Impacts of future climate change on water ecosystem services in the watershed of river Homem (Northwest Portugal)

Emanuel Nestor Escobar Juipa
Mestrado em Ecologia e Ambiente
Departamento de Biologia
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Orientador
Cláudia Carvalho-Santos, Investigadora Auxiliar, Centro de Biologia Molecular e Ambiental (CBMA), Universidade do Minho

Coorientador
João Pradinho Honrado, Professor Auxiliar, Faculdade de Ciências da Universidade do Porto

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Foreword

This study has already been presented as a poster presentation on:

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Abstract

The watershed of river Homem, in northwest Portugal, is an important water source for hydropower production, agricultural and urban use, and tourism activities, as well as for biodiversity conservation. Climate change is expected to alter the water cycle. In fact, climate models project an increase in temperature and a decrease in precipitation, affecting water resources and the provision of ecosystem services, in particular at the local level. The general objective of this study, performed in the watershed of river Homem, was to evaluate how future climate change may influence water resources, in order to support decision-making for watershed management. Two specific objectives were addressed: (i) to assess and map the baseline status of water ecosystem services provision; and (ii) to simulate how future climate change will potentially affect the provision of ecosystem services. Modelling exercises can be useful tools to forecast climate change impacts on ecosystem services provision. The Soil and Water Assessment Tool (SWAT) was calibrated and validated for the local conditions of Homem watershed (against daily and monthly discharge and monthly reservoir volumes). Future climate projections (2020-2050) were forced in SWAT, based on four regional climate models and two climate change scenarios (RCP 4.5 and 8.5), to be compared with the historical reference period (1970-2000). Our results confirmed that SWAT has a good performance in quantifying local water dynamics to support estimates of water ecosystem services. Climate change can affect the provision of water services in the focal watershed by reducing the quantity of water by 7% under RCP 8.5, also decreasing the high and low flows during wet and dry months, respectively. Reservoir volume may decrease and severely reduce hydropower production potential, mainly in summer. Soil erosion may increase by 76% (0.26 t/ha year), although still below the threshold of 1t/ha year established as tolerable rate (i.e. compensated by soil formation). These results are of high relevance for building adaptation strategies to reduce climate changes impacts, especially taking into consideration the current European Union focus on nature-based solutions. Overall, our results emphasize the need to evaluate the impacts of climate change at the local level to support strategies for sustainable watershed management.

Keywords: Mapping water ecosystem services; Homem watershed; SWAT; future projections

Resumo

A bacia hidrográfica do Rio Homem, no noroeste de Portugal, é uma importante fonte hídrica para a produção hidroelétrica, agrícola, urbana, turística e conservação da biodiversidade. Espera-se que as alterações climáticas alterem o ciclo da água no futuro. De acordo com os modelos climáticos, espera-se um aumento na temperatura e uma diminuição na precipitação com vincado aumento das diferenças sazonais, afetando os recursos hídricos e a prestação de serviços dos ecossitemas, em particular a nível local. O objetivo geral da tese, usando a bacia hidrográfica do Rio Homem como caso de estudo, foi avaliar como as mudanças climáticas influenciarão os recursos hídricos, para apoiar a tomada de decisões de gestão em bacias hidrográficas. Dois objetivos específicos foram estabelecidos: (i) avaliar e mapear o estado currente da provisão de serviços dos ecossistemas relacionados com a água; e (ii) estimar como as mudanças climáticas afetarão potencialmente a prestação destes serviços. Os exercícios de modelação podem ser ferramentas úteis para prever os impactos das mudanças climáticas na provisão de serviços dos ecosssitemas. A Ferramenta de Avaliação de Solo e Água (SWAT, da sigla em inglês) foi calibrada e validada para as condições locais da bacia do Homem (caudais diários e mensais, bem como volumes mensais da barragem). Projeções climáticas futuras (2020-2050) alimentaram o modelo SWAT com base em quatro modelos regionais de mudança climática e dois cenários (RCP 4.5 e 8.5), para serem comparados com o período de referência (1970-2000). Este estudo mostra que o modelo SWAT tem um bom desempenho na quantificação dos serviços dos ecossistemas relacionados com a água. Para além disso, foi demonstrado que as mudanças climáticas podem afetar a prestação de serviços de água, reduzindo a quantidade de água em 7% sob o cenário RCP 8.5, diminuindo também os caudais de pico e estivais durante os meses úmidos e secos, respectivamente. A diminuição do volume do reservatório pode reduzir drasticamente a produção de energia hidrelétrica, especialemente durante o verão. A erosão do solo poderá aumentar em 76% (0.26 t/ha year), mas ainda assim abaixo do limite toleravel de 1t/ha ano estabelecido como limiar para a formação de solo. É importante enfatizar esses resultados para a construção de estratégias de adaptação para reduzir os impactos das mudanças climáticas, tendo em consideração o foco atual da União Europeia no investimento em soluções baseadas na natureza. Em geral, os resultados enfatizam a necessidade de avaliar os impactos da mudança climática ao nível local para apoiar estratégias de gestão sustentável de bacias hidrográficas.

Palavras-chave: Mapeamento dos serviços ecossistémicos da água; Bacia do Rio Homem; SWAT; projeções futuras

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List of Abbreviations

EDP:	Energias de Portugal
ES:	Ecosystem Services
EU:	European Union
GCM:	General Circulation Model
HRU:	Hydrological Response Units
MA:	Millennium Ecosystem Assessment
InVEST:	Integrated Valuation of Ecosystem Services and Tradeoffs
IPCC:	Intergovernmental Panel on Climate Change
IPMA:	Instituto Português do Mar e da Atmosfera
LUC:	Land cover/use
NSE:	Nash–Sutcliffe Efficiency
PBIAS:	Percent bias
R^2:	Coefficient of determination
RCP:	Representative Concentration Pathways
SNIRH:	Serviço Nacional de Informação de Recursos Hídricos
SWAT:	Soil and Water Assessment Tool
ZPE:	Zona de Proteção Especial

1. Introduction

1.1. Biodiversity and ecosystem services

1.1.1. Nature, biodiversity and ecosystem services

Nature provides goods and services that contribute to improving a good quality of life and human well-being (Díaz *et al*., 2015; 2018). Life on Earth depends on the services that ecosystems provide (e.g. food, protection from disasters, water) (Lipton *et a*l., 2018). The effective functioning of these services is compromised when ecosystems are under pressure by habitat change, land use change, overexploitation, invasive alien species, pollution, and climate change (MA, 2005; Carvalho-Santos *et al*., 2014; Lipton *et al*., 2018). In addition, reports predict that these pressures will continue to increase during the first half of this century (MA, 2005). For these reasons, it is important to assess how ecosystem changes may affect human well-being in the following decades, and what would be the best responses to mitigate these effects and improve ecosystem management (MA, 2003).

Ecosystem services (ES) are the contributions that ecosystems provide to human well-being (MA, 2003; Haines-Young & Potschin, 2018;). According to the Millennium Ecosystem Assessment (MA), ES framework classification was primarily divided in four categories (Figure 1): (i) Supporting services are needed for the production of all other categories (e.g. nutrient cycling, soil formation, primary production); (ii) Regulating services are obtained from the regulation of ecosystem processes (e.g. climate regulation, water regulation, carbon sequestration); (iii) Provisioning services are the products, materials and goods obtained from ecosystems (e.g. food, freshwater, wood), and (iv) Cultural services are the non-material benefits that people obtain from ecosystems (e.g. aesthetic, spiritual, educational).

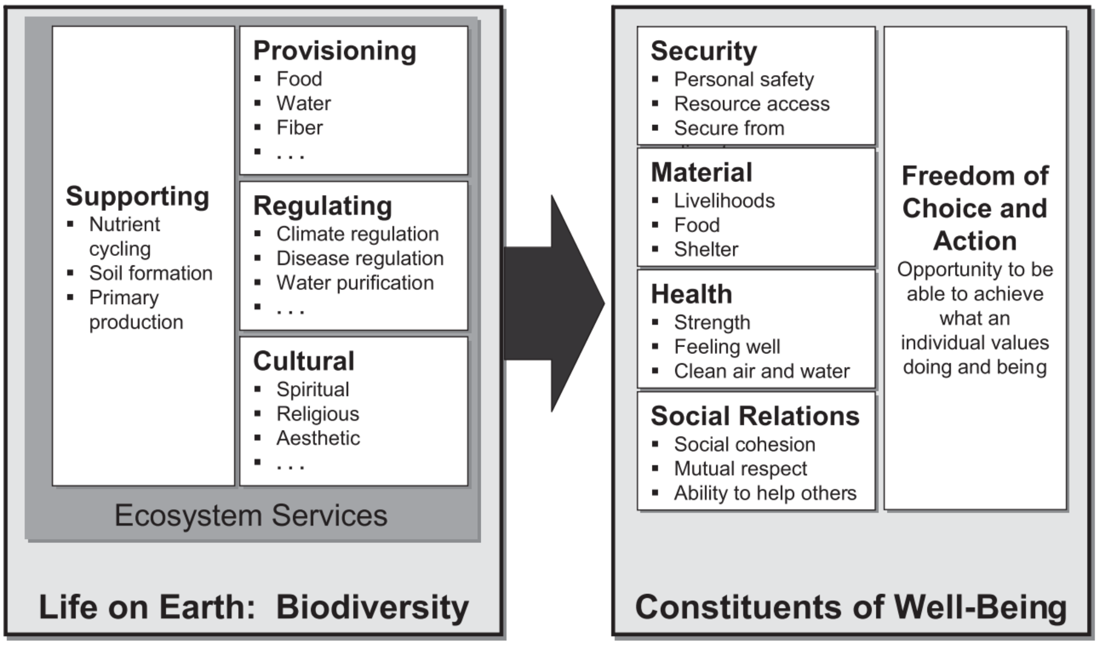

Figure 1. Linkages between the categories (supporting, provisioning, regulating and cultural) of Ecosystem services and human well-being. (Millennium Ecosystem Assessment, 2005).

Since then, many classifications of ES have been developed for different purposes. For instance, The Economics of Ecosystems and Biodiversity (TEEB) added economic concepts and values in biodiversity and ecosystem services (Sukhedv *et al*., 2010). The U.S. Environmental Protection Agency published the National Ecosystem Services Classification System (NESCS) included tracking linkages, and flows of final ecosystem services, between the natural environment and human welfare (EPA, 2015). And recently, The Common International Classification of Ecosystem Services (CICES), from the European Union, has updated for the version 5.1, which divides ES by hierarchical classification (section, division, group, class and codes) to avoid double-counting, including abiotic and biotic ecosystem services (Costanza *et al*., 2017; Haines-Young & Potschin, 2018).

In general terms, biodiversity means the number or richness of different species, but in fact is more complex than this (Brickhill, 2015). According to the Convention on Biological Diversity (CBD), biodiversity is the variability of life, including diversity within species, among species, and of ecosystems (Common Agricultural Policy and farmland biodiversity in an enlarged EU, 1992). Also, it encompasses the variety of life at all levels of organization, classified both by evolutionary (phylogenetic) and ecological (functional) criteria (Colwell, 2009). Biodiversity and ecosystems are closely related concepts (MA, 2003) and are intrinsically linked (Harrison *et al*., 2014). Biodiversity is a fundamental structure in ecosystem functioning (Cardinale *et al*., 2012) and supplies the demand of ecosystem services (Teixeira *et al*., 2019). Mace *et al*. (2012) remarked that biodiversity plays a pivotal role in ecosystems, such as a regulator of ecosystem processes (soil formation), as a final ecosystem service (cultural for having iconic species for conservation), and as a good (timber).

The interactions to produce ecosystem services are complex to understand, because ecosystems are multidimensional, driven by the flows of energy, matter, information, and humans are an integral part too. Figure 2 represents a better dynamic system to understand all the factors that are involved to produce ecosystem services. Natural energy drives an important role in the interactions between the ecosystems with biotic and abiotic components to support ecosystem services. The services provided by ecosystems is also referred to as natural capital. Natural capital must interact with other forms of capital such as built, human and social or cultural, which must be supported by policy and management to maintain the adequate function of ecosystems and subsequently provide benefits to human well-being (MA, 2003; Costanza *et al*., 2017;).

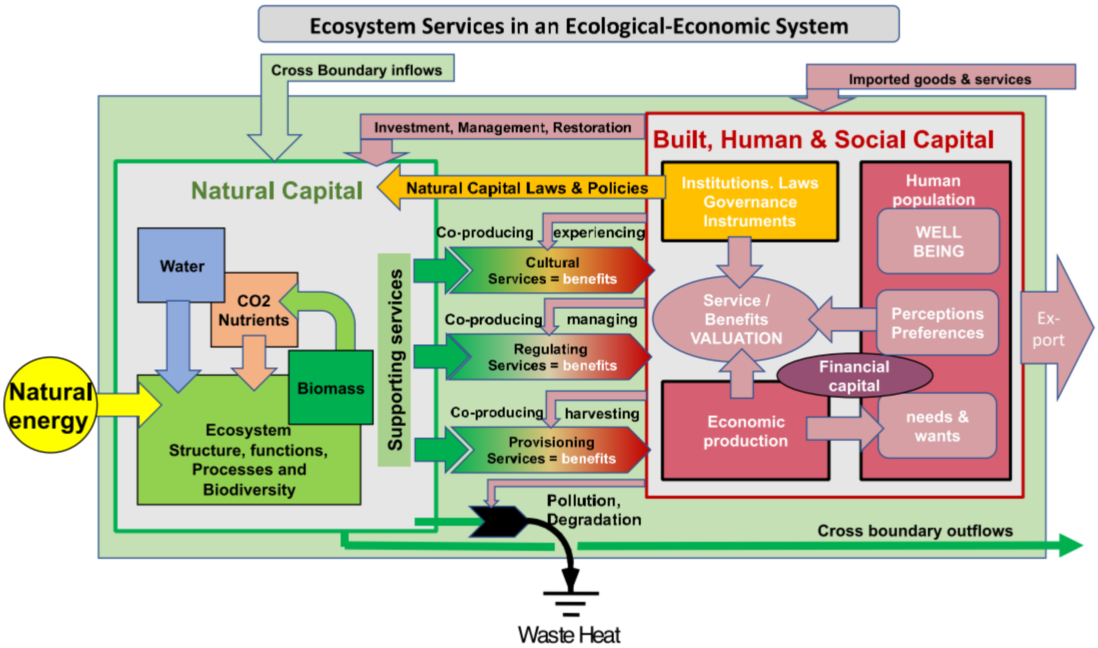

Figure 2. A dynamic system capturing the complex interactions needed to produce ecosystem services at the regional scale (Costanza *et al*., 2017).

1.1.2. Mapping ecosystem services

Mapping ecosystem services helps to understand how ecosystems provide services to human well-being (Burkhard & Maes, 2017). In addition, mapping is a fundamental process to understand and visualize the spatial distribution of services at local, regional and global scale (Häyhä *et al*., 2015). In the last decade, mapping Ecosystem Services has turned gradually an important role in policy and decision-making (Seppelt *et al*., 2011) to promote nature conservation (Maes *et al*., 2015). For instance, the EU Biodiversity Strategy to 2020 established a plan to map and assess the state of ES at national level. Also, each member state of the EU, has to assess the economic value of each Ecosystem Service, and promote the integration of these values in decision making. Crucial issues can be mapped such as: (i) how optimizing ecosystem services promote biodiversity benefits, and vice versa; (ii) how many factors can affect the provision of ecosystem services; (iii) the synergies and trade-offs between different ES; and (iv) the space variability of supply and demand of ecosystem services (Brickhill, 2015).

1.2. Water cycle and resources

1.2.1. Water cycle

Water, indispensable for life on Earth, plays a central role in the ecosystems. It exists in every accessible environment on or near the earth's surface like trees, air, glaciers, streams, lakes, oceans, rocks, and soils (Fitts, 2002; Hagemann *et al*., 2011). Around 70% of the Earth's surface is covered by water. However, 97 % of total water is saline water, stored in oceans, and the remaining 3 % is freshwater. From that 3%, about 2.5 % is frozen in polar ice and stored in groundwater, and surface water is only 0.5 %. An estimate of this surface water, 2 % is found in rivers, 11 % percent in swamps, and about 87 % is contained in lakes and reservoirs (Baker *et al*., 2013).

Water cycle is not merely a circulation of water among oceans, lakes or rivers; it is also a process of purification through the natural cycles with changes on its different states (solid, liquid and vapor) (Oki & Kanae, 2006; Wang, Zhang *et al*., 2015). Additionally, water cycle plays a critical role in the physical functioning of the earth system, as the water phase changes from liquid to vapor, requiring and releasing substantial amounts of heat (Kleidon & Renner, 2013). Solar radiation influences the water cycle (Figure 3) and its movements on Earth (Fitts, 2002). Basically, these movements are described by van Brahana (2008), and include the following: (i) evaporation: water from oceans and open bodies evaporates into the atmosphere; (ii) evapotranspiration: water from plants and soil turns into atmospheric vapor; (iii) condensation: water vapor condensates in liquid or solid (clouds); (iv) precipitation: condensed water or ice falls from the atmosphere back to the ground surface; (v) surface runoff: transport of the precipitated water along a surface slope down to streams, rivers, lakes and oceans, where evaporation and water cycle will take place again; and (vi) infiltration: precipitation infiltrates into subsurface (soil or groundwater) and discharge in their respective reservoirs.

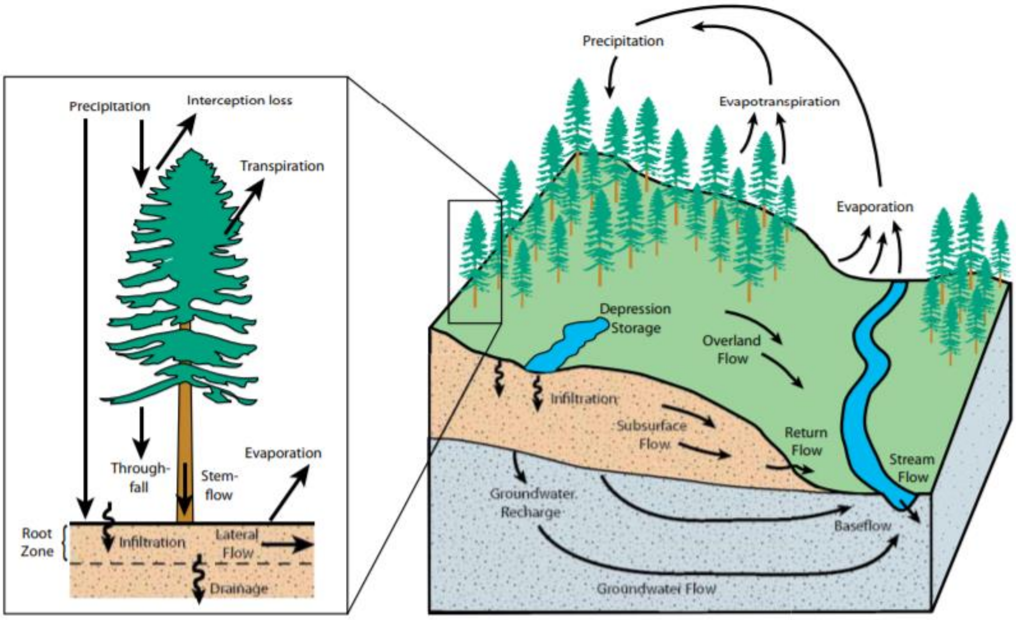

Figure 3. Hydrologic cycle and stand water balance (Winkler *et al*., 2010).

In the hydrological cycle, the annual amount of water should always be dynamically balanced. This dynamic is a precondition for each water body to be with an approximate set amount of water in it. Natural ecosystems such as forests and wetlands play a significant role in managing the hydrological cycle. Vegetation allows the infiltration of water into the soil, recharging the underground aquifers, lowering flood risk and reducing soil erosion (Acreman, 1999).

1.2.2. Reservoirs

Reservoir, an artificial lake, is a water body blocked and contained by embankments or dams (Thornton *et al*., 1996; Uhlmann *et al*., 2010). Dams intercepts the natural course of a river, inundating the upstream (Thornton *et al*., 1996). Galizia Tundisi (2018) considered that reservoirs are artificial ecosystems controlled and managed by humans. According to the World Register of Dams, the current number of large dams (impounding more than 3 million m^3) is more than 58 000 around the world

(ICOLD, 2018), and 85 are in Portugal (EDP, 2012). In fact, reservoirs, essential for water security, have a high level of multi-functionality (Nestmann & Stelzer, 2007) such as water supply (Vicente-Serrano *et al*., 2016), hydropower (Carvalho-Santos *et al*., 2017), irrigation (Tinoco *et al*., 2016), flood regulation (Vicente-Serrano *et al*., 2017) and demand of freshwater (Hogeboom *et al*., 2018). On other hand, all the watersheds with reservoirs are affected by their construction and triggering different problems: displacement and relocation of people (Richter *et al*., 2010), modifying the hydrological regimes of streams (Santos *et al*., 2017), fragmentation of habitats and biodiversity loss (Marques *et al*., 2018), and changes in the natural flow of sediments in the rivers (Zarfl & Lucía, 2018). To reduce these impacts, scientists, water resource managers, and policy leaders are implementing environmental flows in dams (Lehner *et al*., 2011). The Brisbane Declaration defines an environmental flow, as *an appropriate quantity, quality, and timing of water flows required to sustain freshwater and estuarine ecosystems and the human livelihoods and well-being that depend on these ecosystems* (The Brisbane Declaration, 2007). Recent studies identified pressures (e.g. climate change, overpopulation) that would affect reservoirs for the next decades. These studies project hydropower productivity to be reduced in 10 % to 50% under climate change (Lobanova *et al*., 2016) and water quantity stored may be reduced by 2050, committing several uses (Carvalho-Santos *et al*., 2017; Naz *et al*., 2018).

1.3. Water and ecosystem services

1.3.1. Water ecosystem services

Ecosystem services, important for water resources, provide benefits to humans and society (MA, 2003). People rely on ecosystems to provide many water-related services from the supply of water for household use to the mitigation of flood damages. Brauman (2015) described hydrological services as the way terrestrial ecosystems affect freshwater resources. In addition, water services, the benefits that people receive, are organized into five categories (Figure 4): (i) diverted water supply, includes uses for municipal, agricultural, commercial, industrial, and thermoelectric power use; (ii) in situ water supply, includes hydropower generation, water recreation, and transportation, and freshwater for fish production; (iii) water damage mitigation, includes the regulating services of ecosystems that mitigate flood damage, sedimentation of water bodies, saltwater intrusion into groundwater, and dry- land salinization; (iv) spiritual and aesthetic including the spiritual uses, aesthetic appreciation, and tourism; and (v) supporting includes the provision of water for plant growth and to create habitat for other organism.

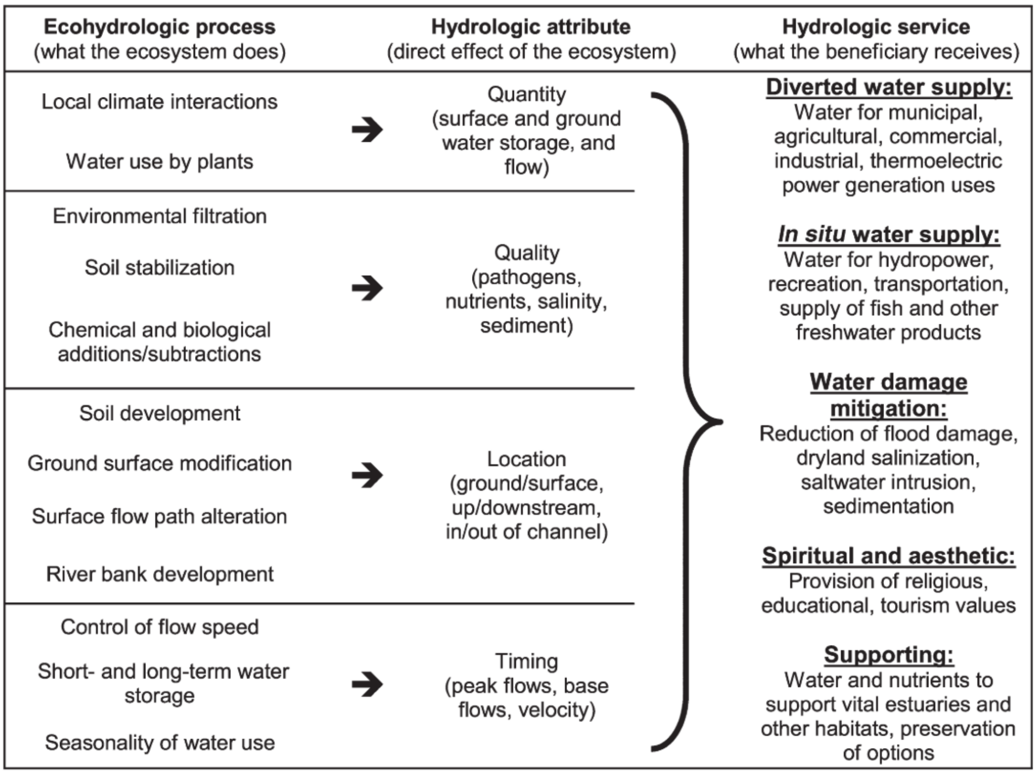

Figure 4. Relationship of hydrologic ecosystem processes to hydrologic services. Each service has attributes of quantity, quality, location, and timing of flow. For example, water for hydropower production requires not only quantity of water, but also requires seasonal timing for the entire year. A number of ecosystem processes affect each attribute (Brauman *et al*., 2007).

Hydrological attributes, directly impacted by ecosystems, are defined by quantity, quality, location and timing of flow (Brauman *et al*., 2007; Elmqvist *et al*., 2010; Carvalho-Santos *et al*., 2013). Impacted attributes could improve or degrade the supply of hydrological services. Different ecohydrologic processes may have competing effects on the same attribute or have simultaneously positive and negative effects on different attributes of a particular service (Brauman *et al*., 2007).

1.3.2. Tools for mapping water ecosystem services

In the past few decades different tools and models for mapping water and hydrological services have evolved, and these advances have helped to quantify ecosystem services processes (Burkhard & Maes, 2017; Francesconi *et al*., 2016). These models can evaluate, track, asses and forecast the quantity, timing, and quality of water resources and, therefore, help in the water management and understanding the interactions of the water cycle with climate and ecosystem services (Carvalho-Santos, 2014).

Different hydrological tools has based on river basin scale for better water resource management. Currently two groups of hydrological services models exist: (i) a traditional hydrological tool, such as SWAT (Soil and Water Assessment Tool) (Arnold *et al*, 1998) or VIC (Variable Infiltration Capacity) (Liang *et al*., 1994); and (ii) new group of ecosystem services specific tools, such as InVEST (Integrated Valuation of Ecosystem Services and Tradeoffs) (Tallis & Polasky, 2009) and ARIES (Artificial Intelligence for Ecosystem Services) (Villa *et al*., 2009). Each model requires various and different inputs (e.g. precipitation, topography, soil type, land cover) that provide specific outputs (e.g. water yield, evapotranspiration, sediment retained) (Vigerstol & Aukema, 2011). Traditional hydrological models, robust tools, need a detailed dataset for measure the volume and quality of water on a daily basis at the watershed scale (Arnold *et al*., 2012a), and require expert knowledge to handle them. It should be emphasized that each model has advantages and disadvantages in measuring ecosystem services, and the correct use depends on data availability, study area scale, knowledge about models, and detailed or generic ecosystem services information (Bagstad *et al*., 2013; Sharps *et al*., 2017; Neugarten *et al*., 2018).

1.3.3. The Soil and Water Assessment Tool (SWAT)

1.3.3.1. Definition

Soil and Water Assessment Tool (SWAT) is a hydrological model, developed by US Department of Agricultural Research. SWAT is a physically based, deterministic and semi-distributed model to assess the impact of management and climate on water supplies and non-point source pollution in the watershed, in small to large river basins. SWAT operates on a daily time step, and is used for routing runoff and chemicals through a watershed, and for routing flows through streams and reservoirs over long time of periods (Arnold & Fohrer, 2005).

1.3.3.2. Current application of SWAT

Since SWAT was created in the early 1990s, it is being recognized as an integrated tool for multi-disciplinary studies at the regional scale in different physiographic and climatic conditions, and is now one of the most widely applied river basin-scale models. For instance, SWAT was applied for multiple topics such as nutrients and conservation analysis, climate change impact, land-use change impact impoundments and wetlands, irrigation, bioenergy crops, and combined climate and land-use change impacts (Krysanova & White, 2015). Additionally, SWAT has been used as an effective tool for mapping water ecosystem services. Provisioning and regulating services are the most commonly analyzed and measured, and, on the other hand, supporting and cultural services are less evaluated (Francesconi *et al*., 2016). At the beginning, SWAT was only being applied in the United States; however, it has been popularized around the world. Portugal is a clear example of SWAT application, and it has been applied for different country regions such as in the north (Carvalho-Santos *et al*., 2016a; 2017), and in the center to south (Nunes *et al*., 2008).

1.4. Climate change and impacts on water resources

As defined by the World Meteorological Organization, climate is the average weather values, or more rigorously, as the statistical description in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands of years. The classical period for averaging these variables is 30 years (climatic normal). Temperature and precipitation are the most commonly values used; however, other values may include wind, solar radiation, pressure and relative humidity (Houghton, 2002).

Climate change is an alteration of climate generated by direct or indirect human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time period (IPCC, 2007). Since of the industrial revolution, human activities have caused an increase in temperature about 1.0°C, and it is expected to reach 1.5°C for 2050 (IPCC, 2018). Climate change is anticipated to impact all the levels of biodiversity and ecosystem functioning (Bellard *et al*., 2014), which consequently affects the provision of ecosystem services (Brickhill, 2015). Moreover, changes in temperatures are expected to accelerate the water cycle, with more increase rates of evaporation and precipitation (Oki & Kanae, 2006; Kundzewicz, 2008). Precipitation is expected to increase globally and in many river basins, but to decrease in many others. Furthermore, precipitation may increase in one season and decrease in another (IPCC, 2007). Several hydrological ecosystem services may be affected such as water supply, control of floods and water quality (Veiga da Cunha *et al*., 2005).

General Circulation Model (GCM), a type of climate model, is used for weather forecasting, understanding the climate and projecting climate change (Ghil & Robertson, 1999). GCM can be an effective tool to model and project changes on water resources under climate change scenarios for different scales. For example, global surface runoff (Figure 5) is expected to increase in high latitudes of North America and Eurasia, with increases of 10 to 40% until the end of the 21st century. With higher uncertainty, surface runoff can be expected to increase in the wet tropics by 10 to 30% including the Mediterranean, southern Africa, and western USA and Mexico (Milly *et al*., 2014).

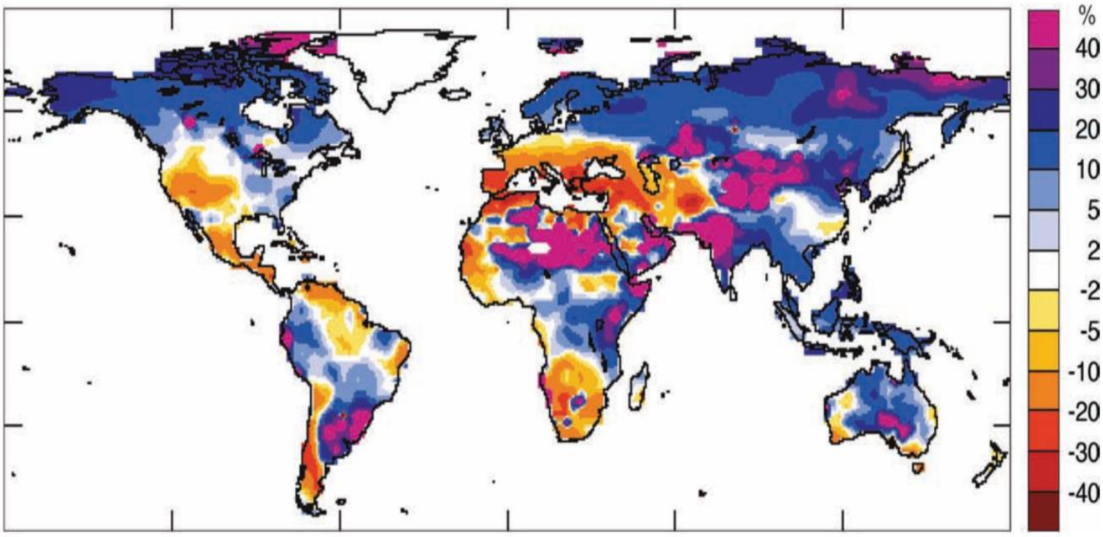

Figure 5. Change in annual surface runoff by 2041-60 relative to 1900-70, in percent, under the SRES A1B emissions scenario and based on an ensemble of 12 climate models (IPCC, 2007).

Another projection illustrated that significant changes in drought are expected in Europe (Figure 6). The region is most prone to a rise in flood frequencies are northern and north-eastern Europe, while southern and south-eastern Europe show significant increases in drought frequencies by 2070. Models estimated that a 100-year drought of today magnitude would return more frequently than every 10 years in parts of Spain and Portugal, western France, Poland, and western Turkey (Lehner *et al*., 2006)

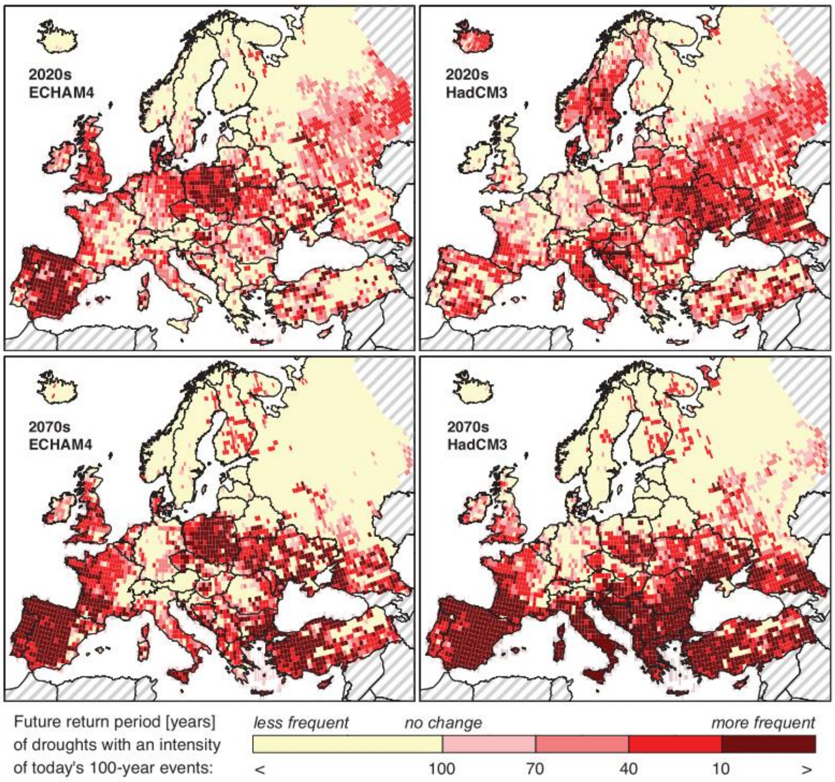

Figure 6. Change in recurrence of 100-year droughts, based on comparisons between today's climate and water use (1961–1990) and simulations for the 2020s and 2070s (Lehner *et al*. , 2006).

At the national scale under the scope of Climate Change in Portugal, Scenarios, Impacts and Adaptation Measures (SIAM) project, Portugal may suffer a decrease in precipitation with more evapotranspiration related to temperature increase. Models did not show a clear tendency of annual surface runoff; however, all the models emphasize a reduction of surface runoff in summer and spring. As shown in figure 7, the severest scenario model, HadCM3-A2c, predicts a surface runoff reduction by 2100 between 30 % in the north Douro, and 80% in Algarve. Another model, HadRM2, predicts an increase from 20% to 40% (Veiga da Cunha *et al*., 2006).

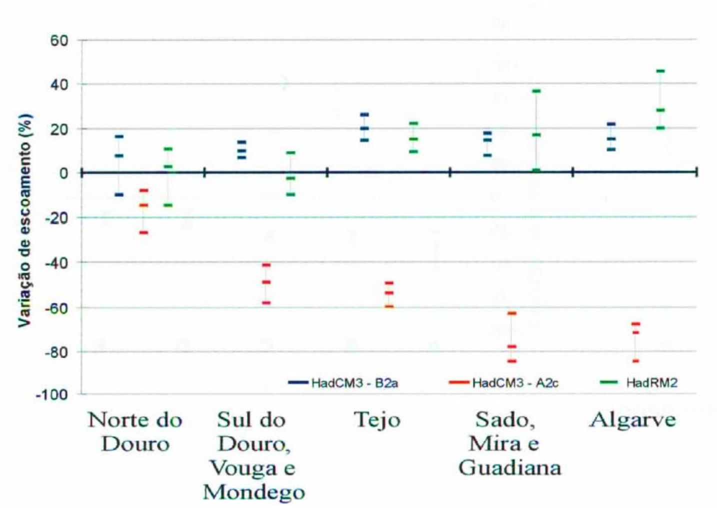

Figure 7. Annual surface runoff variability by 2100 (Veiga da Cunha *et al*., 2006).

Climate change may affect water resources at all scale levels. In other words, consideration of climate change in planning and management of water resources is crucial. Climate change projections are provided at global and continental spatial scale (IPCC, 2007). However, these projections do not define the particular needs of sub-national plans (Trzaska & Schnarr, 2014). The effects of climate change lead to challenges for stakeholders in water resources, who need to define and implement strategies at the regional to local level, in order to reduce vulnerability (Campos *et al*., 2017). On the other hand, decision-makers are increasingly demanding climate information at the national to local scale in order to address the risk posed by projected climate changes and their anticipated impacts (Trzaska & Schnarr, 2014). Hence, it is important to transpose global climate information into regional or local climate information, which can assist in assessing local impacts (Flato *et al*., 2013).

Several studies assessed the effects of climate change on water resources management in Portugal, predicting a decrease in annual discharge in rivers, mainly in spring and summer (Nunes *et al*., 2008; Carvalho-Santos *et al*., 2016a). Some studies had evaluated combined effects of climate and land cover change (Carvalho-Santos *et* *al*., 2016a), as well as climate effect on of the functioning of dams for water storage and hydropower production (Lobanova *et al*., 2016; Carvalho-Santos *et al*., 2017). These future projections have shown that dam water levels can be severely affected by climate change. With this in mind, it is crucial to adopt regional and national strategies to adapt to climate change. For instance, the EU strategy aims to make Europe more climate-resilient by improving the management of water resources and ecosystems (European Commission, 2009). At national level, Portugal has been developing its National Strategy for Adaptation to Climate Change to manage water resources as a priority problem.

1.5. Motivation

As previously described, people are dependent on water ecosystem services for their survival and quality of life (Brauman *et al*., 2007). Water is a critical component in maintaining ecosystem functions, and determines the characteristics of several services (Coates *et al*., 2013). In many countries, water resources are under pressure by rapid population growth and climate change. Climate change is expected to affect water resources and cause serious impacts on local watersheds (IPCC, 2001), and subsequently may reduce the capacity of ecosystems to provide hydrological services (Bangash *et al*., 2013). The Mediterranean region, particularly Portugal, is highly susceptible to climate change (Giorgi, 2006; Bangash *et al*., 2013), and in some summers suffers water stress and droughts which results in less water availability (Nunes *et al*., 2008).

Homem watershed is very valuable for the preservation of water resources and biodiversity conservation, being one third inside Peneda-Gerês National Park. Therefore, it is essential to map, quantify and monitor the current water ecosystem service and to assess the effects of climate change on ecosystem services at local scale (Trzaska & Schnarr, 2014). Apart from this, water ecosystem services under future climate projections can help to determine the choices that local stakeholders will take over the next few decades for a successful management and planning of water resources.

1.6. Objectives

The general objective of this research, performed in the watershed of river Homem (northwest Portugal), was to evaluate how future climate change may influence water resources, aiming to support decision-making for knowledge-based watershed management. The services to be quantified were: water supply (provisioning service), water timing (regulation service), and soil erosion control (regulation service).

Two main specific objectives were established and addressed in sequence:

(i) to assess and map the baseline status of hydrological ecosystem services provision at the watershed scale; and

(ii) to simulate how future climate change will potentially affect the provision of hydrological ecosystem services.

2. Data and Methods

2.1. Study area

2.1.1. Homem River watershed

Homem watershed, located in the Peneda-Gerês National Park (northwest of Portugal), has an approximate area of 257 km^2 and is one of the main tributaries of Cávado River. Average precipitation varies from 1600 mm/year (Caldelas station) in the valley and 2100 mm/year (Portela do Homem station) in the highlands, with heavily precipitations from October to April (autumn–winter). Topography (Figure 8) ranges from 21 m to 1 508 m. Slope ranges in classes from 0-10 %, 10-25 % and > 25 % in 20 %, 36 % and 44 % of the watershed territory, respectively. The geological landscape is strongly marked by granites massif and small bands of schist, and five main soil types (Figure 9) characterizing the watershed: Humic Regosols (43 %) and Eutric Leptosols (26 %) prevail in highlands; Dystric Antrosols (27 %), Fluvisols (2 %) and Urban (2 %) in lowlands.

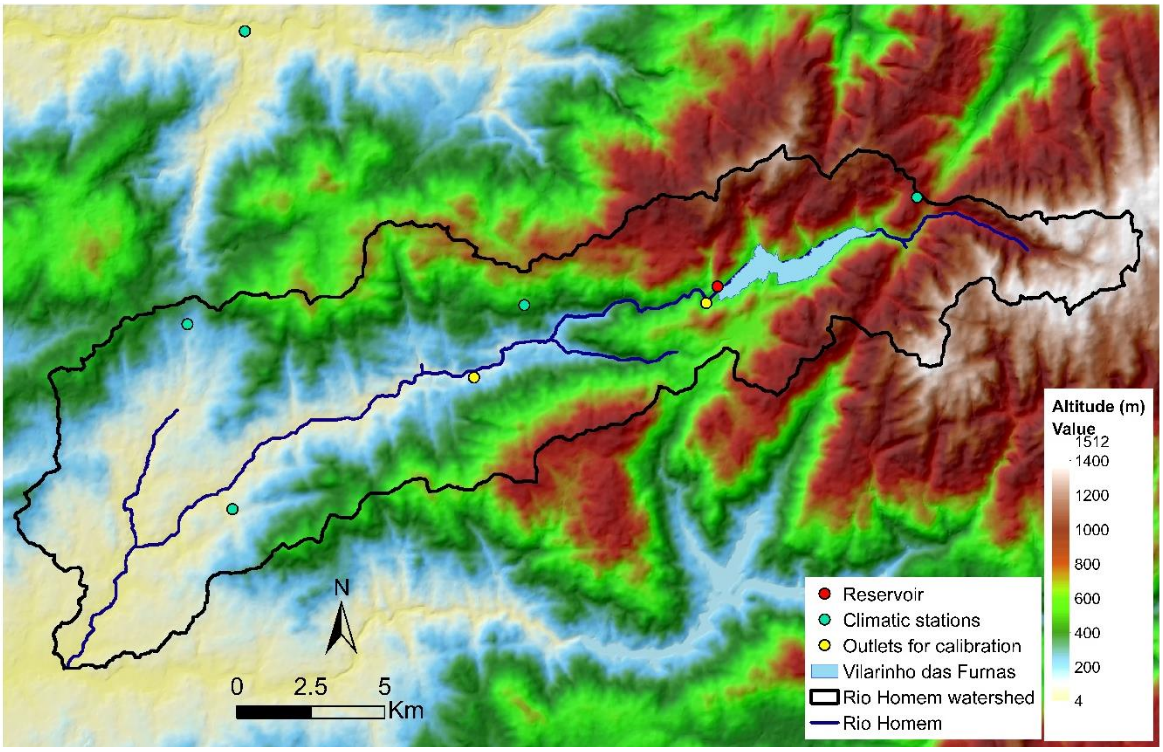

Figure 8. Study area, Homem River watershed with observed climatic stations (black line limits). Source: Copernicus Programme (2016).

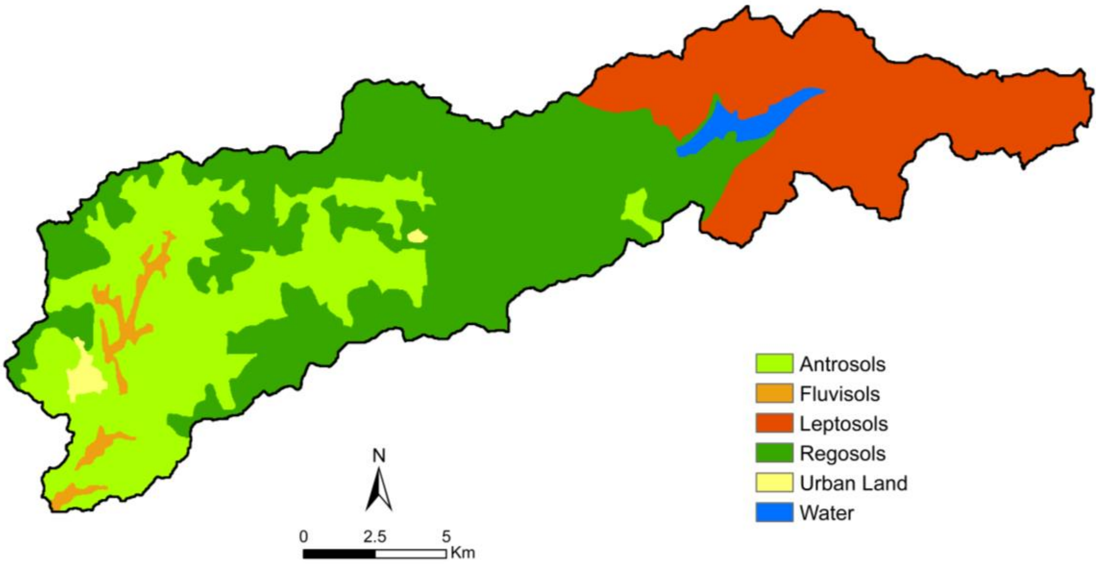

Figure 9. Soils classification of Homem watershed. Ministry of Agriculture, performed by Agroconsultores & Geometral (1995).

Concerning land cover/use (LUC), Homem watershed is highly influenced by Vilarinho das Furnas reservoir and in particular by the presence of the mountainous and natural landscape upstream the reservoir and the lowlands downstream the reservoir where urban, forest and agricultural areas prevail. The top of the mountains is associated with open areas of bare rock and sparsely vegetation. Shrublands with scattered woodland areas occupy the medium and high altitudes of the mountains. At lowlands, traditional agricultural land is associated with forest areas of European oak (*Quercus robur*), Eucalypts (*Eucalyptus globulus*), and Maritime pine (*Pinus pinaster*). At the margins of the Homem River, urban areas are established mainly in downstream areas, but usually with low density (Table 1 and Figure 10).

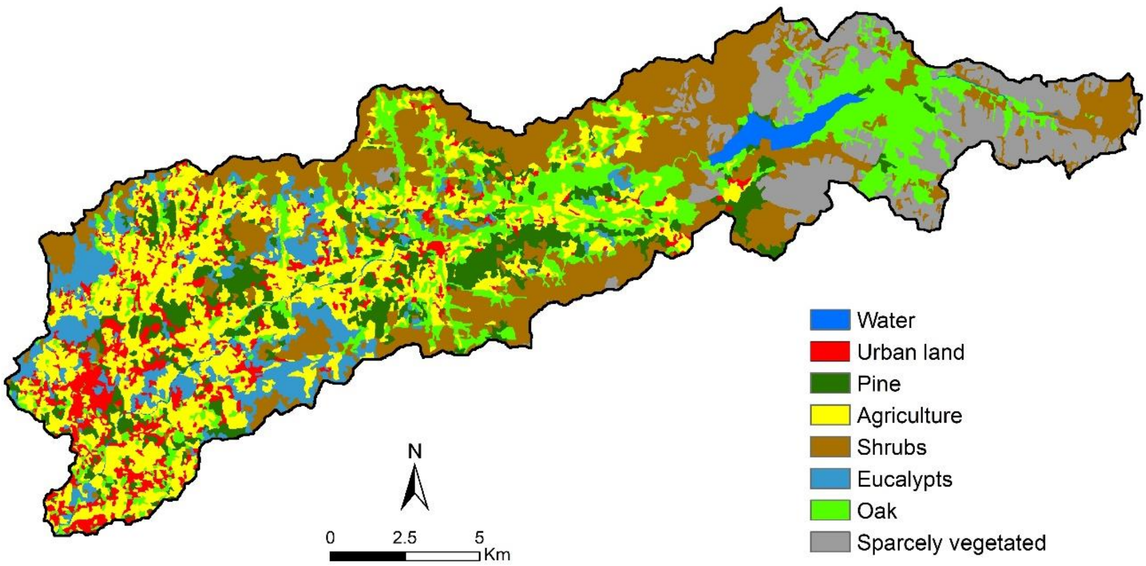

Figure 10. Land cover/use of Homem watershed. Source: dgT (General Direction of Territory), 2007.

Table 1. Land cover classes and respective percentage of occupation used in SWAT.

SWAT Class	Identification	Major vegetation species	%
URLD	Urban low density		7.5
CORN	Agriculture - Corn (60%) and Pasture (40%)	Corn and wheat	20.5
PINE	Pines	*Pinus pinaster*	10
OAK	Oak and other broadleaved trees	*Quercus robur*, *Quercus pyrenaica*	15.7
EUCL	Eucalypts	*Eucalyptus globulus*	8.0
BSVG	Baren rock and sparsely vegetated	Heath (*Erica* spp.) and dry perennial grasslands	12
MIGS	Atlantic grass shrubland Atlantic forest shrubland	Heath (*Erica* spp.) and other shrubs	25.8
PRAD	Pasture	Grasses and other herbaceous plants	0.5

Homem watershed is highly valuable for biodiversity protection. In fact, 30 % of the total watershed is considered as a special protection area and more than 50% is part of EU Natura 2000 network (EC, 2000), and is included in the Peneda-Gerês National Park (Figure 11). Peneda-Gerês National Park was the first protected area created in Portugal, is the only one with the status of National Park, where there are ecosystems in their natural state, with little or no human influence, integrated into a humanized landscape.

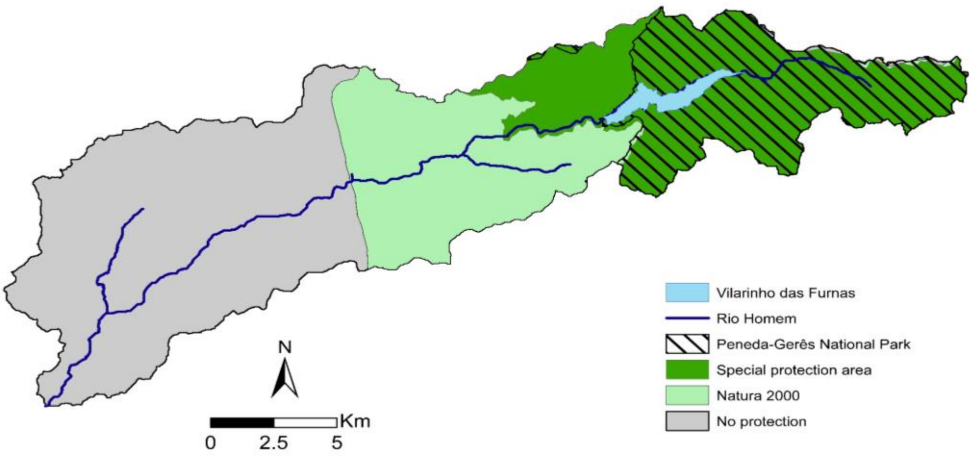

Figure 11. Biodiversity protection levels in Homem watershed. Source ICNF (Instituto para a Conservação da Natureza e Florestas).

2.1.2. Vilarinho das Furnas reservoir

The reservoir of Vilarinho das Furnas is located in the Homem River watershed, originating in the Gerês mountains. The central and dam of Vilarinho das Furnas entered in service in 1972. Having taken its name due to the village that today is submerged by its reservoir. The dam of Vilarinho das Furnas is used mainly for the production of electric power generation. This hydroelectric power system was the last large-scale be built in the north of Portugal.

The dam of Vilarinho das Furnas, a concrete infrastructure, is of the type asymmetrical vault of double curvature, with horizontal parabolic arches. It has a maximum height of 94 meters and 398.3 meters of development at the level of the crown. The total capacity of the reservoir is 117.7 hm^3, a surface flooding area of 344 ha, and a useful capacity is 97.5 hm^3. It is equipped with an environmental flow device, which can maintain a downstream flow up to a maximum of 2.95 m^3/s, it is also equipped with a flood dump located on the right bank and is independent of the dam. Two generator sets have been working, with a total installed capacity of 125 MW. The average annual productivity of Vilarinho das Furnas is 194 GWh. The hydraulic circuit about 7.6 km long, consisting of a tunnel, discharges on the margin of one of the arms of the Caniçada reservoir on the Cávado river, where the turbine water is restored (EDP, 2012)

In addition, this reservoir is fed by the inflows of secondary watersheds, from the right bank (Gemesura and Brufe), and the left bank (Campo do Gerês). The reservoir is partially inserted in the Peneda-Gerês National Park, and its zone of influence covers the counties of Terras de Bouro and Vieira do Minho.

2.2. SWAT Hydrological model and input datasets

2.2.1. SWAT Equation model

SWAT is based on the water balance equation, and this equation took into account soil water content, precipitation, surface runoff, evapotranspiration, percolation and bypass flow, and return flow. In SWAT, the hydrological cycle is based on the following equation:

Eq. 1 $$SW_t = SW_0 + \sum_{i=1}^{t}\left(R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw}\right)$$

Where SW_t is the final soil water content (mm H_2O); SW_0 is the initial soil water content on day i (mm H_2O); t is the time (days); R_{day} is the amount of precipitation on day i (mm H_2O); Q_{surf} is the amount of surface runoff on day i (mm H_2O); E_a is the amount of evapotranspiration on day i (mm H_2O); W_{seep} is the amount of water entering the vadose zone from the soil profile on day i (mm H_2O); and Q_{gw} is the amount of return flow on day i (mm H_2O) (Neitsch *et al*., 2011).

2.2.2. SWAT Indicators for ecosystem services

SWAT is a conceptual, continuous time (monthly and daily) model that predicts the impact of water management, sediment and chemical yields in watersheds. (Arnold & Fohrer, 2005). The watershed is divided into unique composed of combinations of homogeneous slope, soil and land cover, called Hydrological Response Units (HRU). To estimate surface runoff, Each HRU is simulated independently from one another, including canopy interception of precipitation, partitioning of precipitation, snowmelt water, and irrigation water between surface runoff and infiltration, redistribution of water within the soil profile, evapotranspiration, lateral subsurface flow from the soil profile, and return flow from shallow aquifers (Gassman *et al*., 2007).

SWAT is based on curve number (CN) equation, surface runoff is determined by empirical model, developed in more than 20 years of studies around the United States; this model is based on rainfall-runoff relationships under various land use and soil types. SWAT can also simulate crop and trees growth, considering plant phenological development, leaf area, radiation interception and biomass (Gassman *et al*., 2007). Research by Carvalho-Santos *et al*. (2016a) illustrated that SWAT itself provides hydrological services information (potential supply of services) (Table 2).

2.2.3. Complement tools for SWAT

Complement tools have been developed to improve the performance of the SWAT model. For instance, Geographic Information System (GIS) have been successfully complemented with SWAT, allowing to collect, manipulate and visualize the inputs and outputs. ArcSWAT, the most popular interface, runs with ArcGIS (ESRI software), and have been used to generate input data needed by the SWAT model (Dile *et al*., 2016). For this study, ArcSWAT 2012.10.21 interface was used (Winchell *et al*., 2013).

Table 2. SWAT indicators for ecosystem services provision analysis used in the Homem River watershed, based on Carvalho-Santos *et al*., 2016a).

Ecosystem Service	**SWAT output (HRU)**	**Indicators for service provision**
Water supply		
Quantity	WYLD - Water yield (mm/year)	Contribution of each HRU in delivering water for the watershed
Timing	FLOW_OUT – river discharge - Q95 (m^3/s)	Flow duration curves (low flows)
Water damage mitigation		
Soil erosion control	SYLD – sediment exports (t/ha year)	The higher the exports, the lower the contribution to the erosion control services
Flood regulation	FLOW_OUT – river discharge - Q5 (m^3/s)	Flow duration curves (high flows)

2.2.4. Inputs of SWAT

ArcSWAT interface must follow systematically steps to run correctly. First, using a digital elevation model (DEM), a watershed is delimited and divided into multiple sub-basins, which are then further subdivided into HRU.

Input datasets and sources for SWAT calibration in the Homem River watershed are presented in Table 3. Digital elevation model (DEM) was used with 25 meters of grid resolution provided by the Copernicus Program. Land cover classes of the original dataset were aggregated into eight major groups, representing the similarities in terms of hydrological traits (Table 2). Five major soil groups were used (Figure 9). The general parameterization of vegetation and soil was based on previous SWAT studies in Portugal (Nunes *et al*., 2008; Carvalho-Santos *et al*., 2016a; Carvalho-Santos *et al*., 2017;;).

Model setup was done using the ArcSWAT 2012.10.21 interface for ArcGis (Winchell *et al*., 2013). To delineate the watershed, DEM was used, resulting in 11 sub-basins. After, slope, land cover and soil data (Table 3) were applied for model parameterization, resulting in 454 HRUs (threshold not used to maintain the number of combinations and integral HRU). Slope classes were based on previous SWAT studies (Carvalho-Santos *et al*., 2016a; 2017), so it was divided in 3 classes, defined in order to represent the differences of this variable in the watershed: 0 - 10%; 10 - 25%; > 25%.

Subsequently, daily climatic datasets (1995-2009) were used from four precipitation stations inside the watershed (Caldelas, Cibões, Portela do Homem and Portela do Vade), and one climatic station (Ponte da Barca) outside (8 km) for other climatic parameters (temperature, solar radiation, relative humidity and wind speed). Precipitation data were collected from SNIRH in hourly values and then was converted into daily data. In particular, days with less than 20 h values per day were considered as a gap that was further filled based on regression analysis method. Regression was chosen because of the high coefficient of determination among neighbouring stations (R^2 above 0.9). Data correlation was done with neighbouring stations such as Bouca, Cabana, Casal, and Leonte. According to Hasan & Croke (2013), filling the gaps in daily precipitation data is therefore a crucial issue for hydrological modelling to improve calibration issues.

Moreover, the land cover class MIGS was defined as grass shrubs and forest shrubs (Table 2). Also, the class CORN was divided into 60% corn and 40% pasture (permanent grassland), according to traditional agricultural practices in the region. In addition, two management operations were applied for corn and pasture based on knowledge and fieldwork on crop management practices in the watershed. For corn, first a tillage operation was applied at the middle of April, followed by a model-managed fertilization, based on soil N deficiency, with 20-20-00 fertilizer (250 kg/ha maximum) starting in the end of April. Then, auto-irrigation and auto-fertilization were applied in the first two days of May. Finally, harvest operations were applied in September. In December a tillage operation for winter pasture was applied, which is finally harvested in late March to start again the corn cultivation. For the class PRAD, two management operations were implemented, growing pasture in January and second day of June, and harvesting operation in the first day of June.

For reservoir parameters, the total and useful capacity of the reservoir and a surface flooding area were based on SNIRH data. Maximum daily outflow for the month (m^3/s) was based on the environmental flows stablished by EDP. The beginning of the month of non-flood season was established in May and the ending month was in October, so the model can realistically simulate major high and low flow periods.

Table 3. Input datasets of SWAT.

Variables	Source	Description
DEM	Copernicus Programme, (2016)	Version v1.1. with 25 m resolution grid
Land cover – COS 2007	dgT(General Direction of Territory) (2007)	Divided into 8 main land cover classes
Soil	Ministry of Agriculture, performed by Geometral Agroconsultores (1995)	Soil map 1:100 000 Divided in 5 main soil types (Humic Regosols, Humic Leptsols, Dystrics Fluvisols, Antrosols and Urban
Precipitation	SNIRH - National Hydrological Resources Information System, SNIRH, 2018	Hourly precipitation values (mm) turned into daily values; Calibration period 2002-2009 (4 year initialization period) Validation (1995-2002)
Maximum and minimum temperature		Hourly temperatures values (°C) were converted into maximum and minimum values
Solar radiation **Relative humidity** **Wind speed**		Daily values of wind speed (m/s) relative humidity (%) and solar radiation (Watts).
Daily river discharge at Covas		Hourly discharge values (m^3/s) turned into daily values; Calibration period 2006-2009 (4 year initialization period) Validation (2000-2003)
Monthly reservoir volumes at Albufeira Vilarinho das Furnas		Monthly Reservoir volume (m^3)
Monthly discharge at Albufeira Vilarinho das Furnas	EDP	Environmental flow for twelve months

2.2.5. SWAT calibration

Calibration is the process of changing sensitive parameter values to reduce variation between observed and simulated values (Moriasi *et al*., 2007). SWAT input parameters are process-based and must be held within a realistic uncertainty range. Hence, the calibration process is important to produce simulated values that are within a certain range of the observed data. Calibration can be fulfilled manually or using auto-calibration tools in SWAT or SWAT-CUP (Abbaspour *et al*., 2007). Manual calibration, a conventional method, forces the user to better understand the important variables in the watershed process, and know what are the more sensitive parameters according to the characteristics of the watershed. On the other hand, SWAT-CUP, semi-automated approach, uses manual and automated calibration incorporating sensitivity and uncertainty analysis, and provides a powerful approach to watershed calibration (Arnold *et al*., 2012b).

The model was forced with daily climatic parameters (precipitation, maximum and minimum temperature, solar radiation, relative humidity and wind speed). SWAT calibration was applied for the period (2006-2009), including a four year of model warm-up (2002–2005). A period warm-up was used to minimize the impacts of uncertain initial conditions. Manual calibration was made for sensitive parameters against daily and monthly discharge (m^3/s) at Covas and monthly reservoir volume (m^3) at Vilarinho das Furnas. The parameters changed to improve model performance were (Table 4): GW_DELAY (initial value: 31, calibration value: 1), RCHRG_DP (initial value: 0.5, calibration value 0), Cn2 (-10 for each land-cover class), WURESN (initial value: 0 for all months, calibration value: January to February, (5) March to April (11), May (20), June to July (50), August (25), September (15), October (25), November (30) and December (4), and USLE_K (initial value 0.23 to 0.02). USLE_K parameter for the northwest of Portugal was based on Panagos *et al*. (2014). For instance, Carvalho-Santos *et al*. (2016a) used this calibrated parameter for Vez watershed as a reliable source, with further comparison with a set of observed total suspended sediments in the river. In this work, the comparison with observed suspended sediments was impossible due to unavailability of data in SNIRH for Homem watershed. In addition for this work, reservoir inflow at Vilarinho das Furnas was not taken into calibration and validation process, because observed discharge data are a sum of three discharges around the reservoir (Gemesura, Brufe and Campo Gerês), and SWAT only considers one independent discharge data. Calibration in Covas, which is in the middle of the basin, was assumed as a valid calibration for the entire basin.

Table 4. Modified SWAT general parameters for Homem watershed.

Parameters	Description in SWAT	Initial value	Calibration
Groundwater			
GW_DELAY	Groundwater delay time (days)	31	1
RCHRG_DP	Deep aquifer percolation fraction	0.5	0
Cn2	Curve number for moisture condition II	Various	-10
Reservoir			
WURESN	Monthly average of water withdrawn from reservoir for consumptive use (10^4 m^3)	0	January to February (5) March to April (11) May (20) June to July (50) August (25) September (15) October (25) November (30) December (4)
Soil			
USLE_K	Erodibility factor	0.23	0.02

2.2.6. SWAT validation

Validation is the final step of any model exercise and involves running the model using the same parameters that were determined throughout the calibration process (Refsgaard, 1997). Validation should be run to assess the performance of the calibrated parameters. In addition, the principal condition is that validation should be applied with an independent set of data in a different period, with no extra adjustment of parameters (Arnold *et al*., 2012b).

Validation process for discharge and reservoir volume was applied for 1995-2003 using the same parameters from the calibration process.

2.2.7. SWAT Model Performance

The performance of the model can be evaluated by graphical techniques or using numerous quantitative statistics (Moriasi *et al.*, 2007), but it is recommend to use at least three statistics for evaluation. These statistics are described at the following: (i) Coefficient of determination (R^2) describes the degree of collinearity between simulated and observed data. R^2 ranges from 0 to 1; values greater than 0.5 are considered acceptable; (ii) Nash-Sutcliffe efficiency (NSE) is a normalized statistic that determines the relative magnitude of the residual variance compared to the observed data variance. NSE varies from $-\infty$ and 1.0, with NSE = 1 being the optimal value (values between 0.0 and 1.0 are generally viewed as acceptable levels of performance); and (iii) Percent bias (PBIAS %) measures the average tendency of the simulated data to be larger or smaller than their observed data. The optimal value (PBIAS = 0.0) indicates accurate model simulation. Positive values indicate model underestimation bias, and negative values indicate model overestimation bias. PBIAS and NSE formulas are more detailed in Appendix A.

Model performance was measured using statistical methods in hydrological modelling such as R^2, PBIAS % and the NSE. The performance rating was classified in very good, good, satisfactory and unsatisfactory for calibration and validation values by Moriasi *et al*. (2007) (Table 5).

Table 5. General performance ratings for recommended statistics for a monthly time step (Moriasi *et al*., 2007).

Performance Rating	**NSE**	**PBIAS (%) Discharge**
Very good	0.75 < NSE ≤ 1.00	PBIAS < ± 10
Good	0.65 < NSE ≤ 0.75	± 10 ≤ PBIAS < ± 15
Satisfactory	0.50 < NSE ≤ 0.65	± 15 ≤ PBIAS < ± 25
Unsatisfactory	NSE ≤ 0.50	PBIAS ≥ 25

2.3. Climate change scenarios

Accordingly to Du *et al*. (2019), several works recommended to include a number of climate models and various greenhouse gas emission scenarios or Representative Concentration Pathways (RCP) to assess climate change impacts on hydrology and water quality. Hence, the future climate projections for this study, were obtained from four realizations of the SMHI-RCA4 Regional Climate Model driven by four Global Climate Models (GCMs) providing boundary conditions for regional simulations.

Regional simulations were based on the European Coordinated Regional Climate Downscaling Experiment (EURO-CORDEX, http://www.euro-cordex.net/), which is the European branch of the international CORDEX initiative. The four driving GCMs, namely CNRM-CM5, EC-EARTH, IPSL-CM5A-MR and MPI-ESM-LR, belong to the ensemble of models used as a basis in the Fifth Assessment Report of the IPCC (AR5, IPCC 2013) and are part of the Coupled Model Intercomparison Project phase 5 (CMIP5). Future projections considered two representative concentration pathway (RCP) scenarios, which are RCP 4.5 and RCP 8.5 (Leong *et al*., 2017). The RCP 4.5 scenario is the stabilization of the radiative forcing at 4.5 W/m^2 before 2100 by applying a range of strategies and technologies to reduce the emission of greenhouse gases. In contrast, the RCP 8.5 scenario is a very high greenhouse gases emission scenario, with a rising radiative forcing pathway reaching to 8.5 W/m^2 by 2100.

For this study, we considered the following RCA4 model variables extracted over the region in interest: daily maximum and minimum temperature, precipitation, surface downwelling shortwave radiation and relative humidity. The temperature and precipitation data have been bias-adjusted considering as a reference the observed climatologies of E-OBS (Haylock *et al*., 2008), available for the European domain at 0.25 degrees (~25 km) from 1970 up to 2005. The bias adjusted temperature and precipitation data were further downscaled using orographic (lapse-rate) correction for the former and a stochastic downscaling method, RainFARM (D'Onofrio *et al*., 2014; Terzago *et al*., 2018) for the latter. We recall that these datasets were produced in the framework of the ECOPOTENTIAL project and have been described in the project documents available in the project web page (www.ecopotentialproject.eu).

Data from the four regional climate models have been used to project future changes under the RCP 4.5 and RCP 8.5 scenarios in the medium time horizon 2020-2050 and to reproduce past conditions as a guideline with input of the "historical" model data over 1970-2000.

3. Results and Discussions

3.1. SWAT model performance

The daily simulated river discharge values at Covas fit well with the observed data in the calibration and validation periods. SWAT was able to capture and reproduce the average flows and seasonal variations in Homem watershed, except during high flows and extreme conditions, as it was the case for the periods between the end of 2000 to the first months of 2001, and the final months of 2002 to the beginning of 2003 (Figure 12b). During the monthly calibration period (figure 12a), the Nash-Sutcliffe coefficient (NES) was 0.77, the value of R^2 was 0.88, and PBIAS was 24% (Moriasi *et al*., 2007), as shown in Table 6. The monthly simulated discharge was considered to be very good for values of NSE > 0.75, also considered acceptable for R^2 > 0.5 values, and considered satisfactory for PBIAS < 25, according to Moriasi *et al*. (2007) standards (Table 5). For daily simulated discharge, PBIAS daily was equal to PBIAS monthly (24 %); however, R^2 and NSE values were 0.64 and 0.32, respectively, so daily performance was considered only as satisfactory. The same performance repeats for validation period (2000-2003), except for daily validation performance, R^2 was 0.47, and it was considered as not acceptable R^2 < 0.5. This variation can be partially explained, because validation climatic dataset, particularly for precipitation, was collected once per day (9:00 h) before 2003, and it was quantified by conventional station. Since the middle of 2003, climatic parameters, especially precipitation, have been quantified hourly by automatic station and this may influence the quantity of rain inputted into the model, being more representative. As it was expected, model performance on validation period was typically lower than calibration, which is a pattern for previous studies (Engel *et al*., 2007).

For an ideal calibration, Gan *et al*. (1997) recommended that a calibration period should use 3 to 5 years of data that includes average, wet, and dry years. For the current study, the calibration period was between 2006 to 2009 (4 years) and had dry years (2007 and 2009), and wet years (2006), so these hydrologic events had activated all model constituent processes during the calibration period.

Covas

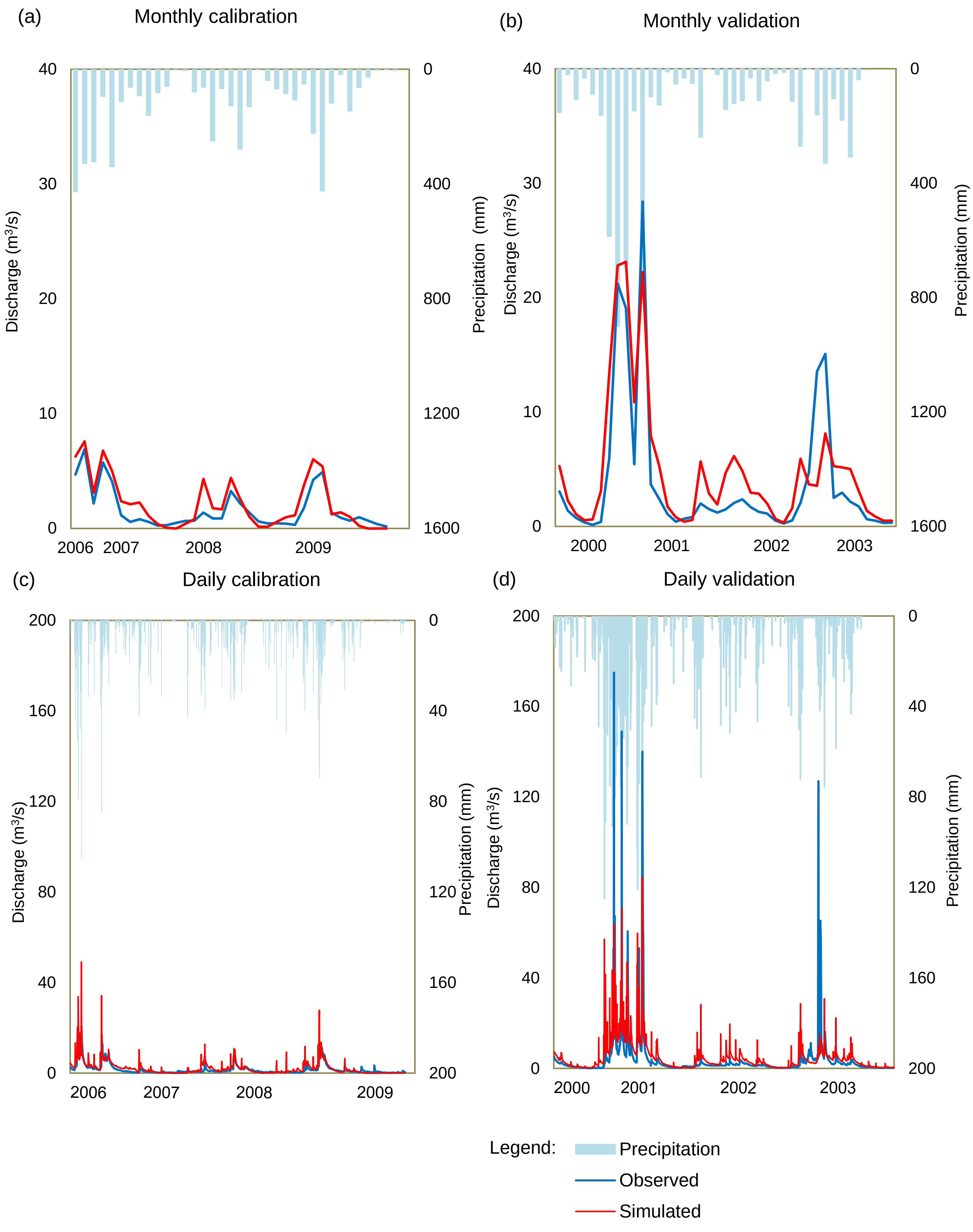

Figure 12. SWAT calibration (2006-2009) and validation (2000-2003) discharge at Covas: (a) Monthly calibration (b) Monthly validation (c) Daily calibration, (d) Daily validation.

Table 6. Calibration and validation goodness-of-fit statistics for discharge in SWAT model.

	Calibration (2006-2009)		**Validation (2000-2003)**	
	Monthly	Daily	Monthly	Daily
R^2	0.88	0.64	0.77	0.47
PBIAS (%)	24	24	22	21
NSE	0.77	0.32	0.76	0.47

The monthly volume simulated by the SWAT model was in good agreement with observed data, as shown in Figure 13. The modeling performance is shown in Table 7. For calibration, the R^2 was > 0.5, and it was considered as acceptable. NSE = 0.65 was considered as satisfactory, and PBIAS 7 % considered as very good (Moriasi *et al.*, 2007). The validation period (2000-2003) was considered as unsatisfactory (PBIAS = 34 %, NSE = 0.64), but R^2 was greater than 0.5, so its performance rating was acceptable. Possible reasons for these differences between calibration and validation period can be the lack of data, especially precipitation, and the lower quality of volume data in Vilarinho das Furnas for the validation period. Besides, extreme precipitation from 2000 to 2001, considered wet years, could possibly affect volume data for the validation period due to bad representation.

Vilarinho das Furnas

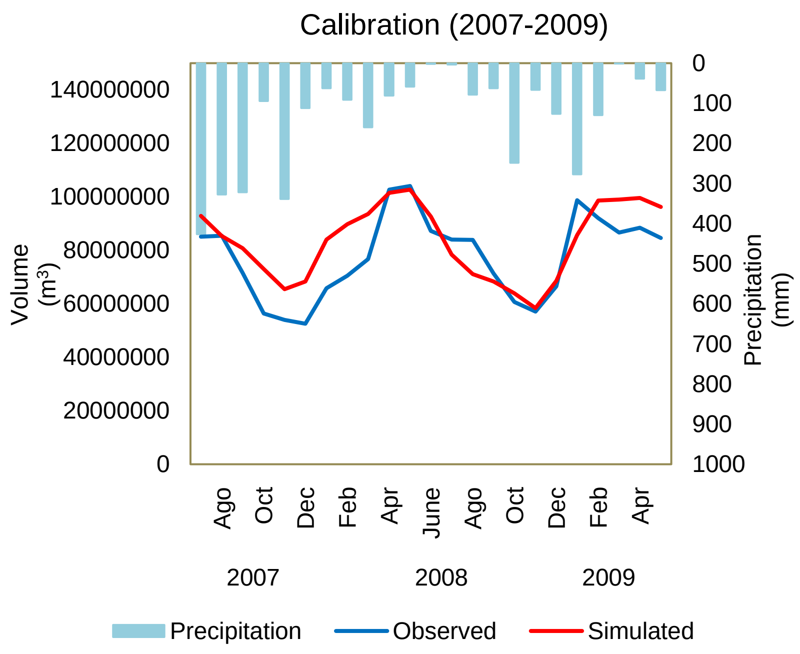

Figure 13. SWAT monthly calibration (2007-2009) at Vilarinho das Furnas reservoir.

Table 7. Calibration and validation goodness-of-fit statistics for reservoir's volume SWAT model.

	Calibration (2006-2009)	Validation (2000-2003)
	Monthly	Monthly
R^2	0.64	0.65
PBIAS (%)	7	34
NSE	0.64	0.64

Leaf area index on SWAT simulation was evaluated for the calibration period by land cover type (Table 1) to see if the temporal performance was according to the standard cycle. LAI simulated shows the tendency and peak values for vegetation growth, indicating adequate evapotranspiration performance for each category. LAI performance is more detailed in Appendix B.

3.2. Mapping ecosystem services

Mapping is a fundamental process to understand, visualize the spatial distribution of services (Häyhä *et al*., 2015), and identify the prioritized areas to improve the provision of certain service at watershed scale (Hauck *et al*., 2013). SWAT results were mapped for water ecosystem services representation at sub-basin scale. Figure 14 shows the average quantity of surface water yield at sub-basin scale. In highlands, current conditions contribute with more water quantity for the watershed, these values range between 90 to 100 mm/year. These results are related to precipitation patterns in this region, with a great amount of precipitation in the highlands approximately 2100 mm/year. In addition, highland areas increase surface water yield, because there are protected by the Peneda-Gerês National Park status, where there are occupied by large and dense native shrubland vegetation and deciduous forest of oak and beech, which demands less water for its growth. Moreover, highland areas are associated with bare rock and thin soils. Carvalho-Santos *et al*. (2016b) found the same patterns for Vez watershed, with more quantity of water at highlands under shrubs cover (current scenario), also mentioned that eucalypt/pine scenario reduces the quantity of water because of its rapid growth rate, and highlighted to promote to plant native forest to promote ecosystem services and biodiversity.

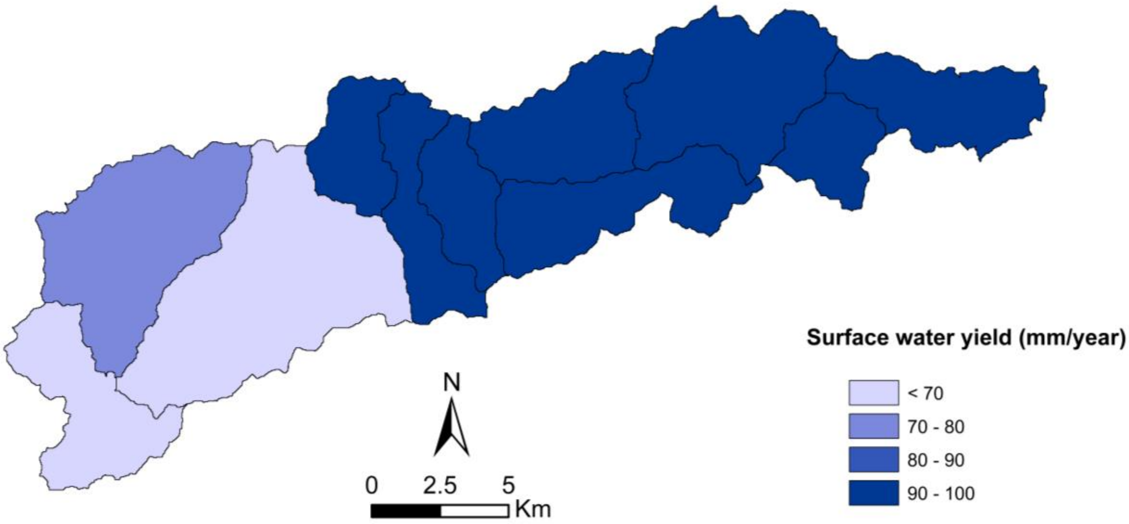

Figure 14. Average surface water yield (mm/year) at sub-basin scale in the Homem watershed.

Sediments export values are not homogeneous at sub-basin scale (Figure 15). This can be related to modification of the natural hydrological flows (construction of Vilarinho das Furnas reservoir), more steepness of the terrain and more susceptibility of land cover for soil erosion. In the valley, sediments exports are high; this is related to great accumulation of agricultural lands. On the other hand, at the top of the watershed, soil erosion is lower, because of its natural vegetation and type of soil, which is thinner and rockier, not prone to erosion. The spatial distribution of sediments export (erosion) is in accordance with previous work at the watershed level by Carvalho-Santos *et al*. (2016b), who showed less erosion at the top of the mountains, where soil is rocky and thin, not susceptible to erosion, and more erosion in the valley where agricultural activities prevail. However, values are low when compared to other agricultural areas, due to the mitigation effect of terraces and traditional agricultural practices (Carvalho-Santos *et al*. 2016a).

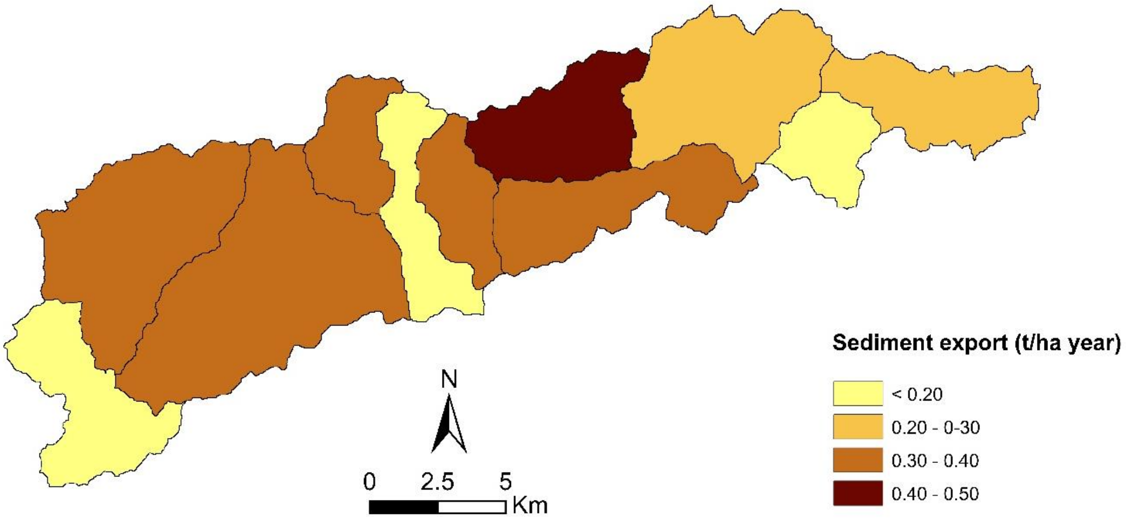

Figure 15. Average sediment exports (t/ha year) at sub-basin scale in the Homem watershed.

SWAT results have helped to model and map ecosystem services at the watershed scale, also was proved that it is an important tool for mapping, particularly water ecosystem services (Francesconi *et al.*, 2016).

3.3. Climate change projections

Figure 16 shows the variability in average precipitation and temperature for the future (2020–2050) relative to the historic period (1970–2000) in the Homem watershed, according to 4 climate models with respective 2 climate scenarios (RCP 4.5 and 8.5). The horizontal axis in the figures indicates anomaly in precipitation (%), while vertical axis represents absolute changes in temperature (°C). The small symbols correspond to 4 different future scenarios (4 GCMs) under two RCP 4.5 and 8.5. In general, temperature is expected to increase and precipitation will decrease. It is clear that average temperature will increase about 1 to 1.5 °C under RCP 8.5. However, precipitation predictions differ from each model because of the uncertain range in the seasonal variability. The reduction of precipitation and the increase of temperature are similar with previous studies in Portugal (Veiga da Cunha *et al.*, 2005; Nunes *et al.*, 2008; Lobanova *et al.*, 2016; Carvalho-Santos *et al.*, 2017). In addition, 7 of 8 projections predict a decrease in precipitation approximately to 5 to 20 %, except the EC-EARTH RCP 4.5 scenario that shows an increase in precipitation patterns of about 5 %. This uncertainty between models are inherent in future projections (Trzaska & Schnarr, 2014).

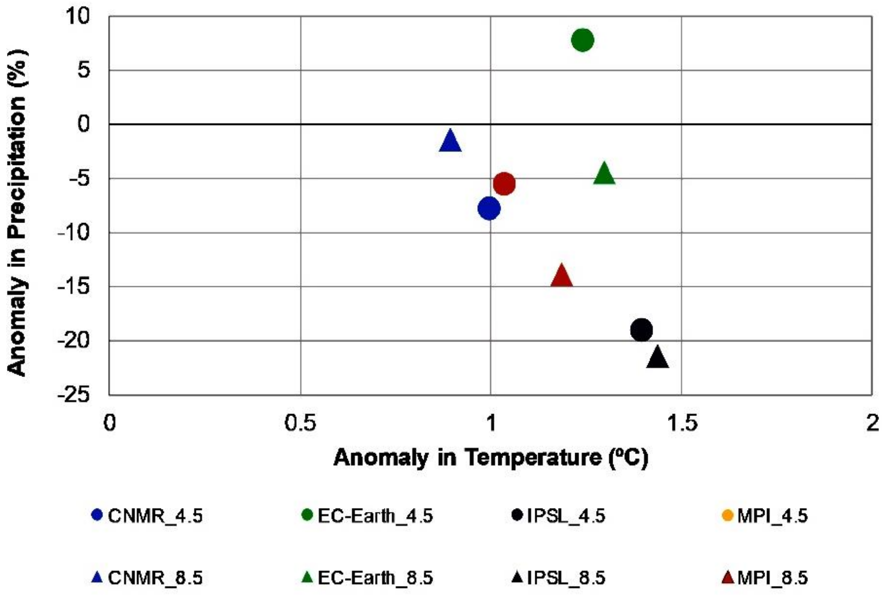

Figure 16. Variability of the four different global climate models (CNRM-CM5; EC-EARTH; IPSL-CM5A and MPI-ESM-LR) under two RCP 4.5 and 8.5, related to changes in precipitation (%) and temperature (°C) for 2020-2050 relative to 1970-2000 (Carvalho-Santos *et al*., in preparation).

3.4. Future water ecosystem services supply

Water supply quantity

SWAT was run for a monthly and daily time step to simulate water ecosystem services under future scenarios. Future projections were simulated for each model in SWAT (daily runs), but results are presented as ensemble (in Annex C results are presented by climate model). From this ensemble of model outputs, total annual surface water yield (mm) was calculated to represent the quantity of water available for supply. The quantity of water is expected to decrease in 5 % under RCP 4.5 and 7 % under the RCP 8.5 for the period 2020-2050 (Table 8). These results are similar with two SWAT studies; the first, in the northwest of Portugal, for the Vez watershed, predicted 2 % of reduction for 2021-2040, and 7 % for 2041-2060 (Carvalho-Santos *et al*., 2016a); and the second, in Galicia, predictions showed a decrease in annual discharge of about 6.03% and 12.68% for two scenarios though for another time period (2071-2100) (Raposo *et al*., 2013). These effects are highly influenced by changes in precipitation (Figure 16).

Table 8. Future climate effects on water ecosystem services under RCP 4.5 and RCP 8.5 scenarios for 2020–2050, comparing with historic scenario 1970–2000. ET = evapotranspiration.

		Water supply quantity		Water timing and flooding		Soil erosion control
	ET (mm)	Total annual yield (mm)	% of climate change effect	Q5 (m^3/s)	Q95 (m^3/s)	Average sediment export\t (t/ha year)
Historic	333.60	891.88		8.85	0.18	0.13
RCP 4.5	327.45	853.42	-5	8.31	0.09	0.19
RCP 8.5	322.33	836.74	-7	7.73	0.10	0.23

Water timing and flooding

Q5 and Q95 quantiles were calculated from river discharge to represent high and low flow conditions for future climate scenarios. Low flows can be a proxy indicator of water timing related to the supply of water for irrigation during the dry period of summer. Climate change will have an effect on the reduction of low flows, of about 50% reduction comparing to the historical value for low flows, particularly in RCP 4.5. The consequences of this discharge reduction in the river during summer are unpredictable, with possible constraints on the habitat for freshwater species and habitats. The projected average daily discharge for high flows is 8.31 and 7.73 m^3/s under RCP 4.5 and 8.5, respectively. There is a decreasing trend in high flows discharge comparing with historic scenario (Table 9). These projections are expected to reduce in 7 % and 13% under RCP 4.5 and 8.5, respectively, and more evident with RCP 8.5 scenario. This could have a positive effect on the mitigation of flood risk. Overall, these tendencies are in line with Carvalho-Santos *et al*. (2016a), which indicated that high flows will be slightly reduced by climate change scenarios.

Soil erosion control

Average sediment export is projected to increase, which may be related with increasing precipitation episodes in winter. In other words, soil erosion is expected to increase by 76 % under RCP 8.5 (Figure 17). The results are consistent with a previous study (Carvalho-Santos *et al*., 2016a) that predicted an increase of 34.7% for the period 2021-2040 under RCP 4.5, but it was influenced by agriculture/vine scenario for the Vez watershed. Even though, the average values for soil erosion are far below of 1 ha/t year, which is considered the tolerable rate for soil formation (Verheijen *et al*., 2012).

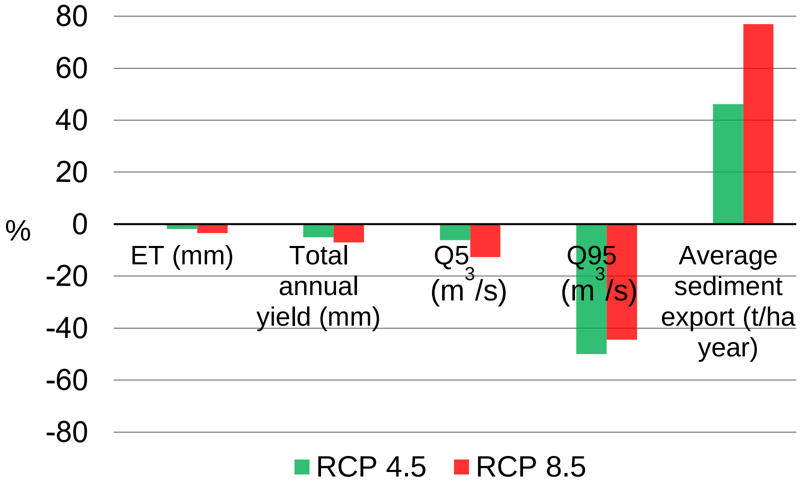

Figure 17. Water ecosystem services variability (%) under the RCP 4.5 and 8.5 for 2020-2050, comparing with historical baseline (1970-2000).

In this study, the changes in land cover and water management were not considered for discharge projections as suggested by Lorenzo-Lacruz *et al*. (2012) for the Iberian Peninsula. An increase of forested land and an expansion of the irrigated surface, play an important issue in the flows within the Iberian Peninsula, sometimes more significantly than climate change.

3.5. Seasonal discharge and reservoir volume under Climate Change

According to the patterns presented before, results show a tendency to decrease in discharge under the RCP 4.5 and 8.5, as shown in figure 18. However, RCP 4.5 shows a barely increase in winter due to more precipitation. In summer, discharge shows a stabilization in all scenarios. In other words, discharge will decrease in spring and autumn in all scenarios. The discharge projections of each model are more detailed in Appendix C. It is important to mention that different climatic models show different projections, namely models CNMR-CM5 and IPSL-CM5A with more negative projections, and the two others with more favourable projections.

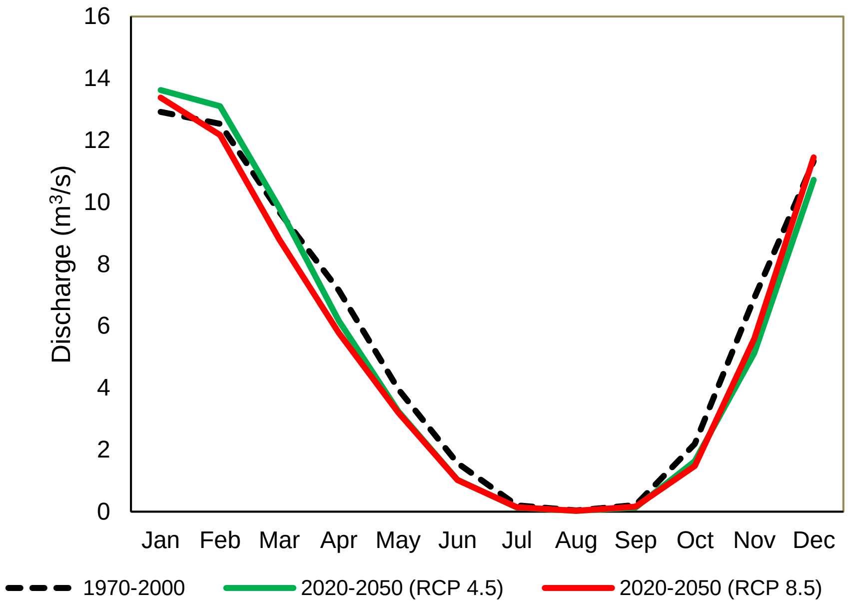

Figure 18. Average monthly discharge (m^3/s) under future climate conditions at the outlet of the watershed.

Volume in Vilarinho das Furnas reservoir would be decreased under the two future scenarios, more significantly under RCP 8.5 (Figure 19). Additionally, the reduction in volume is more evident in spring, summer and autumn for both scenarios. In Appendix D, volume projections of each model are more detailed. These models show different volume projections, namely models CNMR-CM5, IPSL-CM5A and MPI-ESM-LR with more negative projections, and the EC-EARTH with more positive projections.

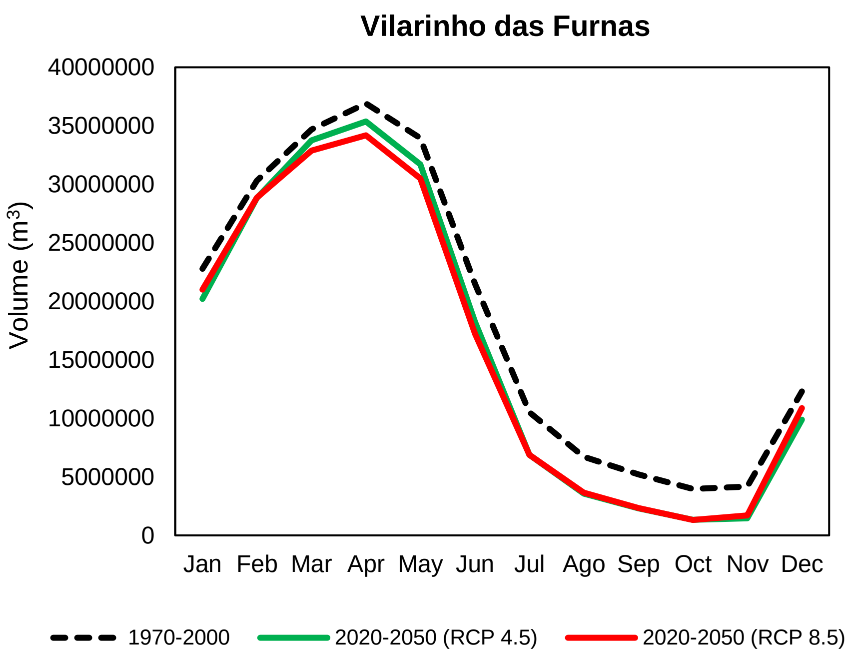

Figure 19. Average monthly reservoir's volume (m^3) under future climate conditions.

These considerable reductions may reduce the hydropower production, especially in summer. Other studies in Portugal using SWAT model, project a decrease in reservoir volume in Serra Serrada reservoir (NE), more drastic in summer under RCP 4.5 for the period 2041-2060 (Carvalho-Santos *et al*., 2017). Also, projections in Fratel reservoir show an annual reduction (-10 %) of hydropower production for 2021-2050 under RCP 4.5 (Lobanova *et al*., 2016).

Unfortunately, it was not possible to evaluate the influence of reservoir reduction on hydropower production in Vilarinho das Furnas reservoir and predict the population possibly may be affected.

3.6. Adaptation strategies to climate change

As shown in our results, discharge and reservoir volume are expected to decrease in Homem watershed. Climate change is full of uncertainty (Zandvoort *et al*., 2017) and projections show the same pattern (Trzaska & Schnarr, 2014); therefore adaptation should involve a portfolio of response options (Zandvoort *et al*., 2017). Here, some adaptation strategies will be addressed, according to a scheme adapted from Cross *et al*. (2012), grouped by forests, agriculture, reservoir and riparian vegetation.

Native Forest Management

It is widely recognized that forest areas influence water ecosystem services such as small reduction in annual water yield; however, a potential forest area increase in Homem watershed will contribute to a decrease in surface runoff, reduction of sediment loading, an increase in infiltration rates and buffering water-related hazards, particularly floods and potentially a more steady supply of water during summer months (Carvalho-Santos *et al*., 2016a). Conservation strategies considering incentives for the use of native species, especially inside protected areas, would be a good option to promote biodiversity and water ecosystem services. For instance, a previous study demonstrated that oak scenario showed the best performance for the water supply service (quantity, timing and quality) (Carvalho-Santos *et al*., 2016b). This is related to oaks being in dormant state during winter months (deciduous trees), decreasing rain interception and transpiration fluxes, allowing water to either infiltrate or run to the rivers as surface runoff (Carvalho-Santos *et al*., 2016b). Moreover, understanding the dynamics of forest systems such as the long-life span of many tree species, lag times in response under climate change, will be important to integrate into the context of climate change adaptation but taking into consideration possible trade-offs (Hagerman & Pelai, 2018).

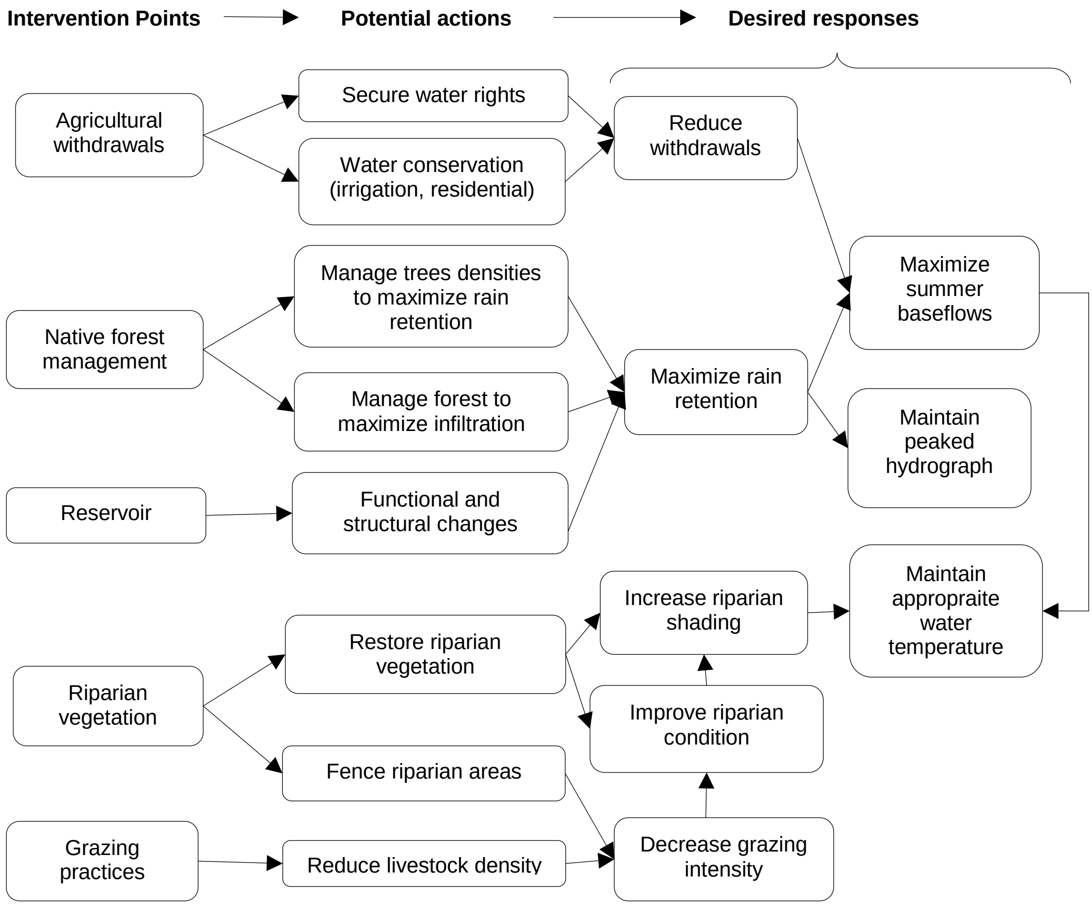

Figure 20. Management strategies proposed to maintain Homem watershed flows as the climate becomes warmer. Adapted from The Adaptation for Conservation Targets (ACT) Framework (Cross *et al*., 2012).

Agricultural withdrawals

In Homem watershed, extensive traditional farming is practiced. Climate change projections for the next decades are expected to bring important challenges to the Portuguese agriculture. To face these problems, farmers need to cooperate with other farmers, and they should receive more technical support from the public agencies in charge of water resources and agriculture. If these two changes were made, the shift from existing crops to other less water-demanding crops would be feasible. Faysse *et al*. (2018) remarked that Portuguese farmers and the staff from public organizations in charge of agriculture and water resource management had limited history of shared communication (south of Portugal), and mentioned that participatory analyses can be implemented in situations which may initially appear to be unfavourable. The participation of local actors (participatory analyses) in the development of adaptive management to climate change is considered as a cornerstone of its success.

Reservoir

Adapting to warmer temperatures and dry conditions are the challenges that reservoirs would face in the following decades. Vilarinho das Furnas reservoir is a grey infrastructure; however, the strategies to adapt to climate change can be based on green infrastructures such as improving the infiltration capacity and water retention with native trees to promote water ecosystem services around its zone of influence. On the other hand, several studies recommended a grey infrastructure (e.g. increase dam height to store more water during wet months). It is clear that Vilarinho das Furnas managers (EDP) have to implement climate change strategies in their current activities, taken into account that the reservoir is inserted on Peneda-Gerês National Park. Furthermore, functional changes need to be implemented to coordinate flood management, update flood criteria and develop operation models that provide flexibility during dry and wet conditions (ICOLD, 2018).

Riparian vegetation

Riparian areas are typically biodiversity hotspots for both plants and animals. They also play a significant role in maintaining functional hydrologic regimes in watersheds and providing cool water and temperatures. In Homem watershed, those areas have been heavily impacted by land use and Vilarinho das Furnas reservoir, therefore are also more vulnerable to flooding and wildfire, whereas less degraded areas may be more resilient to climate-related stressors. Including climate change as a consideration in riparian management will mostly refine and prioritize, rather than transform, current practices in riparian areas. Plant communities adjacent to small springs and narrow, ephemeral streams, are expected to be among the first areas affected by altered hydrology as the climate continues to warm, and timely adaptation may be necessary to maintain their functionality. Riparian buffer, a current strategy, has been used for many years to reduce soil erosion, protect water from pollution, improve waterways, provide a refuge for wildlife and provide a connected network of natural areas (for biodiversity, and climate change adaptation) (Buffler *et al.*, 2005).

4. Conclusions

In this study, the SWAT model was calibrated and validated against daily and monthly discharge in Covas, and monthly volume reservoir in Vilarinho das Furnas reservoir, in the Homem watershed (Northwest Portugal).

As shown in the results, SWAT had a good accuracy on calibration period between observed and calibrated data for monthly volume reservoir, monthly and daily discharge; however, the performance in the validation period reduced slightly, due to some limitations on input precipitation data. Overall, the model was fit to be used for scenario analysis. In this case, it was used to run future climate projections, for two scenarios (RCP 4.5 and 8.5) according to four climatic models carried out for 2020-2050, compared to 1970-2000.

In general, future climate projections predict an increase in temperature in the Homem watershed, and a decrease in precipitation with increased seasonal patterns.

Climate change may influence the reduction of the total annual surface water yield, high and low flows. These effects are notably during spring and autumn. On the other hand, soil erosion is expected to increase about 72 %, but with values below the threshold of 1 t/ha year that it is a set tolerable rate for soil erosion in the Mediterranean areas.

Vilarinho das Furnas water volume was projected to reduce, and the hydropower production can be severely affected by climate change conditions under the two scenarios, particularly during summer. Reservoirs plays an important role in the watershed to store, regulate and supply water for direct benefits (e.g. hydropower production).

It is important to emphasize the relevance of our results for building adaptation strategies to mitigate climate change impacts, taking into consideration the current European Union focus on climate change adaptation. Different strategies may reduce climate change effects such as native forest plantation to promote water ecosystem services, restore riparian areas to maintain adequate water temperature, and adapt reservoir function with green and grey infrastructures.

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APPENDIX A: Equations for model performance

Equations used for model evaluation performance based on Moriasi *et al*. (2007).

Nash-Sutcliffe efficiency (NSE)

NSE indicates how well the plot of observed versus simulated data fits the 1:1 line. NSE is computed as shown in the next equation:

$$NSE = 1 - \left[\frac{\sum_{i=1}^{n}\left(Y_i^{obs} - Y_i^{sim}\right)^2}{\sum_{i=1}^{n}\left(Y_i^{obs} - Y_i^{mean}\right)^2}\right]$$

Where Y_i^{obs} is the ith observation for the constituent being evaluated, Y_i^{sim} is the ith simulated value for the constituent being evaluated, Y_i^{mean} is the mean of observed data for the constituent being evaluated, and n is the total number of observations.

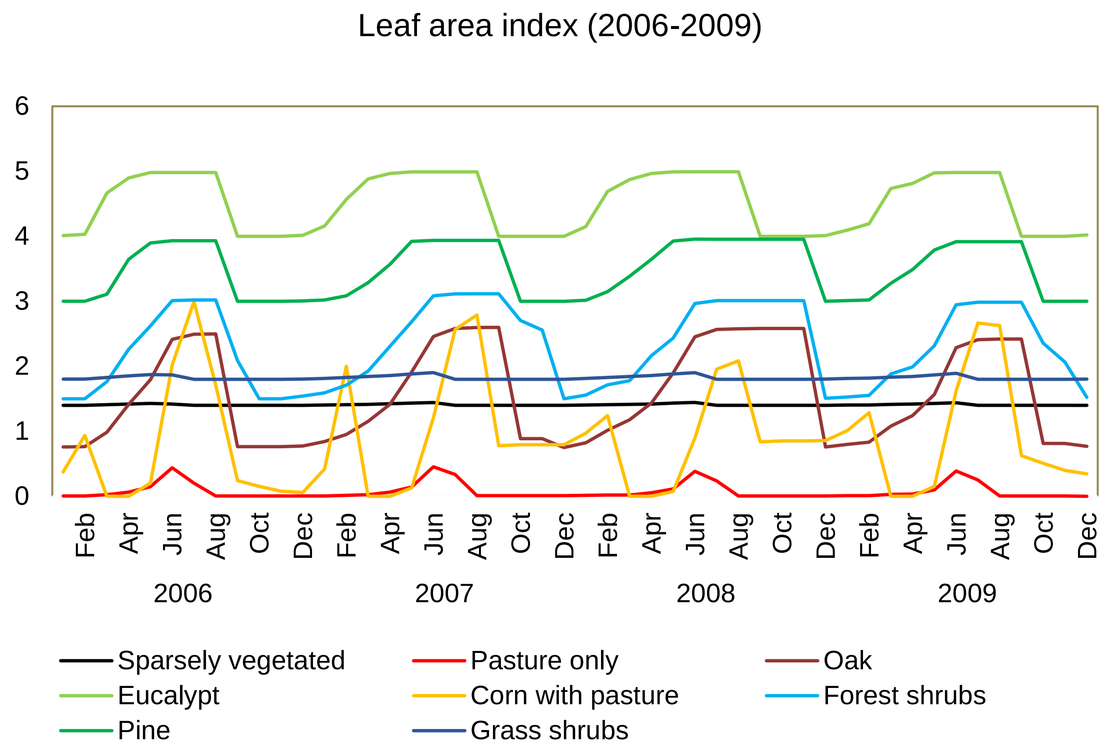
Percent bias (PBIAS)

Percent bias (PBIAS) measures the average tendency of the simulated data to be larger or smaller than the observed data. The optimal value of PBIAS is 0.0, with low-magnitude values indicating accurate model simulation. PBIAS equation is presented below:

$$PBIAS = \left[\frac{\sum_{i=1}^{n}\left(Y_i^{obs} - Y_i^{sim}\right) * (100)}{\sum_{i=1}^{n}\left(Y_i^{obs}\right)}\right]$$

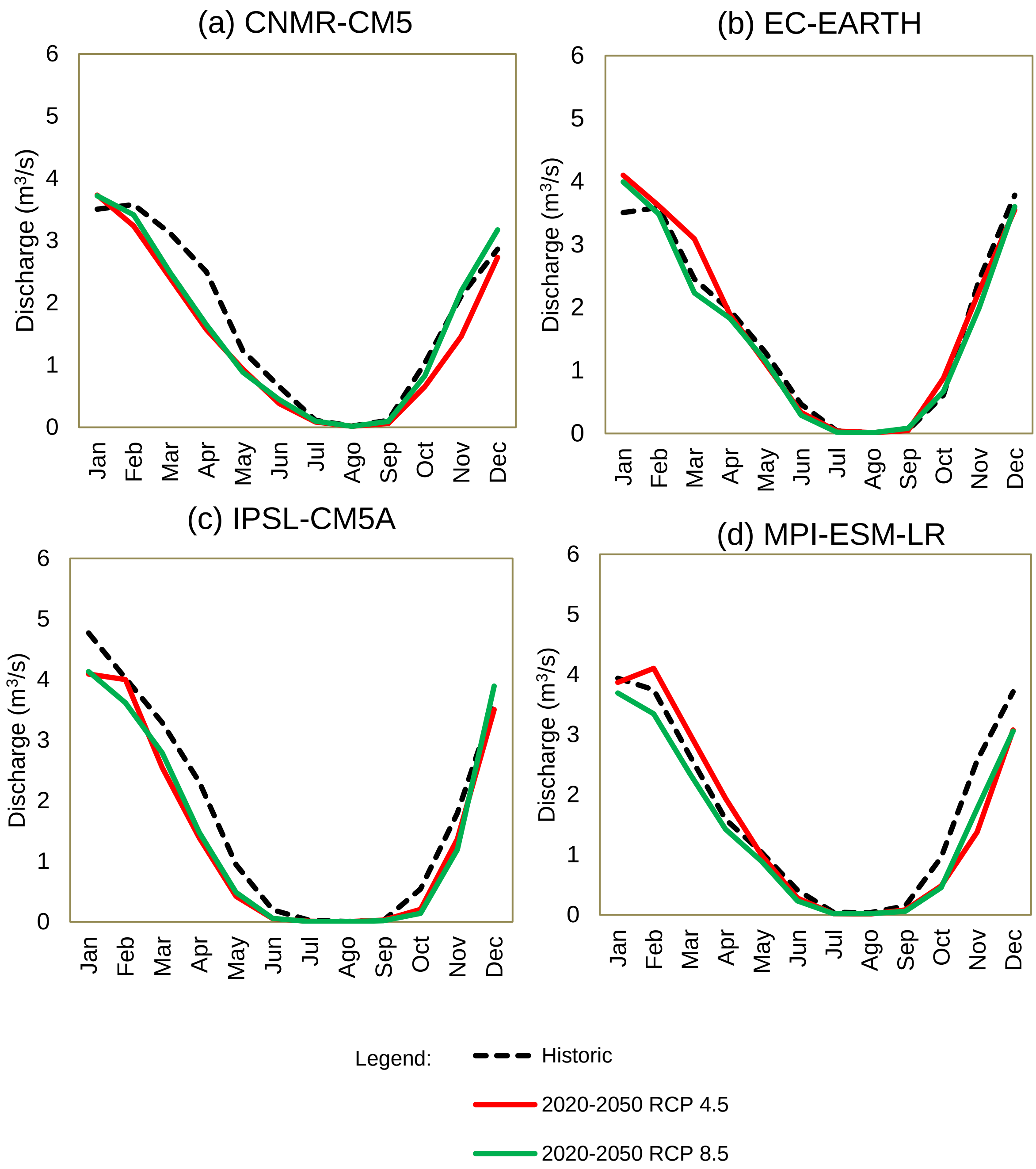
Where Y_i^{obs} is the ith observation for the constituent being evaluated, Y_i^{sim} is the ith simulated value for the constituent being evaluated, and n is the total number of observations.

APPENDIX B: Leaf area index



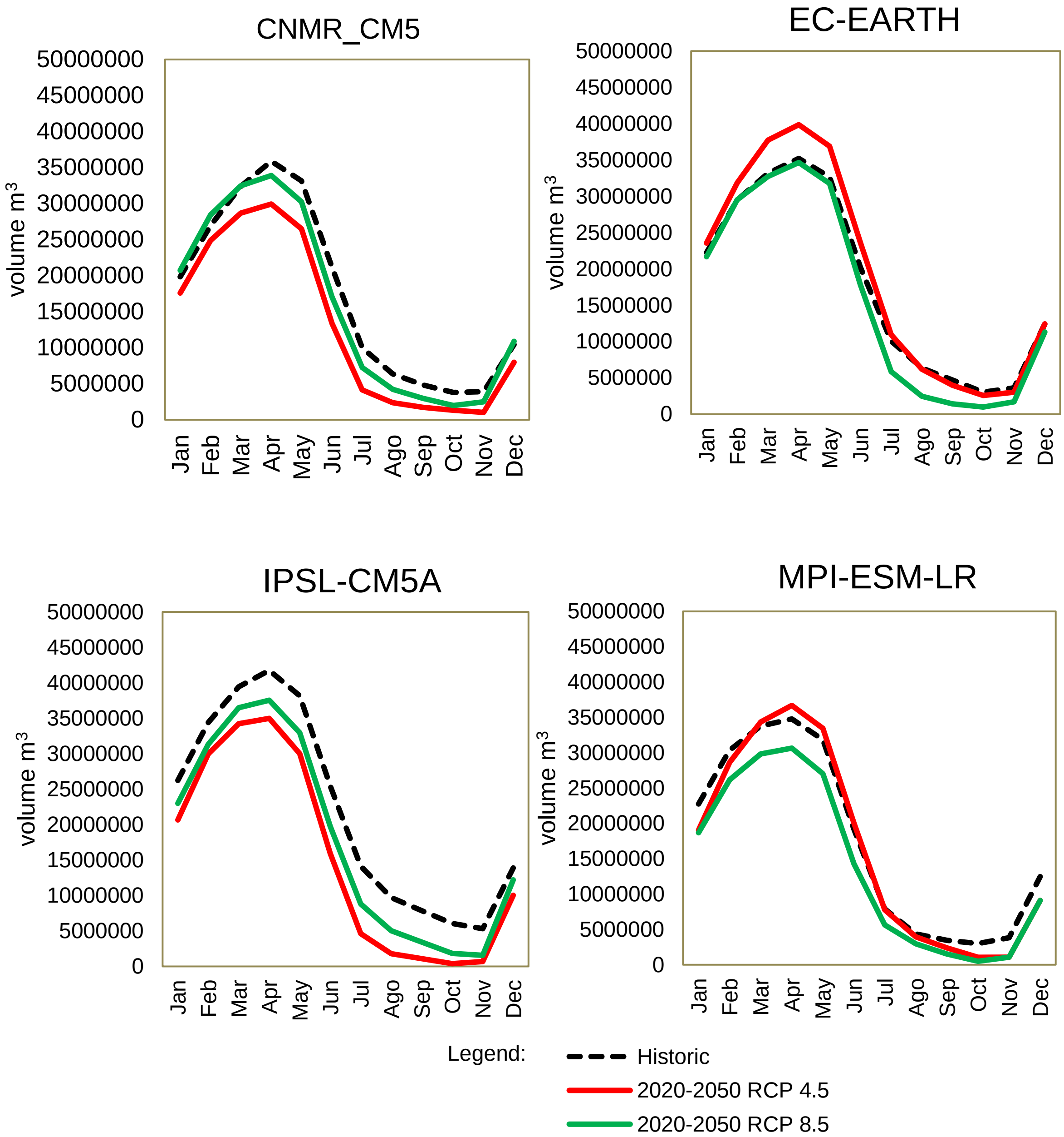
Vegetation growth of each crop during calibration period (2006-2009).

APPENDIX C: Four discharge projections in Covas



Different discharge projections in Covas, using four models: (a) CNRM-CM5, (b) EC-EARTH, (c) IPSL-CM5A-MR and (d) MPI-ESM-LR

APPENDIX D: Four Volume projections for Vilarinho das Furnas reservoir



Different volume projections in Vilarinho das Furnas, using four models: (a) CNRM-CM5, (b) EC-EARTH, (c) IPSL-CM5A-MR and (d) MPI-ESM-LR

APPENDIX E: Poster presented in ECCA

Date: 28/05/2019

Place: Centro Cultural Belem – Lisbon - Portugal