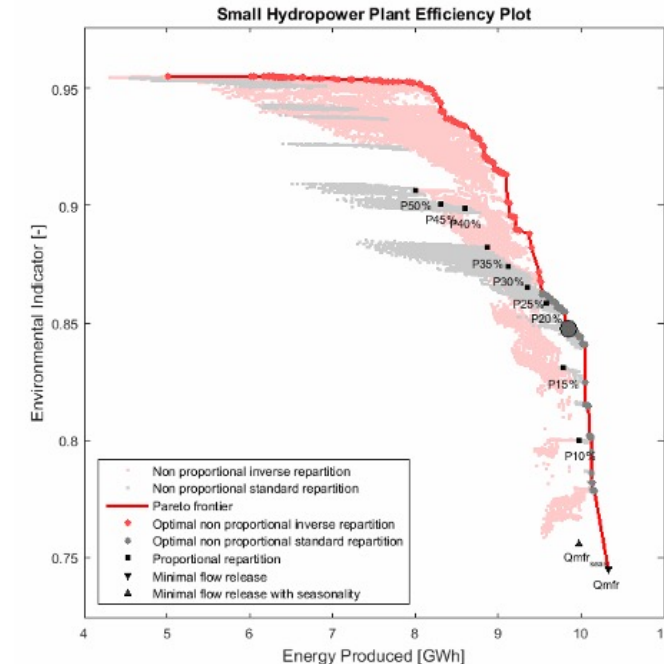


Water Resources Engineering and Management

(CIVIL-466, A.Y. 2024-2025)

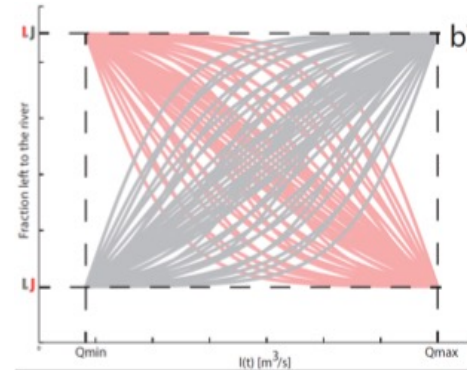
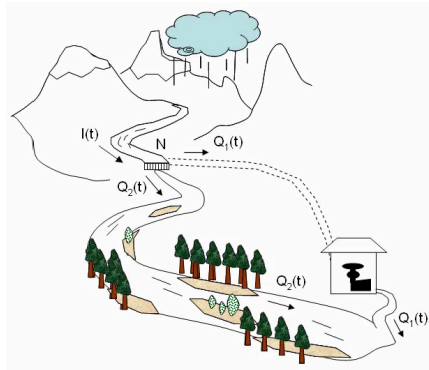
5 ETCS, Master course

Prof. P. Perona
Platform of hydraulic constructions



Lecture 10-3: Simulation and Pareto optimal allocation, GUI non-proportional rules

Small hydropower: optimal allocation policies

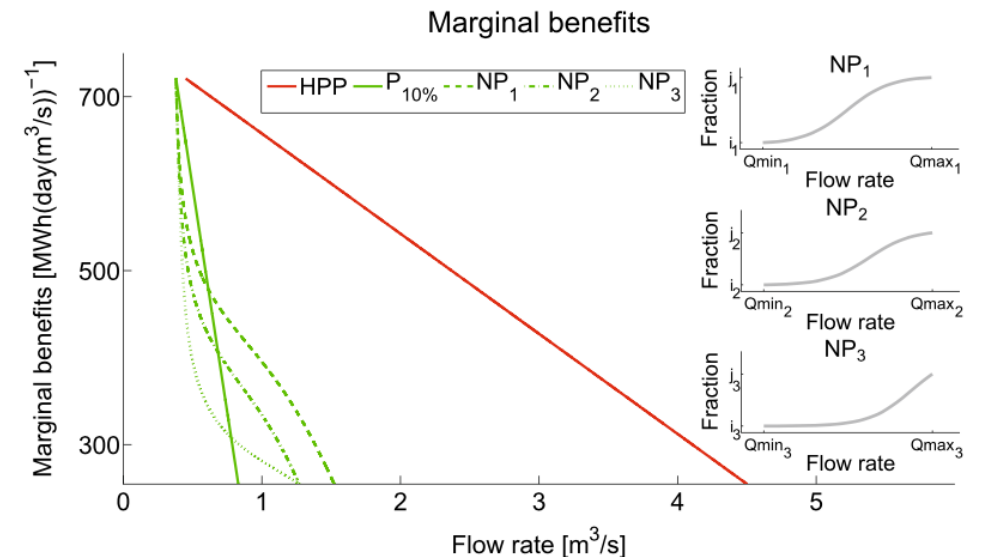
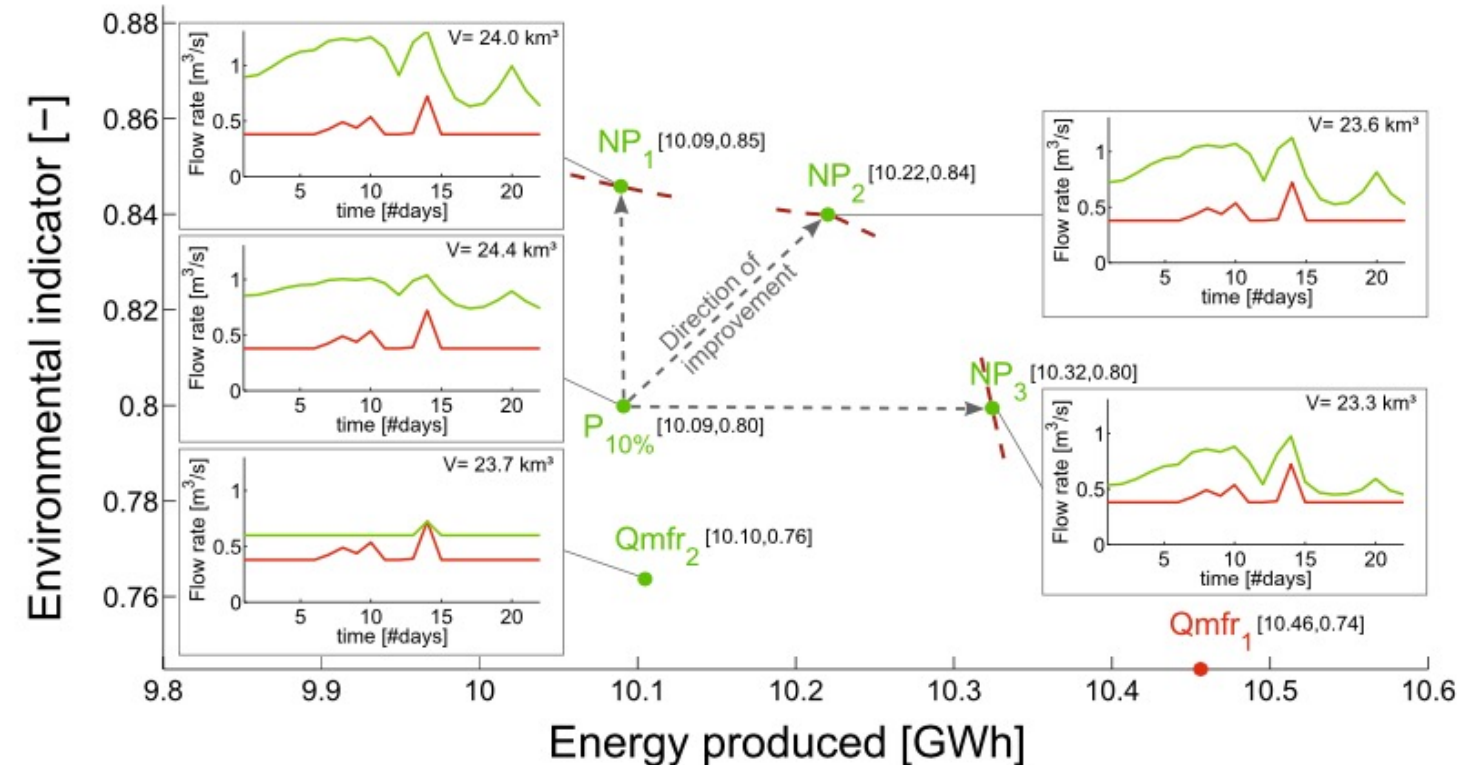


Razurel et al., WRM, 2015; ADW 2018

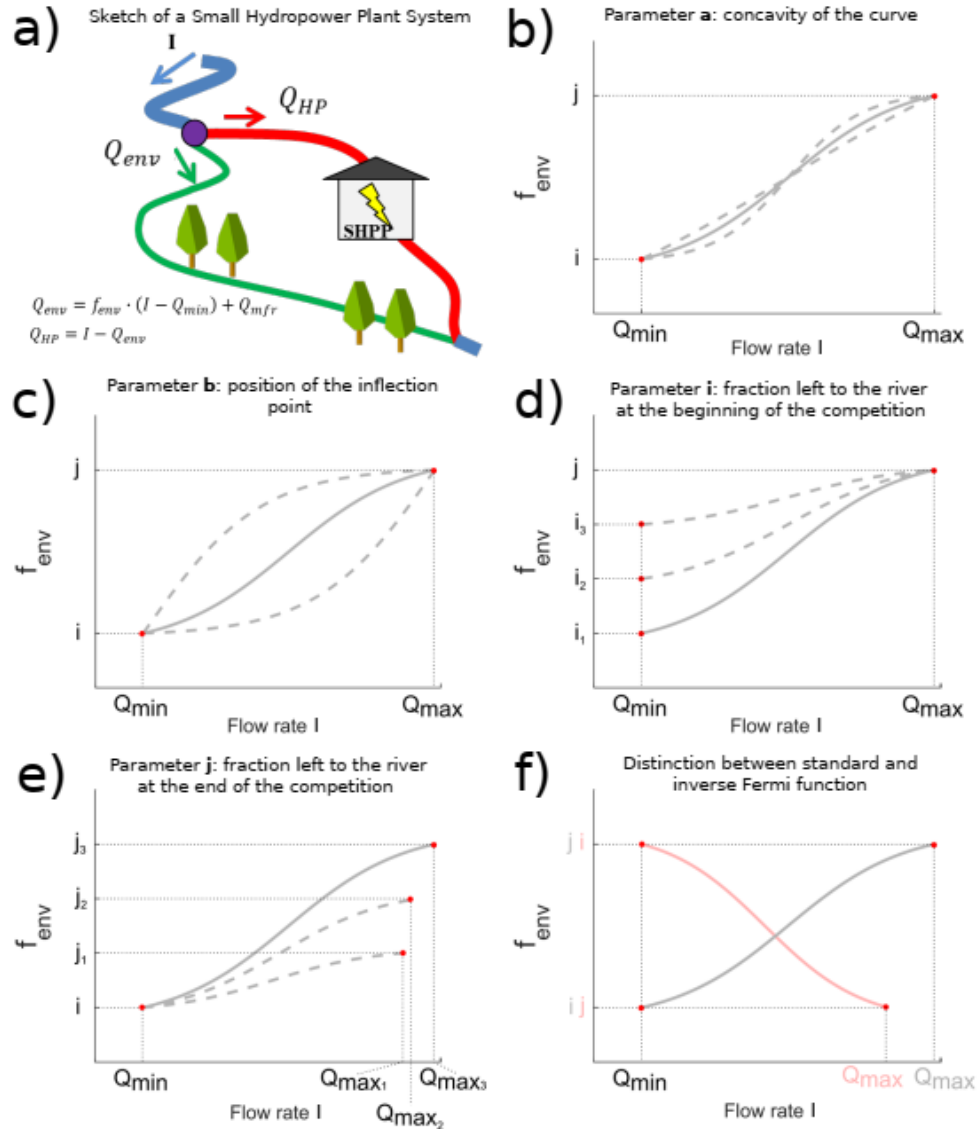
Perona et al., Frontiers Env Sci. (2021)

What did we learn?

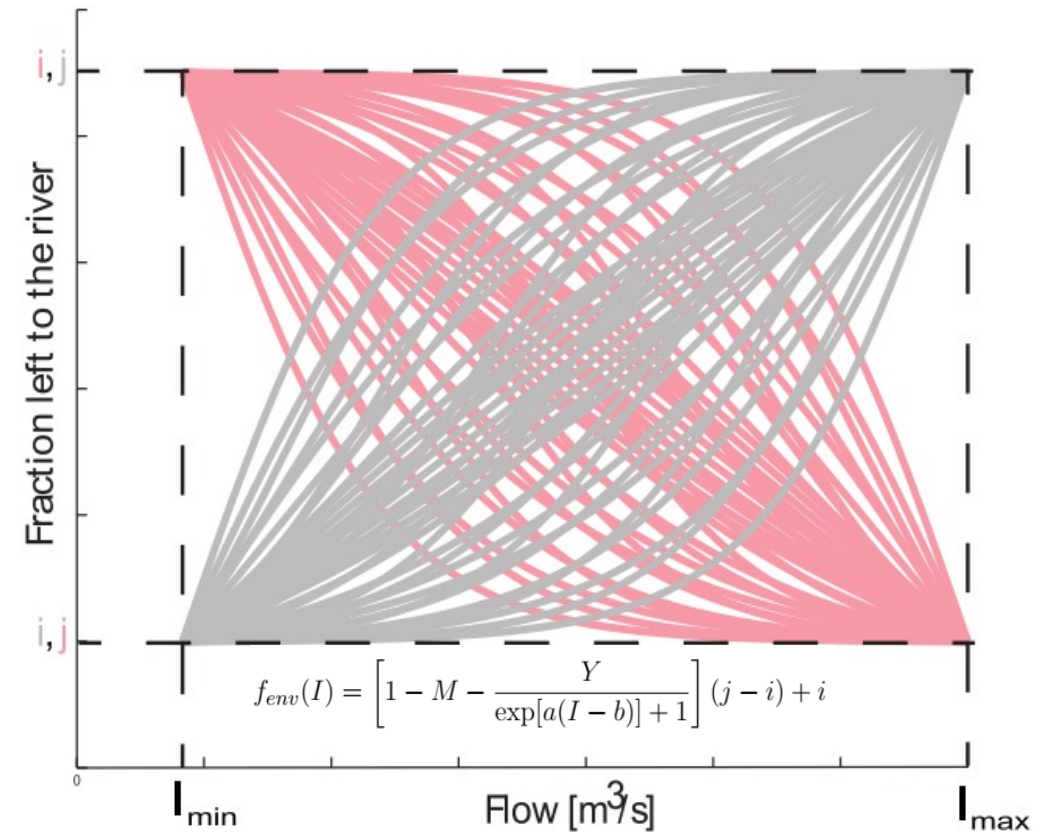
We learned that dynamic allocation policies non necessarily imply loosing water, but they are generally better to maintain more natural flow like variability in the regulated river reach



Non-proportional flow release: proof of concept



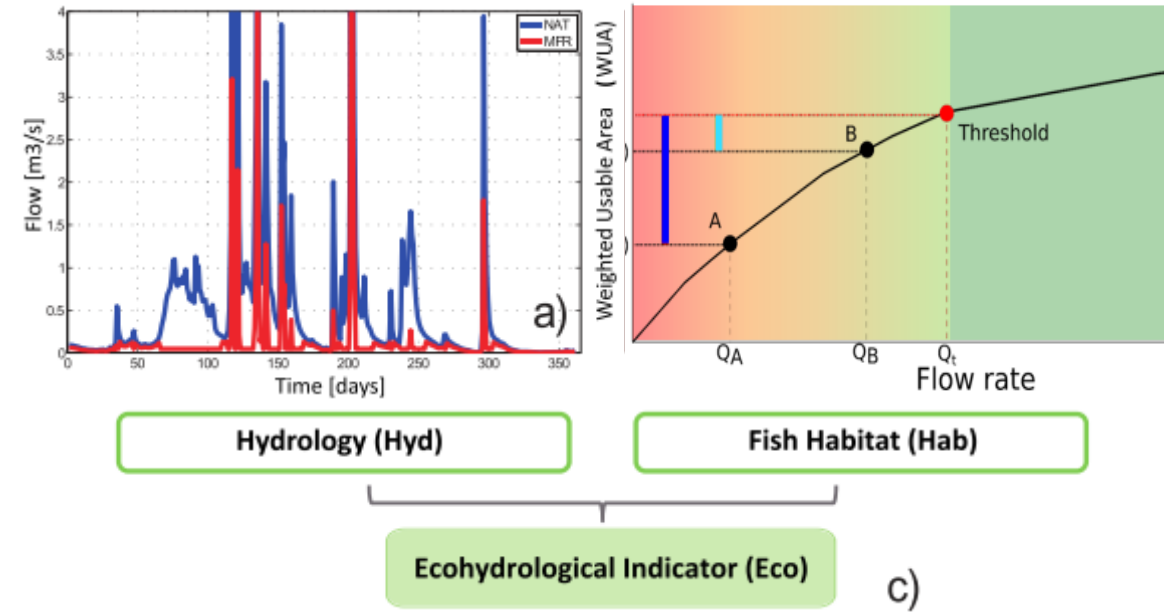
We tested hundreds of thousand redistribution policies in order to identify the most efficient (in Pareto sense) one



Assessment of ecological performances

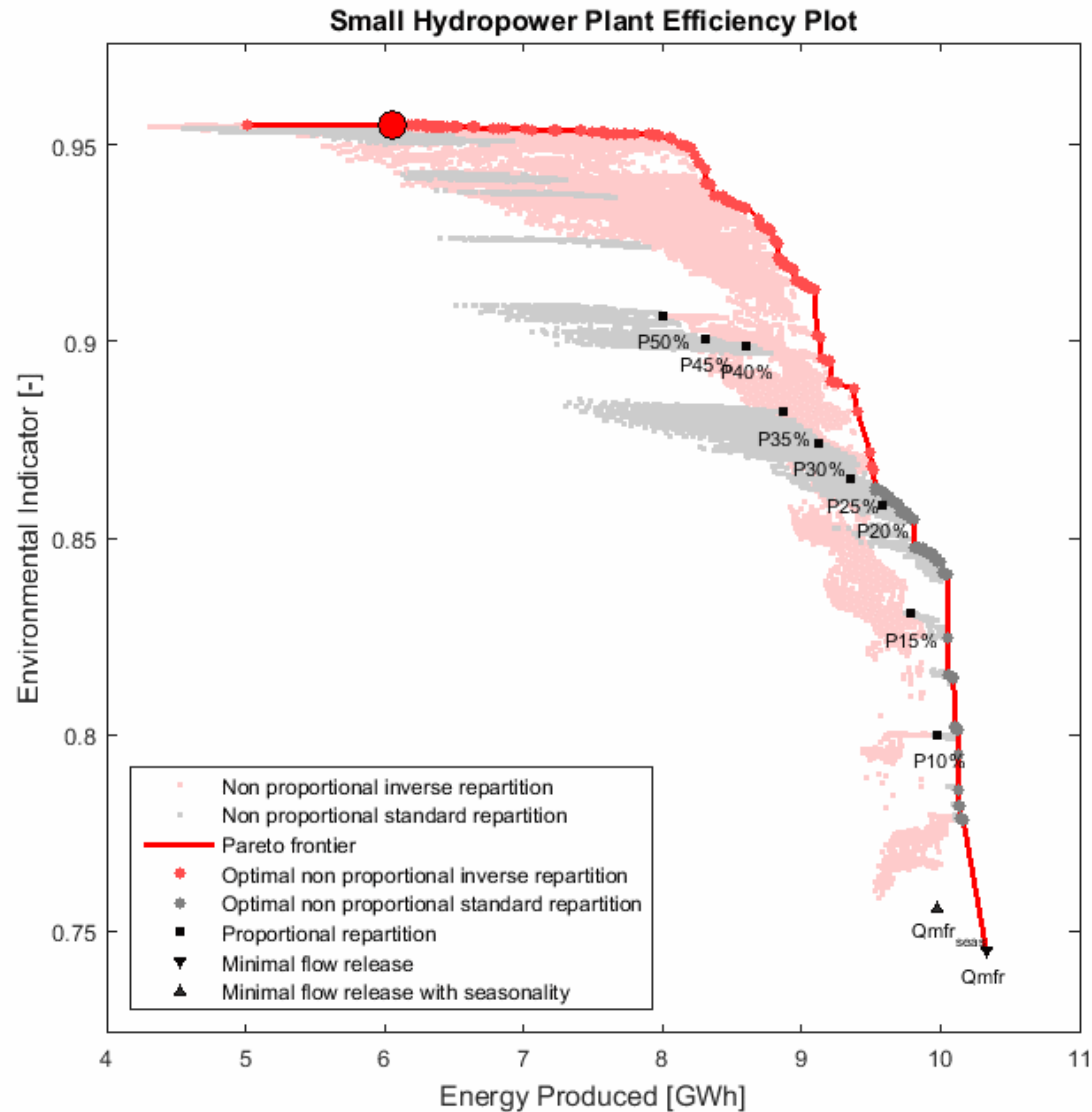
Global performances in respect of Q_{347} using Richter's hydrological indicators for flow variability

IHA statistics group	Regime characteristics	Hydrologic parameters
Group 1: Magnitudes of monthly water conditions	Magnitude Timing	Mean value for each calendar month
Group 2: Magnitudes and duration of annual extreme water conditions	Magnitude Duration	Annual minima 1-d mean Annual maxima 1-d mean Annual minima 3-d mean Annual maxima 3-d mean Annual minima 7-d mean Annual maxima 7-d mean Annual minima 30-d mean Annual maxima 30-d mean Annual minima 90-d mean Annual maxima 90-d mean
Group 3: Timing of annual extreme water conditions	Timing	Julian date of annual 1-d maxima Julian date of annual 1-d minima
Group 4: Frequency and duration of high and low pulses	Magnitude Frequency Duration	No. of high pulses each year No. of low pulses each year Mean duration of high pulses per year Mean duration of low pulses per year
Group 5: Rate and frequency of water condition changes	Frequency Rate of change	Means of all positive differences between consecutive daily means Means of all negative differences between consecutive daily values No. of rises No. of falls

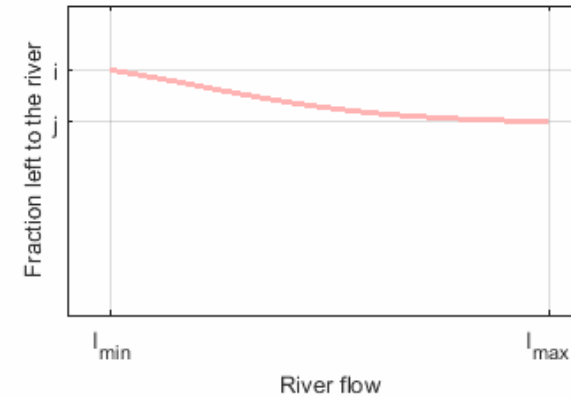


Alternative	Definition
Eco_{V1}	$\max(\sum \text{consecutive days under threshold})$
Eco_{V2}	$\max(\sum_{i=1}^d (WUA(Q_i) - WUA(Q_t))^2)$
Eco_{V3}	$Eco_{V1} \cdot \sum (\text{total days under threshold}) / (\text{total number of days})$

Pareto frontier for hydropower and ecology



Use the arrows to select a point on the Pareto frontier (red line) and plot the correspondent Fermi repartition function in the graphic below.



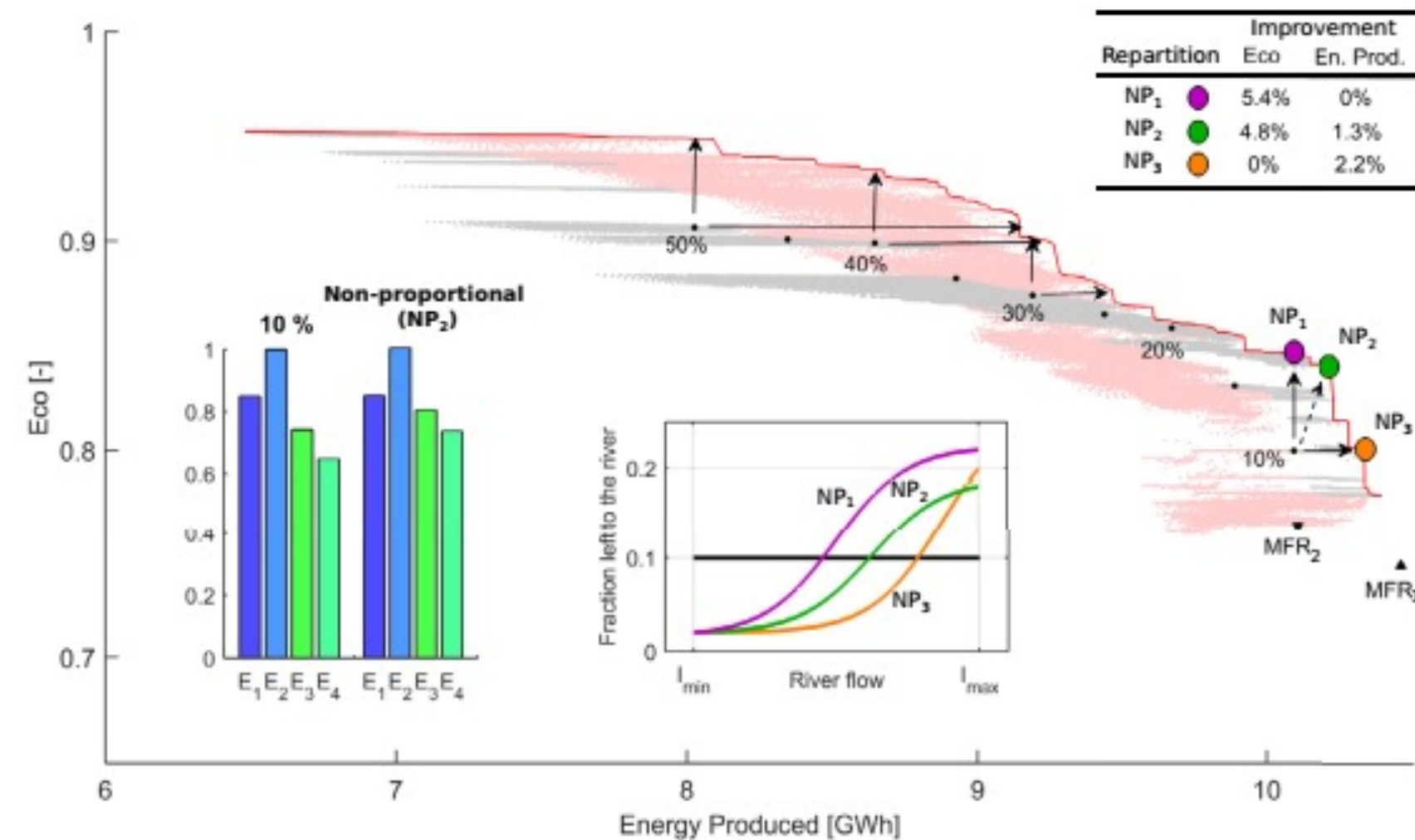
River flow range for repartition
 $l_{min} = 0.83 \text{ m}^3/\text{s}$
 $l_{max} = 14.97 \text{ m}^3/\text{s}$

Parameter values of the Fermi function
 $i = 0.85$
 $j = 0.65$
 $a = 4.50$
 $b = 0.20$

Save the screen as a pdf

The Pareto Frontier is almost entirely composed by non-proportional policies!

Typically used policies worldwide lie all below the Pareto frontier



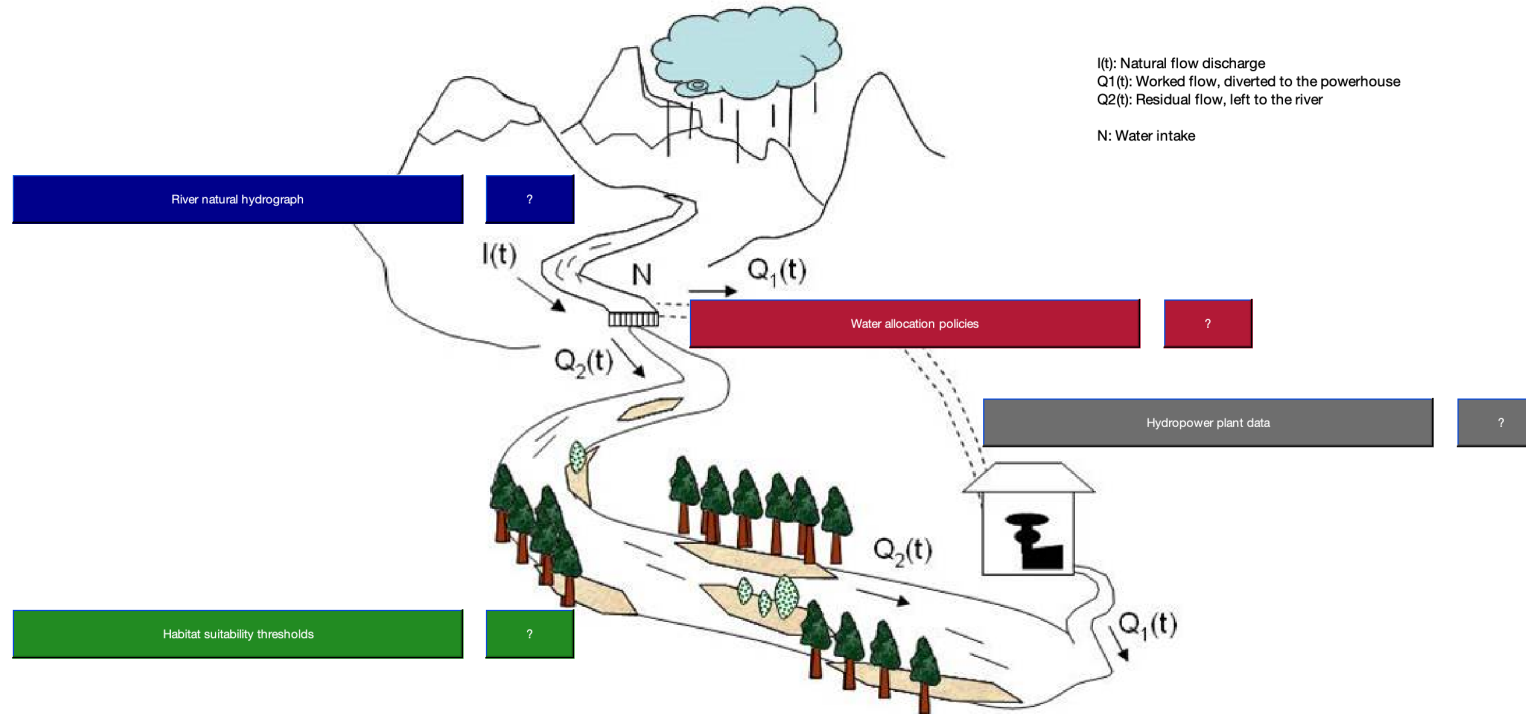
Although this proves that better alternatives exist with respect to the MFR and proportional distribution, they are far from being implemented yet

Graphical User Interface for hydropower

SMALL HYDROPOWER PLANT (Run-of-River)

Goal: Find the optimal water allocation policies that maximize energy production and preserve riverine ecosystem

Method: This model simulate different water repartition rules applied at the water intake, in the case of a small hydropower plant.
Results are presented as an efficiency plot showing, for each scenario, the Environmental Indicator vs the Energy Produced

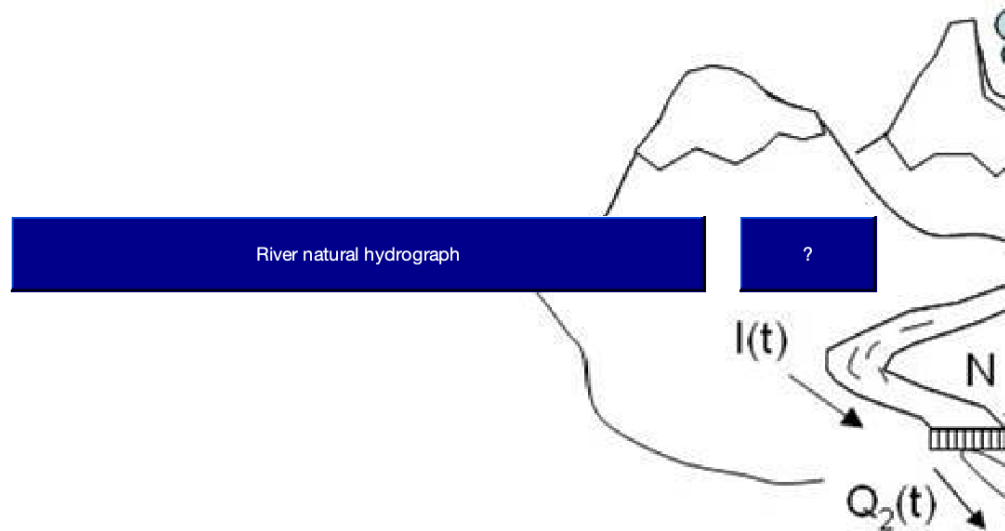


EVALUATION OF THE DIFFERENT FLOW REDISTRIBUTION POLICIES - DISPLAY THE EFFICIENCY PLOT

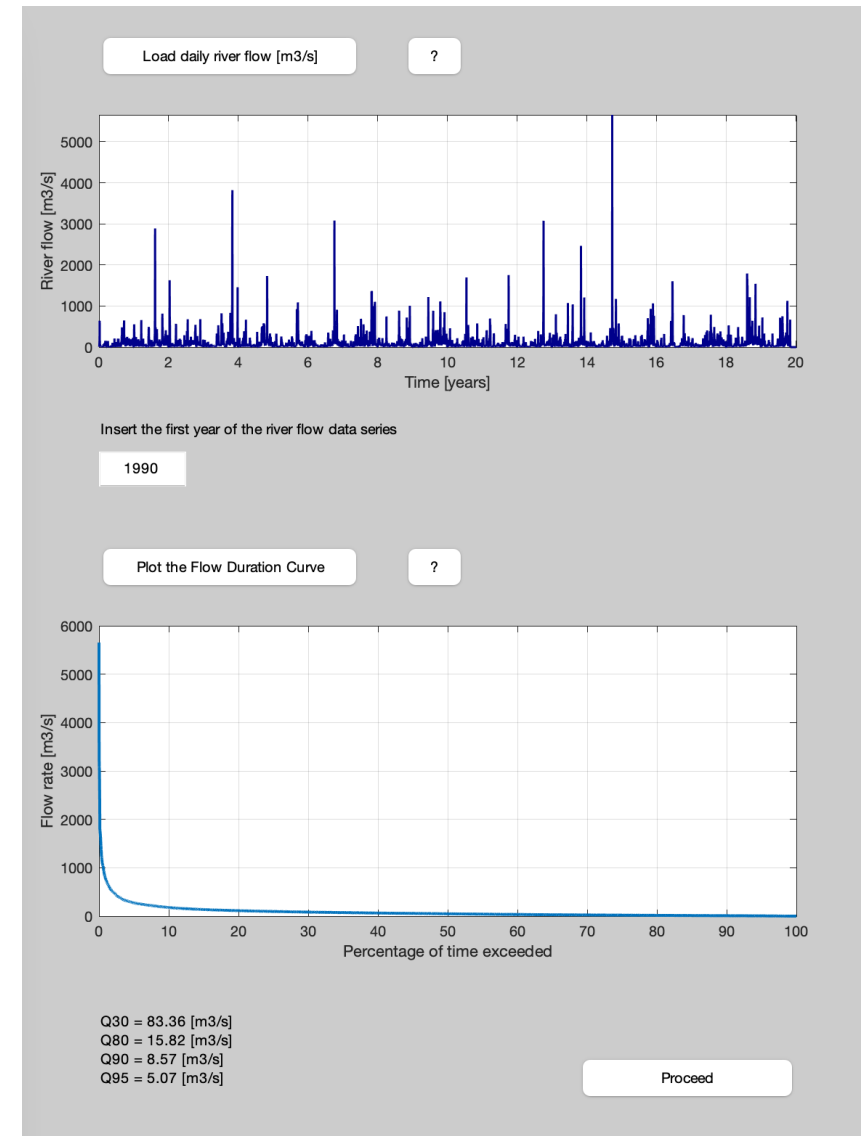
Complete all the fields before you can launch the simulations

This GUI runs in Matlab and produces a phase space plot of energy generation vs ecological efficiency for a mixed small hydropower system without storage reservoir. The efficiency plot also highlights the Pareto frontiers of efficient solutions for comparing redistribution policies

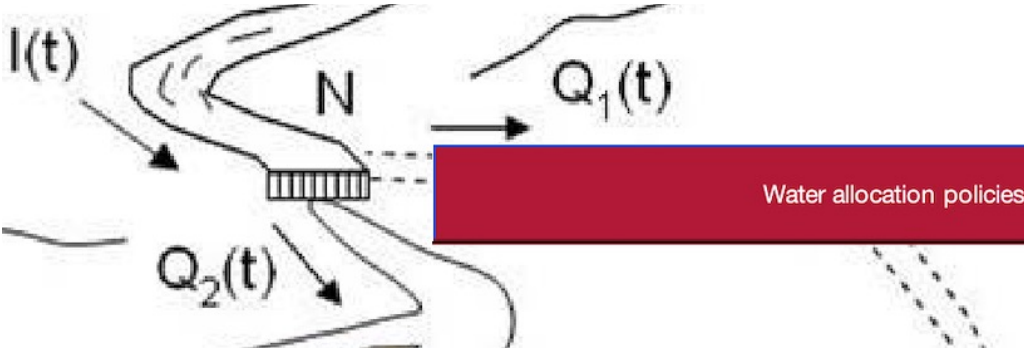
User steps: 1. River natural hydrograph



Here you enter the river data series as a sequence of daily data. The program calculates the main statistics



User steps: 2. Water allocation policies



Here you enter the water allocation policies that you want to test. These include minimal flow with and without seasonal variation, proportional policies and non-proportional ones belonging to the Fermi function family

Water allocation policies

Water allocation policies

Insert the minimal flow release m3/s

And select the water allocation policies you want to test

☒ Minimal flow release

☒ Minimal flow release with seasonality

☒ Proportional repartition rules

☒ Non proportional repartition rules (Fermi functions)

Insert data

Choose the proportional rules

Choose the non proportional rules

Proceed

Minimal flow release with seasonality

Minimal flow release with seasonality

Insert the higher threshold of the minimal flow release m3/s

Insert the julian date correspondent to the beginning of the higher threshold of the minimal flow release

Insert the julian date correspondent to the beginning of the lower threshold of the minimal flow release

Proceed

Proportional repartition rules

Proportional repartition rules

Use default values

Insert the fixed percentages of the incoming river flow left to the environment. The inserted values must be separated by a whitespace.

%

Proceed

Non proportional repartition rules (Fermi functions)

Non proportional repartition rules (Fermi functions)

Use default values

Parameter i	[0-1]	<input type="text"/>	Min value	<input type="text"/>	Max value	<input type="text"/>	N° of steps
Parameter j	[0-1]	<input type="text"/>	Min value	<input type="text"/>	Max value	<input type="text"/>	N° of steps
Parameter a	[2-8]	<input type="text"/>	Min value	<input type="text"/>	Max value	<input type="text"/>	N° of steps
Parameter b	[0-1]	<input type="text"/>	Min value	<input type="text"/>	Max value	<input type="text"/>	N° of steps

The fraction of water given to the environment depends on the value of the incoming flow

visualize the Fermi function

Fraction left to the river

River flow rate

Q_{min} Q_{max}

i j

$i = 0$

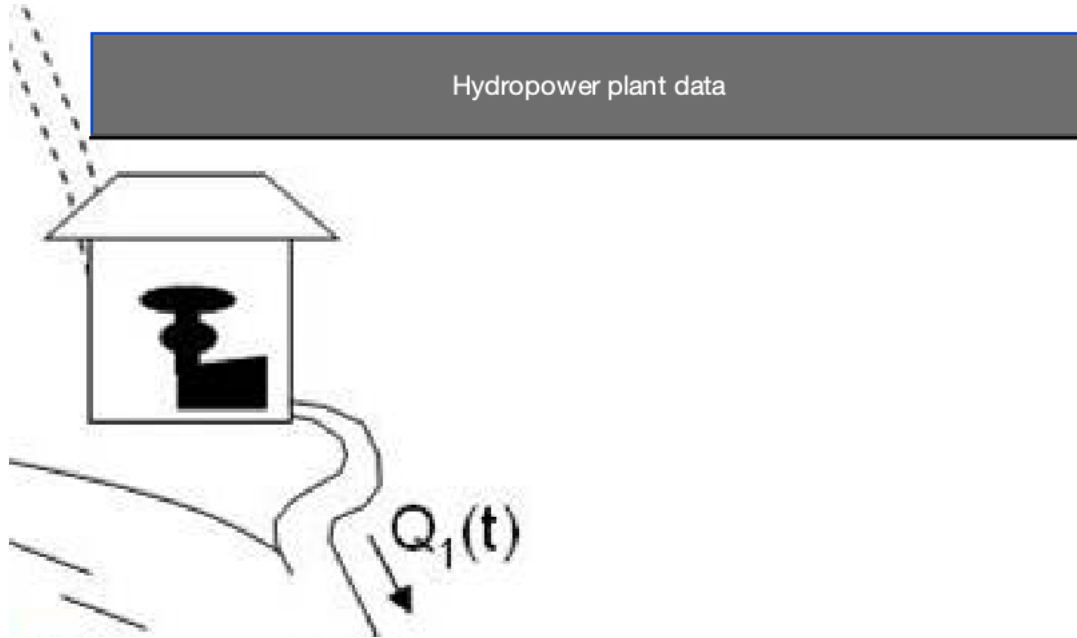
$j = 0.9$

$a = 8$

$b = 0$

Proceed

User steps: 3. Power plant data



Here you enter the technical data of the power plant that you want to test, including minimal and maximum operating flow as well as the number of consecutive days per year of maintenance work. These are then fixed randomly along the year. The power data defines the operating range of the power plant and the power generated; whether at the alternator or by the turbine depends on which efficiency is used to generate the data points.

Power Plant Data

Characteristics of the SHPP

Minimal operating flow rate of the power plant m3/s

Maximal operating flow rate of the turbine (nominal flow rate) m3/s

Number of days a year in which the power plant stops due to maintenance works

Power [kW] $\times 10^7$

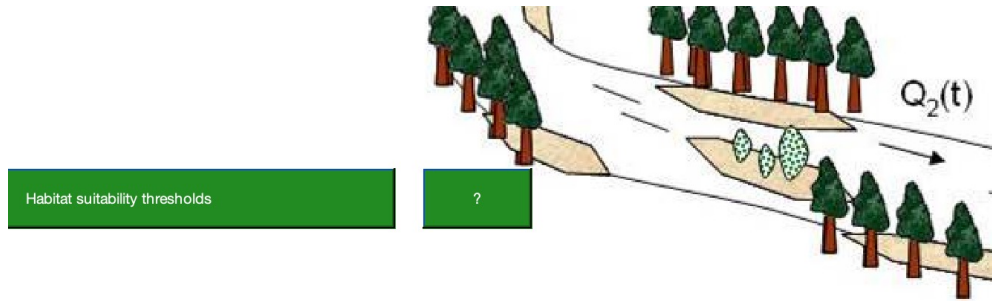
River flow [m3/s]

Fit a 2° degree polynomial curve

The graph displays a linear relationship between river flow and power. The x-axis represents River flow in m³/s, ranging from 30 to 100. The y-axis represents Power in kW, scaled by 10⁷, ranging from 4 to 14. Three data points are plotted at approximately (35, 4.5), (75, 9.5), and (100, 12.5). A red line represents a 2nd-degree polynomial fit passing through these points.

River flow [m3/s]	Power [kW] $\times 10^7$
35	4.5
75	9.5
100	12.5

User steps: 4. Habitat suitability thresholds



Here you enter the thresholds for young and adult reference fish species below which fish are in stress and a penalty function is calculated.

Ecosystem Data

Habitat suitability thresholds for the Brown Trout

The fish habitat indicator correspond to the maximal number of consecutive days under the thresholds corresponding to the longest stress period for the fish population.

Load the WUA curve for JUVENILE fishes

?

River flow [m3/s]	WUA [-]
20	200
40	400
60	600
80	800
100	1000
120	1100
200	1400
300	1500
450	1600
500	1650

Fit a 2° degree polynomial curve

Insert the flow threshold for juvenile fishes :

100

m3/s

?

Load the WUA curve for ADULT fishes

?

River flow [m3/s]	WUA [-]
20	200
40	400
60	600
80	800
100	1000
200	1000
350	1500
500	2000

Fit a 2° degree polynomial curve

Insert the flow threshold for adult fishes :

200

m3/s

?

Proceed