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

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Introduction

In the last years, the analysis of climate change impact on water resources has been a key environmental research target. A broadly shared conclusion is that, in Mediterranean areas, average temperature is expected to increase while average precipitation is expected to decrease. Extreme events are also expected to increase their magnitude and frequency (Alpert et al., 2002). Nevertheless, little is known about the impact of climate change on water and sediment cycles at the catchment scale. Past studies focused this problem, although climate change impact quantification is still a quite difficult task. Given the high complexity of rainfall – runoff transformation, soil detachment and sediment transport phenomena, physically based distributed hydrological and environmental modelling is proposed as a tool to estimate the effect of climate change on water and sediment cycle. In this study, the TETIS hydrological and sedimentological model (Francés et al., 2007; Bussi et al., 2013) is coupled with climatological model scenarios in order to obtain climate change-affected series of several hydrological and sedimentological variables, which are later analysed in order to understand the impact of future climatological evolutions on hydrology and sediment transport of a highly erodible Mediterranean catchment.

Methods

The TETIS model was implemented at the Ésera River catchment, a medium size catchment (1510 km^2) draining to the Barasona reservoir (storage volume 92.2 Hm^3). It is located in the Central Southern Pyrenees (Spain), in an area characterized by high reliefs and slopes (Fig. 1). Main land uses are pine forest, shrubland, and arable land. The climate is strongly influenced by the Mediterranean Sea, with dry winters and torrential rainfall episodes in summer.

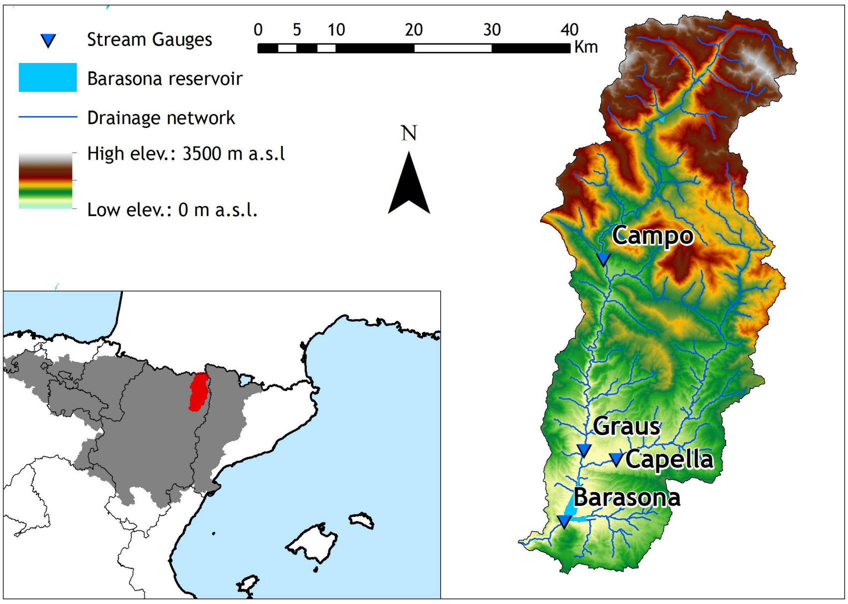

Figure 1: Ésera River catchment location

The catchment is defined as a highly erodible catchment (López-Tarazón et al., 2009), as it shows frequent badlands areas in its central part. Due to this characteristic, the Barasona reservoir is experiencing severe siltation since its building (1932). Several bathymetries were carried out since 1984 in order to control the reservoir storage volume. Flushing and dredging operation were also carried out along the reservoir life, although the extracted volume is unknown.

The TETIS model was implemented at the Éserva River catchment. Meteorological data (precipitation and temperature) was taken from *Spain02* gridded dataset (Herrera et al., 2010). The hydrological sub-module was calibrated by adjusting simulated water discharge at the Capella station (Fig. 1) in order to reproduce observed water discharge records provided by the CEDEX (Experimental Studies Centre). The hydrological sub-model showed a satisfactory behaviour, as calibration Nash and Sutcliffe efficiency was 0.72 and spatio-temporal validation at the Barasona reservoir obtained an efficiency of 0.71.

The sediment sub-model was calibrated by adjusting simulated total load in order to reproduce the sediment volume accumulated at the bottom of the Barasona reservoir. The sediment trap efficiency of the Barasona reservoir was taken into account by using the Brune curves, which provided trap efficiency raging between 82% and 88%. The deposit dry bulk density was computed by means of the Miller formula, using Lane and Koelzer coefficients, and validated with measured density values. The chosen calibration period was from 1998 to 2008. During this period, three bathymetries were carried out, allowing splitting this period into two sub-series, one used for calibration and the other for validation. The results are shown in Fig. 2. The model obtained a validation volume error of 23%.

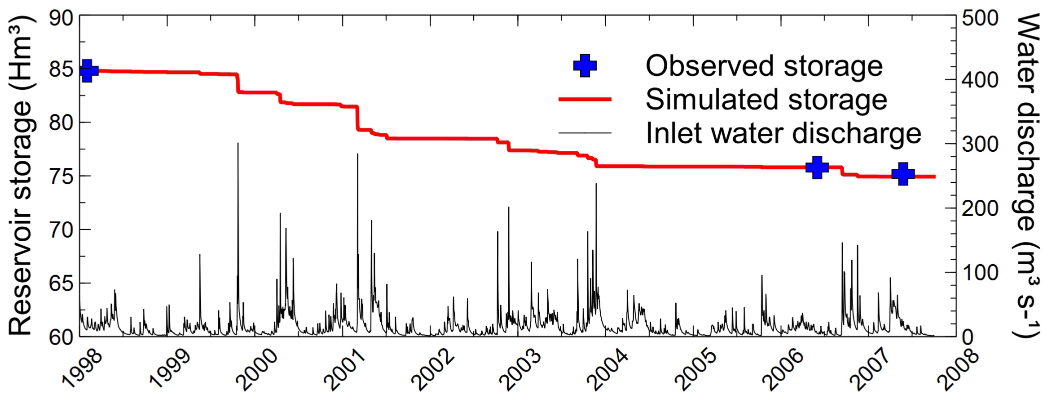

Figure 2: observed vs simulated evolution of the reservoir storage capacity.

The TETIS model was subsequently coupled with meteorological output (precipitation and temperature) produced by the ARPEGE atmospheric regional model in the framework of the PRUDENCE project (Christensen et al., 2007). Three climatological scenarios were simulated: a control scenario (1961-1990), representing the current climate, A2 scenario (2071-2100) and B2 scenario (2071-2100), both representing two different future climate evolution (elaborated within the Special Report on Emissions Scenarios). A2 scenario forecasts a stronger temperature increase and precipitation decrease tan B2. Previous to their use, climatological precipitation and temperatura were corrected in order to reproduce more precisely the Ésera River catchment climate. The correction was done base on quantiles plots (q-q plots), as suggested, for example, by Déqué (2007). The results are presented as follows.

Results and conclusions

The Ésera River catchment TETIS model was run using as input the daily temperature and precipitation series produced by the ARPEGE model. TETIS provided daily series of several hydrosedimentological variables, such as mean catchment precipitation and temperature, water and sediment discharge, mean catchment soil moisture and water-equivalent snow depth. Results, presented in Tab. 1, show that precipitation tends to decrease and temperature tends to increase, as expected. The variation is more pronounced for A2 scenario, which is more pessimistic than B2 scenario. These variations cause a strong decrease in both soil saturation and snow depth. All these hydrometeorological variables affect total water yield, which is expected to decrease by 40% under A2 scenario and by 35% under B2 scenario. Nevertheless, sediment yield does not follow the same trend, as it is expected to strongly decrease under A2 scenario and to increase under B2 scenario. Given the highly non-linear relationship between water and sediment discharge, an analysis of extreme values is needed in order to understand this apparent contradiction.

Variable	**Control**	**A2 variation**	**B2 variation**
Precipitation (mm/year)	686	596	607
Temperature (ºC)	7.99	12.06	11.01
Soil saturation (%)	74	54	57
Snow depth (mm eq.)	49	15	19
Water yield (Hm^3/year)	690	418	446
Sediment yield (ton/ha/year)	6.33	3.62	7.04

Table 1: model results, averaged on the whole 31-year series and over the entire catchment.

In Fig.3 the Gumbel distribution functions of annual maximum of daily precipitation, water discharge and sediment discharge are shown. They show that extreme values do not behave accordingly to mean values observed in Tab. 1. This is because extreme precipitation is expected to increase (i.e. precipitation is expected to become more torrential, as pointed out for example by Alpert et al., 2002). This increase is not sufficient to obtain increasing values of extreme water discharge, given that the decrease in soil moisture compensates this effect. Nevertheless, extreme sediment discharge values show an increase under B2 scenario and a decrease under A2 scenario. This is because B2 scenario is more torrential than A2 scenario, as can be seen in the extreme daily precipitation plot in Fig. 3.

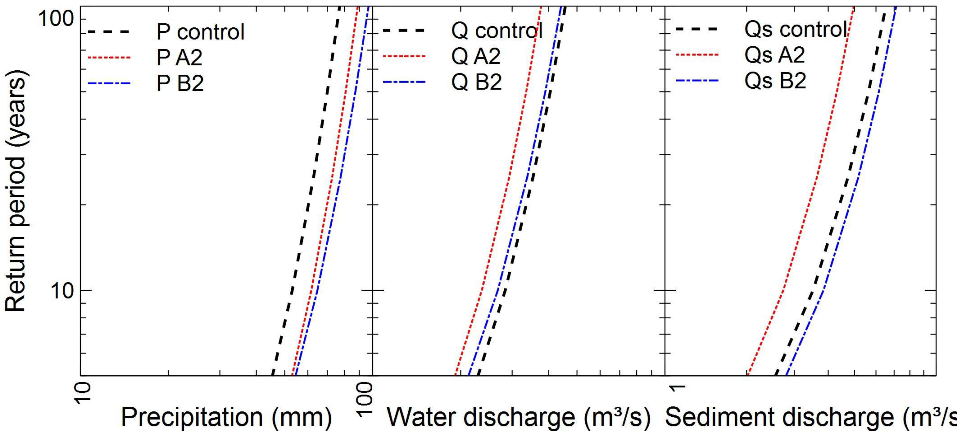

Figure 3: Gumbel distribution functions of annual maximum daily precipitation, water discharge and sediment discharge.

Another interesting phenomenon, which can be noted analysing the model results, is the time compression alteration. Time compression describes the contribution of largest events to the total load. In this case study, the 5 largest events accounted for 39.6%, 36.9% and 49.8% of total sediment yield for control, A2 and B2 scenario respectively, the 10 largest events for 52.7%, 54.8% and 65.1% and the 20 largest events for 62.0%, 70.2% and 78.8%. This indicates that time compression is expected to increase, following model results, and, as a consequence, the Ésera River sediment cycle is expected to become more large event-dependent in the future, regardless of total sediment load.

Another interesting feature that model results allow analysing is the spatial variation of soil erosion (Fig. 4). The most affected zones are located in the northern part of the catchment, due to high slopes and badland presence. Soil erosion is expected to expand under B2 scenario and to reduce under A2 scenario. The main sources of sediments are located in the badland areas in the central part of the catchment for all scenarios, although for scenario B2 the surface of badland zones appears to increase and for scenario A2 to decrease.

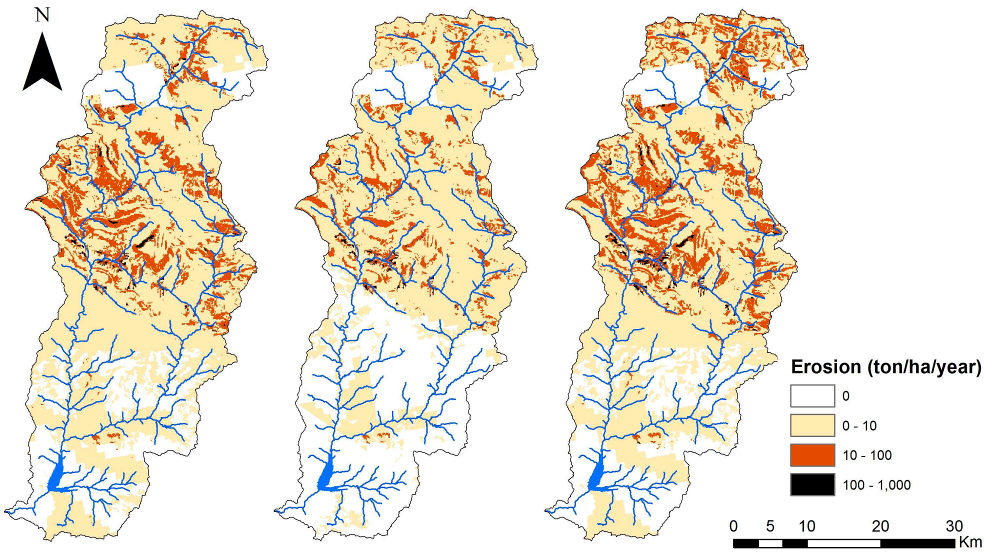

Figure 4: spatial variation of soil erosion (from left to right: control period, A2 scenario and B2 scenario).

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