Climate Change effects on the hydrological regime in the Ladra River Basin (NW Spain)

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Soil & Water Assessment Tool SWAT

Outline

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Scientifical Context

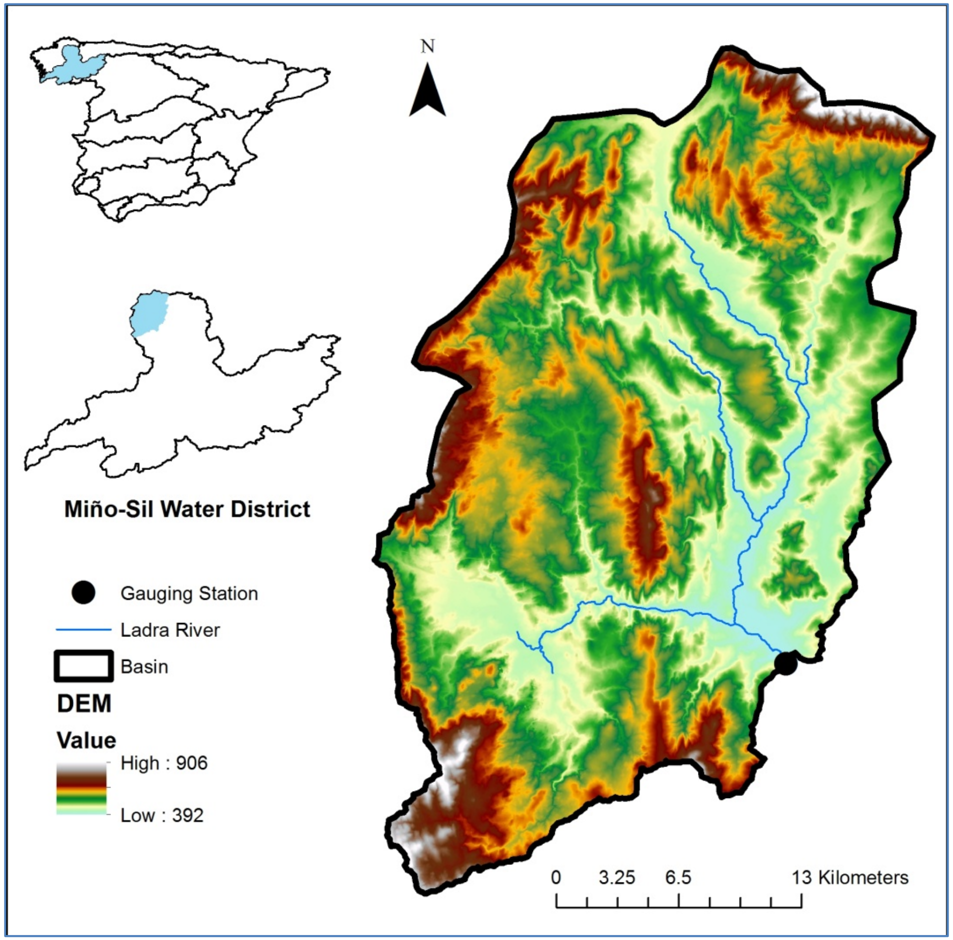
- According to the Intergovernamental Panel on Climate Change the precipitation pattern and temperature will significantly change by the end of 21st century, which will affect the ***hydrologic regime***.
- Streamflow conditions are crucial to determining the abiotic structure and biotic composition of riverine ecosystems.
- The success in the conservation of the biodiversity depend on our ability to know, protect and/or restore the main components of the natural flow regime.

Objective

- Calibrate and validate, in daily basis, the Ladra River basin (NW Spain) using SWAT model in order to assess the climate change impact on the hydrological regime in the Ladra River Basin for 2071-2100 period using RCA4 regional climate model driven by the CNRM-CM5 global circulation model.
- Check the use of some tools recommended in the Spanish Hydrologic Planning Instruction in order to assess the impact on hydrological regime.
  - Indicators of Hydrologic Alteration in Rivers (IAHRIS)
  - Basic Flow Methodology (BFM)

- The Ladra River is one of the most unique water ecosystems in the Atlantic region in the Iberian Peninsula. It is located in the northwest of Spain, within Terras do Miño ***Biosphere Reserve*** (declared in 2002 by UNESCO) and was selected as a ***Site of Community Importance*** (SCI) by the European Union.

Area	843 km^2
Elevation	392 – 906 m
Precipitation	1139 mm
Discharge	17.9 m^3/s



SWAT Model. Data Collection

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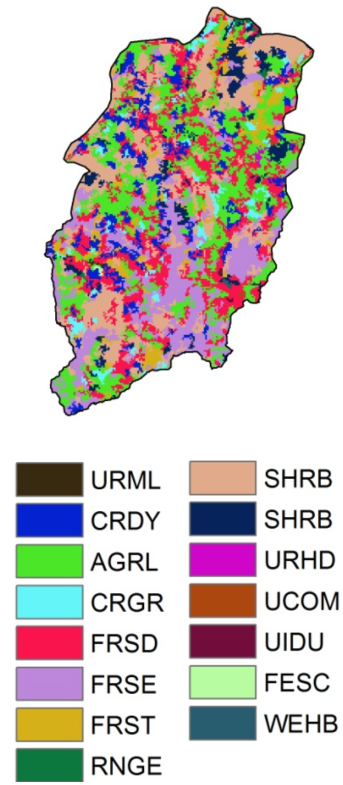
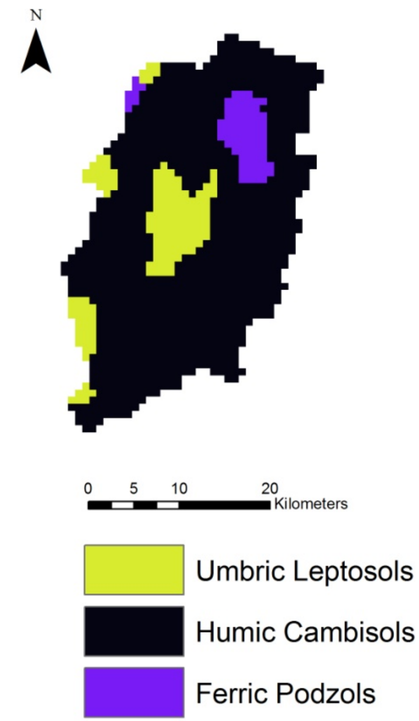
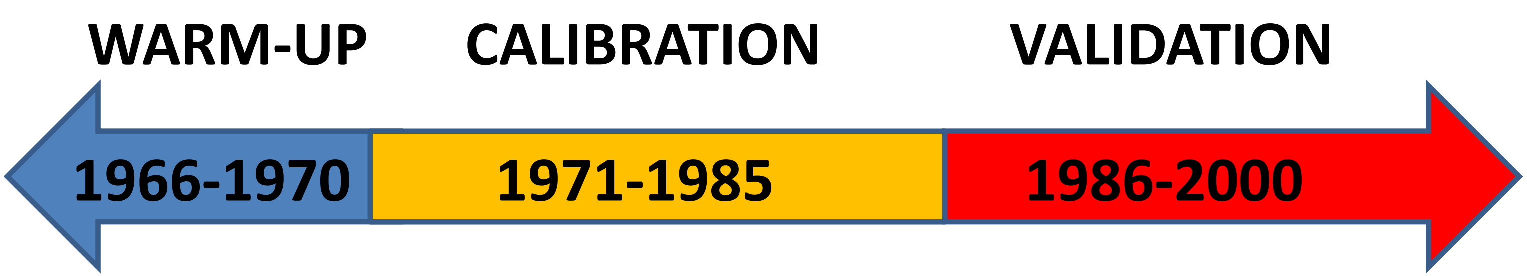
Data type	Source and Description
DEM	Extracted from the Spanish National Geographic Institute (IGN) with a resolution ratio of 25 m.
Land Use Map	Obtained from the CORINE Land Cover 1:100,000 vector map
Soil Map	Obtained from the Harmonized World Soil Database (HWSD) with a resolution of 1 km
Weather Data	Daily temperature and precipitation data were extracted from Spain02 (Herrera et al., 2012). The dataset is available on daily time scale with resolution of 12 km.
Stream Discharge	Stream discharge taken from CEDEX site no. 1619 located at Begonte for the study period.

SWAT Model. Model Set-up

- Sentivity analysis
- Calibration was performed using SUFI2 routing in SWAT-CUP (1000 runs)
- KGE as objective function
- The model was calibrated at a daily scale







Climate Change Impact Assessment Study

- Weather input data for SWAT has been extracted from the climate model outputs
- Regional Climate Model: RCA4
- Parent GCM: CNRM-CM5
- Grid Resolution: 0.11 deg ≈ 12.5 km
- CORDEX Domain: EURO-CORDEX
- Modeling Agency: Swedish Meteorological and Hydrological Institute (SMHI)
- Scenarios: RCP 4.5, RCP 8.5
- Bias Correction Technique: Distribution Mapping (CMHyd)
- Land use pattern is considered same for the future scenario

Indicators of Hydrologic Alteration in Rivers (IAHRIS)

- IAHRIS is a software designed to obtain ***parameters*** that characterize the flow regime, both the natural and the altered regime, in a section of the river.
- The software calculates a set of ***indicators*** that evaluate the degree of alteration of the most relevant environmental aspects of the flow regime based on the Spanish Hydrologic Planning Instruction.
- IAHRIS is a free software, available at the website: http://www.ecogesfor.org/IAHRIS_en.html

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Parameters for the characterization of the flow regime

COMPONENTS OF THE REGIME		ASPECT	PARAMETER
HABITUAL DISCHARGE	MONTHLY OR ANNUAL VOLUMES	MAGNITUDE	Average of the annual volumes
		VARIABILITY	Difference between the maximum and the minimum monthly volume along the year
		SEASONALITY	Month with the maximum and the minimum water volume along the year
	DAILY FLOWS	VARIABILITY	Difference between the average flows associated to the percentiles 10% and 90%
EXTREME DATA	MAXIMUM VALUES of the daily flows (FLOODS)	MAGNITUDE AND FREQUENCY	Average of the maximum daily flows along the year Effective discharge Connectivity discharge Flushing flood (Q5%)
		VARIABILITY	Coefficient of variation of the maximum daily flows along the year Coefficient of variation of the flushing flood series
		DURATION	Maximum number of consecutive days in the year with q> Q 5%
		SEASONALITY	Average number of days in the month with q> Q 5%
	MINIMUM VALUES of the daily flows (DROUGHTS)	MAGNITUDE AND FREQUENCY	Average minimum daily flows along the year Ordinary drought discharge (Q 95%)
		VARIABILITY	Coefficient of variation of the minimum daily flows along the year Coefficient of variation of the ordinary droughts series
		DURATION	Maximum number of consecutive days in the year with q < Q 95%
			Average number of days in the month with a daily flow equal to zero
		SEASONALITY	Average number of days in the month with q<Q 95%

List of Indicators of Hydrologic Alteration

ASPECT		CODE	NAME
HABITUAL DISCHARGE	MAGNITUDE	IAH 1	Magnitude of the annual volumes
		IAH 2	Magnitude of the monthly volumes
	VARIABILITY	IAH 3	Habitual variability
		IAH 4	Extreme variability
	SEASONALITY	IAH 5	Seasonality of maximum values
		IAH 6	Seasonality of minimum values
FLOODS	MAGNITUDE AND FREQUENCY	IAH 7	Magnitude of the maximum floods
		IAH 8	Magnitude of the effective discharge
		IAH 9	Magnitude of the connectivity discharge
		IAH 10	Magnitude of the flushing floods
	VARIABILITY	IAH 11	Variability of the maximum floods
		IAH 12	Variability of the flushing floods
	DURATION	IAH 13	Flood duration
	SEASONALITY	IAH 14	Flood seasonality (12 values, one for each month)
DROUGHTS	MAGNITUDE AND FREQUENCY	IAH 15	Magnitude of the extreme droughts
		IAH 16	Magnitude of the habitual droughts
	VARIABILITY	IAH 17	Variability of the extreme droughts
		IAH 18	Variability of the habitual droughts
	DURATION	IAH 19	Droughts duration
		IAH 20	Number of days with null flow (12 values, one for each month)
	SEASONALITY	IAH 21	Droughts seasonality (12 values, one for each month)

Basic Flow Methodology (BFM)

- The BFM is a hydrological methodology used to calculate environmental flow needs for river regulation.
- It has been established as a method of reference gathered in the Spanish Hydrologic Planning Instruction.
- The BFM does not provide a unique minimum flow value, but an environmental or maintenance flow regime:
  - ***Basic Flow***
  - Bankfull Flow
  - Maximum Flow
  - Rate of Flow Change

Basic Flow Methodology (BFM)

1) $a_i^k = \frac{1}{k} \cdot \sum_{j=1}^{k+i-1} q_j \; ; 1 \le i \le 366 - k; 1 \le k \le 100$ **2)** $v_k = \min_i \left(a_i^k \right)$

año 1	Q_{med}	1	2	3	4	5	.	.	.	.	.	.	.	98	99	100
		Matriz de medias móviles														
1		A		B												
2																
3																
.																
.																
266																D
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.																
.			C													
365																
		$v_{1,1}$														$v_{100,1}$

A=media de 1 día empezando el día 1
B=media de 3 días empezando el día 1
C=media de 2 días empezando el día 364
D=media de 100 dias empezando el día 266

3) $b_k = \frac{v_k - v_{k-1}}{v_{k-1}} ; \mathrm{k} = 2,3, \dots 100$ **4)** $Qb_j = \max_k (b_k); 2 \le k \le 100$

5) $Qm_i = (Q_b + Q_a) \cdot \sqrt{\frac{\overline{Qmes_i}}{\overline{Qmed_{min}}}} ; i = 1,2, \dots, 12$

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THE BASIC FLOW METHOD FOR INCORPORATING FLOW VARIABILITY IN ENVIRONMENTAL FLOWS

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ABSTRACT

The Basic Flow is a methodology used to calculate environmental flow needs for river regulation. It has gained increased recognition in Spain for hydrological planning. It is based on the study of irregularities in hydrological series of daily mean flows using the simple moving average model as a tool to extract the relevant information. The Basic Flow Methodology (BFM), beyond providing a unique minimum flow value, constitutes a complex management proposal for regulated rivers which includes other management aspects affecting the biological functioning of a river (such as the necessity of flow variability, bankfull flows or varying flow rates) through the establishment of monthly instream flow requirements.

This paper presents a practical application of the BFM in the Silvan stream, a natural mountain stream impacted by a hydroelectric regulation project. Results are discussed in terms of physical habitat created and compared to those obtained from the application of another method based on the Instream Flow Incremental Methodology, using a set of computer programs (RHYHABSIM) for physical habitat simulation. Copyright © 2010 John Wiley & Sons, Ltd.

KEY WORDS: basic flow; environmental flow; regulated river management

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Review

Application of indicators of hydrologic alterations in the designation of heavily modified water bodies in Spain

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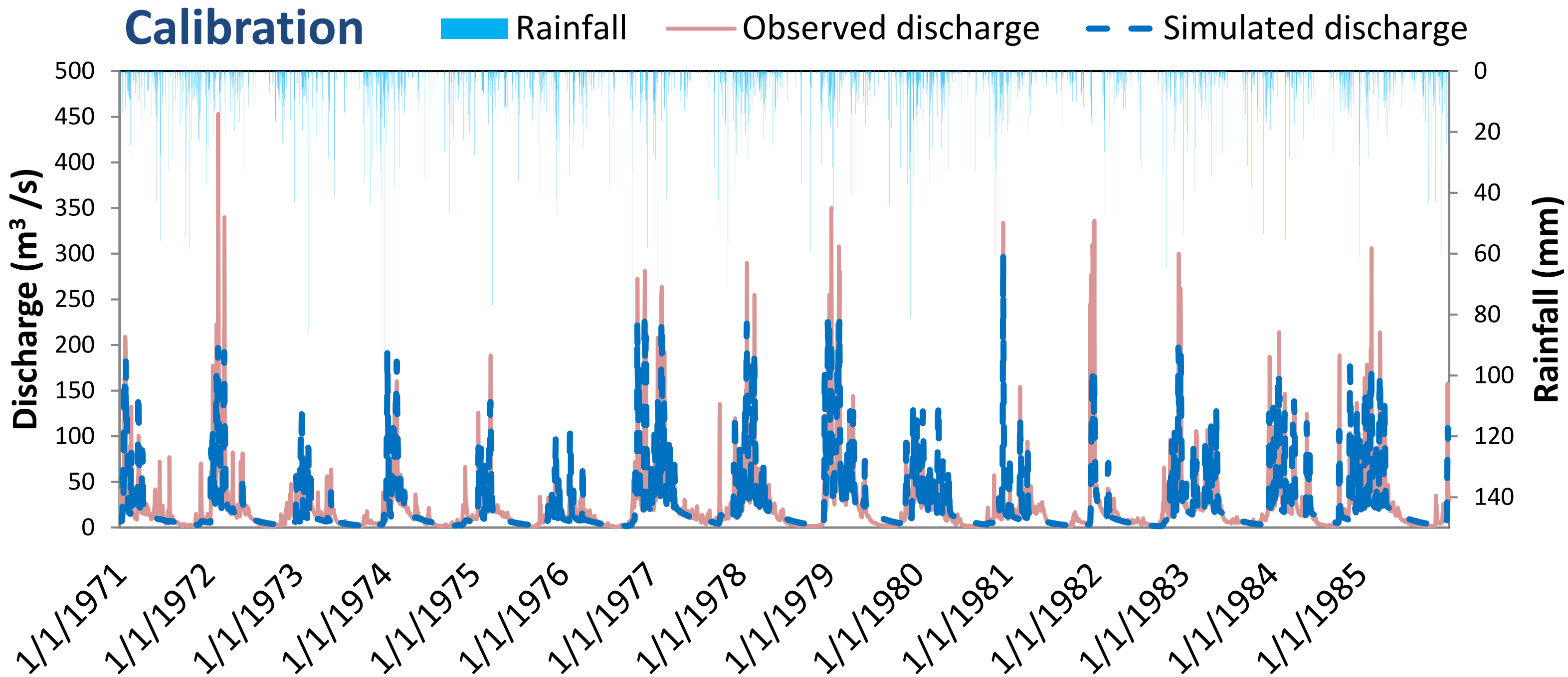
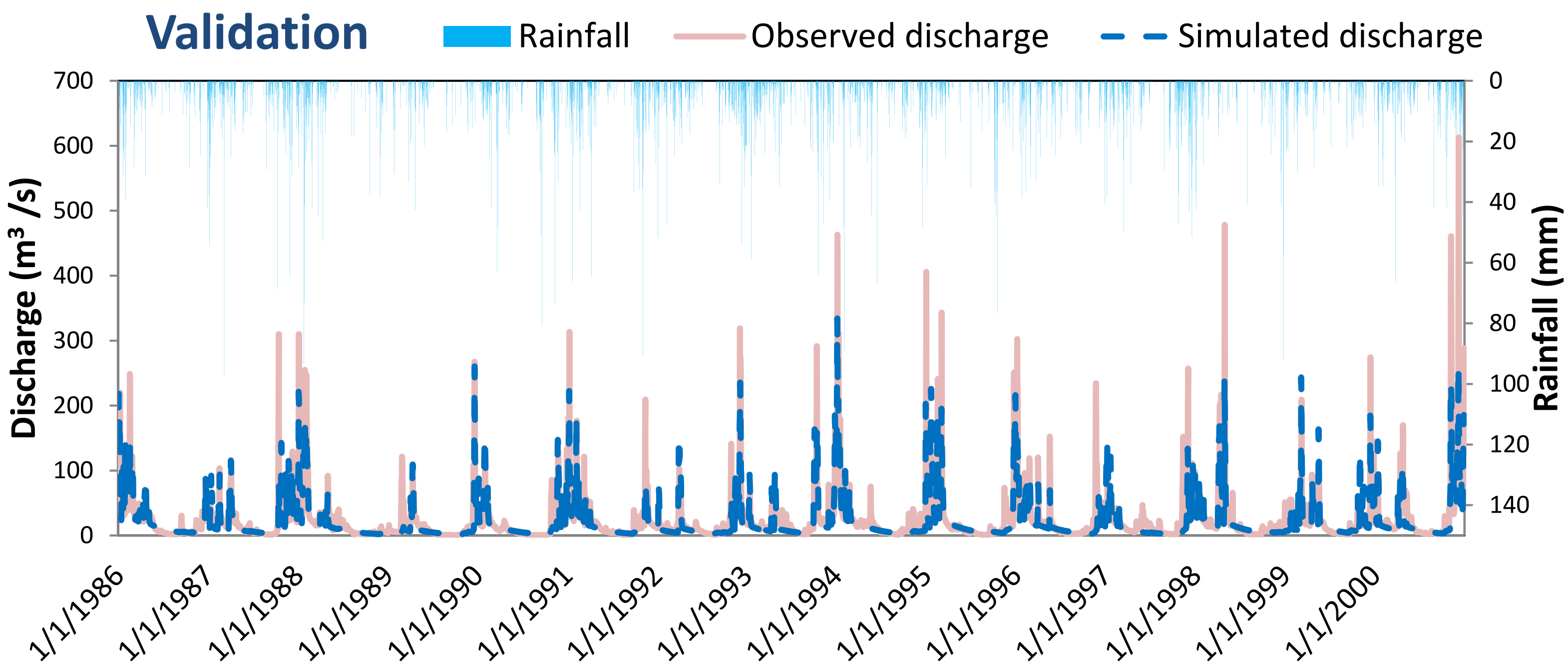
Model Performance



	Calibration
NSE	0.69
RSR	0.55
PBIAS	-2.54
R2	0.72

Model Performance



	Validation
NSE	0.63
RSR	0.61
PBIAS	7.22
R2	0.65

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❑ Climate Change Impacts

Mean Annual Precipitation

	1971-2000 Baseline	2071-2100 RCP4.5	2071-2100 RCP8.5
Precipitation (mm)	1138.96	1047.87	1003.65
Δ (mm)	-	-91.09	-135.31
Δ (%)	-	-8.00	-11.88

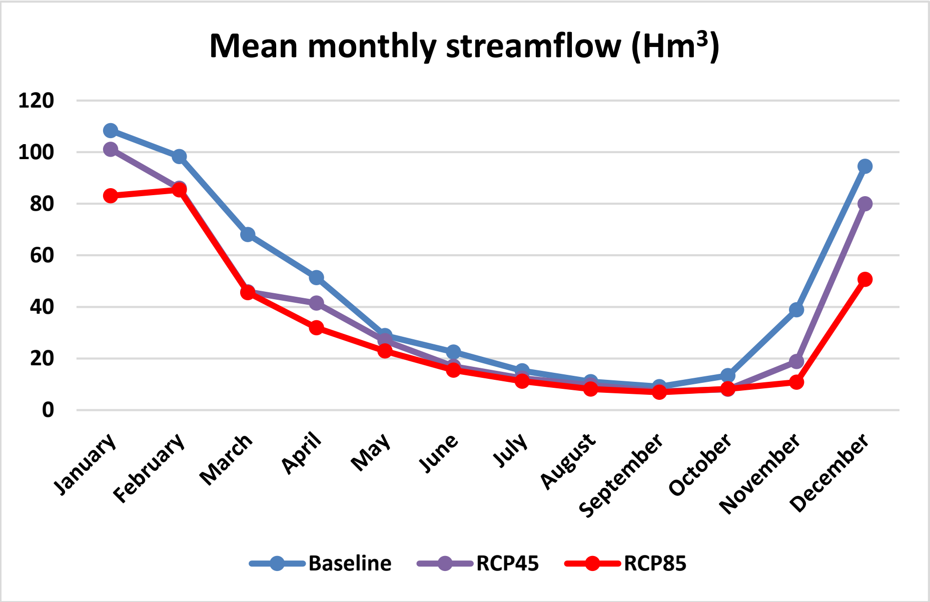
Mean Annual Temperatures

	1971-2000 Baseline	2071-2100 RCP4.5	2071-2100 RCP8.5
T_{max} (°C)	15.92	17.72	19.73
T_{min} (°C)	5.95	7.46	9.18
ΔT_{max} (°C)	-	1.80	3.81
ΔT_{min} (°C)	-	1.51	3.22

❑ Climate Change Impacts

Mean Annual Streamflow

	1971-2000 Baseline	2071-2100 RCP45	2071-2100 RCP85
Mean annual streamflow (Hm³)	564.62	458.41	382.43
Δ Streamflow (Hm³)	-	-106.22	-182.19
Δ Streamflow (%)	-	-18.81	-32.27



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Basic Flow

	Baseline	RCP45	RCP85	ΔRCP45 (%)	ΔRCP85 (%)
January	4.82	4.10	4.05	-14.88	-15.98
February	4.64	4.02	3.98	-13.36	-14.16
March	4.48	3.75	3.69	-16.12	-17.59
April	4.36	3.85	3.61	-11.73	-17.16
May	4.17	3.64	3.54	-12.84	-15.18
June	4.16	3.57	3.51	-14.14	-15.63
July	4.13	3.57	3.51	-13.54	-15.02
August	4.13	3.58	3.51	-13.30	-14.98
September	4.15	3.57	3.53	-13.95	-14.88
October	4.34	3.65	3.57	-15.89	-17.71
November	4.52	3.86	3.63	-14.63	-19.58
December	4.99	4.51	4.25	-9.63	-14.80

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IAHRIS (RCP 8.5)

ASPECTO		INDICES DE ALTERACIÓN HIDROLÓGICA (IAH)			NIVEL I	NIVEL II	NIVEL III	NIVEL IV	NIVEL V
		VALOR	CÓDIGO	DENOMINACIÓN	0,8< I ≤1	0,6< I ≤0,8	0,4< I ≤0,6	0,2< I ≤0,4	0< I ≤0,2
FLOODS	MAGNITUDE	0.84	IAH7	Magnitude of the maximum floods	■				
		1.00	IAH8	Magnitude of the effective discharge	■				
		0.88	IAH9	Frequency of the connectivity discharge	■				
		0.65	IAH10	Magnitud e of the flushing floods		■			
	VARIABILITY	0.59	IAH11	Variability of the maximum floods			■		
		0.53	IAH12	Variability of the flushing floods			■		
	DURATION	0.69	IAH13	Floods duration		■			
	SEASONALITY	0.83	IAH14	Floods seasonality	■				
DROUGHTS	MAGNITUDE	0.75	IAH15	Magnitude of the extreme droughts		■			
		0.76	IAH16	Magnitude of the habitual droughts		■			
	VARIABILITY	0.70	IAH17	Variability of the extreme droughts		■			
		0.69	IAH18	Variability of the habitual droughts		■			
	DURATION	0.44	IAH19	Droughts duration			■		
	SEASONALITY	1.00	IAH20	Number of days with null flow	■				
	VARIABILITY	0.44	IAH21	Droughts seasonality			■		

- The SWAT model has been applied in the Ladra River basin and it showed a general good performance.
- Climate change scenarios showed a noticeable impact on water flow, decreasing up to 32%.
- The results show an important risk of more frequent and severe drought conditions.
- Climate change will also affect the variability of floods.
- The model provides guidelines to decision makers and sets the possibility to test further scenarios.

Thanks for your attention