National Roadmap for Adaptation 2100

Portuguese Territorial Climate Change Vulnerability Assessment for XXI Century

REPORT

WP4 – SECTORAL IMPACTS MODELLING
WP4.1/4 – Hydrological Balance & Agroforestry

Portugal Mainland

Final Version

National Roadmap for Adaptation 2100

Portuguese Territorial Climate Change Vulnerability Assessment for XXI Century

Title: RNA2100 – Sectoral Impacts Modelling - Hydrological Balance & Agroforestry - Portugal Mainland

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February 2024

This report is a product of the National Roadmap for Adaptation 2100 project.

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1. Introduction

This report presents the results of WP4.1 & WP4.4 of the RNA2100 project concerning the hydrological balance and agroforestry sectors/domains (see Table 1).

Sector / Domain	**Responsible partner**	**Participant partners**	**Considerations**
Hydrological balance	FCUL (Luís Dias)	APA	Water availability assessment using the SWAT model under current and climate change scenarios. Evaluation of drought probability under climate change scenarios. Modelling of adaptation measures and respective effects on the hydrological balance (measures must be structural and can be defined by APA / stakeholders, e.g., dams, wastewater reuse, reduction of water losses, change of crops, natural water retention measures).
Agroforestry	FCUL (Luís Dias)	-	Crop modelling under climate change scenarios using EPIC model embedded in SWAT (calibration and validation for current climate). Calculation of crop water requirements. Effects of climate change on crop yields. Focus on the main Mediterranean agricultural systems, particularly permanent irrigated crops (olive groves, vines, fruit trees), maize and vegetables (tomatoes), and extensive rainfed systems, including Montados.

Table 1 - Proposed tasks for the assessment of climate change impacts on Portugal's mainland's hydrological balance & agroforestry.

Since this is a preliminary report, the information presented may be subject to change in future reports, allowing for updates and the introduction of relevant information by other consortium members.

As part of this task, hydrological and crop modeling of the main crops produced in mainland Portugal has been carried out to identify the impacts of climate change on water availability, crop productivity, and irrigation needs. The Soil Water Assessment Tool Plus (SWAT+) model was used to achieve this goal due to its reliability for the intended assessment and its ability to incorporate reservoir operations, which is particularly relevant in this context.

2. Material and Methods

SWAT has been widely used to assess the availability of water resources, water quality, and the development of agricultural crops, considering different land use strategies [1]. It is constantly under development to improve its analysis and incorporate new modelling processes [2].

The methodology applied for the assessment of water resources in climate change scenarios for mainland Portugal uses the restructured and recently available version of this model, SWAT+, which allows the assessment of projected water availability in climate change scenarios, water needs for the agroforestry sector and the modelling of adaptation measures to minimize the impacts of climate change.

Figure 1 provides an overview of the methodology employed in this study.

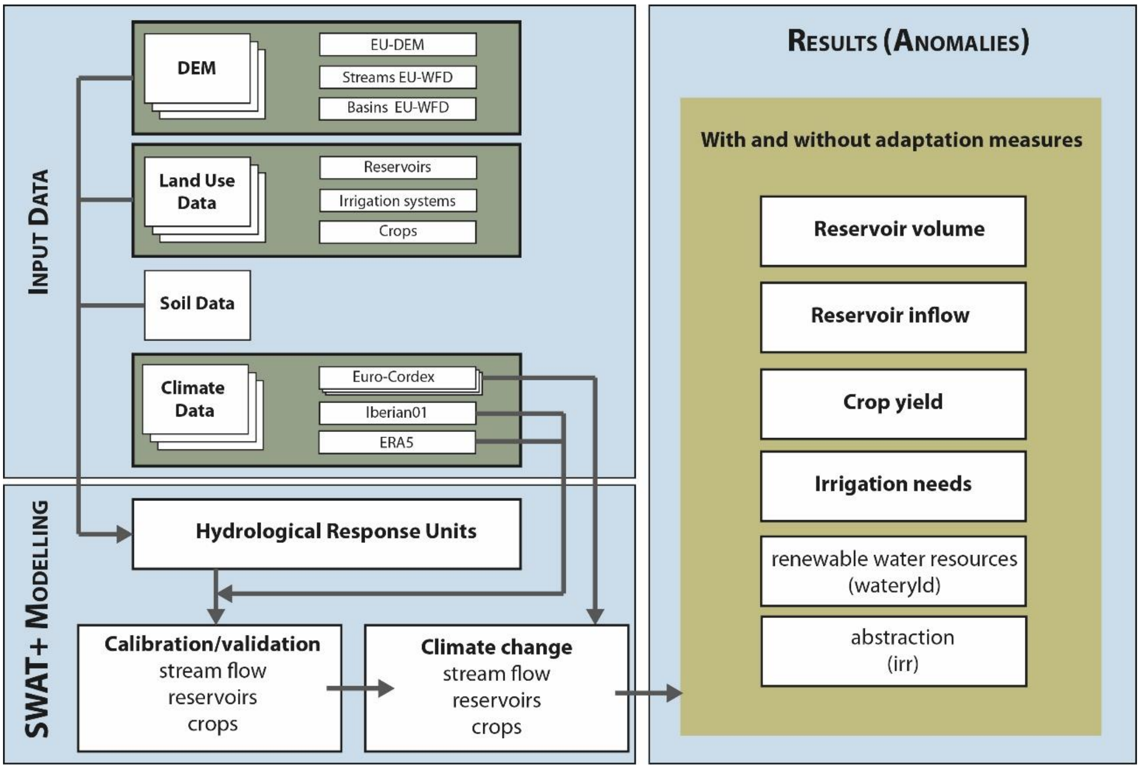

Figure 1 - Graphical summary of the assessment of climate change impacts on the hydrological balance and agroforestry productivity

2.1. Study Area

Mainland Portugal lies between latitudes 42°09 and 36°57 N, in a transition zone between the subtropical anticyclone and an area of subpolar depressions. In addition to latitude, its orography accentuates the contrast between a northern region of high rainfall and a drier climate in southern Portugal. The effect of proximity to the Atlantic Ocean versus continentality is also relevant to the country's climatic conditions. Therefore, climate variables such as precipitation and temperature show a strong north-south and west-east gradient. According to Koppen's classification, the climate of mainland Portugal is divided into two regions: Csb - temperate climate with dry and mild summer, present in almost all regions north of the Montejunto-Estrela mountain system and on the west coast of Alentejo and Algarve; and Csa - temperate climate with hot and dry summer present in the interior regions of the Douro valley, and south of the Montejunto-Estrela mountain system.

The study area includes the whole continental Portugal territory and all the international river basins contributing to the national flows (Figure 2). Continental Portugal's water bodies and river basin districts delimited under the Water Framework Directive (WFD) were considered for modelling purposes.

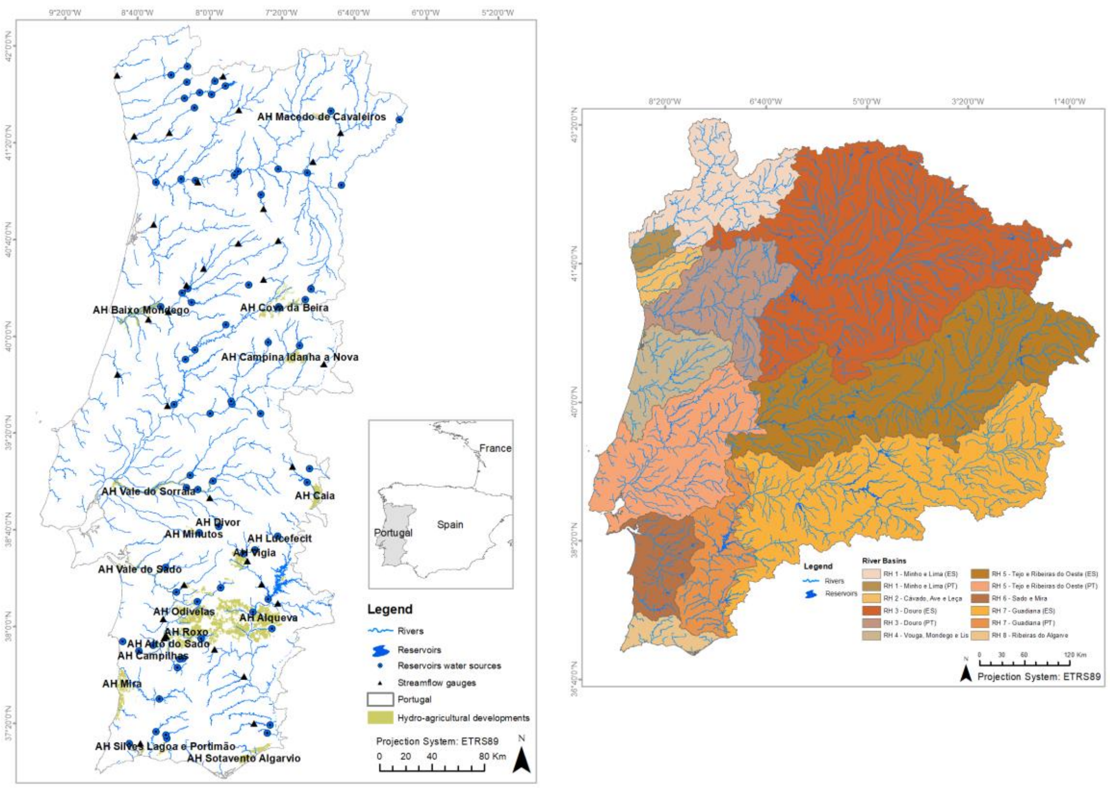

Figure 2 - Framing of the study area. Left image: Location of dams, hydrometric stations, and hydro-agricultural facilities, considered in this study for continental Portugal. Right image: Identification of the river basin districts of continental Portugal and Spanish basins that contribute to each of the Portuguese river basin districts.

2.2. MODEL SETUP

We used the SWAT+ version (rev. 60.5.4) to assemble and implement the model in QGIS.

Table 2 summarizes the input data. The model is divided into landscape units, coinciding with the WFD water bodies, which in turn are subdivided into hydrological response units (HRU). The HRUs consist of the main hydrological modelling unit of the SWAT model and represent areas of each sub-basin that drain to a single point. Each HRU has homogeneous hydrologic characteristics resulting from the intersection of topography, soil type, and land use and are derived from a digital terrain model (DEM), a soil type database, and a land use map (Table 2). HRUs are the basis for estimates of runoff, soil erosion, water quality, and other hydrological variables at different locations within basins and sub-basins [3].

The preparation of the HRUs started with the definition of the topography through the choice of the digital terrain model (DEM), having adopted the EU-DEM dataset developed by Copernicus with a spatial resolution of 25 meters (Table 2). This option considers the modeling areas' total size and the existence of international basins.

Data	**Source**
DEM	European Digital Elevation Model (v1.1) [4]
Land Cover	COS2010 (v1.0) [5], Corine Land Cover 2012 (v2020_20u1) [6], Irrigation Infrastructures [7]
Soils	Harmonized World Soil Database (v1.2) [8]
Meteorological data (temperature, precipitation, solar radiation, relative humidity, wind speed)	Iberia 01 dataset [9], ERA5 [10]
Climate change data	EURO-CORDEX [11], [12]
Hydrometric data	SNIRH [13], SAIH [14]

Table 2 - Data used for SWAT+ setup and the respective sources.

For the land uses and due to the need to cover Portugal and Spain, we used the Land Use Map (2010), provided by the Directorate General of the Territory, and the Corine Land Cover Land Use Map (2012), provided by the European Environment Agency and Copernicus. The choice of this information and temporal period stems from the greater discretization of land uses existing in the COS2010 concerning more recent versions, examples being different classes of orchards (citrus, almond trees), irrigation (separation between rainfed and irrigated crop), or the representation of the sclerophyllous vegetation, the latter being quite relevant for the calibration of the flows. This choice also considered the model validation and calibration period that will be described later.

To introduce the hydro-agricultural developments (AH) of mainland Portugal (Figure 1), the perimeters provided by the Directorate-General for Agriculture and Rural Development (DGADR) and the Alqueva Multipurpose Project (EFMA) were used. This his involved replacing the pre-existing land uses from the COS2010 dataset with representative crops of each specific AH (Figure 3). The hydro-agricultural developments utilized for the calibration and validation of models are based on data from the year 2010, and subsequently updated to account for developments up until the year 2020.

The crops associated with each land use were disaggregated using the 2009 Agricultural Census provided by the National Statistics Institute (INE) in the cases where their location is outside the AH, and using the field reports of the different AH, provided by the respective associations of irrigators, in the remaining cases. This breakdown includes the main Mediterranean crops, namely irrigated permanent crops (olive trees, vines, fruit trees), maize, vegetables (tomatoes), and non-irrigated extensive crops such as cork oak forests. The choice of the 2009 agricultural census is based on the land use map in use corresponding to the year 2010.

Finally, the different land use classes were matched with the crops/classes available for the SWAT+ model [15], [16] (see also Appendix A. Supplementary data (land use)).

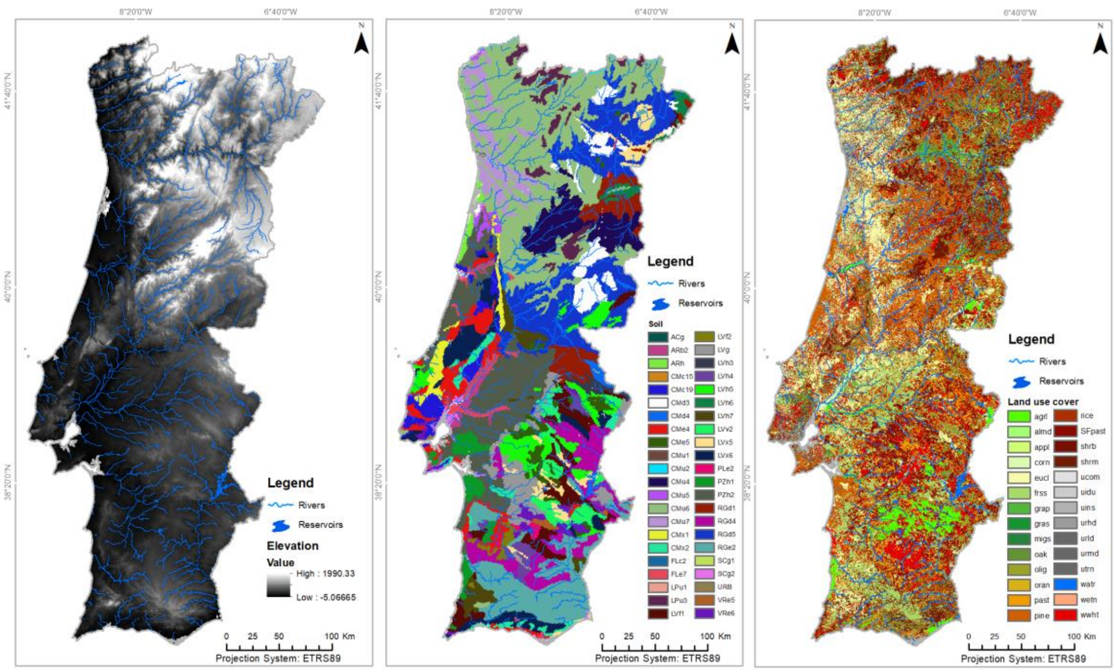

Figure 3 - Terrain digital model (left), soil types (center) and land use and land cover of the study area.

The soil types and respective parameterization for Portugal and Spain result from the Harmonized World Soil Database (v1.2) (2012), which has a resolution of 30 arcseconds per pixel [8] (Figure 3). This database combines and updates national and regional information, such as the European Soil Database, provided by the Joint Research Centre (JRC), with data from the World Soil Map at a scale of 1:5000000 (FAO, 1971-1981). Some parameters, such as the K factor related to soil erodibility, were further analyzed, and updated in the database according to information published for Europe by [17].

The use of pedotransfer functions to estimate saturated soil hydraulic conductivity and available water capacity were also contemplated using recently available scientific publications [18].

Finally, the slopes were calculated using the digital terrain model. The slope classes were chosen after analysis of the slope histogram and the one proposed by the Food and Agriculture Organization of the United Nation (FAO)[1]. Three classes resulted from these analyses: 0-2%, 2%-10%, and >10%.

Portugal's hydrographic regions, water bodies, and water lines were used to divide the country's hydrographic basins and delineate watercourses in modelling areas according to the Water Law, which transposes the Water Framework Directive (WFD) into the national legislation. For Spain, a more simplified approach was chosen, where sub-basins and watercourses were automatically generated by SWAT+ using the digital terrain model, with delimitation based on drainage areas equal to or larger than 50 km2. This approach does not impose any limitations on the results for mainland Portugal, ensuring greater efficiency in the modeling process while improve confidence in the accuracy of the inflows from Spain.

After defining the modelling areas, the intakes/outlets were included, namely dams (reservoirs) and hydrometric stations (daily flow).

The largest reservoirs were included in the model. Specifically, reservoirs with a volume greater than 10,000 m^3 were selected for continental Portugal, while reservoirs with a volume greater than 50,000 m^3 were selected for Spain. The data sources and parameters required for the analysis came from the National Water Resources Information System (SNIRH) and the Spanish Ministry for Ecological Transition and Demographic Challenge.

For Portugal, the reservoirs with a volume greater than 10,000 dam3 were the basis for selecting the hydro-agricultural developments (AH) included in the model. They represented all AH having at least one reservoir with these characteristics. After this selection and to represent those AH as realistically as possible, all reservoirs contributing to this exploitation were subsequently included, regardless of their stored volume (for dams considered and parameters used, see

[1] 0-2%, 2-5%, 5-8%, 8-16%, 16-30%, 30-45% and > 45%

Appendix B. Supplementary data - reservoirs). The remaining AH are represented using the Land Use Map - COS2010, specifically relying on the Temporary Irrigated Crops class. This map is the most recent version that represents different types of orchards (citrus, almond trees) and distinguishes between rainfed and irrigated temporary crops. Consequently, the irrigated areas and remaining AH are considered for calculating water needs and availability, as well as for all results carried out by the model to achieve the project objectives.

2.2.1. METEOROLOGICAL DATA

The SWAT+ model provides different approaches to calculating potential evapotranspiration using either the Hargreaves or the Penman-Monteith method. The second method was used for this study as it is considered the most accurate. Its calculation requires daily air temperature, relative humidity, wind speed, and solar radiation data. The Iberia 01 dataset was used for the meteorological data on daily air temperature and precipitation. This dataset is publicly available and results from a dense network of thousands of weather stations operated by the Spanish Meteorological Agency (AEMET), the Portuguese Institute for Sea and Atmosphere (IPMA), and the Portuguese Environment Agency (APA). The network underwent rigorous quality control, which required stations to have at least 15 years of data from the period between 1951 and 2015, with less than 10% of annual precipitation (and temperature) data missing. The observation network used includes 3486 stations for precipitation and 275 stations for temperature. For detailed information about this dataset, including the data sources, methodology applied, and conclusions of the study, it can be consulted at [19]. The Iberia 01 grid has a resolution of 0.1°x0.1°, which allows adequate representation of regional and local variations of each sub-basin, water body, and HRU. For daily mean wind speed, daily relative humidity, and daily solar radiation, the necessary information was obtained using the ERA5 reanalysis with a resolution of 0.25°x0.25° [10]. The data period was chosen to cover the maximum common interval between the two databases. The period between 1979 and 2015 was used for model calibration and validation.

2.2.2. CLIMATE CHANGE SCENARIOS

The climate change scenarios will consider the projections for the following climate variables: precipitation, temperature, average wind speed, relative humidity, and radiation. Projections of availability, demand for water resources, and agricultural productivity will then be estimated for these scenarios.

Table 3 synthesizes the climate models with available data that include RCP2.6, 4.5, and 8.5. These datasets are duly compiled and treated for continental Portugal, as described in [11].

GCM	Institute	RCM	RCP2.6	RCP4.5	RCP8.5
CNRM-CM5	CNRM	ALADIN63	X	X	X
	KNMI	RACMO22E	X	X	X
EC-Earth	CLM	CCLM4-8-17	X	X	X
	DMI	HIRHAM5	X	X	X
	KNMI	RACMO22E	X	X	X
	SMHI	RCA4	X	X	X
HadGEM2-ES	DMI	HIRHAM5	X	X	X
	KNMI	RACMO22E	X	X	X
	SMHI	RCA4	X	X	X
MPI-ESM-LR	MPI	REMO2009	X	X	X
	SMHI	RCA4	X	X	X
NorESM1-M	GERICS	REMO2015	X	X	X
	SMHI	RCA4	X	X	X

Table 3 - Climate models provided by EURO-CORDEX with available data for RCP2.6, 4.5 and 8.5 to be used in water resources assessment.

The models are run for the simulated historical climate (1981-2000) and the projected future climate (2041-2100) to calculate monthly ensembles of anomalies between the periods analyzed in the different scenarios (RCP2.6, 4.5, and 8.5). Anomaly ensembles are applied to historical data on water availability, water needs, reservoir water balance, and agricultural productivity for model crops. This approach follows [20], [21]. It replaces bias correction of different climate model variables, an operation that would introduce temporal inconsistencies between corrected variables, among other difficulties [22].

2.3. Calibration and validation of the SWAT+ model

The calibration and validation process of the SWAT+ model included two components: hydrological and agricultural. The first consisted of comparing the model results with the daily flows observed at various hydrometric stations located in the different hydrographic regions of Portugal and in Spanish waters bodies that drain into our country. The second compared agricultural productivity model results with productivity statistics for the main crops published by the National Statistics Institute.

2.3.1. HYDROLOGICAL COMPONENT

Hydrometric stations with a drainage area of at least 100 km^2 for continental Portugal and 1000 km^2 for the Spanish basins contributing to the national rivers were selected to calibrate and validate the model flows. Other criteria used were the availability of data in the period 1980-2010 and the coincidence between the WFD basin boundaries and the location of the hydrometric stations, which must be close to the end of these boundaries since SWAT+ is a semi-distributed model. This last factor was the main constraint in the selection of these stations.

The model calibration process was carried out in two stages: manually and automatically, using SWAT+ Toolbox[2] software. In the manual calibration phase, a literature review of previous SWAT model applications in Portugal [23]–[29] was performed to identify the most sensitive parameters for the study area (Table 4). These parameters were applied in different combinations and intervals, followed by a self-calibration process that included at least 100 model runs with different combinations and intervals to obtain a good representation of the daily flows of one or more hydrometric stations, resulting in a set of values for each parameter.

The calibration of the hydrological component considered i) availability (daily), ii) demand for the resource (monthly) and iii) volume stored in dams (monthly) according to information provided by SNIRH.

Availability for model calibration was obtained from hydrometric stations with daily runoff, storage volumes and daily inflows to dams. Demand results from the interconnection of dams with irrigation perimeters (and associated crops, as described in 2.3.2. Agroforestry component) and is assessed through the observed storage volume in dams and the demand available at the SNIRH, compared with the model output.

The calibration and validation procedure results from comparing observed and simulated values. The choice of the periods results from evaluating the quality of the observations through different approaches and considering the validity of the available flow curves. Considering the observed meteorology (between 1979-2015), the land use data (referring to 2010-2012), and the quality of the observed flow data, an attempt was made to calibrate the model between 1982[3] and 1986 and to verify the calibration parameters for one or more subsequent periods, preferably with five years of data, trying to have one of these periods as close as possible to the 2010 decade.

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[2] Version 1.0

[3] For the SWAT+ model to produce consistent results it needs a warming period of no less than two years. In this case it was decided to extend that period to three years

Group	Parameter	Description	Unit	Default values	Range	
					Min.	Max.
Ground water flow	flo_min	Water table depth for return flow to occur	m	5	0	50
	alpha_bf	Alpha factor for groundwater recession curve	1/days	0.048	0	1
	bf_max	Baseflow rate when entire area is contributing to baseflow	mm	1	0.1	2
	rchg_dp	Recharge to deep aquifer (the fraction of root zone percolation that reaches the deep aquifer)	-	0.05	0	1
	spec_yld	Specific yield for shallow aquifer	m^3/m^3	0.003	0	0.4
	revap	Threshold depth of water in shallow aquifer required to allow revap to occur	mm	0.02	0.02	0.25
	revap_min	Water table depth for revap to occur	m	3	0	50
Surface Retention	latq_co	Plant ET curve number coefficient	-	1	0	1
	esco	Soil evaporation compensation factor	-	0.95	0.01	1
	epco	Plant uptake compensation factor	-	1	0.01	1
	perco	Percolation coefficient - adjusts soil moisture for perc to occur (1.0 = fc)	-	1	0	1
	cn3_swf	Pothole evaporation coefficient (Soil water at CN3: 0=fc, 0.99=near saturation)	-	0	0	1
	surq_lag	Surface runoff lag coefficient	-	4	0	24
	cn2	Initial SCS runoff curve number for moisture AMC-II	-	Multiple	0	100
	lat_len	Slope length for lateral subsurface flow	m	Multiple	0	100
Soil characteristics	dp	Depth to bottom of soil layer	mm	Multiple	0	3500
	bd	Moist bulk density of soil layer	mg/m^3 or g/cm^3	Multiple	0.09	2.5
	awc	Available water capacity of soil layer	mm/mm	Multiple	0	1
	soil_k	Saturated hydraulic conductivity of soil layer	mm/hr	Multiple	0.0001	2000

Table 4 - Parameters used for calibration of the SWAT+ model, aggregated by ground water, surface retention and soil characteristics parameters.

Model performance was assessed using statistics comparing model results with observations. Preference was given to methods that are widely used in hydrology and whose results can be unambiguously estimated because of their widespread use. Following [30], [31], the coefficient of determination (R^2), the Nash–Sutcliffe model efficiency coefficient (NSE), and the bias (PBIAS) were calculated, and the statistical results were evaluated in performance intervals, which are presented in Table 5.

Time step	Performance rating	PBIAS (%)	NSE	R^2
Daily	**Very good**	-	NSE >0.80	R2 > 0.85
	Good	-	0.70 ≤ NSE ≤ 0.80	0.70 ≤ R2 ≤ 0.85
	Satisfactory	-	0.50 < NSE < 0.70	0.50 < R2 < 0.70
	Unsatisfactory	-	NSE ≤ 0.50	R2 ≤ 0.50
Monthly	**Very good**	PBIAS < ±10	NSE > 0.85	R2 > 0.85
	Good	±10 ≤ PBIAS < ±15	0.70 ≤ NSE ≤ 0.85	0.80 ≤ R2 ≤ 0.85

Time step	Performance rating	PBIAS (%)	NSE	R^2
	Satisfactory	±15 ≤ PBIAS < ±25	0.55 < NSE < 0.70	0.70 < R2 < 0.80
	Unsatisfactory	PBIAS ≥ ±25	NSE ≤ 0.55	R2 ≤ 0.70

Table 5 - Performance evaluation criteria for recommended statistical performance measures for watershed and field-scale models based on the distribution of existing data. Adapted from [30], [31].

2.3.2. AGROFORESTRY COMPONENT

The SWAT+ crop growth module is based on a simplified version of the Environmental Policy Integrated Climate (EPIC) model[4]. This module has been shown to be effective in simulating plant growth for different crop types, climatic conditions, agricultural practices, and soil management [32]–[35]. It considers leaf area development, light interception, and its conversion to biomass and productivity in combination with the effects of temperature, water stress, and salt stress [36], [37].

The calibration of the agroforestry component is carried out in an integrated way in the SWAT+ model, being necessary to define the agricultural practices, namely land tillage, fertilization scheme, planting and harvesting calendars, in line with the agricultural calendar, or crop rotation, if applicable.

In this study, the approach used to schedule these operations was degree days, rather than using specific dates, to allow for the fact that all operations (e.g., planting, harvesting, ploughing) are dependent on climatic factors, which allows for the automatic change of these schedules under climate change scenarios. The objective of this approach is for the model to adopt a behavior that closely resembles reality, incorporating certain decisions in line with observed agricultural practices. This includes farmers adjusting their agricultural calendars and the timing of planting or sowing according to observed climatic factors or meteorological forecasts to maximize production and, whenever feasible, minimize water requirements.

The calibration process of this module is carried out together with the hydrological component because the runoff conditions depend on the crops present in the different hydrographic basins. The information collected and integrated into the model for this process resulted from different sources to adjust all the crop processes to the average observed productivity values in the last years for continental Portugal [38]. Also, issues related to plant phenology were considered, and vast bibliographic research was carried out to adjust the crop parameters provided by the SWAT database to the national reality (Table 11).

[4] https://epicapex.tamu.edu/epic/

In this regard, several options have been adopted to identify changes in agricultural productivity due to climate change. One of these options is related to the maximum availability of nutrients necessary for full plant growth, regardless of the soil in which they are found (Table 10). Thus, crop growth factors are mainly related to climatic factors and water availability.

The link between the hydrological and agricultural components also exists between the reservoirs and the irrigation perimeters of hydro-agricultural developments. The reservoirs are the water source for all these perimeters, summarized in Table 6. For water sources outside the irrigation perimeters, we used the irrigation approach provided in SWAT+ called unlimited.

N	Hydro-agricultural Development	River Basin	Water origins (reservoirs)
1	Macedo de Cavaleiros	Douro	Azibo
2	Cova da Beira	Douro	Sabugal
2	Cova da Beira	Tejo	Meimoa
2	Cova da Beira	Tejo	Capinha
3	Divor	Tejo	Divor
4	Vale do Sorraia	Tejo	Maranhão
4	Vale do Sorraia	Tejo	Montargil
5	Minutos	Tejo	Minutos
6	Idanha-a-Nova	Tejo	Idanha
7	Baixo Mondego	Mondego	Aguieira
7	Baixo Mondego	Mondego	Raiva
7	Baixo Mondego	Mondego	Fronhas
7	Baixo Mondego	Mondego	Açude-Ponte Coimbra
8	Campilhas e Alto Sado	Sado	Monte da Rocha
8	Campilhas e Alto Sado	Sado	Fonte Serne[5]
8	Campilhas e Alto Sado	Sado	Campilhas[6]
8	Campilhas e Alto Sado	Sado	Monte Gato[7]
8	Campilhas e Alto Sado	Sado	Monte Migueis[7]
9	Mira	Mira	Santa Clara
10	Odivelas	Sado	Alvito[8]
10	Odivelas	Sado	Odivelas[9]
11	Roxo	Sado	Roxo[10]
12	Vale do Sado	Sado	Pêgo do Altar
12	Vale do Sado	Sado	Vale do Gaio[11]
13	Alqueva (EFMA)	Guadiana	Alqueva
13	Alqueva (EFMA)	Guadiana	Pedrogão
13	Alqueva (EFMA)	Guadiana	Enxoé

[5] For modelling purposes this source supplies the AH Fonte Serne.
[6] For modelling purposes this source supplies the AH Campilhas.
[7] For modelling purposes this source supplies the AH Monte Gato e Migueis.
[8] The model includes the connection to the Alqueva reservoir.
[9] The model includes the connection to the Alqueva, via Alvito reservoir.
[10] The model includes the connection to the Alqueva, via Alvito reservoir.
[11] The model includes the connection to the Alqueva, via Alvito reservoir.

N	Hydro-agricultural Development	River Basin	Water origins (reservoirs)
14	Caia	Guadiana	Caia
15	Lucefecit	Guadiana	Lucefecit
16	Sotavento Algarvio	Guadiana	Beliche
16	Sotavento Algarvio	Guadiana	Odeleite
17	Vigia	Guadiana	Vigia
18	Alvor	Odeáxere	Bravura
19	Silves Lagoa e Portimão	Arade	Arade
19	Silves Lagoa e Portimão	Arade	Funcho

Table 6 - Hydro-agricultural developments evaluated and respective water origins.

3. Results

The calibration and validation of the hydrological model were carried out in the following order: i) calibration of the observed flows in each RH, ii) calibration of the productivity and irrigation of each crop, iii) calibration of the volume stored in the reservoirs, and iv) validation of all the flows and volumes stored in the reservoirs simulated by the model without any additional parameter adjustment. The results of this process include the hydrological component and the agricultural component. The results are presented in the following subchapters.

3.1. CALIBRATION AND VALIDATION OF THE SWAT+ MODEL

3.1.1. HYDROLOGICAL COMPONENT

As previously mentioned, a literature review was conducted to identify the parameters to which SWAT+ results are more sensitive for continental Portugal Table 7 summarizes those parameters, explaining the model default values and the values used for calibration purposes in each hydrographic region of the study area. The model parameters were changed within the recommended ranges, in order not to compromise the physical relationships of the model and to obtain the best fit between observed and simulated values. The values may vary within the same river basin district due to the need for calibration of specific areas (set of Hydrologic Response Units - HRUs or sub-basins) that exhibit distinct hydrological responses. In these cases, Table 7 shows the range of values used, separated by commas.

In Table 4 the descriptions of each parameter used for calibrating the model can be found.

Parameter	Default values	RH1	RH2	RH3	RH4	RH5	RH6	RH7	RH8
flo_min	5	4.9, 12.9	9.1, 12.9	4.9, 12.9	0.5	2.0	0.3	0.3, 18	0.3
alpha_bf	0.048	0.5, 0.7	0.6, 0.7	0.5, 0.7	0.3	0.7	1	0.05, 1	1
bf_max	1	0.5, 0.7	0.5, 0.7	0.5, 0.7	0.3	0.3	0.2	0.3, 1.3	0.3
rchg_dp	0.05	0.05	0.05	0.05	0.01	0.2	0.05	0.05	0.05
spec_yld	0.003	0.05	0.05	0.05	0.05	0.2	0.05	0.05	0.05
revap	0.02	0.04, 0.18	0.15, 0.18	0.04, 0.18	0.027	0.07	0.055	0.055, 0.168	0.055
revap_min	3	3.0, 24.7	19.5, 24.7	3.0, 24.7	0.5	5.0	5.7	5.7, 41.3	5.7
latq_co	1	0.5, 0.9	0.9	0.5, 0.9	0.6	0.6	0.6	0.03, 0.7	0.6

Parameter	Default values	RH1	RH2	RH3	RH4	RH5	RH6	RH7	RH8
esco	0.95	0.04, 0.3	0.3	0.04, 0.3	0.5	0.2	0.6	0.01, 0.6	0.6
epco	1	0.048, 0.357	0.357	0.048, 0.357	0.037	0.037	0.016	0.016, 0.115	0.016
perco	1	6.0, 34.1	34.1, 42.5	6.0, 34.1	1.9	-0.9	4.2	-8.8, 37.9	4.2
cn3_swf	0	0.4, 0.9	0.9, 1	0.4, 0.9	0.4	0.4	0.3	0.3, 1	0.23
surq_lag	4	6.1	6.1	6.1	2.4	2.4	5.9	5.955	5.955
cn2*	Multiple	-30.3, -31.2	-44.9, -31.2	-30.3, -31.2	-0.4	-0.4	-6.1	-6.1, -38.6	-6.1
lat_len*	Multiple	-1.2, -14.1	-28.3, -14.1	-1.2, -14.1	-20	-20	-21.9	-35.4, 32.9	-21.9
dp*	Multiple	7.7, 11.2	9.4, 11.2	7.7, 11.2	0	0	-23.2	-39.8, 9.3	-3.6
bd*	Multiple	-19.7, 0	0	-19.7, 0	0	0	-3.6	-23.2, 28.1	-23.2
awc*	Multiple	-35.3, -1.4	-1.7, -1.4	-35.3, -1.4	14[a]	14[a]	18	-3.2, 30.7	18
soil_k*	Multiple	59.0, 78.4	75.3, 78.4	59.0, 78.4	30[a]	30[a]	34.628[a]	5.2, 34.6	34.6

Table 7 - Calibration parameters of SWAT model with their default and calibrated values. *Multiplying factor to be applied to the parameter original value.

Table 8 presents the values of the daily and monthly model performance indicators for the calibration and validation periods for each hydrometric station. The statistical values in which the model presents different performance levels are marked[12], as proposed by [30], [31].

RBD	Station	Time step	Calibration				Validation			
			Period[13]	PBIAS (%)	NSE	R^2	Period[11]	PBIAS (%)	NSE	R^2
RH1	Aspra (03D/01H)	Daily	1982-1985	-	0.61	0.63	1986-1989	-	0.53	0.55
		Monthly		-16.6	**0.81**	**0.89**		**-12.1**	**0.77**	0.79
RH2	Alto Cávado Total (R.E.) (03J/06H)	Daily	1982-1987	-	0.40	**0.73**	1988-1993	-	0.65	**0.72**
		Monthly		**13.4**	**0.85**	**0.91**		**8.5**	**0.90**	**0.90**
	Ponte Brandão (05G/01H)	Daily	1982-1985	-	0.12	0.68	1986-1989	-	0.65	**0.74**
		Monthly		**13.0**	0.34	**0.82**		20.1	**0.78**	**0.89**
	Ponte Junqueira (05E/01H)	Daily	1982-1986	-	0.67	**0.71**	1987-1990	-	**0.76**	**0.81**
		Monthly		**6.3**	**0.72**	0.76		**-8.5**	**0.8**	**0.83**

[12] **Bolt and underlined**: "very good", **Bolt** = "good", underlined = "satisfactory" and normal = "not satisfactory"

[13] hydrological years

RBD	Station	Time step	Calibration				Validation			
			Period[13]	PBIAS (%)	NSE	R^2	Period[11]	PBIAS (%)	NSE	R^2
RH3	Azibo (R.E.) (05Q/01H)	Daily	1982-1987	-	0.55	0.55	1988-1993	-	0.57	0.62
		Monthly		**5.6**	0.64	0.66		**13.0**	**0.73**	0.76
	Cabriz (R.E.) (07I/04H)	Daily	1982-1987	-	0.50	0.66	1999-2003	-	0.51	0.68
		Monthly		39.7	0.59	**0.87**		28.6	**0.81**	**0.93**
	Parada Monteiros (R.E.) (04K/01H)	Daily	1983-1986	-	**0.82**	**0.86**	1987-1990	-	**0.80**	**0.88**
		Monthly		25.2	**0.86**	**0.94**		34.4	**0.84**	**0.95**
	Quinta das Laranjeiras (R.E.) (06O/03H)	Daily	1982-1987	-	0.50	0.57	2000-2005	-	0.64	0.67
		Monthly		54	0.53	0.77		33.2	**0.86**	**0.92**
	Quinta Rape (R.E.) (08L/01H)	Daily	1982-1987	-	0.53	0.58	1999-2003	-	0.55	0.58
		Monthly		**4.0**	**0.74**	0.76		**6.7**	**0.79**	**0.82**
RH4	Celorico da Beira (09M/01H)	Daily	1982-1986	-	0.64	**0.71**	1986-1989	-	**0.73**	**0.76**
		Monthly		-35.06	**0.71**	**0.88**		-21.95	**0.83**	**0.92**
	Moinhos de Pepim (10K/04H)	Daily	1982-1986	-	0.50	**0.70**	1986-1989	-	0.60	**0.78**
		Monthly		-41.44	0.60	**0.83**		-35.12	**0.76**	**0.96**
	Ponte Cabouco (12G/02H)	Daily	1982-1986	-	**0.70**	**0.73**	1986-1989	-	0.69	**0.76**
		Monthly		24.5	**0.81**	**0.90**		24.99	**0.82**	**0.91**
	Ponte Casével (13F/02H)	Daily	1982-1986	-	-0.13	0.64	1986-1989	-	-0.07	0.61
		Monthly		17.67	**0.86**	**0.96**		**0.22**	**0.90**	**0.94**
	Ponte Dinha (11I/07H)	Daily	1982-1986	-	0.66	0.67	1986-1989	-	0.66	0.67
		Monthly		**-1.8**	**0.86**	**0.88**		-18.06	**0.89**	**0.94**
	Ponte Mestras (15E/03H)	Daily	1982-1986	-	-1.09	0.66	1986-1989	-	-1.25	0.65
		Monthly		25.81	0.65	**0.92**		19.58	0.56	**0.83**
	Ponte Minhoteira (09F/01H)	Daily	1982-1985	-	0.16	0.55	1985-1990	-	0.09	0.50
		Monthly		**-14.17**	**0.81**	**0.89**		-23.1	0.67	0.79
	Quinta Carvalhal do Freixo (11H/04H)	Daily	1982-1986	-	0.69	**0.74**	1986-1989	-	**0.71**	**0.73**
		Monthly		16.04	**0.89**	**0.92**		19.51	**0.73**	**0.82**
	Ponte Dobreira (10K/06H)	Daily	1983-1985	-	0.46	0.48	1985-1988	-	0.52	0.53
		Monthly		21.27	**0.79**	**0.82**		26.39	**0.72**	0.74
RH5	Fábrica Da Matrena (16G/01H)	Daily	1998-2004	-	-0.47	**0.74**	2004-2009	-	0.22	**0.73**
		Monthly		31.8	0.65	**0.94**		**-4.59**	**0.88**	**0.95**
	Manteigas (R.E.) (11L/01H)	Daily	1987-1991	-	0.38	0.56	1991-1995	-	0.51	0.60
		Monthly		**4.48**	**0.93**	**0.94**		**-13.58**	**0.90**	**0.92**
	Pavia (20I/04H)	Daily	1982-1986	-	**0.70**	**0.72**	1986-1990	-	0.54	0.68
		Monthly		-18.83	**0.82**	**0.93**		-48.33	0.54	**0.89**

RBD	Station	Time step	Calibration				Validation			
			Period[13]	PBIAS (%)	NSE	R^2	Period[11]	PBIAS (%)	NSE	R^2
	Segura (R.E.) (15P/01H)	Daily	1984-1990	-	**0.80**	**0.82**	1990-1996	-	**0.76**	**0.77**
		Monthly		-25.74	**0.87**	**0.93**		-28.4	**0.78**	**0.93**
RH6	Moinho do Bravo (25G/02H)	Daily	1982-1985	-	0.56	**0.73**	1986-1989	-	0.57	0.68
		Monthly		-45.7	0.56	**0.88**		-43.1	0.63	**0.86**
	Ponte Alvalade - Campilhas (26G/04H)	Daily	1982-1987	-	0.65	0.67	1988-1993	-	0.63	**0.73**
		Monthly		**-14.4**	**0.84**	**0.86**		**-1.7**	**0.96**	**0.96**
	Ponte Alvalade - Sado (26G/05H)	Daily	1982-1987	-	0.67	0.68	1988-1993	-	0.54	0.6
							1994-1999	-	0.5	0.51
		Monthly		-31.2	0.67	0.73	1988-1993	-32.7	**0.77**	**0.86**
							1994-1999	17.6	**0.98**	**0.98**
	Torrão do Alentejo (24H/03H)	Daily	1982-1987	-	0.69	0.69	1988-1993	-	**0.71**	**0.73**
							2004-2009	-	0.53	0.56
		Monthly		-37.5	**0.75**	**0.86**	1988-1993	-32.1	**0.89**	**0.92**
							2004-2009	-50.7	**0.75**	**0.87**
RH7	Albernoa (26J/01H)	Daily	1982-1987	-	0.21	0.25	1988-1993	-	0.31	0.33
		Monthly		-80.9	0.23	0.49		-64.6	**0.73**	**0.89**
	Amieira (24L/01H)	Daily	1982-1987	-	**0.75**	**0.85**	1988-1993	-	0.52	0.56
							1995-2000	-	**0.82**	**0.82**
		Monthly		**-6.7**	**0.78**	**0.90**	1988-1993	-31.9	**0.71**	0.77
							1995-2000	**4.1**	**0.94**	**0.95**
	Ardila (Foz) (25M/01H)	Daily	1982-1987	-	0.69	**0.74**	1988-1993	-	**0.71**	**0.8**
		Monthly		**-9.7**	**0.77**	**0.80**		**3.37**	**0.97**	**0.98**
	Monte dos Fortes (29l/01h)	Daily	1982-1987	-	0.64	0.66	1988-1993	-	0.46	0.47
							1994-1999	-	0.66	0.67
		Monthly		**-12.9**	**0.86**	**0.86**	1988-1993	**-13.5**	**0.79**	**0.81**
							1994-1999	-22.6	**0.85**	**0.86**
	Monte Pisão (19N/01H)	Daily	1982-1987	-	0.61	**0.7**	1988-1993	-	**0.8**	**0.85**
							2004-2009	-	0.64	0.67
		Monthly		**-12.1**	**0.82**	**0.83**	1988-1993	**-3.9**	**0.99**	**0.99**
							2004-2009	-15.8	**0.78**	**0.91**
	Oeiras (28K/02H)	Daily	1982-1987	-	0.58	0.64	1988-1993	-	0.56	0.59
							1996-2001	-	0.55	0.56
		Monthly		-36.9	**0.7**	**0.87**	1988-1993	**-10.9**	**0.91**	**0.91**
							1996-2001	-18.9	**0.82**	**0.85**

RBD	Station	Time step	Calibration				Validation			
			Period[13]	PBIAS (%)	NSE	R^2	Period[11]	PBIAS (%)	NSE	R^2
	Vendinha (23K/01H)	Daily	1982-1987	-	0.68	**0.78**	1988-1993	-	0.68	**0.77**
		Monthly		-23.2	**0.72**	**0.89**		16.4	**0.93**	**0.94**
RH8	Vidigal (30F/02H)	Daily	1982-1987	-	0.61	**0.71**	1988-1993	-	0.62	0.63
							1995-2000	-	**0.7**	**0.72**
		Monthly		41.2	**0.76**	**0.86**	1988-1993	**10.3**	**0.89**	**0.92**
							1995-2000	**14.7**	**0.84**	**0.88**

Table 8 – SWAT+ performance in reproducing daily and monthly streamflow for inland Portugal.

In Appendix C. Supplementary data (calibr./valid.), the graphs are available for comparing the observed and simulated values of daily flow rates and annual runoff during the calibration and validation periods[14].

From the statistics used to evaluate the model, and in a general way, it is verified that at least two performance indicators are above the values considered acceptable. The model represents the daily flows in most of the hydrometric stations at least in a satisfactory way and it can be assumed that the monthly performance is generally good to very good.

Regarding the reservoirs, the model performance statistics can be seen in Table 9.

RBD	Reservoir	Time step	Calibration				Validation			
			Period[15]	PBIAS (%)	NSE	R^2	Period[13]	PBIAS (%)	NSE	R^2
RH1	Alto Lindoso (R.E.) (02H/01A)	Daily	2000-2004	7.7	0.2	0.44	2005-2009	18.3	0.0	0.54
RH2	Paradela (R.E.) (03J/01A)	Daily	2000-2004	2.8	0.66	0.7	2005-2009	-9.9	0.19	0.47
RH3	Pocinho (R.E.) (07O/02A)	Daily	2000-2004	0.8	-0.18	0.01	2005-2009	1.0	-0.12	0.0
RH4	Aguieira (R.E.) (11H/01A)	Daily	2001-2004	1.1	0.05	0.32	2004-2009	2.9	0.05	0.34
RH5	Maranhão (19J/01A)	Daily	1982-1986	-15.43	0.66	0.9	1986-1989	-19.4	0.52	0.72
	Montargil (19H/01A)	Daily	1982-1986	6.42	0.9	0.93	1986-1989	-1.24	0.38	0.72
RH6	Monte da Rocha (27H/01A)	Daily	1990-1993	-5.2	0.83	0.91	1994-1997	-3.3	0.87	0.88
	Santa Clara (28G/01A)	Daily	1990-1994	4.1	0.86	0.98	1995-2000	0.4	0.68	0.78
RH7	Alqueva (R.E.) (24M/07A)	Daily	2005-2006	-3.8	0.33	0.83	2011-2012	0.7	0.47	0.63

[14] In this appendix are eight examples, one for each river basin district.

[15] hydrological years

RBD	Reservoir	Time step	Calibration				Validation			
			Period[15]	PBIAS (%)	NSE	R^2	Period[13]	PBIAS (%)	NSE	R^2
	Vigia (22L/01A)	Daily	1996-2000	10.8	0.74	0.82	2009-2014	8.4	0.77	0.86
RH8	Odeleite (30M/05F)	Daily	2001-2005	15.5	0.28	0.63	2010-2013	-7	0.6	0.87
	Bravura (30E/01A)	Daily	1990-1993	6.3	0.83	0.87	1994-1999	4.7	0.95	0.96

Table 9 - SWAT+ performance in reproducing daily reservoir volume for inland Portugal.

Though standardized methods to assess how accurately hydrological models depict reservoir storage volumes are missing, the model does well in capturing this aspect for most of the studied reservoirs, as shown by the statistical values.

3.1.2. AGROFORESTRY COMPONENT

The agroforestry model is prepared to quantify the modifications in productivity and irrigation needs arising from climate change. To this end, it was sought to ensure that all crops have the necessary nutrients, given their full growth, through the application of fertilizers in the maximum quantities required by the plants (Table 10). Besides soil quality and climatic conditions, the main limiting factor for this full growth is mainly limited by irrigation. This methodological option implies that the productivity of different crops is generally close to the maximum values observed for mainland Portugal, which limits the inter-annual variability of some crops, especially those that are more resistant to drought but allows the comparability of yields and irrigation needs between the current climate and climate change scenarios.

The agroforestry component of the model was prepared considering these assumptions in the scope of the project objectives, with the need to adjust some crop parameters to reflect the national reality in the last decade. According to [39], the most sensitive and calibrated parameters for biomass production by plants consist of radiation use efficiency (bm_e), the base temperature needed for plant growth (tmp_base), the optimal temperature for plant growth (tmp_opt), fraction of growing season when leaf area declines (hu_lai_decl), while the base temperature needed for plant growth (tmp_base) and the Maximum potential leaf area index (lai_pot), are used to calibrate the irrigation needs. These parameters were calibrated based on the team's experience and supported by indicators from other published studies[16] Table 11. In this context, it is also worth mentioning that the irrigation results were compared with the irrigation needs made available by DGADR in [40] after requesting the watering allocations to the same institution.

[16] see column "sources" in Table 11 for a complete list of publications.

Crop	Application	Fertilize type	Application Times (n)	Quantity per application (kg/ha)	Application type	Source
Almond	stress test	N	1-5	20	broadcast	[41], [42]
		P	1-2	25		
Apple	side dress	11_52_00	1	800	inject	[43]
	side dress/stress test	N	2/1	60	broadcast	
Bermuda grass	stress test	N	10	25	broadcast	[44]
		P	6	20		
Meadow Bromegrass	side dress	N	5	25	broadcast	[45]
	side dress	P	2	60		
Cabbage	side dressing	10_10_22	1	1000	inject	[46]
	side dress/stress test	N	2/1	100	broadcast	
Corn	side dress	20_08_10	1	1400	inject	[47]
	side dress/stress test	N	1/1	90	broadcast	
Silage (Corn)	side dress	20_08_10	1	900	inject	[47]
	side dress/stress test	N	1/1	90	broadcast	
Eucalyptus forest	NA	NA	NA	NA	NA	-
Dense sclerophyll forest	NA	NA	NA	NA	NA	-

Crop	Application	Fertilize type	Application Times (n)	Quantity per application (kg/ha)	Application type	Source
Grape	stress test	N	1	70	broadcast	[48]
		P	1	70	broadcast	
Grassland	NA	NA	NA	NA	NA	-
Sorghum	side dress	N	5	30	broadcast	[49]
	side dress	P	2	50	broadcast	
Hay	side dress	N	5	25	broadcast	[45]
	side dress	P	2	20	broadcast	
Lettuce	side dress	10_28_00	1	1300	inject	[50]
	stress test	N	3	50	broadcast	
	stress test	P	5	50	broadcast	
Mixed Grassland/ Shrubland	NA	NA	NA	NA	NA	-
Oak	NA	NA	NA	NA	NA	-
Olive Grove	stress test	N	5	20	broadcast	[51]
	stress test	P	2	35	broadcast	
Orange	side dress	10_34_00	1	1000	inject	[52]
	side dress/stress test	N	1/1	100	broadcast	
Pasture	stress test	N	2	25	broadcast	[53]

Crop	Application	Fertilize type	Application Times (n)	Quantity per application (kg/ha)	Application type	Source
	stress test	P	2	60	broadcast	
Pine	NA	NA	NA	NA	NA	-
Potato	side dress	10_15_00	1	1000	inject	[54]
	side dress	N	1	600	broadcast	
	side dress	N	1	600	broadcast	
Rice	side dress	20_08_10	1	300	inject	[55]
	side dress/stress test	N	1/1	45	broadcast	
Agroforestry system	Grazing	N/P	1	9.272/2.55	manure deposited	[53]
	stress test	N	2	25	broadcast	
	stress test	P	2	60	broadcast	
Shrubland	NA	NA	NA	NA	NA	-
Mediterranean shrubland	NA	NA	NA	NA	NA	-
Strawberry	stress test	N	10	30	fertigate	[56]
	stress test	P	10	15	fertigate	
Sunflower	stress test	N	2	50	broadcast	[57]
	stress test	P	2	40	broadcast	
Tomato	side dress	10_10_10	1	1500	inject	[58]

Crop	Application	Fertilize type	Application Times (n)	Quantity per application (kg/ha)	Application type	Source
	side dress	N	2	40	broadcast	
	side dress	N	2	40	broadcast	
Winter wheat	side dress	10_24_00	1	500	broadcast	[59]
	side dress/stress test	N	1/1	50	broadcast	

Table 10 - Fertilization scheme used in the crops and sources of information.

Crop	Initial leaf area index (lai_init)[17]	Initial biomass (bm_init)[18]	Days to maturity (days_mat)	Radiation use efficiency (bm_e)	harvest index for optimal growing condition (harv_idx)	Maximum [potential] leaf area index (lai_pot)	Fraction of growing season when leaf area declines (hu_lai_decl)	Optimal temperature for plant growth (tmp_opt)	Base temperature needed for plant growth (tmp_base)	Lower harvest index (harv_idx_ws)	Minimum LAI during winter dormant period (lai_min)	Sources
Almond	- (1.2)	- (62500)	0	16.1	0.05 (0.01)	1.2	0.99	30 (35)	10 (12)	0.01	0.75	[41]
Apple	- (4)	- (62500)	0	15	0.1 (0.12)	4	0.99 (0.65)	20 (25)	7	0.05	0.75 (0.01)	[60]–[64]
Bermuda grass	- (4)	- (37500)	0	35	0.9	4	0.99	25	12	0.9	2	-

[17] Full developed tree: based in maximum [potential] leaf area index for each crop.

[18] Full developed tree: based in maximum biomass for forest for each crop.

Crop	Initial leaf area index (lai_init)[17]	Initial biomass (bm_init)[18]	Days to maturity (days_mat)	Radiation use efficiency (bm_e)	harvest index for optimal growing condition (harv_idx)	Maximum [potential] leaf area index (lai_pot)	Fraction of growing season when leaf area declines (hu_lai_decl)	Optimal temperature for plant growth (tmp_opt)	Base temperature needed for plant growth (tmp_base)	Lower harvest index (harv_idx_ws)	Minimum LAI during winter dormant period (lai_min)	Sources
Meadow Bromegrass	- (3)	- (37500)	0	35	0.9	3	0.85	25	6	0.9	2	-
Cabbage	-	-	90 (120)	19 (23)	0.8 (0.95)	3 (3.7)	1	18 (32)	1 (2)	0.95	0.75	[65]–[69]
Corn	-	-	120 (90-120)	39	0.9	4	0.7	25	8	0.9	0	-
Silage (Corn)	-	-	120	39 (43)	0.9	4 (6)	0.7	25 (30)	8	0.9	0	[70], [71]
Eucalyptus forest*	- (4)	- (75000)	- (0)	- (22)	- (0.76)	- (4)	- (0.99)	- (22)	- (9)	- (0.6)	- (3)	[16]
Dense sclerophyll forest*	- (4)	- (125000)	- (0)	- (15)	- (0.1)	- (4)	- (0.99)	- (24.5)	- (10)	- (0.01)	- (3)	[16]
Grape	- (2)	- (12500)	0	30	0.02 (0.08-0.15)	2	0.9 (0.65)	30 (35)	10	0.01	0.01	[72]–[76]
Grassland	- (2)	- (98750)	0	34	0.9	2.5	0.35	25	12	0.9	0.15	-
Sorghum	-	-	110	33.5	0.45	3	0.64	30 (40)	11 (16)	0.25	0	[49], [77]
Hay	-	-	0	35	0.9	4	0.99	25	12	0.9	0.75	[45]

Crop	Initial leaf area index (lai_init)[17]	Initial biomass (bm_init)[18]	Days to maturity (days_mat)	Radiation use efficiency (bm_e)	harvest index for optimal growing condition (harv_idx)	Maximum [potential] leaf area index (lai_pot)	Fraction of growing season when leaf area declines (hu_lai_decl)	Optimal temperature for plant growth (tmp_opt)	Base temperature needed for plant growth (tmp_base)	Lower harvest index (harv_idx_ws)	Minimum LAI during winter dormant period (lai_min)	Sources
Lettuce	-	-	90	23 (25)	0.8 (0.8)	4.2 (6)	1	18 (20)	7	0.01	0	[50], [78], [79]
Mixed Grassland/ Shrubland	- (2.5)	- (95625)	0	34	0.9	2.25	0.35	25	12	0.9	0.15	-
Oak	- (4)	- (125000)	0	15	0.76	5	0.99	30	10	0.01	0.75	-
Olive Grove*	- (1)	- (62500)	- (0)	- (15)	- (0.02, 0.05)	- (1)	- (0.99)	- (30)	- (9)	- (0.01)	- (0.75)	[16], [80]–[82]
Orange	- (1.5)	- (37500)	0	15	0.14 (0.11)	2 (1.5)	0.99	20 (35)	7 (10)	0.09	0.01	[83], [84]
Pasture	- (2)	- (2000)	0	35	0.9	4 (2)	0.99	25 (20)	12 (5.5)	0.9	2	[85], [86]
Pine*	- (5)	- (125000)	- (0)	- (15)	- (0.76)	- (3)	- (0.99)	- (30)	- (9)	- (0.6)	- (2)	[16]
Potato	-	-	100 (150)	25 (28)	0.95	4	0.6	22 (18)	7 (6)	0.95	0	[54]
Rice	-	-	180	22	0.5	5	0.8	25	10	0.25	0	-

Crop	Initial leaf area index (lai_init)[17]	Initial biomass (bm_init)[18]	Days to maturity (days_mat)	Radiation use efficiency (bm_e)	harvest index for optimal growing condition (harv_idx)	Maximum [potential] leaf area index (lai_pot)	Fraction of growing season when leaf area declines (hu_lai_decl)	Optimal temperature for plant growth (tmp_opt)	Base temperature needed for plant growth (tmp_base)	Lower harvest index (harv_idx_ws)	Minimum LAI during winter dormant period (lai_min)	Sources
Agroforestry system**	-	-	-	-	-	-	-	-	-	-	-	-
Shrubland	- (2.5)	- (92500)	0	34	0.9	2	0.35	1	25	12	0.15	-
Mediterranean shrubland*	-	-	- (0)	- (15)	- (0.76)	- (2.5)	- (0.4)	- (23)	- (13)	- (0.01)	- (1.875)	[16]
Strawberry	- (3)	- (25000)	0	30	0.45	3	0.6	32	10	0.25	0 (1.5)	-
Sunflower	-	-	110	46	0.3	3	0.62	25	6	0.18	0	-
Tomato	-	-	90 (180)	30 (33)	0.33 (0.90)	3	0.95	10 (8)	20 (30)	0.15 (0.6)	0	[58], [87]
Winter wheat	-	-	160	30	0.4	4	0.5	18	0	0.2	0	-

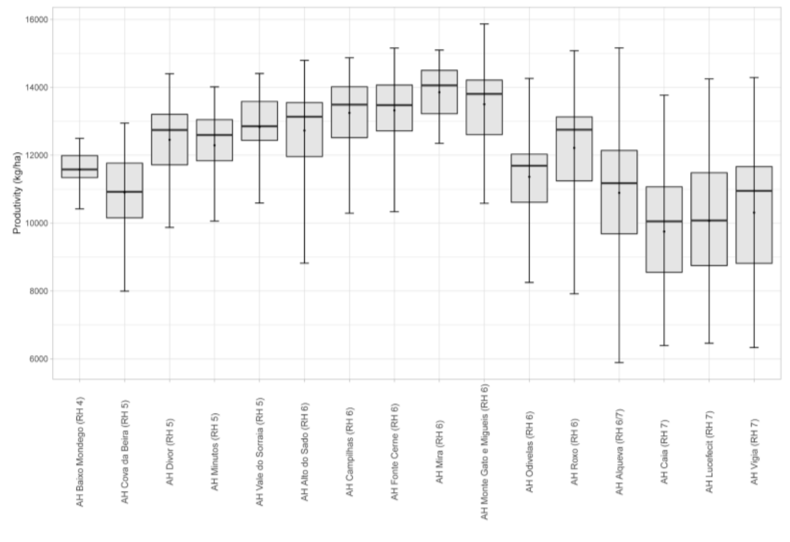
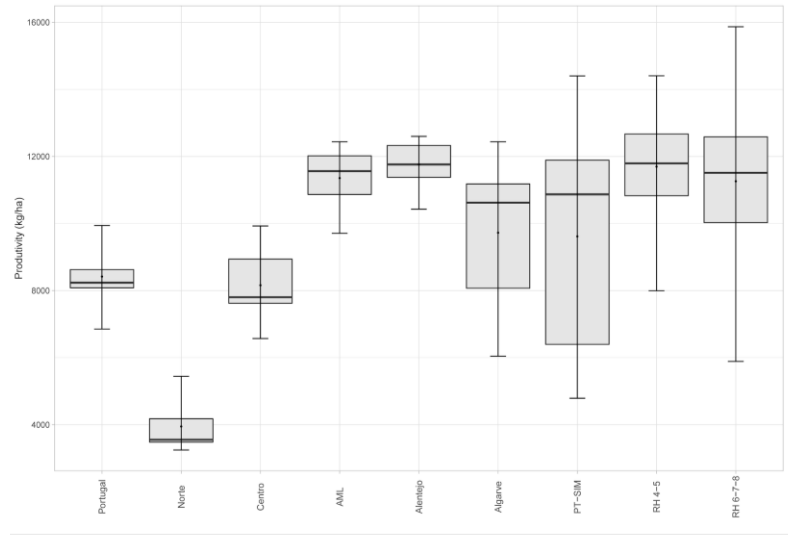
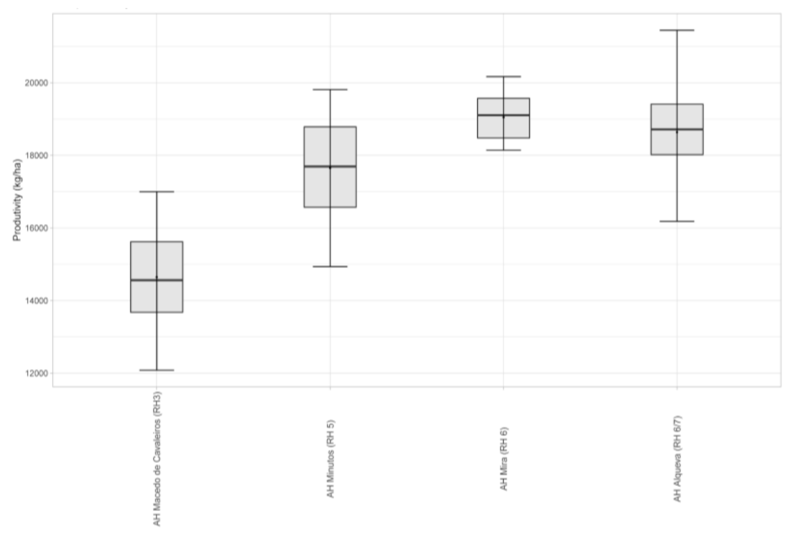
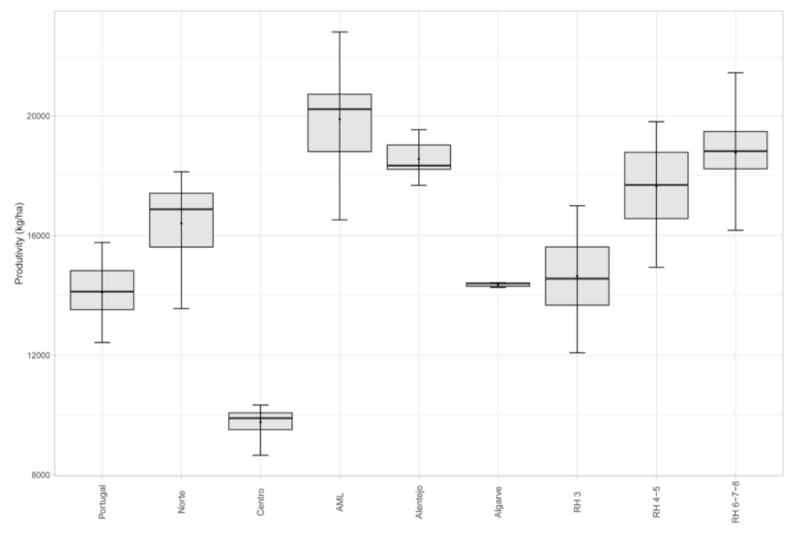
Table 11 - Parameters used for crop calibration. Values in brackets were used as substitutes for the default parameters provided in the SWAT+ library. Default parameters are shown without brackets. *Crops created specifically for Portugal and tested in other SWAT studies [see 15], **Agroforestry system is composed by two crops: Mediterranean shrubland and Pasture. The parameters used are the same as those used for each individual crop.

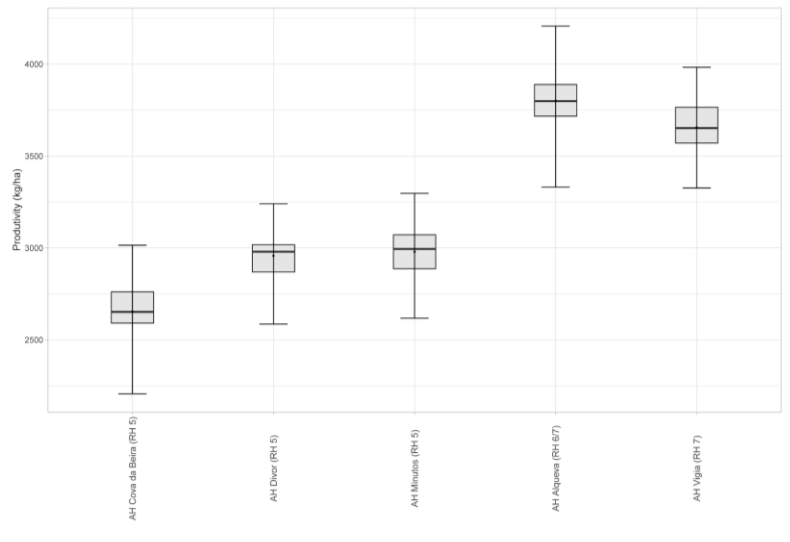
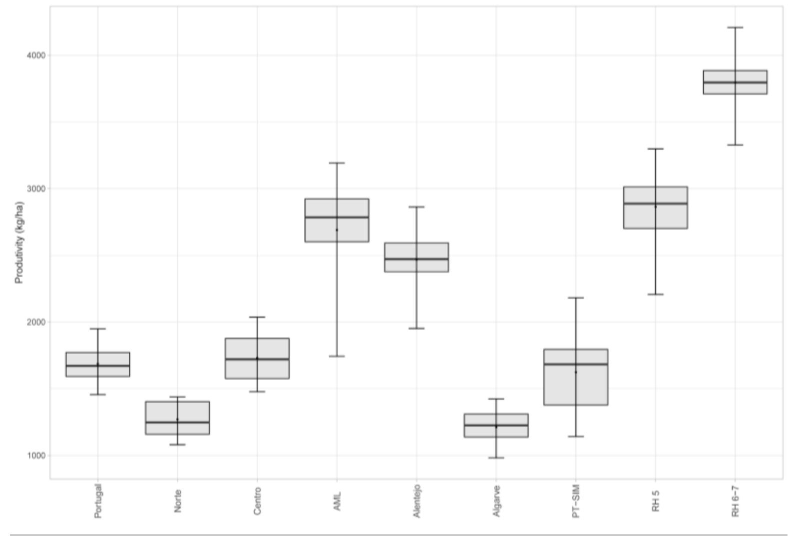
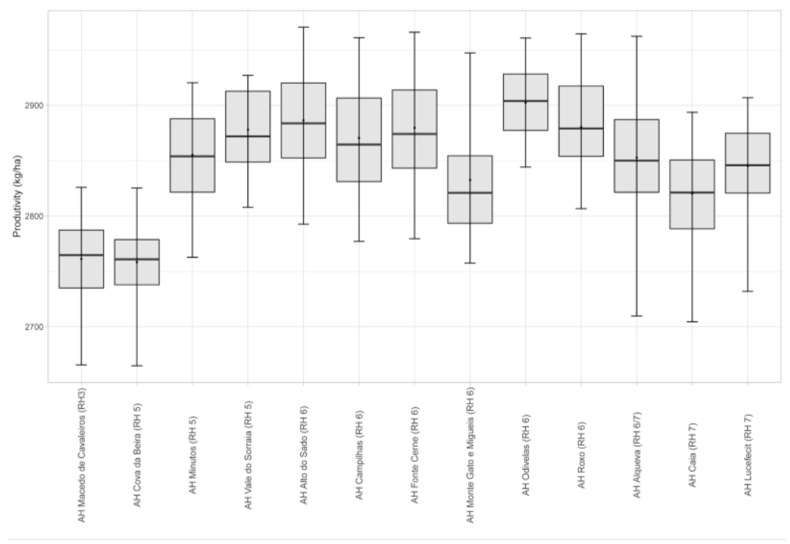
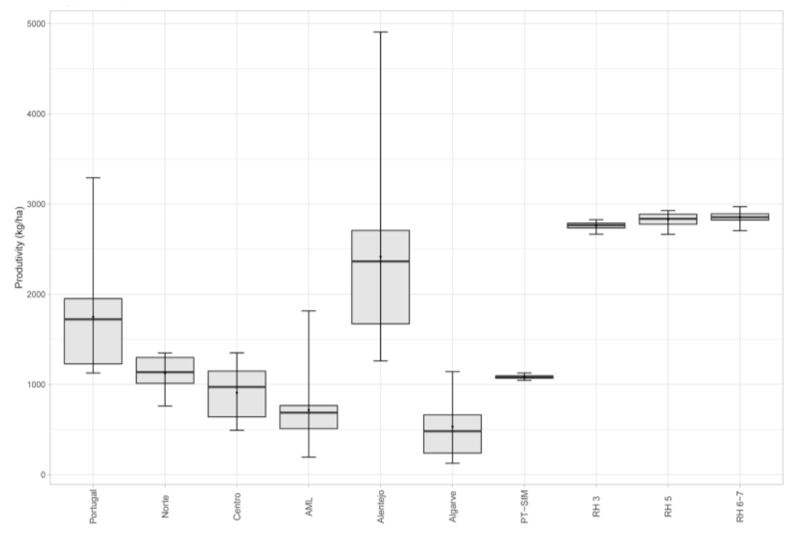
Some of the results of the crop calibration process can be seen in Figure 4 for productivity and Figure 5 for irrigation needs. The yield values calculated by SWAT+ correspond to dry biomass (kg/ha). However, the statistical data published by INE for the productivity of the main agricultural crops in Portugal, corresponds to humid biomass (kg/ha). To compare the values estimated by SWAT+ and the real productivity, the humid biomass was converted into dry biomass (kg/ha), using the standards published by Eurostat in [88].

Figure 4 presents, on the left side, the productivity simulated by the SWAT+ model for corn, (silage) corn, vineyard, olive grove and winter wheat, in the different hydro-agricultural developments in Portugal where this crop is significant. In the same figure, on the right side, are the comparisons of the simulated results with the productivity statistics published by INE between 2010 and 2021. This side of the figure shows the aggregated simulated results by hydrographic region (RH) for the irrigation perimeters and the simulated results for mainland Portugal outside these irrigation perimeters (PT-sim). The statistical information on the productivity of each crop is presented for Portugal and by NUTS II regions of the continent.

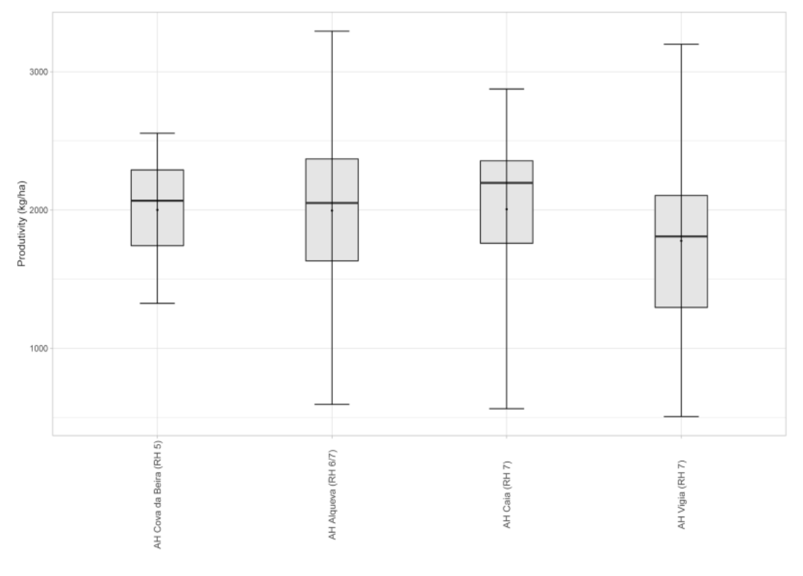
In general, simulated productivity is of the same magnitude as real productivity, being higher in the south of the country than in the north. Productivity is also higher for crops located within irrigation perimeters. This is particularly evident for vineyards or olive groves, where the simulated values in these areas are much higher than the observed values. On the other hand, the values outside the irrigation perimeters (PT-yes) are close to the national average. It should be noted that for these two crops, the observed values are aggregated by region, regardless of whether they are irrigated or rainfed, which makes it very difficult to compare the results.

Regarding irrigation needs (Figure 5), these are within the ranges of values provided in [40], which has information on these needs for different areas of mainland Portugal. As expected, the needs are greater in the south than in the north, with a significant difference between hydro-agricultural developments located north or south of the Tagus River.

Corn productivity -simulation		**Corn productivity - simulation vs observed**	
Silage productivity -simulation		**Silage productivity - simulation vs observed**	

Grape productivity -simulation		**Grape productivity - simulation vs observed**	
Olive grove productivity -simulation		**Olive grove productivity - simulation vs observed**	

Winter wheat productivity -simulation



Winter wheat productivity - simulation vs observed

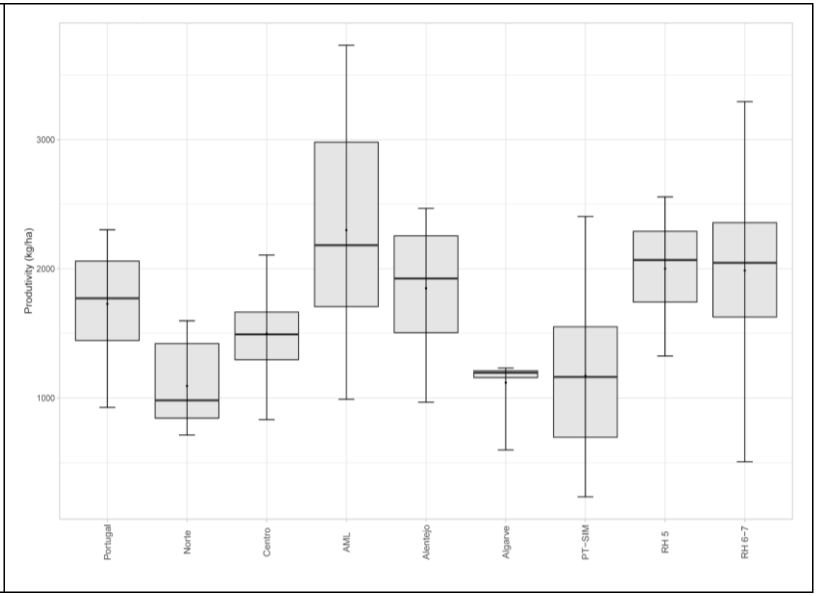


Figure 4 - Simulated crop productivity (left) and comparation between simulated and observed crop productivity (right).

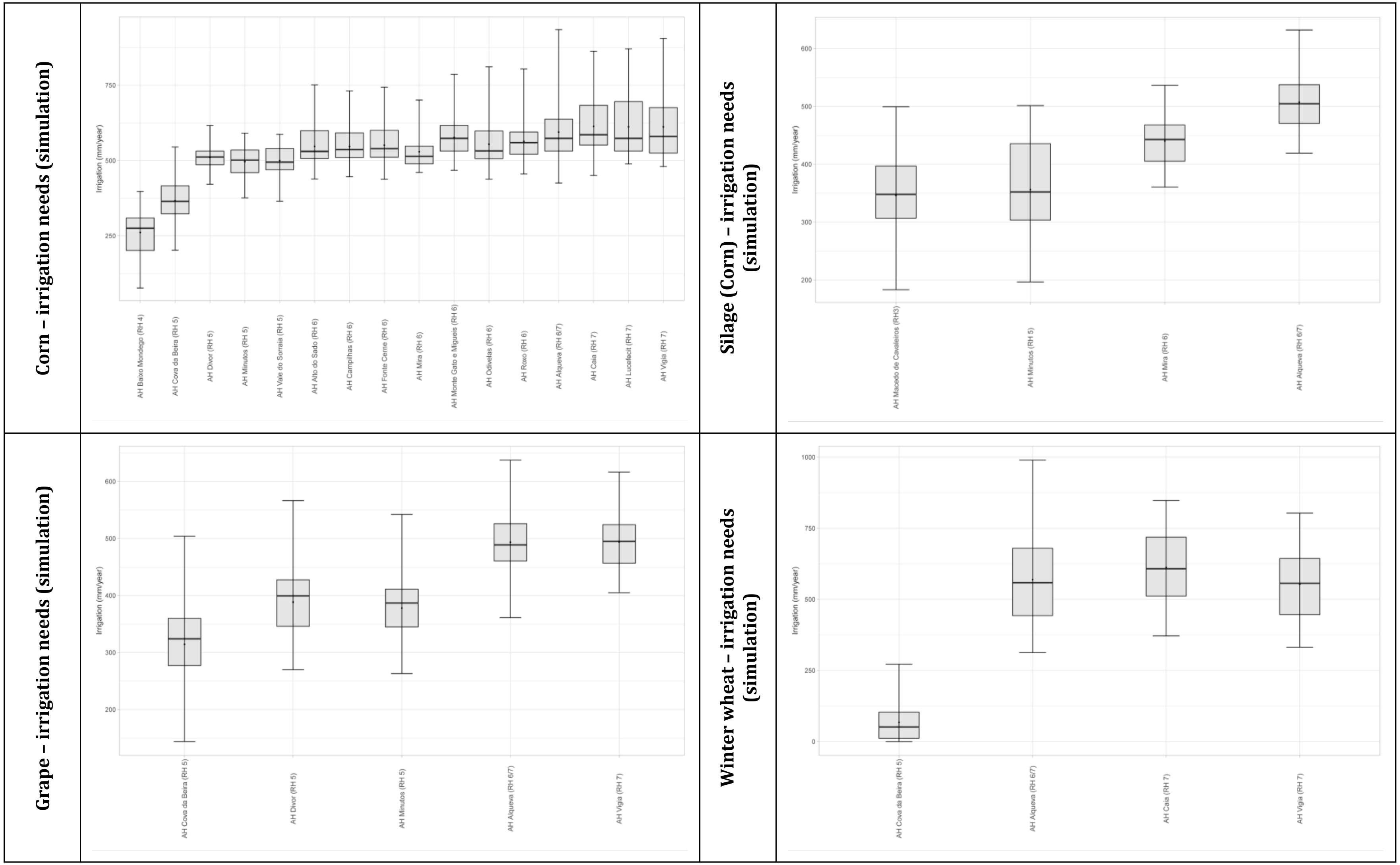


Figure 5 - Simulated irrigation needs.

3.2. CLIMATE CHANGE IMPACTS

The impacts of climate change on the water resources and agroforestry sectors are intricately linked, as the model used incorporates both components (SWAT+ and EPIC). For example, the volume stored in reservoirs used for irrigation depends on the agricultural crops that rely on the water supply from these reservoirs. Thus, there exists an interdependence between variables, which is reflected in the results presented in this section.

All projections under climate change scenarios assume that the current irrigation infrastructure remains in place in the future and that there will be sufficient water available for irrigation. This approach is the same that was use in the PESETA IV project (Projection of Economic impacts of climate change in Sectors of the European Union based on bottom-up Analysis) for the agricultural sectors[19].

Although various studies have shown that higher concentrations of atmospheric carbon dioxide can affect crops by boosting crop yields through an increase in the rate of photosynthesis, promoting growth, and reducing the amount of water lost through transpiration, these results do not account for this change.

In this section, whenever a single value is presented in a specific projection, it reflects to the multi-model ensemble mean, as described in the "WP2 climate projections, extremes, and indices report" developed under this project.

Regarding the outcomes related to the impacts on the hydrological component, projections for water yield are provided for each specific river basin district, along with the inflow and the volume stored in various reservoirs for each respective river basin district, with priority given to reservoirs serving irrigation purposes whenever possible.

In the Agroforestry component, projected anomalies in the productivity of some rainfed crops are presented, namely almond, grape, and olive grove, as well as in the irrigation needs for apple, vineyard, and olive grove.

Please note that the results presented here consist of a summary and do not encompass all the impacts evaluated within the scope of the sectors being addressed.

[19] For more information, consult: https://joint-research-centre.ec.europa.eu/peseta-projects/jrc-peseta-iv/agriculture_en

3.2.1. HYDROLOGICAL COMPONENT

The projection of water yield is dependent on the greenhouse gas emission scenario as well as the river basin districts of mainland Portugal. In general, a slight increase in water yield is observed in the scenario with lower emissions - RCP2.6, while a decrease is seen in the other considered scenarios - RCP4.5 and RCP8.5 (Figure 6).

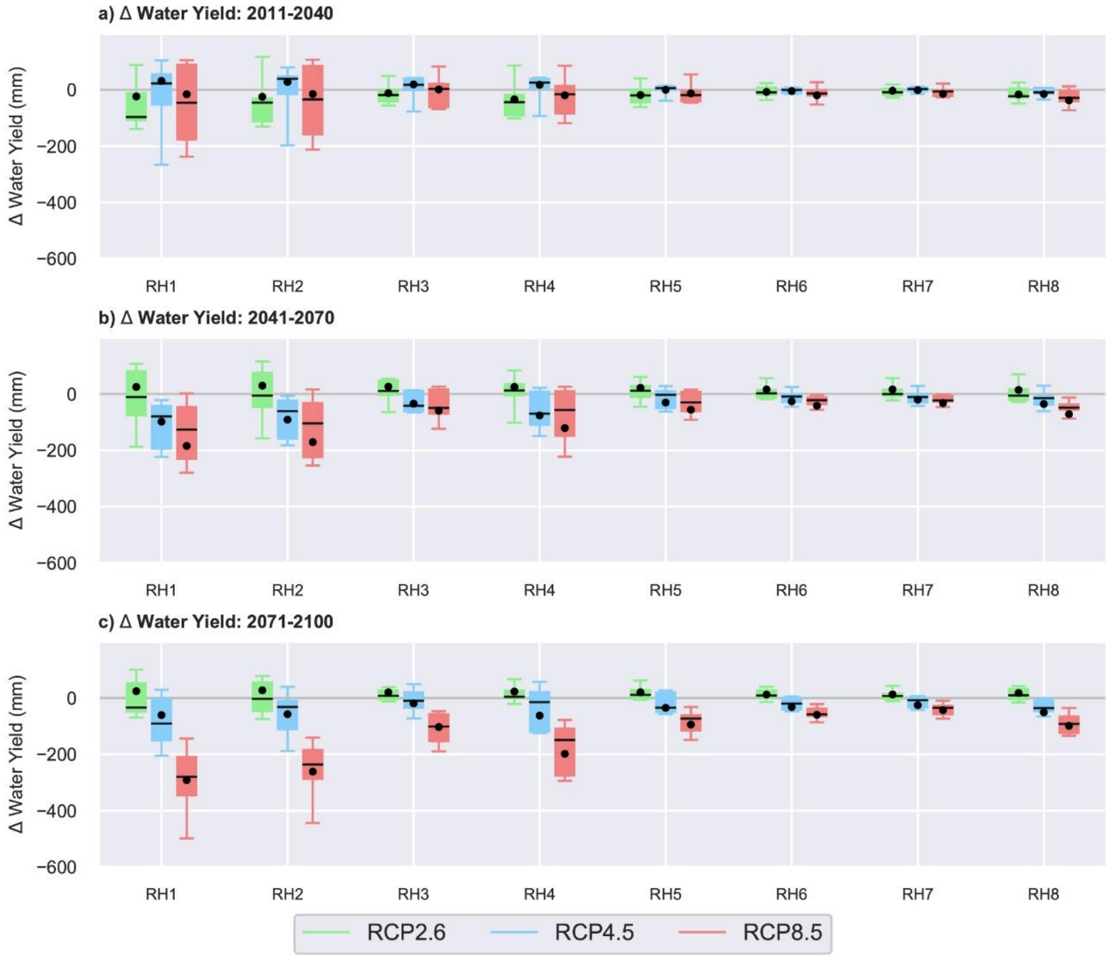


Figure 6 – Projected changes in averaged water yield (mm) for mainland Portugal river basin districts. Three future periods are shown: 2011-2040, 2041-2070, and 2071-2100, under all emission scenarios – RCP2.6 (green), RCP4.5 (blue) and RCP8.5 (red). The black point represents the multi-model ensemble mean.

The largest absolute variations in projected water yield are more significant in the river basin districts RH1, RH2, and RH4, due to the historically higher precipitation in these regions, with lower anomaly and variability values in the remaining regions.

In absolute terms, under the RCP2.6 scenario, a decrease in water yield is projected for the period between 2011-2040, ranging from -3.3 mm [+46.1 to -30.4] mm in RH7 to -33.8 [+124 to -116.6] mm in RH4 per year, relative to historical values (1971-2000). This trend is reversed in the periods 2041-2080 and 2081-2100, with an increase ranging from 14 [-29.7 to +97.5] mm (RH8) to 29.3 [-241.1 to +138.2] mm (RH2) and 12.1 [-22.9 to +57.8] mm (RH6) to 27.3 [-152.7 to +137.5] mm (RH2), respectively.

Under RCP4.5 scenario, the variability is considerably higher, with an increase in water yield in the northern region during the period 2011-2040, reaching up to +31.9 [-330.6 to +129.9] mm in RH1, and a decrease in the southern region up to -14.8 [-34.9 to +14.5] mm in RH8. In this scenario, a significant decrease in water yield is projected in the medium term (ranging from -98.5 [-247.5 to +57.7] mm in RH1 to -30.5 [-74.4 to +51.4] mm in RH5), with a slight improvement in the long term in the North, namely in river basin districts RH1, RH2, RH3 and RH4, compared to the previous period, while water yield losses persist in the remaining regions.

In RCP8.5 scenario, a clear descending trend in water yield is observed throughout the century, reaching absolute values of -291.4 [-82 to -618.6] mm in RH1 or -98.5 [-18.5 to -135.2] mm in RH8. The situation is more critical in the south in relative terms, as current availability is already lower.

Regarding the inflow and stored volume in the reservoirs, a reduction in both parameters is observed in the northern region during the summer months, while an increment is noticed during the winter months for reservoirs primarily designated to energy production (see e.g. Figure 7 – Barragem do Alto Lindoso [RH1], Figure 8 – Barragem da Paradela [RH2], Figure 9 – Barragem do Pocinho [RH3]). In the central region, for the same type of usage, the decreasing trends for both the inflow and stored volume in the reservoirs are more severe in the RCP8.5 scenario, projecting this decrease to occur in practically all months of the year (see e.g. Figure 10 – Barragem da Aguieira [RH4]).

Concerning the reservoirs primarily serving irrigation purposes, even though the inflow increases in some months, particularly in the RCP2.6 scenario, the stored volume decreases due to the increase in irrigation demands for agriculture that is using this infrastructure (see also section 3.2.2. Agroforestry component). Generally, this trend is more pronounced in the RCP4.5 and RCP8.5 scenarios during the periods 2041-2070 and 2071-2100, with a particular severity in the RCP8.5 scenario by the end of the century (see e.g. Figure 11 – Barragem do Maranhão [RH5], Figure 12 – Barragem de Montargil [RH5], Figure 13 – Barragem do Monte da Rocha [RH6], Figure 14 – Barragem de Santa Clara [RH6], Figure 15 – Barragem do Alqueva [RH7], Figure 16 – Barragem da Vigia [RH7], Figure 17 – Barragem da Bravura [RH8], Figure 18 – Barragem de Odeleite [RH8]).

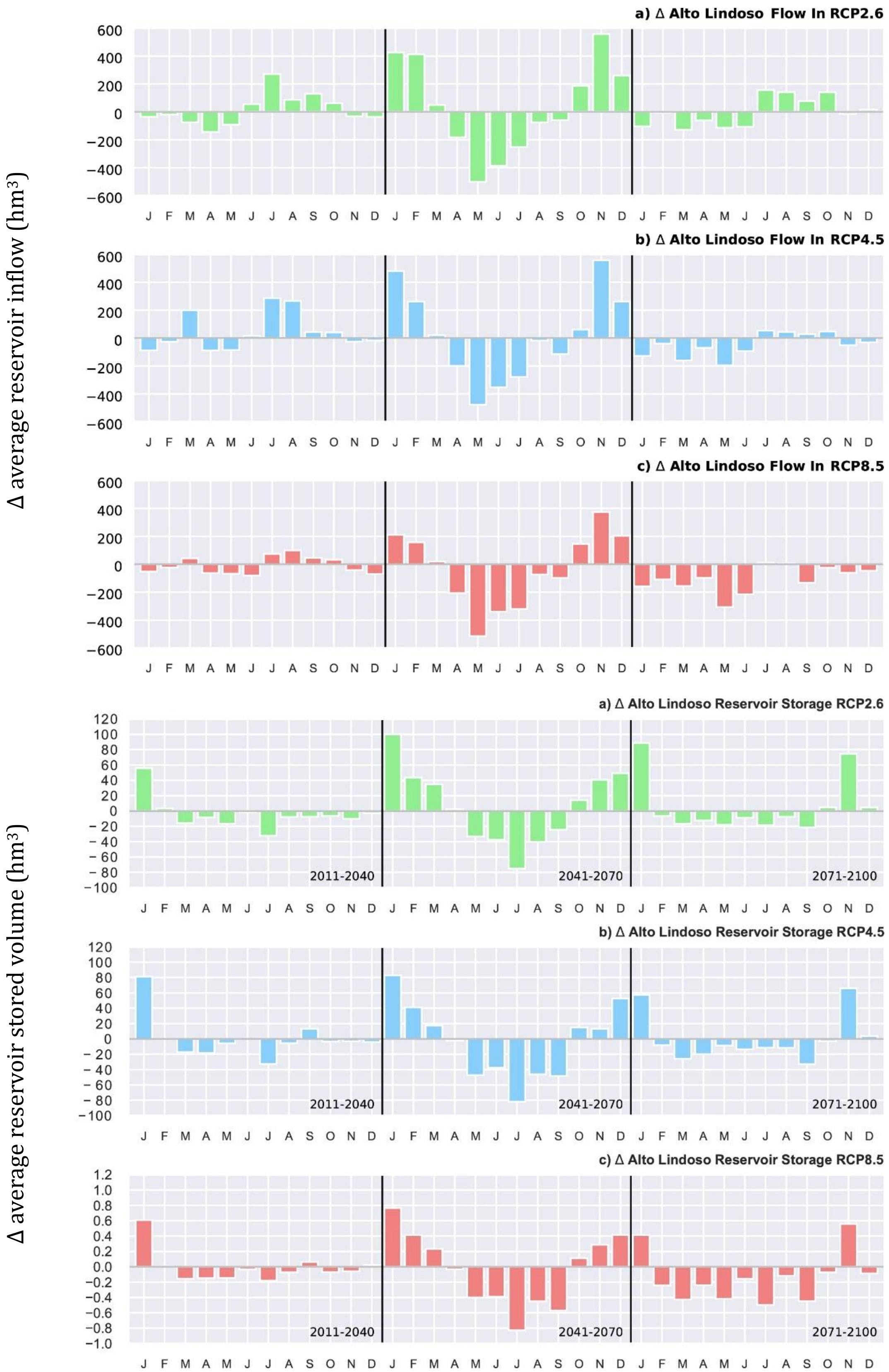


Figure 7 – Projected changes (multi-model ensemble mean) in averaged inflow (top) and volume stored (bottom) in hm^3 for the Alto Lindoso reservoir, located in River Basin District RH1. Three future periods are shown: 2011-2040, 2041-2070, and 2071-2100, under all emission scenarios – RCP2.6 (green), RCP4.5 (blue) and RCP8.5 (red).

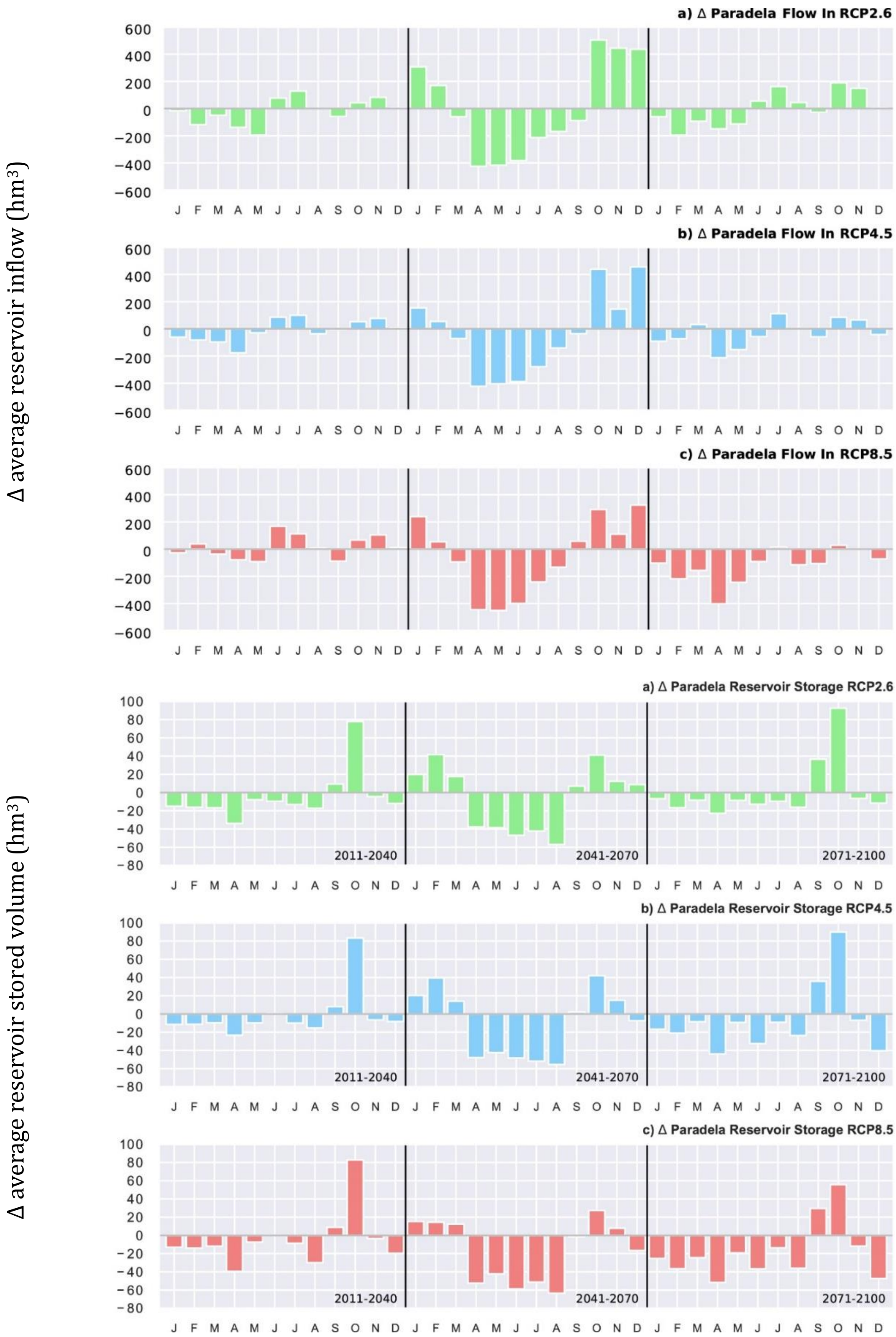


Figure 8 – Projected changes (multi-model ensemble mean) in averaged inflow (top) and volume stored (bottom) in hm^3 for the Paradela reservoir, located in River Basin District RH2. Three future periods are shown: 2011-2040, 2041-2070, and 2071-2100, under all emission scenarios – RCP2.6 (green), RCP4.5 (blue) and RCP8.5 (red).

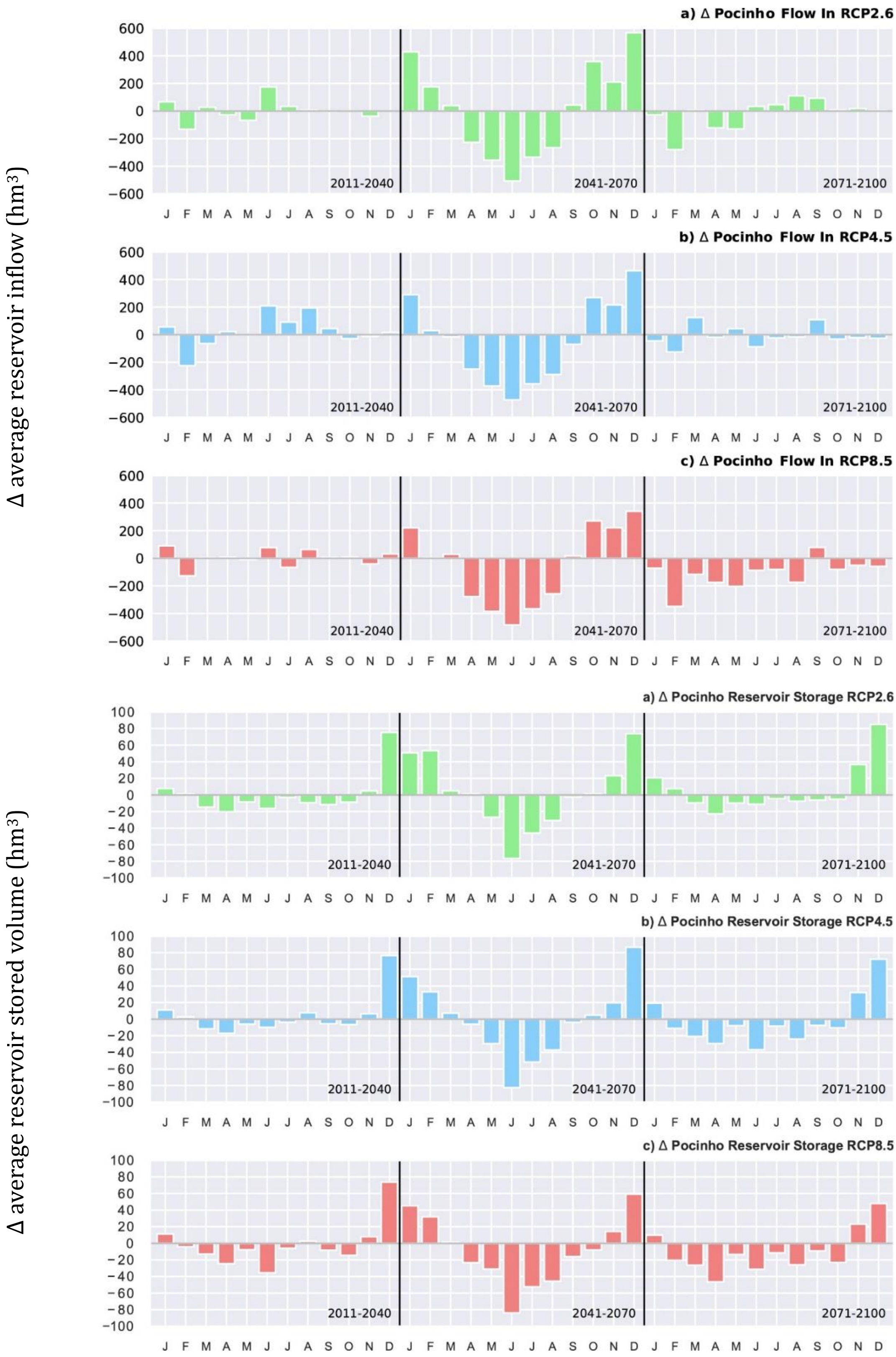


Figure 9 – Projected changes (multi-model ensemble mean) in averaged inflow (top) and volume stored (bottom) in hm^3 for the Pocinho reservoir, located in River Basin District RH3. Three future periods are shown: 2011-2040, 2041-2070, and 2071-2100, under all emission scenarios – RCP2.6 (green), RCP4.5 (blue) and RCP8.5 (red).

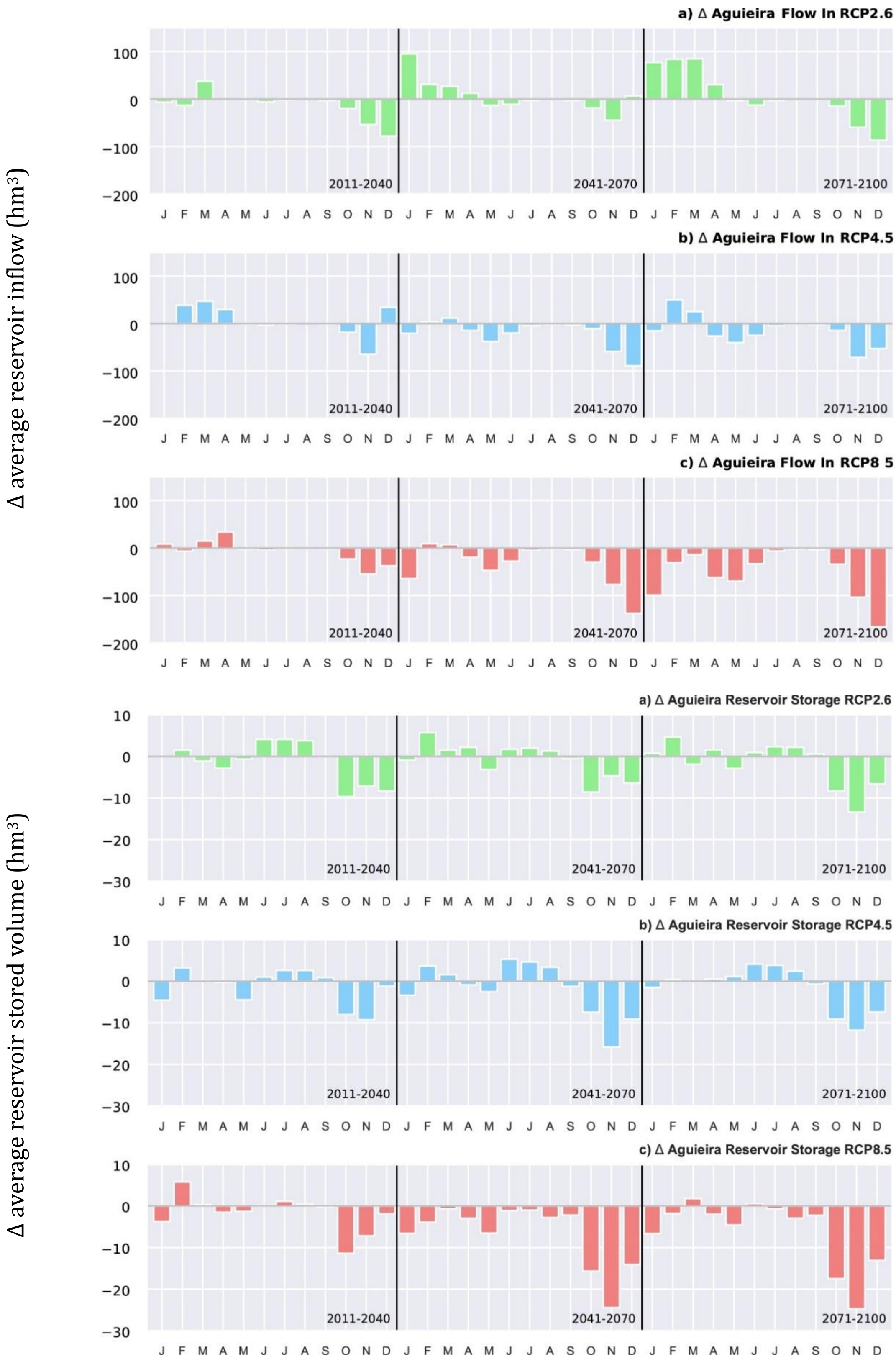


Figure 10 – Projected changes (multi-model ensemble mean) in averaged inflow (top) and volume stored (bottom) in hm^3 for the Aguieira reservoir, located in River Basin District RH4. Three future periods are shown: 2011-2040, 2041-2070, and 2071-2100, under all emission scenarios – RCP2.6 (green), RCP4.5 (blue) and RCP8.5 (red).

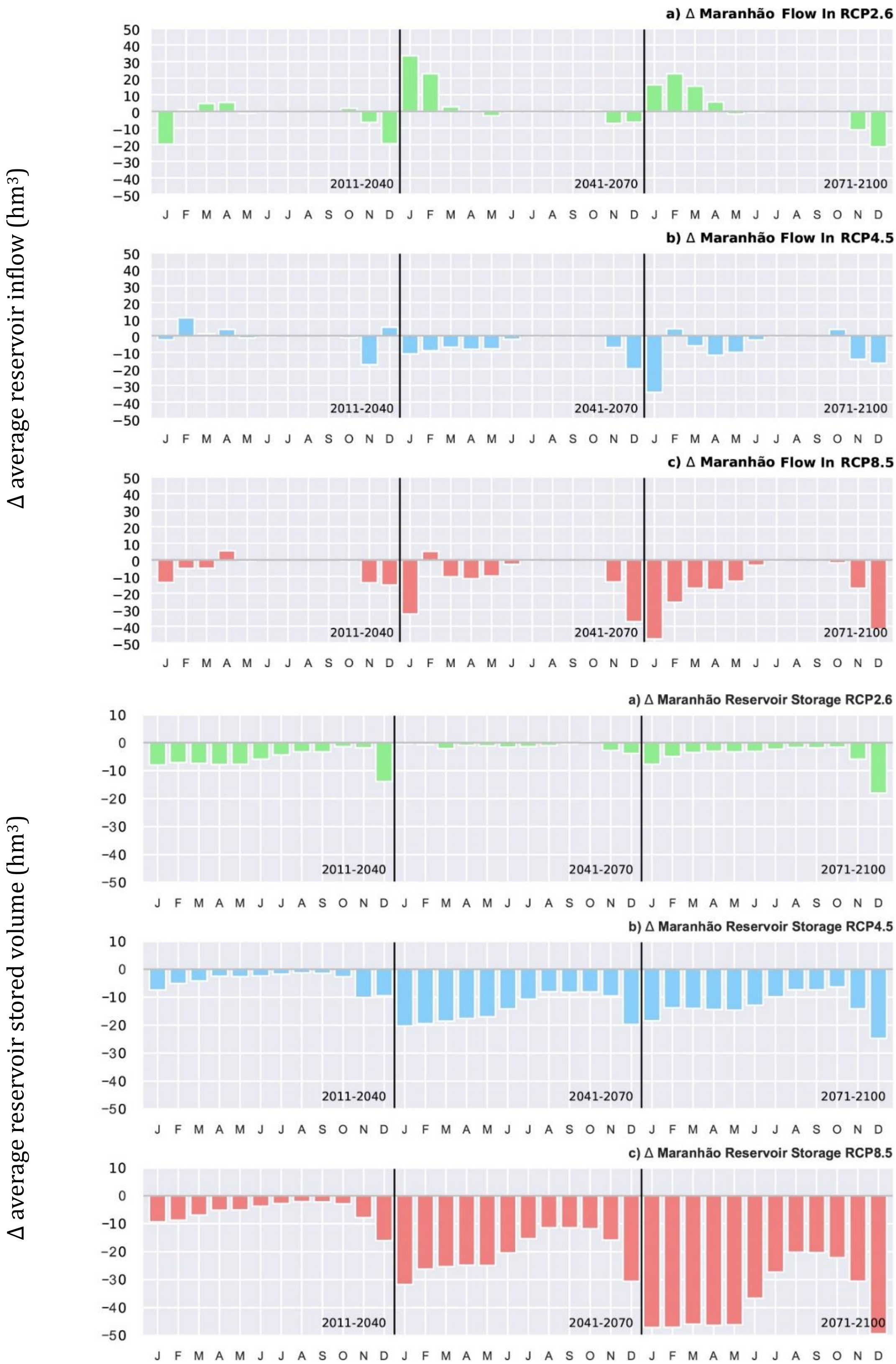


Figure 11 – Projected changes (multi-model ensemble mean) in averaged inflow (top) and volume stored (bottom) in hm^3 for the Maranhão reservoir, located in River Basin District RH5. Three future periods are shown: 2011-2040, 2041-2070, and 2071-2100, under all emission scenarios – RCP2.6 (green), RCP4.5 (blue) and RCP8.5 (red).

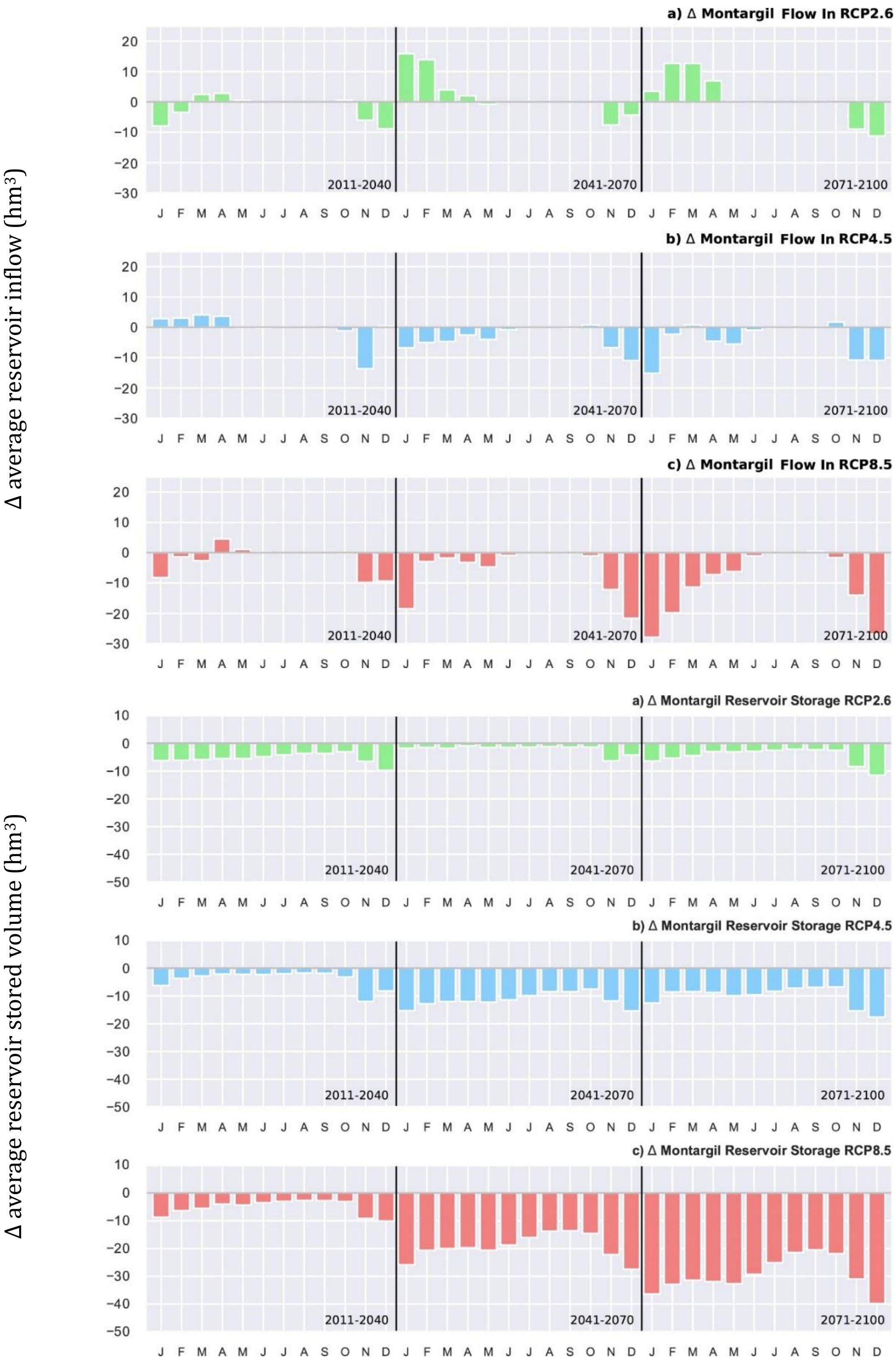


Figure 12 – Projected changes (multi-model ensemble mean) in averaged inflow (top) and volume stored (bottom) in hm^3 for the Montargil reservoir, located in River Basin District RH5. Three future periods are shown: 2011-2040, 2041-2070, and 2071-2100, under all emission scenarios – RCP2.6 (green), RCP4.5 (blue) and RCP8.5 (red).

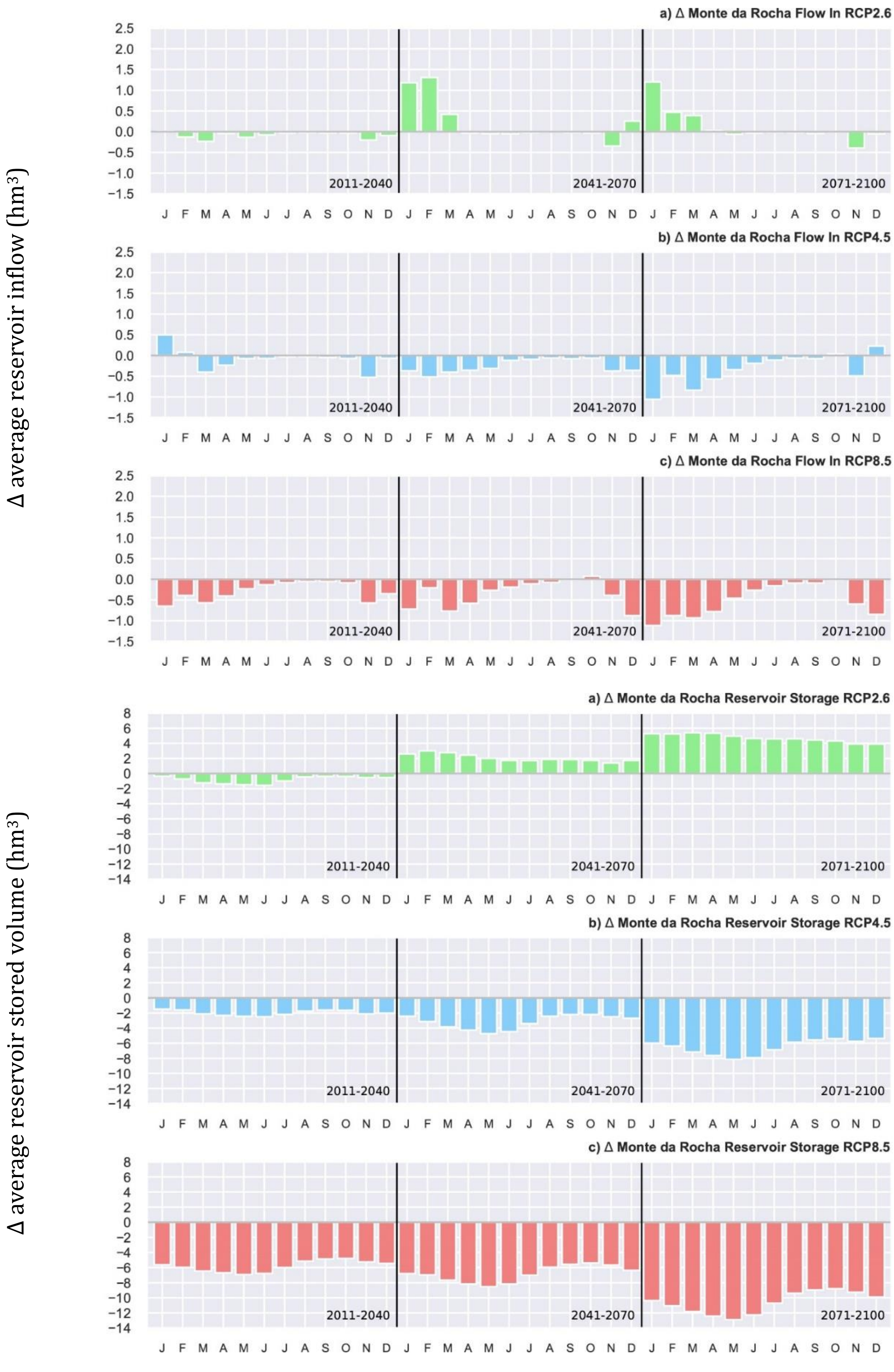


Figure 13 - Projected changes (multi-model ensemble mean) in averaged inflow (top) and volume stored (bottom) in hm^3 for the Monte da Rocha reservoir, located in River Basin District RH6. Three future periods are shown: 2011-2040, 2041-2070, and 2071-2100, under all emission scenarios – RCP2.6 (green), RCP4.5 (blue) and RCP8.5 (red).

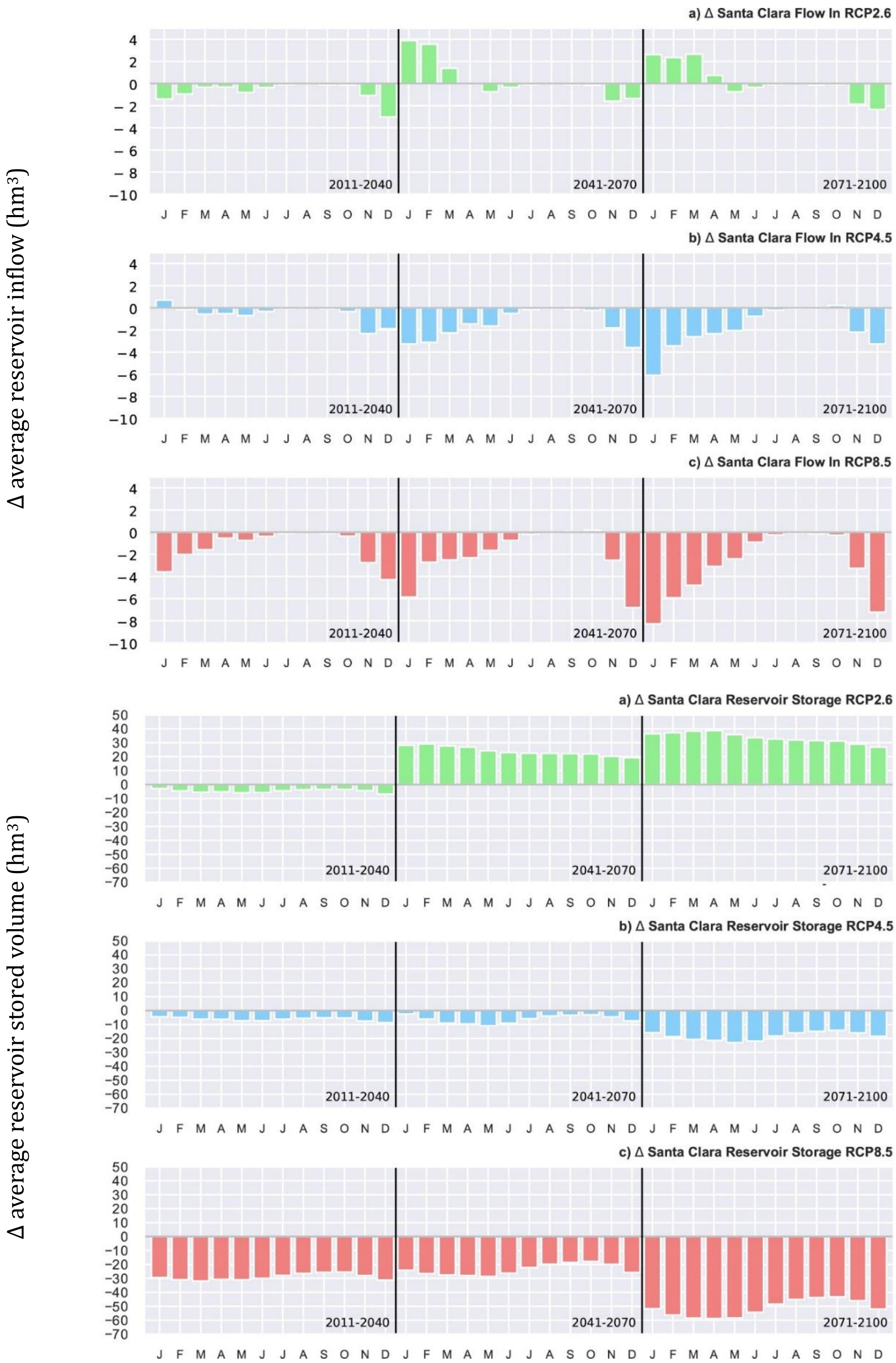


Figure 14 – Projected changes (multi-model ensemble mean) in averaged inflow (top) and volume stored (bottom) in hm^3 for the Santa Clara reservoir, located in River Basin District RH6. Three future periods are shown: 2011-2040, 2041-2070, and 2071-2100, under all emission scenarios – RCP2.6 (green), RCP4.5 (blue) and RCP8.5 (red).

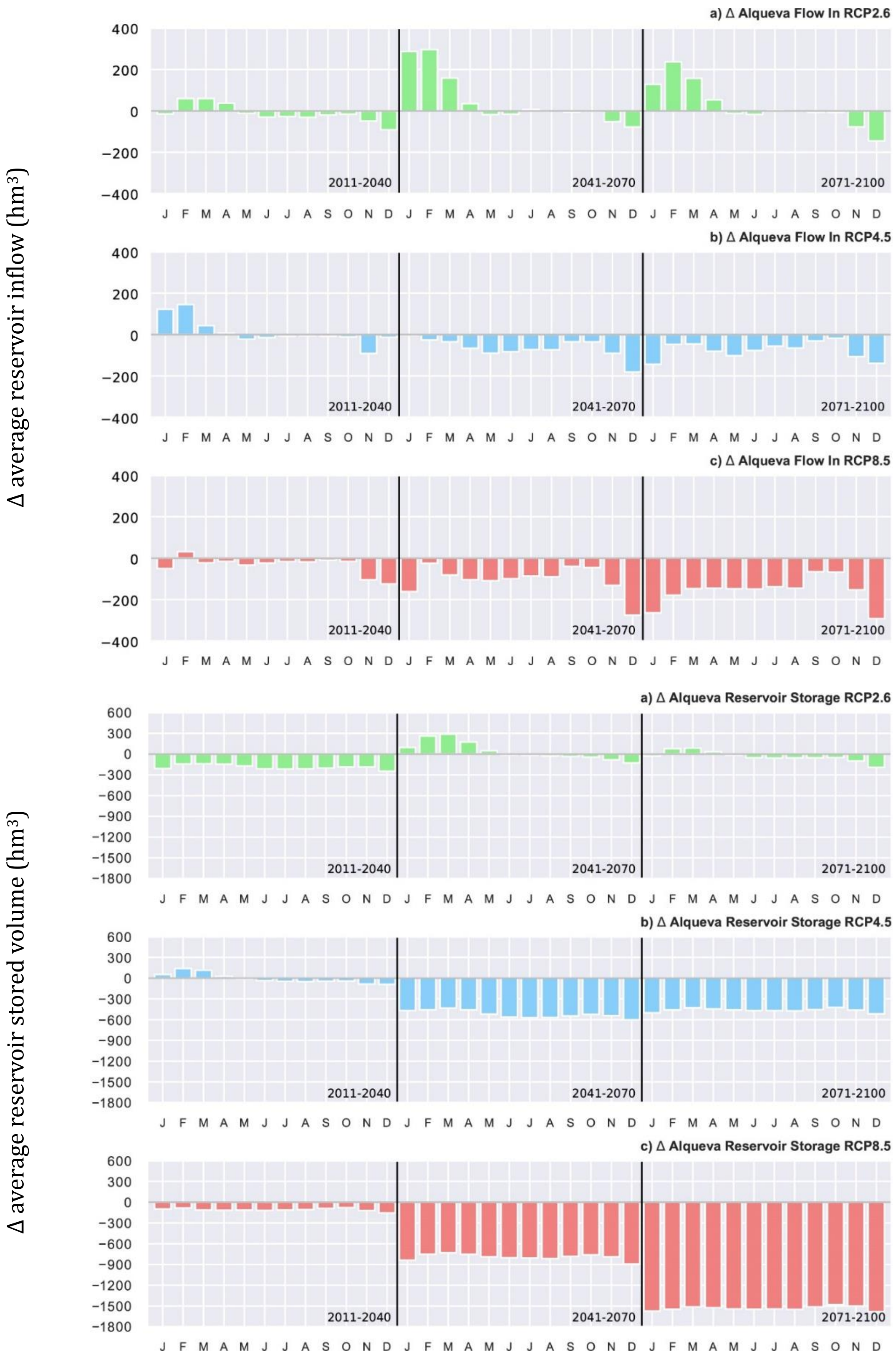


Figure 15 – Projected changes (multi-model ensemble mean) in averaged inflow (top) and volume stored (bottom) in hm^3 for the Alqueva reservoir, located in River Basin District RH7. Three future periods are shown: 2011-2040, 2041-2070, and 2071-2100, under all emission scenarios – RCP2.6 (green), RCP4.5 (blue) and RCP8.5 (red).

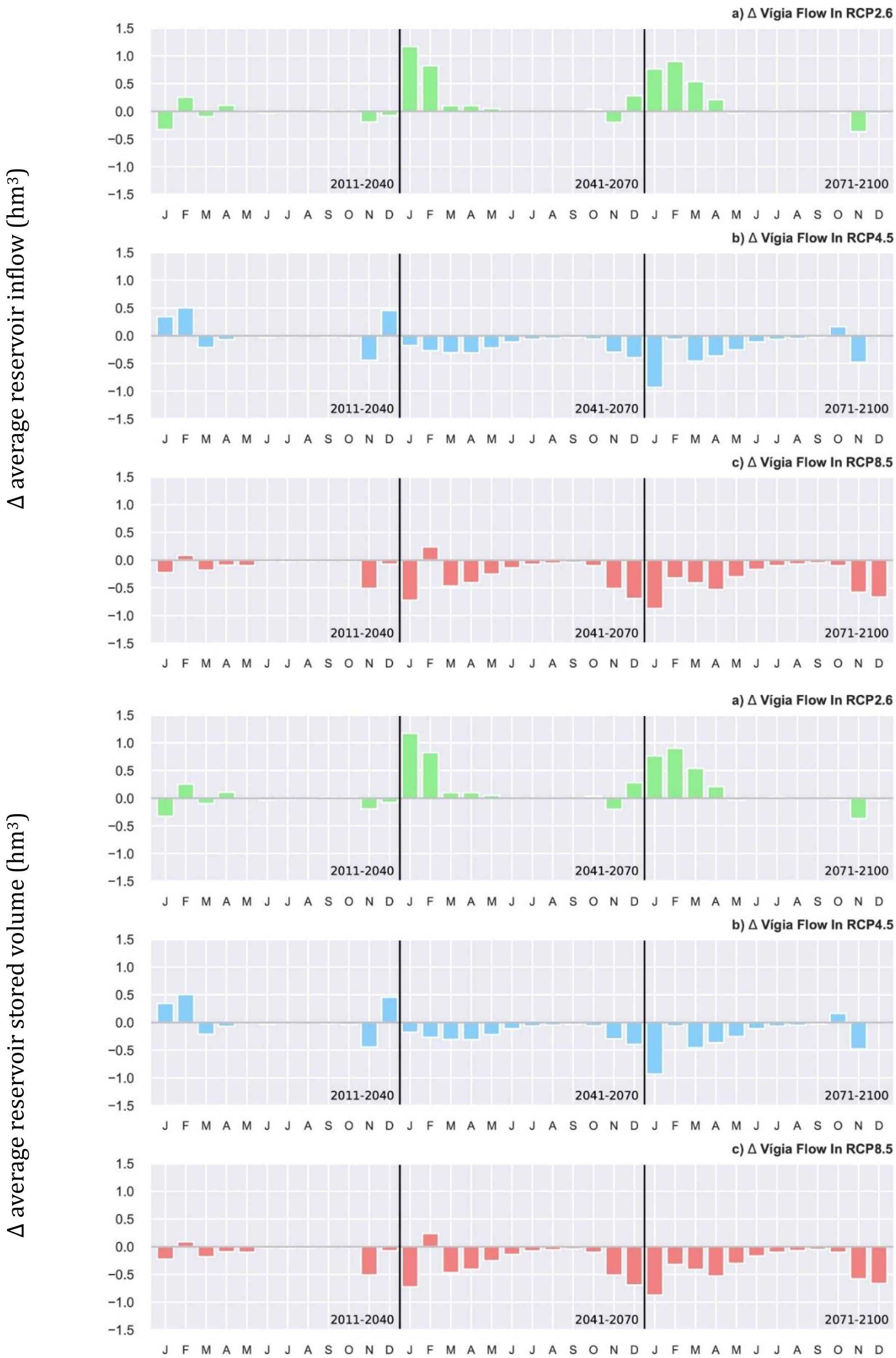


Figure 16 – Projected changes (multi-model ensemble mean) in averaged inflow (top) and volume stored (bottom) in hm^3 for the Vigia reservoir, located in River Basin District RH7. Three future periods are shown: 2011-2040, 2041-2070, and 2071-2100, under all emission scenarios – RCP2.6 (green), RCP4.5 (blue) and RCP8.5 (red).

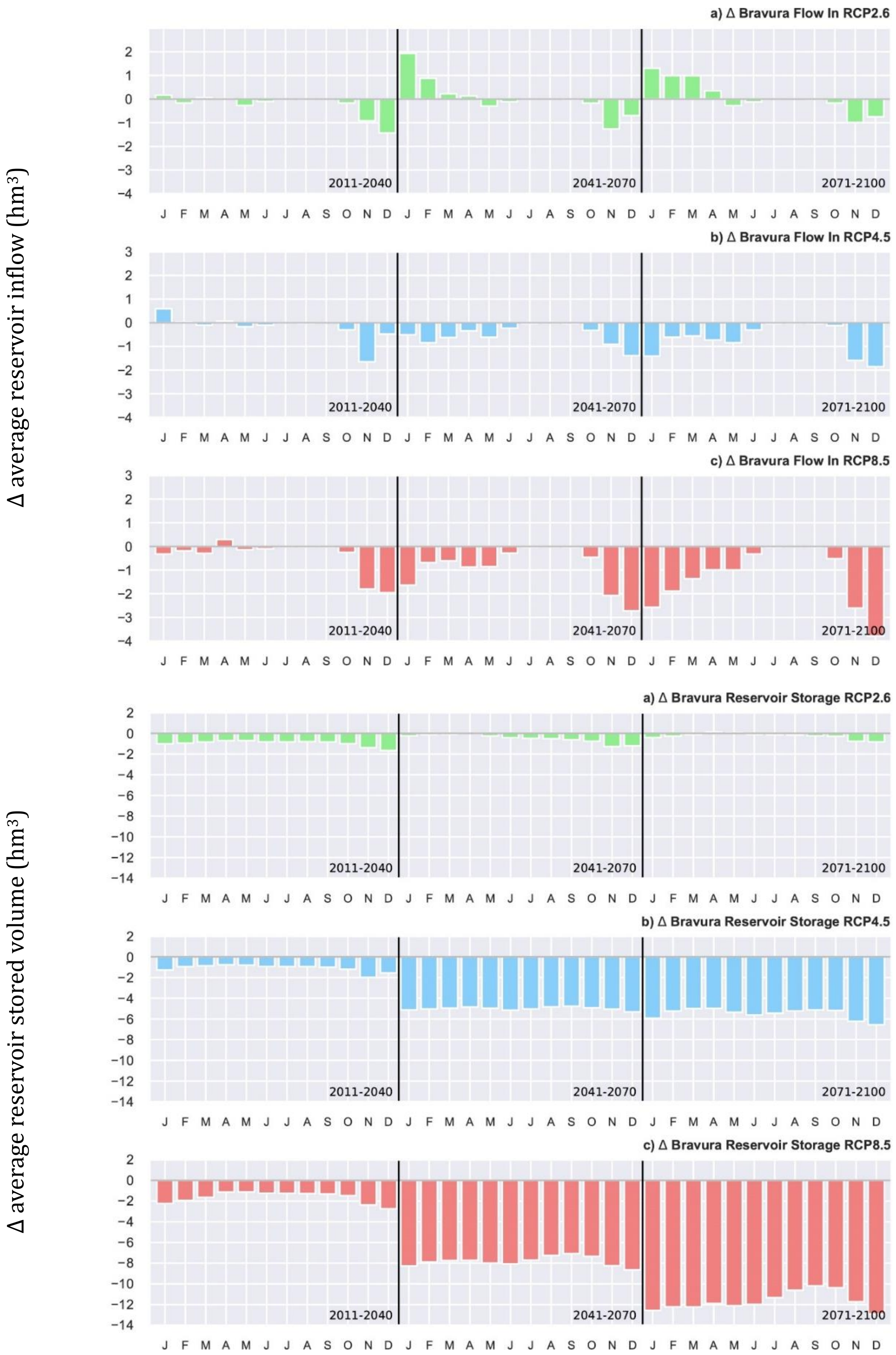


Figure 17 – Projected changes (multi-model ensemble mean) in averaged inflow (top) and volume stored (bottom) in hm^3 for the Bravura reservoir, located in River Basin District RH8. Three future periods are shown: 2011-2040, 2041-2070, and 2071-2100, under all emission scenarios – RCP2.6 (green), RCP4.5 (blue) and RCP8.5 (red).

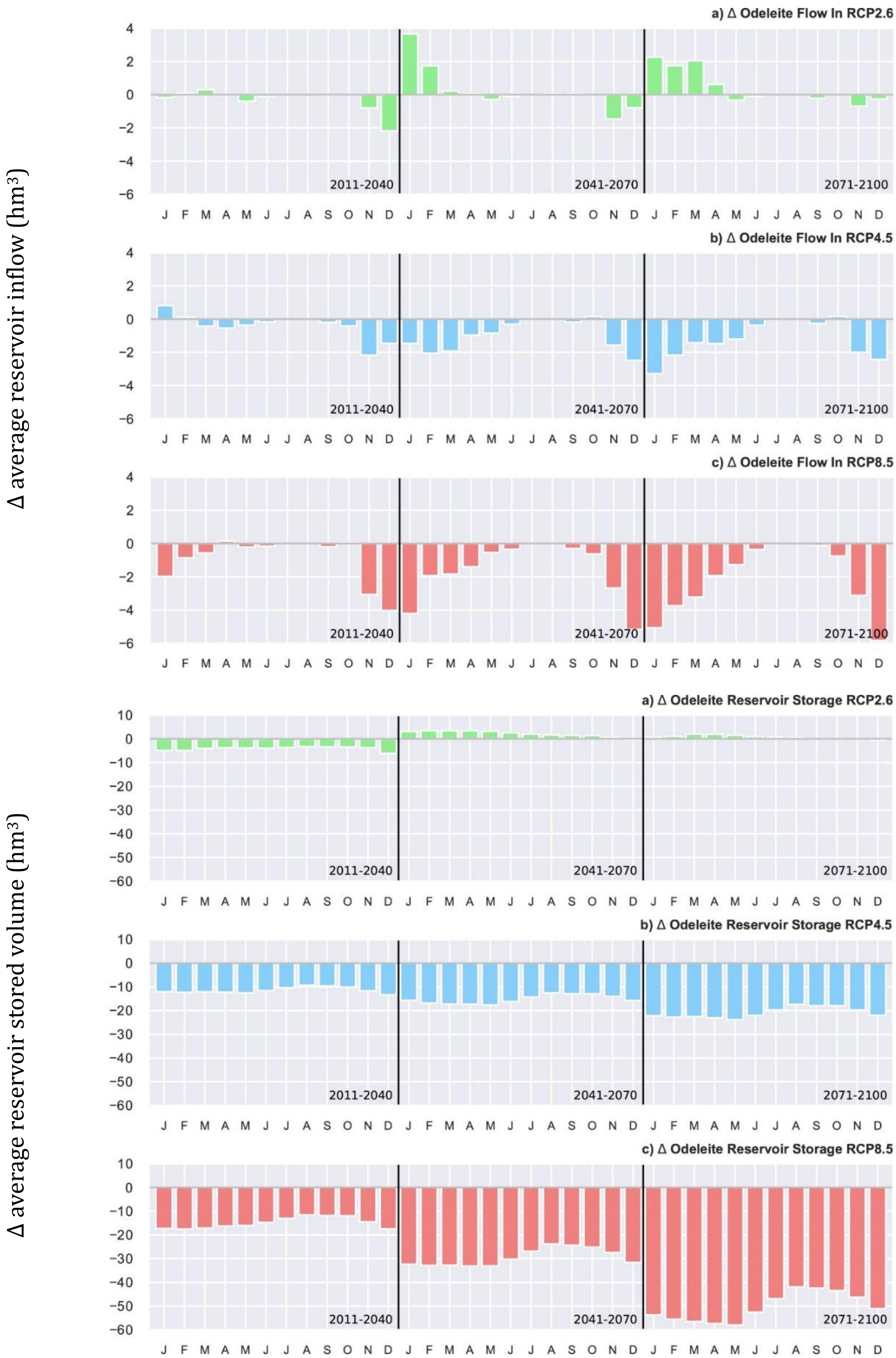


Figure 18 – Projected changes (multi-model ensemble mean) in averaged inflow (top) and volume stored (bottom) in hm^3 for the Odeleite reservoir, located in River Basin District RH8. Three future periods are shown: 2011-2040, 2041-2070, and 2071-2100, under all emission scenarios – RCP2.6 (green), RCP4.5 (blue) and RCP8.5 (red).

3.2.2. Agroforestry component

Climate change will have impacts on both irrigation needs, and the productivity of the main crops cultivated in mainland Portugal. Figure 19 exemplifies these impacts on three rainfed crops, categorized by the geographic regions of Northern, Central, and Southern of mainland Portugal.

For the almond crop, a relative stability is observed across the various considered climate change scenarios. In general, the crop may undergo productivity changes due to climate variations, with only a slight impact compared to the reference period.

Regarding the olive grove, the trend of decreasing productivity is somewhat clearer for the values obtained in the multi-model ensemble mean, although the productivity losses do not exceed 5 kg/ha in any of the considered scenarios or time periods.

For the vineyard, the trend in productivity is more pronounced, particularly more significant in the southern regions than in the northern regions, with a negative trend that worsens over the century, especially in the south. In this latter case, the productivity losses can range between approximately 200 and 300 kg/ha in the most severe scenario.

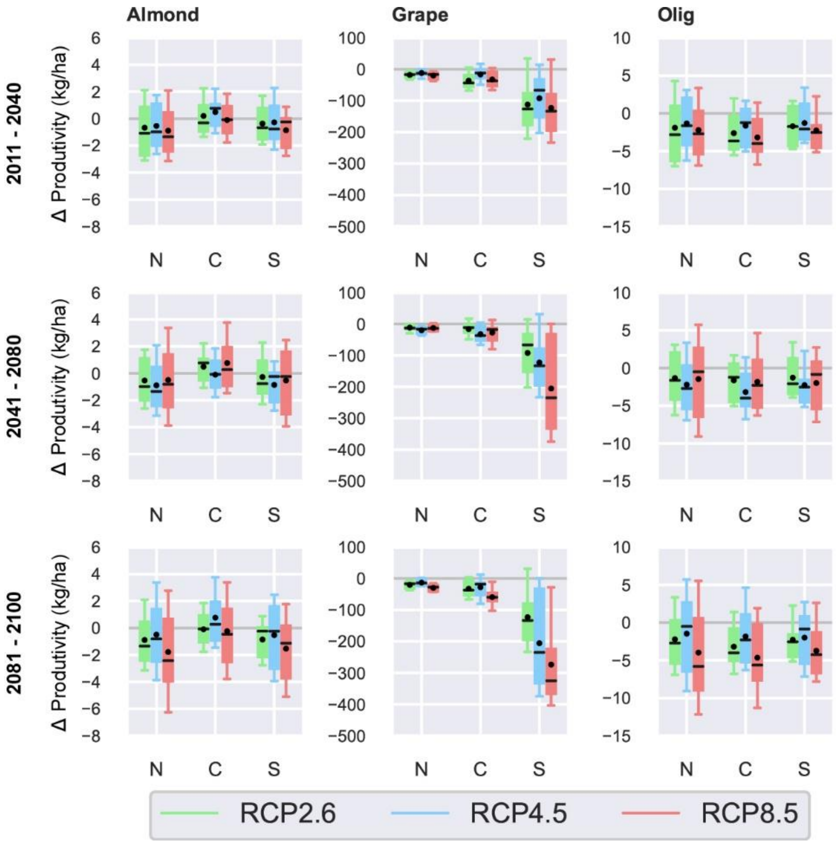


Figure 19 – Projected changes in productivity (km/ha) for almond, grape, and olive grove. N (Nort) corresponds to river basin districts RH1, RH2 and RH3. C (Centre) corresponds to river basin districts RH4 and RH5. S (South) corresponds to river basin districts RH6, RH7 and RH8. Three future periods are shown: 2011-2040, 2041-2070, and 2071-2100, under all emission scenarios – RCP2.6 (green), RCP4.5 (blue) and RCP8.5 (red). The black point represents the multi-model ensemble mean.

The irrigation needs for permanent crops show an increasing trend that can be generalized throughout the entire territory of mainland Portugal.

Regarding apple production, the anticipated increase in irrigation needs is expected to range between 20 and 40 mm/ha/year across all analyzed scenarios during the period 2011-2040.

For the period 2041-2070, the variability among scenarios becomes more significant. Irrigation needs for this crop are projected to be around 40 to 50 mm/ha/year in RCP2.6, 60 to 80 mm/ha/year in RCP4.5, and 70 to 100 mm/ha/year in RCP8.5.

By the end of the century, a decrease in apple irrigation needs is projected relative to the 2041-2070 period in the case of RCP2.6, returning to values like those at the beginning of the century (30 to 40 mm/ha/year). In RCP4.5, there is a slight increase compared to the previous period, while in RCP8.5, the increases in apple irrigation needs can reach values between 100 and 170 mm/ha/year. Regionally, is projected that the southern areas will experience greater increases in irrigation needs compared to the north and center areas of mainland Portugal (Figure 20).

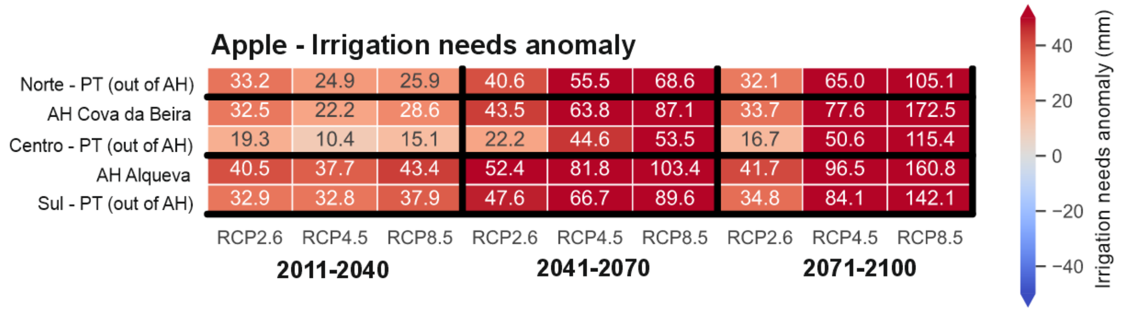


Figure 20 - Projected changes in irrigation needs (mm/ha/year) for the apple crop. Three future periods are shown: 2011-2040, 2041-2070, and 2071-2100, under all emission scenarios – RCP2.6, RCP4.5, and RCP8.5. The presented values refer to the multi-model ensemble mean. "AH" refers to hydro-agricultural developments. "Norte (out of AH)" refers to the crop outside the hydro-agricultural developments in the river basin districts RH1, RH2, and RH3. "Centro (out of AH)" refers to the crop outside the hydro-agricultural developments in the river basin districts RH4 and RH5. "Sul (out of AH)" refers to the crop outside the hydro-agricultural developments in the river basin districts RH6, RH7, and RH8.

Regarding the irrigation needs for the vineyard crop, the trends are like those identified for the apple crop. The main difference between these two crops lies in the absolute values of the anomalies in irrigation requirements, which are slightly higher for the vineyard. In this case, for the 2041-2070 period, the increase in necessary water for the crop is around 40 to 55 mm/ha/year in RCP2.6, 80 to 90 mm/ha/year in RCP4.5, and 110 to 130 mm/ha/year in RCP8.5. In this context, the projection of increases up to 250 mm/ha/year in the RCP8.5 scenario by the end of the century is particularly relevant (Figure 21).

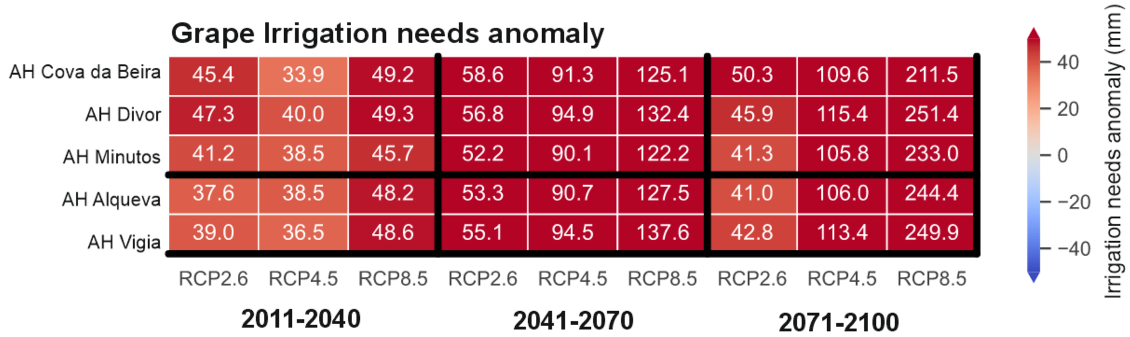


Figure 21 – Projected changes in irrigation needs (mm/ha/year) for the grap crop. Three future periods are shown: 2011-2040, 2041-2070, and 2071-2100, under all emission scenarios – RCP2.6, RCP4.5, and RCP8.5. The presented values refer to the multi-model ensemble mean. "AH" refers to hydro-agricultural developments.

The olive grove crop also demonstrates the same overall trends as the two previously analyzed crops. Generally, in RCP2.6, irrigation needs are higher during the 2041-2070 period. In RCP4.5, there is a significant increase between the 2011-2040 period and the 2041-2070 period, followed by a slight rise towards the end of the century compared to the previous period. Concerning RCP8.5, the trend is consistently increasing between consecutive periods, reaching values of approximately 120 to 150 mm/ha/year of additional needs for the olive grove crop (Figure 22).

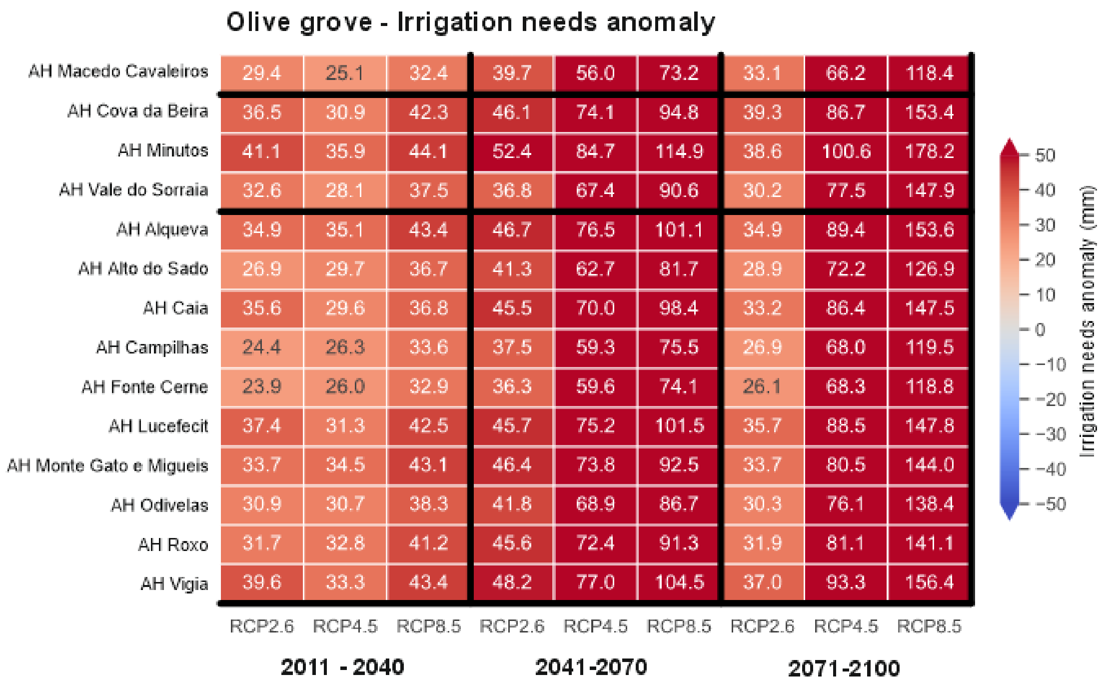


Figure 22 – Projected changes in irrigation needs (mm/ha/year) for the olive grove crop. Three future periods are shown: 2011-2040, 2041-2070, and 2071-2100, under all emission scenarios – RCP2.6, RCP4.5, and RCP8.5. The presented values refer to the multi-model ensemble mean. "AH" refers to hydro-agricultural developments.

3.2.3. WATER EXPLOITATION INDEX PLUS (WEI+)

The analysis of the WEI+ evaluated water stress conditions across the hydrographic regions under three climate scenarios over the century (Table 12). In general, the increase of the WEI+ for the future is a combination of a drier climate, reduced flows, and increased abstractions for irrigated agriculture. Nevertheless, regional asymmetries are depicted, mainly stemming from the distribution of water resources. As expected, water scarcity conditions are more intensified in the Central and Southern regions of Portugal; this fact reflects the climate projections in these areas of a decrease in precipitation over the century. Considering the levels of the WEI+ stated in the PGRHs (2016), RH7 and RH8 could change from actual moderate scarcity (between 20% and 30%) to extreme (>70%) and severe (>50%) scarcity conditions, respectively, under the RCP8.5 by the end of the century. In RH6, which is one of the most severely challenged regions with currently high scarcity conditions (between 30% and 50%), could reach the highest class of WEI+, the extreme scarcity, already in the middle of the century under the RCP8.5. Regarding RH5, lower increases (up to 12%) are expected, changing from current moderate levels to high scarcity conditions. Finally, RH1, RH2, RH3 and RH4 are expected to remain with low or no water stress conditions over the century.

River Basin Districts	2011-2040			2041-2070			2071-2100		
	RCP 2.6	RCP 4.5	RCP 8.5	RCP 2.6	RCP 4.5	RCP 8.5	RCP 2.6	RCP 4.5	RCP 8.5
RH 1	0.41%	0.13%	0.22%	0.33%	0.74%	1.06%	0.28%	0.59%	1.79%
RH 2	0.87%	0.22%	0.39%	0.57%	1.55%	2.47%	0.44%	1.18%	3.88%
RH 3	0.66%	-0.25%	-0.05%	-0.15%	1.03%	1.93%	-0.15%	0.53%	3.23%
RH 4	0.89%	-0.30%	-0.01%	-0.03%	1.34%	2.09%	-0.03%	0.84%	3.58%
RH 5	2.54%	0.48%	0.90%	-0.08%	3.64%	6.51%	0.07%	3.31%	11.88%
RH 6	8.58%	5.04%	8.72%	3.20%	21.69%	34.76%	4.75%	20.17%	56.70%
RH 7	12.18%	6.63%	14.28%	4.58%	33.02%	53.39%	6.90%	29.52%	84.86%
RH 8	5.36%	4.93%	8.46%	2.70%	11.77%	22.10%	1.65%	12.97%	35.86%

Table 12 - Projected changes in WEI + (%). Three future periods are shown: 2011-2040, 2041-2070, and 2071-2100, under all emission scenarios – RCP2.6, RCP4.5, and RCP8.5. The presented values refer to the multi-model ensemble mean.

4. Discussion and conclusions

This report summarizes the main results in the water resources and agroforestry sectors of the RNA2100 project.

The model's performance in the hydrological and agroforestry components can be considered reliable, instilling a high level of confidence in the results obtained under climate change scenarios. Some assumptions were made, particularly in the agroforestry component, where projections under climate change scenarios assume the continued existence of current irrigation infrastructure in the future, the availability of sufficient water for irrigation, and nutrients for plant growth. These assumptions align with those applied in the PESETA IV project (Projection of Economic impacts of climate change in Sectors of the European Union based on bottom-up Analysis).

In summary, the projections indicate a maintenance of water yield in the RCP2.6 scenario and a decrease in the other scenarios, with a more significant decline towards the end of the century for the RCP8.5.

There is also a projected decrease in the inflow to the reservoirs during the summer months, with a potential increase in some winter months due to more concentrated precipitation. However, the stored volume in the reservoirs shows a decreasing trend throughout the century, mainly in reservoirs used for irrigation, with this trend being prominent in the RCP4.5 scenario and even more pronounced in the RCP8.5 scenario. This situation is a result of both the decrease in total inflow and the increase in irrigation needs, which will be particularly high for the main perennial crops, under the scenarios with the most significant climate impact (i.e., RCP4.5 and RCP8.5). There is also a sign of a slight decrease in productivity for rainfed almond and olive grove crops, while these losses are much higher for the vineyard, with potential productivity reductions ranging from 200 to 300 kg/ha in the most severe scenario (RCP8.5).

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Appendix A. Supplementary data (land use)

This appendix presents the aggregation of land uses carried out for modelling purposes, based on the land use classes of the Corine Land Cover 2012 and Carta de Ocupação do Solo (COS) 2010.

CORINE ID	CORINE class description	COS ID	COS class description	SWAT ID	SWAT Land use description
111	Tecido urbano contínuo	1.1.1.01.1	Tecido urbano contínuo predominantemente vertical	urhd	Residential-High Density
		1.1.1.02.1	Tecido urbano contínuo predominantemente horizontal	urhd	Residential-High Density
		1.1.1.03.1	Áreas de estacionamentos e logradouros	urld	Residential-Low Density
112	Tecido urbano descontínuo	1.1.2.01.1	Tecido edificado descontínuo	urmd	Residential-Medium Density
		1.1.2.02.1	Tecido urbano descontínuo esparso	urld	Residential-Low Density
121	Espaços de atividades industriais, comerciais e de equipamentos gerais	1.2.1.01.1	Indústria	uidu	Industrial
		1.2.1.02.1	Comércio	ucom	Commercial
		1.2.1.03.1	Instalações agrícola	ucom	Commercial
		1.2.1.04.1	Equipamentos públicos e privados	uins	Institutional
		1.2.1.05.1	Infraestruturas de produção de energia renovável	gras	grassland
		1.2.1.05.2	Infraestruturas de produção de energia não renovável	uidu	Industrial
		1.2.1.06.1	Infraestruturas de águas e tratamento de resíduos	uidu	Industrial
		1.2.1.07.1	Infraestruturas de captação, tratamento e abastecimento de águas para consumo	uidu	Industrial
122	Infraestruturas da rede de autoestradas e da rede ferroviária	1.2.2.01.1	Rede viária e espaços associados	utrn	Transportation
		1.2.2.02.1	Rede ferroviária e espaços associados	utrn	Transportation
123	Zonas portuárias	1.2.3.01.1	Terminais portuários de mar e de rio	utrn	Transportation
		1.2.3.02.1	Estaleiros navais e docas secas	utrn	Transportation
		1.2.3.03.1	Marinas e docas pesca	utrn	Transportation
124	Aeroportos	1.2.4.01.1	Aeroportos	utrn	Transportation
		1.2.4.02.1	Aeródromos	utrn	Transportation
131	Pedreiras, zonas de extração de areia, minas a céu aberto	1.3.1.01.1	Minas a céu aberto	uins	Institutional

CORINE ID	CORINE class description	COS ID	COS class description	SWAT ID	SWAT Land use description
		1.3.1.02.1	Pedreiras	uins	Institutional
132	Descargas industriais, zonas de espalhamento de lixos	1.3.2.01.1	Aterros	uins	Institutional
		1.3.2.02.1	Lixeiras e Sucatas	uins	Institutional
133	Estaleiros	1.3.3.01.1	Áreas em construção	uins	Institutional
		1.3.3.02.1	Áreas abandonadas em territórios artificializados	uins	Institutional
141	Espaços verdes urbanos	1.4.1.01.1	Parques e jardins	gras	grassland
		1.4.1.02.1	Cemitérios	gras	grassland
142	Zonas com equipamentos desportivos e de ocupação de tempos livres	1.4.2.01.1	Campos de golfe	gras	grassland
		1.4.2.01.2	Outras instalações desportivas	gras	grassland
		1.4.2.02.1	Parques de campismo	gras	grassland
		1.4.2.02.2	Outros equipamentos de lazer	gras	grassland
		1.4.2.03.1	Equipamentos culturais e zonas históricas	uins	Institutional
211	Zonas de utilização agrícola não irrigadas	2.1.1.01.1	Culturas temporárias de sequeiro	wwht	winter_wheat
		2.1.1.02.1	Estufas e Viveiros	corn	corn
212	Zonas de utilização agrícola irrigadas	2.1.2.01.1	Culturas temporárias de regadio	corn	corn
213	Arrozais	2.1.3.01.1	Arrozais	rice	rice
221	Vinhas	2.2.1.01.1	Vinhas	grap	grape
		2.2.1.02.1	Vinhas com pomar	grap	grape
		2.2.1.03.1	Vinhas com olival	grap	grape
222	Pomares	2.2.2.01.1	Pomares de frutos frescos	appl	apple
		2.2.2.01.2	Pomares de amendoeira	almd	almond
		2.2.2.01.3	Pomares de castanheiro	oak	oak
		2.2.2.01.4	Pomares de alfarrobeira	oak	oak
		2.2.2.01.5	Pomares de citrinos	oran	orange
		2.2.2.01.6	Outros pomares	appl	apple
		2.2.2.02.1	Pomares de frutos frescos com vinha	appl	apple
		2.2.2.02.2	Pomares de amendoeira com vinha	almd	almond

CORINE ID	CORINE class description	COS ID	COS class description	SWAT ID	SWAT Land use description
		2.2.2.02.3	Pomares de castanheiro com vinha	oak	oak
		2.2.2.02.4	Pomares de alfarrobeira com vinha	oak	oak
		2.2.2.02.5	Pomares de citrinos com vinha	oran	orange
		2.2.2.02.6	Outros pomares com vinha	appl	apple
		2.2.2.03.1	Pomares de frutos frescos com olival	appl	apple
		2.2.2.03.2	Pomares de amendoeira com olival	almd	almond
		2.2.2.03.3	Pomares de castanheiro com olival	oak	oak
		2.2.2.03.4	Pomares de alfarrobeira com olival	oak	oak
		2.2.2.03.5	Pomares de citrinos com olival	oran	orange
		2.2.2.03.6	Outros pomares com olival	appl	apple
223	Olivais	2.2.3.01.1	Olivais	oliv	olive
		2.2.3.02.1	Olivais com vinha	oliv	olive
		2.2.3.03.1	Olivais com pomar	oliv	olive
231	Pastagens	2.3.1.01.1	Pastagens permanentes	past	pasture
241	Culturas anuais associadas a culturas permanentes	2.4.1.01.1	Culturas temporárias de sequeiro associadas a vinha	wwht	winter_wheat
		2.4.1.01.2	Culturas temporárias de sequeiro associadas a pomar	wwht	winter_wheat
		2.4.1.01.3	Culturas temporárias de sequeiro associadas a olival	wwht	winter_wheat
		2.4.1.02.1	Culturas temporárias de regadio associadas a vinha	corn	corn
		2.4.1.02.2	Culturas temporárias de regadio associadas a pomar	corn	corn
		2.4.1.02.3	Culturas temporárias de regadio associadas a olival	corn	corn
		2.4.1.03.1	Pastagens associadas a vinha	past	pasture
		2.4.1.03.2	Pastagens associadas a pomar	past	pasture
		2.4.1.03.3	Pastagens associadas a olival	past	pasture
242	Sistemas culturais e parcelares complexos	2.4.2.01.1	Sistemas culturais e parcelares complexos	wwht	winter_wheat
243	Terras ocupadas principalmente por agricultura com espaços naturais importantes	2.4.3.01.1	Agricultura com espaços naturais e seminaturais	wwht	winter_wheat
244	Territórios agroflorestais	2.4.4.01.1	SAF de sobreiro com culturas temporárias de sequeiro	past_SAF	pasture_SAF
		2.4.4.01.2	SAF de azinheira com culturas temporárias de sequeiro	past_SAF	pasture_SAF

CORINE ID	CORINE class description	COS ID	COS class description	SWAT ID	SWAT Land use description
		2.4.4.01.3	SAF de outros carvalhos com culturas temporárias de sequeiro	past_SAF	pasture_SAF
		2.4.4.01.4	SAF de pinheiro manso com culturas temporárias de sequeiro	past_SAF	pasture_SAF
		2.4.4.01.5	SAF de outras espécies com culturas temporárias de sequeiro	past_SAF	pasture_SAF
		2.4.4.01.6	SAF de sobreiro com azinheira e com culturas temporárias de sequeiro	past_SAF	pasture_SAF
		2.4.4.01.7	SAF de outras misturas com culturas temporárias de sequeiro	past_SAF	pasture_SAF
		2.4.4.02.1	SAF de sobreiro com culturas temporárias de regadio	past_SAF	pasture_SAF
		2.4.4.02.2	SAF de azinheira com culturas temporárias de regadio	past_SAF	pasture_SAF
		2.4.4.02.3	SAF de outros carvalhos com culturas temporárias de regadio	past_SAF	pasture_SAF
		2.4.4.02.4	SAF de pinheiro manso com culturas temporárias de regadio	past_SAF	pasture_SAF
		2.4.4.02.5	SAF de outras espécies com culturas temporárias de regadio	past_SAF	pasture_SAF
		2.4.4.02.6	SAF de sobreiro com azinheira e com culturas temporárias de regadio	past_SAF	pasture_SAF
		2.4.4.02.7	SAF de outras misturas com culturas temporárias de regadio	past_SAF	pasture_SAF
		2.4.4.03.1	SAF de sobreiro com pastagens	past_SAF	pasture_SAF
		2.4.4.03.2	SAF de azinheira com pastagens	past_SAF	pasture_SAF
		2.4.4.03.3	SAF de outros carvalhos com pastagens	past_SAF	pasture_SAF
		2.4.4.03.4	SAF de pinheiro manso com pastagens	past_SAF	pasture_SAF
		2.4.4.03.5	SAF de outras espécies com pastagens	past_SAF	pasture_SAF
		2.4.4.03.6	SAF de sobreiro com azinheira com pastagens	past_SAF	pasture_SAF
		2.4.4.03.7	SAF de outras misturas com pastagens	past_SAF	pasture_SAF
		2.4.4.04.1	SAF de sobreiro com culturas permanentes	past_SAF	pasture_SAF
		2.4.4.04.2	SAF de azinheira com culturas permanentes	past_SAF	pasture_SAF
		2.4.4.04.3	SAF de outros carvalhos com culturas permanentes	past_SAF	pasture_SAF
		2.4.4.04.4	SAF de pinheiro manso com culturas permanentes	past_SAF	pasture_SAF
		2.4.4.04.5	SAF de outras espécies com culturas permanentes	past_SAF	pasture_SAF
		2.4.4.04.6	SAF de sobreiro com azinheira com culturas permanentes	past_SAF	pasture_SAF
		2.4.4.04.7	SAF de outras misturas com culturas permanentes	past_SAF	pasture_SAF
311	Florestas de folhosas	3.1.1.01.1	Florestas de sobreiro	FRSS	Dense sclerophyll forest

CORINE ID	CORINE class description	COS ID	COS class description	SWAT ID	SWAT Land use description
		3.1.1.01.2	Florestas de azinheira	FRSS	Dense sclerophyll forest
		3.1.1.01.3	Florestas de outros carvalhos	oak	oak
		3.1.1.01.4	Florestas de castanheiro	oak	oak
		3.1.1.01.5	Florestas de eucalipto	EUCL	Eucalyptus forest
		3.1.1.01.6	Florestas de espécies invasoras	EUCL	Eucalyptus forest
		3.1.1.01.7	Florestas de outras folhosas	FRSS	Dense sclerophyll forest
		3.1.1.02.1	Florestas de sobreiro com folhosas	FRSS	Dense sclerophyll forest
		3.1.1.02.2	Florestas de azinheira com folhosas	FRSS	Dense sclerophyll forest
		3.1.1.02.3	Florestas de outros carvalhos com folhosas	oak	oak
		3.1.1.02.4	Florestas de castanheiro com folhosas	oak	oak
		3.1.1.02.5	Florestas de eucalipto com folhosas	EUCL	Eucalyptus forest
		3.1.1.02.6	Florestas de espécies invasoras com folhosas	EUCL	Eucalyptus forest
		3.1.1.02.7	Florestas de outra folhosa com folhosas	oak	oak
312	Florestas de resinosas	3.1.2.01.1	Florestas de pinheiro-bravo	PINE	PINE
		3.1.2.01.2	Florestas de pinheiro manso	PINE	PINE
		3.1.2.01.3	Florestas de outras resinosas	PINE	PINE
		3.1.2.02.1	Florestas de pinheiro-bravo com resinosas	PINE	PINE
		3.1.2.02.2	Florestas de pinheiro manso com resinosas	PINE	PINE
		3.1.2.02.3	Florestas de outra resinosa com resinosas	PINE	PINE
313	Florestas mistas	3.1.3.01.1	Florestas de sobreiro com resinosas	FRSS	Dense sclerophyll forest
		3.1.3.01.2	Florestas de azinheira com resinosas	FRSS	Dense sclerophyll forest
		3.1.3.01.3	Florestas de outros carvalhos com resinosas	oak	oak
		3.1.3.01.4	Florestas de castanheiro com resinosas	oak	oak
		3.1.3.01.5	Florestas de eucalipto com resinosas	EUCL	Eucalyptus forest
		3.1.3.01.6	Florestas de espécies invasoras com resinosas	EUCL	Eucalyptus forest
		3.1.3.01.7	Florestas de outra folhosa com resinosas	oak	oak
		3.1.3.01.8	Florestas de misturas de folhosas com resinosas	oak	oak

CORINE ID	CORINE class description	COS ID	COS class description	SWAT ID	SWAT Land use description
		3.1.3.02.1	Florestas de pinheiro-bravo com folhosas	PINE	PINE
		3.1.3.02.2	Florestas de pinheiro manso com folhosas	PINE	PINE
		3.1.3.02.3	Florestas de outra resinosa com folhosas	PINE	PINE
		3.1.3.02.4	Florestas de misturas de resinosas com folhosas	PINE	PINE
321	Vegetação herbácea natural	3.2.1.01.1	Vegetação herbácea natural	migs	mixed_grassland/shrubland
322	Matos	3.2.2.01.1	Matos densos	shrb	shrubland
		3.2.2.02.1	Matos pouco densos	shrb	shrubland
323	Vegetação esclerófita	3.2.3.01.1	Vegetação esclerófita densa	SHRM	Mediterranean shrubland
		3.2.3.02.1	Vegetação esclerófita pouco densa	SHRM	Mediterranean shrubland
324	Florestas abertas e vegetação arbustiva de transição	3.2.4.01.1	Florestas abertas de sobreiro	FRSS	Dense sclerophyll forest
		3.2.4.01.2	Florestas abertas de azinheira	FRSS	Dense sclerophyll forest
		3.2.4.01.3	Florestas abertas de outros carvalhos	oak	oak
		3.2.4.01.4	Florestas abertas de castanheiro	oak	oak
		3.2.4.01.5	Florestas abertas de eucalipto	EUCL	Eucalyptus forest
		3.2.4.01.6	Florestas abertas de espécies invasoras	EUCL	Eucalyptus forest
		3.2.4.01.7	Florestas abertas de outras folhosas	oak	oak
		3.2.4.02.1	Florestas abertas de sobreiro com folhosas	FRSS	Dense sclerophyll forest
		3.2.4.02.2	Florestas abertas de azinheira com folhosas	FRSS	Dense sclerophyll forest
		3.2.4.02.3	Florestas abertas de outros carvalhos com folhosas	oak	oak
		3.2.4.02.4	Florestas abertas de castanheiro com folhosas	oak	oak
		3.2.4.02.5	Florestas abertas de eucalipto com folhosas	EUCL	Eucalyptus forest
		3.2.4.02.6	Florestas abertas de espécies invasoras com folhosas	EUCL	Eucalyptus forest
		3.2.4.02.7	Florestas abertas de outra folhosa com folhosas	oak	oak
		3.2.4.03.1	Florestas abertas de pinheiro-bravo	PINE	PINE
		3.2.4.03.2	Florestas abertas de pinheiro manso	PINE	PINE
		3.2.4.03.3	Florestas abertas de outras resinosas	PINE	PINE
		3.2.4.04.1	Florestas abertas de pinheiro-bravo com resinosas	PINE	PINE

CORINE ID	CORINE class description	COS ID	COS class description	SWAT ID	SWAT Land use description
		3.2.4.04.2	Florestas abertas de pinheiro manso com resinosas	PINE	PINE
		3.2.4.04.3	Florestas abertas de outra resinosa com resinosas	PINE	PINE
		3.2.4.05.1	Florestas abertas de sobreiro com resinosas	FRSS	Dense sclerophyll forest
		3.2.4.05.2	Florestas abertas de azinheira com resinosas	FRSS	Dense sclerophyll forest
		3.2.4.05.3	Florestas abertas de outros carvalhos com resinosas	oak	oak
		3.2.4.05.4	Florestas abertas de castanheiro com resinosas	oak	oak
		3.2.4.05.5	Florestas abertas de eucalipto com resinosas	EUCL	Eucalyptus forest
		3.2.4.05.6	Florestas abertas de espécies invasoras com resinosas	EUCL	Eucalyptus forest
		3.2.4.05.7	Florestas abertas de outra folhosa com resinosas	oak	oak
		3.2.4.05.8	Florestas abertas de misturas de folhosas com resinosas	oak	oak
		3.2.4.06.1	Florestas abertas de pinheiro-bravo com folhosas	PINE	PINE
		3.2.4.06.2	Florestas abertas de pinheiro manso com folhosas	PINE	PINE
		3.2.4.06.3	Florestas abertas de outras resinosas com folhosas	PINE	PINE
		3.2.4.06.4	Florestas abertas de misturas de resinosas com folhosas	PINE	PINE
		3.2.4.07.1	Outras formações lenhosas	SHRM	Mediterranean shrubland
		3.2.4.08.1	Cortes rasos de florestas de sobreiro	FRSS	Dense sclerophyll forest
		3.2.4.08.2	Cortes rasos de florestas de azinheira	FRSS	Dense sclerophyll forest
		3.2.4.08.3	Cortes rasos de florestas de outros carvalhos	oak	oak
		3.2.4.08.4	Cortes rasos de florestas de castanheiro	oak	oak
		3.2.4.08.5	Cortes rasos de florestas de eucalipto	EUCL	Eucalyptus forest
		3.2.4.08.6	Cortes rasos de florestas de espécies invasoras	EUCL	Eucalyptus forest
		3.2.4.08.7	Cortes rasos de florestas de outras folhosas	oak	oak
		3.2.4.09.1	Cortes rasos de florestas de pinheiro-bravo	PINE	PINE
		3.2.4.09.2	Cortes rasos de florestas de pinheiro manso	PINE	PINE
		3.2.4.09.3	Cortes rasos de florestas de outras resinosas	PINE	PINE
		3.2.4.10.1	Novas plantações de florestas de sobreiro	FRSS	Dense sclerophyll forest
		3.2.4.10.2	Novas plantações de florestas de azinheira	FRSS	Dense sclerophyll forest

CORINE ID	CORINE class description	COS ID	COS class description	SWAT ID	SWAT Land use description
		3.2.4.10.3	Novas plantações de florestas de outros carvalhos	oak	oak
		3.2.4.10.4	Novas plantações de florestas de castanheiro	oak	oak
		3.2.4.10.5	Novas plantações de florestas de eucalipto	EUCL	Eucalyptus forest
		3.2.4.10.6	Novas plantações de florestas de espécies invasoras	EUCL	Eucalyptus forest
		3.2.4.10.7	Novas plantações de florestas de outras folhosas	oak	oak
		3.2.4.11.1	Novas plantações de florestas de pinheiro-bravo	PINE	PINE
		3.2.4.11.2	Novas plantações de florestas de pinheiro manso	PINE	PINE
		3.2.4.11.3	Novas plantações de florestas de outras resinosas	PINE	PINE
		3.2.4.12.1	Viveiros florestais	PINE	PINE
		3.2.4.13.1	Aceiros e/ou corta-fogos	gras	grassland
331	Praias, dunas, areais e solos sem cobertura vegetal	3.3.1.01.1	Praias, dunas e areais interiores	gras	grassland
		3.3.1.02.1	Praias, dunas e areais costeiros	gras	grassland
332	Rochas nuas	3.3.2.01.1	Rocha nua	gras	grassland
333	Vegetação esparsa	3.3.3.01.1	Vegetação esparsa	SHRM	Mediterranean shrubland
334	Áreas ardidas	3.3.4.01.1	Áreas ardidas não florestais	wwht	winter_wheat
		3.3.4.02.1	Áreas ardidas em florestas de sobreiro	FRSS	Dense sclerophyll forest
		3.3.4.02.2	Áreas ardidas em florestas de azinheira	FRSS	Dense sclerophyll forest
		3.3.4.02.3	Áreas ardidas em florestas de outros carvalhos	oak	oak
		3.3.4.02.4	Áreas ardidas em florestas de castanheiro	oak	oak
		3.3.4.02.5	Áreas ardidas em florestas de eucalipto	EUCL	Eucalyptus forest
		3.3.4.02.6	Áreas ardidas em florestas de espécies invasoras	EUCL	Eucalyptus forest
		3.3.4.02.7	Áreas ardidas em florestas de outras folhosas	oak	oak
		3.3.4.03.1	Áreas ardidas em florestas de pinheiro-bravo	PINE	PINE
		3.3.4.03.2	Áreas ardidas em florestas de pinheiro manso	PINE	PINE
		3.3.4.03.3	Áreas ardidas em florestas de outras resinosas	PINE	PINE
411	Zonas apaúladas	4.1.1.01.1	Paúis	wetn	wetlands_non_forested
412	Turfeiras	4.1.2.01.1	Turfeiras	wetn	wetlands_non_forested

CORINE ID	CORINE class description	COS ID	COS class description	SWAT ID	SWAT Land use description
421	Sapais	4.2.1.01.1	Sapais	wetn	wetlands_non_forested
422	Salinas	4.2.2.01.1	Salinas	wetn	wetlands_non_forested
		4.2.2.02.1	Aquicultura litoral	watr	water_arid
423	Zonas intertidais	4.2.3.01.1	Zonas entremarés	watr	water_arid
511	Cursos de água	5.1.1.01.1	Cursos de água naturais	watr	water_arid
		5.1.1.02.1	Canais artificiais	watr	water_arid
512	Planos de água	5.1.2.01.1	Lagos e lagoas interiores artificiais	watr	water_arid
		5.1.2.01.2	Lagos e lagoas interiores naturais	watr	water_arid
		5.1.2.02.1	Reservatórios de barragens	watr	water_arid
		5.1.2.03.1	Reservatórios de represas ou de açudes	watr	water_arid
		5.1.2.03.2	Charcas	watr	water_arid
		5.1.2.03.3	Aquicultura interior	watr	water_arid
521	Lagoas costeiras	5.2.1.01.1	Lagoas costeiras	watr	water_arid
522	Estuários	5.2.2.01.1	Desembocaduras fluviais	watr	water_arid
523	Mar e Oceano	5.2.3.01.1	Oceano	watr	water_arid

Table 12 - Land use classes from Corine Land Cover 2010 and Carta de Ocupação do Solo (COS) 2010 and classes aggregation performed for modelling purposes in SWAT+

Appendix B. Supplementary data (reservoirs)

This appendix contains the integrated reservoirs of the SWAT+ model as well as some of the parameters used. The basins in parentheses correspond to the basin to which the reservoir contributes to mainland Portugal, not the basin where that reservoir is geographically located.

River basin districts	Name	Basin	Year	Uses*	Area at FRL** (ha)	Volume at FRL** (10^4 m^3)
RH1	Alto Lindoso	Lima	1992	E	1072	37901
	Touvedo	Lima	1993	E,S	172	1550
	Albarellos	(Minho)	1971	E	314	9100
	Bao	(Minho)	1960	E	820	23800
	Barcena	(Minho)	1960	I,S,E	986	34150
	Belesar	(Minho)	1963	E	1828	64000
	Castrelo	(Minho)	1969	E	560	6600
	Cenza	(Minho)	1993	E	238	4300
	Chandreja	(Minho)	1953	E	245	6100
	Conchas	(Minho)	1949	E	645	8000
	Frieira	(Minho)	1970	E	466	4400
	Matalavilla	(Minho)	1967	E	188	6493.2
	Peares	(Minho)	1955	E	600	18200
	Portas	(Minho)	1974	E	1183	53600
	Prada	(Minho)	1958	E	605	12200
	Salas	(Minho)	1971	E	686	8700
	San esteban	(Minho)	1955	E	737	21350
	San sebastian	(Minho)	1959	E	194	4600
RH2	Guilhofrei (Ermal)	Ave	1939	E	163	2120
	Alto Rabagão	Cávado	1964	E,S	2224	56870
	Caniçada	Cávado	1955	E	578	15930
	Paradela	Cávado	1956	E	396	16440
	Salamonde	Cávado	1953	E	236	6500
	Venda Nova	Cávado	1951	E,S	400	9450
	Vilarinho das Furnas	Cávado	1972	E	346	11770
RH3	Azibo	Douro	1982	I, S	410	5440
	Bemposta	Douro	1964	E,S	405	12880
	Carrapatelo	Douro	1972	E,S	952	15020
	Crestuma - Lever	Douro	1985	S,E	1298	11000
	Miranda	Douro	1961	E,S	122	2810
	Picote	Douro	1958	E,S	233	6300
	Pocinho	Douro	1982	E,S	829	8290
	Régua	Douro	1973	E,S	850	9500
	Sabugal	Douro	2000	I,E,S	732	11430
	Torrão	Douro	1988	E,S	650	1240
	Valeira	Douro	1975	E	795	9850
	Varosa	Douro	1934	E	70	1290
	Vilar - Tabuaço	Douro	1965	E,S	670	10000
	Aguilar de campo	(Douro)	1964	I,E	177	24700
	Aldeadavila	(Douro)	1963	E	368	11560
	Almendra	(Douro)	1970	E	8.65	264900
	Barrios de luna	(Douro)	1956	I,S,E	1.3	30800
	Camporredondo	(Douro)	1930	I,E	388	7100
	Castro de las cogotas	(Douro)	1994	S	280	5960
	Cernadilla	(Douro)	1969	I,E	1394	25500
	Compuerto	(Douro)	1960	I,E	376	9530
	Cuerda del pozo	(Douro)	1941	I,S,E	2176	22900
	Irueña	(Douro)	2008	I	1025	21000
	Linares del arroyo	(Douro)	1951	I,S,E	550	5800
	Porma (juan benet)	(Douro)	1968	I	1153	31800
	Requejada, la	(Douro)	1940	I,E	363	6500
	Riaño	(Douro)	1988	I,E	2.3	64135
	Ricobayo	(Douro)	1934	E	5855	117890
	Santa teresa	(Douro)	1960	I,E	2663	49600
	Saucelle	(Douro)	1956	E	582	18150

River basin districts	Name	Basin	Year	Uses*	Area at FRL** (ha)	Volume at FRL** (10^4 m^3)
	Uzquiza	(Douro)	1988	S	313	7590
	Valparaiso	(Douro)	1988	E	1244	16850
	Villalcampo	(Douro)	1949	E	445	6650
RH4	Aç. Ponte Coimbra	Mondego	1981	I, S	92.5	160
	Aç. Raiva	Mondego	1981	E	230	2440
	Aguieira	Mondego	1981	E, I, S	2000	42300
	Fronhas	Mondego	1985	E, S	535	6210
	Lagoa Comprida	Mondego	1958	E	75	1388
RH5	Aç. Furadouro	Tejo	1958	I	3.6	40
	Aç. Gameiro	Tejo	1960	I	7.2	130
	Belver	Tejo	1952	I	286	1250
	Bouçã	Tejo	1955	E	500	4840
	Cabril	Tejo	1965	E, S	2023	72000
	Capinha	Tejo	1987	I	9.7	52.2
	Castelo de Bode	Tejo	1951	S	3500	109500
	Divôr	Tejo	1965	I	239	1190
	Fratel	Tejo	1974	E	1000	9300
	Idanha	Tejo	1947	I, E	678	7810
	Maranhão	Tejo	1957	I, E	1960	20540
	Meimoa	Tejo	1985	S, I	222	4090
	Minutos	Tejo	2003	I	530	5210
	Montargil	Tejo	1958	I, E	1646	16430
	Póvoa e Meadas	Tejo	1928	I, S	236	2200
	Pracana	Tejo	1950	E	547	11190
	Sta. Águeda (Marateca)	Tejo	1990	S, I	634	3720
	Sta. Luzia	Tejo	1942	S, E	246	5370
	Alcorlo	(Tejo)	1978	I, S	599	13520
	Atazar. El	(Tejo)	1972	S	1069	42600
	Azutan	(Tejo)	1969	I, E	1250	11300
	Beleña	(Tejo)	1982	S	245	5030
	Borbollon	(Tejo)	1954	I, E	888	8500
	Buendia	(Tejo)	1958	I, E	8195	145800
	Burguillo. El	(Tejo)	1913	I, E	910	19770
	Cedillo	(Tejo)	1978	E	1400	26000
	Entrepeñas	(Tejo)	1956	I, E	3213	87400
	Finisterre	(Tejo)	1977	E	1200	13100
	Gabriel y galan	(Tejo)	1961	I, E	4683	92400
	Jerte-plasencia	(Tejo)	1985	I, S	667	6300
	Alcantara	(Tejo)	1969	E	1400	320000
	Puentes viejas	(Tejo)	1940	S	280	5000
	Riosequillo	(Tejo)	1956	S	326	5000
	Rivera de gata	(Tejo)	1990	I	311	4700
	Rosarito	(Tejo)	1958	I, E	1475	8400
	San juan	(Tejo)	1955	I, E	650	13770
	Tajera. La	(Tejo)	1993	I	409	7000
	Torrejon-tajo	(Tejo)	1966	E	1041	17600
	Vado. El	(Tejo)	1954	S	260	5600
	Valdecañas	(Tejo)	1964	I, E	7300	144600
	Valdeobispo	(Tejo)	1965	I, E	357	5300
	Valmayor	(Tejo)	1975	S	755	12400
	Manzanares el real	(Tejo)	1969	I, S, E	1044	9124
RH6	Alvito (Sado)	Sado	1977	I, S, E	1480	13250
	Campilhas	Sado	1954	I	333	2716
	Fonte Serne	Sado	1977	I	105	515
	Monte da Rocha	Sado	1972	I, S	1100	10450
	Monte Gato	Sado	1991	I	18	65.3
	Monte Migueis	Sado	1991	I	27	93.7
	Morgavel	R. Alentejo	1980	S, E	340	3250
	Odivelas	Sado	1972	I	973	9600
	Pêgo do Altar	Sado	1949	I, E	655	9400
	Roxo	Sado	1967	I, S, E	1378	9631
	Santa Clara	Mira	1968	I, S	1986	48500
	Vale do Gaio	Sado	1949	I, E	550	6300
RH7	Abrilongo	Guadiana	2000	I	295	1990
	Açude de Pedrogão	Guadiana	2005	I, E	1104	10600

River basin districts	Name	Basin	Year	Uses*	Area at FRL** (ha)	Volume at FRL** (10^4 m^3)
	Alqueva	Guadiana	2002	I, S, E	25000	415000
	Beliche	Guadiana	1986	I, S	292	4800
	Caia	Guadiana	1967	I, S	1970	20300
	Enxoé	Guadiana	1998	I, S	205	1250
	Lucefecit	Guadiana	1982	I	168	1023
	Monte Novo	Guadiana	1982	I, S	277	1528
	Odeleite	Guadiana	1996	I, S	720	13000
	Vigia	Guadiana	1981	I, S	262	1673
	Alange	(Guadiana)	1992	S, E	5040	85200
	Andevalo	(Guadiana)	2005	S, E	3630	100900
	Chanza	(Guadiana)	1989	S, E	2219	38400
	Cijara	(Guadiana)	1956	I, S, E	6556	167000
	Colada	(Guadiana)	2006	S	529	5770
	Garcia de Sola	(Guadiana)	1962	S, E	3550	55400
	Orellana	(Guadiana)	1961	I, S, E	5557	80800
	Peñarroya	(Guadiana)	1959	I, S	412	5050
	Serena	(Guadiana)	1990	I, S, E	13949	323200
	Sierra Brava	(Guadiana)	1996	I, S, E	1650	23200
	Torre de Abraham	(Guadiana)	1994	I, S	980	18340
	Villar del Rey	(Guadiana)	1987	I, S, E	1784	14050
	Zujar	(Guadiana)	1964	I, S, E	1587	72300
RH8	Arade	Arade	1956	I	182	2839
	Bravura	R. Algarve	1958	I, S	285	3483
	Funcho	Arade	1993	I	360	4772
	Odelouca	Arade	2009	S	780	15700

Table 13 - Reservoir integrated in SWAT+ model. *S (supply) I, (irrigation), E (energy) ** Full Reservoir Level

Appendix C. Supplementary data (calibr./valid.)

This appendix presented an example by each Portuguese river basin districts of the comparison between observed and simulated SWAT+ flows. For each hydrometric station (Aspra, Alto Cávado, Parada Monteiros, Ponte Cabouco, Pavia, Torrão do Alentejo, Ardila and Vidigal) comparisons are shown for the daily and monthly time step, and for the model calibration and validation period. In the graphs, the dashed black lines refer to the observed values, while the solid red lines refer to the values simulated by the SWAT+ model.

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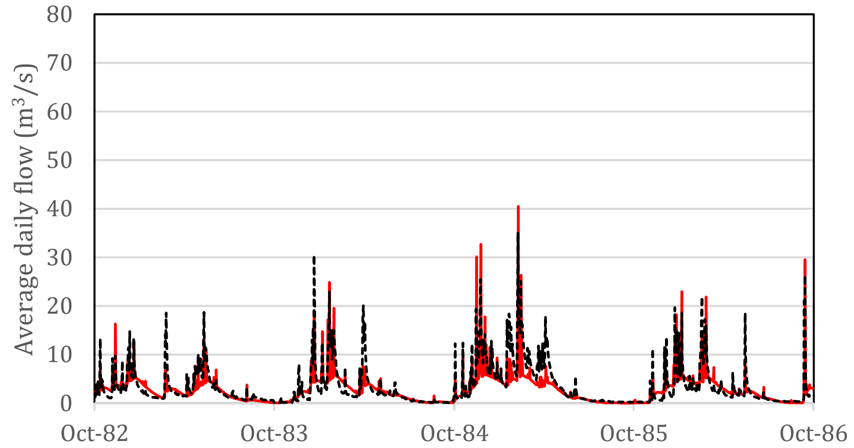
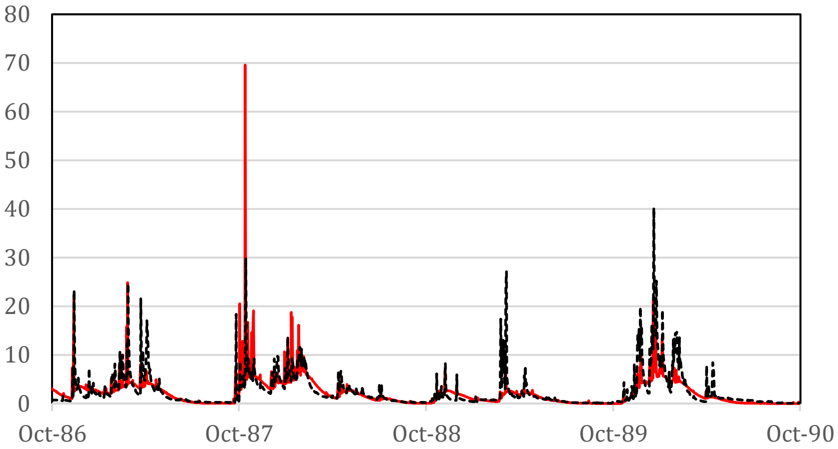
<tr><td rowspan="2">RH1 – Average flow</td><td>
</td><td>
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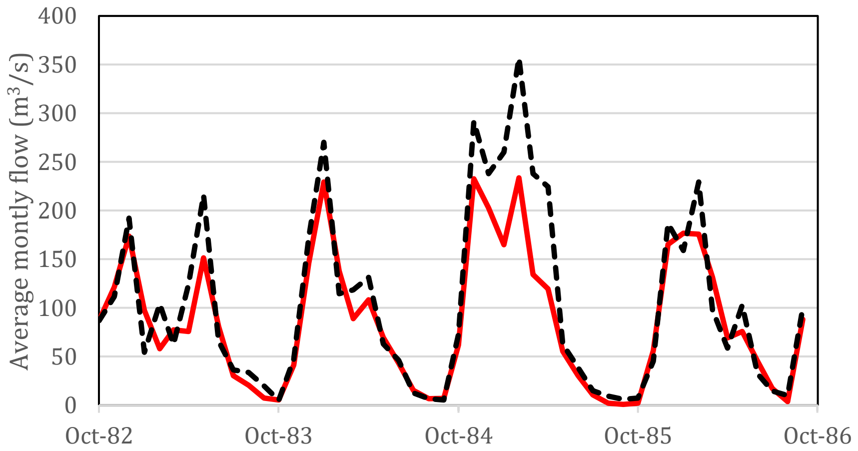
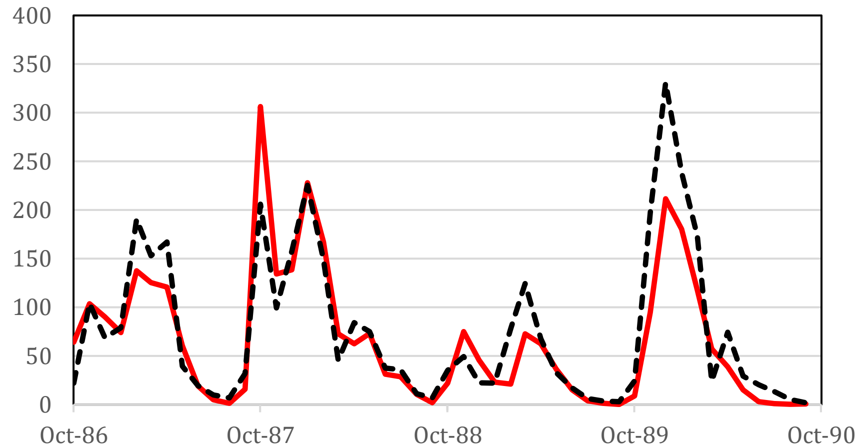
<tr><td>
</td><td>
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	Calibration	Validation
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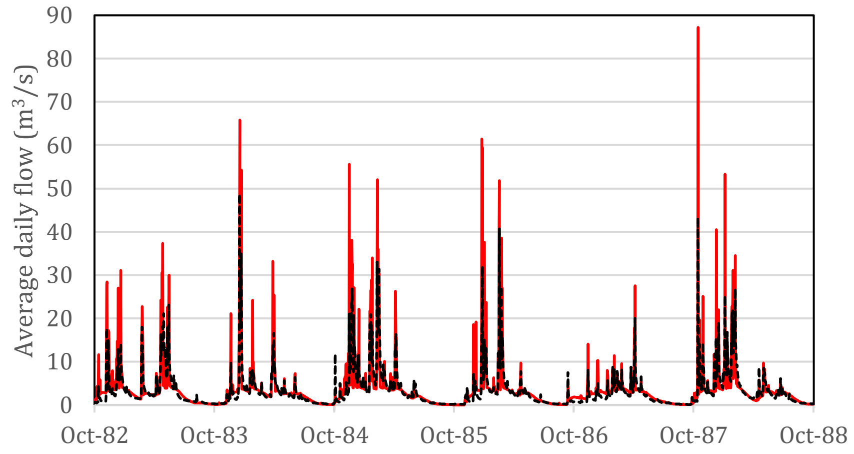
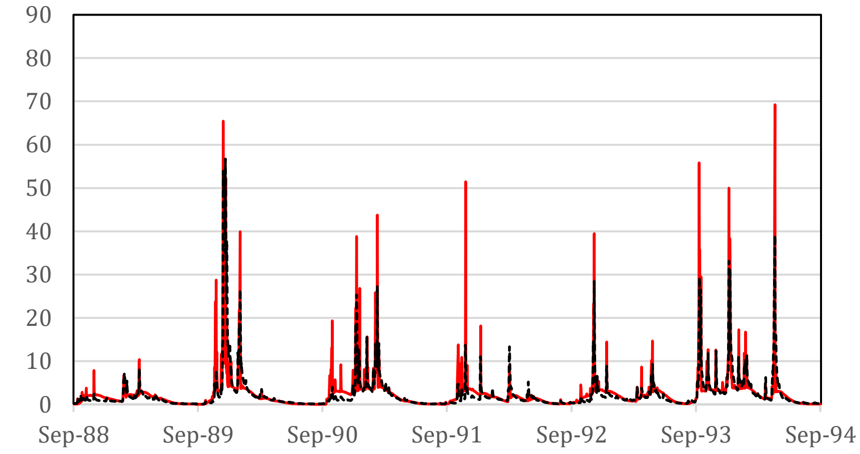
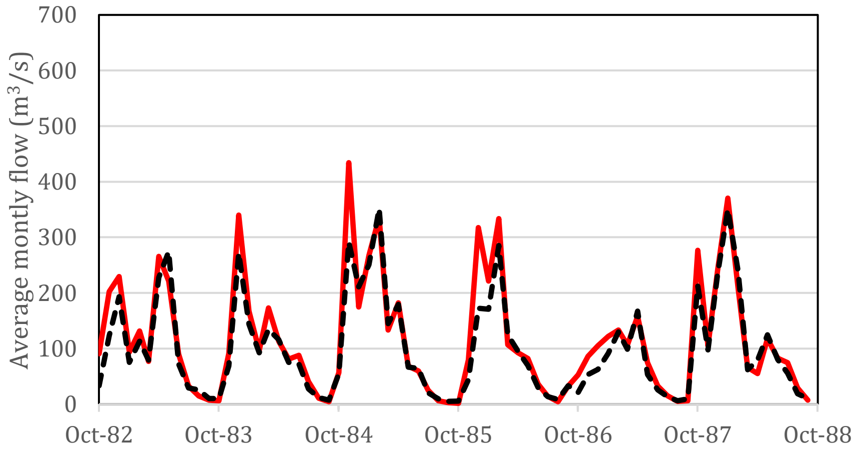
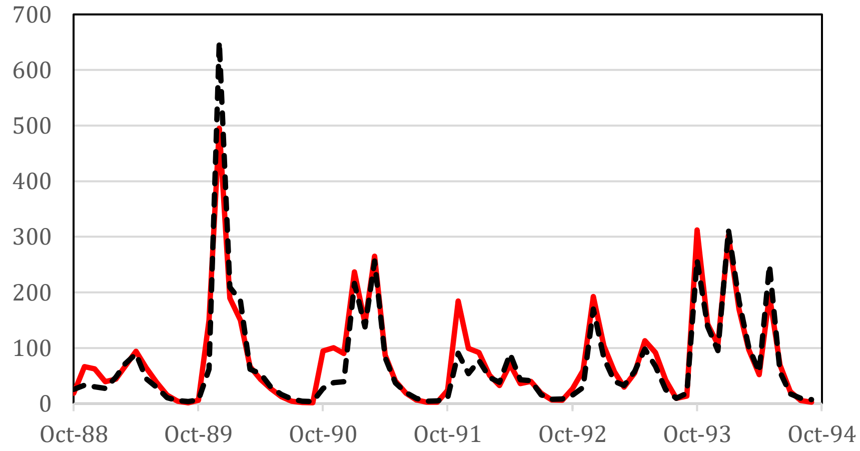
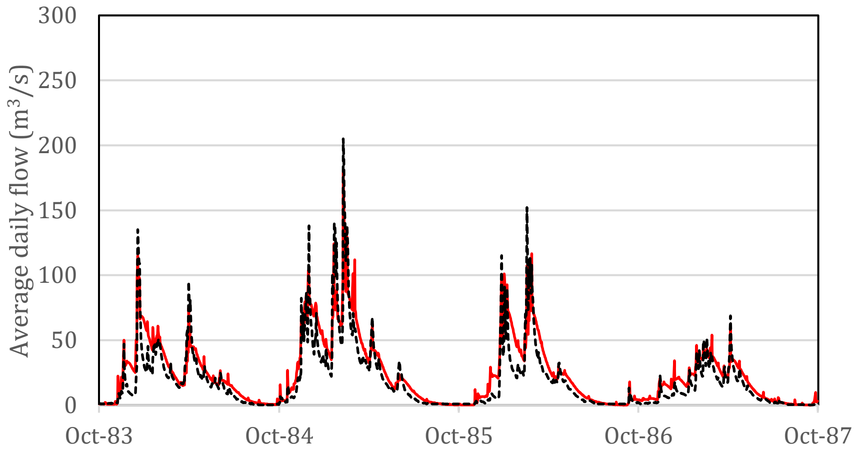
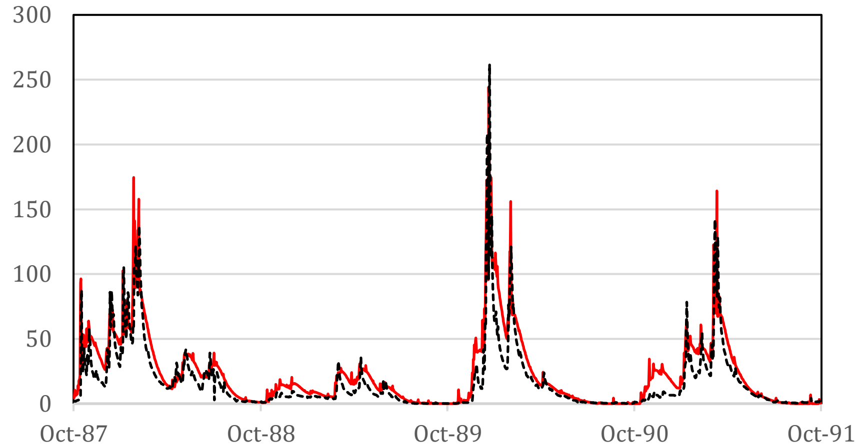
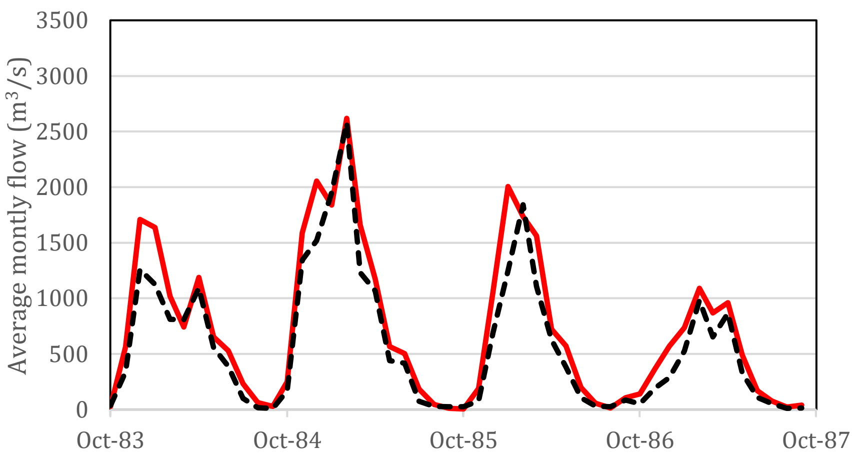
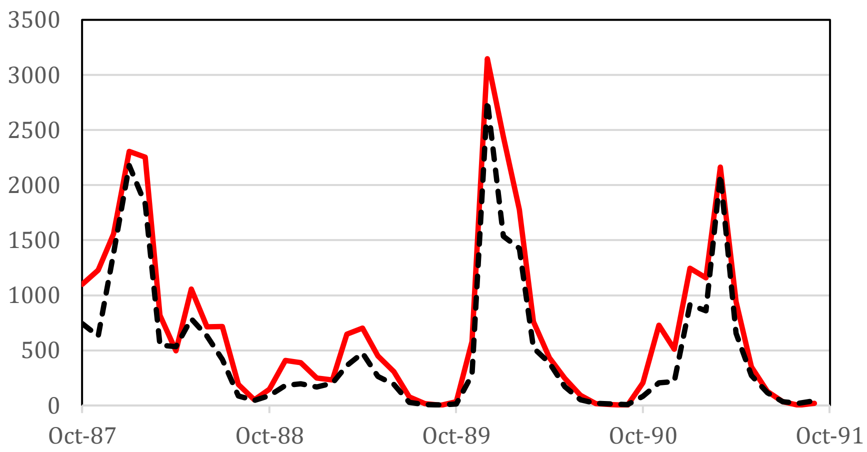
RH2 – Average flow		
		

	Calibration	Validation
	Parada Monteiros (R.E.) (04K/01H)	
		
RH3 – Average flow		

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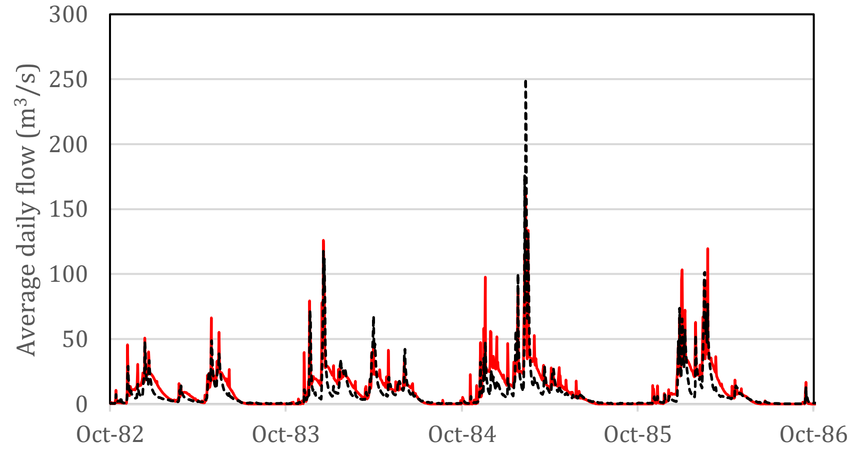
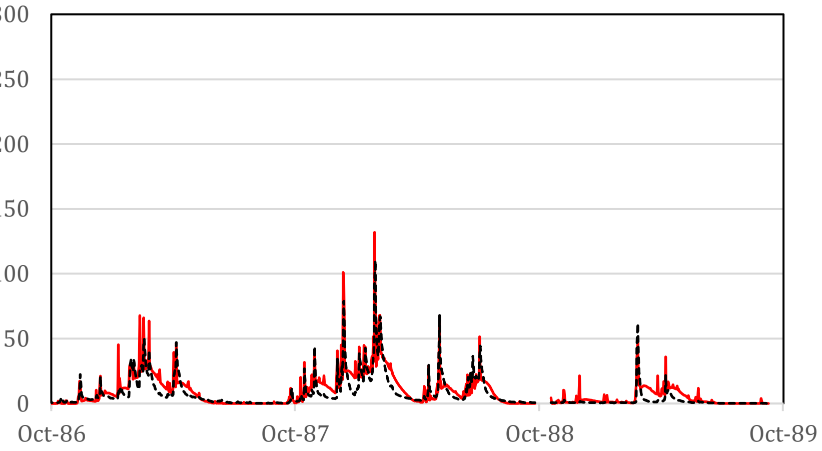
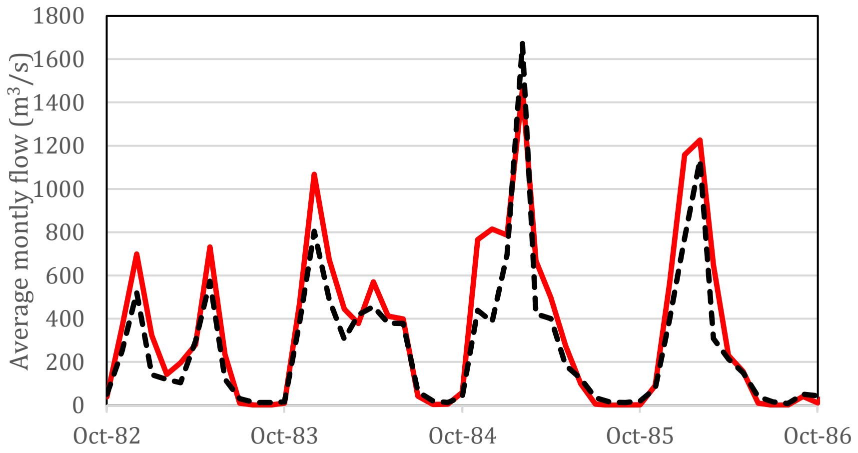
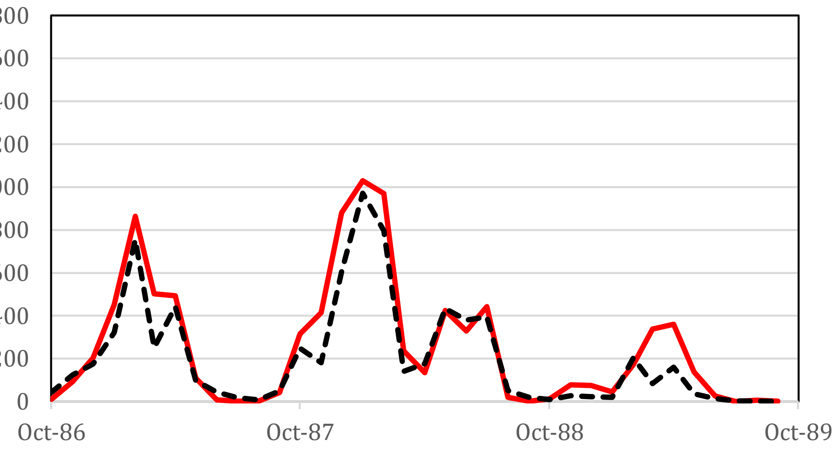
RH4 – Average flow		
		

	Calibration	Validation
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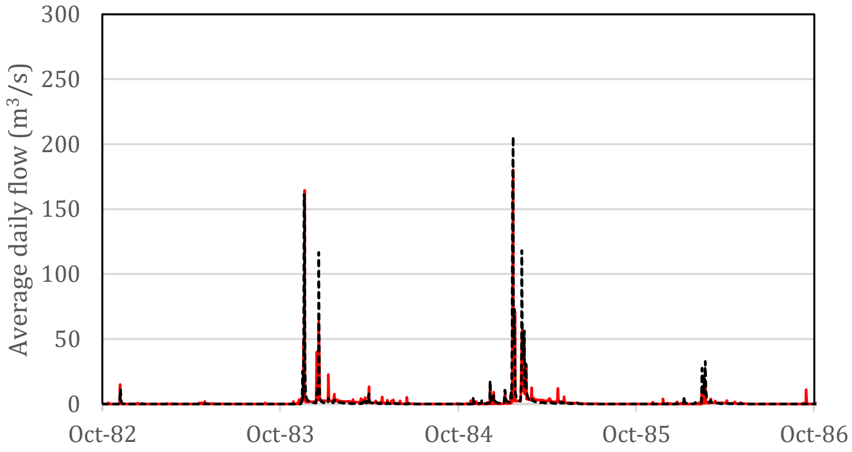
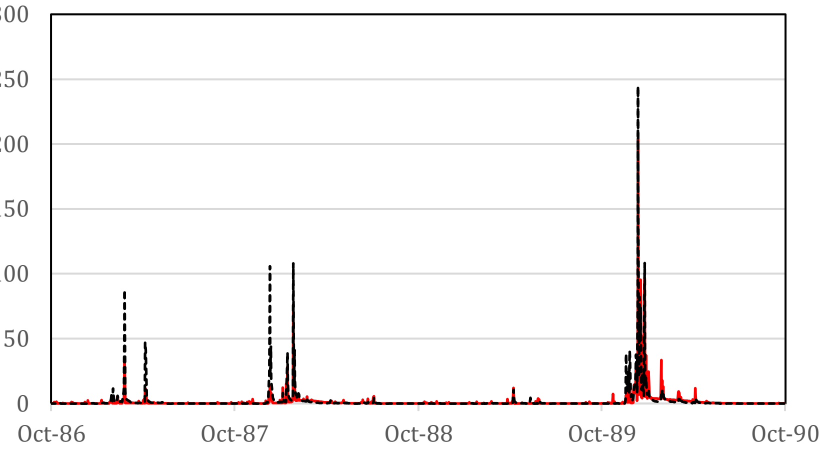
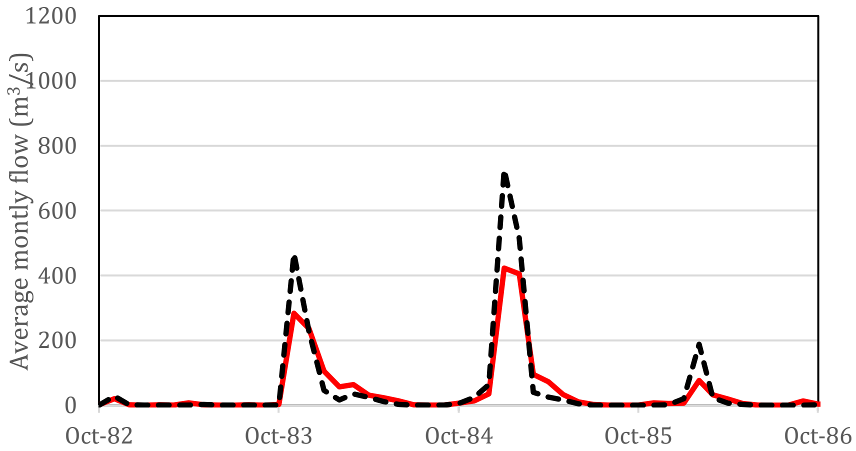
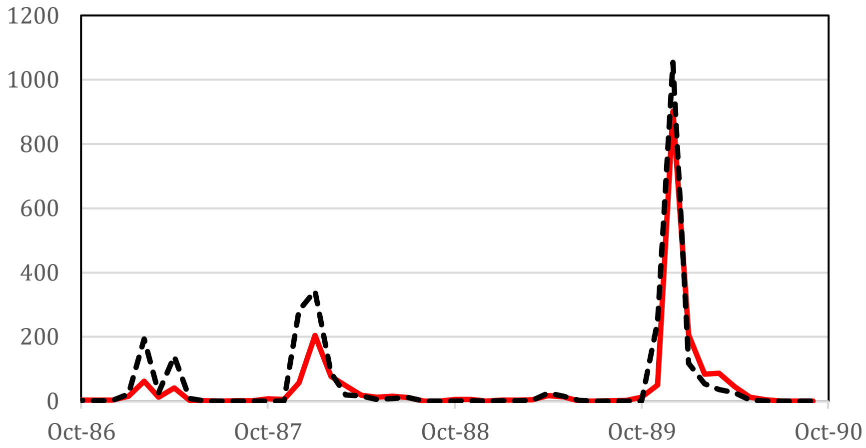
RH5 – Average flow		
		

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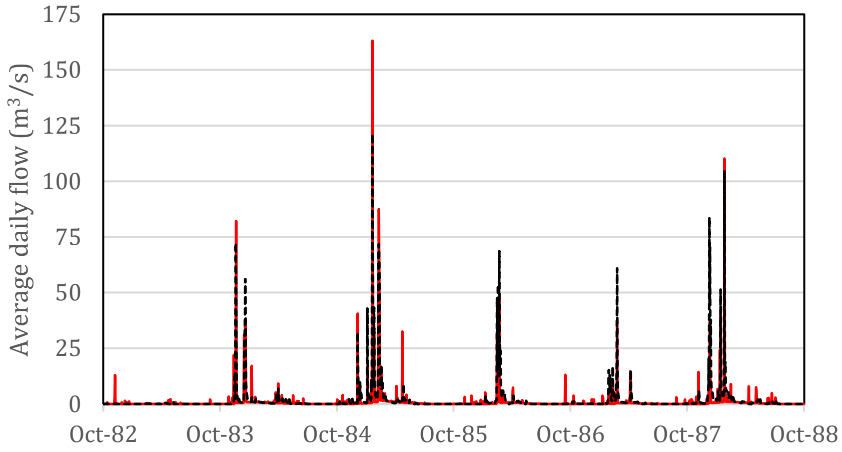

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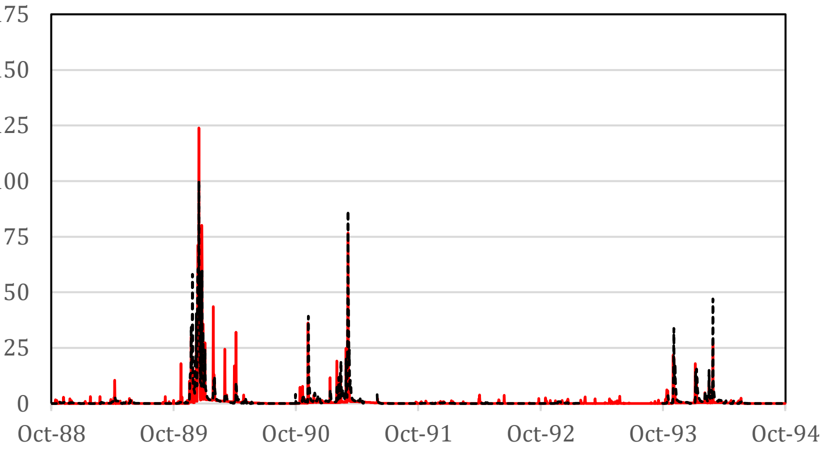

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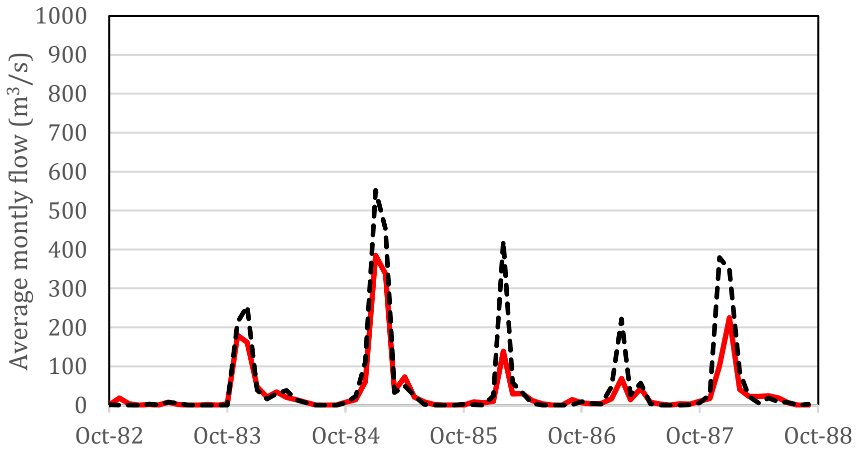

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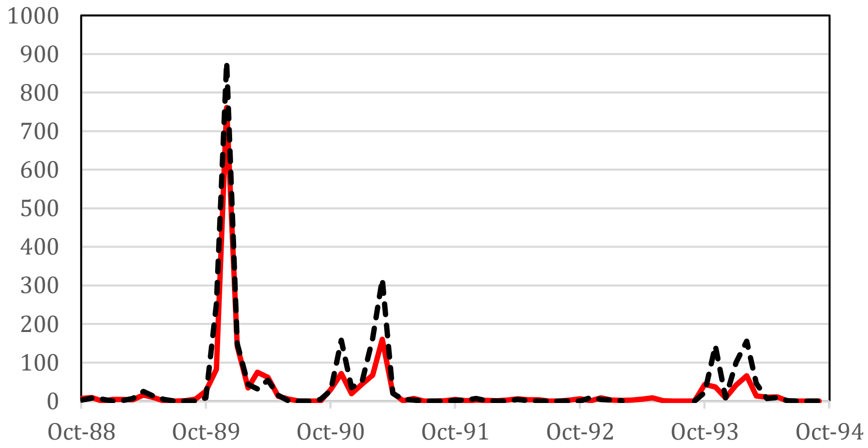

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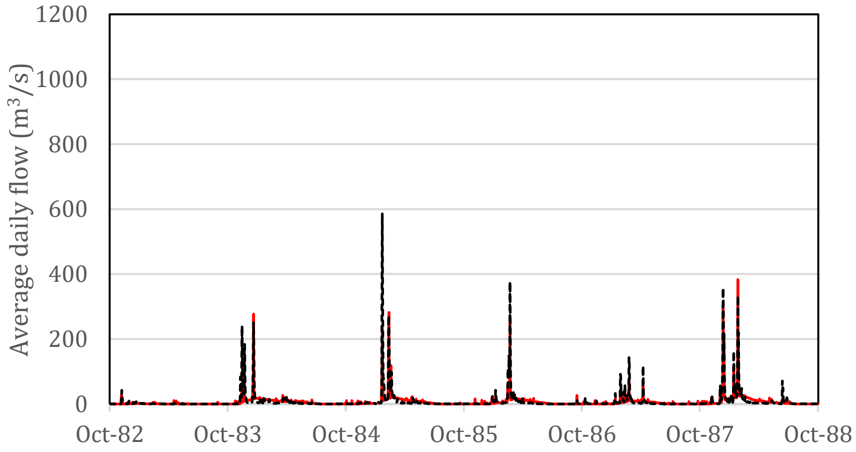
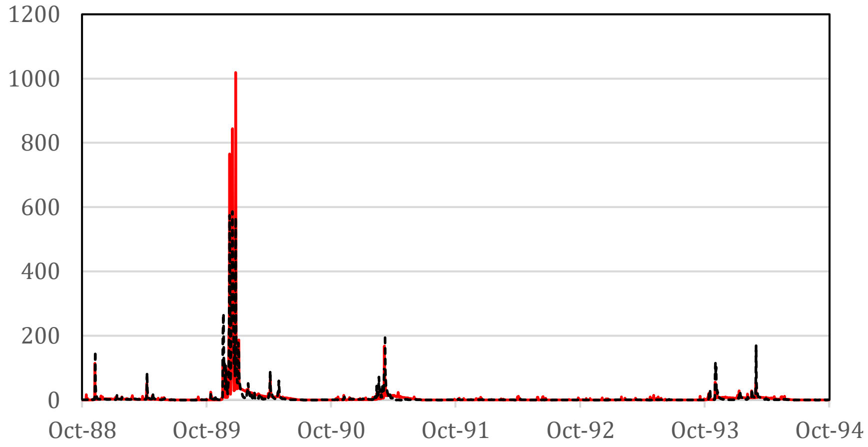
<tr><td></td><td>Calibration</td><td>Validation</td></tr>
<tr><td colspan="3">ARDILA (FOZ) (25M/01H)</td></tr>
<tr><td rowspan="2">RH7 – Average flow</td><td>
</td><td>
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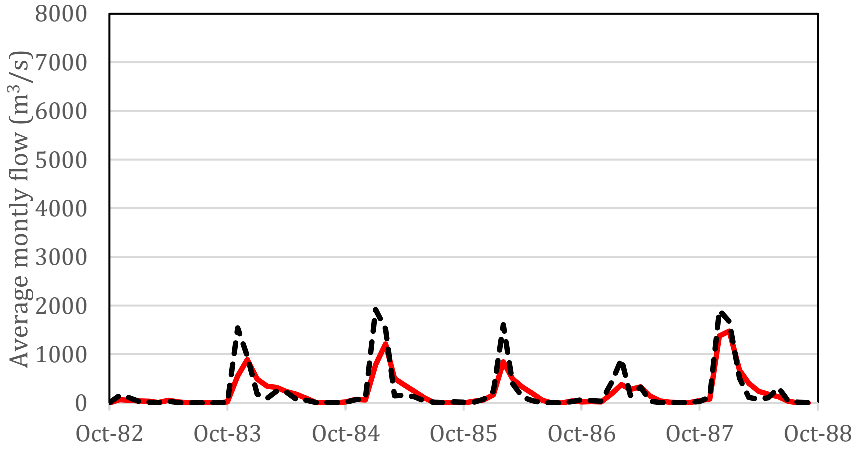
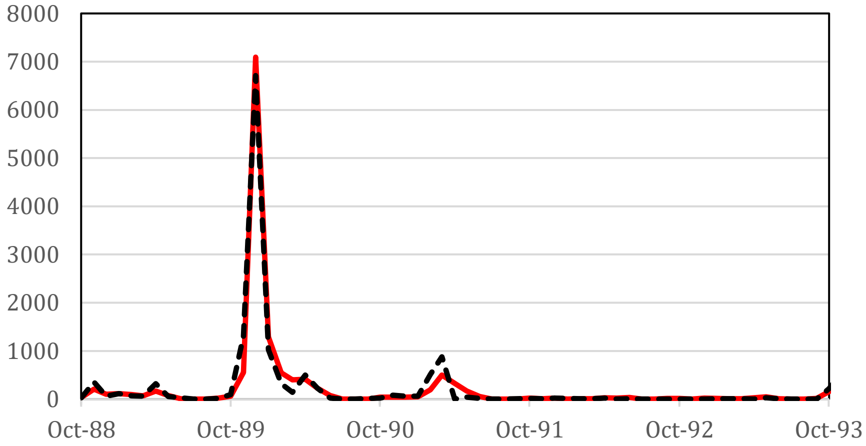
<tr><td>
</td><td>
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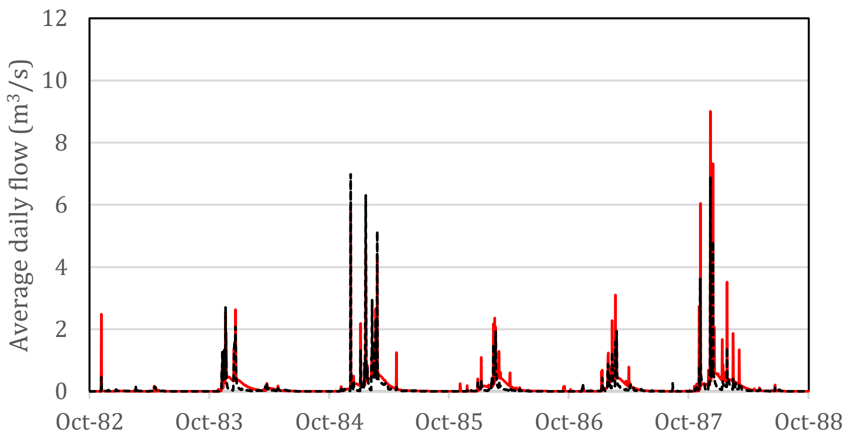
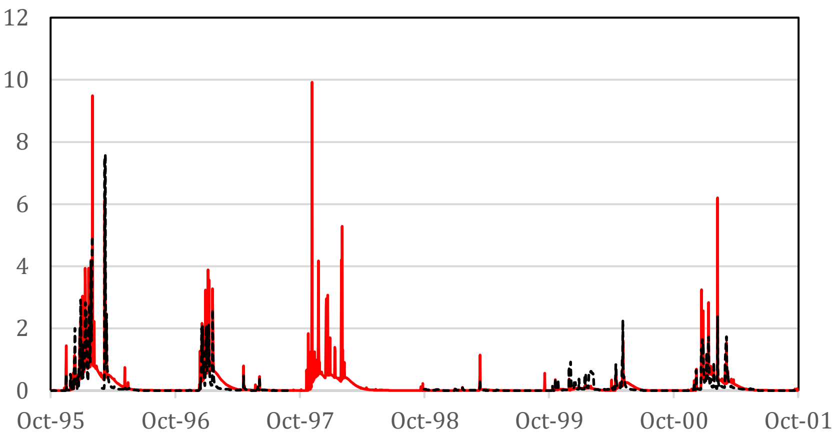
<table>
<tr><th></th><th>Calibration</th><th>Validation</th></tr>
<tr><th colspan="3">Vidigal (30F/02H)</th></tr>
<tr><td rowspan="2">RH8 – Average flow</td><td>
</td><td>
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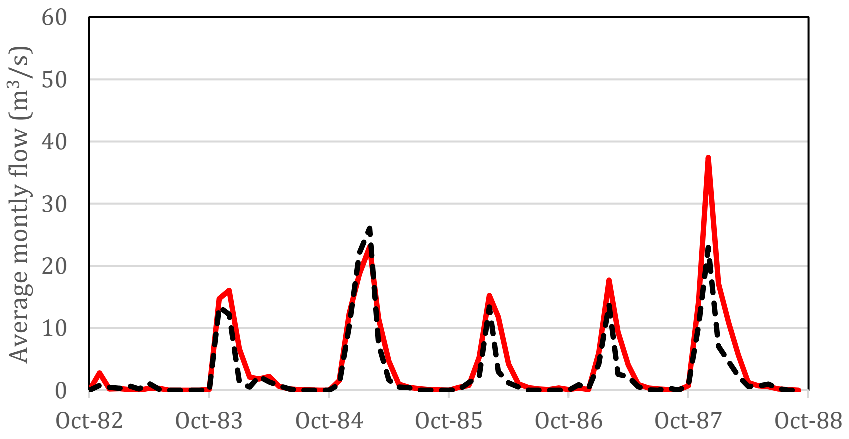
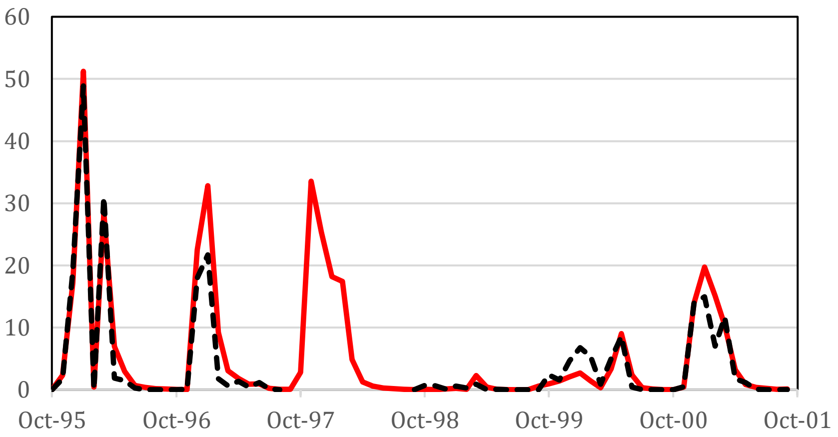
<tr><td>
</td><td>
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Table 14 - Comparison between observed and simulated flows for the calibration and validation period (daily and/or monthly).