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Hydrological and sediment model calibration at ungauged basins using check dam stratigraphy as proxy data in a Mediterranean catchment

G. Bussi and F. Francés

Research Institute of Water and Environmental Engineering, ***Universitat Politècnica de València***, *Spain*

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Introduction

- *Problem*: hydrological modelling in Mediterranean semi-arid zones is limited by **data availability**:
  - **Good** data availability: rainfall, temperature, land use, …
  - **Scarce** data: water & sediment discharge, soil properties, …

- *Aim of the work*: calibration and validation of a hydrological model in a semi-arid catchment without discharge data.
  - 1 – simplifying the model by making realistic hypothesis;
  - 2 – using proxy data: **check dam sedimentation volume**;
  - 3 – using multidisciplinary techniques:
    - **stratigraphical analysis**
    - **hydrological modelling**
    - **reservoir sedimentation modelling**

Introduction

- Methodology:
  - 1 – Reconstruction of the **depositional record** of a check dam infill deposit by means of a stratigraphical description;
  - 2 – **Calibration and validation** of a hydrological and sediment model using the reconstructed depositional record;
  - 3 – **Verification** of the model performance by comparing simulated and observed water discharge at the streamgauge station;
  - 4 – **Sensitivity analysis** (Monte Carlo simulation).

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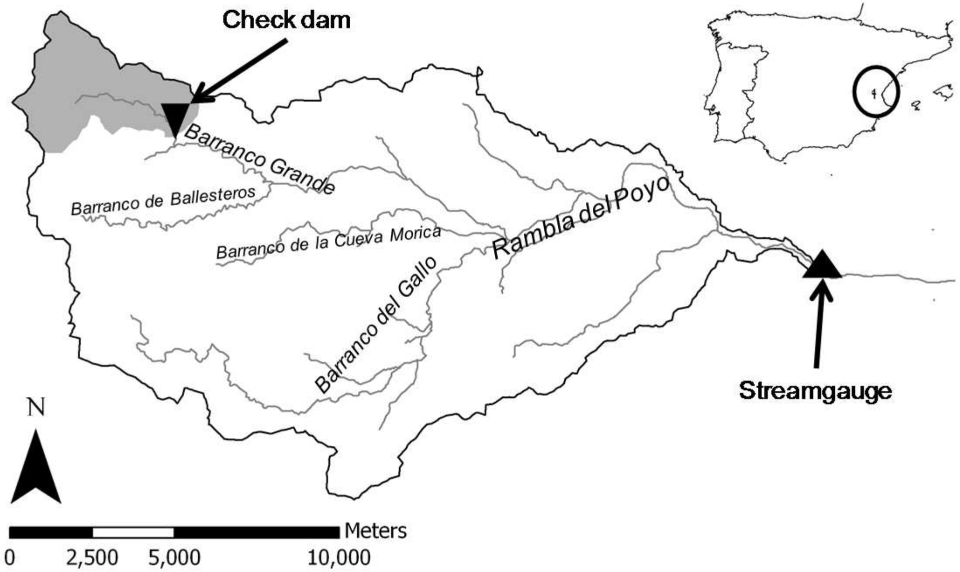
Study area

- Rambla del Poyo catchment (Valencia, SE Spain)
  - Semi-arid climate (rainfall = 450 mm/year; ET0 = 1,100 mm/year)
  - Geology dominated by limestone
  - Shrubland cover (*matorral*)
  - Studied catchment: 12.9 km^2
  - Streamgauge catchment: 184 km^2



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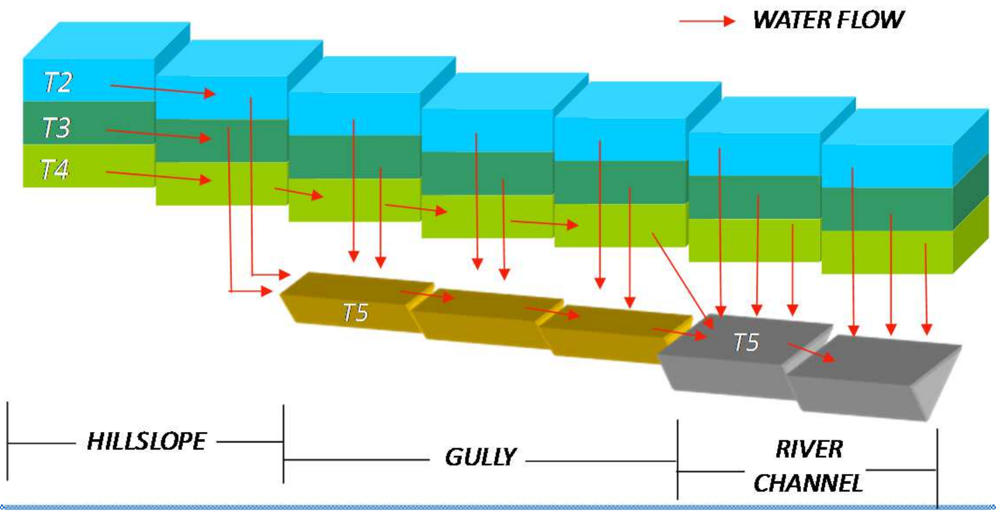
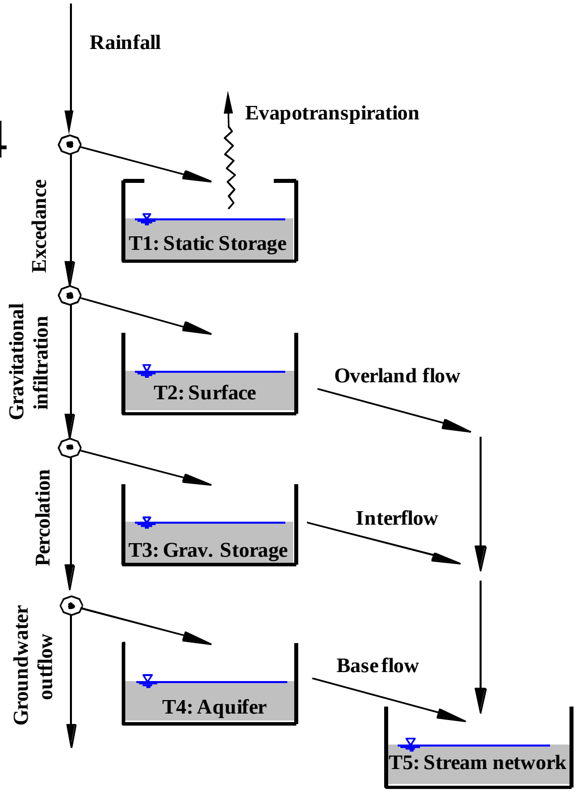
The model

- TETIS model: hydrological sub-model
  - Developed in the TU of Valencia since 1994
  - Distributed and conceptual (tank structure) model, with physically based parameters
  - Reproduction of hydrological cycle spatial variability
  - It uses all spatial information available



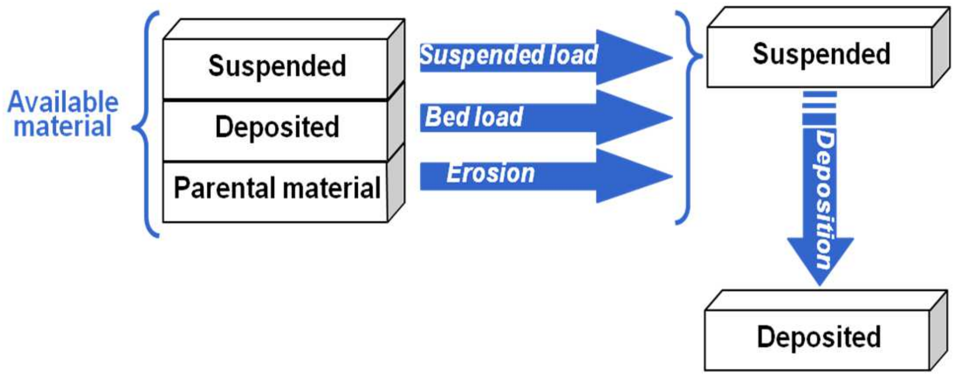


The model

- TETIS model: sediment sub-model
  - Integration of CASC2D-SED (Julien and Rojas, 2002) in TETIS
  - Balance between water transport capacity and sediment availability
  - Hillslope transport capacity: modified Kilinc – Richardson equation (Julien, 1995) (1)
  - Gully and channel transport: Engelund – Hansen equation (2)

(1) $$Q_h = \frac{1}{\gamma_s} W \alpha S_o^{1.66} \left(\frac{Q}{W}\right)^{2.035} \frac{K}{0.15} C P$$

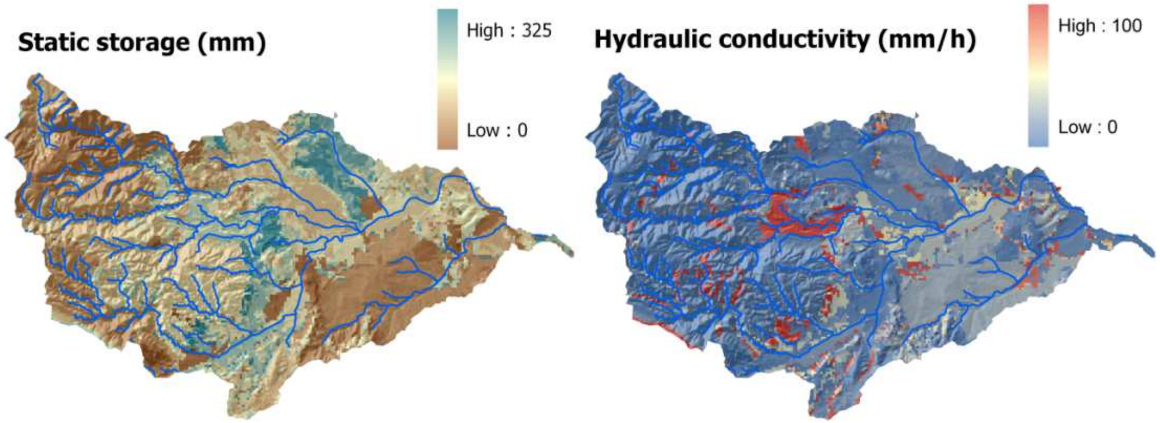
(2) $$C_{w,i} = \beta \left(\frac{G}{G-1}\right) \frac{V S_f}{\sqrt{(G-1) g d_i}} \sqrt{\frac{R_h S_f}{(G-1) d_i}}$$



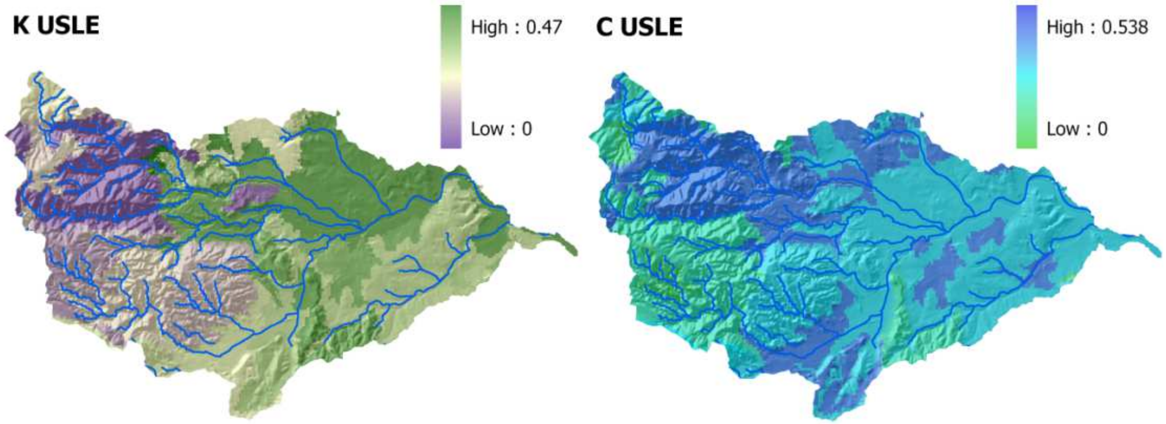
  - Reservoir sedimentation: **STEP model** (Verstraeten and Poesen, 2001)

The model parameters

- Model parameters:
  - Soil hydrological properties (static storage, hydraulic conductivity, …);



  - Sediment production properties (C, K and P factor of USLE and soil texture).



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Sediment proxy data

- Check dam infill volume
  - Many small check dams (2 – 10 m tall) were built in Spanish Mediterranean during 90s as sediment traps;
  - A partially filled check dam was chosen:
    - Height: 4.5 m;
    - Catchment: 12.9 km^2;
    - Capacity: 3000 m^3;
    - Total infill ~ 1400 m^3.

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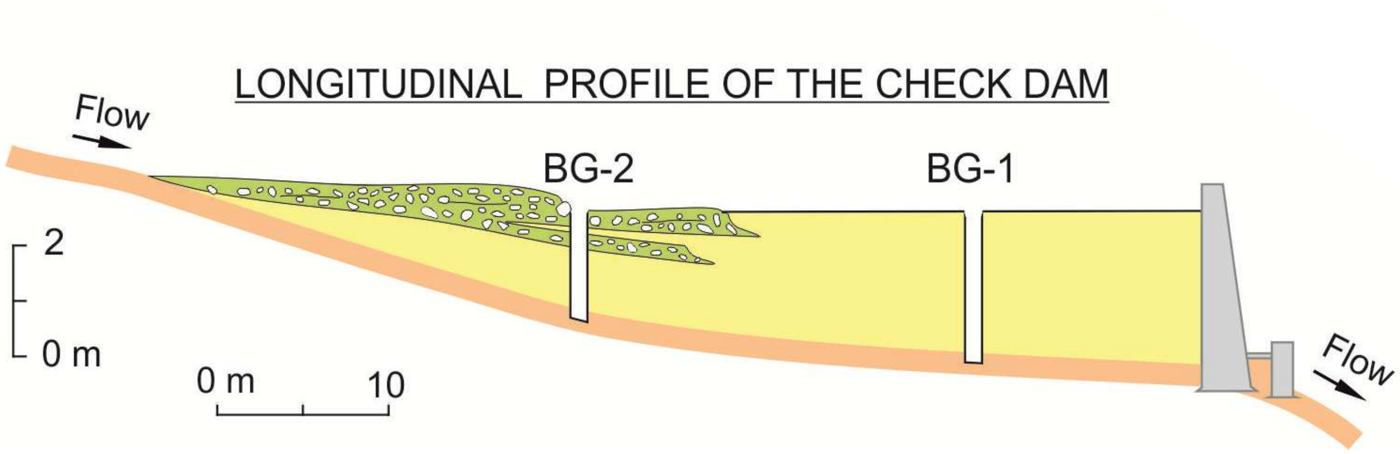
Sediment proxy data

- ❑ GPS survey for infill volume estimation
- ❑ Two 10 x 2.5 m trenches dug across the dam infill
- ❑ Detailed stratigraphic panels with 1 m mesh
    - detection of alluvial layers deposited by different floods (the separation is defined by a break in deposition)



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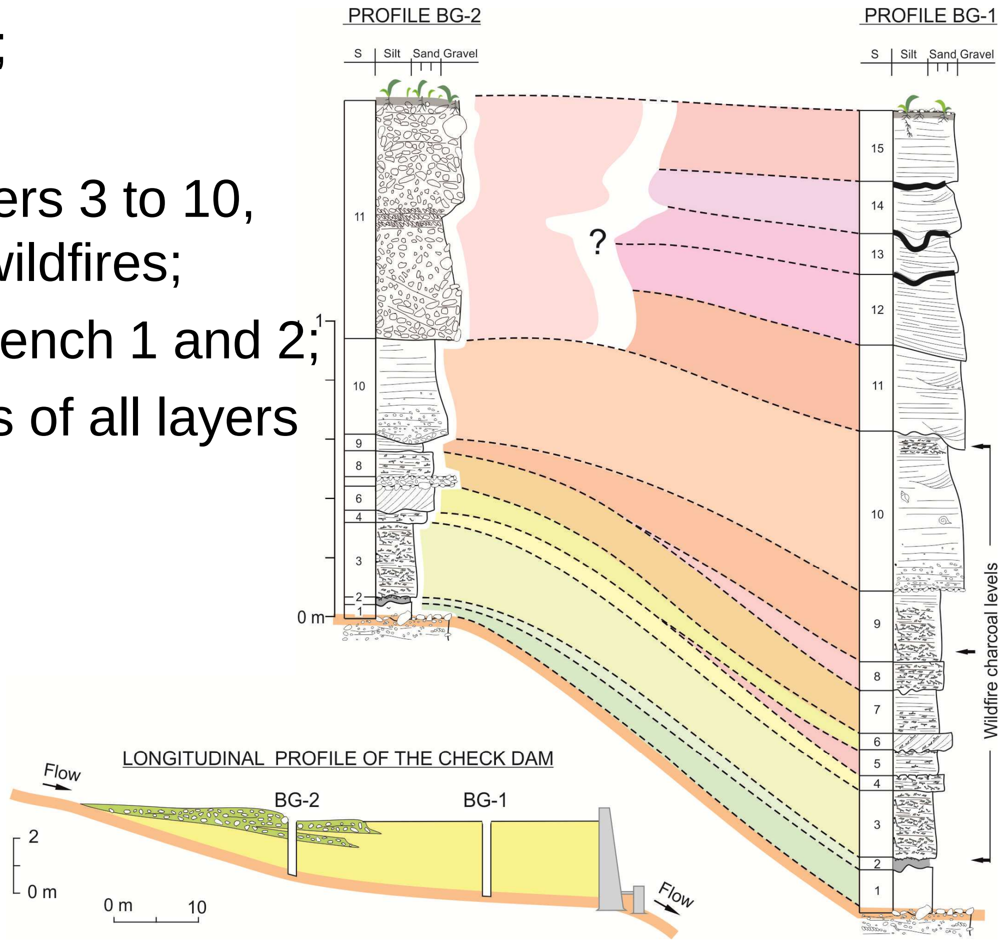
Infill volume estimation

- Stratigraphical description
  - 2.5 m sediment column;
  - 15 layers (flood units);
  - rests of **charcoal** in layers 3 to 10, due to 1994 and 2000 wildfires;
  - 8 layers found in both trench 1 and 2;
  - granulometrical analysis of all layers (sandy sediments);



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HESS Discussion

Infill volume estimation

- Two methodologies:

1 – **wedge approach**: every layer volume was calculated as if each flood unit had a wedge shape.

2 - **proportional approach**: by subtracting to the actual deposits the average layer depth.

Flood unit	Volume *i)* (m^3)	Volume *ii)* (m^3)
1	*34*	*38*
2	*8*	*28*
3	*172*	*78*
4	*10*	*27*
5	*14*	*18*
6	*55*	*18*
7	*22*	*11*
8	*20*	*41*
9	*195*	*96*
10	*153*	*233*
11	*75*	*110*
12	*8*	*11*
13	*37*	*46*
14	*30*	*23*
15	*18*	*22*
surface	*582*	*448*
tot	*1434*	*1248*

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Calibration and validation

- The model need to be **simplified**

- Some hypothesis(confirmed by field observations):
  - Hortonian flow
  - Very little interflow
  - No base flow

- Parameters to calibrate (5 most influential parameters):
  - Upper soil static storage
  - Upper soil vertical hydraulic conductivity
  - Upper soil horizontal hydraulic conductivity
  - Routing correction coefficient
  - α: Kilinc – Richardson sediment production coefficient

Calibration and validation

- Dating:
  - Using charcoal and knowing wildfires dates (1994 and 2000);
  - Model results help dating;

- Calibration
  - The model is calibrated simulating the reservoir observed deposited volume of the **October 2000 event** (the most extreme event in the historical series) with a **daily** Δt;
  - The October 2000 deposited layer is formed by flood units 8 + 9 +10;
  - Deposited volume is ~ 370 m^3;

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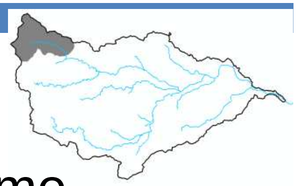
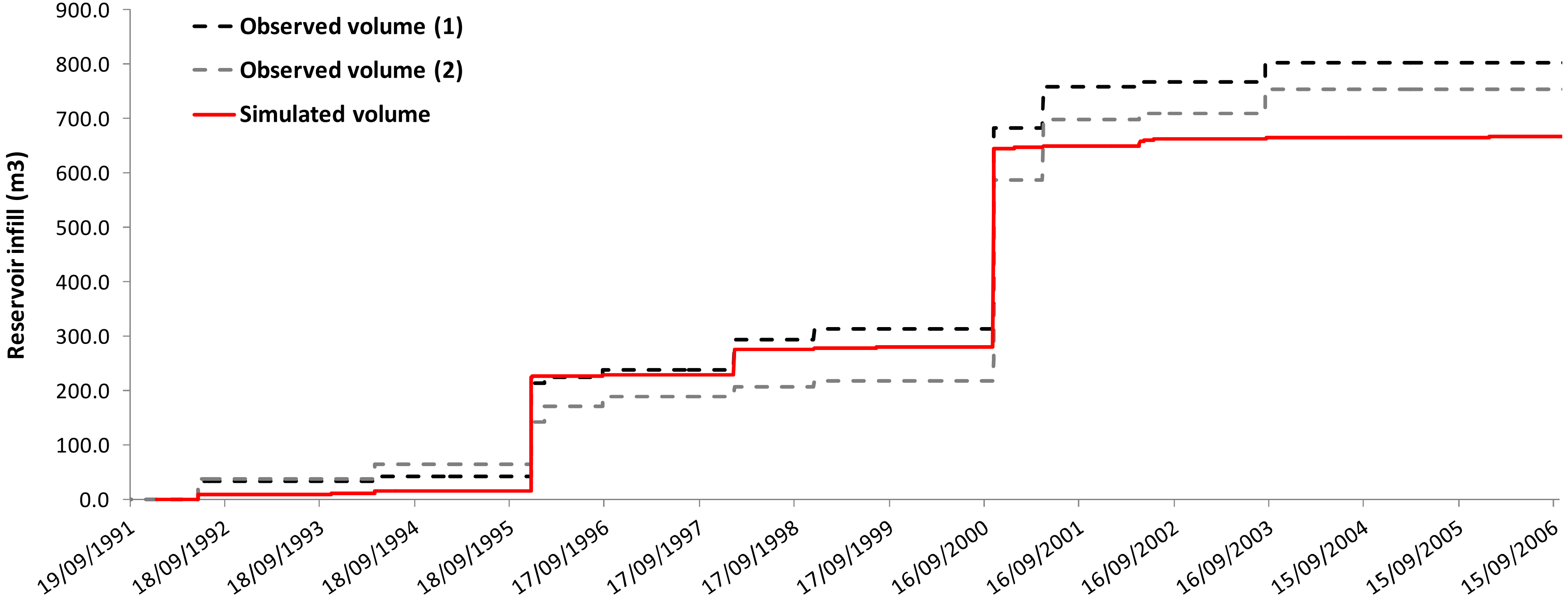
Calibration and validation

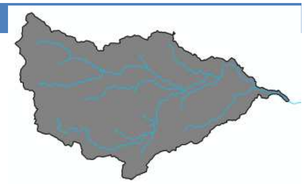


❑ **Sediment** model validation

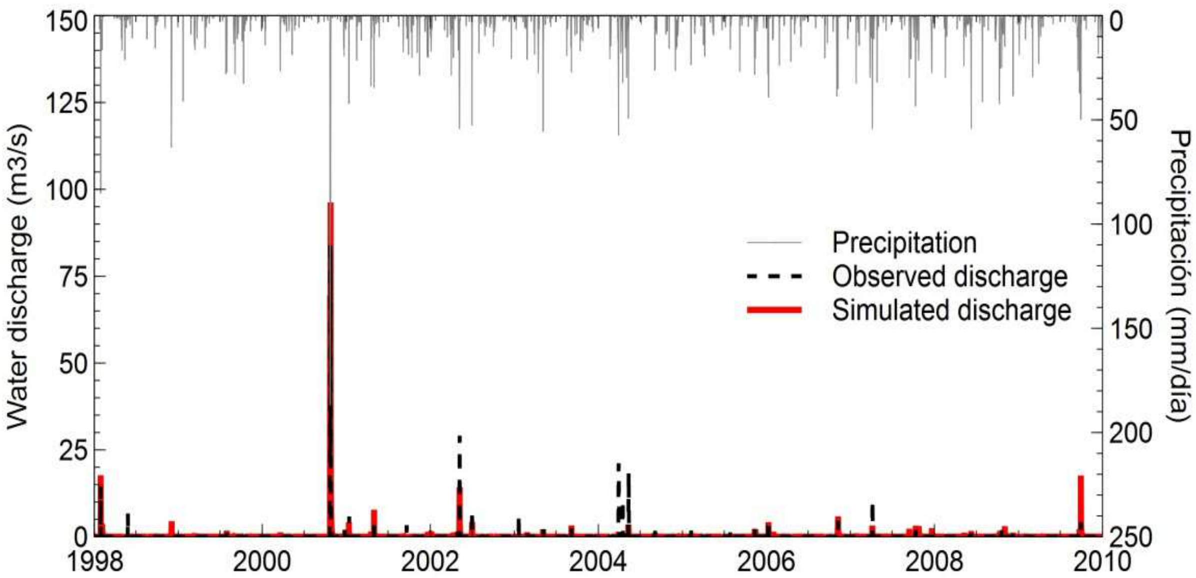
- The model is validated *vs* observed reservoir infill volume (reconstructed from stratigraphical description) – 12.9 km^2
- **Feedback** process: model results help dating sediment layers

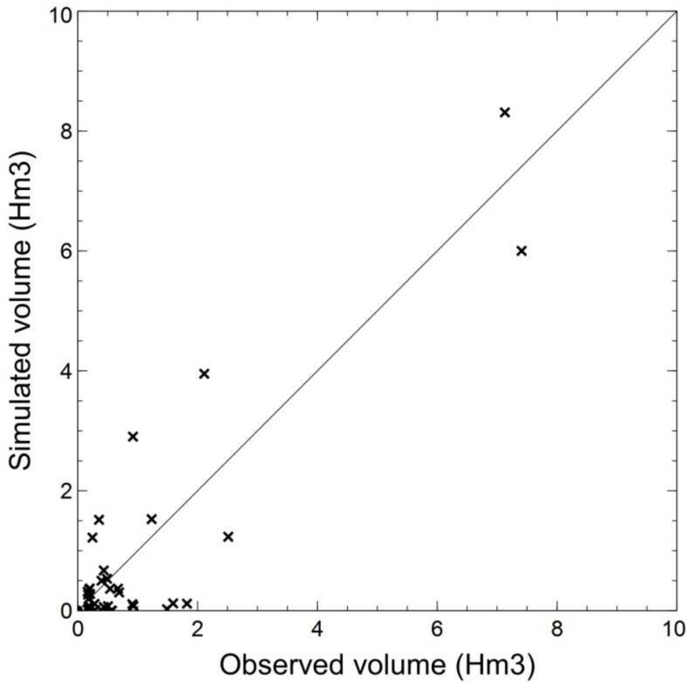


Calibration and validation



- **Water** discharge validation
  - The model is validated vs water discharge from the Rambla del Poyo streamgauge (184 km^2)





NSE index = 0.86

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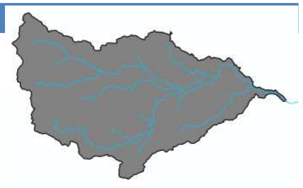
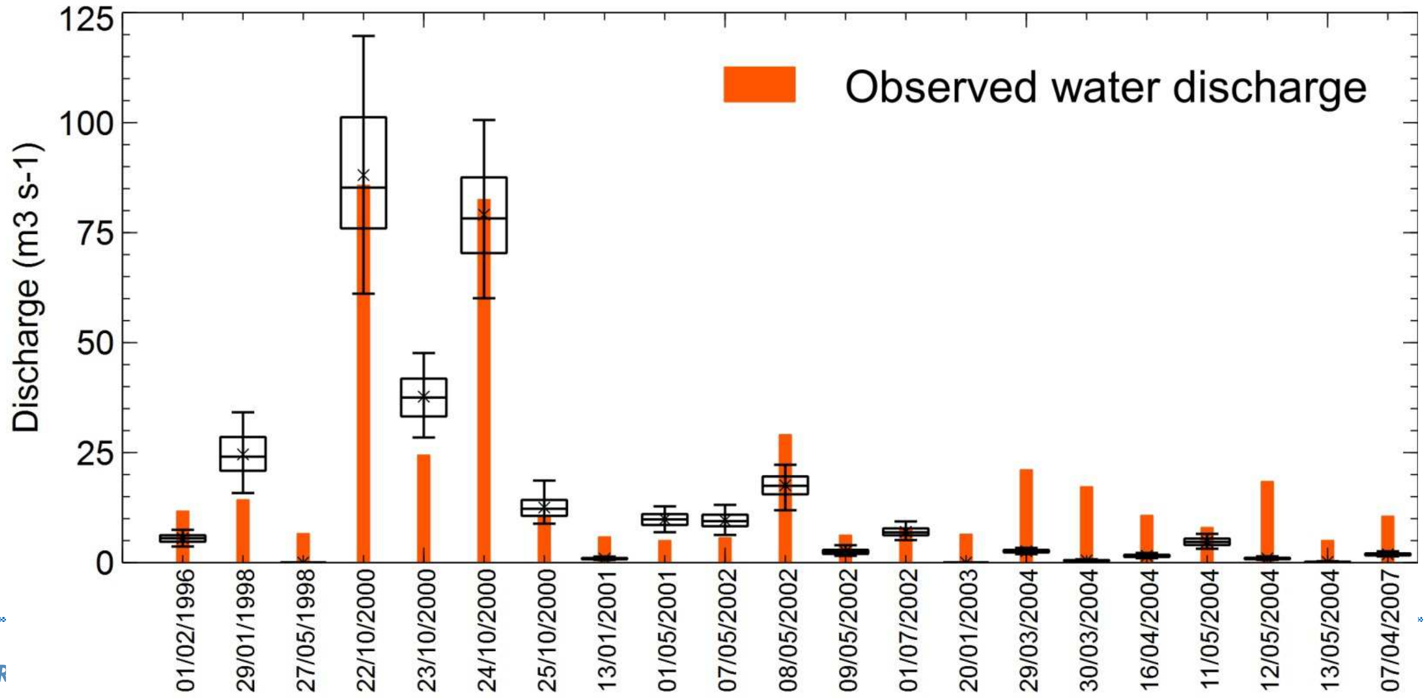
Sensitivity analysis



- Monte Carlo simulation
  - 50,000 simulations with random values of the 4 most influent parameters;
  - The best 100 simulations in terms of total infill **volume error** *at the check dam* are tested *at the stream gauge* in terms of **NSE**.



Conclusions

- Sediment proxy data help constrain water cycle model calibration (**transfer of information** from sediment cycle to water cycle);

- **Multidisciplinarity**: coupling hydrological modelling and palaeohydrological techniques for improving catchment knowledge;

- **Small data requirement**: rainfall and temperature, soil data, land use and partially filled check dams;

- **Generalization**: this technique can be used in almost all Mediterranean small and medium size catchment

Thanks for your attention!

Gianbattista Bussi (gbussi@upvnet.upv.es)

Research Group of Hydrological and Environmental Modelling
lluvia.dihma.upv.es

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