Analysis of climate change effects on water and sediment cycle in a Mediterranean catchment

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Objectives

- Climate change impact on the sediment cycle of a high erodible catchment
  - Complexity: interactions between water balance, floods and sediments
  - Spatial variability of inputs and processes
  - Few sediment data: explore posibilities of using reservoir sedimentation volumes as a proxy of sediment yield

- Tool: **global** and **distributed** model for reproduction of the hydrological and sedimentological cycle

General methodology

Analysis of CO_2 emission evolution:
- Selection of CO_2 emission scenarios

↓

Climatic models and downscaling
- Series of inputs (precipitation and temperature)

→

Comparison with observations in the control period
- Model selection and correction

↓

Hydrological model implementation
- Output series (discharge, snow and sediments)

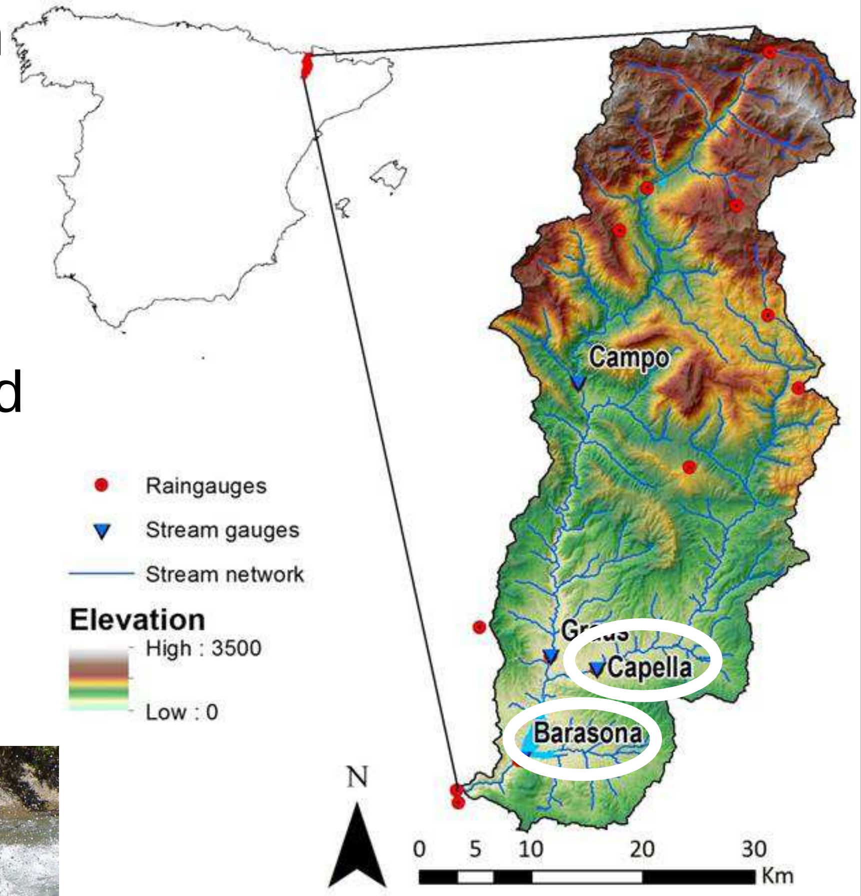
↓

Comparison of results between present and future scenarios
- Analysis and decision making

Case study

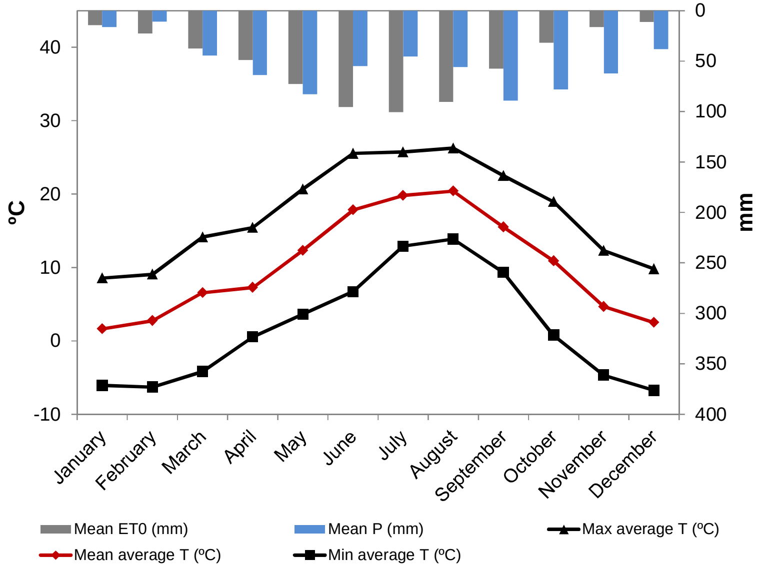
The catchment: Ésera River

- Southern Central Pyrenees, Spain
- 1532 km^2
- Mountain catchment
- Drained by a large reservoir
- Sediment gauged data: suspended sed. at Capella station (Isábena River)



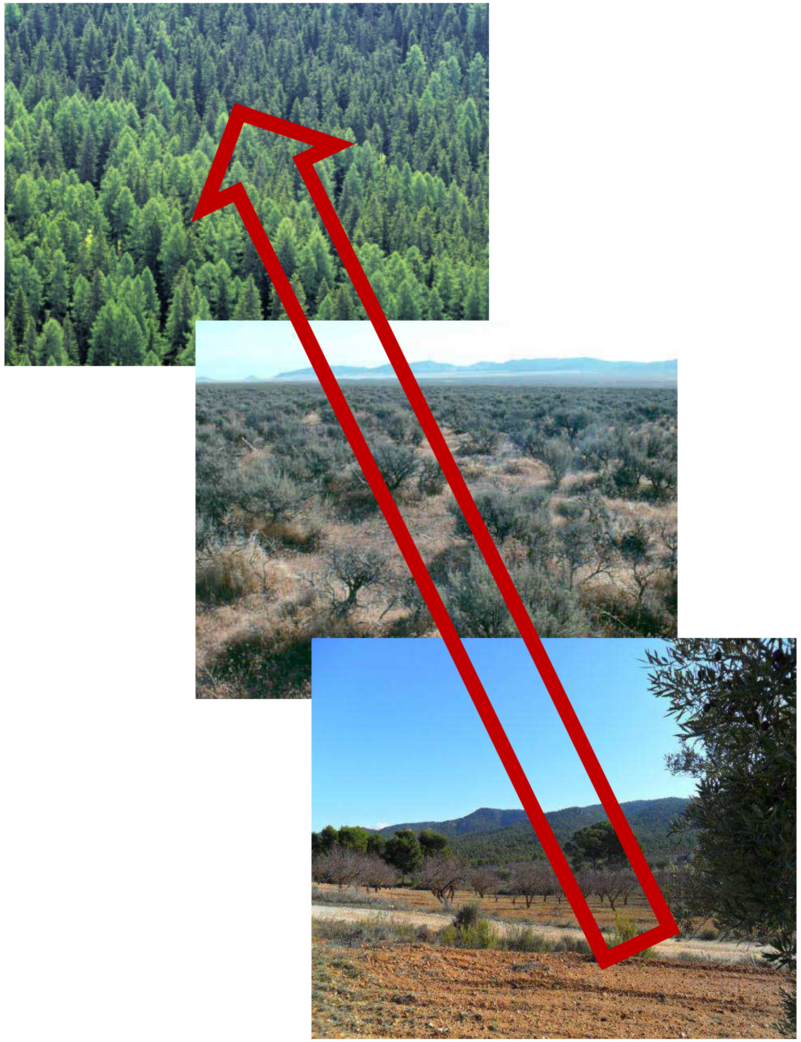
The catchment: Ésera River

Annual precipitation	642 mm
Annual mean temp.	10ºC
Annual ET0	601 mm



- Mountain – Mediterranean climate
  - Dry and cold winters
  - Stormy summers with frequent floods

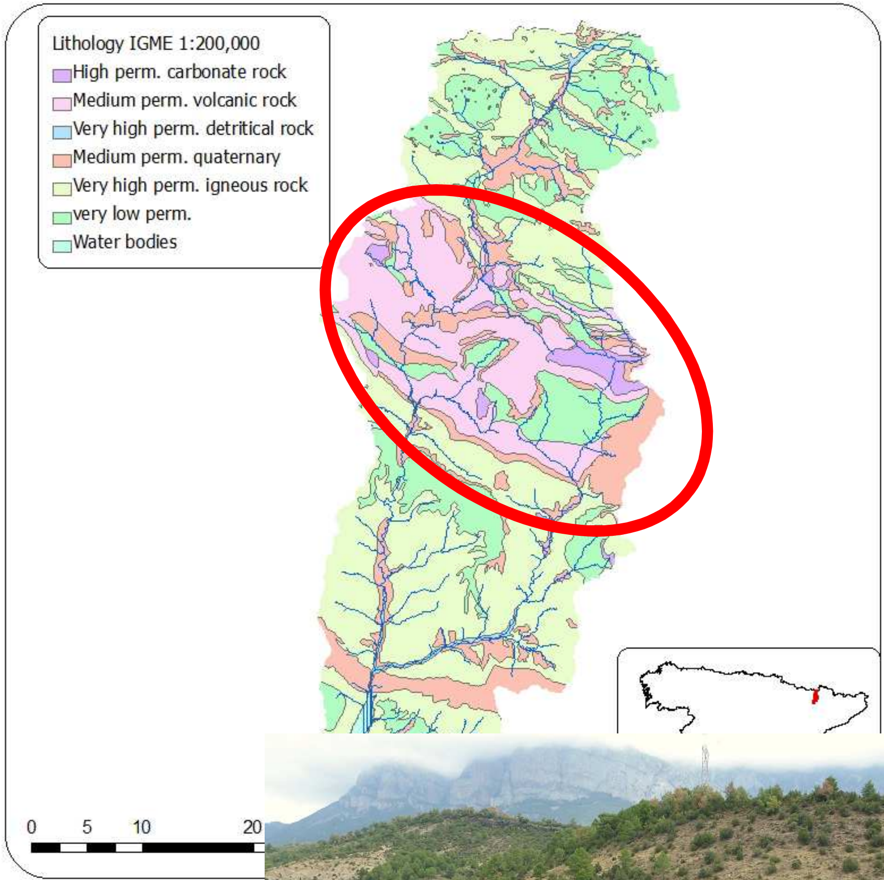
The catchment: Ésera River



- ❑ Present land use:
  - ❑ Forest (34%)
  - ❑ Shrubland (27%)
  - ❑ Pasture (12%) and
  - ❑ Arable dryland (10%)

➢ **Historical expansion of forest due to agricultural abandonment**

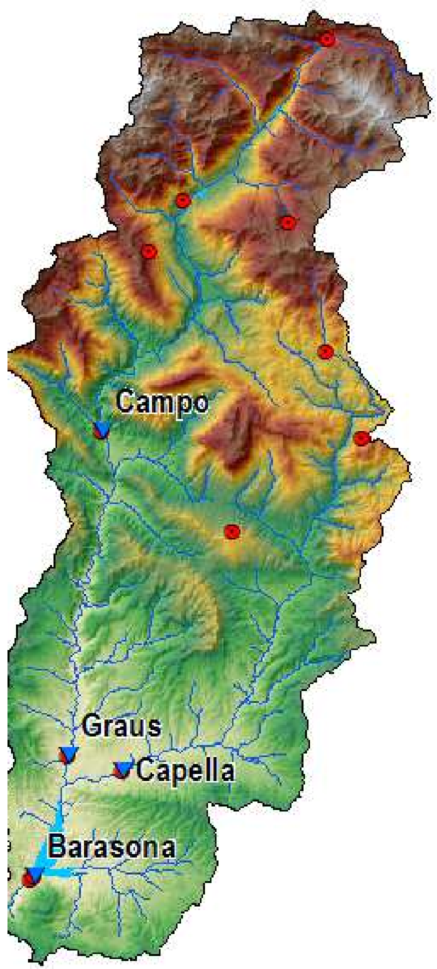
The catchment: Ésera River



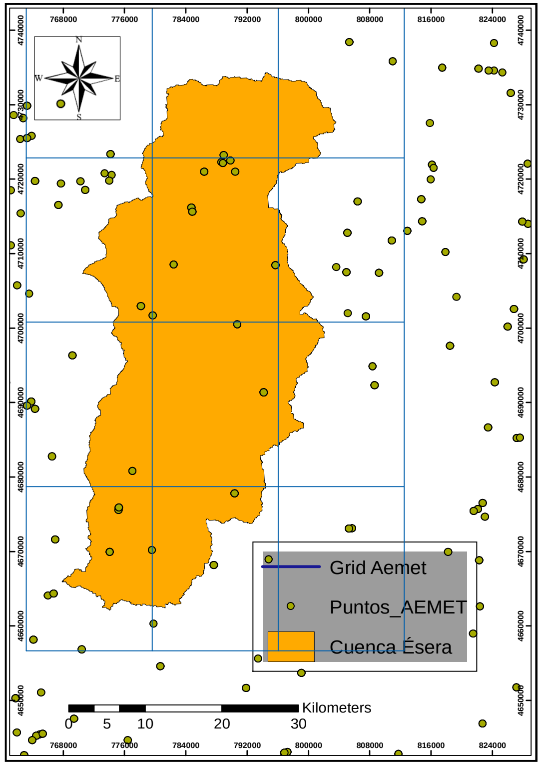
- Geology:
  - Limestone and sandstone in headwaters
  - Marls in the central part, **high erosion rates** and badland landscape
  - Conglomerates and sandstones in the south
- Pedology:
  - Shallow soils with low O.M. content
  - Silty clay and sandy silt soils

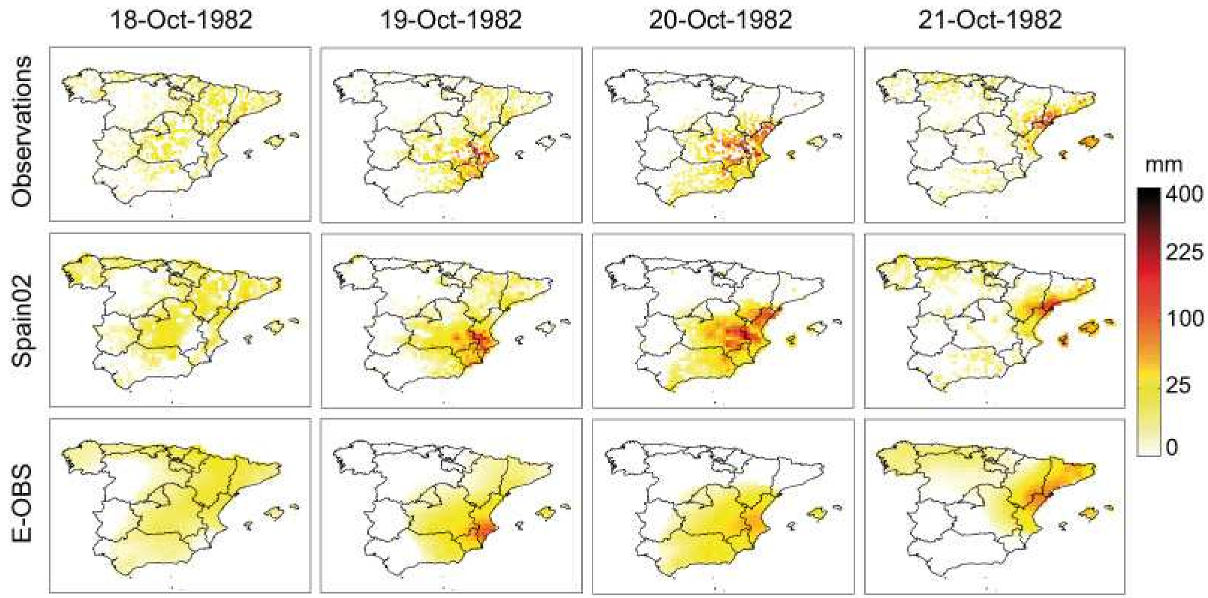
Hydrometeorology

- Daily monitoring with long series:
  - 12 termometers and raingauges (AEMET)
  - Several stream gauges (CHE, CEH-CEDEX)
  - Barasona reservoir data (CHE, CEH-CEDEX)
- 15-minute monitoring since 10/1997 (SAIH-CHE):
  - 11 raingauges and 6 termometers
  - **3 stream gauges**
  - **Barasona reservoir**



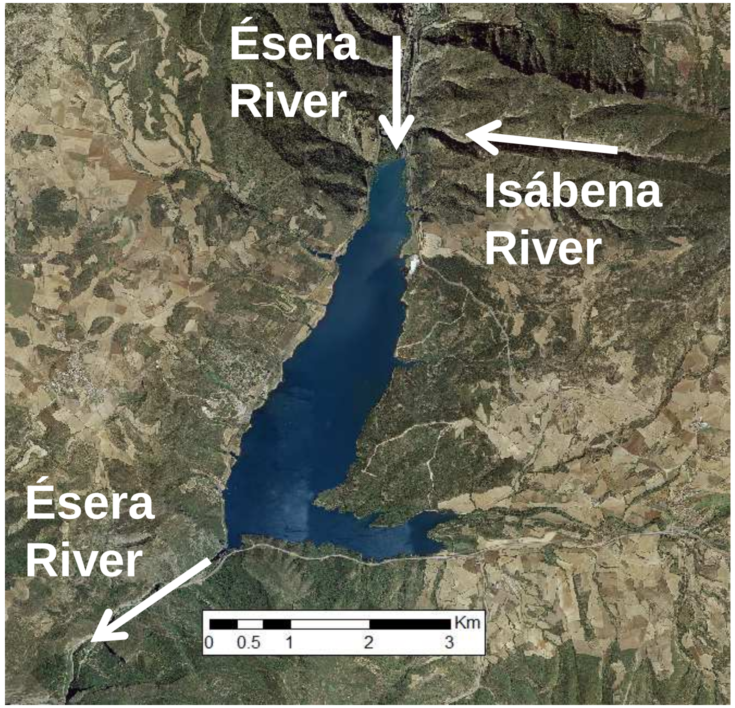
- **Spain02**: Regional interpolation of **daily** precipitation and temperature, ~ 20x20 km and from1950 to 2008



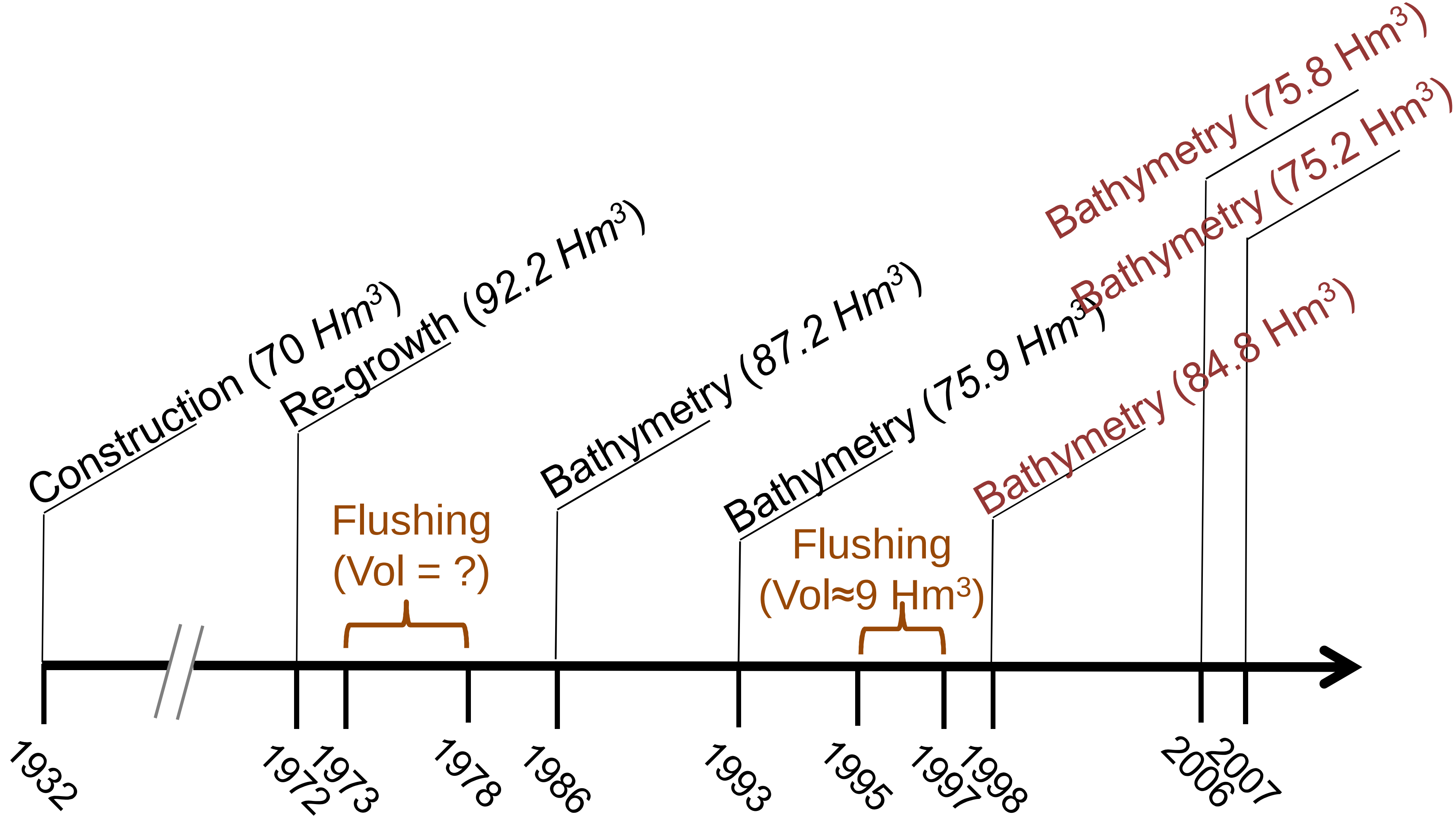


The Barasona reservoir

- Regulation reservoir built in 1932 (70 Hm^3)
- Regrown in 1972 (92.2 Hm^3)
  - High siltation rates
  - 5 bathymetries available



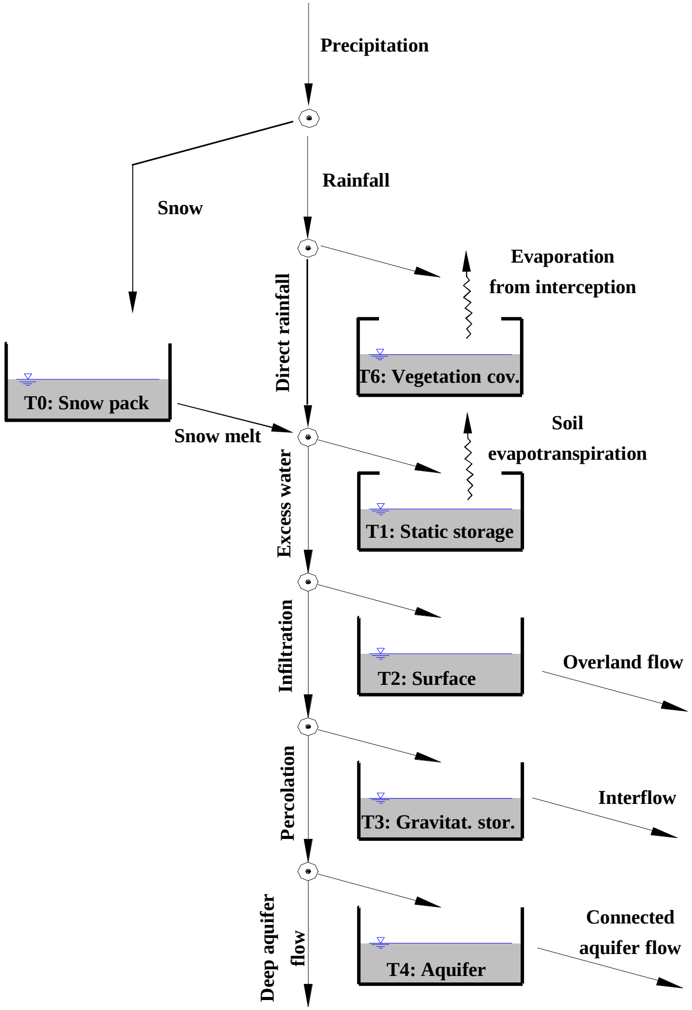
The Barasona reservoir



Model implementation

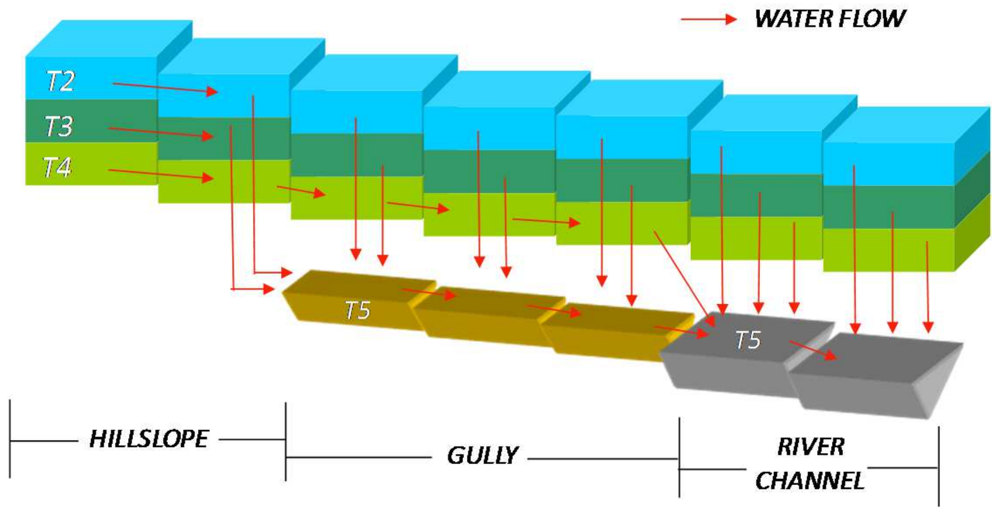
TETIS model

- Developed in TU of Valencia since 1994 (version 8.2.7 on the web)
- Conceptual (tank structure) model, with **physically based parameters**
- **Global** model: water resources, floods, sediments, … dynamic vegetation, water quality, …



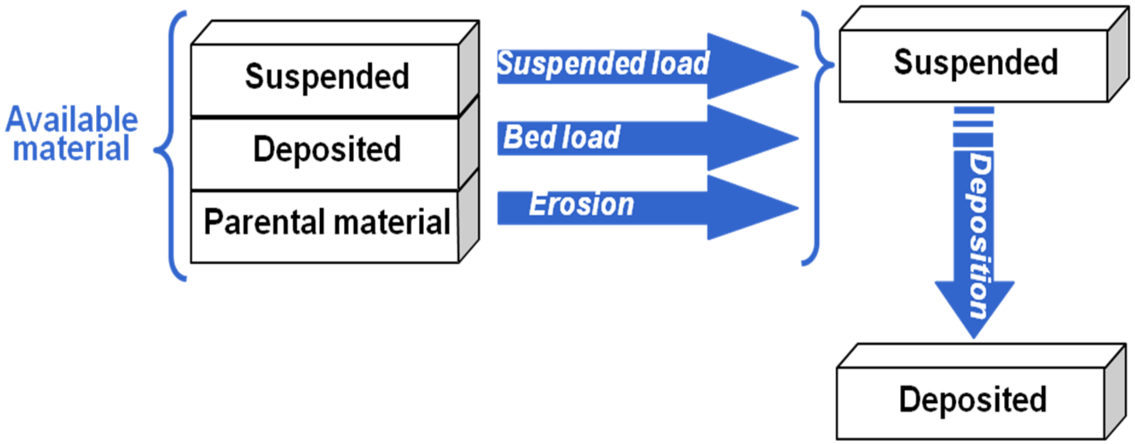
TETIS model

- **Distributed** in space:
  - reproduction of hydrological cycle spatial variability
  - Results at any point
- Split effective model parameter structure
  - It uses all spatial information available
  - Powerful **automatic calibration** algorithm



TETIS model: hillslope erosion

- 3 additional tanks

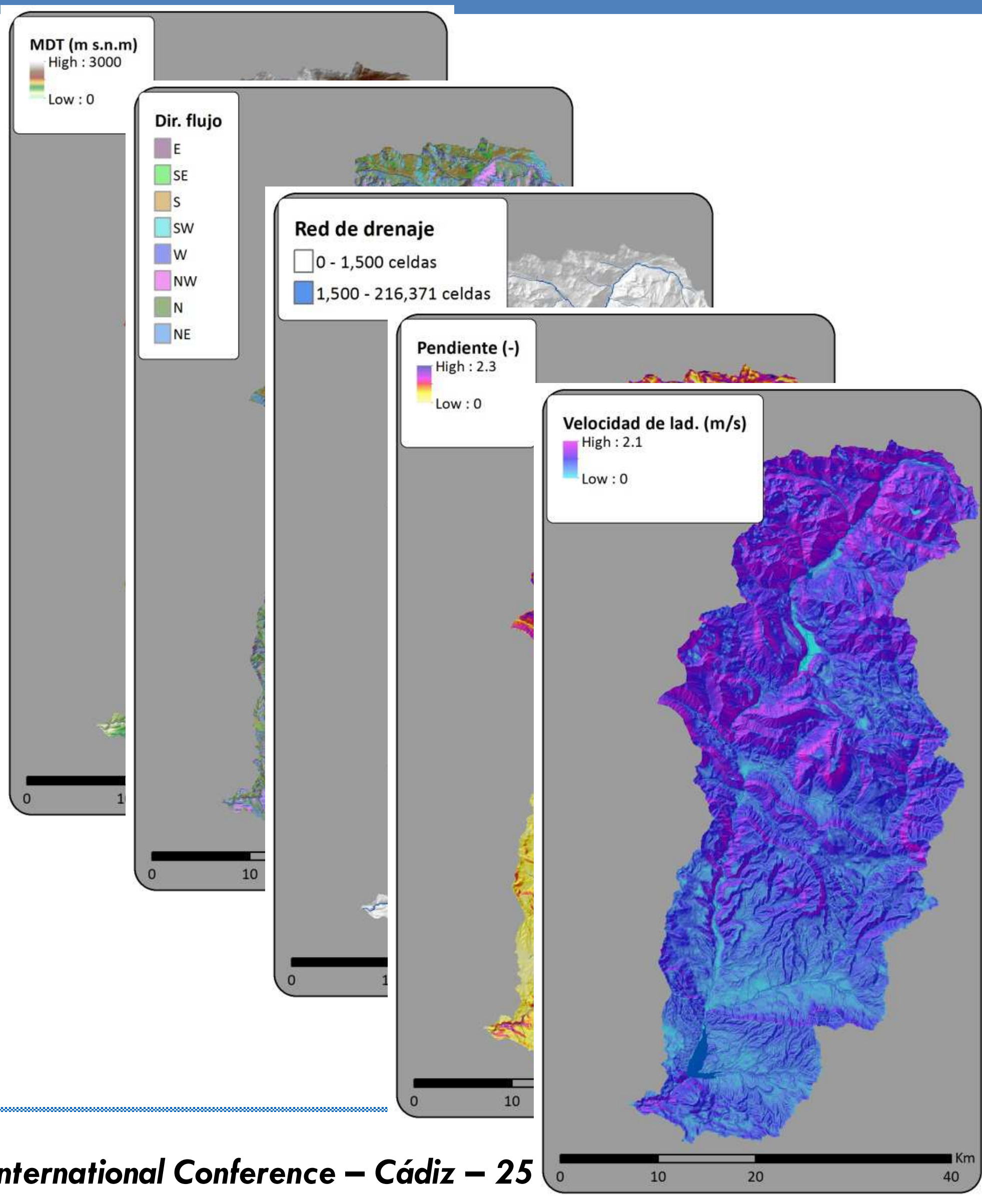


- Balance between water **transport capacity** and sediment availability
- Hillslope transport capacity: modified Kilinc – Richardson equation (Julien, 1995)

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

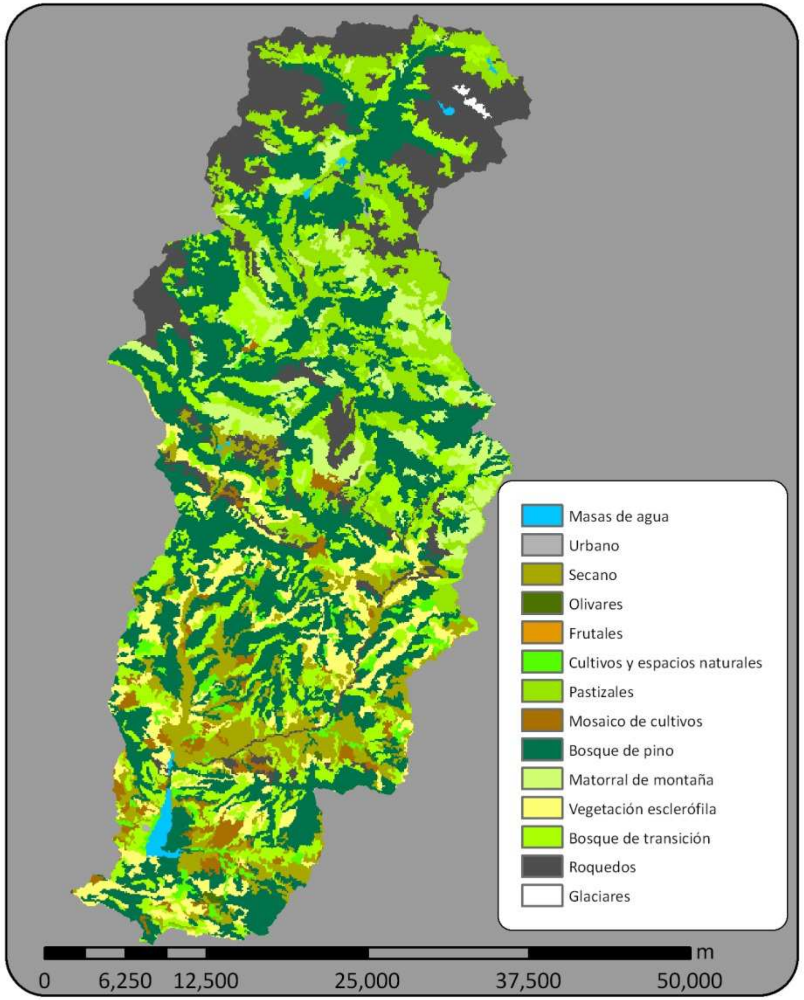
Initial parameter estimation

- DEM
  - Source: National DEM from IGN at 25m => re-scaled to 100 m and **corrected**
- Derived from DEM
  - Flow direction
  - Slope
  - Accumulated area
  - Hillslope velocity



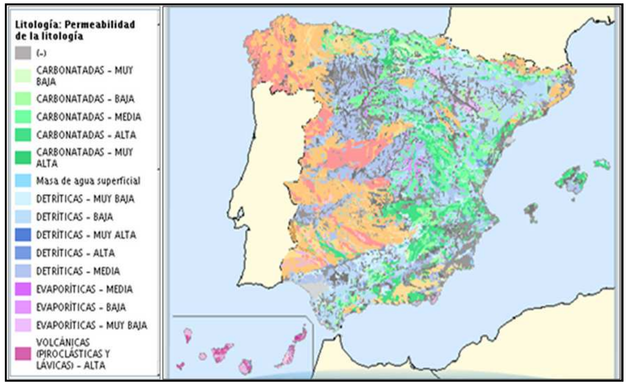
Initial parameter estimation

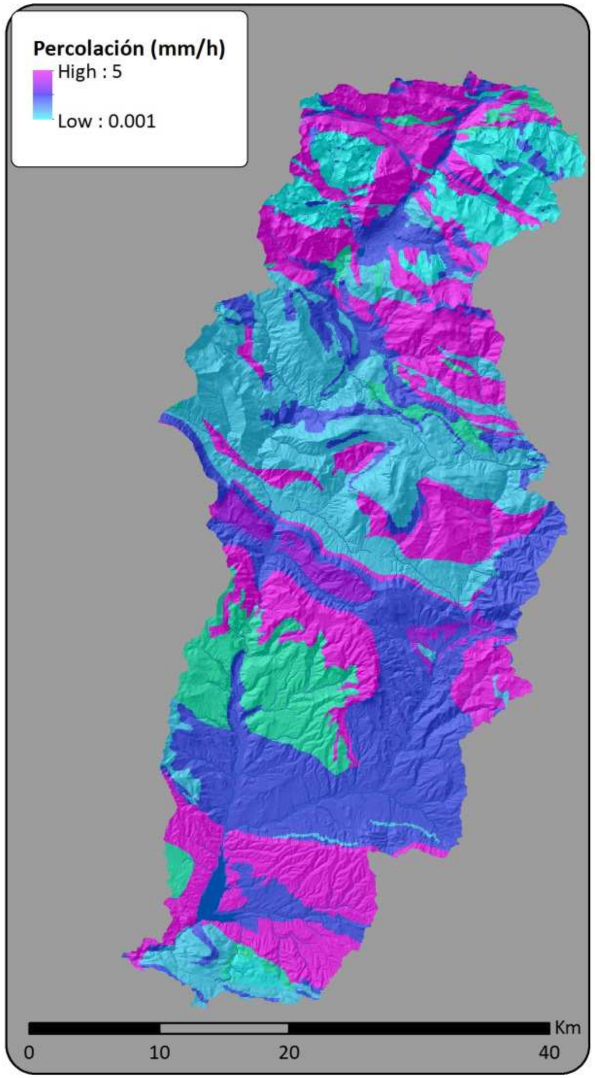
- Land cover (vegetation coef. and interception)
  - Source: Corine 2006 (1:100,000)



Initial parameter estimation

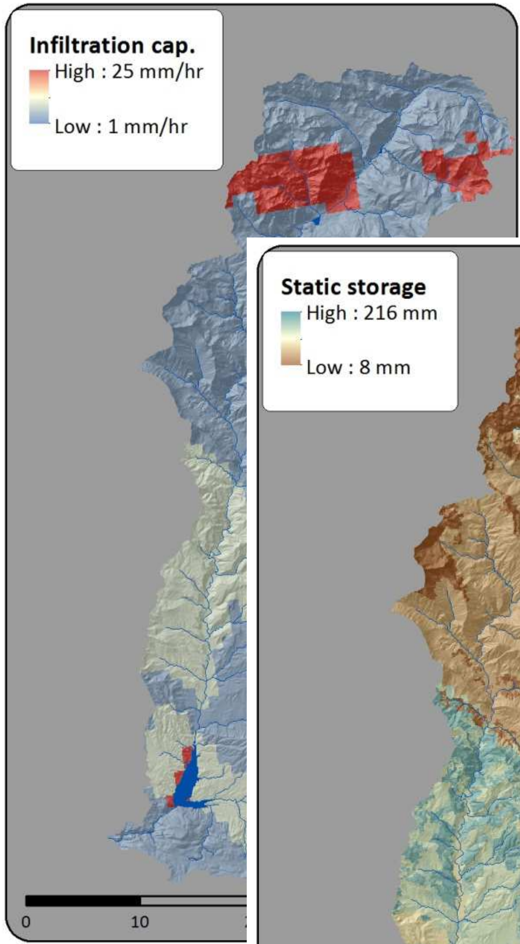
- Sustrate/aquifer permeability
  - Source: Litological Map from IGME (1:200,000)

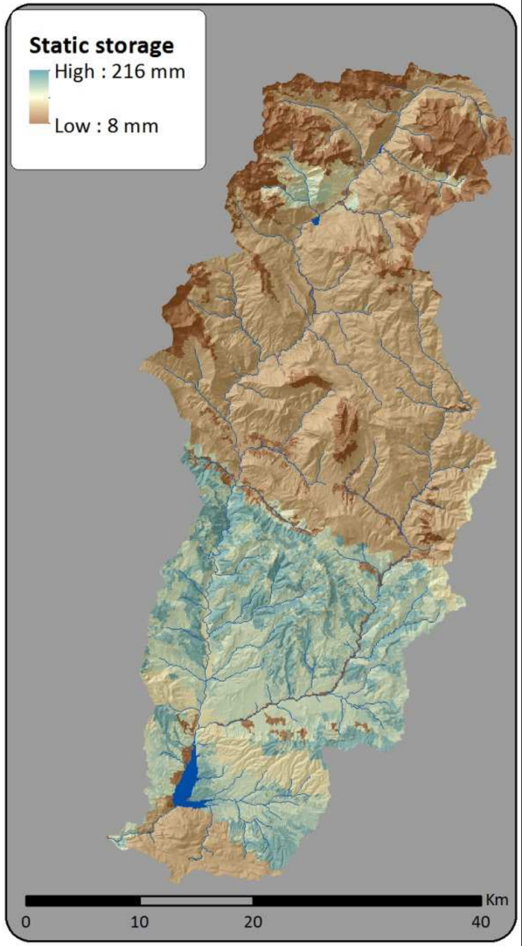




Initial parameter estimation

- ❑ Upper soil permeability
  - Source: European Soil Database (1:1,000,000)
- ❑ Capillary storage capacity
  - Source: ESD + Corine land cover

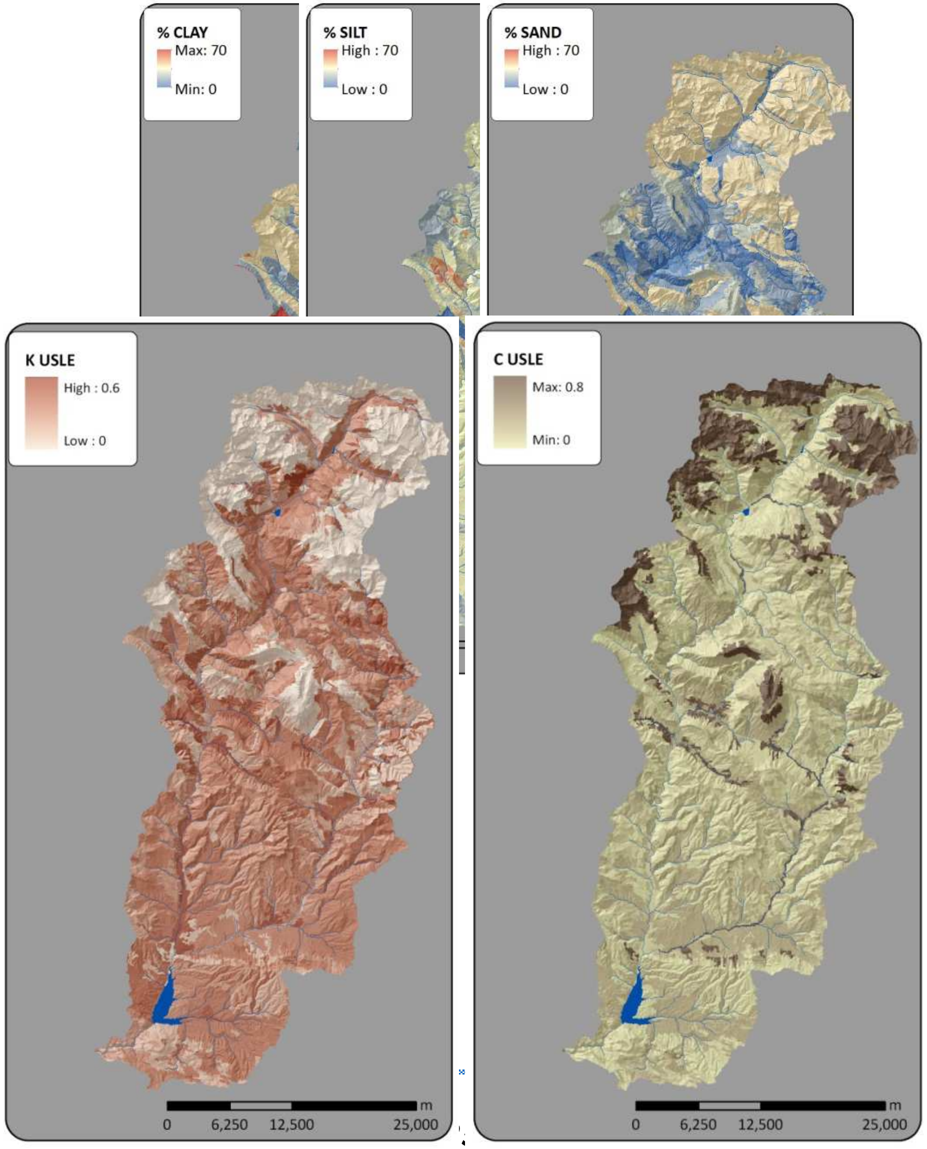




Initial parameter estimation

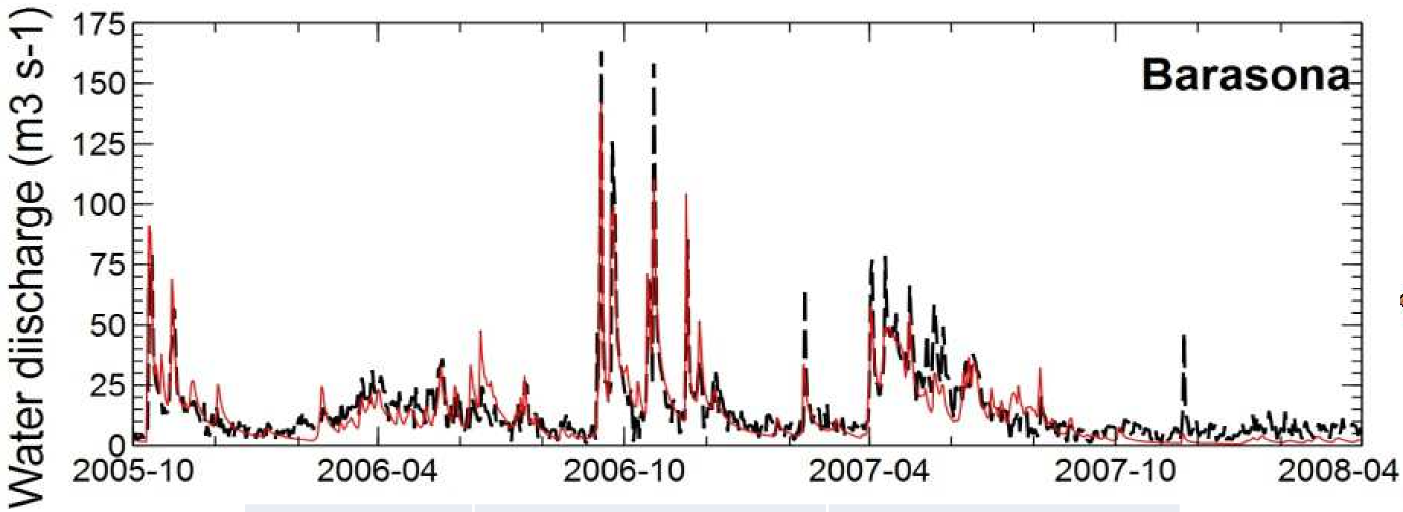
- Texture maps
  - Source: European Soil Database (1:1,000,000)

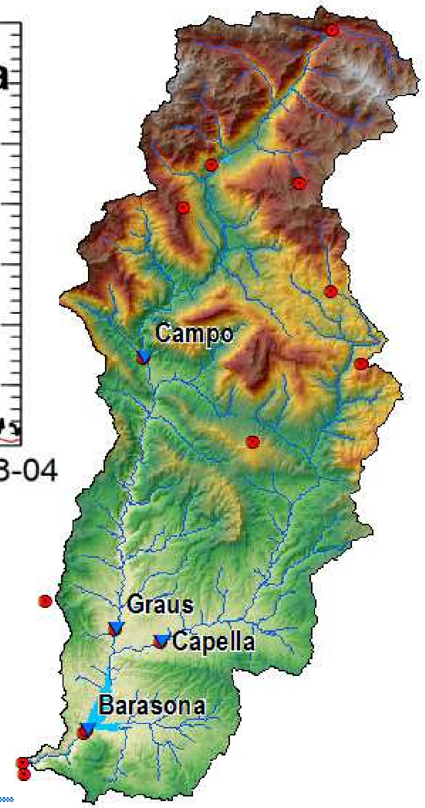
- USLE factors
  - Source: previous scientific publication (*Alatorre et al.*, 2010)



Model implementation

- Hydrological sub-model:
  - Calibration at Capella station (2005-2008)
  - Validation at Graus, Campo, Barasona and Capella (1997-2005)





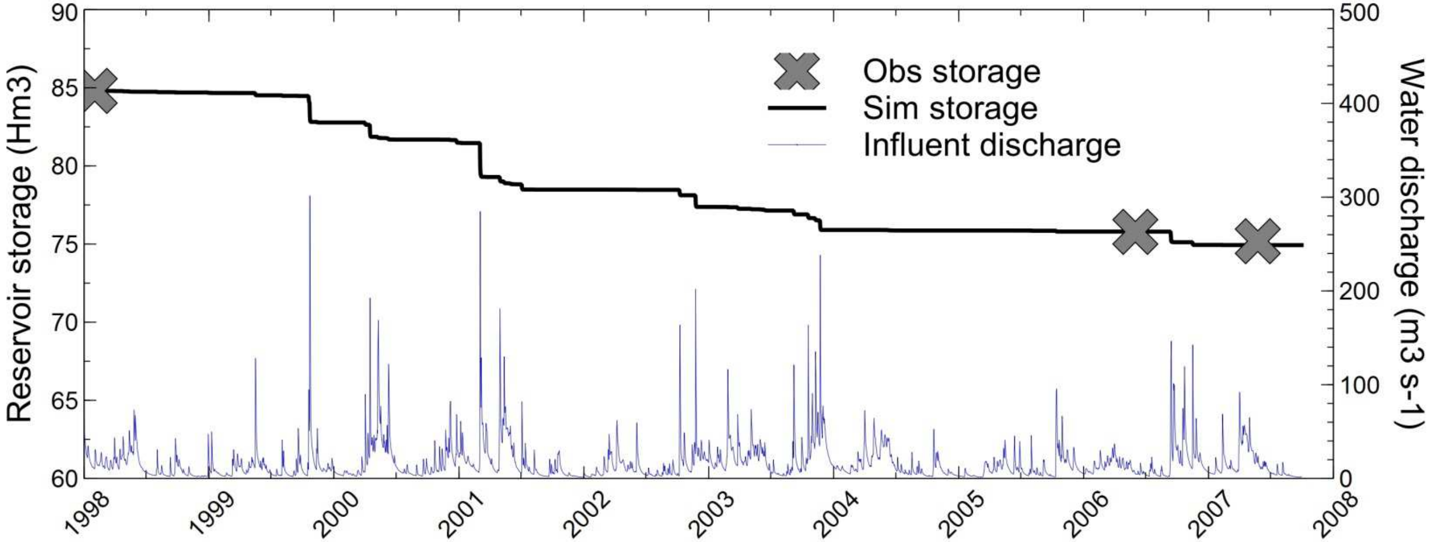
	Calibration period		Validation period	
Station	**NSE**	**VE%**	**NSE**	**VE%**
Capella	**0.720**	**-6%**	0.686	-39%
Graus	0.581	-28%	0.704	-61%
Campo	0.294	-44%	0.455	-35%
Barasona	0.708	-10%	0.529	-22%

Model implementation

- Sediment sub-model:
  - Calibration and validation vs Barasona volumes:

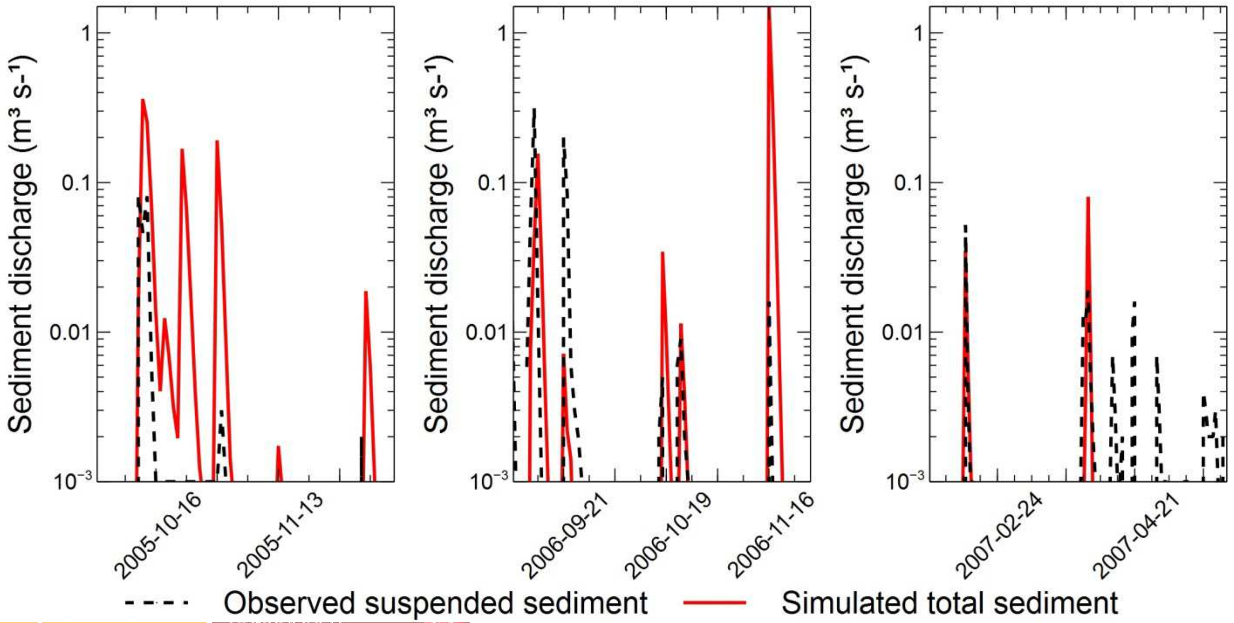
Period	Accumulated sediments Hm³	Specific sediment yield t km⁻² year⁻¹	Simulated volume Hm³
1998-2006	9.02	820	9.02
2006-2007	0.60	435	0.76

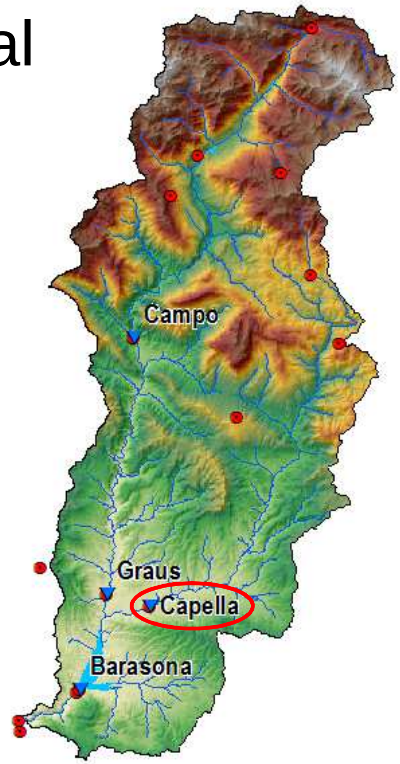
  - Reconstruction of the storage evolution



Sediment extra-validation

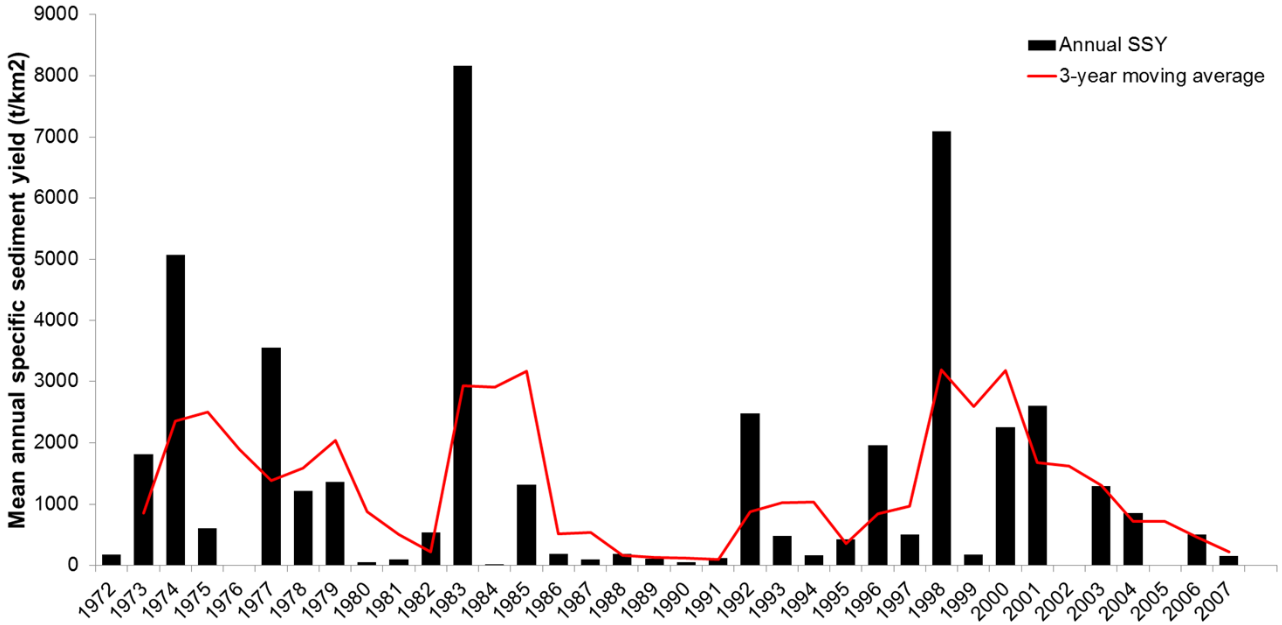
- Sediment sub-model: validation in experimental station at Capella
  - Model results (total load) vs gauged data (suspended load);
  - Measurement errors: turbidimeter measurements can be misleading with high concentrations (Regües & Nadal-Romero 2012, CATENA)

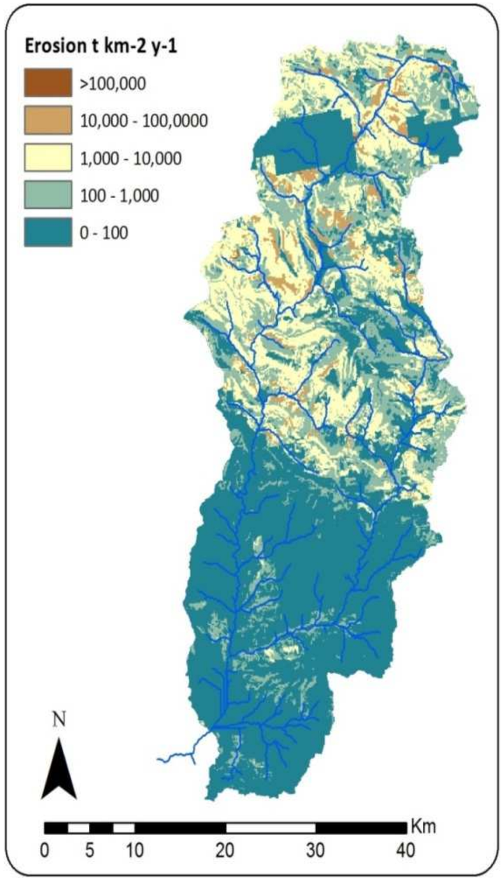




Sediment sub-model results

- Sediment sub-model:
  - Erosion zones: central marl strip and headwater:
  - Annual sediment yield:



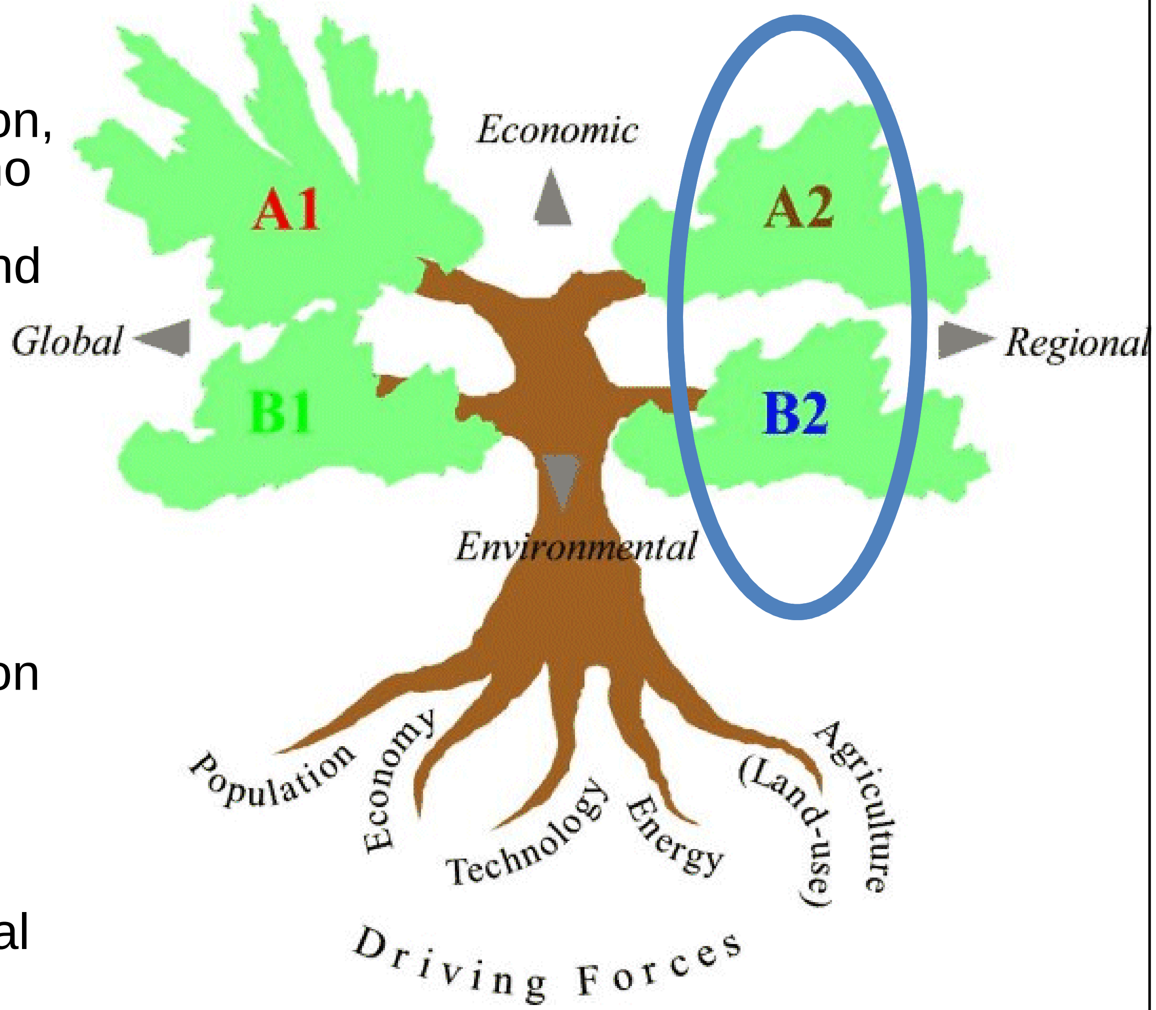


Climate Change Scenarios

Emission scenarios 2071-2100

- **Scenario A2: Very pessimistic**
  - Growing world population, growing economy, but no coordination: heterogeneous world and indipendent countries
  - Slow and odd technological changes.

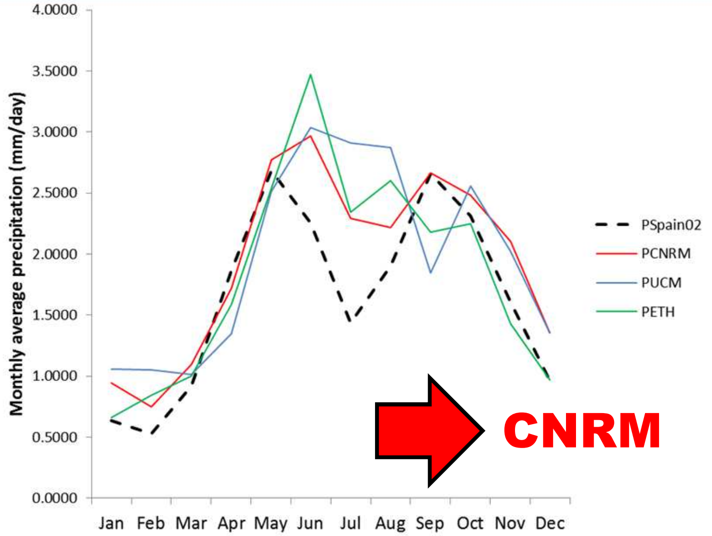
- **Sencario B2: less pessimistic**
  - Growing world population (less than A2), intermediate economic development.
  - Local soutions to environmental and social sutainability

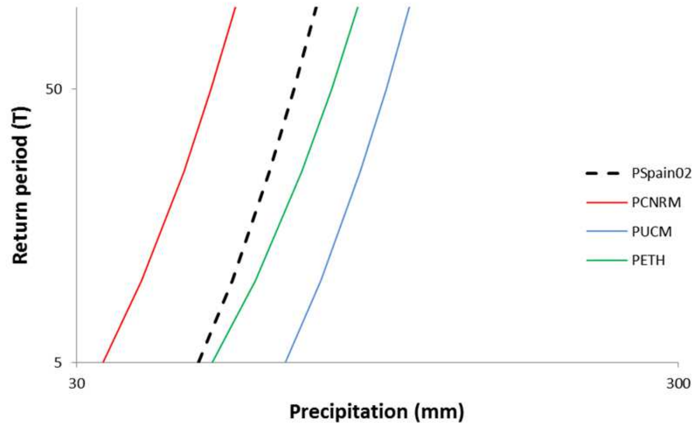


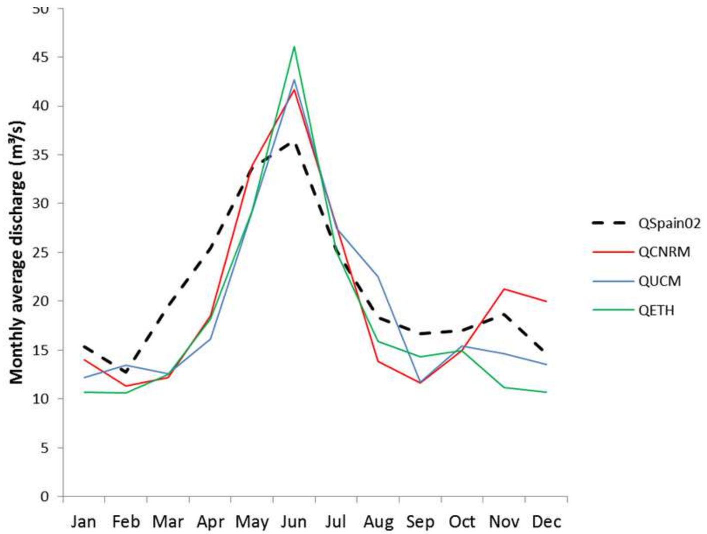
Climatic models

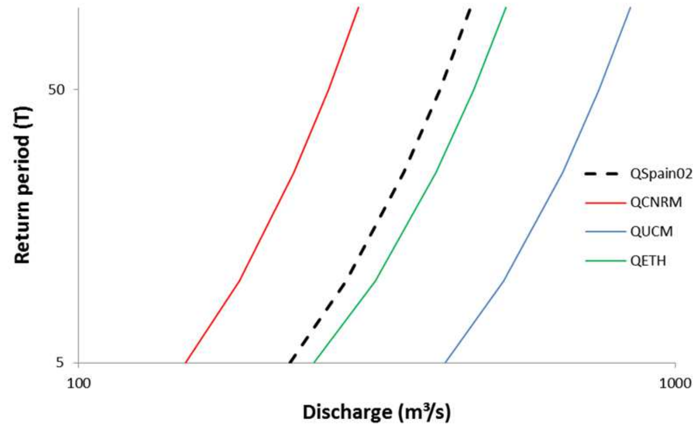
- In the area at daily time scale 3 models from PRUDENCE project, with the same global circulation model, but different regional downscaling:
  - **UCM** University of Castilla la Mancha, Spain (hadAM3+ PROMES)
    - **CRNM** National Center for Meteorological Research, France (hadAM3+ARPEGE)
  - **ETH Zurich** Swiss Federal Institute of Technology (hadAM3+ CHRM)
- Selection by comparison with observations (Spain02) during the control period 1961-1990:

Climatic model selection

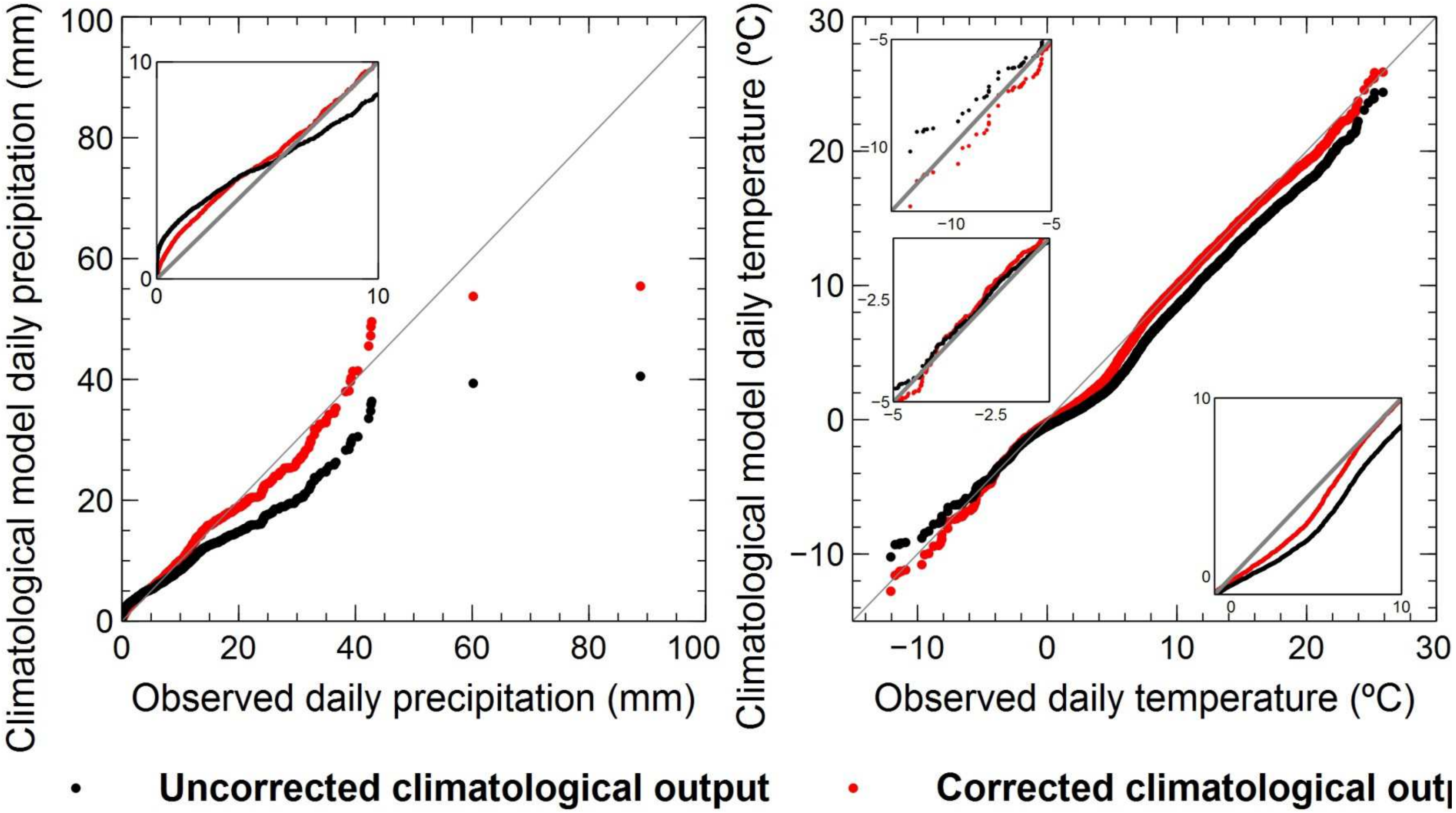




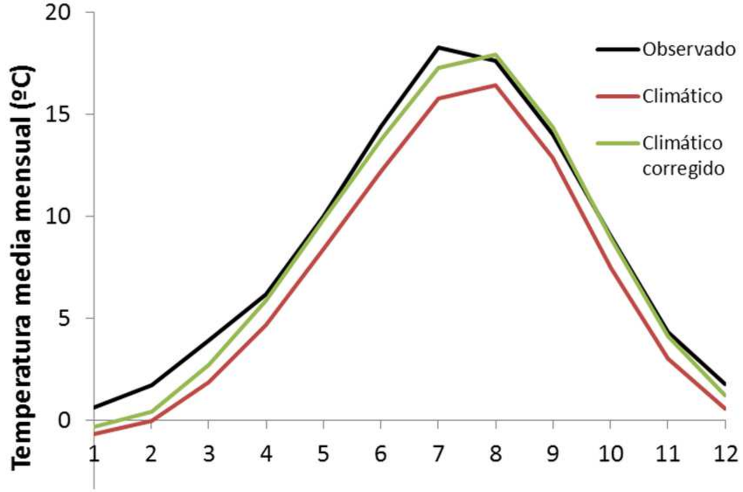


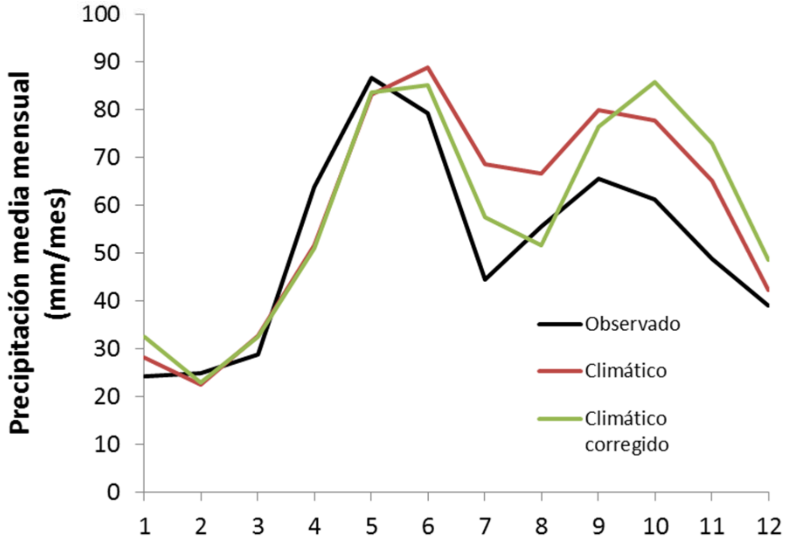


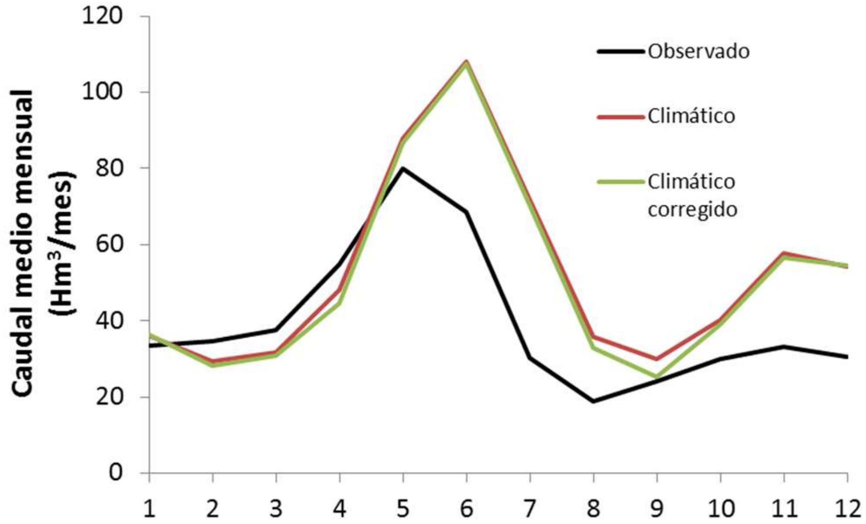
Input correction



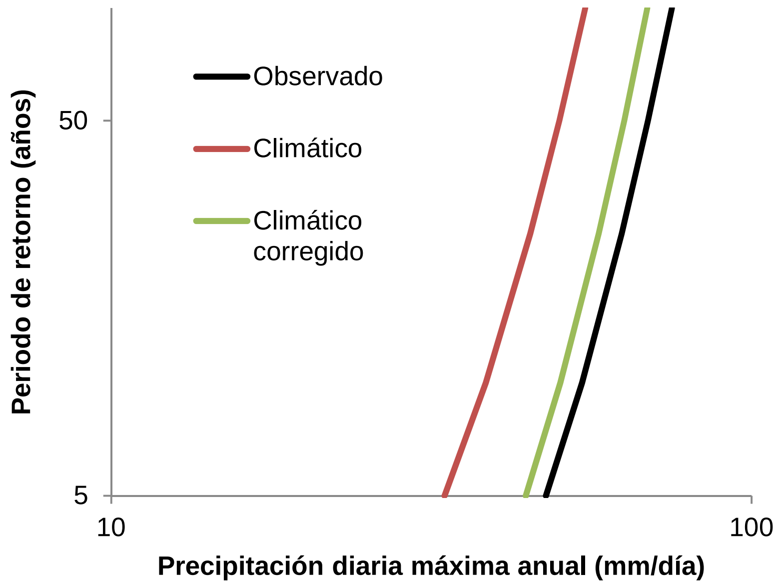
Effect of correction on seasonality

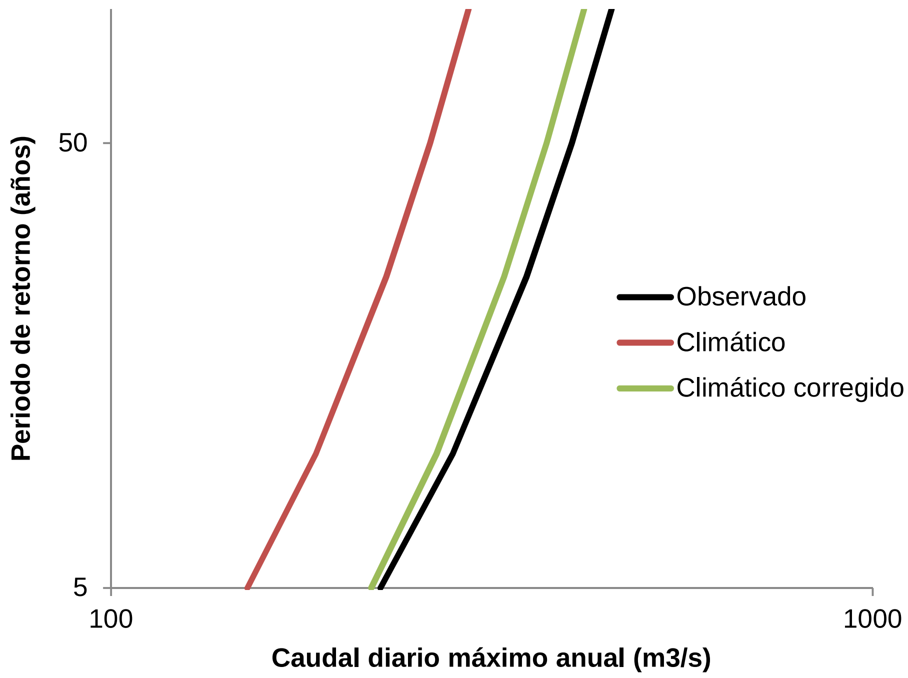






Effect of correction on extremes



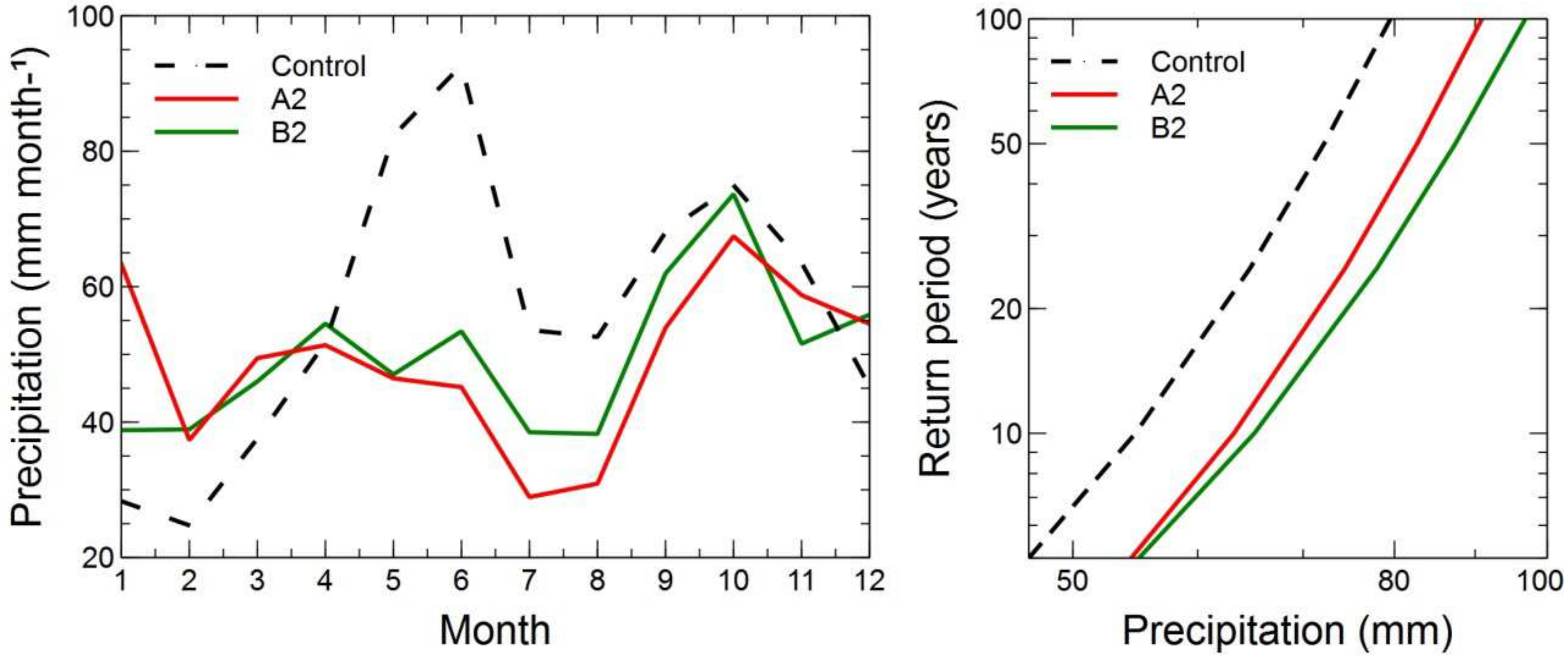


Results and discussion

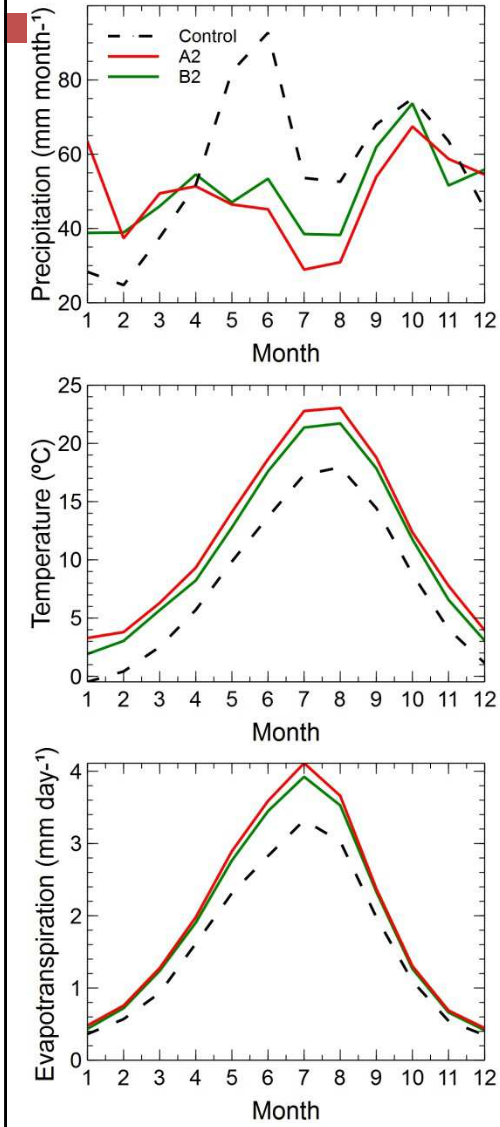
Mean values

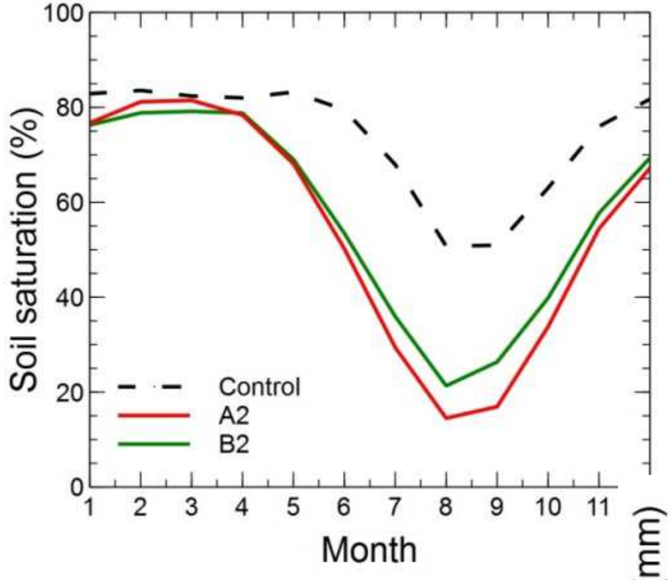
Variable	Control	A2	B2	Variation A2	Variation B2
Precipitation (mm/year)	655	571	581	-13%	-11%
Mean temperature (ºC)	6.9	10.7	9.7	+3.8ºC	+2.8ºC
Soil saturation (%)	66%				
Snowpack (mm eq.)	0.573				
Water yield (Hm^3/year)	594				
Sediment yield (ton/ha/year)	5.23				

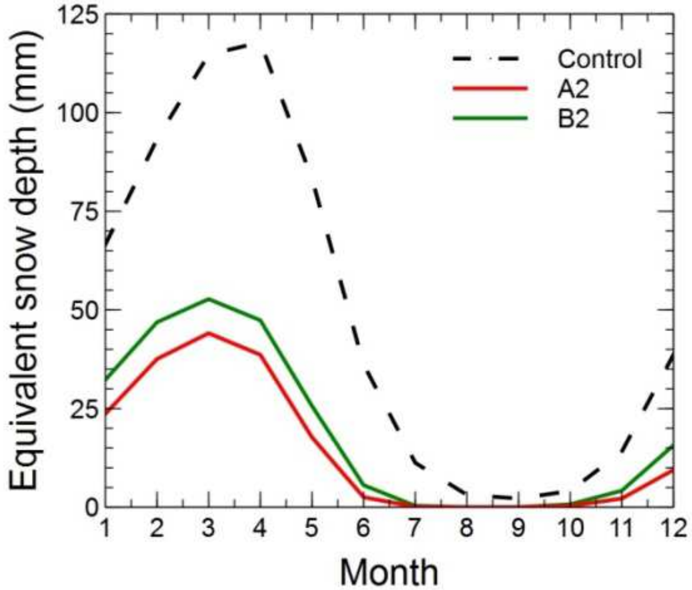
Precipitation



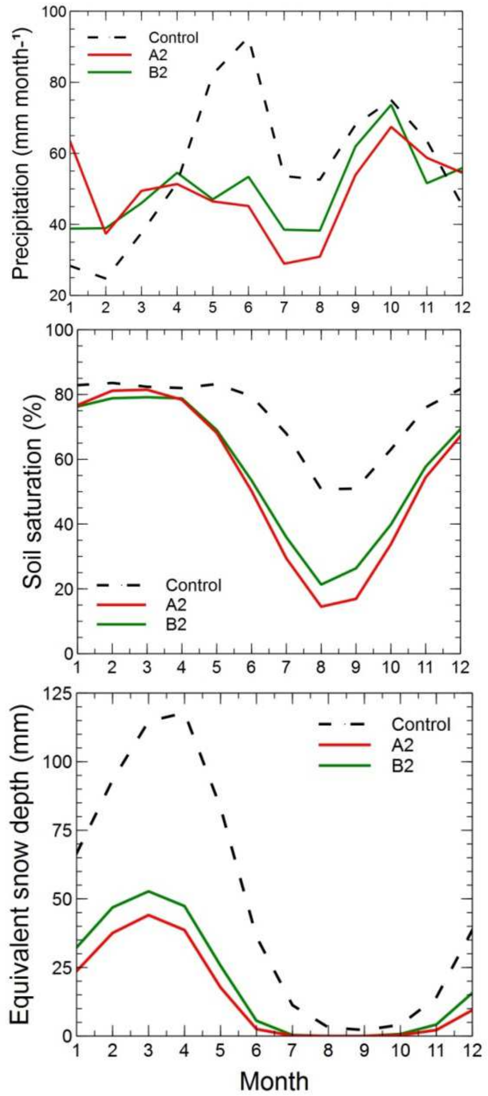
Soil moisture and snowpack

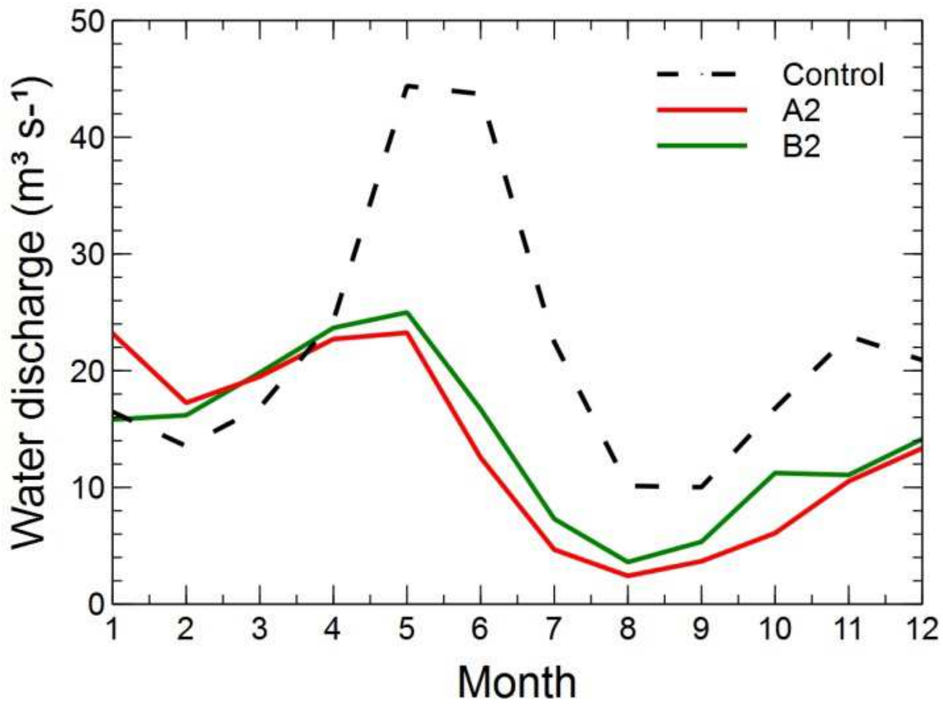




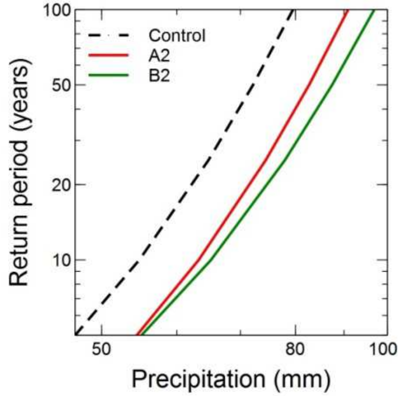


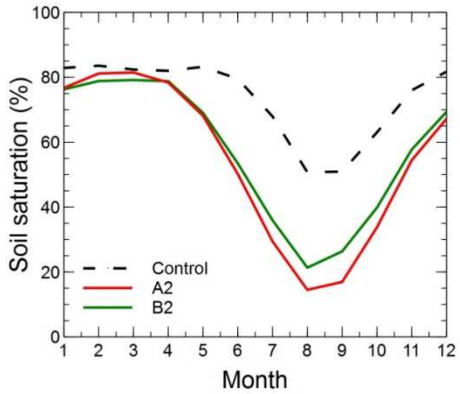
Water discharges

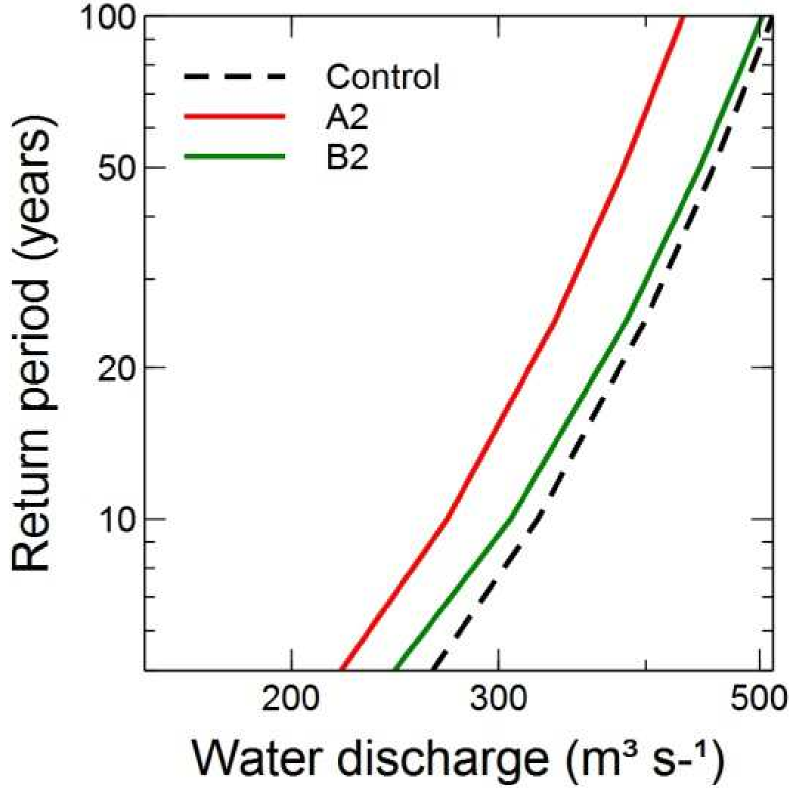




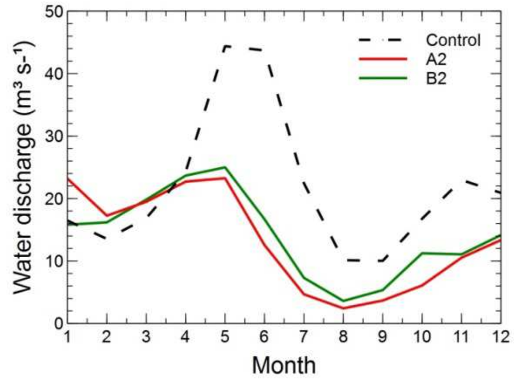
Floods

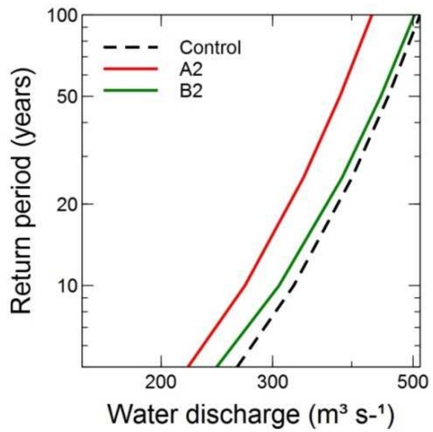

Return period (years)
Precipitation (mm)
Control
A2
B2
100
50
20
10
50
80
100

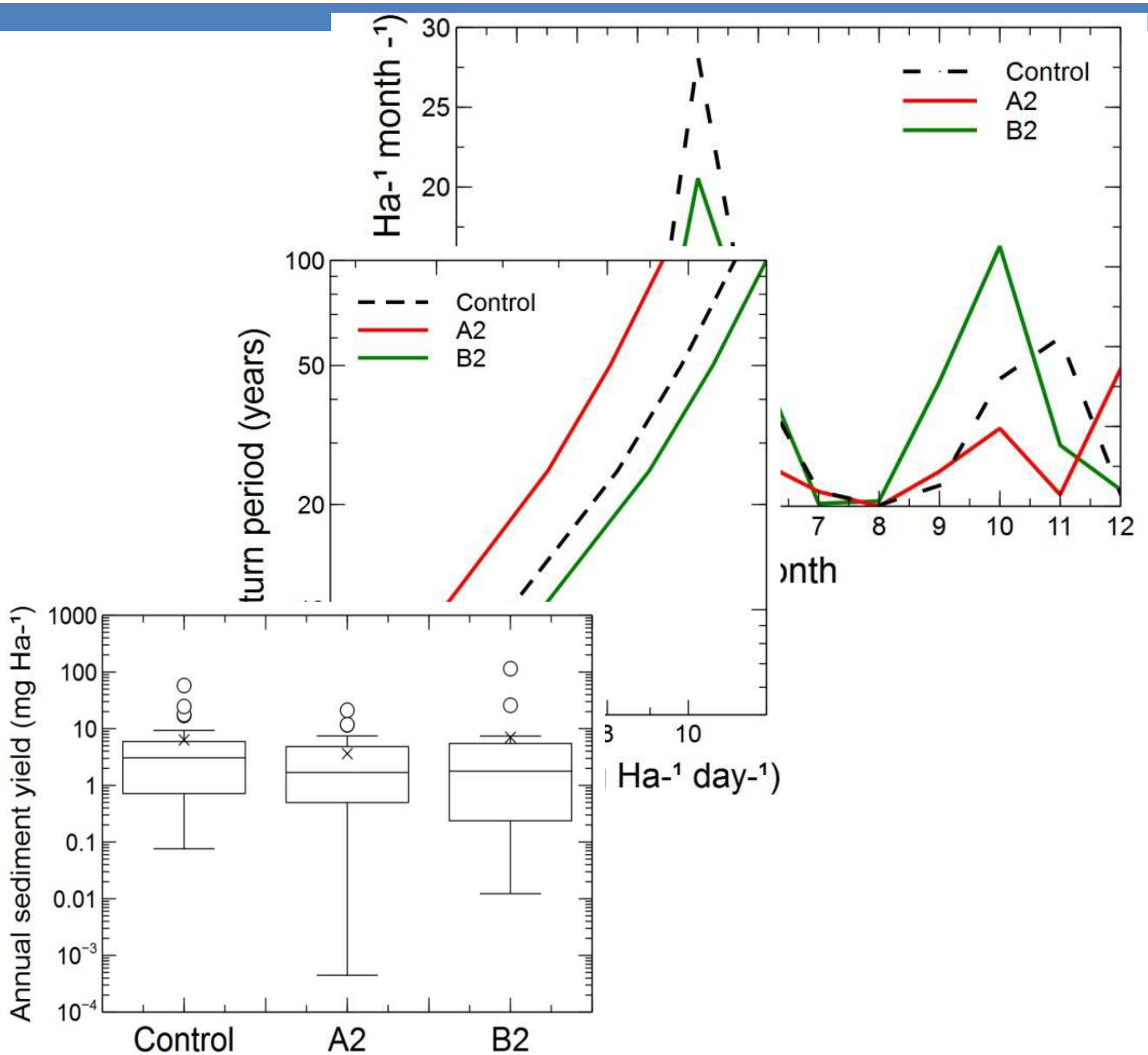

Soil saturation (%)
Month
Control
A2
B2


Return period (years)
Water discharge (m³ s-¹)
Control
A2
B2
100
50
20
10
200
300
500

Sediment

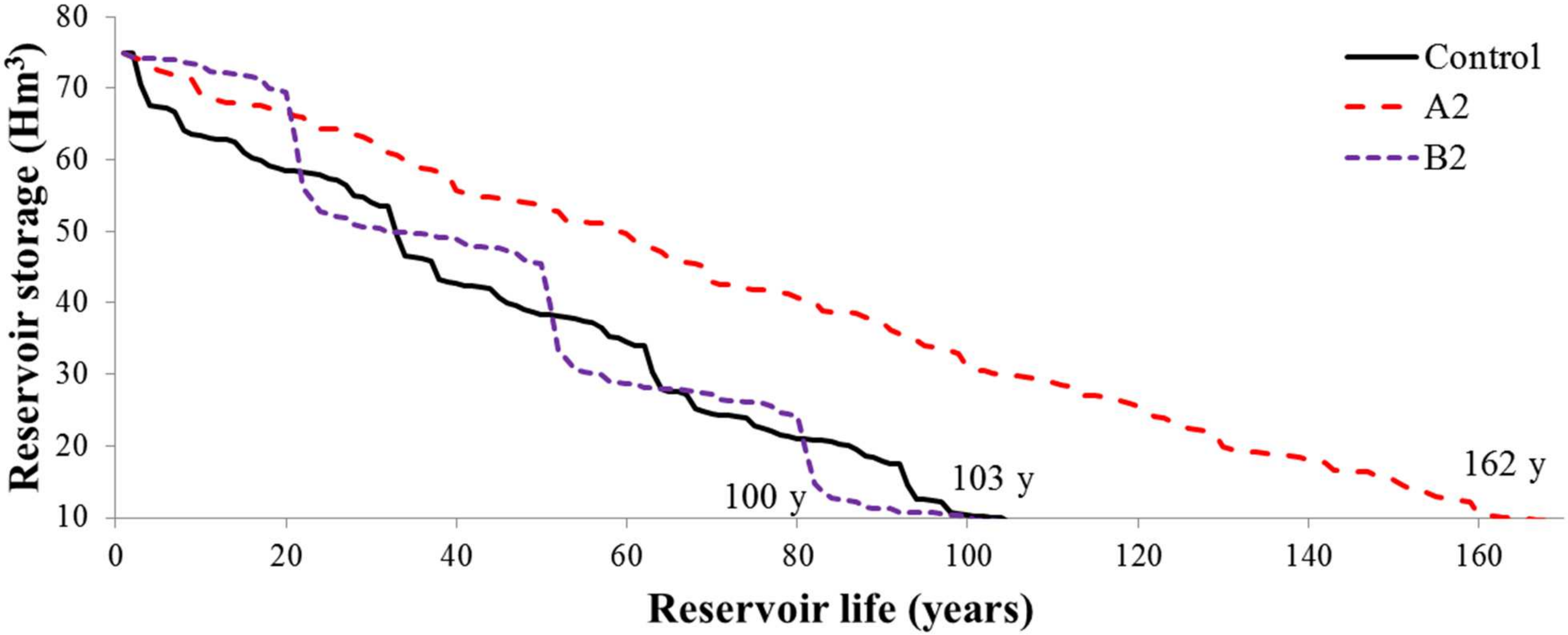

Water discharge (m³ s-¹)
Month
Control
A2
B2


Return period (years)
Water discharge (m³ s-¹)
Control
A2
B2


Ha-¹ month -¹)
Control
A2
B2
turn period (years)
Ha-¹ day-¹)
Annual sediment yield (mg Ha-¹)
Control
A2
B2

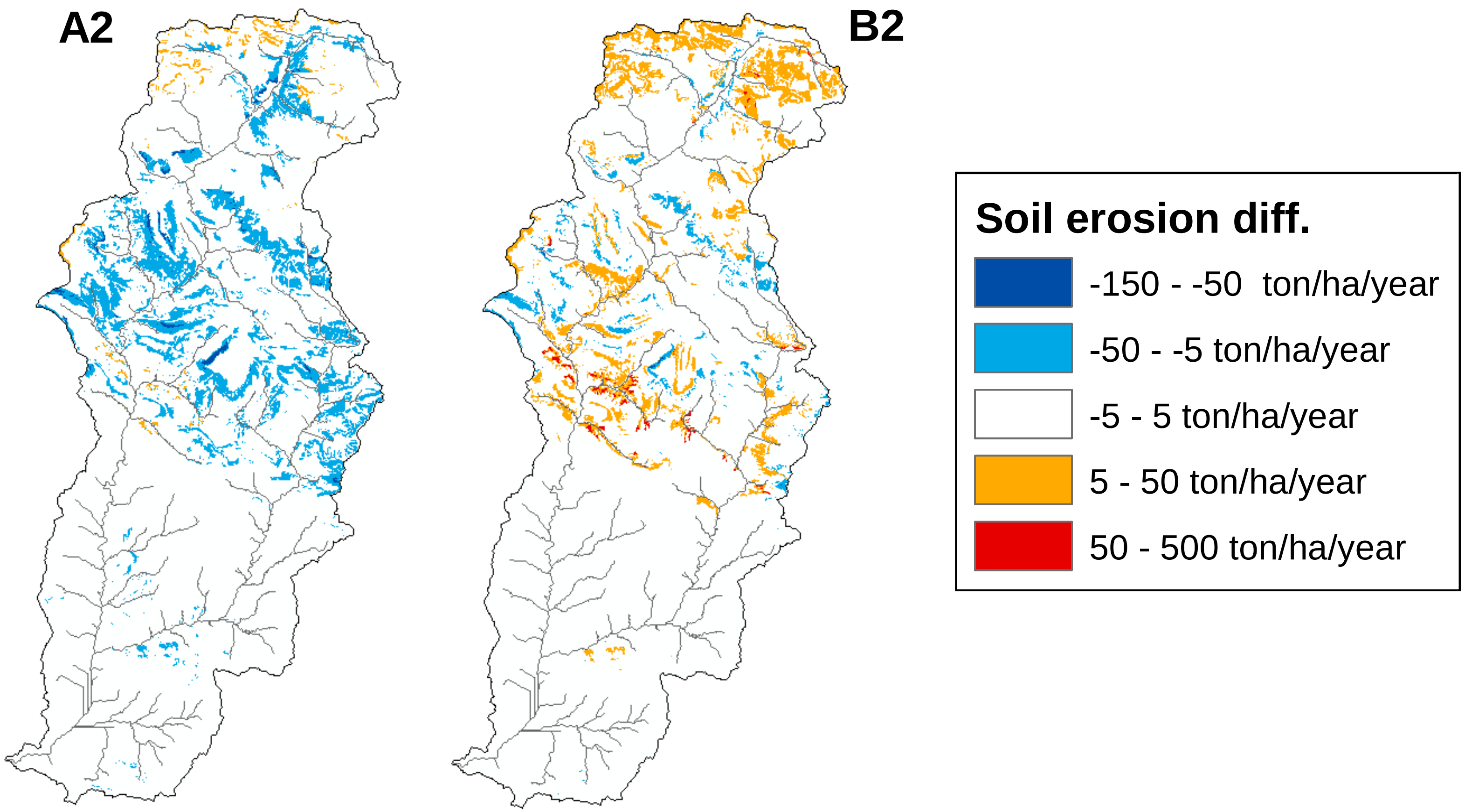
Barasona sedimentation

- Reservoir useful life (higher than 10 Hm^3):



Spatial variability of soil erosion

- Difference between future and control period erosion:



Conclusions

- Model implementation:
  - Distributed sediment model implementation without direct sediment data (reservoir sedimentation can be used as proxy data for model calibration and validation)
  - The methodology can be extended to all catchments drained by a reservoir with **bathymetries**
  - The TETIS water sub-model behaves very good, and the sediment sub-model result are **satisfactory**
  - The main sediment source is the central marl area

Conclusions

- Climate change scenarios: precipitation decreases, although its torrentiality increases; mean temperature increases;
  - High uncertainty => selection and correction
- Significant decrease in water yield
- Significant change in snow: amount and seasonality
- Compensation effects for floods and sediment yield, especially for A2 scenario:
  - Soil moisture decreases => drier initial soil moisture
  - less snow melting

Thank you for your attention!

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