NH1.4 - Advances in Flood Risk Modelling: Forecasting, Monitoring, Assessment, Mitigation and Recovery

Nonlinear flood peak mitigation driven by initial reservoir conditions

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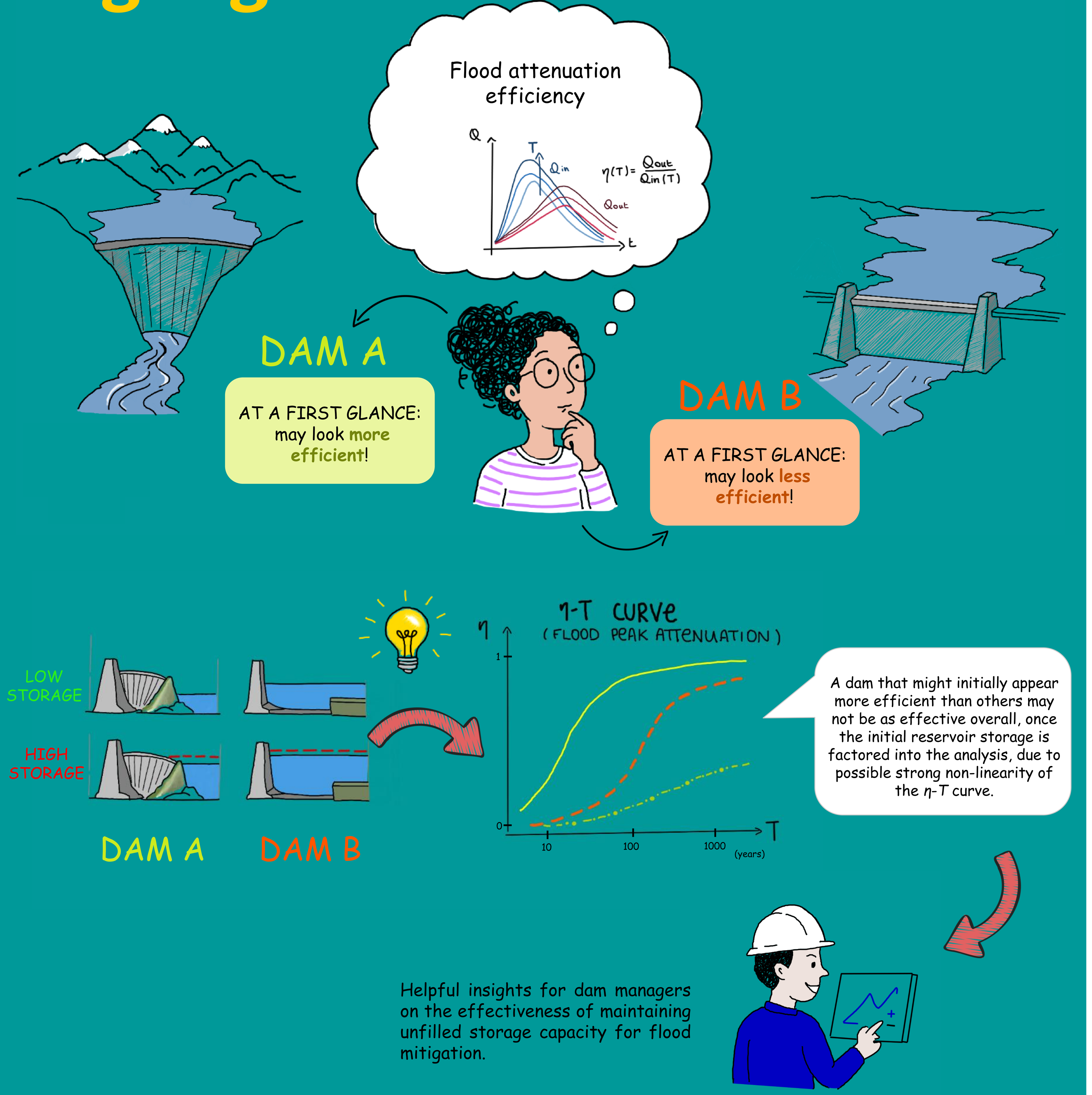
Link to paper

Highlights



Introduction

The assumption of a reservoir being at full capacity when a flood occurs, while conservative, is an uncommon scenario due to:

Operational factors
Approximately 30% of Italian dams operate under limited or experimental conditions while awaiting functional and technical testing.

Climatic-hydrological factors
Storage state of reservoirs in Italy over the past 5 years has been heavily impacted by prolonged droughts, particularly in southern regions. Reduced inflows have left many reservoirs nearly dry.

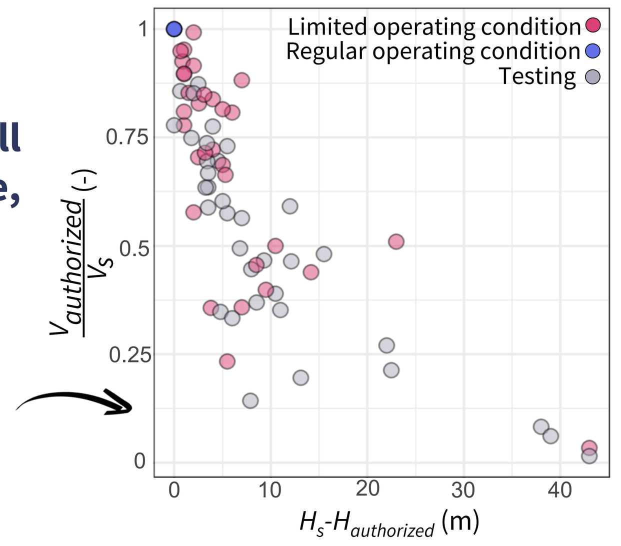


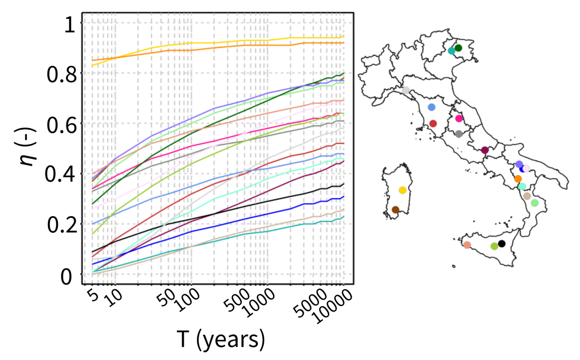
Figure 1: Percentage of authorized volume (V_{aut}) to total storage capacity (V_s) as a function of the difference between the elevation of the spillway crest (H_s) and the authorized water level (H_{aut}) for reservoirs under different operating conditions. Dot transparency reflects data point density, with lower transparency representing fewer points.

Results - 1

The slope of the η-T lines varies between groups, highlighting differences in attenuation characteristics among the classified dam categories

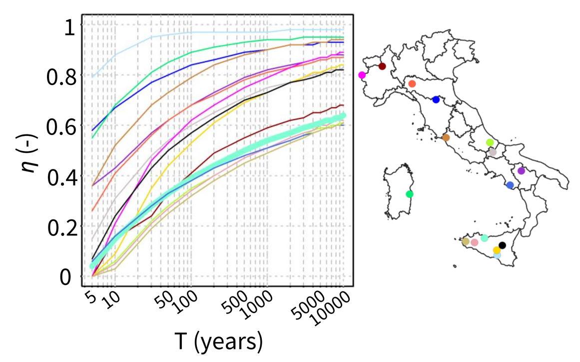
Variability of Flood Peak Attenuation With Flood Return Periods

Group 1 (20)



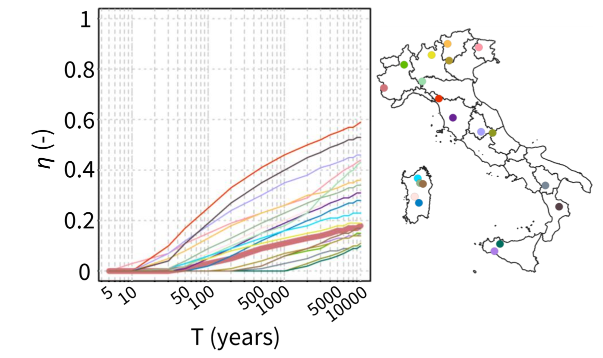
Monotonically increasing in the semi-logarithmic plot, with only minor incremental variations.

Group 2 (16)

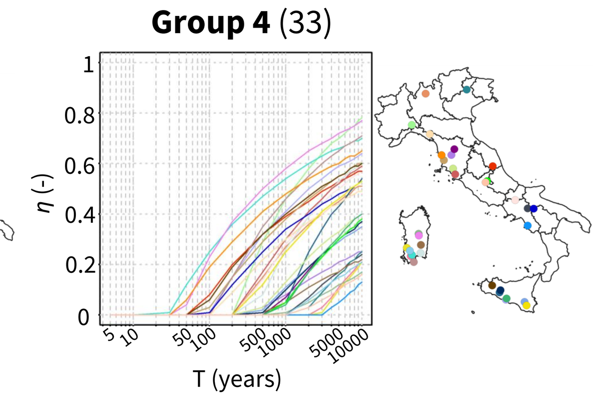


Curved lines in the semi-logarithmic plot.

Group 3 (20)

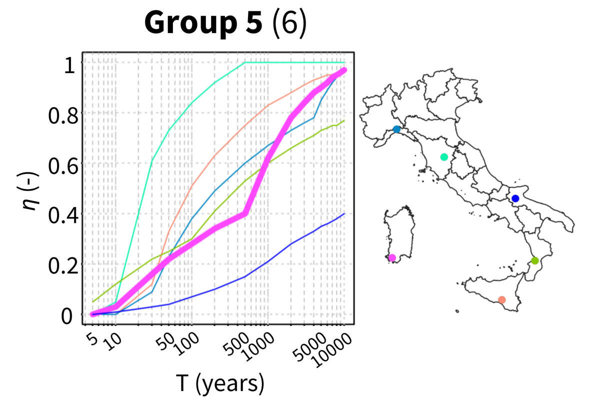


Group 4 (33)



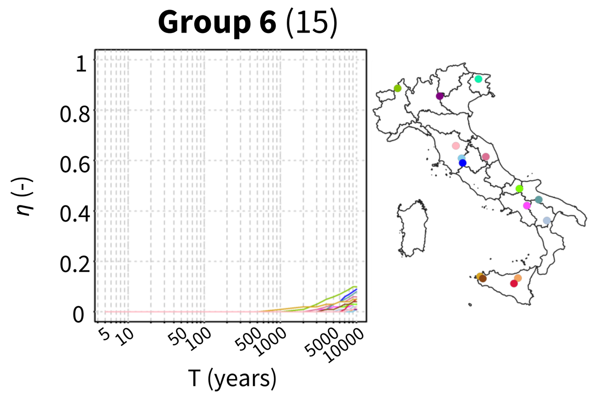
Threshold behavior, in which outflow initiation occurs only once a specific return period is exceeded, with Group 4 showing a steeper rise compared to Group 3.

Group 5 (6)



Irregular η-T curves, which do not follow a consistent pattern

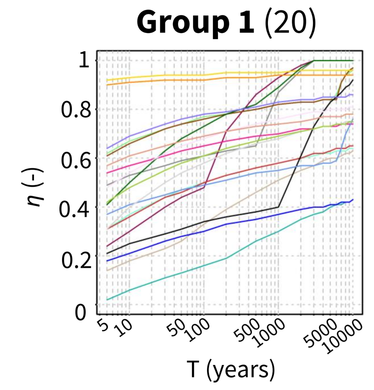
Group 6 (15)



Threshold behaviour, with a very small increase in η as T increases.

Figure 3: Attenuation coefficients η as a function of return period T for 6 of the groups identified. A runoff coefficient C = 0.5 and a ISL ≠ 1 were used to compute η.

Group 1 (20)



Sensitivity of Flood Peak Attenuation to different Scenarios

Doubling the flood peak does not result in a proportional reduction in the dam attenuation efficiency, but rather leads to a non-linear larger decrease in attenuation efficiency as the system's limits are approached.

Figure 4: Attenuation coefficients η as a function of return period T for Group 1. A runoff coefficient C = 1 and a ISL ≠ 1 were used to compute η.

Methods

Flood hydrographs are estimated via a simplified hydrological model and full hydraulic routing is applied under different scenarios of initial reservoir storage, informed by regional flood seasonality and historical reservoir time series

Average day of the year on which the 10 most extreme floods occurred between 1960 and 2020 calculated for each dam, using the methodology described in Blöschl et al. (*Science*, 2017).

Empirical monthly **median storage level**, computed from historical reservoir time series for 70 reservoirs and generalized for dams where historical observations are unavailable based on (i) dam elevation and (ii) regional climatology:

$$MSL = \frac{V}{V_{authorized}}$$

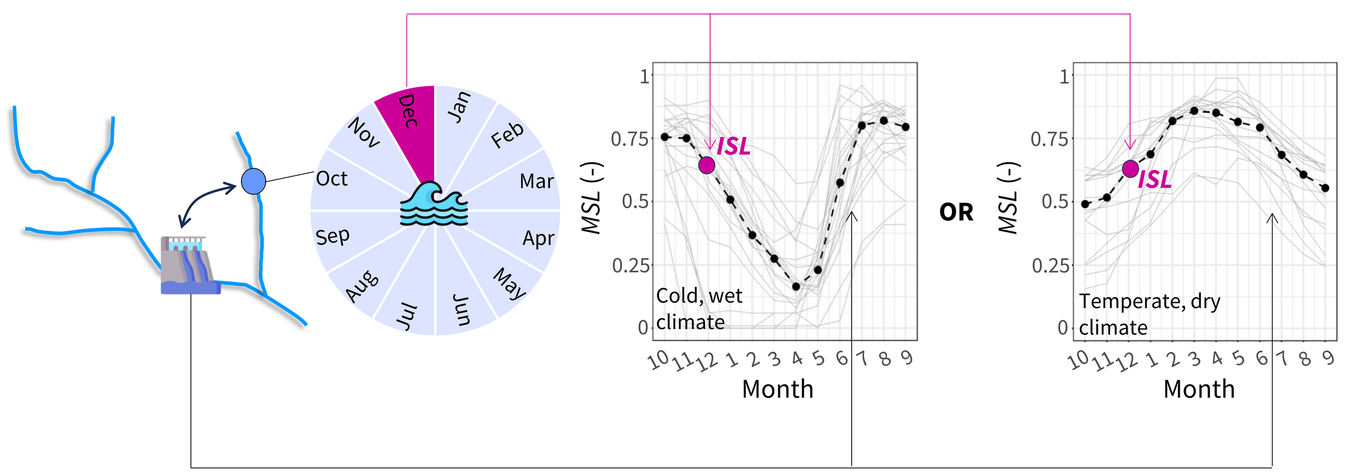
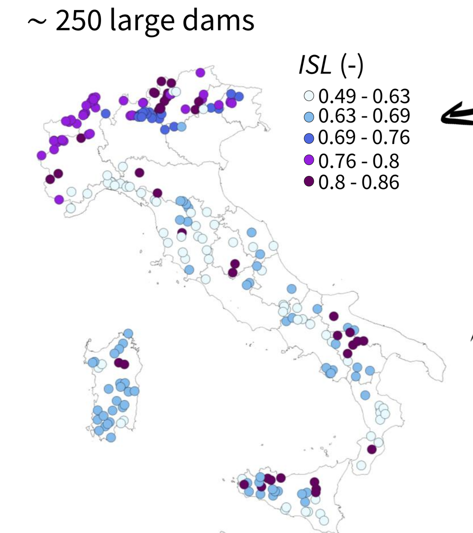


Figure 2: Reconstruction of the initial reservoir storage level (ISL) based on regional flood seasonality. The average month of flood occurrence is assigned to each dam based on data from the nearest gauged site. The ISL is identified along the annual curve of the median reservoir storage level (MSL, dashed black line), which is derived for each dam by generalizing observed reservoir storage level data (thin gray lines).

~ 250 large dams



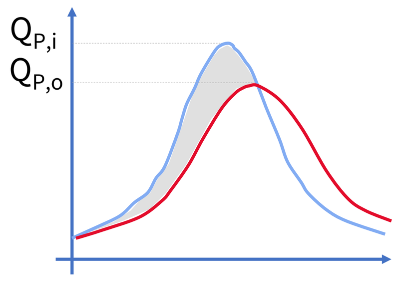
$$ISL = \frac{V_{initial}}{V_{authorized}}$$

Initial storage level, depending on the month on the annual MSL curve when, on average, the highest floods occur at each dam.

Initial condition for dam routing

$$Q_i(t) - Q_o(h(t)) = \frac{dV(h(t))}{dt}$$

$$\eta = \frac{Q_{P,o}}{Q_{P,i}}$$



Results - 2

A synthetic indicator explains dam group classification

$$\delta = \frac{k}{t_c} \ (-)$$

k = storage coefficient, defined as the ratio between the stored volume for a water level of 1 m above the spillway crest, and the outgoing discharge for the same water level.
t_c = catchment time of concentration.

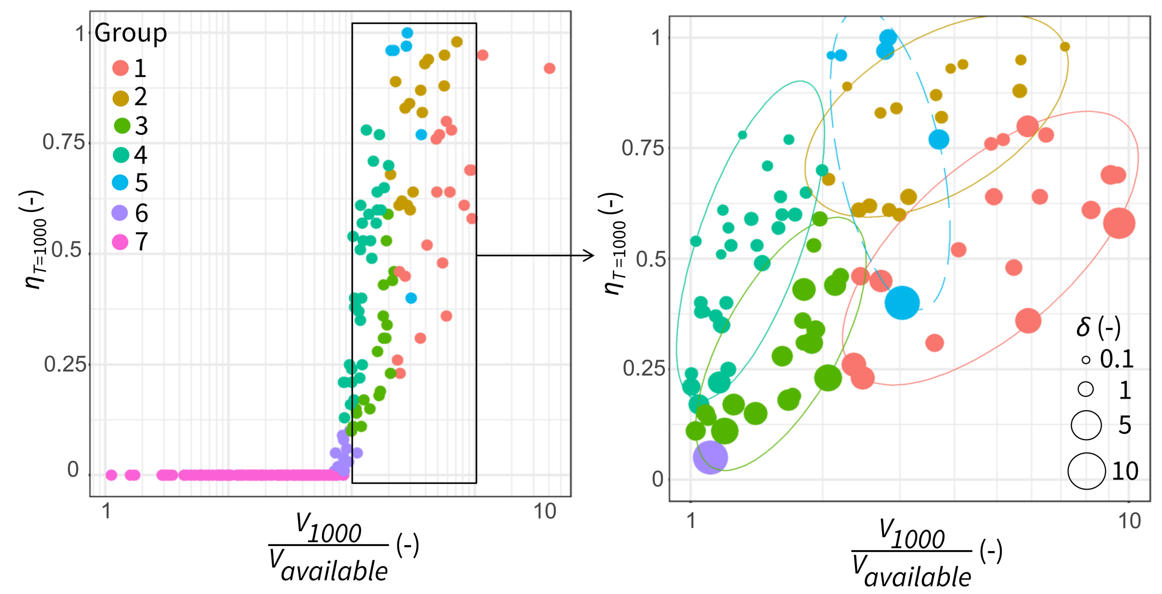


Figure 5: Relationship between the attenuation coefficient η for a return period of T = 1000 years and the ratio of the 1000-year flood volume to the available storage capacity, with data points color-coded according to dam grouping (a).The ellipses plotted represent the smallest enclosing ellipses that encompass all the points within each group, while point sizes correspond to the δ value, defined as the ratio of the storage coefficient to the time of concentration.

For a given $V_{1000}/V_{available}$ ratio, the assignment of a dam to a particular group is influenced by the corresponding δ value: for low $V_{1000}/V_{available}$ values, high δ corresponds to Group 3, while low δ corresponds to Group 4. Conversely, for high $V_{1000}/V_{available}$ values, high δ corresponds to Group 1, and low δ corresponds to Group 2.

And Group 7?
Spillways are not being activated, take a look at the paper for more details.

Results - 3

Considering reservoirs to be at maximum capacity, combined with conservative flood peak estimates, tends to produce overly cautious outcomes

Around 50 dams reach their maximum allowed water level for flood return periods of 100 years or less when a runoff coefficient of C = 1 is used and full reservoir conditions are assumed at flood onset.

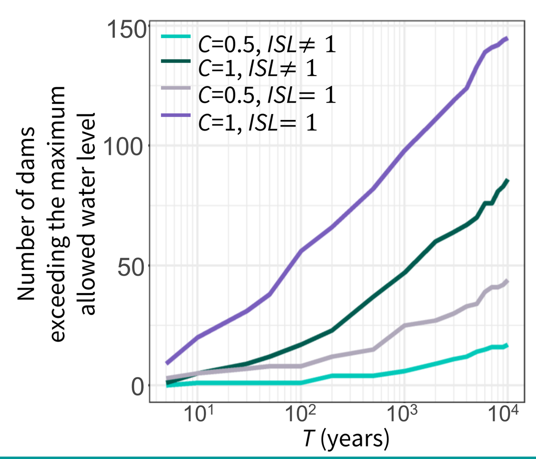


Figure 6: Number of dams reaching their maximum allowed water level as the flood return period increases, under different scenarios of hydrological forcings (C = 0.5 or C = 1) and initial reservoir condition (ISL ≠ 1 or ISL = 1).

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