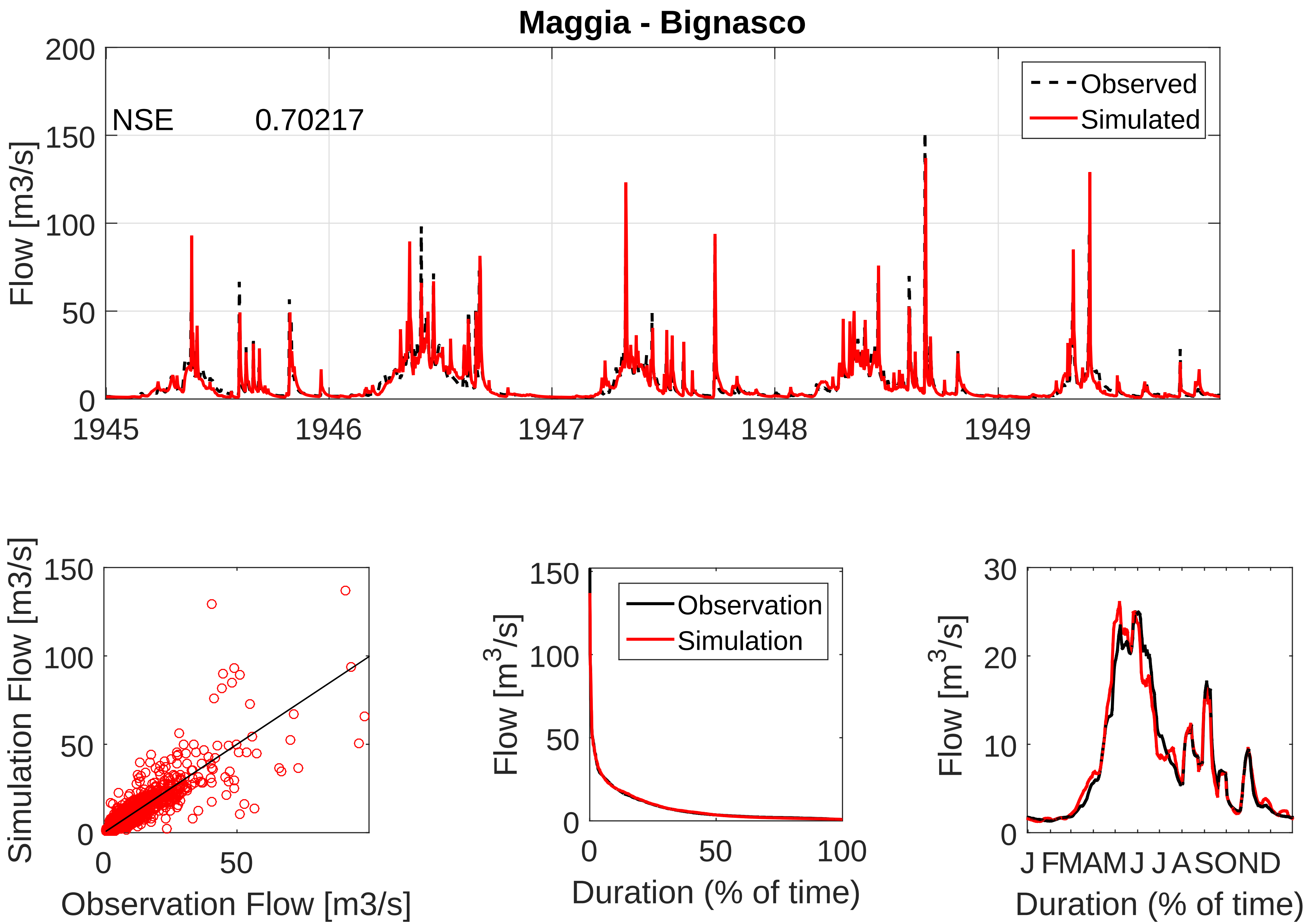
Two setups:
- pre-dam: pristine ecosystem
- post-dam: current condition

Common features:
- Temporal resolution ≤ 1 day
- Spatial resolution = 250 m



Topkapi-ETH hydrological model

Hydrological modelling – pre dam validation



Hydropower operations model

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Objective:

- simulate historical operations
- simulate the effects of different environmental conditions on hydropower performance
- exploring different trade-off operations that aim at balancing hydropower performance and ecosystem conditions

Multi-objective optimization:

- maximize net electricity production (production – pumping)
- maximize net revenue
- maximize ecosystem quality

solved by means of Evolutionary Multi-Objective Direct Policy Search

HP system layout and Optimisation Model details (OFIMA approved)

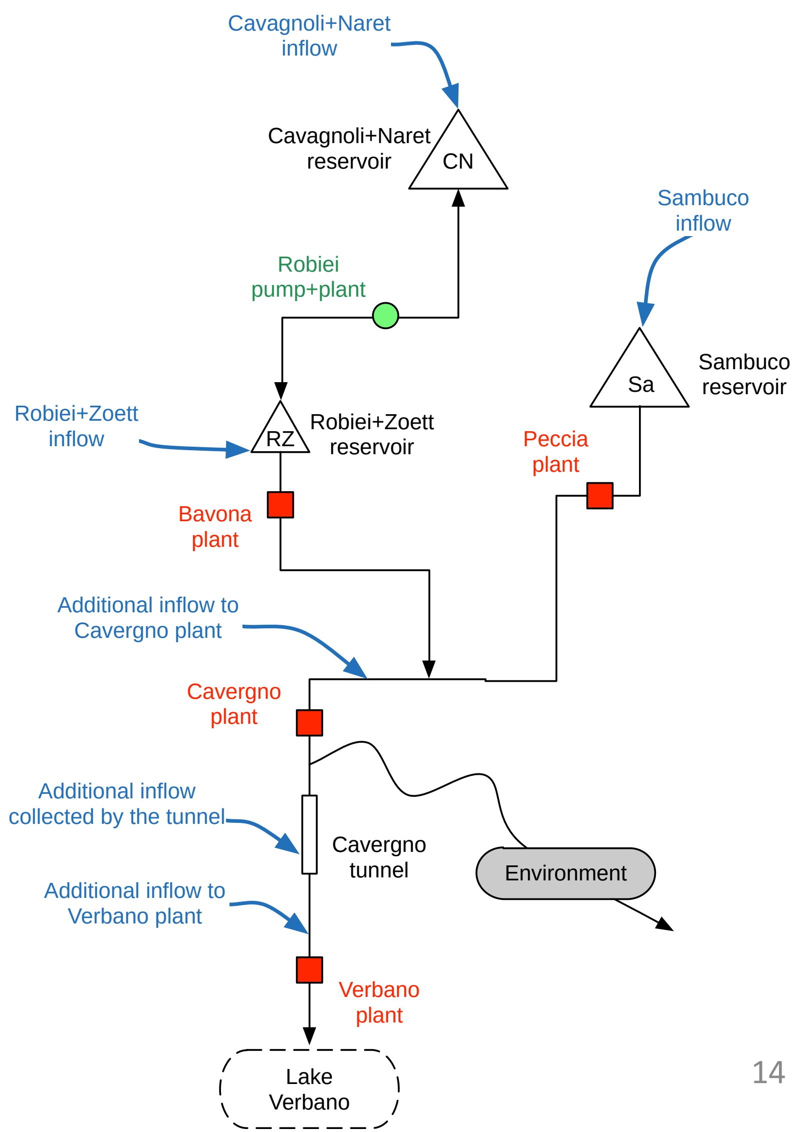
Hydropower model features:

- 3 reservoirs (3 state var.s)
- 1 prod./pump. plant (2 decision var.s)
- 4 prod. plants (2 decision var.s)
- 1 environmental flow (1 decision var.)
- 6 uncontrolled flows (6 disturbances)

Reservoir operating policies:

- Radial basis functions (170 parameters)
- 700-800 thousand function evaluations to get the Pareto Frontier
- computational time: 10 days on the ETH cluster (parallel computing)

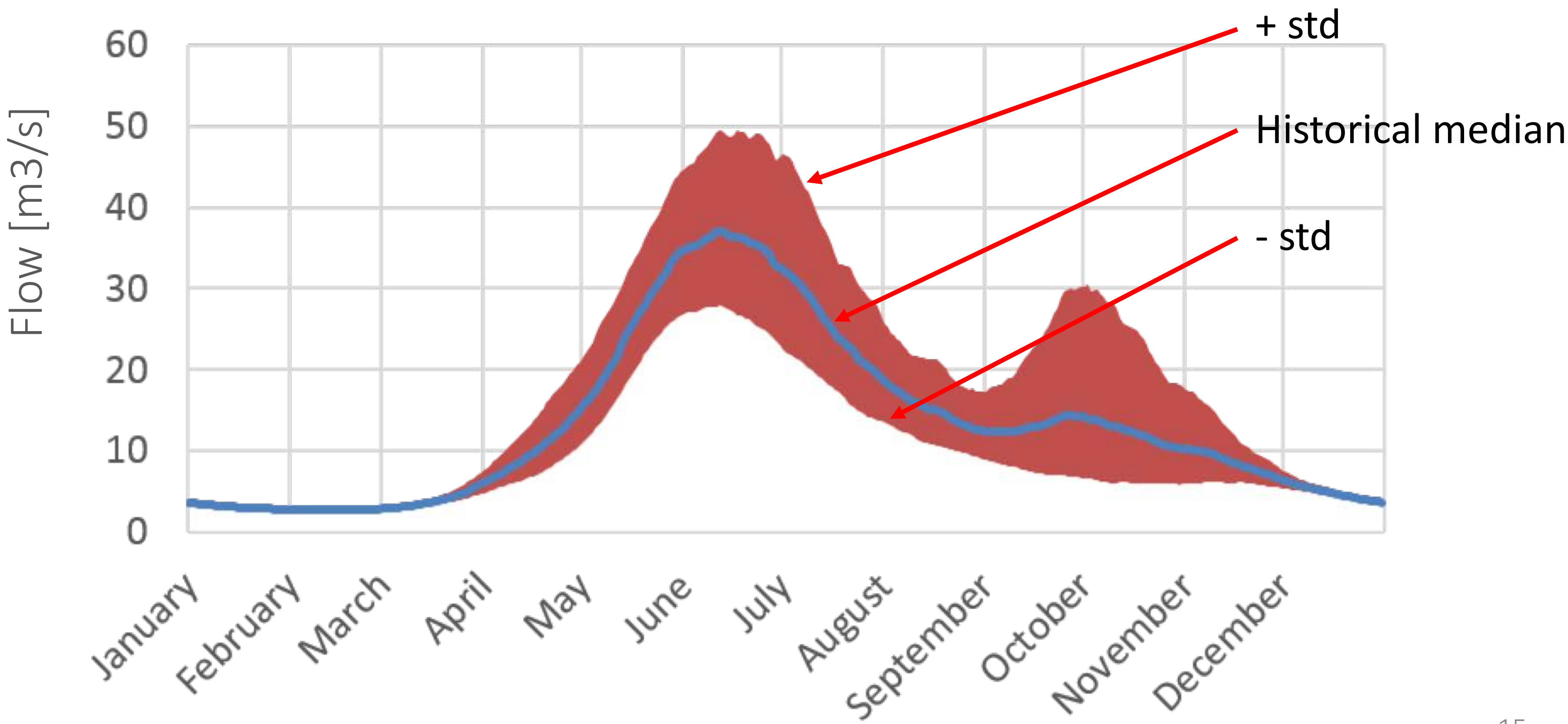
MODELLED SYSTEM



How do we measure ecosystem quality?

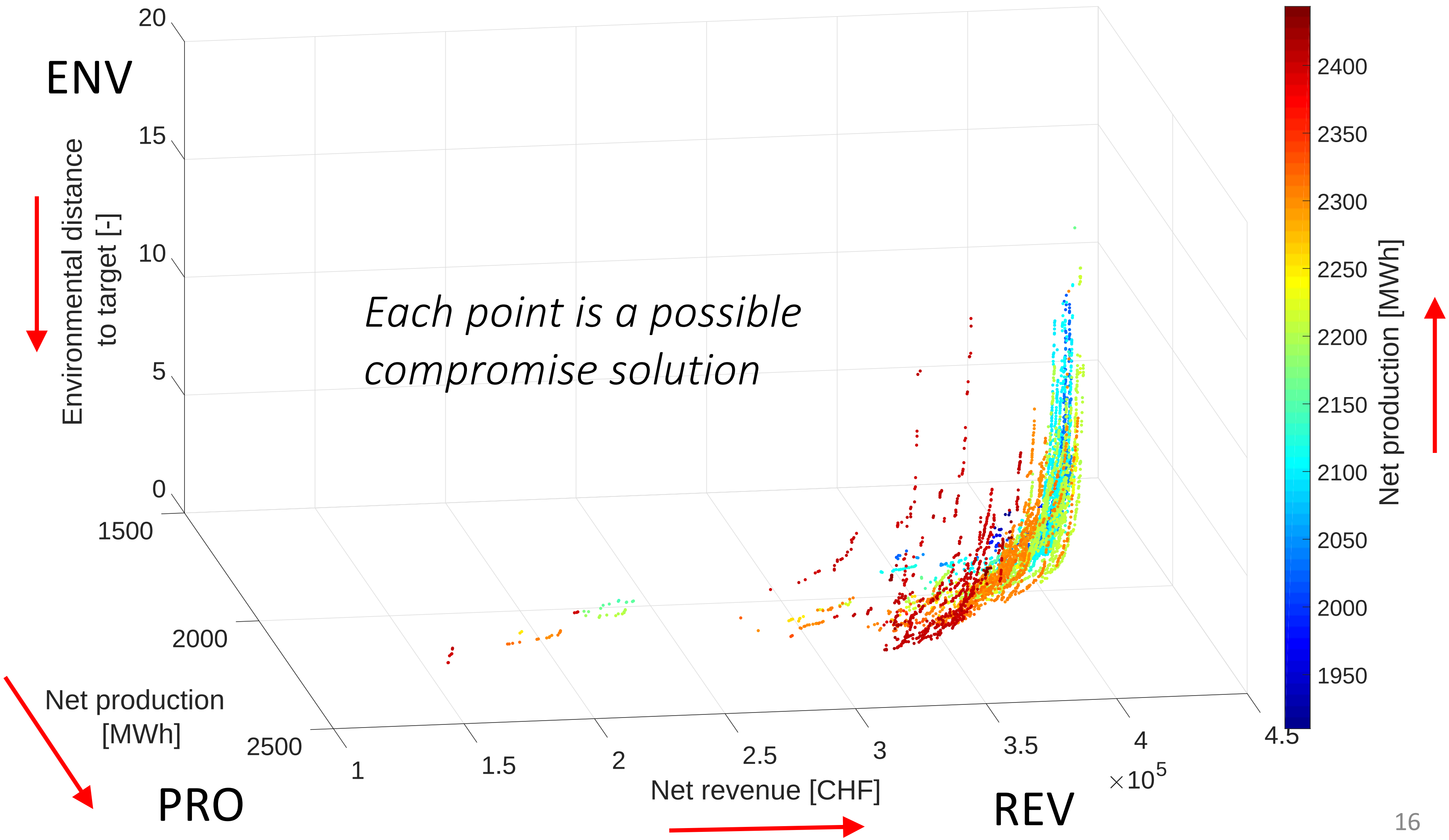
We consider the pre-dam (natural) flow regime as a reference, i.e. target for the optimization

The relevant indicator to measure the impact of a given HP operational policy is the *distance from the pre-dam condition*



Example of hydropower optimisation result

The different points represent Pareto optimal *trade-offs* between the 3 objective functions (production, revenue, environment).



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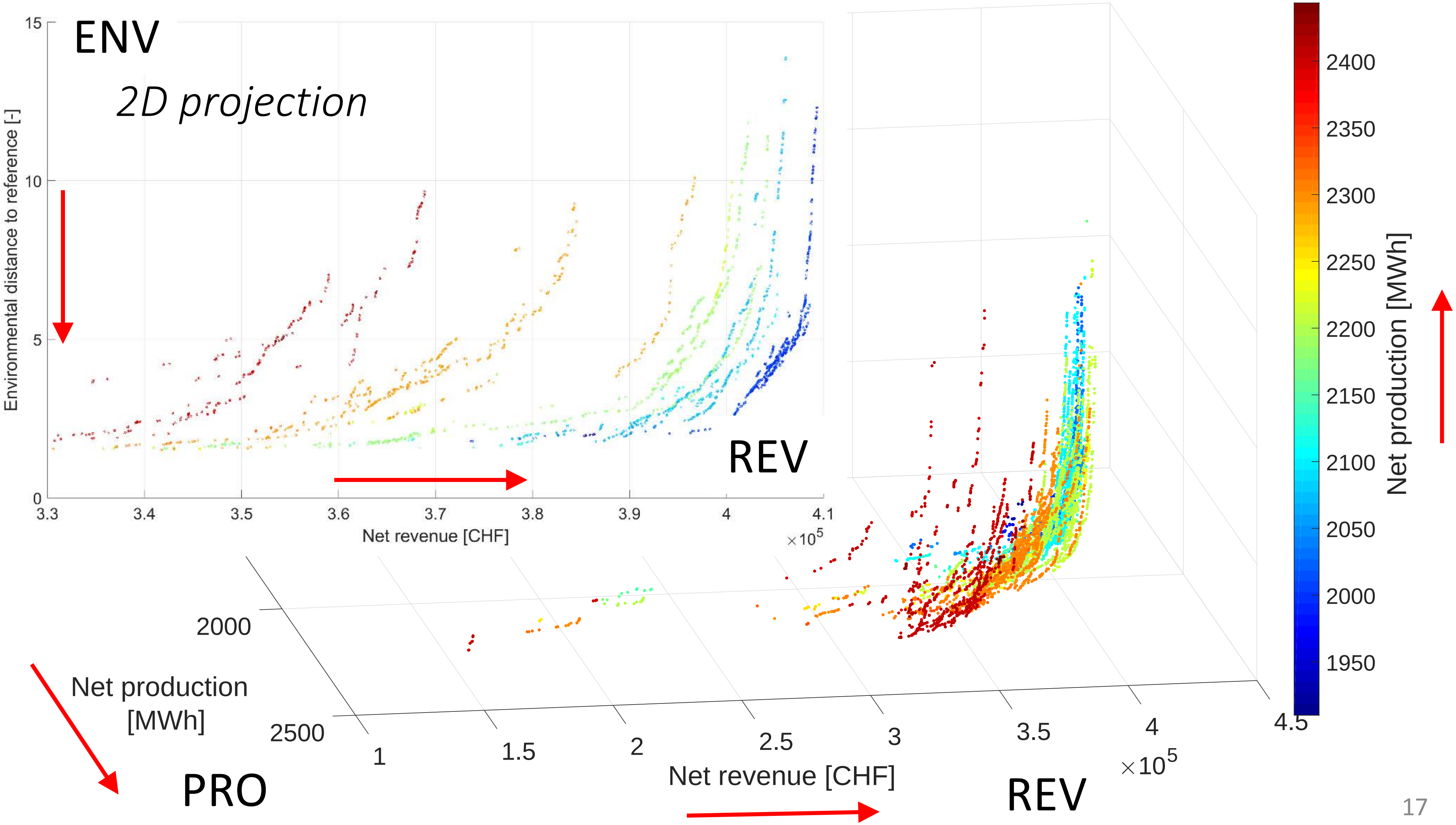

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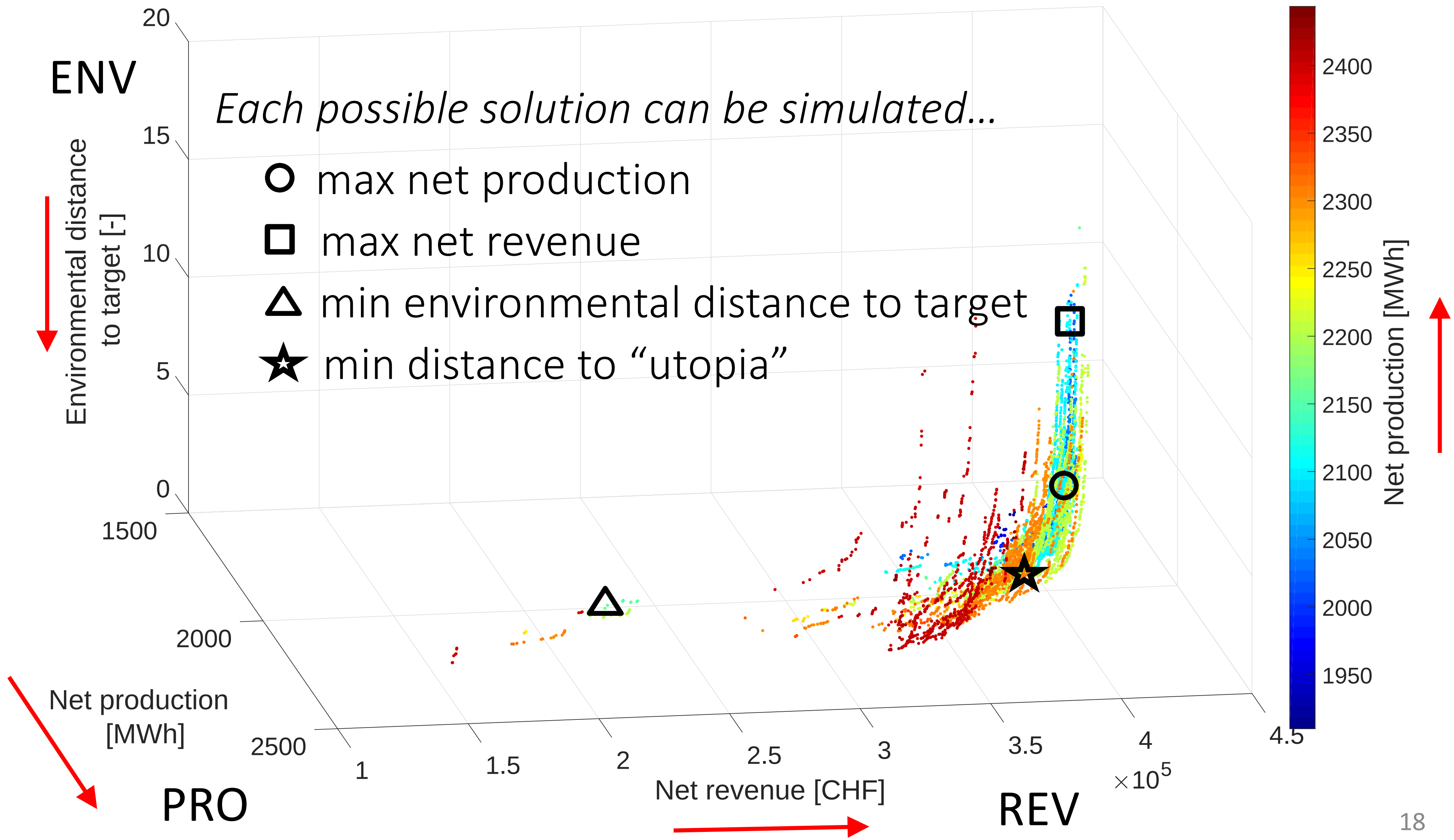
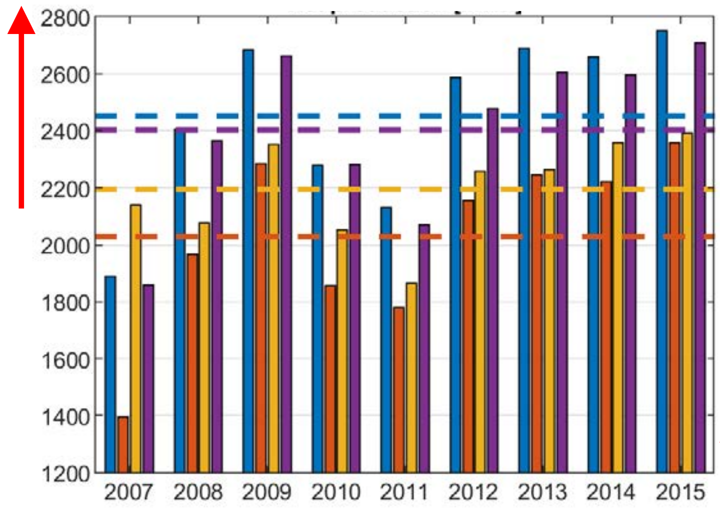


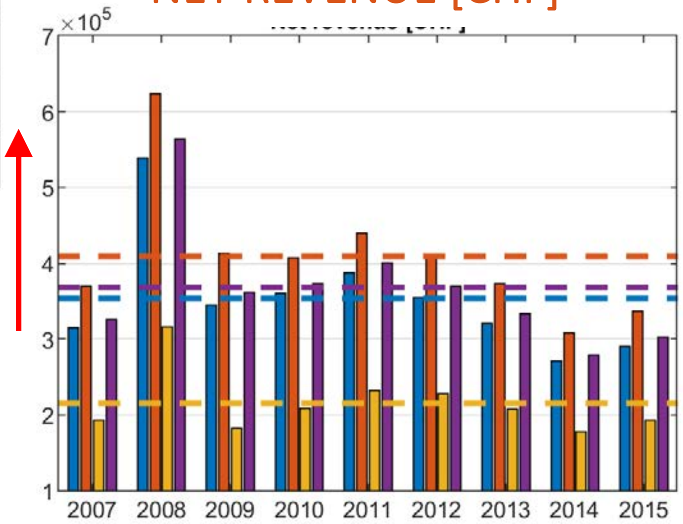
Example of hydropower optimisation result

... to assess the hydropower operations and the effects on the environment

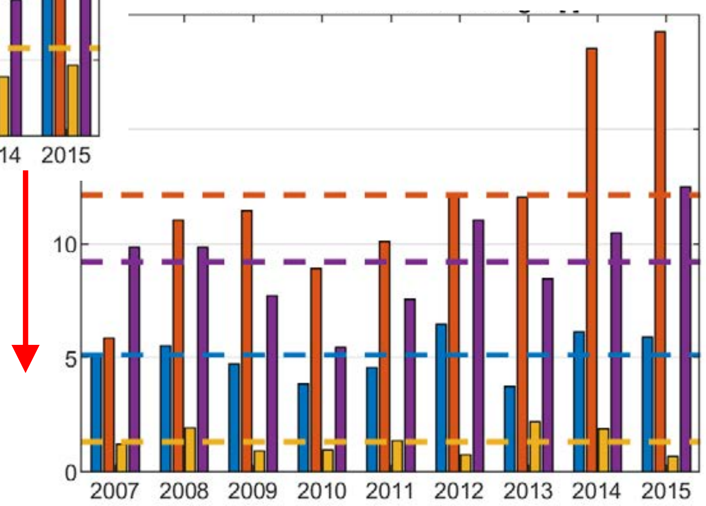
NET PRODUCTION [MWh]



NET REVENUE [CHF]



ENVIRONMENTAL DISTANCE TO TARGET [-]



- ○ max net production
- □ max net revenue
- △ min environmental distance to target
- ★ min distance to "utopia"

Example of hydropower optimisation result

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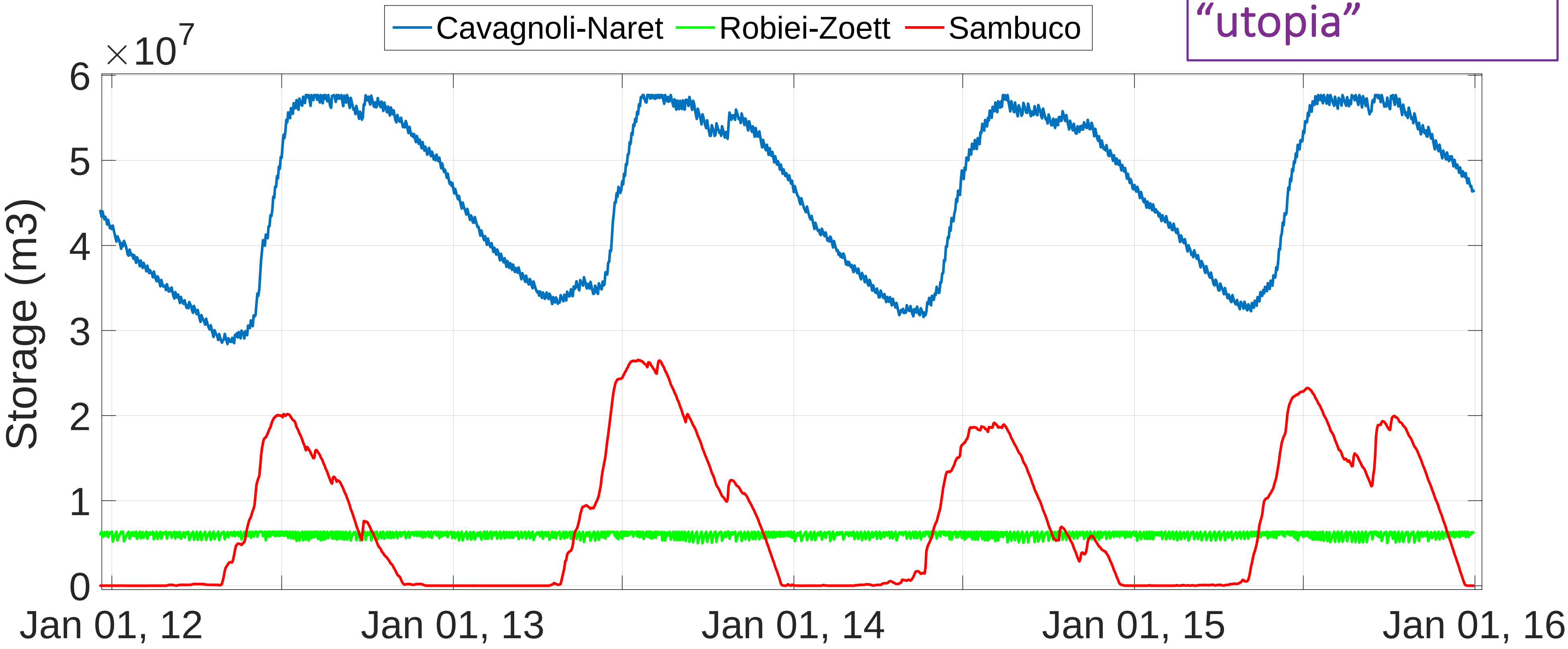
Reservoir storages simulated using historical inflows and electricity price and one of the compromise operating policy:

★ min distance to "utopia"



… and to analyse storage variable trajectories

What comes next?

- Use of *climate change (CC) projections* from a high resolution space-time stochastic weather generator to explore CC effects on water availability and hydropower system operations also accounting for the uncertainty due to the natural variability of climate (robust optimization).
- Use of *price projections* (PP) to assess their effects on the hydropower system operations and pumping.
- *Joint CC and PP scenarios* effects on the multiobjective Pareto Frontier.
- Flow simulations for policies selected in agreement with HP company used to *feed a coupled surface-groundwater model* of the Maggia floodplain, in turn connected to a vegetation response model and/or habitat model (link to/cooperation with the SNF NFP70 Project "HydroEnv").
- Comparison of the *Pareto Frontier resulting from different formulations of the environment objective function*, e.g. fixed vs various dynamic EFs release strategies also provided by the "HydroEnv" project.

What could come next?
(pending 3rd phase funding)

- Inclusion of *technical adaptations* (following outcomes of WP3) in the representation of the HP systems within the hydrological and hydropower models
- Adding a new forcing represented by the *change in the demand structure and magnitude* (e.g. due to higher presence of new renewables).
- Extension of the current (and future) analysis to *other exemplary HP systems*, to extrapolate conclusions for the entire Swiss HP landscape.
- Extension to exploration of *other objectives for multipurpose* reservoir use (irrigation, water supply, …)

Thank you for your attention !