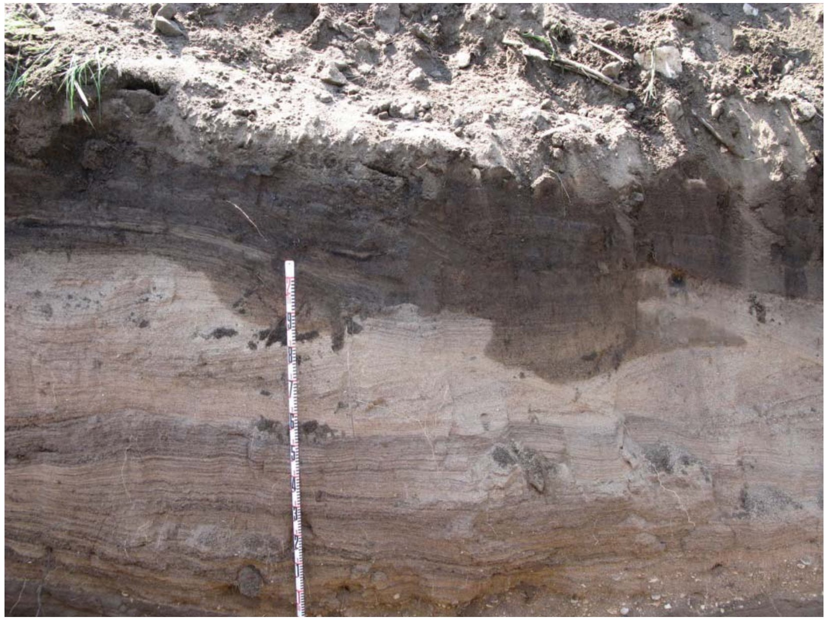
Universitat Politècnica de València
Departamento de Ingeniería Hidráulica y Medio Ambiente
Programa de doctorado en Ingeniería del Agua y Medioambiental



Implementation of a distributed sediment model in different data availability scenarios

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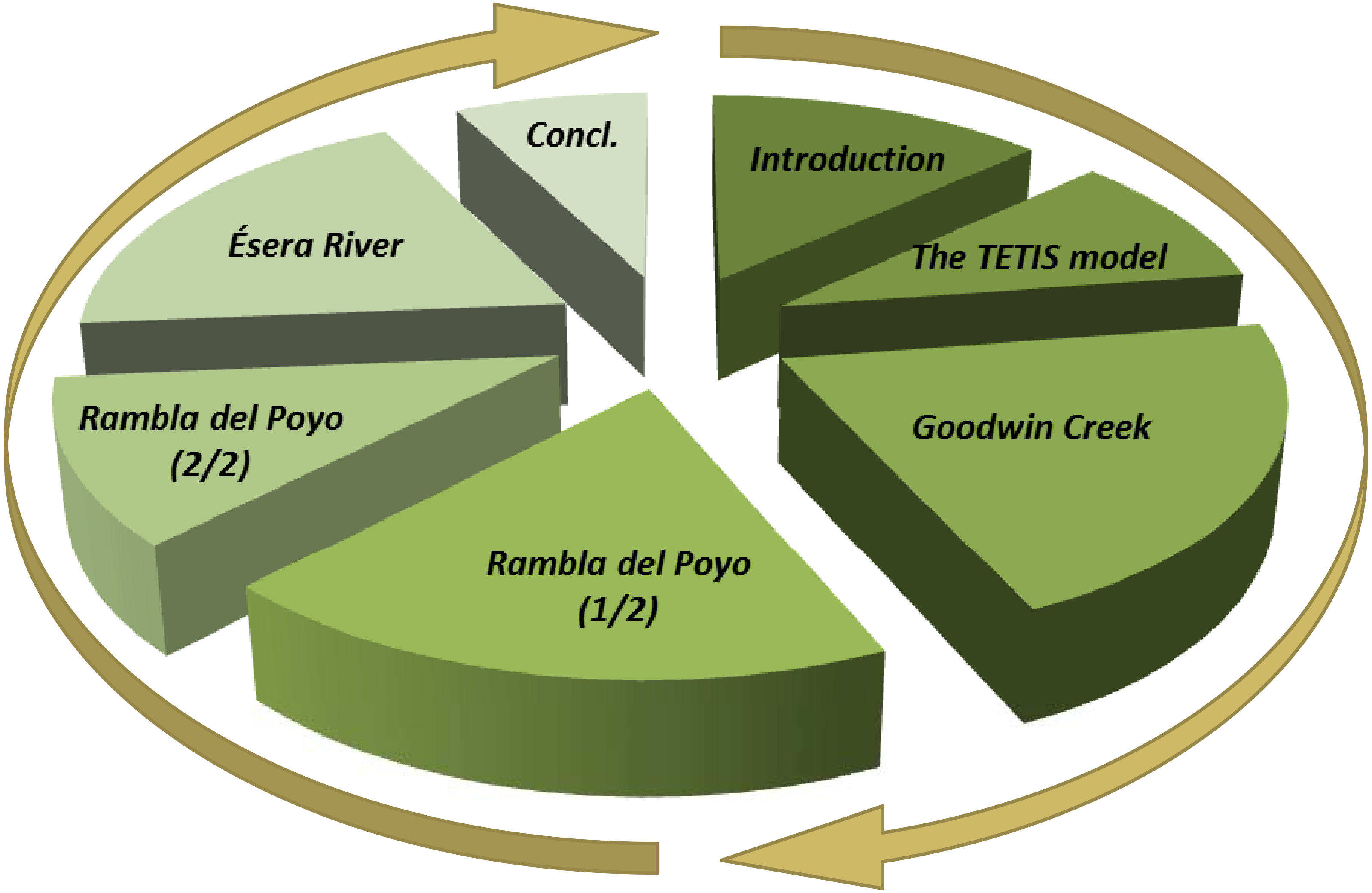
Valencia, February 2014

Presentation outline

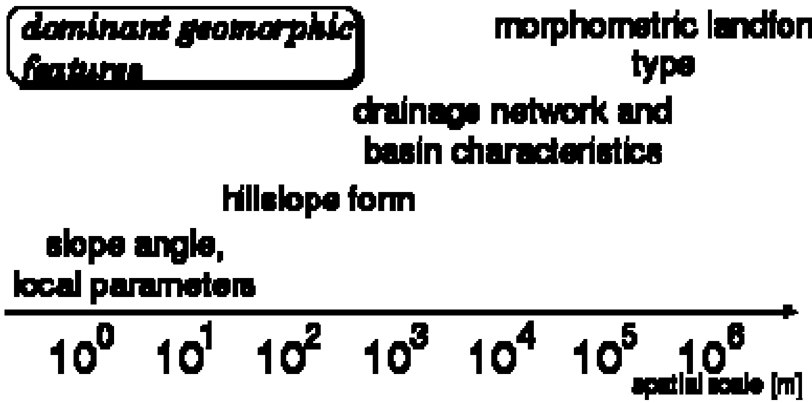


Introduction

- Importance of soil erosion and sediment transport forecasting:
  - Agriculture management
  - Soil productivity loss prevention
  - Reservoir design
  - Hydraulic infrastructure design support
  - Ecohydrological applications
  - Contaminant cycle and fate analysis
  - Etc.

- Highly complex and non-linear physical processes: mathematical modelling approach

- Mathematical modelling of the sediment cycle:
  - Developed since ’60 (first model: USLE)
  - Classification:
    - By conceptualization:
      - Empirical
      - Physically based
      - Conceptual
    - By temporal scale:
      - Event scale
      - Continuous simulation
    - By spatial scale:

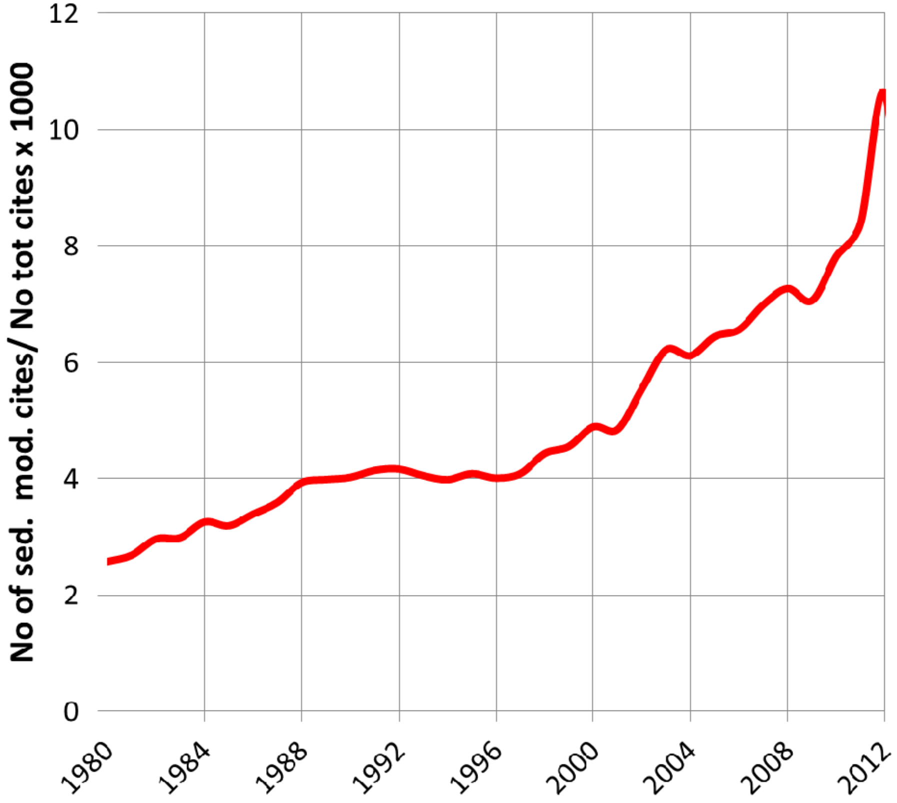


Anderson and Burt, 1990

- Sedimentological models:

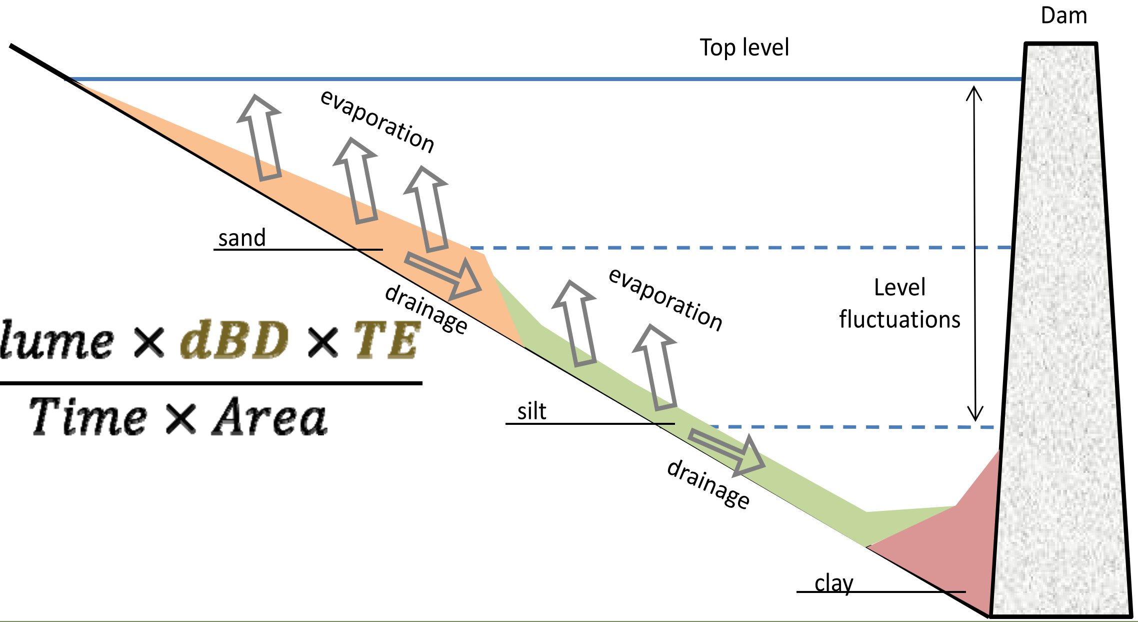
Model	Reference
USLE	*Wischmeier and Smith, 1961*
ANSWERS	*Beasley et al., 1980*
CREAMS	*Knisel, 1980*
KINEROS	*Smith, 1981*
SEM	*Storm et al., 1987*
WESP	*Lopes, 1987*
AGNPS	*Young et al., 1989*
WEPP	*Laflen et al., 1991*
GUEST	*Misra and Rose, 1996*
SHESED	*Wicks and Bathurst, 1996*
LISEM	*de Roo et al., 1996*
SWAT	*Arnold et al., 1998*
EUROSEM	*Morgan et al., 1998*
LASCAM	*Viney and Sivapalan, 1999*
SEDD	*Ferro and Porto, 2000*
WATEM/SEDEM	*Van Rompaey et al., 2001*
CASC2D-SED	*Ogden and Heilig, 2001*
WASA-SED	*Mamede, 2008*

Google scholar search:
"sediment erosion model"



- Main **limitations** of sediment models:
  - Process representation
    - What grade of **process complexity** should be reproduced?
  - Need for reliable implementation (calibration and validation)
    - **Data is needed!**
  - Spatial and temporal scale effects
    - Sediment transport equations often obtained at plot or reach scale
  - Model sensitivity to its parameters
    - Especially physically based models

- Reservoir sedimentation:
  - 380,000 large reservoirs in the world (ICOLD)
  - A few million small reservoirs or ponds (*Verstraeten and Poesen*, 2000)
  - Used since 60s to estimate inter-annual sediment yield



$$SY[Mg\ Ha\ y^{-1}] = \frac{Volume \times dBD \times TE}{Time \times Area}$$

Introduction

- Main goals of the dissertation:

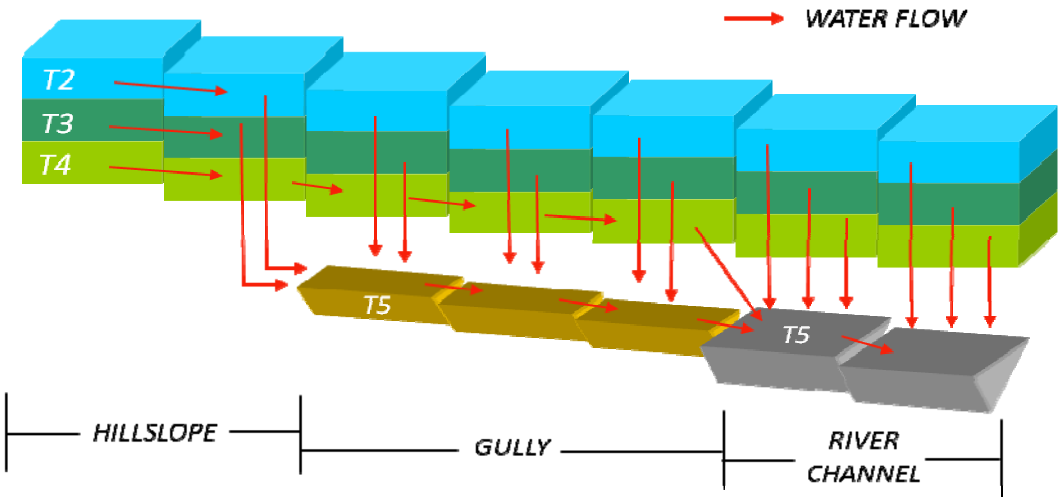
  - To present TETIS model and its last and new improvements

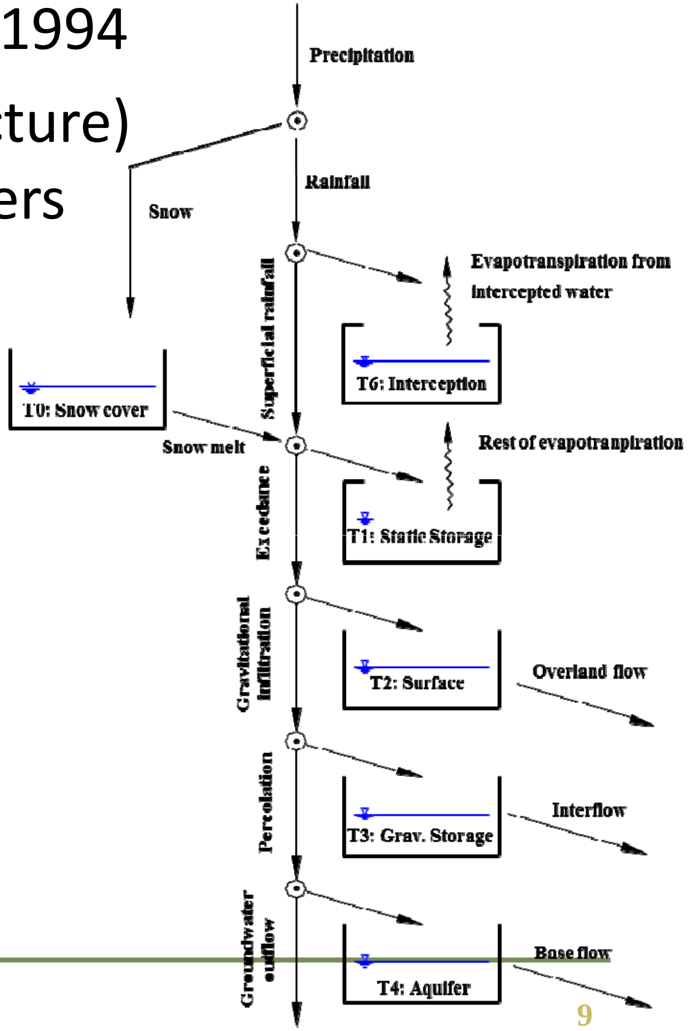
  - To explore the possible applications of the model in different data availability scenarios

  - To investigate the use of sediment proxy data such as reservoir sedimentation deposits for model implementation

The TETIS model

- Hydrological sub-model
  - Developed in the TU of Valencia since 1994
  - Distributed and conceptual (tank structure) model, with physically based parameters
  - Automatic calibration algorithm



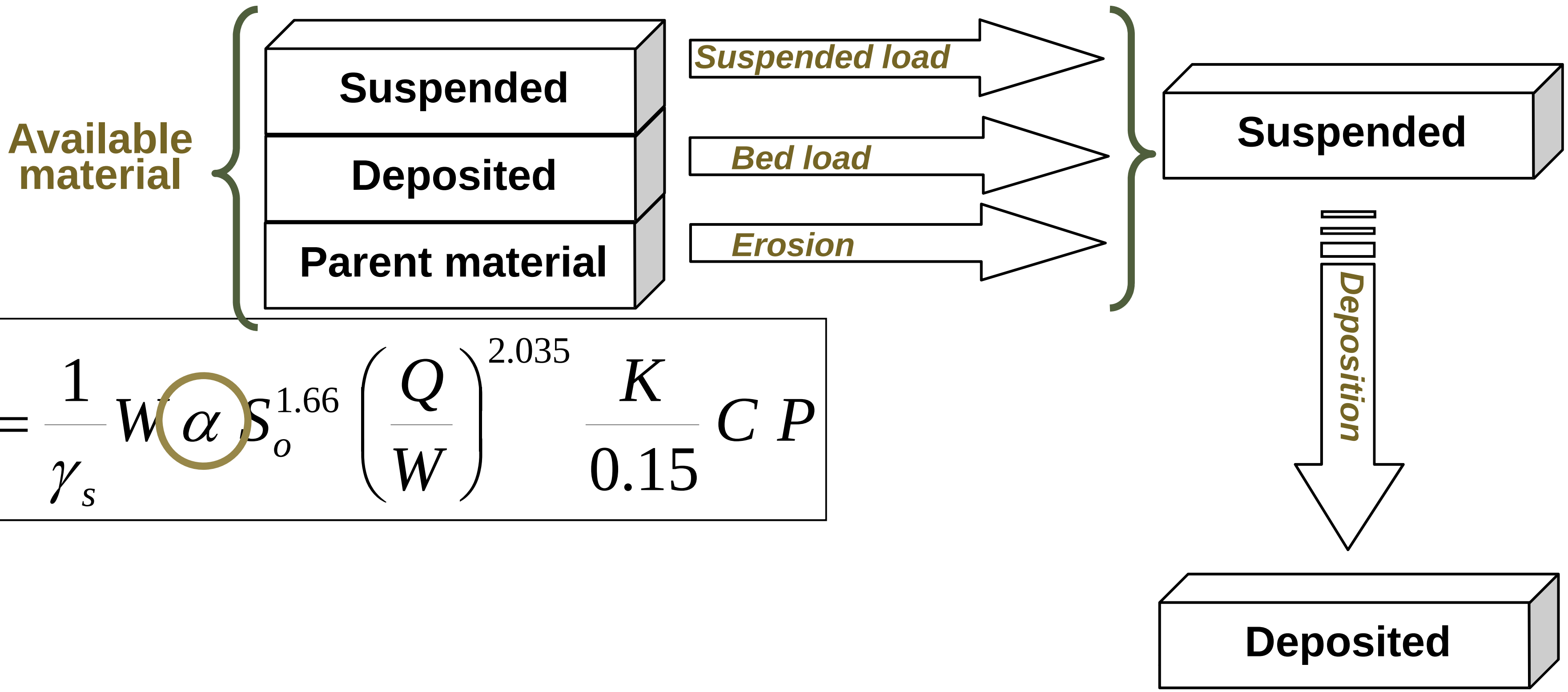


The TETIS model

- Sedimentological sub-model
  - Integration of CASC2D-SED model (COLOSTATE Uni., USA)
  - Balance between:
    - Transport capacity
    - Sediment availability

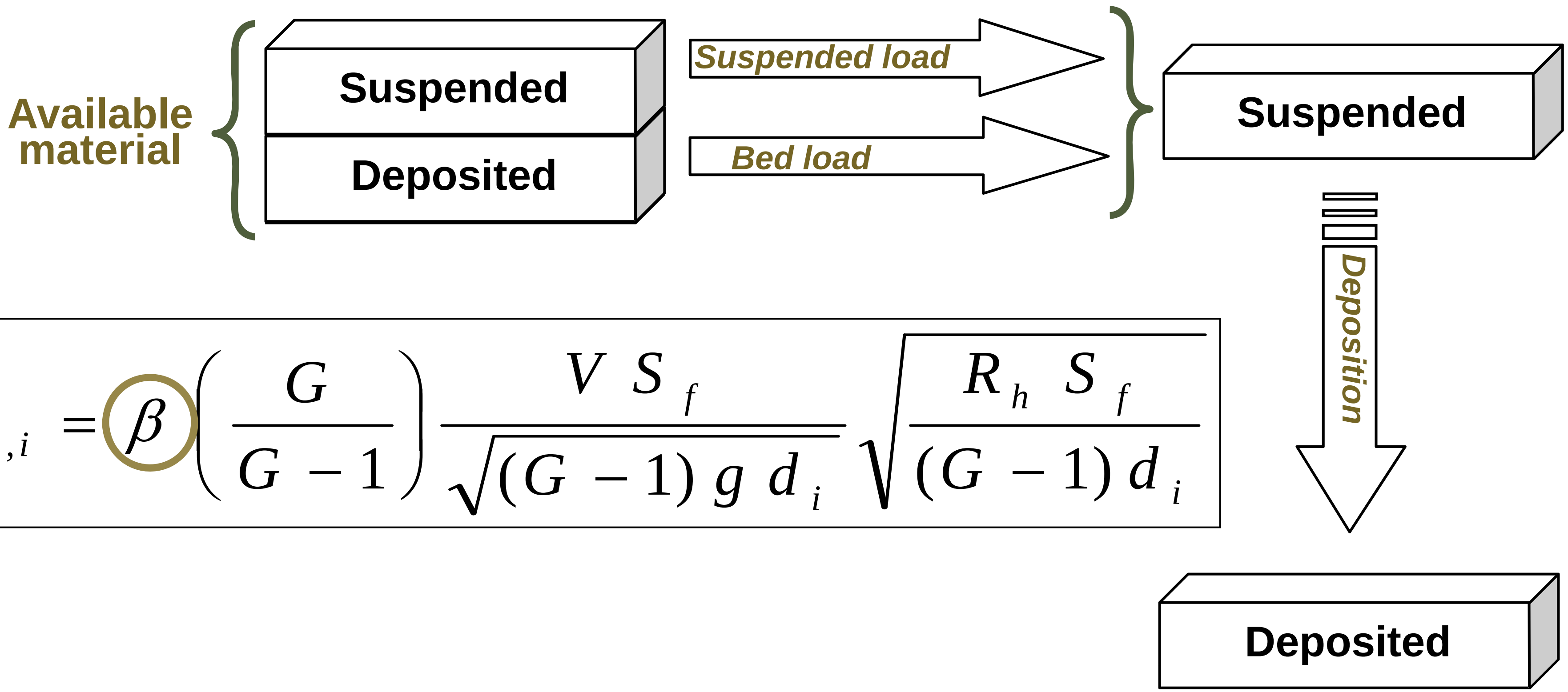
    (by textural classes)
  - Conceptual model
    - Physical basis
    - Empirical factors

- Sedimentological sub-model
  - Hillslope transport capacity: modified Kilinc – Richardson equation (Julien, 1995)



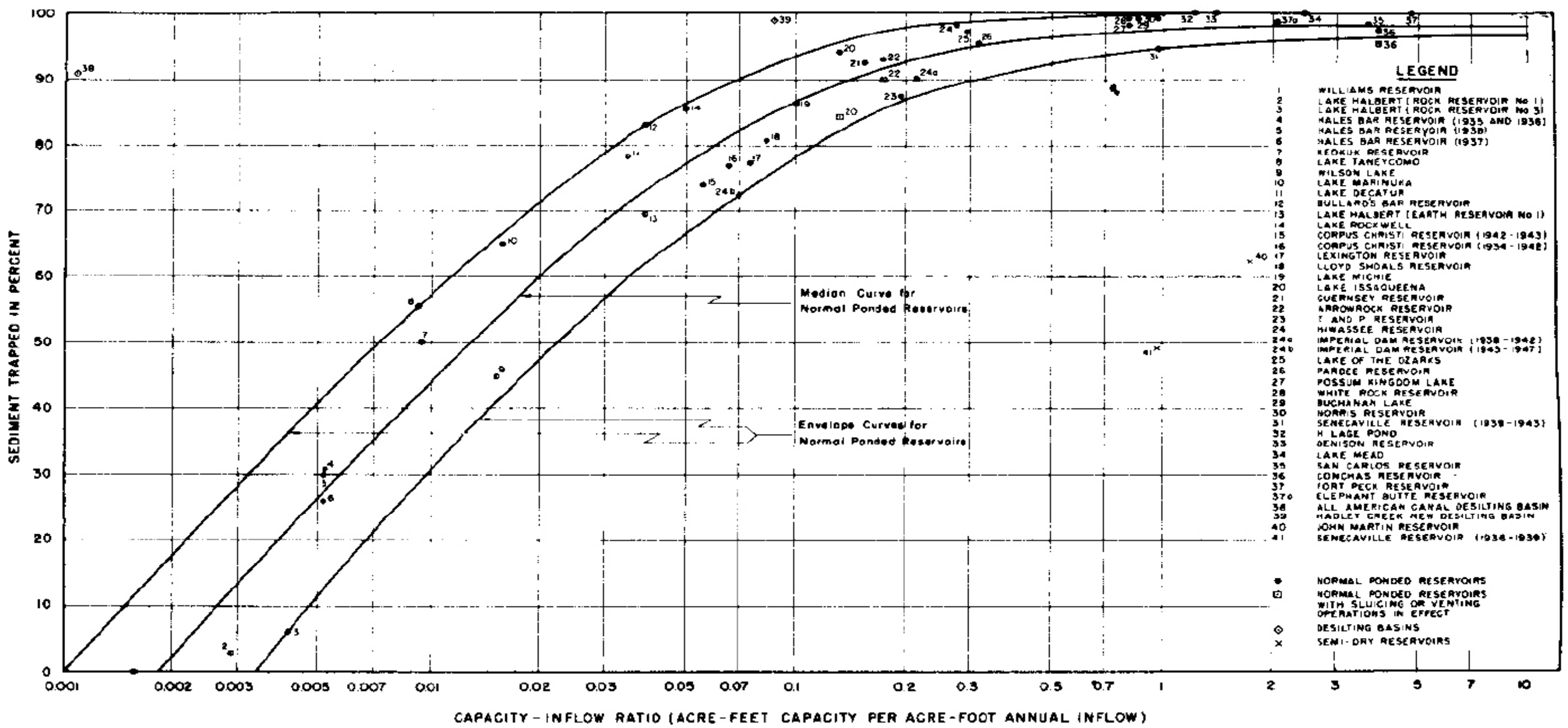
$$Q_s = \frac{1}{\gamma_s} W \alpha S_o^{1.66} \left(\frac{Q}{W}\right)^{2.035} \frac{K}{0.15} C\ P$$

- Sedimentological sub-model
  - Gully and channel transport: Engelund – Hansen equation



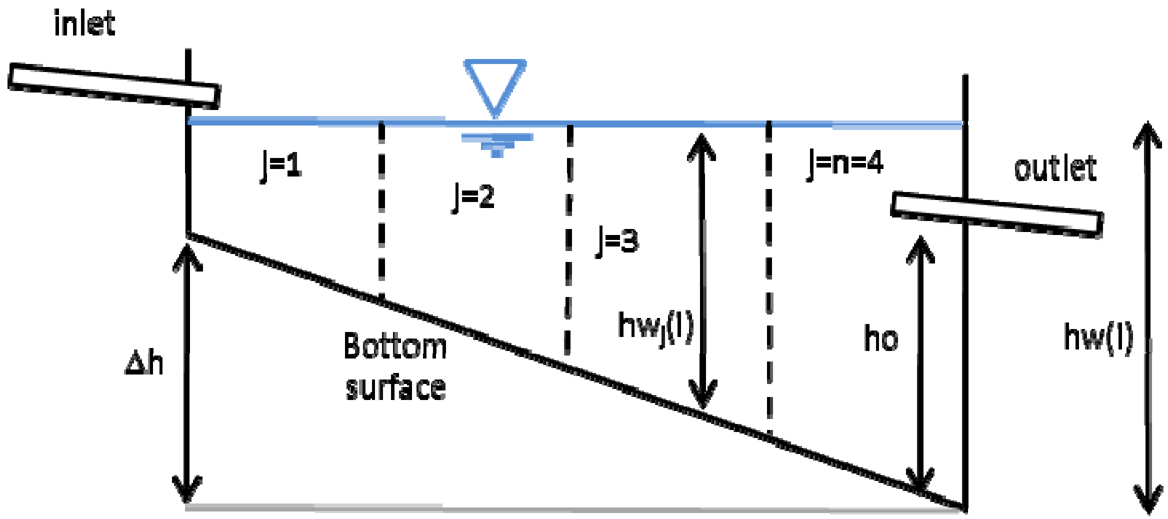
$$C_{w,i} = \beta \left(\frac{G}{G-1} \right) \frac{V \, S_f}{\sqrt{(G-1)\, g \, d_i}} \sqrt{\frac{R_h \, S_f}{(G-1)\, d_i}}$$

- Trap efficiency for large reservoir:
  - Brune curves (1953)
    - Not coupled with TETIS



The TETIS model

- Trap efficiency for small reservoirs:
  - STEP model (Verstraeten and Poesen, 2001)
    - Developed for small reservoirs
    - Simple, parsimonious and up-to-date
    - Easily coupled with TETIS



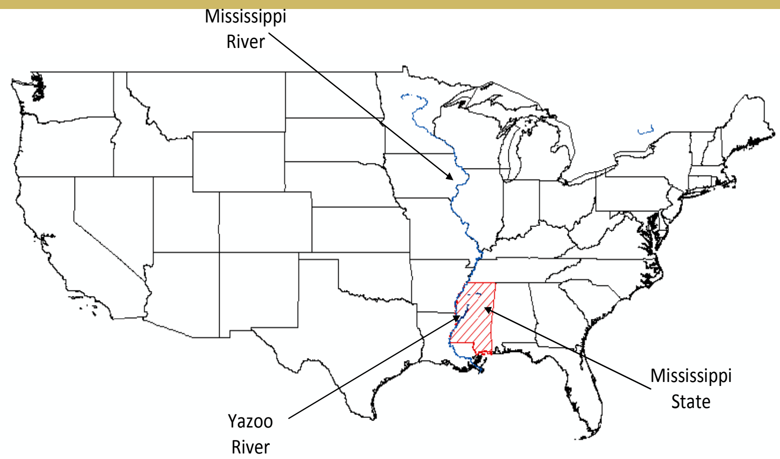
Goodwin Creek

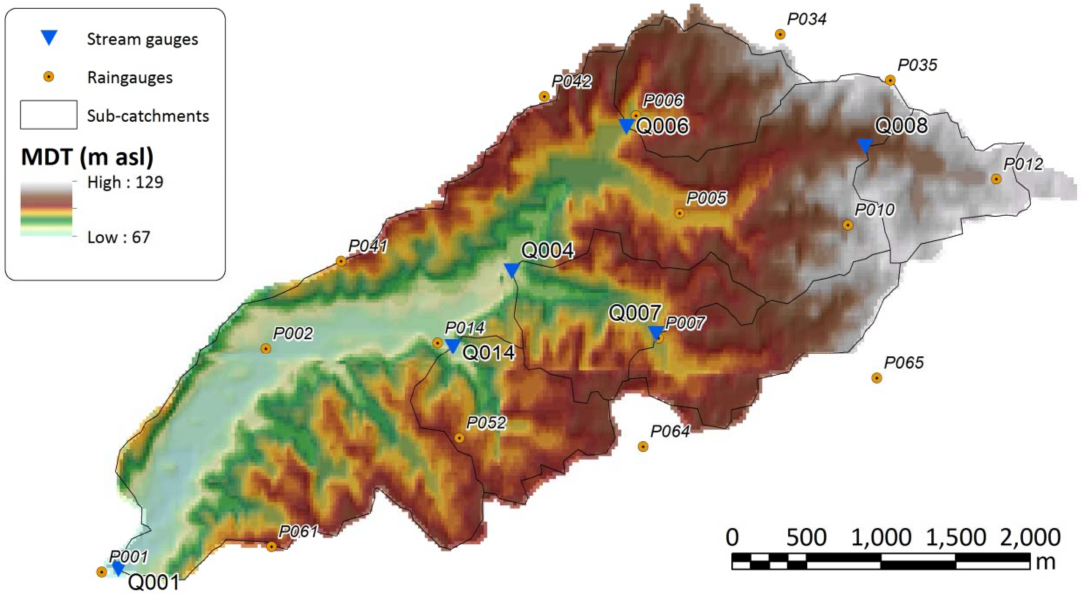
- Data availability:
  - Experimental catchment

- Goals of the application:
  - Sediment sub-model testing;
  - Analysis of the influence of initial sediment deposits on the model results;
  - Comparison of different methodologies for initial sediment deposits estimation.

Goodwin Creek

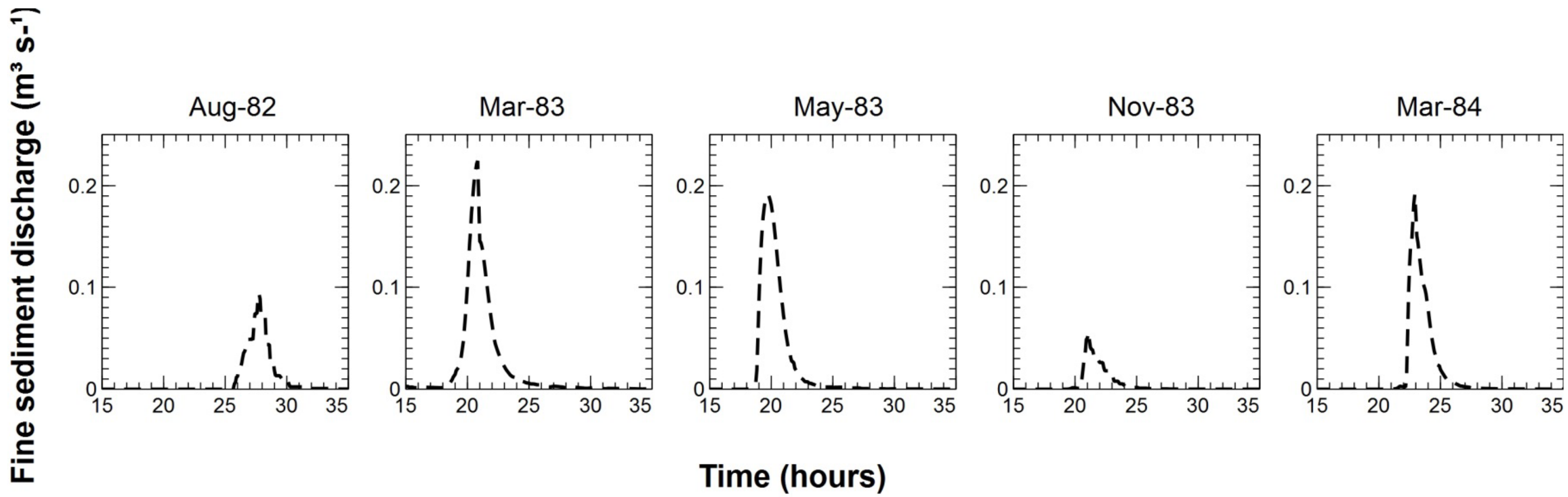
- Catchment description
  - 21.3 km^2
  - Average prec. 1440 mm/year
  - Hortonian behaviour
  - Highly erodible (badlands)





Goodwin Creek

- Available data
  - 31 raingauges (16 used)
  - 14 stream gauges (6 used)
  - 6 fine sediment continuous samplers (Ø<0.062 mm) - total load only measured at Q01 (not available)
- Model approach: event scale (5 events)



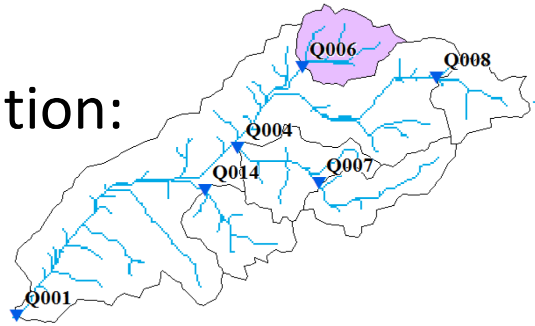
Goodwin Creek

- Methodology

A – Hydrological sub-model implementation

B – Sediment sub-model calibration and validation:

- Separate calibration for $\alpha + \beta_1$ (Q06) and β_2 (Q01)

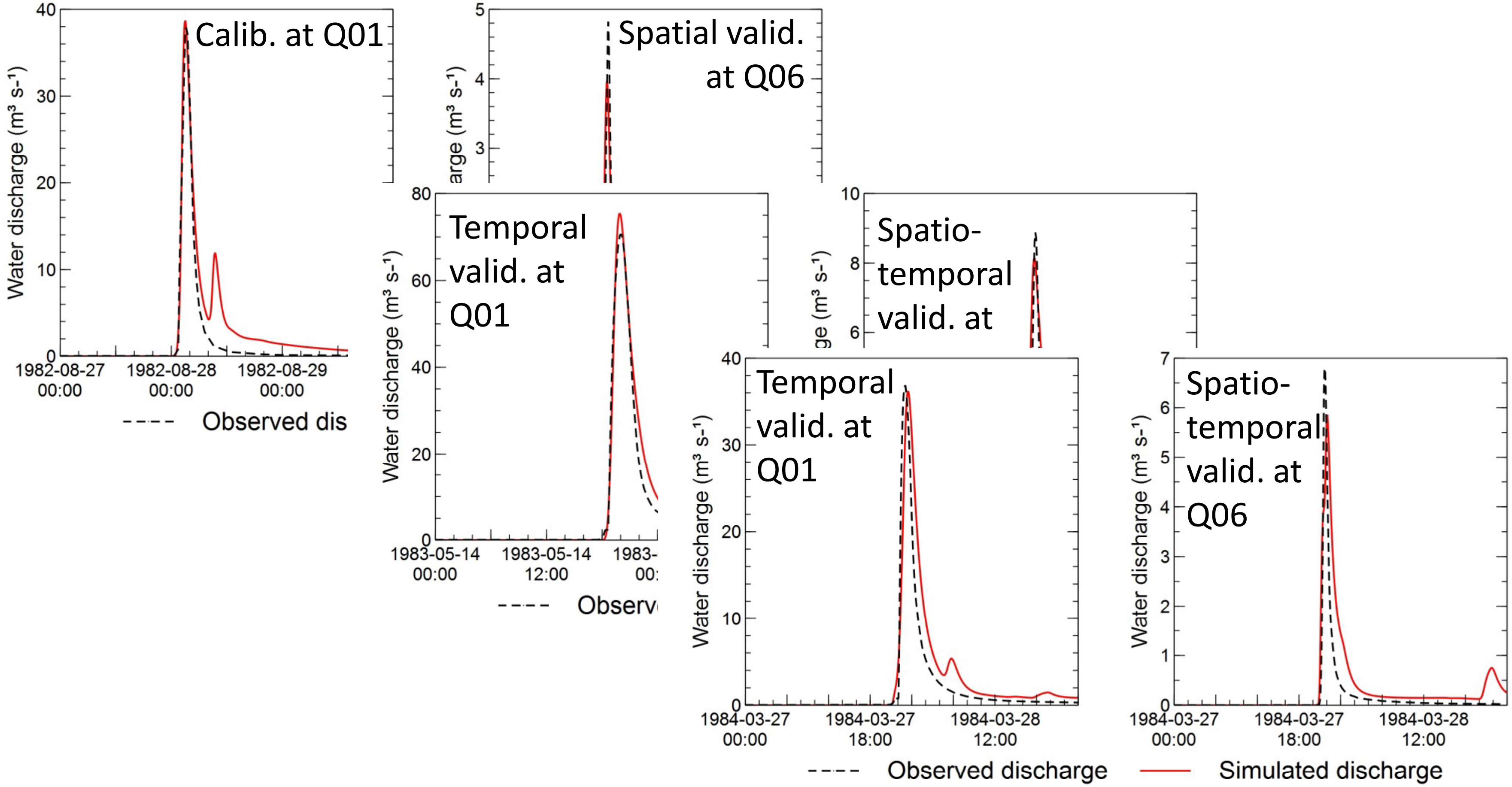


C – Initial condition estimation through 3 methods:

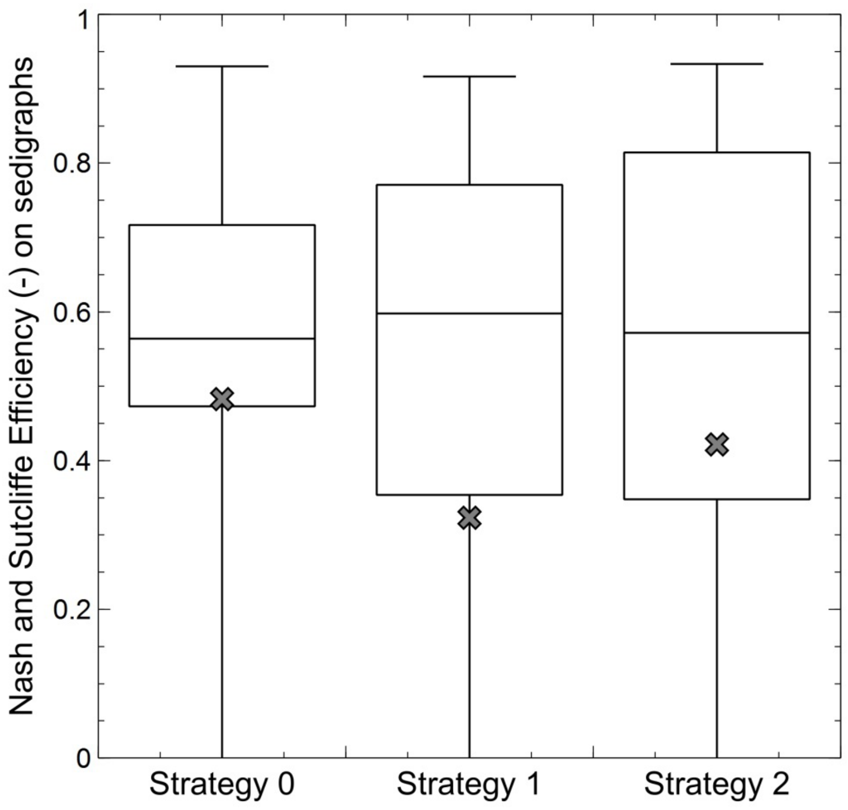
- **STRATEGY 0**: no initial deposits
- **STRATEGY 1**: manual calibration of the initial deposit volumes (a different calibration for each event)
- **STRATEGY 2**: initial deposit volume estimation by warm up simulation

D – Continuous simulation application

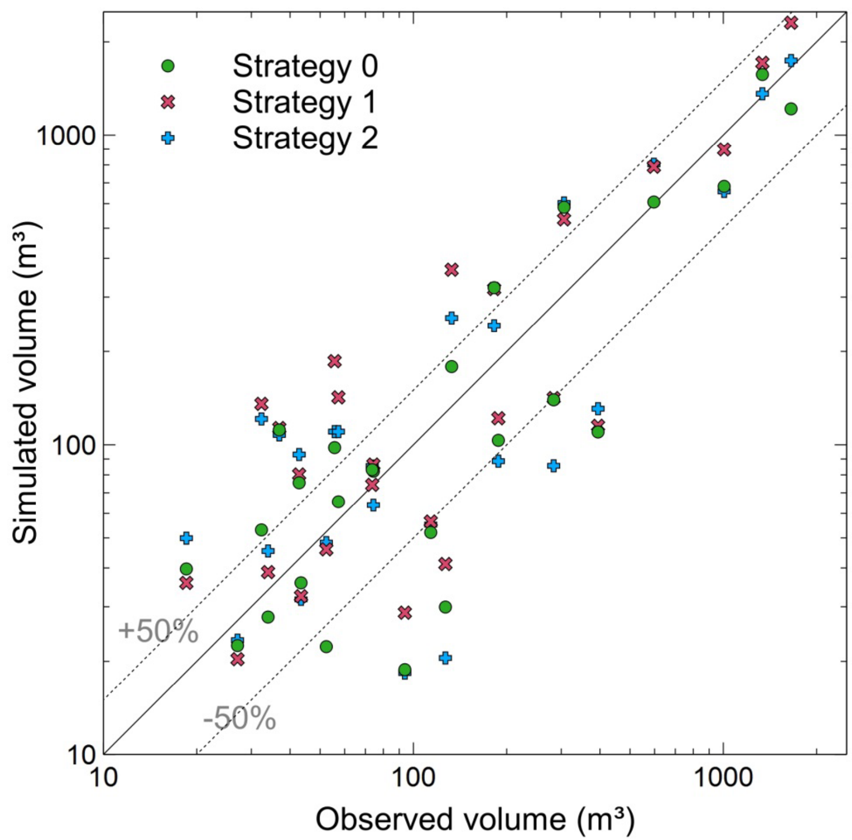
- Results: hydrological sub-model implementation



- Results: sediment sub-model implementation

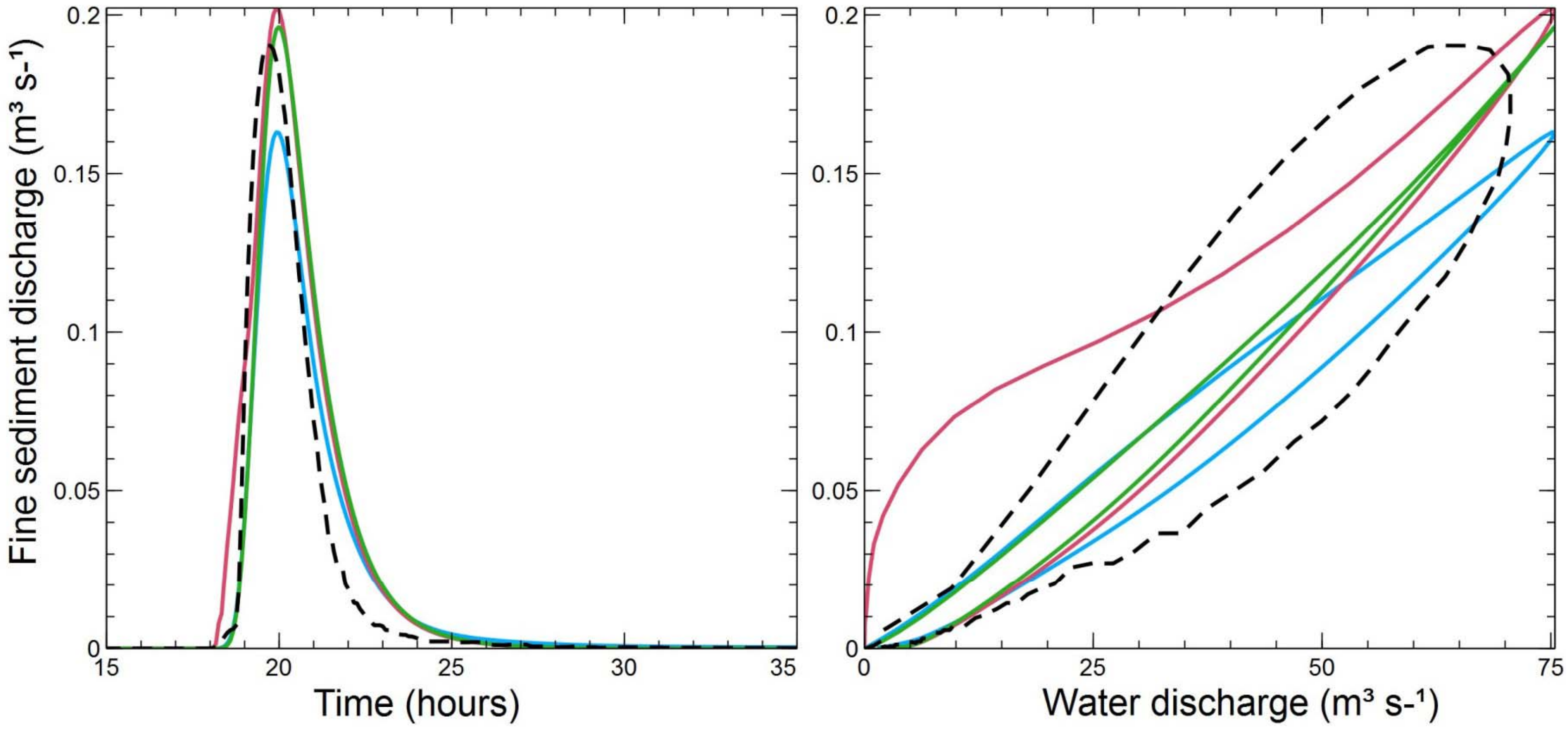


Nash and Sutcliffe Efficiency



Volume error

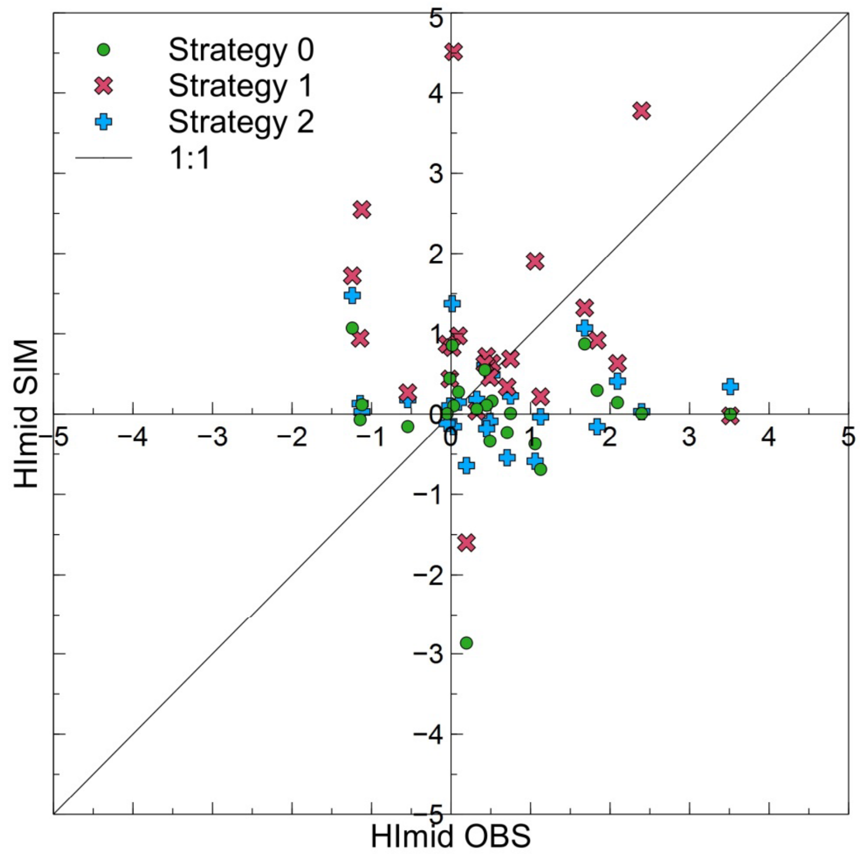
- Results: sedigraphs and hysteresis loops in Q01 – event #3



❑ Results: hysteresis loops

		OBS	0	1	2
Aug-82	Q01	*Counter clockwise*			
	Q04	*Clockwise*			
	Q06	*Clockwise*			
	Q07	*Clockwise*			
	Q08	*Eight-shaped*			
Mar-83	Q01	*Clockwise*			
	Q04	*Clockwise*			
	Q06	*Clockwise*			
	Q07	*Clockwise*			
	Q08	*Clockwise*			
May-83	Q01	*Clockwise*			
	Q04	*Clockwise*			
	Q06	*Counter clockwise*			
	Q07	*Clockwise*			
	Q08	*Unique curve*			
Nov-83	Q01	*Clockwise*			
	Q04	*Clockwise*			
	Q06	*Eight-shaped*			
	Q07	*Clockwise*			
	Q08	*Clockwise*			
Mar-84	Q01	*Clockwise*			
	Q04	*Eight-shaped*			
	Q06	*Counter clockwise*			
	Q07	*Clockwise*			
	Q08	*Clockwise*			

Hysteresis Index *(Lawler et al, 2006, Sci Total Environ, 360, 109–26)*

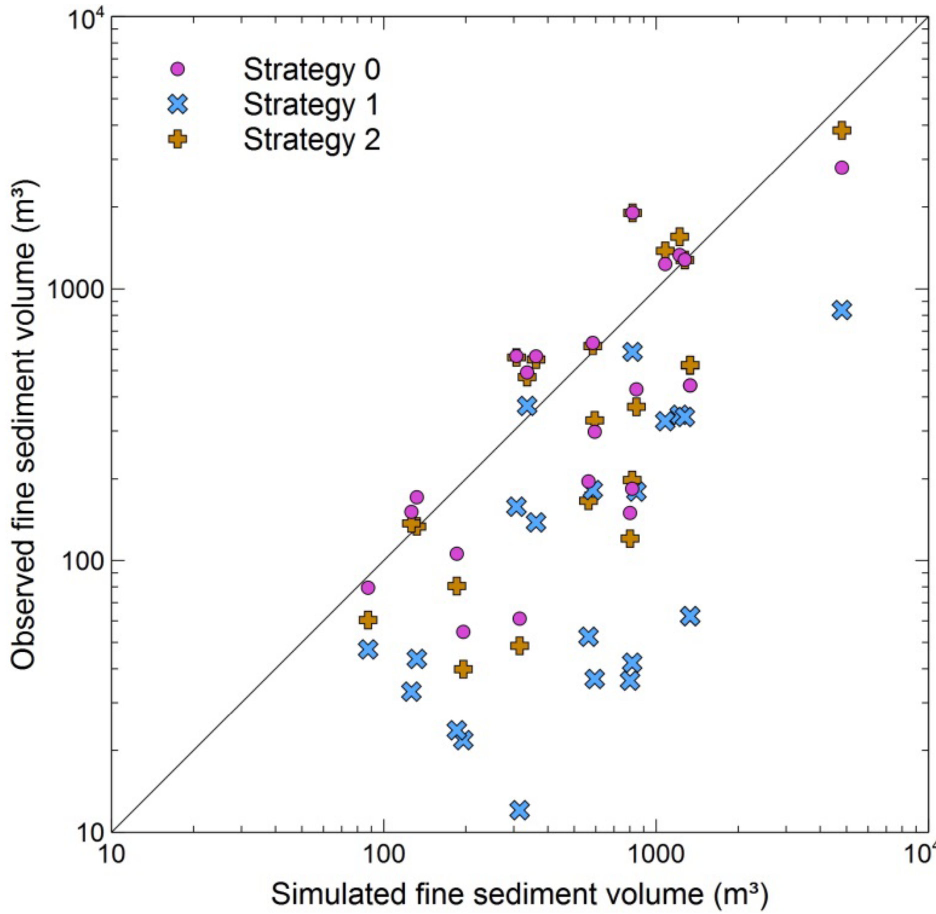


Goodwin Creek

- Results: continuous simulation:

  - From 1981 to 1984

  - Sediment yield:
    - OBS: 1.3 Mg ha y^{-1}
    - S0: 1.2 Mg ha y^{-1}
    - S1: 0.6 Mg ha y^{-1}
    - S2: 1.4 Mg ha y^{-1}



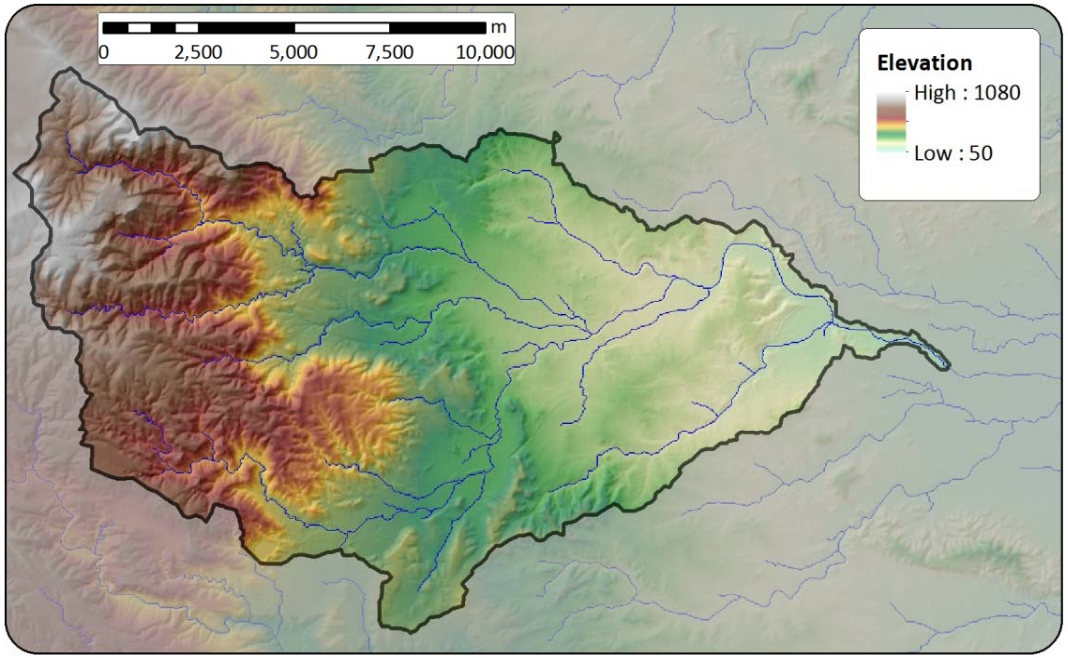
Rambla del Poyo (1/2)

- Data availability:
  - Precipitation and water discharge are monitored
  - Sediment transport is not monitored

- Goals of the application:
  - Applying TETIS to a sediment ungauged catchment
  - Applying STEP model for small reservoirs sediment dynamic reproduction
  - Checking the usefulness of check dam deposits as a source of sediment proxy data for model calibration and validation

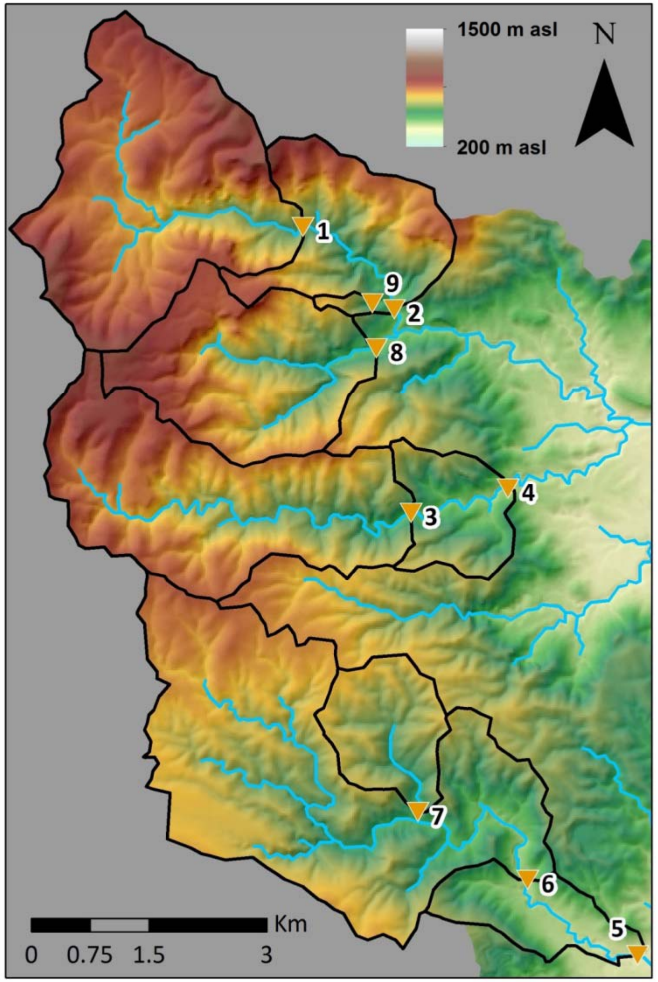
Rambla del Poyo (1/2)

- Catchment description
  - 184 km^2 at SAIH flow gauge station
  - Prec. 450 mm/year – ET0 1,100 mm/year
  - Draining to a coastal lagoon (Albufera)
  - Shrubland vegetation
  - Limestone lithology
  - Frequent wildfires



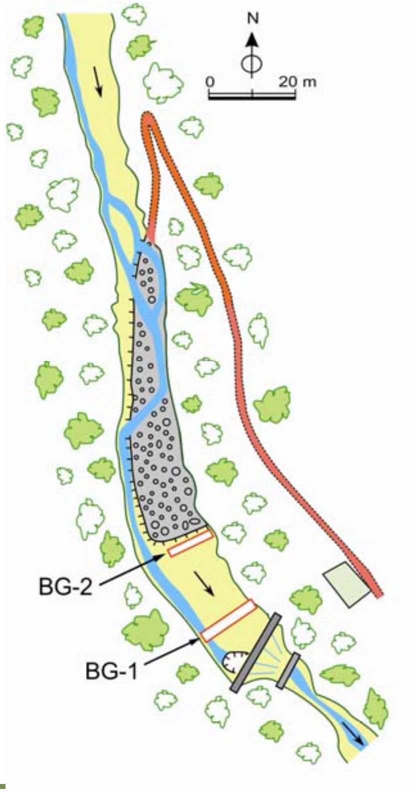
Rambla del Poyo (1/2)

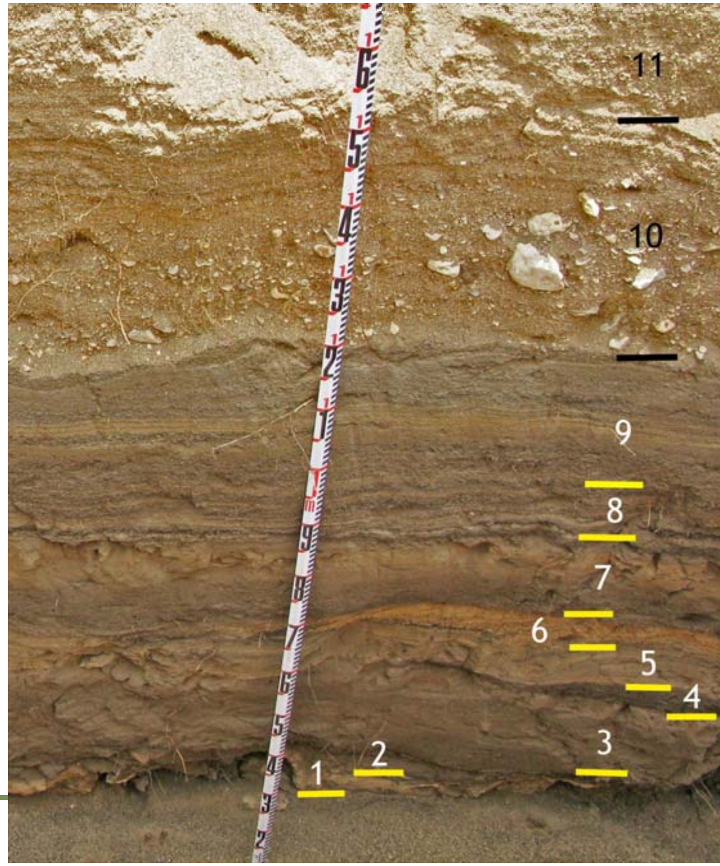
- Available data
  - 1 raingauge and 1 stream gauge
  - Proxy sediment data: 9 partially filled check dams



Rambla del Poyo (1/2)

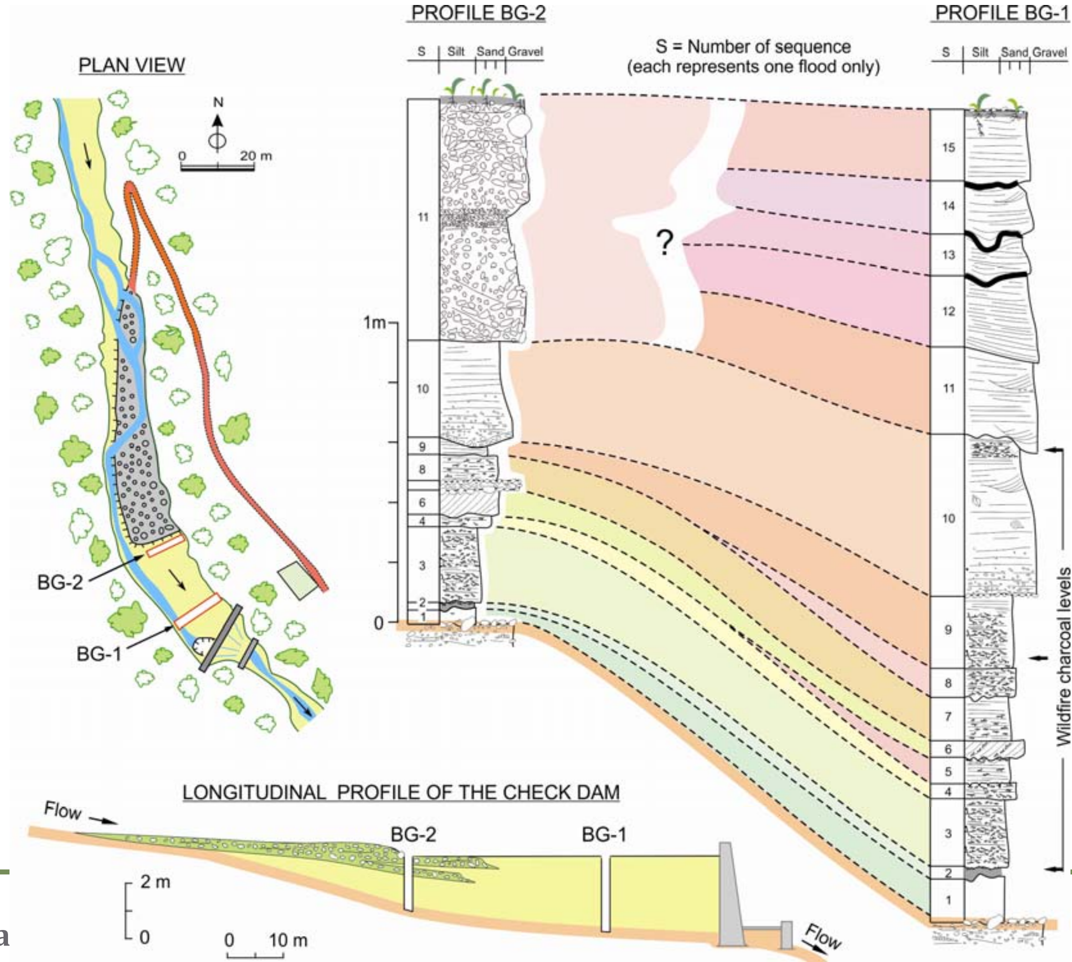
- Available data
  - Stratigraphical reconstruction of the dam 2 deposit (G. Benito and the palaeohydrology group @ MNCN-CSIC)





Rambla del Poyo (1/2)

- Results: stratigraphical reconstruction:
  - Volume estimation: two methodologies



Rambla del Poyo (1/2)

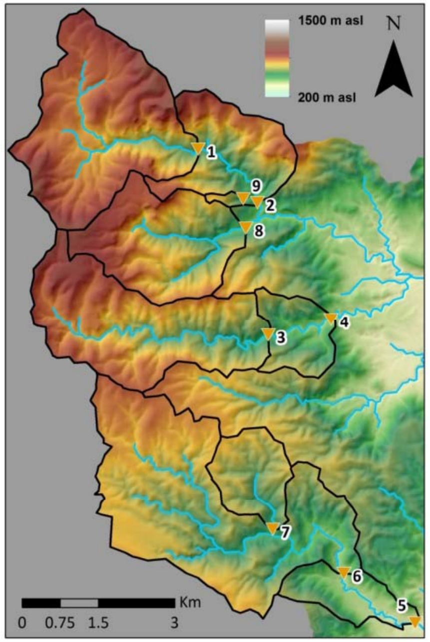
- Methodology

  A – Hydrological sub-model implementation

  - Calibration and validation data: water discharge records at Rambla del Poyo stream gauge

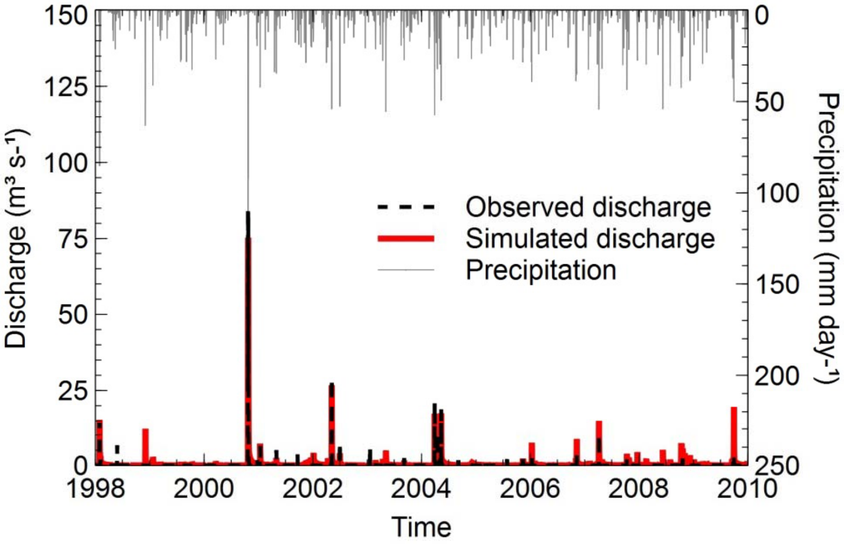
  B – Sediment sub-model implementation:

  - Calibration data: check dam 2 total deposit
  - Temporal validation data: check dam 2 stratigraphic reconstruction
  - Spatial validation data: other check dam total deposits

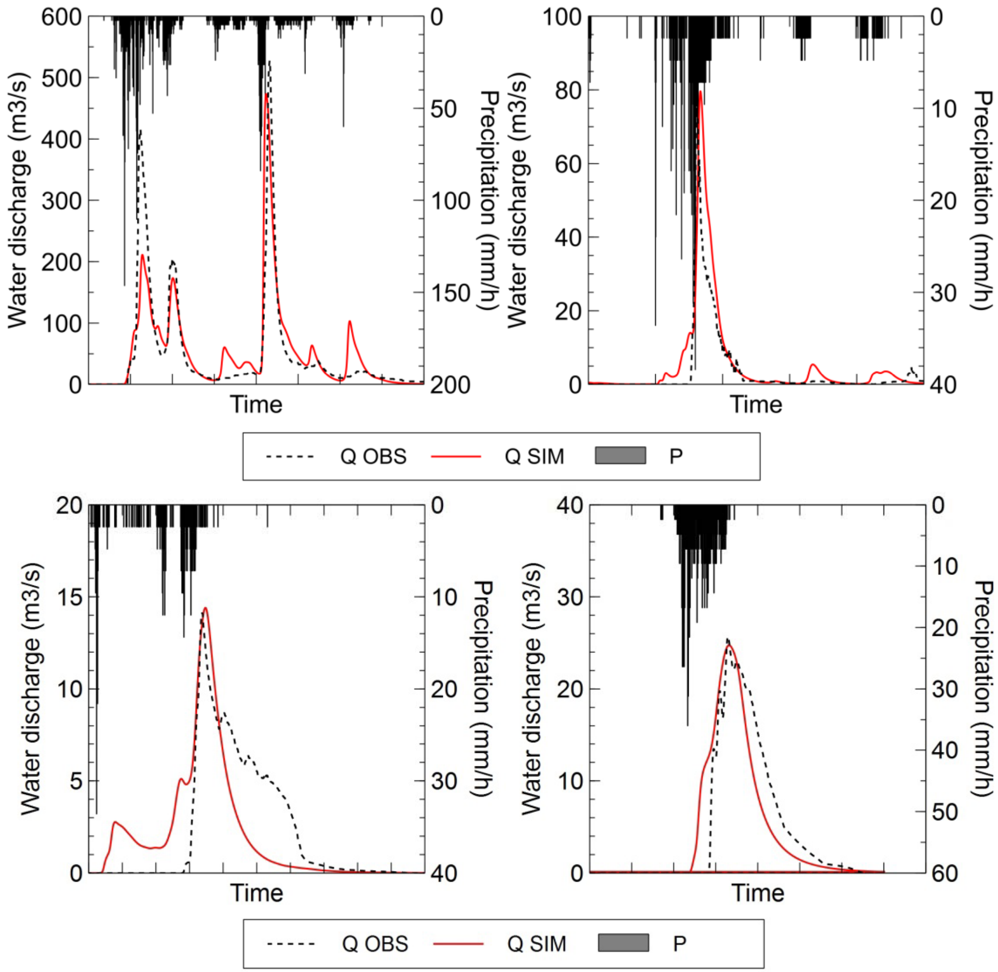


Rambla del Poyo (1/2)

- Results: hydrological sub-model implementation (2 models)



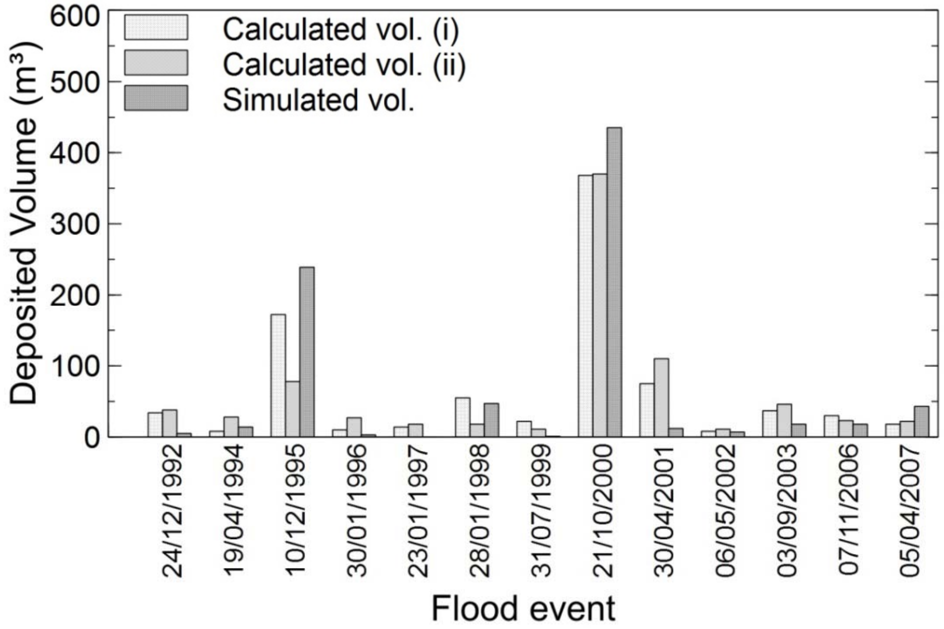
Daily Δt model



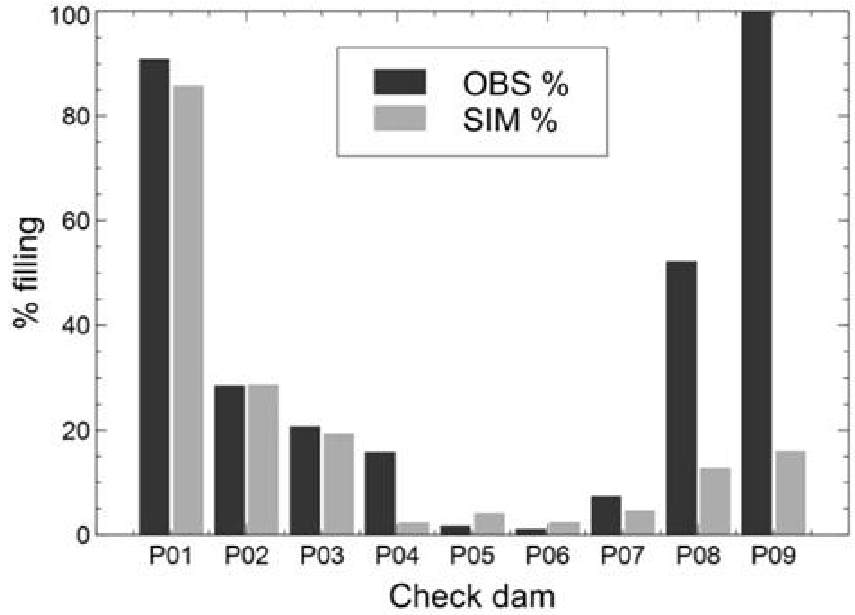
5-min Δt model

Rambla del Poyo (1/2)

❑ Results: sediment sub-model implementation



Temporal validation



Spatial validation

Rambla del Poyo (2/2)

- Data availability:
  - Precipitation and water discharge are monitored
  - Sediment transport is not monitored

- Goals of the application
  - Calibration and validation of a hydrological model without employing water discharge records
  - Analysis of the interactions between water and sediment cycle for constraining model calibration

Rambla del Poyo (2/2)

- Methodology

A – Constraining model calibration on field observations

B – Model calibration and validation (both water and sediment sub-models)

- Calibration data: total sedimentation volume behind check dam 2
- Validation data: stratigraphical reconstruction of check dam 2 infill

C – Model testing

- Data: observed water discharge at the Rambla del Poyo station

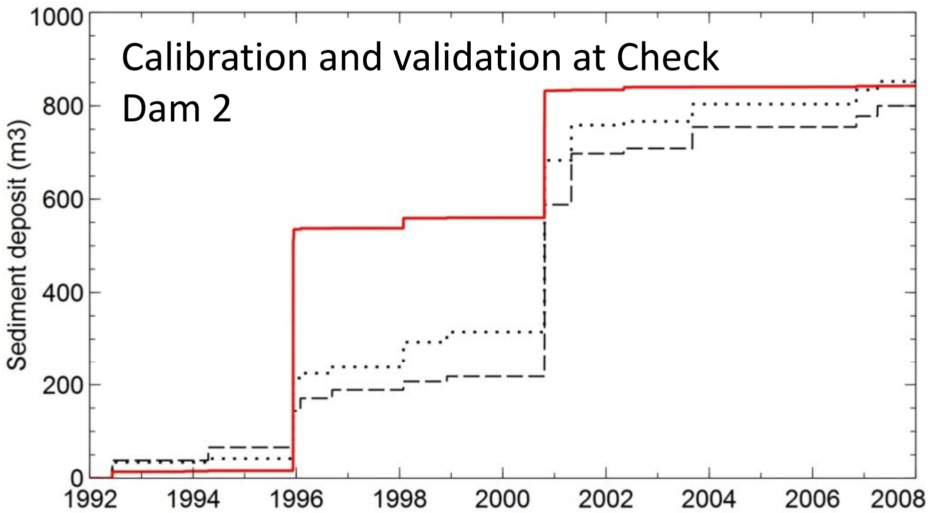
Rambla del Poyo (2/2)

- Results: model simplification depending on field observations
  - No base flow
  - Small interflow
  - Quasi-hortonian flow

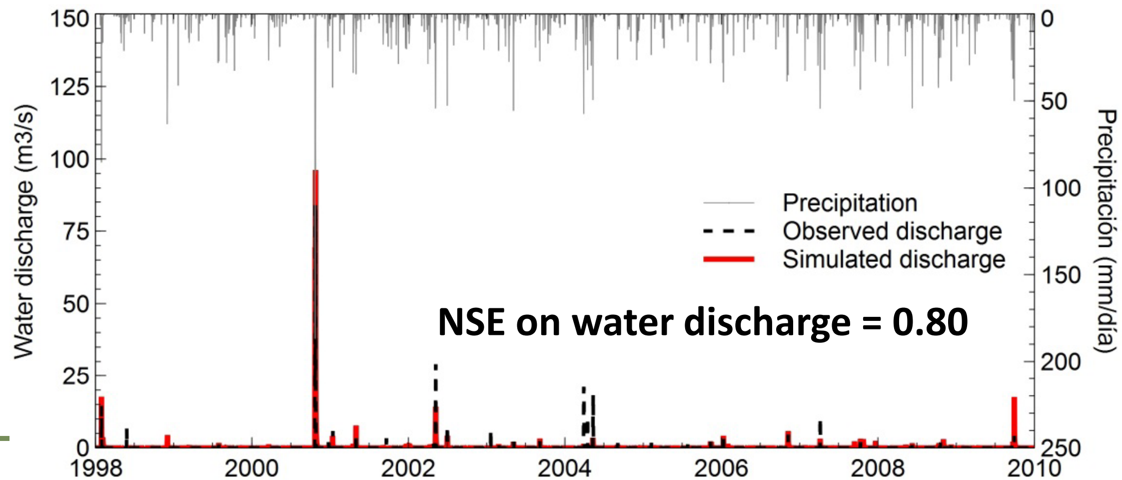
  - Parameters to be calibrated:
    - Maximum soil static storage
    - Infiltration capacity at saturation
    - Interflow velocity
    - Channel flow velocity
    - Maximum transport capacity for hillslopes

Rambla del Poyo (2/2)

- Results: calibration, validation and testing



Model testing (further validation) at Rambla del Poyo stream gauge station



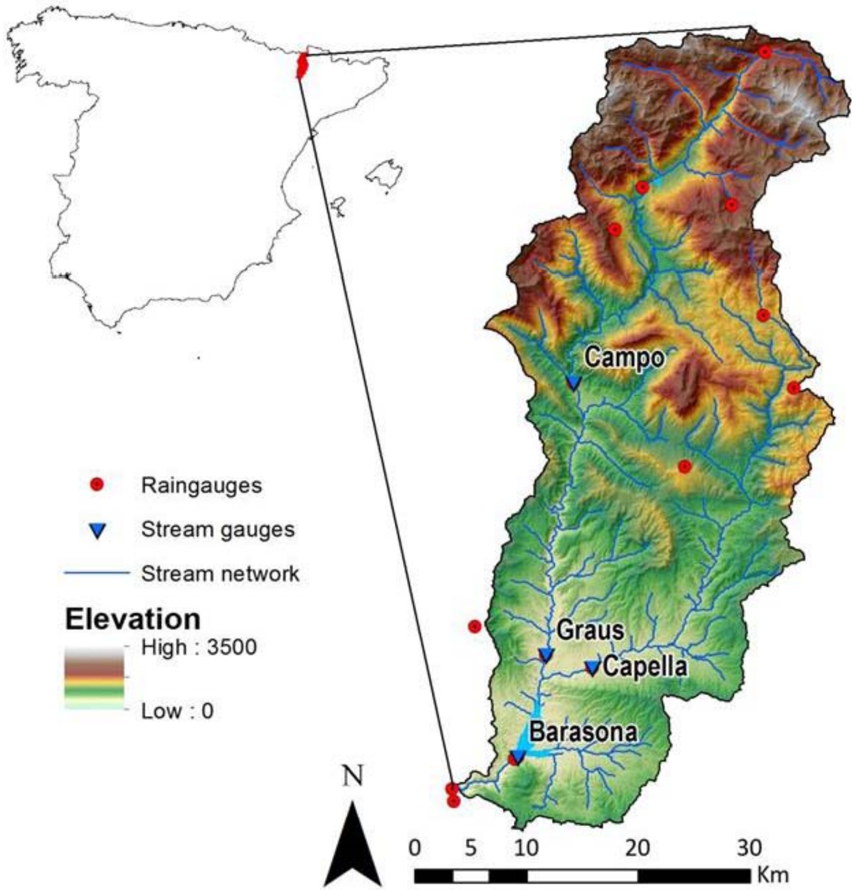
Ésera River

- Data availability:
  - Precipitation, temperature and water discharge
  - Large reservoir bathymetries
  - Measured suspended sediment series (at only one station)

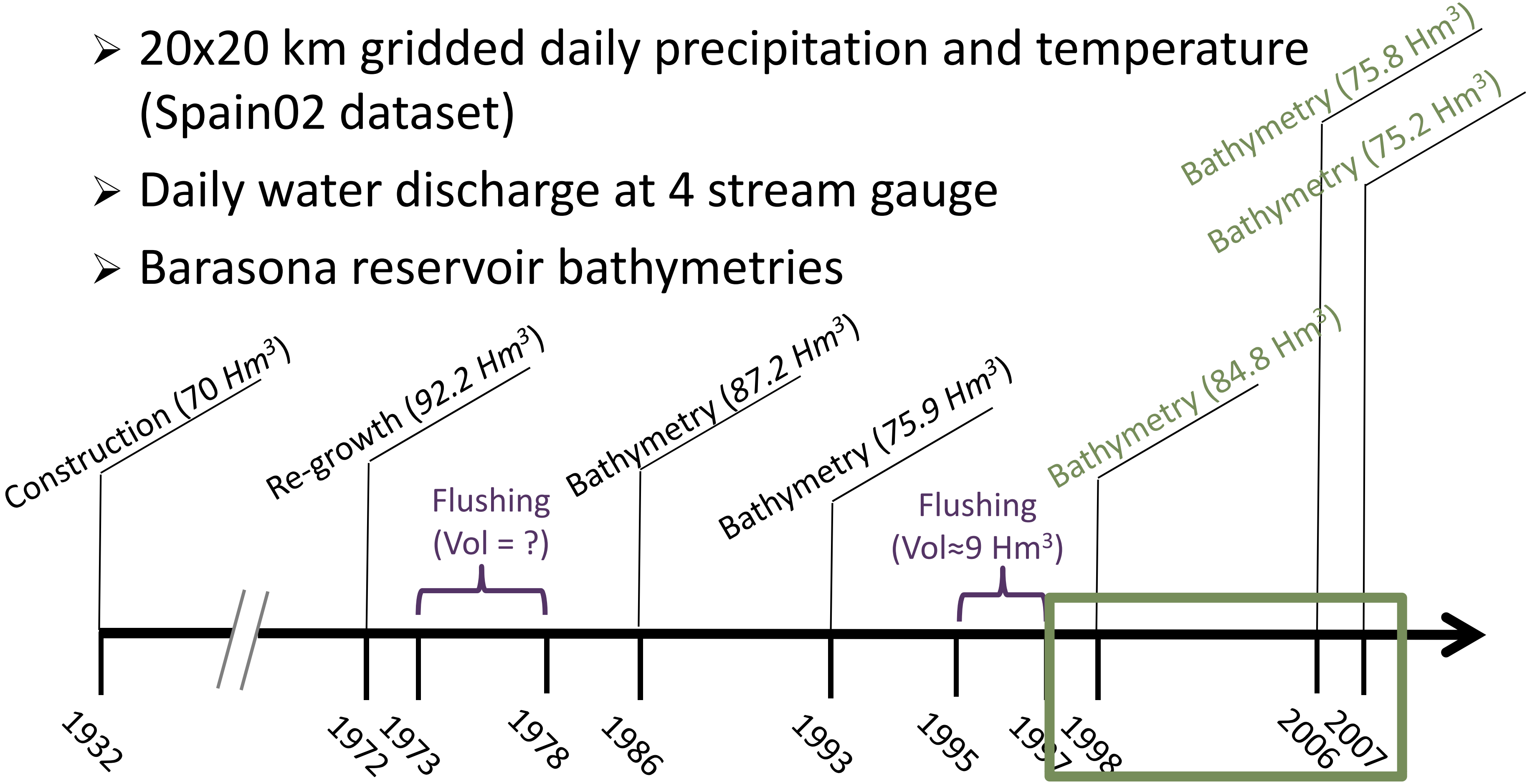
- Goals of the application:
  - Calibration and validation of a sediment model using large reservoir sedimentation volumes
  - Implementation of a sediment model to be used in climate change impact analysis

Ésera River

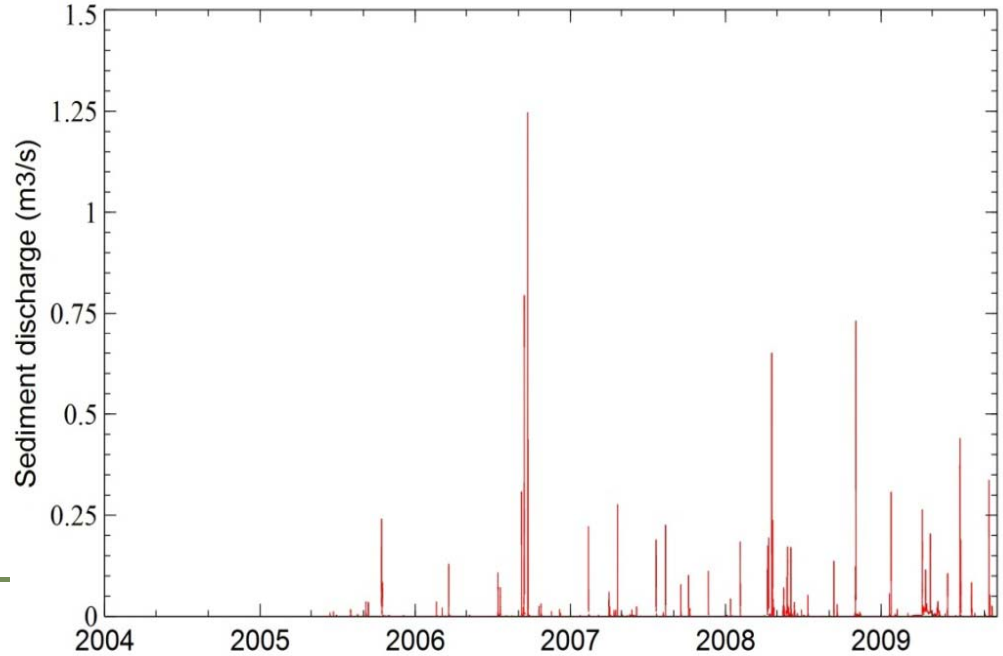
- Catchment description
  - 1,532 km^2
  - Prec. 600 mm/year
  - Mountain catchment
  - Draining to a large reservoir
  - Highly erodible due to the presence of badland areas



- Available data
  - 20x20 km gridded daily precipitation and temperature (Spain02 dataset)
  - Daily water discharge at 4 stream gauge
  - Barasona reservoir bathymetries



- Available data
  - Measured suspended sediments
    - Gauged by the University of Lleida (Spain) team – *López-Tarazón et al. 2009, Geomorphology*;
    - Only suspended sediment (the bed load fraction is almost negligible);
    - Very high concentrations: up to 300 g/l;
    - Techniques:
      - Manual sampling
      - Turbidimeter

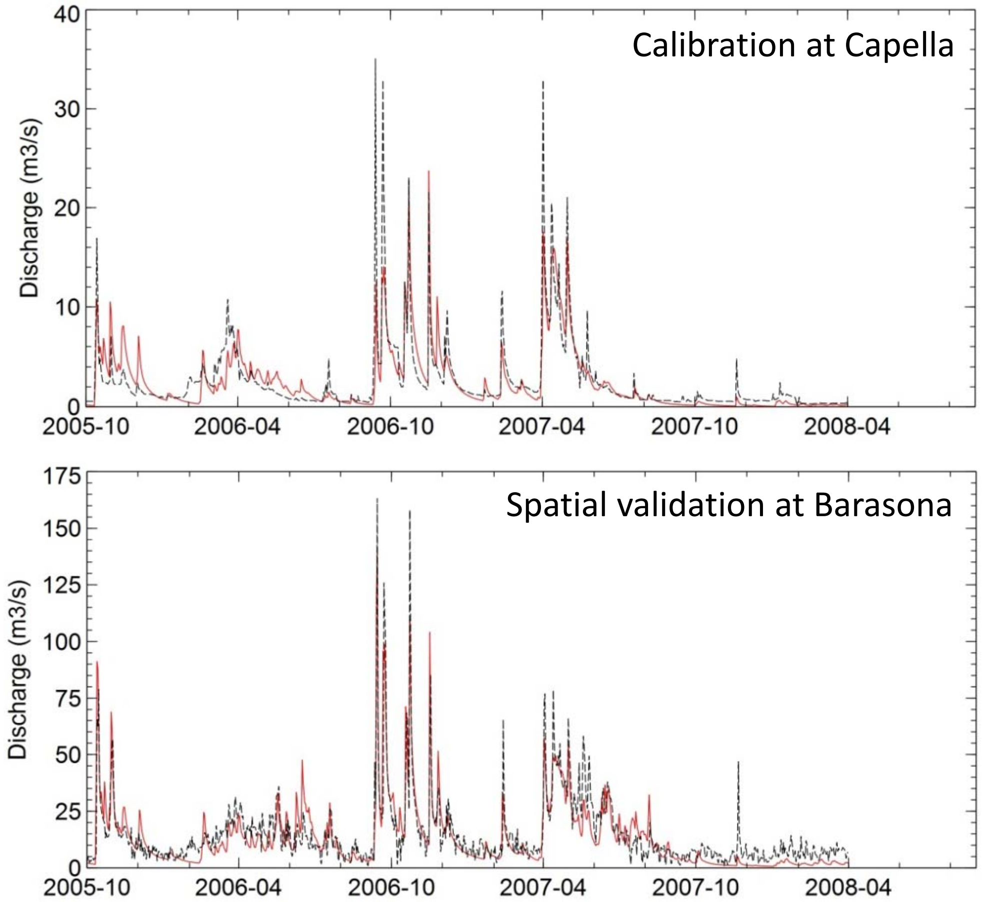


- Methodology:

  - A – Hydrological sub-model implementation
    - Calibration and validation data: water discharge records

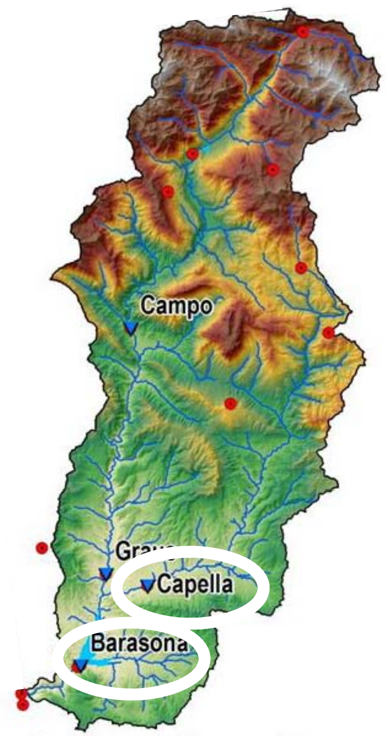
  - B – Sediment sub-model implementation:
    - Calibration and validation data: reservoir sedimentation volumes from bathymetries
    - Model testing data: suspended sediment measured at Capella station

- Results: hydrological sub-model implementation



Temporal validation

Station	NSE
Capella	0.686
Graus	0.704
Campo	0.455
Barasona	0.529

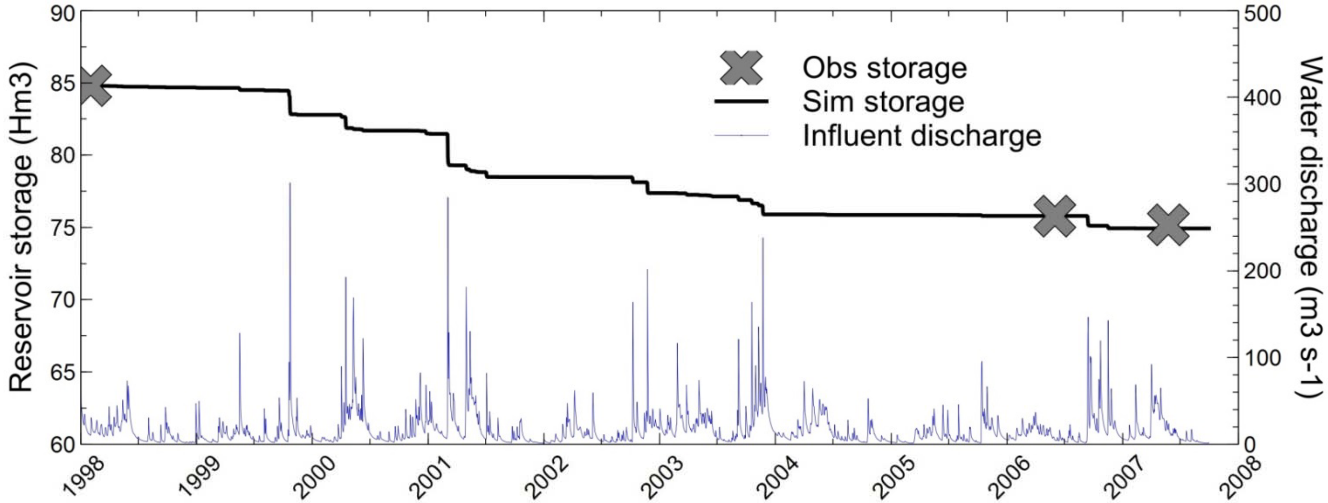


- Results: sediment sub-model implementation
  - Dry Bulk Density:
    - Miller formula (Lane and Koelzer coefficients);
    - Sediment texture: provided by the TETIS model;
    - Results validated against measured value (1.112 t m^{-3} in 1986).
  - Trap efficiency:
    - Brune curves, function of reservoir capacity and average inflow;
    - Average inflow calculated previously;
    - Reservoir capacity calculated by the model;
    - Avendaño Salas et al. (1995) → 86%.

- Results: sediment sub-model implementation
  - Calibration and validation vs Barasona storage volumes

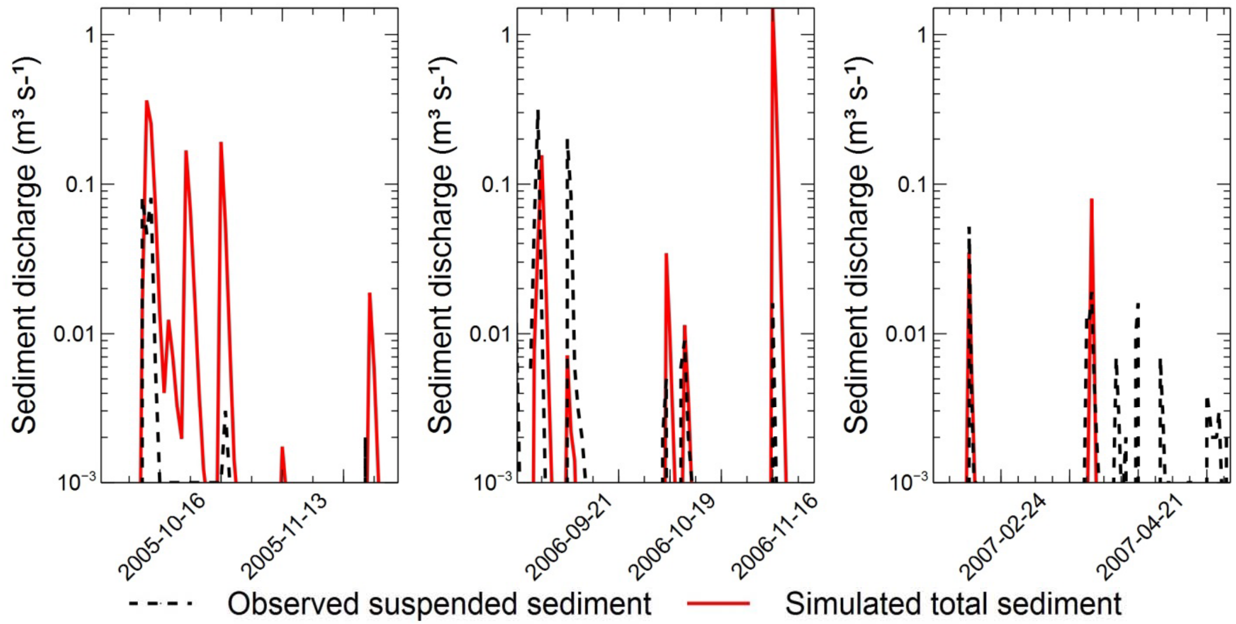
Period	Observed volume Hm3	Simulated volume Hm3	VE %
1998-2006	9.02	9.02	0%
2006-2007	0.60	0.76	23%

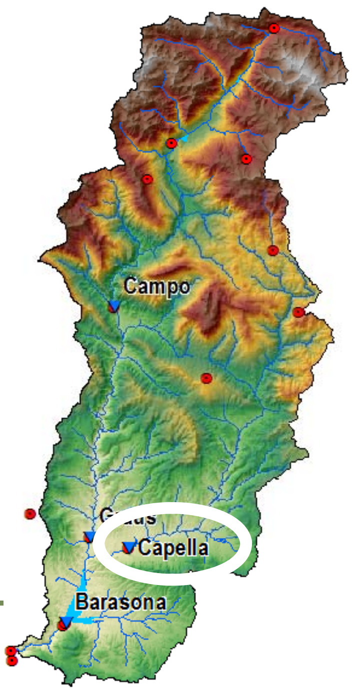
  - Reconstruction of the storage evolution



Ésera River

- Results: sediment sub-model testing
  - Sediment sub-model: validation @ Capella
    - Model results (total load) VS gauged data (suspended load);
    - Measurement errors: turbidimeter measurements can be misleading with high concentrations (Regües & Nadal-Romero 2012, CATENA)





Conclusions

- Dissertation contributions (model implementation):
  - TETIS sediment sub-model satisfactorily tested (3 catchments, 4 case-studies)
  - Analysis of the effect of the sediment initial condition on model implementation and model results: warm up strategy is the most reliable
  - Analysis of the use of small (check dams) and large reservoir sedimentation volumes as sediment proxy data for model calibration and validation
  - Integration of stratigraphical reconstruction into modelling
  - Development of a methodology for model calibration and validation in ungauged catchments (small data requirement, it can be extended to many Mediterranean catchments)

Conclusions

- Dissertation contributions (TETIS model structure):

  - New sediment initial condition setting tool

  - Extension of automatic calibration algorithm to the sediment sub-model

  - Calibration strategy (separated calibration of $\alpha+\beta_1$ and β_2)

  - New check dam and small reservoir sediment retention module, based on STEP model

Conclusions

- Limitations and future research lines:
  - No uncertainty assessment!
  - Improving precision of reservoir sedimentation volumes estimation techniques
  - Using different techniques to date sediment layers (e.g. radionuclides)
  - Model results sensitivity analysis and uncertainty assess.
  - Further developments of the model: e.g. contaminants,…

Conclusions

- Publications derived from this dissertation (3 scientific papers):
  - **G. Bussi**, X. Rodríguez, F. Francés, G. Benito, Y. Sánchez-Moya, A. Sopeña. 2013. Sediment yield model implementation based on check dam infill stratigraphy in a semiarid Mediterranean catchment. Hydrology and Earth System Science, 17, 3339-3354. doi:10.5194/hess-17-3339-2013
  - **G. Bussi**, F. Francés, E. Horel, J.A. López-Tarazón, R.J. Batalla. 2014. Modelling the impact of climate change on sediment yield in a highly erodible Mediterranean catchment. Journal of Soils and Sediments. *Under review (minor revisions)*
  - **G. Bussi**, F. Francés, J.J. Montoya, P. Julien. 2014. Distributed sediment yield modelling at Goodwin Creek: importance of initial sediment conditions. Environmental Modelling & Software. *Under review (minor revisions)*

Conclusions

- 14 posters and oral presentations at national and international congresses derived from this dissertation:
  - ICCE/IAHS 2014. New Orleans, US. December 2014
  - IAHS Symposium. Bologna, Italy. June 2014
  - EGU General Assembly 2014. Vienna, Austria. May 2014
  - 4th SCARCE International Conference. Cádiz, Spain, November 2013
  - 3rd JIA. Valencia, Spain, October 2013
  - 6th ICWRER. Koblenz, Germany. June 2013
  - EGU General Assembly 2013. Vienna, Austria. April 2013
  - IAHS - PUB Symposium. Delft, Netherlands, October 2012
  - 12th Reunión Nacional de Geomorfología. Santander, Spain, September 2012
  - EGU General Assembly 2012. Vienna, Austria. April 2012 (**OSP award**)
  - EGU General Assembly 2011. Vienna, Austria. April 2011
  - 1st SCARCE annual conference. Girona, Spain. December 2010
  - EGU General Assembly 2010. Vienna, Austria. May 2010
  - 1st JIA 2009. Madrid, Spain, November 2009

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