Indian Committee on Large Dams
Young Engineers Forum

INTERNATIONAL
DAM SAFETY CONFERENCE

Dam Rehabilitation & Improvement Project

Central Water Commission

Assessment of current reservoir sedimentation rate and storage capacity loss: an Italian overview

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10-12 October 2022 at Jaipur, Rajasthan (India)

RELAID: REnaissance of LArge Italian Dams

The project intends to set guidelines for a functional re-habilitation of large dams, i.e. the one associated to water-related issues, addressing the following issues:

- re-think of design scenarios of dams accounting for modified climate conditions, and considering not only the streamflow variable, but including also sediment transport and debris inflows;
- update of dam operations to accommodate modified forcings and needs;
- update of the criteria to map hazard scenarios in downstream and riparian areas;
- illustrate demonstrative cases considering post-construction assessment of dam-reservoir systems and future scenarios.

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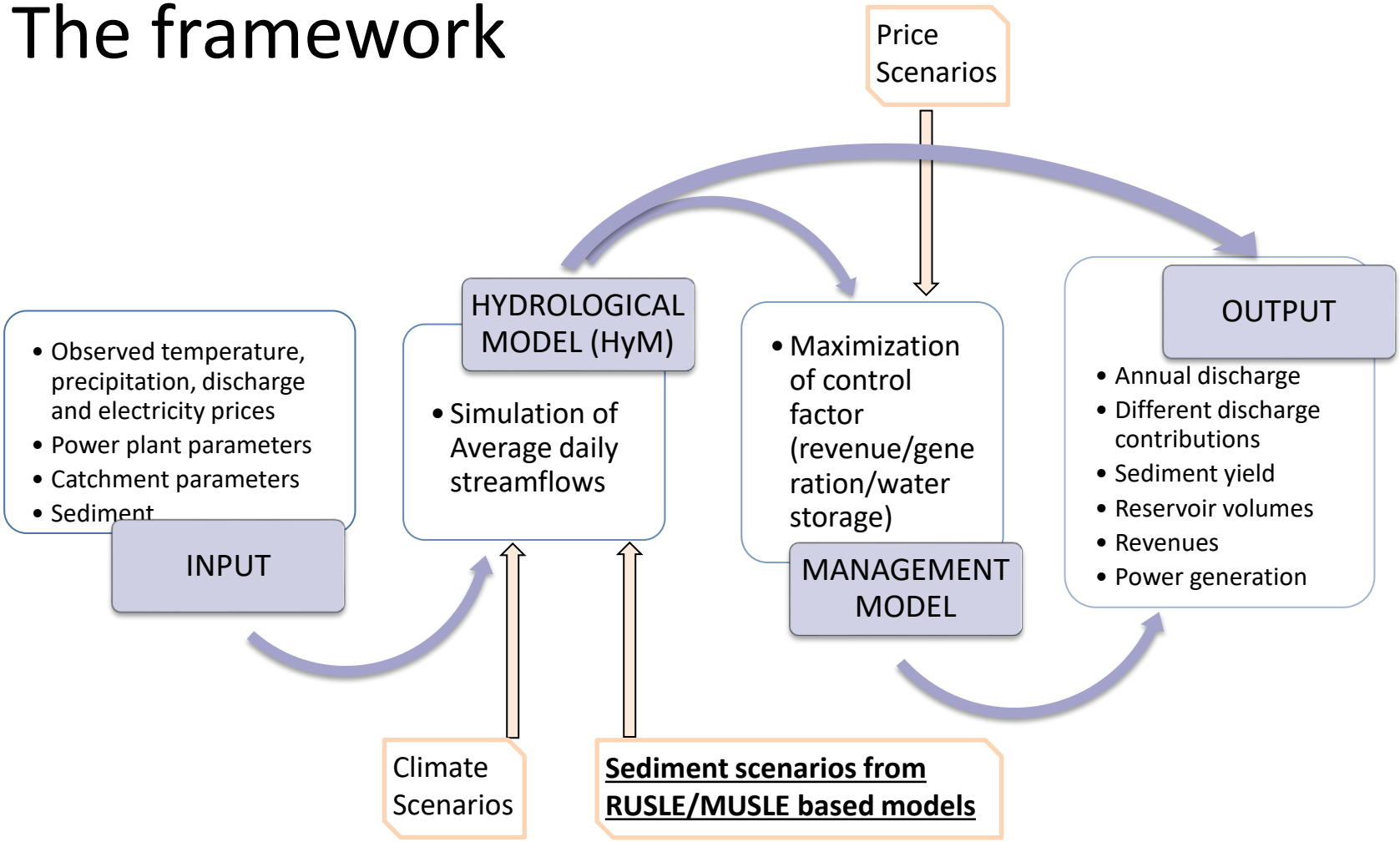
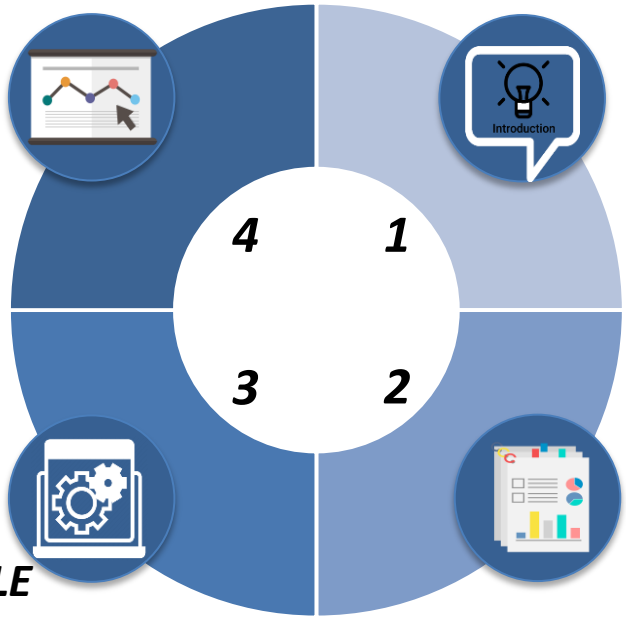
The framework



Health of Italian dams and reservoirs

4. *Sediment Delivery Ratio (SDR) model*
Regression and parameters

1. *Reservoir sedimentation*
Definations, data collection and parameter evaluation



3. *Application of the RUSLE model for the calculation of gross soil erosion*
Description and characteristics of the model, dataset and implementation in GIS

2. *Health of 50 Italian Reservoirs and sediemnt yield*

(associated paper: Patro et al. 2022, Journal of Environmental Management, https://doi.org/10.1016/j.jenvman.2022.115826)

Study Area

DATA

- Reservoirs analyzed are distributed throughout Italy, majorly within the following ten administrative regions of Piemonte, Emilia-Romagna, Abruzzo, Lazio, Sicily, Tuscany, Marche, Veneto, Sardegna, and Lombardy.
- Topographic/ catchment data
- Reservoir characteristics and bathymetry data

Status of 50 Italian reservoirs

Reservoir sediment volume $[m^3]$

$$(V_{INT})_{\Delta T} = V(T_i) - (T_f)$$

Trap efficiency %

$$TE = 1 - \frac{1}{1 + 0.0021D\frac{V}{A}} \ (\%)$$

Specific Sediment Yield

$$SSY = \frac{(V_{INT})_{\Delta T}}{TE \cdot A \cdot \Delta T} \left[\frac{m^3}{km^2 \cdot anno}\right]$$

% loss of reservoir capacity

$$GI\% = \frac{(V_{INT})_{\Delta T}}{V_{orig}} \cdot 100$$

Annual depletion rate

$$\mathrm{TI}\% = \frac{GI\%}{\Delta T}$$

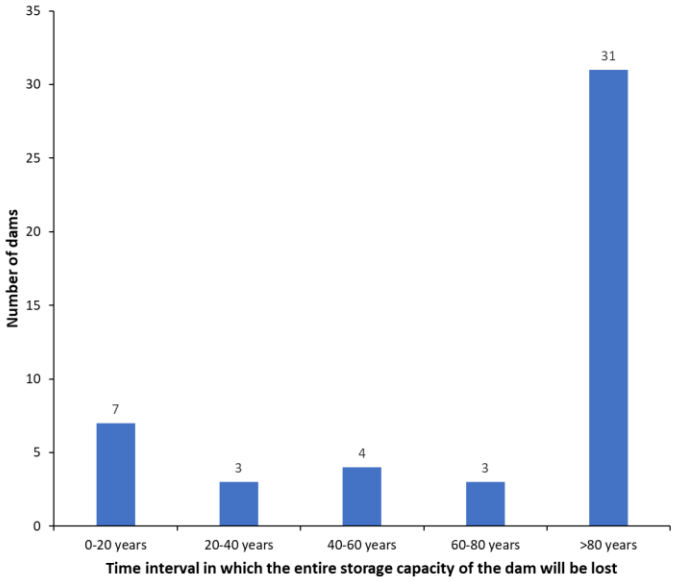
Half-life year

$$t_{1/2} = T_i + \left((V_{orig}/(SY * A))/2\right)$$

- The average age of all dams considered is 69 years.
- the average value of GI for all dams turns out to be equal to 38%.
- None of the fifty dams examined has $TI > 2\%$.
- Ten reservoirs (20%) had a significant decrease in TE greater than -50%, nine reservoirs (18%) have percentage decrease in TE in the range of -25 to -50%, while only 31 reservoirs (62%) had a decrease in TE less than -25%,

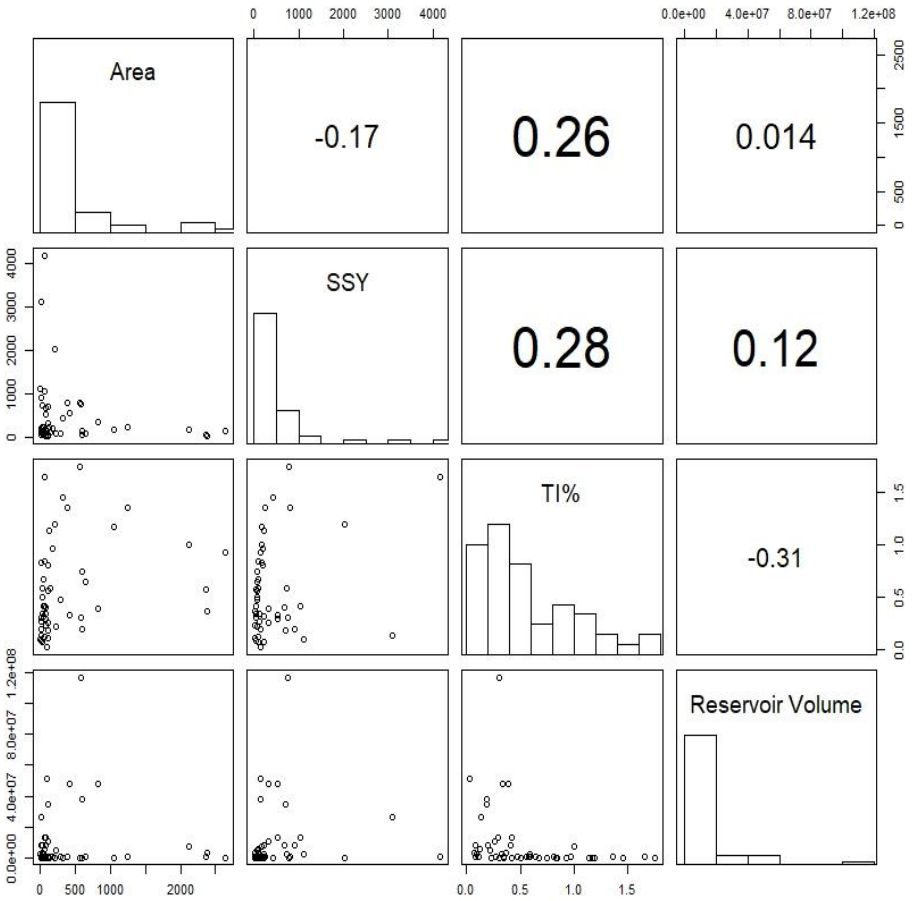
Percentage loss of reservoir capacity, aggregation by macro-areas.

Macro-area	Number of reservoirs	$GI < 5\%$	$GI \geq 5\%$	Average GI
Alpine	26	2	24	33%
Apennine	24	0	24	43%
All	50	2	48	



The number of reservoirs versus the time interval in which the entire storage capacity is exhausted.

- The catchment area of the fifty dams examined varies from a minimum of 2.10 km^2 to a maximum of 2642.01 km^2
- For increasing catchment area, a net decrease in the *SSY* is observed.
- increase in catchment area the *TI* also increases.
- a decreasing trend was observed with TI as the reservoir capacity increases.



Application of the RUSLE model for the calculation of soil loss – *GIS*

$$A = R \cdot K \cdot LS \cdot C \cdot P$$

- A: *Gross Erosion* $[t \cdot ha^{-1} \cdot anno^{-1}]$
- R: *Rainfall erosivity factor* $[MJ \cdot mm \cdot h^{-1} \cdot ha^{-1} \cdot anno^{-1}]$
- K: *Erodibility factor* $[t \cdot h \cdot MJ^{-1} \cdot mm^{-1}]$
- LS: *Slope Length factor* $[-]$
- C: *Coverage factor* $[-]$
- P: *Support practice factor* $[-]$

Dataset:

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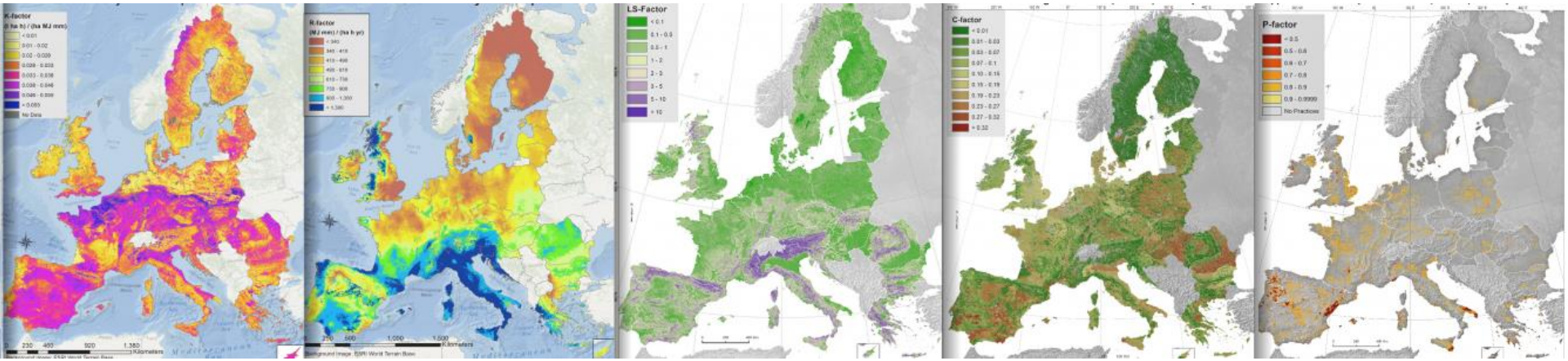
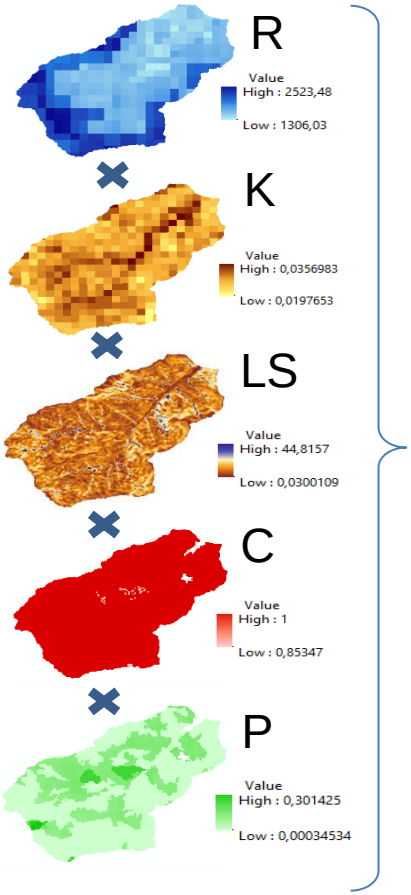
EUROPEAN SOIL DATA CENTRE (ESDAC)



For each basin, the average soil loss value expressed in $[t \cdot ha^{-1} \cdot year^{-1}]$ calculated automatically by the GIS software is taken as the annual average soil loss value.

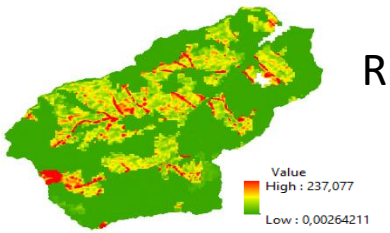
Resolution
$20m \times 20m$

in WGS84



Map algebra

$$A = R \cdot K \cdot LS \cdot C \cdot P$$



RUSLE

Soil erosion map
of the catchment

Sediment Delivery Ratio (SDR)

Understanding how much sediemnt reaches the dam (*Specific Sediment Yield*, SSY)

RUSLE → GE, GROSS EROSION OF THE CATCHEMNT

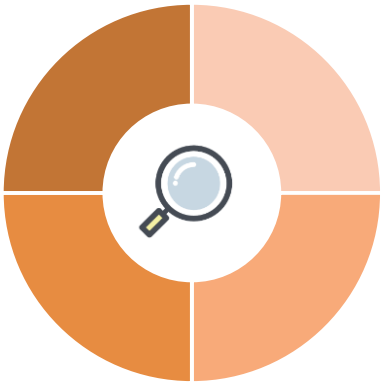
? → SSY?

Sediment Delivery Ratio (SDR)

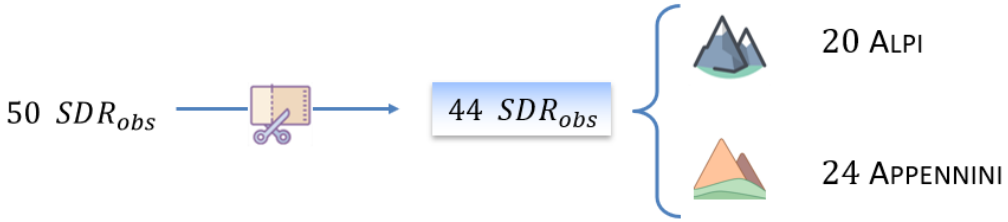
$$SDR = {}^{SSY}/_{GE}$$

$$0 \leq SDR \leq 1$$

MODELING SDR



Sediment Delivery Ratio model

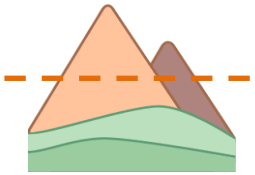


an empirical relationship between SDR and the representative variables of climatic, morphological, and hydrological catchment characteristics, and land use from multi-parametric statistical regressions.

13 variables initially

4 variables found to be significant

$R_c = 4\pi A / P^2$



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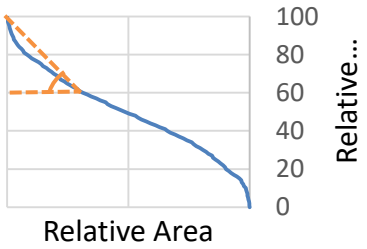
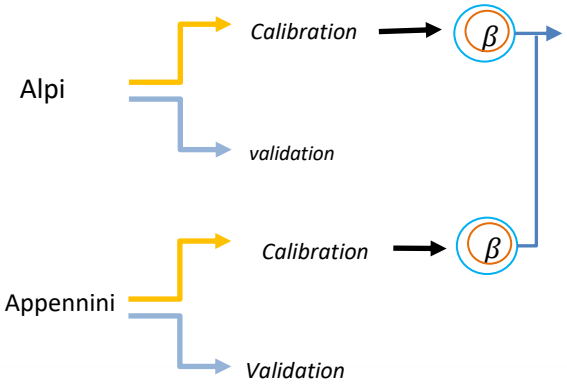


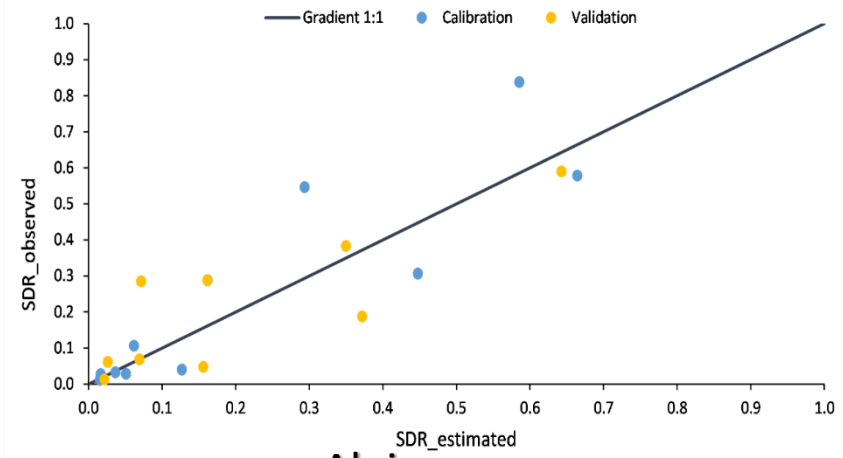
P_{60}

JACKKNIFE REGRESSIONE MODEL:

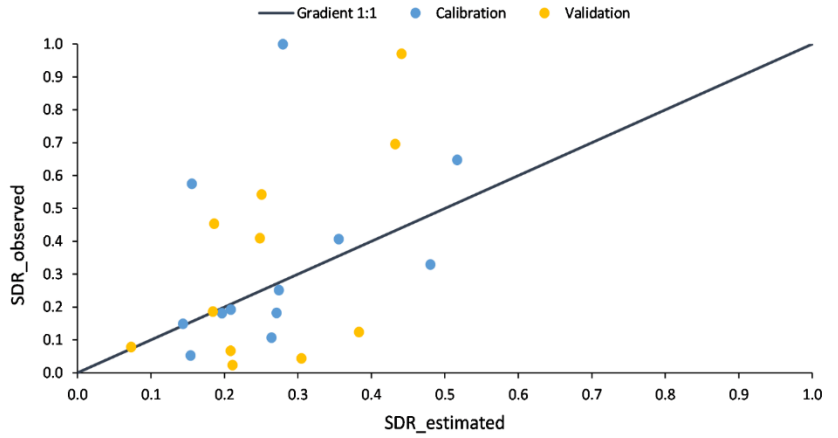
$$logSDR = \beta_1 logR_c + \beta_2 logE + \beta_3 logA + \beta_4 logP_{60} + \beta_0$$



Jackknife estimation of coefficients and intercept			
Coefficient	Variable	Alpi	Appennini
β_1	R_c	-3.16	-3.22
β_2	E	-2.94	-0.26
β_3	A	-0.61	-0.53
β_4	P_{60}	1.43	-0.21
β_0	intercept	7.67	-0.43



Alpine group

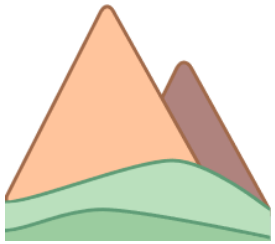


Apennine group

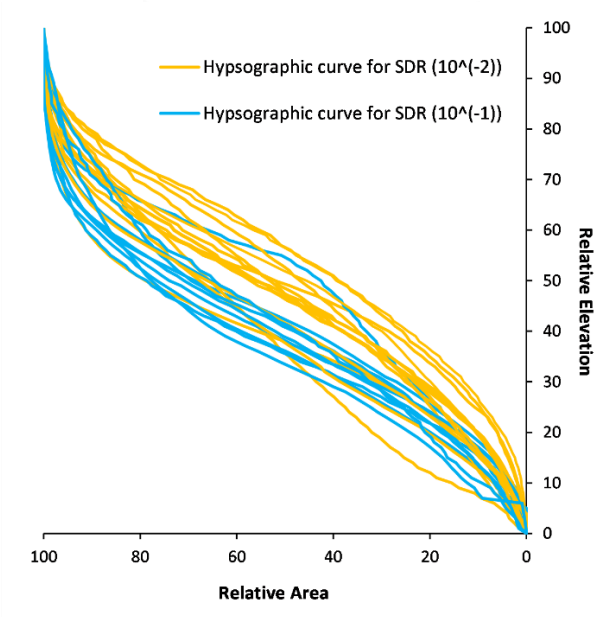
SDR distribution

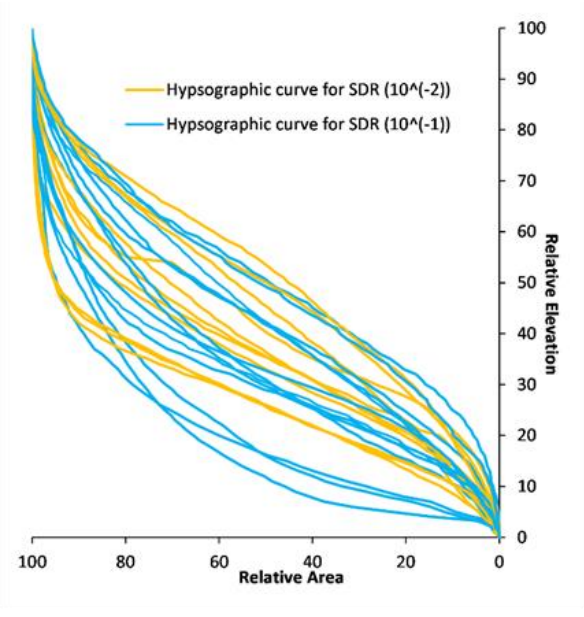
ALPI

APPENNINI



Hypsographic curves





Conclusion

Reservoir sedimentation threatens the functionality of the dam-reservoir system.

A continuous-time monitoring of this variable would be very attractive;

-A new SDR model with good performance in Alpine region.
-Performs better than empirical SDR models developed for Italian regions in the past.

ALPI VS APPENNINI : Different approach is needed both in management and in formulating legislations.

-Existing legislations on reservoir sediment management are inadequate.
-Sediment mitigation measures are not often properly planned/applied by dam operators in Italy

The impact of climate change on sediment production in turn on hydropower generation are rarely studied.