Balancing Hydropower Production and Environment Through Flexible Operation

Andrea Castelletti, Matteo Giuliani, Enrico Weber, and Paolo Burlando

ETHZ – HWRM

Lausanne, 13.09.2019
Hydropower has a number of benefits ...

**Clean**: contributing to decarbonisation

**Versatile**: can generate power to the grid immediately

**Flexible**: can be used for balancing increased variability induced by RES

... and many others

3500 new dams being planned or built around the world
long-term narrowing of the active braided channel system, a decrease in pioneer vegetation stages, and a gradual maturing of the floodplain forest

evidence of short-term response following large floods, reworking of the channel bed, increase in morphological heterogeneity, vegetation uprooting due to scour

evidence of changes in tributary dynamics due to streamflow regulation

[Sturzenegger, 2005]
Can we internalize these externalities?
Traditional approach: e-flow constraint

- **CONSTANT**
  - e-flow remains steady from January to December.

- **TIME VARYING**
  - e-flow shows periodic changes from January to December.
Traditional approach: e-flow constraint

**CONSTANT**

**TIME VARYING**

Der Bund korrigit das Ausbaupotenzial der Wasserkraft nach unten.

Höher als 2012 angenommen sind zudem die künftigen Produktionsverluste, die aus Umweltschutzgründen entstehen. So müssen Werke, die ihre Konzession erneuern, strengere Restwasserbestimmungen einhalten, sie müssen also mehr Wasser ungenutzt durch den natürlichen Wasserlauf lassen als bisher.
IDEA: dynamic e-flow

- **CONSTANT**
  - e-flow graph from Jan to Dec
  - Fixed value throughout the period

- **TIME VARYING**
  - e-flow graph from Jan to Dec
  - Steps indicating a changing pattern

- **DYNAMIC**
  - Release graph from Jan to Dec
  - Waveform with multiple peaks and troughs
How to design a dynamic e-flows

by transforming the e-flow constraint into an operating target

PRODUCTION or REVENUE

max HP

max ECO

ECOSYSTEM QUALITY

release

Jan

Dec

DYNAMIC
Numerical experiments on the Maggia valley hydropower system
The Maggia valley – battery of the Tessin

MAIN FEATURES
Storage capacity: 134.22 Mm$^3$
Annual inflow: 749 Mm$^3$
Installed power: 600 MW
Annual production: 1265 GWh
The Maggia valley – a unique riparian ecosystem
New 2018 e-flow regulation

vs DYNAMIC e-flow

new e-flow
past e-flow
Multi-objective modelling framework

**CLIMATE DRIVERS**
- Precipitation
- Temperature
- Evaporation...

**Socio-economic Drivers**
- Energy demand
- Energy prices...

**Hydrological Model**
- Reservoir release
- Flow
- Sediment...

**HP-Operation Model**
- HP production
- Profit
- Reliability
- Environment...

**Environmental Protection Levels**
- Minimum Environmental flow

**Operation Constraints**
- Min/Max production
- Sediment threshold...

**Multi-objective modeling framework**
Hydrological modelling: TPK-ETH

**Setup** (preliminary, historical data):
- Temporal resolution = 1 day
- Spatial resolution = 250 m
Reservoir operating policies:

- Radial basis functions (170 parameters)
- 1 million function evaluations x 20 random trials
- Computational time: **5600 hours** on the ETH cluster
Multi-objective optimization:
• maximize electricity production
• maximize revenue
• maximize ecosystem quality

How do we measure ecosystem quality?
Numerical Results
Trade-off analysis (past e-flow)
Trade-off analysis (past e-flow)

- best production
- best environment
Trade-off analysis (past e-flow)

best production

flow to Maggia

best environment
Contrasting past, new, and dynamic e-flow
Contrasting past, new, and dynamic e-flow

past e-flow operation

- past e-flow
- new e-flow
- dynamic e-flow
Contrasting past, new, and dynamic e-flow
Alternative strategies

![Graph showing past e-flow, new e-flow, and alternative to new e-flow operations.]

- Past e-flow
- New e-flow
- Alternative to new e-flow

- Dynamic e-flow
Alternative strategies

alternative to new e-flow
Alternative strategies 2

alternative to past e-flow

past e-flow operation

new e-flow operation

production

environment

past e-flow
new e-flow
dynamic e-flow
1. Dynamic e-flow allows for win-win solutions

2. Key aspect is the definition of the environmental operating target

3. Coupling with high resolution ecohydrological model to assess impact on a finer scale
Thank you