H11J-1270 AGU FALL MEETING San Francisco | 9–13 December 2013

Università degli Studi di Padova | unine Université de Neuchâtel | eawag aquatic research

Small run-of-river hydropower: tradeoff among energy production, profitability and hydrologic impact

Stefano Basso[1,2], Gianluca Lazzaro[3], Mario Schirmer[1,2], Gianluca Botter[3]

[1] Department W+T, Swiss Federal Institute of Aquatic Science and Technology (Eawag), Dübendorf, Switzerland; [2] Centre for Hydrogeology and Geothermics, University of Neuchâtel, Neuchâtel, Switzerland; [3] Department of Civil, Architectural and Environmental Engineering, University of Padova, Padua, Italy.

AVAILABLE WATER RESOURCES

Physically-based model of streamflow production to overcome the lack of flow measurements

ANALYTICAL EXPRESSIONS for the **STREAMFLOW PDF** and the **FLOW DURATION CURVE**

$$p(q)=\frac{(\alpha k)^{-\frac{\lambda}{k}}}{\Gamma(\lambda/k)}q^{\frac{\lambda}{k}-1}e^{-\frac{q}{\alpha k}}$$

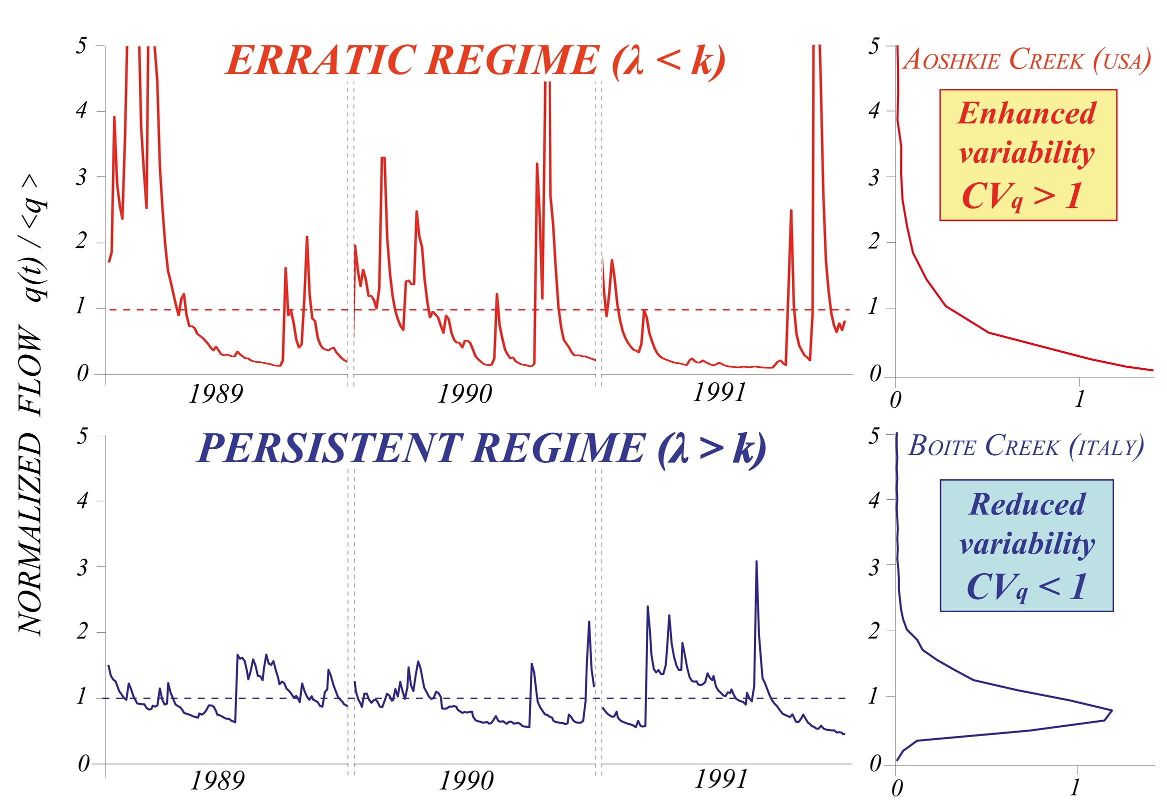
[Botter et al., WRR 2007]

$$D(q)=\frac{\Gamma(\lambda/k,q/\alpha k)}{\Gamma(\lambda/k)}$$

[Botter et al., WRR 2008]

in terms of three physical parameters estimated from hydrologic/climatic/morphologic data:

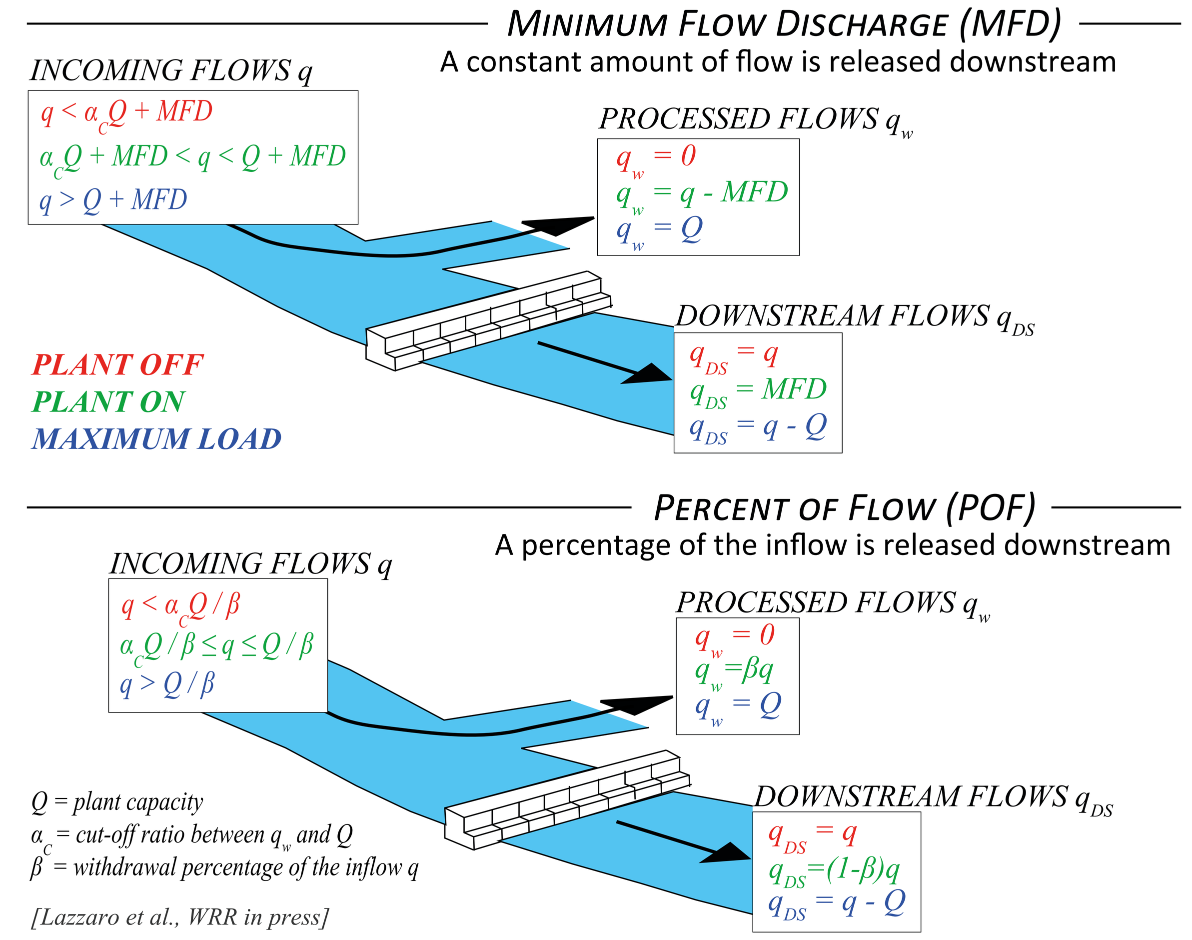
- α = mean rainfall depth → precipitation
- λ = frequency of effective rainfall $=f(\lambda_p, ET_{max}, ...)$ → precipitation, climate, land cover
- $1/k$ = mean catchment response time → recession curves, DTM



OPTIMAL PLANT CAPACITY: analytic formulation

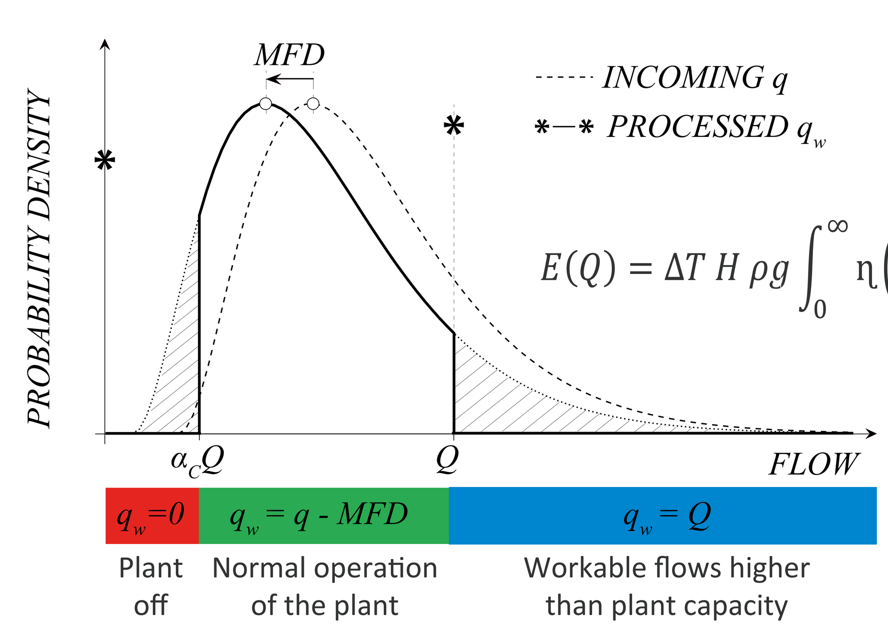
MANAGEMENT RULES

Comparison of alternative management strategies



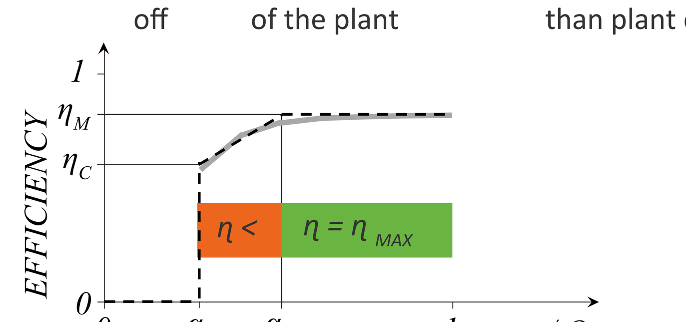
ENERGY PRODUCTION

The interplay of varying turbine efficiency and range of flows processed (both functions of the plant capacity Q) sets the overall produced energy.



$$E(Q)=\Delta T\ H\ \rho g\int_0^\infty \eta\left(\frac{q_w}{Q}\right)p_w(q_w)\ q_w\ dq_w$$

maximization $\frac{dE(Q)}{dQ}=0$



Energy optimum (optimal exploitation of hydropower potential)

[Basso and Botter, WRR 2012]

ECONOMIC PROFITABILITY

Revenue from energy sell

Annual revenue $R_1(Q)=e_P E_1(Q)$

Total revenue (in plant lifetime n)

$$R_n(Q)=\sum_{k=1}^{n}\frac{1}{(1+r)^k}R_1(Q)$$

Construction costs

$$C(Q)=aQ^b$$

a,b = empirical parameters
e_P = energy price (subsidized)
r = interest rate

Net present value of the plant

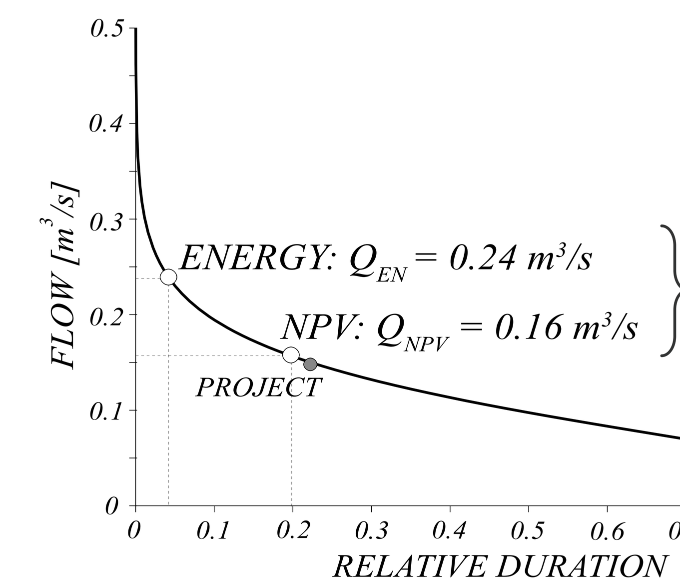
$$NPV(Q)=R_n(Q)-C(Q)$$

maximization $\frac{d\,NPV(Q)}{dQ}=0$ → **Economic optimum** (max profit)

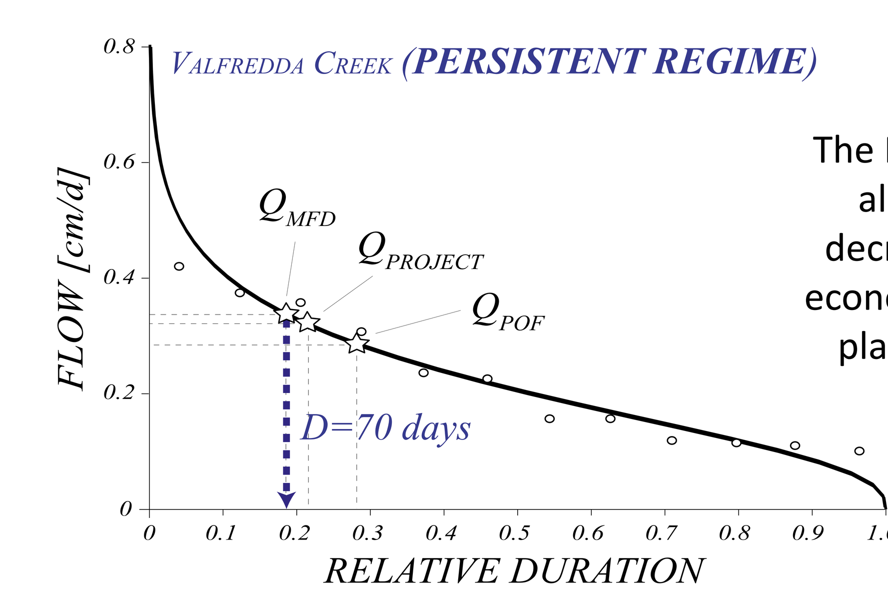
OPTIMAL PLANT CAPACITY: results

ENERGY AND ECONOMIC OPTIMA

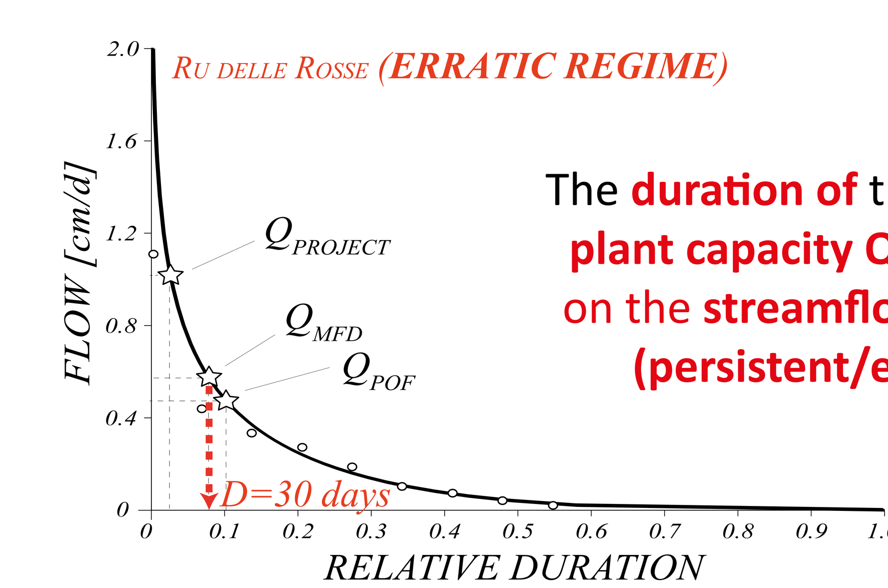
Analytical/graphical solutions for the plant capacity Q maximizing profitability or produced energy as a function of the flow regime of the river and technical and economic features of the plant.



ROLE OF THE HYDROLOGIC REGIME



The POF strategy allows for a decrease of the economic optimal plant capacity



The **duration of the optimal plant capacity Q depends on the streamflow regime (persistent/erratic)**

TARGETED INCENTIVE POLICIES

Policies targeted to reduce the gap between energy and economic optimizations.

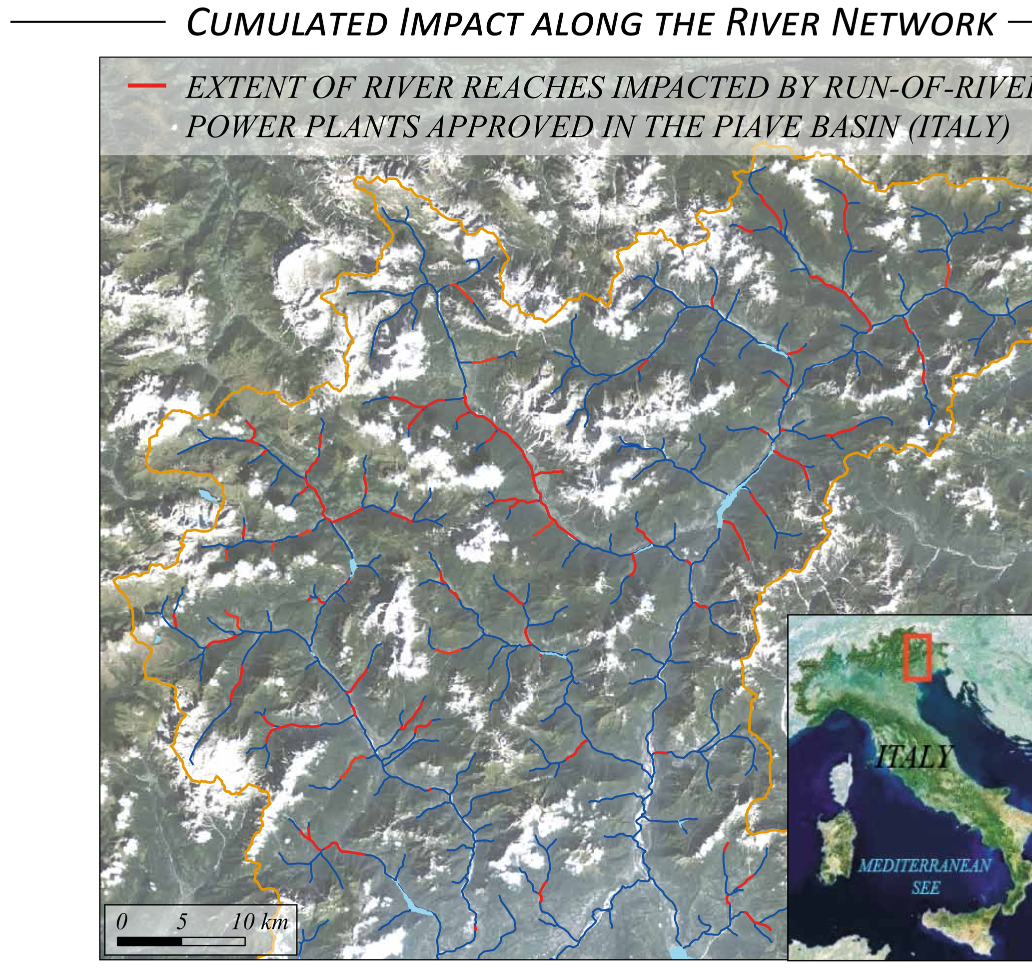
- Changes of the subsidized energy price cause different impacts on profitabilities of plants exploiting flows of persistent or erratic rivers (safety of the investment).
- Decreasing construction costs by subsidies is more efficient than paying a fixed price for the energy produced.

[Basso and Botter, WRR 2012]

HYDROLOGIC DISTURBANCE

SIGNIFICANCE OF HYDROLOGIC DISTURBANCE BY SMALL RUN-OF-RIVER POWER PLANTS

Cumulated impact along the river network

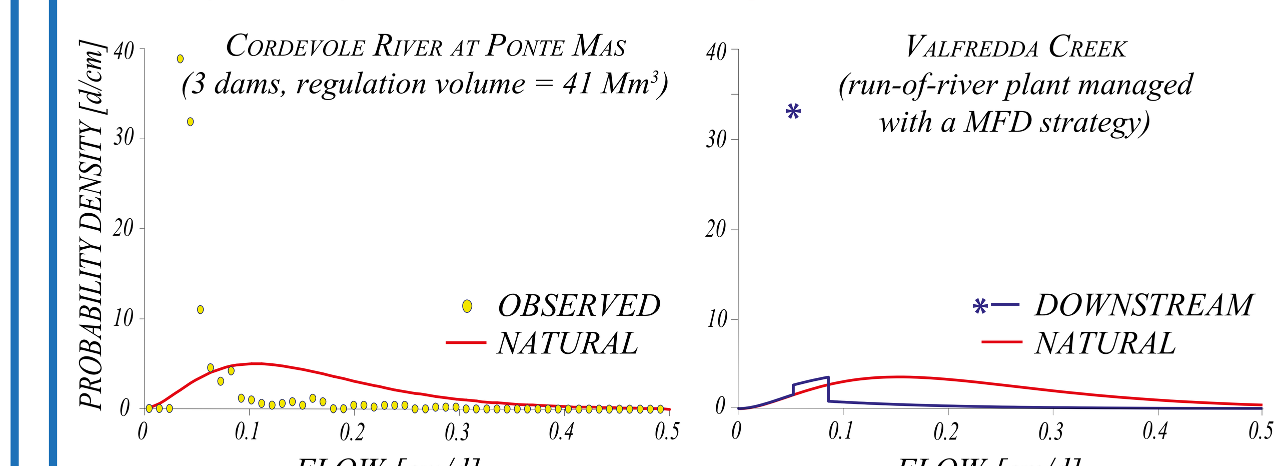


Overall 150 km of river network affected [Lazzaro et al., WRR in press]

Small run-of-river power plants built in cascade along the same river result in a widespread cumulated impact

Small run-of-river vs reservoir

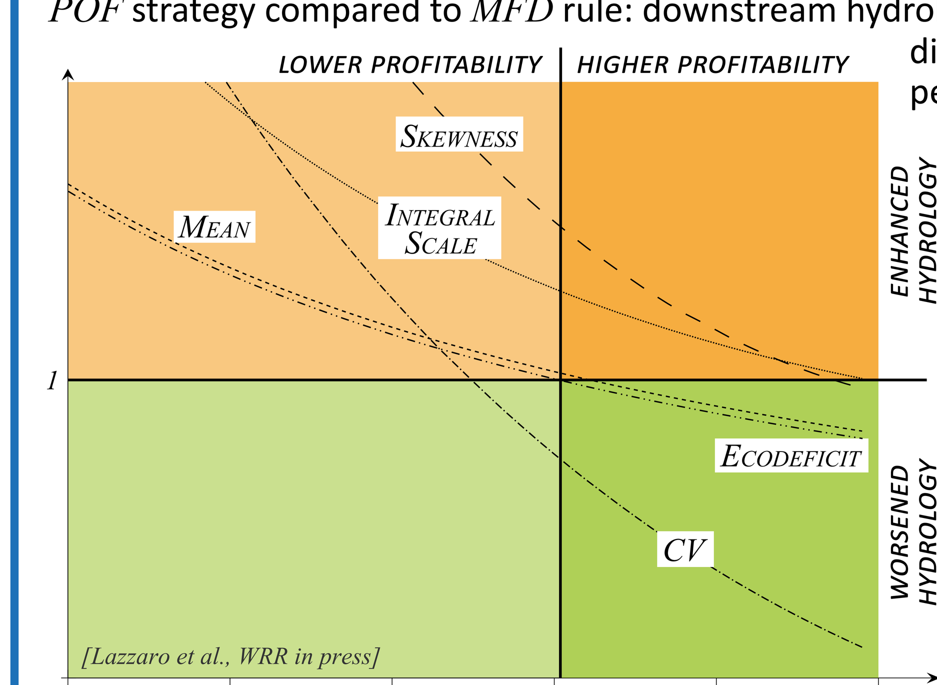
Analytical expressions for the flow regime downstream an intake



Disturbances caused by small run-of-river plants resemble those of reservoirs

TRADEOFF PROFITABILITY - HYDROLOGIC IMPACT

POF strategy compared to MFD rule: downstream hydrologic conditions for different withdrawal percentages β



The POF strategy allows for an improvement of most of the downstream hydrological conditions

Tradeoffs between maximization of **NPV** (economic value) and minimization of **hydrologic impact** (environmental disvalue)

References

Estimate of available water resources

Botter, G., S. Basso, I. Rodriguez-Iturbe, and A. Rinaldo (2013), Resilience of river flow regimes, *PNAS*, 110, 32, 12925-12930, doi:10.1073/pnas.1311920110.

Botter, G., S. Zanardo, A. Porporato, I. Rodriguez-Iturbe, and A. Rinaldo (2008), Ecohydrological model of flow duration curves and annual minima, *Water Resour. Res.*, 44, W08418, doi: 10.1029/2007WR006814.

Botter, G., A. Porporato, I. Rodriguez-Iturbe, and A. Rinaldo (2007), Basin-scale soil moisture dynamics and the probabilistic characterization of carrier hydrologic flows: slow, leaching-prone components of the hydrologic response, *Water Resour. Res.*, 43, W02417, doi: 10.1029/2006WR005043.

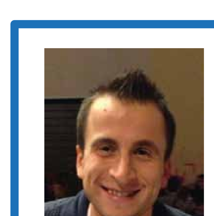
Hydropower: optimal design, policies and hydrologic disturbances

Lazzaro, G., S. Basso, M. Schirmer, and G. Botter, Water management strategies for run-of-river power plants: profitability and hydrologic impact between the intake and the outflow, *Water Resour. Res.*, in press.

Basso, S., and G. Botter (2012), Streamflow variability and optimal capacity of run-of-river hydropower plants, *Water Resour. Res.*, 48, W10527, doi:10.1029/2012WR012017.

Botter, G., S. Basso, A. Porporato, I. Rodriguez-Iturbe, and A. Rinaldo (2010), Natural streamflow regime alterations: Damming of the Piave river basin (Italy), *Water Resour. Res.*, 46, W06522, doi: 10.1029/2009WR008523.

Contacts



Stefano Basso
mail: stefano.basso@eawag.ch

Contact me if you are interested to further discuss the topic!