The impact of climate change on water provision under a low flow regime: A case study of the ecosystems services in the Francoli river basin

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ABSTRACT

Mediterranean basin is considered one of the most vulnerable regions of the world to climate change and with high probability to face acute water scarcity problem in the coming years. Francolí River basin (NE Spain), located in this vulnerable region is selected as a case study to evaluate the impact of climate change on the delivery of water considering the IPCC scenarios A2 and B1 for the time spans 2011-2040, 2041-2070 and 2071-2100. InVEST model is applied in a low flow river as a new case study, which reported successful results after its model validation. The studied hydrological ecosystem services will be highly impacted by climate change at Francolí River basin. Water yield is expected to be reduced between 11.5 and 44% while total drinking water provisioning will decrease between 13 and 50% having adverse consequences on the water quality of the river. Focusing at regional scale, Prades Mountains and Brugent Tributary provide most of the provision of water and also considered highly vulnerable areas to climate change. However, the most vulnerable part is the northern area which has the lowest provision of water. Francolí River basin is likely to experience desertification at this area drying Anguera and Vallverd tributaries.

Keywords:
Climate change scenarios
Water scarcity
Mapping freshwater ecosystem services
InVEST

1. Introduction

Changing Climate is an intrinsic characteristic of the Earth's system. During the Quaternary, long cold and dry periods alternated with relatively short warm periods [1]. Each of these periods was affected by climatic variability at different temporal scales [2, 3]. Climate change may be due to natural internal processes or external forcing, or to persistent anthropogenic changes in the composition of the atmosphere or in land-use [4]. The Mediterranean region lies in a transition zone between the arid climate of North Africa and the temperate and rainy climate of central Europe and it is affected by interactions between mid-latitude and tropical processes [5]. This area has been globally identified as one of the most vulnerable to climate change [6]. Climate change will intensify the hydrological cycle in semi-arid areas through global increases in temperature, rainfall concentration in short periods of the year, and more extended droughts [7].

Ecosystems services are the benefits that humans derive from ecosystems, which include provisioning, regulatory, supporting and cultural services [8]. It is well known that the services of natural ecosystems are clearly important to our societies: probably there would not be life without them. Climate change has the potential to cause abrupt negative changes in ecosystems and associated ecosystem services [9]. It is likely that first impacts will be felt in the Mediterranean water resource system through increased frequency of water shortages and decline in water quality [10].

The variety of ecosystem services which are derived from freshwater are commonly referred to as hydrological ecosystem services. They are often regulated by terrestrial ecosystem [11] and include provisioning services such as water supply for drinking, power production, industrial use and irrigation, as well as regulating services such as water purification and erosion control [12]. Their provision depends on watershed characteristics, such as topography, land use and land cover (LULC), and climate, parameters which have governing roles on the delivery of services. It is important to note that climate has greater determination in semi-arid basins like Mediterranean area. However, the quantity and quality of freshwater flows and hydrological ecosystem services supply is closely related to the management of the territory [13].

The low flow regime characteristic of some Mediterranean river basins also results from natural factors besides anthropogenic effects that includes the hydraulic characteristics and extent of the aquifers, infiltration characteristics of soils, frequency and amount of recharge, evapotranspiration rates, vegetation types, topography and last but not least the climate. On one hand a low flow is a seasonal phenomenon, and an integral component of a flow regime of any river. On the other hand, a drought is a natural event resulting from a less than normal precipitation for an extended period of time [10]. Mapping of ecosystem services has been a major topic at the regional to global scale [14]. Low flow river provides same ecosystem services as provided by high flow rivers, however modelling low flow river basin has always been a challenge due to lack of sufficient data. Low flow hydrological features are crucial for efficient development and integrated water resources management and a lot of effort has been made by the scientific community to deal with low flow parameters estimation in ungauged sites [15]. Several studies have assessed the anthropogenic effect on land use and cover, but few have focused on the impact of climate change on the reduction of hydrological ecosystem services. Moreover, lack of policy and regulation interests for low flow river basins also hinders the consistency of the links between decisions and the parallel analysis of the hydrological processes.

This manuscript aims to evaluate the impacts of climate change on water provisioning services in the Mediterranean basin of Francolí River, showing the possible degree of impact as well as the spatial distribution of these impacts. Estimated results for the IPCC climate change scenarios A2 and B1 for the time spans 2011-2040, 2041-2070, 2071-2100 are obtained and compared to the base scenario of 1971-2000. This study is inevitable in a situation when the river basin is already under high pressure and located in semi-arid Mediterranean area, where water scarcity can restrict activities dependant on water consumption. Adequate freshwater supplies are fundamental in ensuring the sustainability of agriculture, industry and the natural environment. Results of this study can be used to compare alternative management options in terms of biophysical measures of services [16].

2. Materials and methods

2.1. Study site

Francolí River in the Mediterranean area of northern Spain is about 85 km in length, and including main tributaries is 109 km, constituting approximately a basin of

855 km^2. The mainstream flows from Espluga de Francolí and leads into Mediterranean Sea through coastal mountains passing by cities like Montblanc, La Riba and Vallmoll (**Fig. 1**). Coastal mountains are a source area for river basins where precipitation is scarce, evapotranspiration is intense and there is marked seasonality of rainfall, often causing drought periods during summer [17]. In this case, Brugent River flows through Prades mountains being the major tributary of Francolí River.

The low flow is a special characteristic of Francolí River which can be subject to high interannual and seasonal variability of precipitations, with long and intense dry periods or extreme rainfall and floods. Thus, the flow depends on the rainfall intensity during spring and autumn and occasional summer rains. Even though water is relatively scarce throughout most of the year, there have been some flash floods such as one occurred on 10th October 1994. This severe flash flood during the autumn rainy season in the Mediterranean area, lasted less than a day but caused severe damage throughout the Francolí basin [18].

Regions in Mediterranean basins could suffer evermore frequent regional shortages due to the twin problems of climate change and rising demand. Francolí River basin has been under considerable pressure for water availability and water quality over the last decades because of the low flow and the prolonged drought period. The main anthropogenic factors have been the population growth and related increasing demand. Household water constitutes the most important annual consumptive demand of water resources (88%) followed by industry (11%) and agriculture (1%) [19]. The watershed was solely dependent on groundwater and surface water before the inter-basin transfer water supply schemes from Ebro River was started in 1989. Moreover, climate change is becoming an added key factor to worsen the already existing water stress situation in the Francolí watershed. Less precipitation will cause less watershed runoff and lower availability of water in the river basin [10]. Moreover a flow decrease may have an obvious direct effect on the dilution factor, giving rise to an increase in the concentration of pollutants and thus to a corresponding increase in risk for the aquatic ecosystems [20]. Consequently, it is expected that the hydrological ecosystem services in terms of water provisioning are being affected enormously causing water scarcity and a decrease of the river flow quality.

2.2. Model application

Natural Capital Project, a group based at Stanford University in California, has developed models that quantify and map the values of environmental services, such as *Integrated Valuation of Environmental Services and Tradeoffs* (InVEST). InVEST 2.4.2 has been used for this study.

InVEST 2.4.2 model runs as script tool in the ArcGIS 10 ArcToolBox on a gridded map at an annual average time step, and its results can be reported in either biophysical or monetary terms, depending on the needs and the availability of information. It is most effectively used within a decision making process that starts with a series of stakeholder consultations to identify questions and services of interest to policy makers, communities, and various interest groups. These questions may concern current service delivery and how services may be affected by new programs, policies, and conditions in the future. For questions regarding the future, stakeholders develop scenarios of management interventions or natural changes to explore the consequences of potential changes on natural resources [21]. This tool informs managers and policy makers about the impacts of alternative resource management choices on the economy, human well-being, and the environment, in an integrated way [22]. The spatial resolution of analyses is flexible, allowing users to address questions at the local, regional or global scales.

2.2.1. Data preparation

Data collection and processing is a rigorous and basic activity in ecosystem services model development. For this study, we used projected coordinate system of European Datum: Zone 31N of UTM. Year 1950.

The data inputs required for each model development vary depending on the service to be analysed. But most of the input data formats are in GIS raster grids, GIS shapefiles, database tables [23] or constants (**Table 1**).

The greatest sensitive input parameter is precipitation and the least are Zhang coefficient and evapotranspiration as it is explained by Sánchez-Canales [24]. However, it is required to use the precipitation map that best represent the region under study, due to the fact that this input becomes crucial as a result of the sensitivity analysis performed.

2.2.2. Water provisioning models

InVEST hydrological models are based on simplifications of well-known hydrological relationships [23] of the natural ecosystems. The biophysical models calculate the relative contribution of the different parts of the landscape to the provision of services.

This work is focused on the water provisioning service, included in the InVEST freshwater module. This service brings information about the total amount of water available in a basin [24]. Freshwater module is based on development of two interlinked models; water yield model and water scarcity model. In water yield model, the amount of water provisioned from each cell in the landscape was obtained by calculating the net hydrological balance [25] as the difference between precipitation and evapotranspiration, determined by the cell vegetation characteristics [26] (**Fig. 2**). In water scarcity model, the amount of water available for drinking uses was obtained by subtracting the water demand by each land use/land cover from the already calculated water yield.

The first step (water yield) uses data on average time span precipitation, annual reference evapotranspiration, soil depth, plant available water content, land use and land cover, root depth, evapotranspiration coefficient by each land use and land cover and a seasonality factor of rainfall (Zhang coefficient). Regarding the model sensitivity to parameters performed in previous studies, high changes in the precipitation input values causes significant changes in water yield, especially in more humid areas of the watershed where precipitation is high and evapotranspiration low. Hence, decrease in water yield expected for the future scenarios is mainly related to the precipitation decrease while the evapotranspiration increase has a minor influence. On the other hand, the Zhang coefficient in Mediterranean basins does not seem to be an important factor in water yield calculations that gives values within a range of same output.

The second step (water scarcity) adds water demand by each land use/land cover to determine the water available for drinking purposes (water supply) (**Table 2**).

InVEST water provisioning models are applied for each scenario and time span for climate change impact assessment. The model was run seven times, changing in each run the inputs related to the climatic factors. Thus, the average annual reference evapotranspiration and the average annual rainfall were different according to the projected variations in temperature and precipitation patterns (**Table 3**) established by regionalized IPCC scenarios. A2 scenario expects severe changes in temperature and precipitation schemes, while B1 scenario expects more moderate variations. Land use and water demand are kept constant for all the scenarios because the main objective of this paper is to assess exclusively the impacts related to climate change.

InVEST model does not differentiate between surface, subsurface and baseflow, but assumes that the water yield from each and every pixel reaches the point of interest via one of these pathways. The model calculates the sum and averages of water yield at sub-watershed level. The pixel-scale calculations allow representing the heterogeneity of key driving factors in water yield such as soil type, vegetation and temperature. InVEST ensures good interpretation of these models at sub-watershed scale, and all outputs are summed and/or averaged to the watershed scale.

Water yield model is based on the Budyko curve [27] and annual average precipitation. First, the annual water yield (Y_{jx}) for each pixel on the landscape (x=1, 2, 3…X) is determined in the **Eq. 1**:

$$Y_{xj} = \left(1 - \frac{AET_{XJ}}{P_x}\right) \cdot P_x \qquad \textbf{Eq. 1}$$

AET_{xj} is the annual actual evapotranspiration on the pixel x with land use land cover (LULC) j. P_x is the annual precipitation on the pixel x.

The evapotranspiration partition of the water balance shown in the **Eq. 2** ($\frac{AET_{xj}}{P_x}$) is an approximation of the Budyko curve developed by Zhang [28]:

$$\frac{AET_{xj}}{P_x} = \frac{1 + w_x R_{xj}}{1 + w_x R_{xj} + \frac{1}{R_{xj}}} \qquad \textbf{Eq. 2}$$

R_{xj} is de dimensionless Budyko Dryness index on pixel x with land use and cover j, defined as the ratio of potential evapotranspiration to precipitation [27] and w_x (**Eq. 3**) is a modified dimensionless ratio of plant accessible water storage to expected precipitation during the year. As defined by Zhang [28] is a non-physical parameter to characterize the natural climatic-soil properties.

$$w_x = Z \frac{AWC_x}{P_X} \qquad \textbf{Eq. 3}$$

AWC_x is the volumetric (mm) plant available water content and Z is the Zhang coefficient which has already been explained before.

Finally, the Budyko dryness index was defined with **Eq. 4**, where R_{xj} values which are greater than one denote pixels that are potentially arid [27], as follows:

$$R_{xj} = \frac{k_{xj} \cdot ETo_x}{P_x} \qquad \textbf{Eq. 4}$$

Where ETo_x is the reference evapotranspiration from pixel x and k_{xj} is the plant (vegetation) evapotranspiration coefficient associated with the land use land cover j on pixel x. ETo_x represents an index climatic demand while k_{xj} is largely determined by x's vegetative characteristics [29].

Water supply for drinking purposes is calculated as the difference between water yield and water consumptive use in the watershed.

2.2.3. Model validation

The wide-spread use of numerical models for the study of ecological and environmental phenomena requires some means of assessing model correctness [30]. Validation is an attempt to increase the degree of confidence that the events inferred by a model occur under the assumed conditions.

The validation of InVEST application was performed by comparing InVEST water yield results with Sacramento model runoff values which were validated with observed values by Catalan Water Agency (ACA). Sacramento is a conceptual model which generates the flow as surface runoff from waterproof and porous basin areas, together with the subsurface flow and low levels of base flow. The model represents the basin as a set of storages with specific capacities which retains water temporarily and then gradually yield, as their content decreases because of percolation, evapotranspiration and lateral drain [31]. As it is shown in **Table 4**, the required input data for Sacramento model is precipitation, temperature and evaporation in order to calculate the basin flow. As such, the model analyse the hydrological behaviour of the basin, through the determination of different percentages of water layers like snow retention, evaporation, surface flow or groundwater flow. InVEST requires input data of climatic and regional parameters of the land and generates a single water yield which includes surface, subsurface and growndwater flow.

Catalan Water Agency (ACA) provided average values of surface and groundwater flow for twelve different sub-watersheds evenly distributed in the Francolí

River basin for a base period from 1970-2000. To validate InVEST performance, both model values were compared through the calculation of Nash-Sutcliffe model efficiency index [32].

3. Results and discussion

3.1- Water yield

InVEST tool calculates water yield as the difference between precipitation and the actual evapotranspiration (AET). The actual water yield volume for Francolí River basin is 47.77 hm^3yr^{-1}, but as it is shown in the **Fig. 3,** each sub-watershed contributes in different proportion as a consequence of the variation of the parameters like precipitation and AET, through the watershed. The highest water yield contribution per unit area comes from the western part of the watershed with the course of Brugent River which flows through the Prades Mountains. These mountains, which are situated at the Coastal Mountains chain, have high annual rainfall and low average annual evapotranspiration causing a water yield of 1,150 $m^3ha^{-1}yr^{-1}$. On the other hand, the lowest water yield values, which are around 300 $m^3ha^{-1}yr^{-1}$ belongs to the northern sub-watersheds. This area is confluence of two low flow tributaries of Francoli River, called as Anguera and Vallverd River, and both are under water stress situation. This part of the watershed is characterized for having low annual rainfall as well as high average annual evapotranspiration. Tarragona sub-watershed, located at the southernmost region of the Francolí River basin, has a water yield volume of 800 $m^3ha^{-1}yr^{-1}$. Although the low annual rainfall and the high average annual evapotranspiration, this area has this high water yield volume as a result of the groundwater that flows through the watershed recharging the aquifer of this sub-watershed.

Climate change impact on water yield varies from watershed to watershed in Francolí River basin. The **Fig. 4** shows the expected percentages of reduction of the actual water yield volume considering two different regionalized IPCC scenarios (A2 and B1) for the time spans 2011-2040, 2041-2070 and 2071-2100.

The scenario A2, expects the highest impacts with an average reduction from 21% to 44% (**Table 5**) in terms of water yield for the whole watershed. However, each sub-watershed has a different percentage of decrease as a result of regional differences of the land showing reductions from above 0% to 60%. As it is shown in the **Fig. 3**, for all time spans more impact is observed in the northern part, less impact in the southern area, and medium-high impact in the western part. Water yield from northern part will decrease a total of 30% for the time spans 2011-2040 and 2041-2070, and up to 60% for the time span 2071-2100. Western sub-watersheds expect reductions of 20%, 30% and 50% for the time spans 2011-2040, 2041-2070 and 2071-2100 respectively. Southern part will be the less impacted area in Francolí watershed. Total reductions of 20% for the time spans 2011-2040, 2041-2070 and 30% for the time span 2071-2100 are expected.

Considering B1 scenario, the expected impacts are lower than scenario A2, with an expected average reduction from 11.5% to 33% in terms of water yield for the whole watershed. The projected reduction for each sub-watershed will be the same for the time spans 2011-2040 and 2041-2070, with a total decrease of 20% in the northern area, and 10% for the rest of the watershed in comparison with the base scenario. For the time span 2071-2100, highest impacts on water yield are expected at the northern, north-western and central area with a reduction of 40%, whereas western and southern part will decrease up to 30%.

Each region of Francolí river basin undergoes different percentage of reductions as a consequence of the regional differences of the land. Both selected scenarios agree to show the most impacted area is at the northern sub-watersheds, followed by western, central and southern ones as a consequence of the difference in the land characteristics. Northern sub-watersheds match up with the lowest water yield part; this poor area in terms of water yield will be the most effected part of Francolí watershed. Two rapidly drying low flow related tributaries in this part: Anguera and Vallverd, are causing water stress situation in this area. Western sub-watersheds, region which belongs to Francolí River source and Francolí tributary Brugent River, are expected to be highly impacted. Any change in precipitation patterns in these sub-watersheds will highly affect the whole watershed, threatening the water availability for different uses. However, the Tarragona sub-watershed has a medium-high water yield volume being mainly groundwater, and medium-low reduction impact in this region is expected. This area is considered as the most preserved region at Francolí watershed in terms of water yield.

3.2- Water supply for drinking purposes

Reductions in water yield impacts negatively the basin capacity of providing water for drinking purposes. This value is defined by water scarcity analysis as the difference between the yield and consumptive uses of water by each land use. This actual value in Francolí watershed is 41.86 hm^3yr^{-1}. However, as it is shown in **Fig. 5**, these values vary at sub-watershed scale from 250 $m^3ha^{-1}yr^{-1}$ in Anguera and Vallverd sub-watersheds to 1,100 $m^3ha^{-1}yr^{-1}$ in Prades and Brugent River sub-watersheds. Water supply for drinking purposes is slightly lower than the actual water yield as a result of the water demand defined by each land use, but it is important to note that sub-watersheds of urban areas and irrigated crop land undergo higher decreases in availability of water for drinking purposes.

Climate change will also impact on Francolí River basin by affecting negatively the basin capacity of providing drinking water. As it is shown in **Table 5**, as well as in the impact assessment maps shown in **Fig. 6**, the total annual volume of water for drinking use is expected to reduce in all the selected scenarios but with greater percentages in comparison to the water yield assessment.

For the A2 scenario, reductions from 24% to 50% at watershed scale are expected as mentioned in **Table 5**. At sub-watershed scale, the same impacts are expected for the time span 2011-2040 and 2041-2070, showing reductions up to 40% at three sub-watersheds located at the northern area and one of the central part, as well as 30% of reduction for the others sub-watersheds. However, the time span 2071-2100 expects higher impacts with reductions up to 60% at the northern and central sub-watersheds, as well as reductions up to 50% for the rest of the watershed. In general, each sub-watershed of urban and irrigated crops lands undergo higher decreases. The main reason is because more water is needed as a result of the high water demand by domestic and agricultural uses. These results (**Fig. 6**) show these higher expected negative impacts in the projected future scenarios in comparison with expected impacts on water yield (**Fig. 4**). In this study, water demand has been considered constant for future scenarios because this study aims to assess only the impact related to climatic factors.

In the B1 scenario assessment, reductions from 13% to 38% of the actual water supply (41.86 hm^3 yr^{-1}) are expected. As well as for the A2 scenario, the same degree of reduction at sub-watershed scale is expected for the time span 2011-2040 and 2041-2070 but they are slightly lower. There is a group of three northern sub-watersheds and one sub-watershed located at the central part which expects decrease up to 30% whereas the rest of the watershed expects 20% of reduction. The last time span, 2071-2100, expects impacts up to 50% of reduction at the northern sub-watersheds and three sub-watersheds located at the central area, while the rest of the watershed expects decrease up to 40%.

Following the same pattern as in water yield assessment, northern and western sub-watersheds are the most impacted area, and the time span 2071-2100 is the worst expected scenario in terms of availability of water for drinking purposes. However, in A2 scenario as well as in B1 scenario, there are some sub-watersheds which become more impacted in water supply for drinking purpose assessment than in water yield as a consequence of the different land use and land cover and its related water demand. For each time span, the northern area, which is always the most impacted region, is formed by three sub-watersheds instead of two in water yield case. The reason is because in this added sub-watershed there is urban area which belongs to Espluga de Francolí which causes a high water demand depending on Francolí supply, and consequently has a higher impact. Regarding to these higher impacts, central sub-watersheds also become more impacted than in water yield case because of its irrigated crop land and urban areas such as La Selva, Vallmoll and Valls.

InVEST works on annual basis and the climate trend of Mediterranean river basins is to undergo an average precipitation decrease and an average temperature increase over the years. However, it is important to note that climate change expects to concentrate the rainfall in shorter periods of the year, and suffer more extended droughts. Hence, it could be interesting to consider the impact of extreme wet and dry years on the delivery of hydrological ecosystem services. As it has been studied by Terrado et al [25], for the Llobregat watershed in the same Mediterranean region, the basin capacity of providing drinking water is likely to experience reductions up to 80% in dry years and to be increased up to 160% at least in wet years. In a similar way for Francolí river basin during a dry season, it is assumed that water supply for drinking purposes will be reduced up to 8.37 hm^3 while during a wet season an increase of 108.84 hm^3 is expected.

3.3- Validation results

As it has been explained in the methodology part, after plotting the regression line resulting from InVEST and Sacramento values, the validation was measured through the calculation of coefficient of Nash-Sutcliffe model efficiency index [32] in order to decide if linear adjustment is enough or if it is necessary to apply alternative models. The obtained index result was 0.92 (**Fig. 7**), value that shows the proper application of InVEST in the low flow Francolí River.

4. Conclusions

This paper illustrates the application of the ecosystem services model InVEST in Francolí River basin (NE Spain) to assess how changes in temperature and precipitation patterns related to climate change impact on water provisioning ecosystem services. InVEST has been largely applied to map ecosystem services in a high flow rivers [16, 24]. After model validation, InVEST seems to be a valuable tool to map ecosystem services in a river with a low flow hydrological regime.

The evaluation of climate change impacts on the selected hydrological ecosystem services shows that water provisioning is highly sensitive to climate change in Francolí River basin. In terms of water provisioning, the analysis shows that areas responsible for least and most of the provision of water service will be the most impacted, causing desertification in the low flow areas and at the same time reductions in the source areas are expected which cause flow decreases at the whole watershed. In terms of water supply for drinking purposes, in addition to these mentioned impacted areas, the central region will be also highly impacted because of the water consumption demand by urban areas and irrigated crops land showing the importance of the land use in this second analysis. A reduction in stream flow might lead to increase in peak concentrations of certain chemical compounds [33]. Therefore, the highest impacted regions are likely to undergo the highest decreases in water flow quality.

Because of all these expected impacts mentioned above, urgent measures should be taken to mitigate the already existing water stress in the basin. Decision making and policy aimed at achieving sustainability goals can be improved with accurate and defendable methods for quantifying ecosystem services [34]. The approach is designed to enhance on-site benefits, contribute to state-wide policy initiatives, and also inform the mitigation of negative impacts where necessary [35] through the introduction of River Basin Management Plan to assure the provision of water in the basin. Future attention will be focused on to predict the water quality of the river flow considering these expected impacts.

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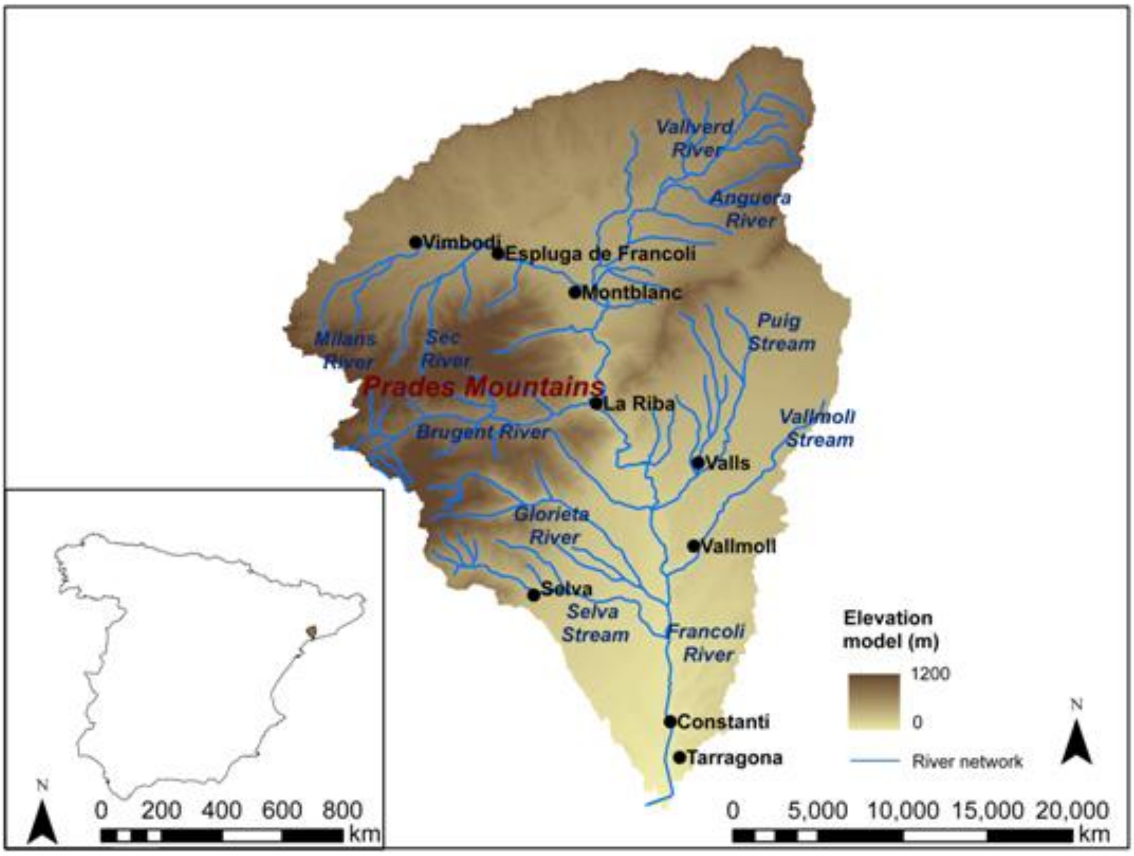

Fig. 1. Francolí river basin.

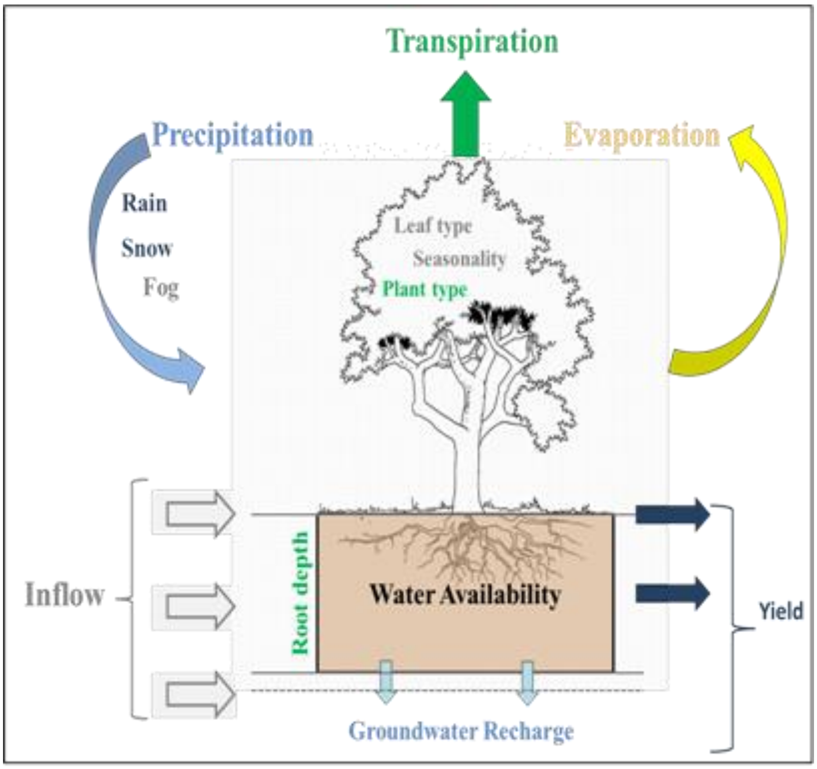

Fig. 2. Water balance model used in InVEST hydrological models. Only parameters shown in color are inclued, and parameters shown in grey are ignored.

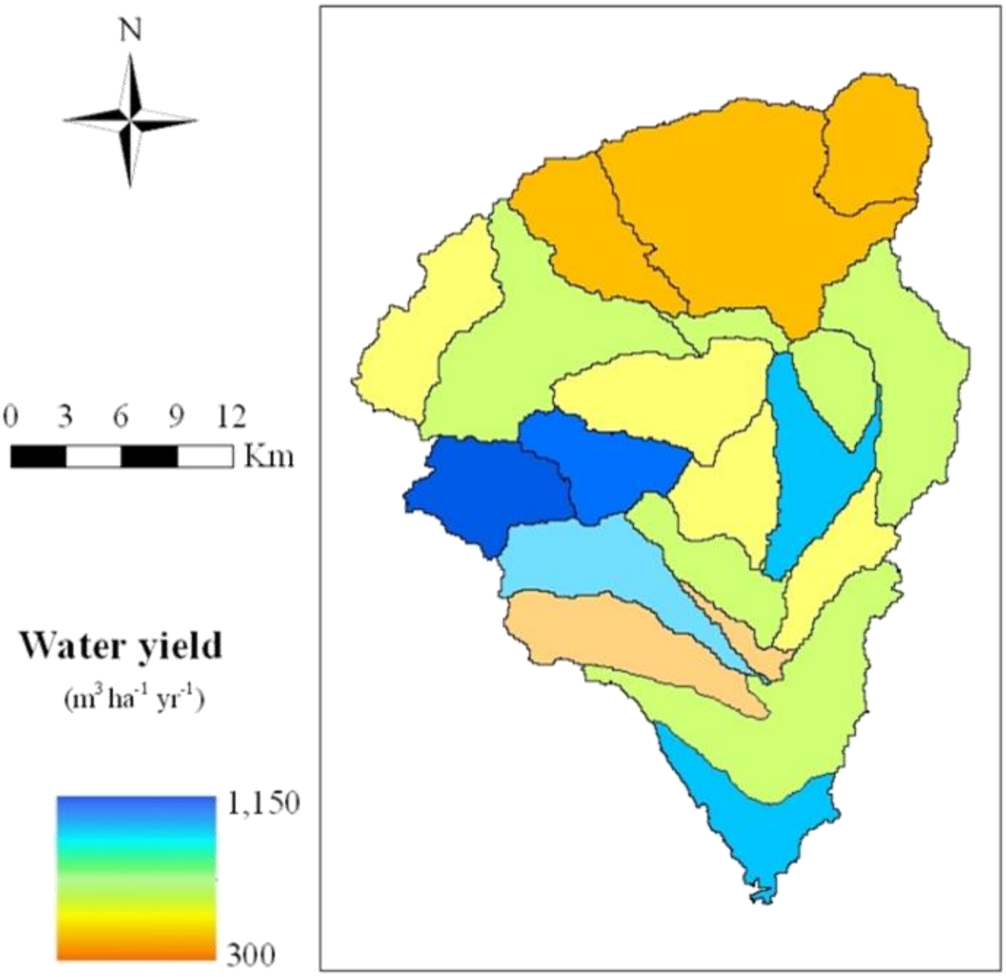

Fig. 3. Actual water yield in Francolí river basin.

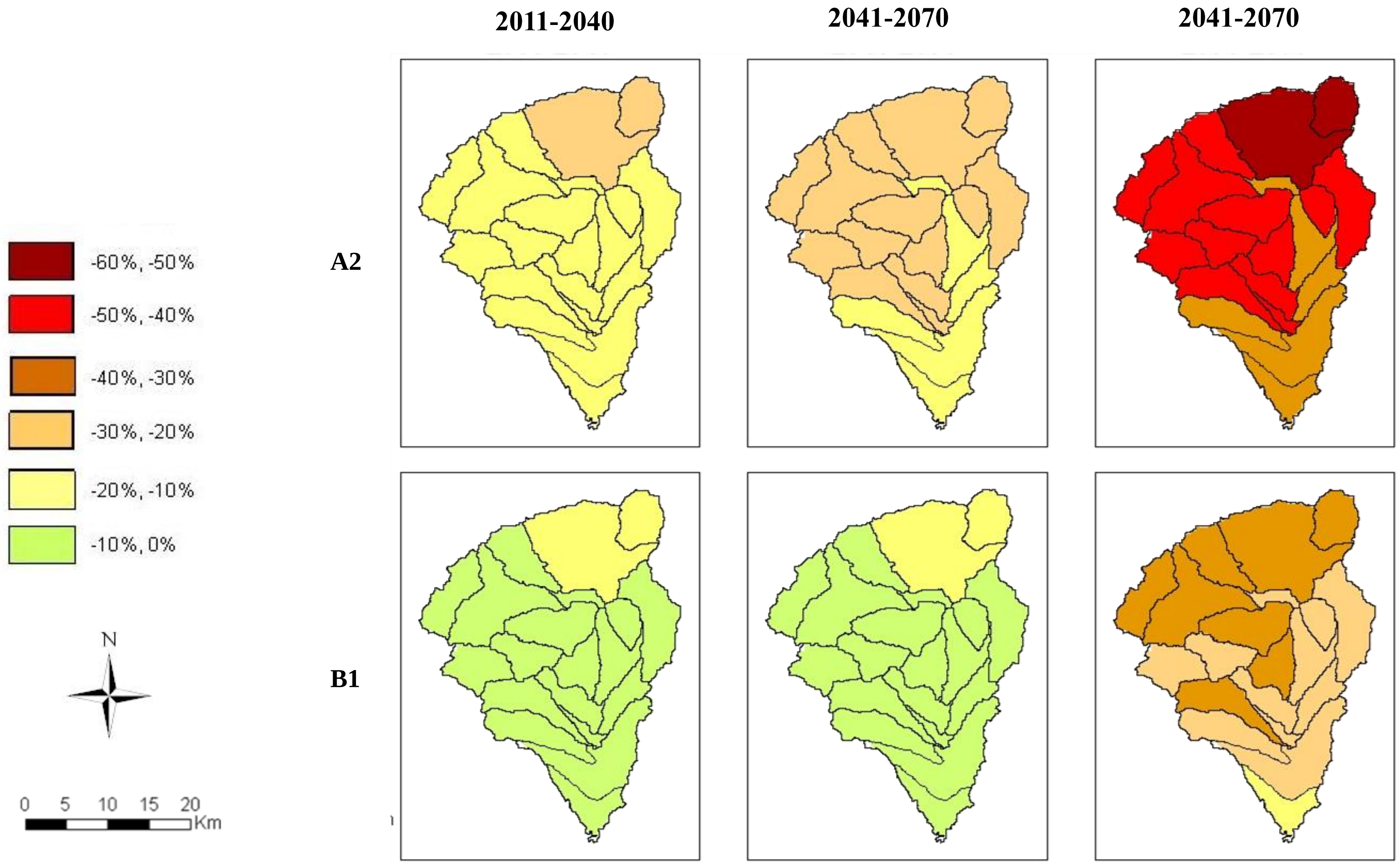

Fig. 4. Percentage of reduction of the actual water yield.

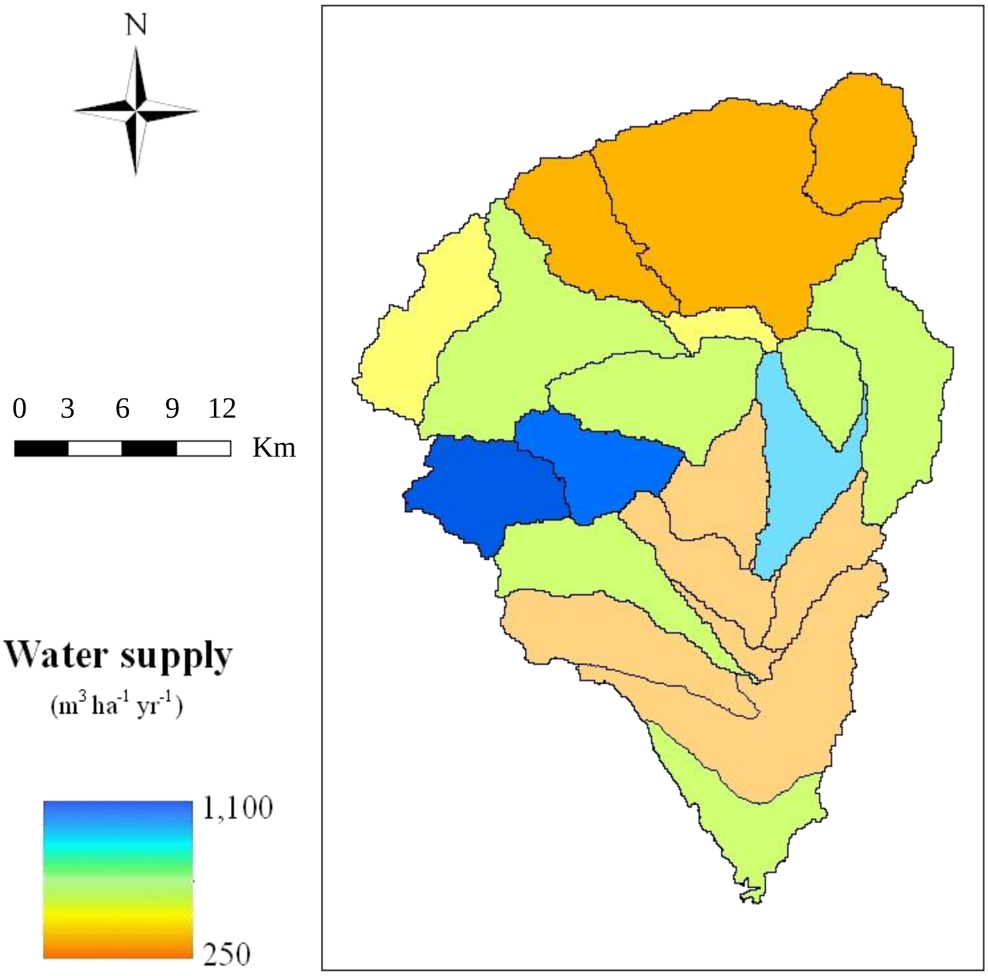

Fig. 5. Actual water available for drinking purposes in Francolí river basin**.**

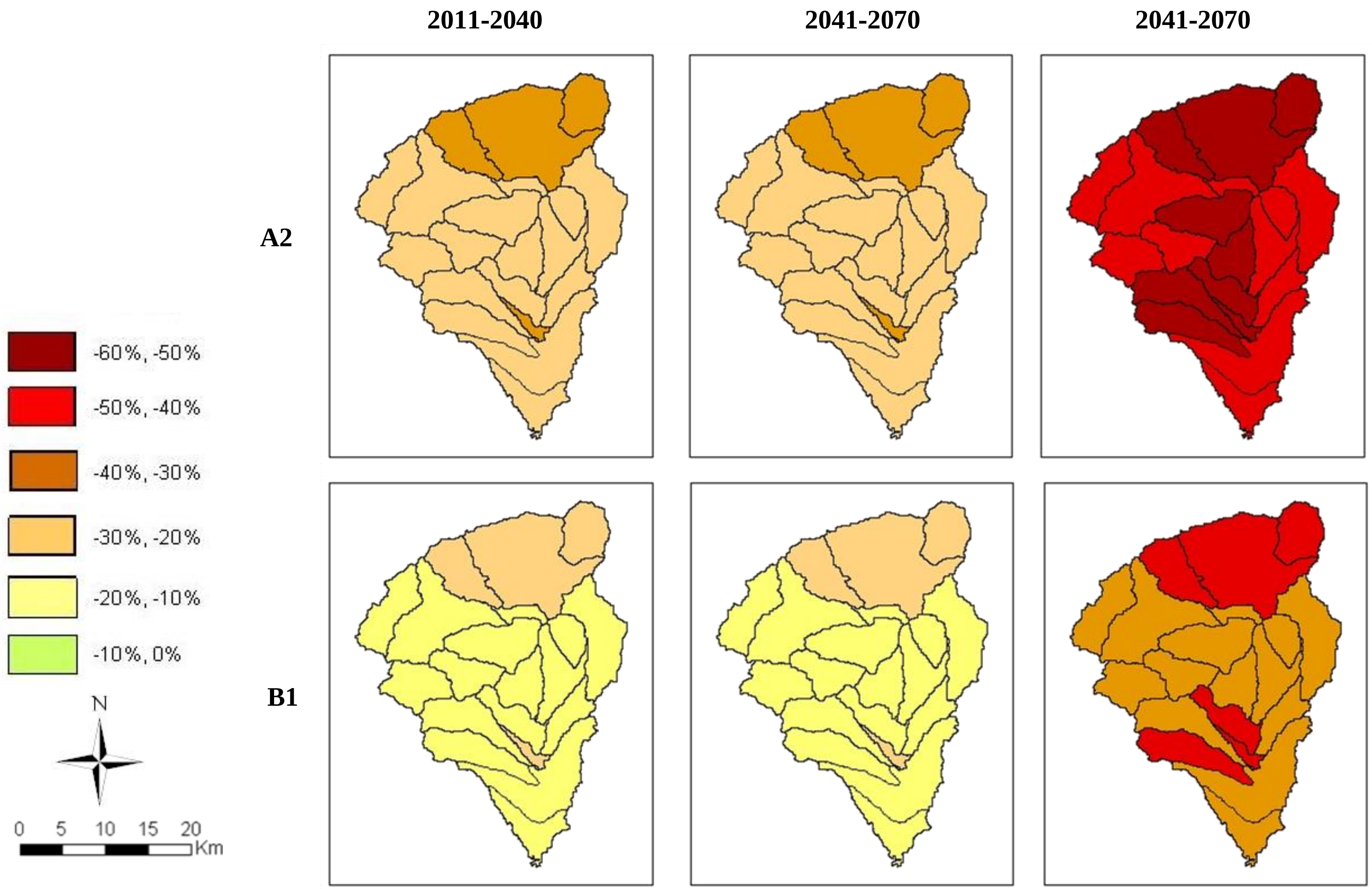

Fig. 6. Percentage of reduction of the actual water available for drinking purposes.

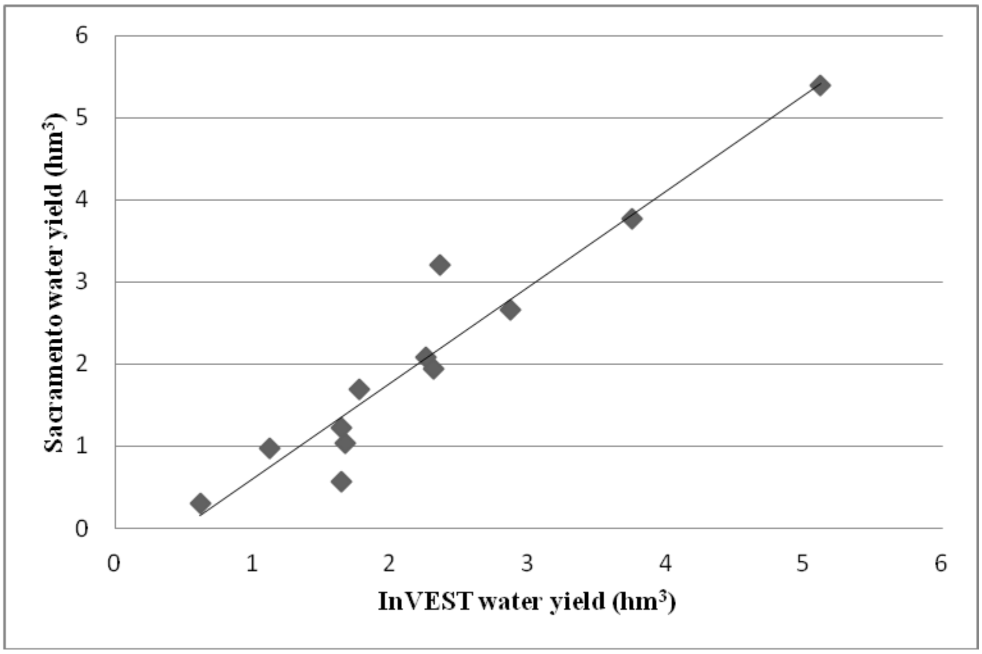

Fig. 7. InVEST versus Sacramento annual water yield at different sub-watersheds distributed along Francolí river basin.

Table 1

Maps, tables and constants used as input to InVEST with reference to the source and the spatial discretization.

Data type	Data source	Spatial discretization
GIS raster grids maps		
Topography/DEM	ICC (Institut Cartogràfic de Catalunya, www.icc.cat)	30 x 30 m^2
Average annual rainfall	Catalan Water Agency data	20 sub-watersheds
Average annual rainfall for the future scenarios	Catalan Meteorological Service	20 sub-watersheds
Average annual reference Evapotranspiration	Climatic atlas of Catalonia temperature data. Calculated (Hamon 1961, Wolock and McCabe 1999) and interpolated.	30 x 30 m^2
Average annual reference Evapotranspiration for the future scenarios	Catalan Meteorological Service	30 x 30 m^2
Land use/land cover	Centre for ecological research and forestry application	30 x 30 m^2
Effective soil depth	European Soil Database	30 x 30 m^2
Plant available water content	European Soil Database Calculated with Bech et al., 2008	10 x 10 km^2
GIS shapefiles maps		
Watershed boundary	Extracted from Digital Elevation Model (DEM) using ArcGIS hydrological tools	As DEM, 30 x 30 m^2
Sub-watershed boundary	Provided by Catalan Water Agency	As DEM, 30 x 30 m^2
Database tables		
Maximum root depth	Canadell et al., 1996	
Evapotranspiration coefficient	Extracted from InVEST User's guide. Tallis et al., 2011. Literature review of Mediterranean area	
Water demand table	Catalan Water Agency and Catalan Statistics Institute	
Constant		
Zhang coefficient	Zhang and McFarlane, 1995; Zhang et al., 2001, 2004; Milly, 1994	

Table 2

Components and description of two steps of the water provisioning module.

Step	**Data requirements**	**Process**	**Outputs**
Water yield	Land use/land cover Annual average precipitation Annual average reference evapotranspiration Plant available water content Evapotranspiration coefficient Root depth Effective soil depth Zhang coefficient	Calculates yield as difference between precipitation and actual evapotranspiration $Y = P - AET$ where: Y= water yield P= precipitation AET= actual evapotranspiration	Annual average water yield (mm·watershed^{-1} · year^{-1}, mm·subwatershed^{-1} year^{-1})
Water supply for drinking purposes	Water demand by each land use/land cover	Substracts water consumed by each land use/land cover as below: $V_{in} = Y - u_d$ where: V_{in}= water supply Y= water yield u_d= water consumption by each land use/land cover	Annual average water supply (mm·watershed^{-1} · year^{-1}, mm·subwatershed^{-1} year^{-1})

Table 3

Temperature and precipitation variations at Francolí watershed for selected scenarios and time spans.

Scenario	**Time span**	**Average annual temperature variation (ºC)**	**Average annual precipitation variation (%)**
A2	2011-2040	+ 0.8	- 8
	2041-2070	+ 2.1	- 8
	2071-2100	+ 3.6	- 16.5
B1	2011-2040	+ 0.9	- 1.4
	2041-2070	+ 1.4	- 3.8
	2071-2100	+ 2.5	- 10.5

Table 4

Required data for Sacramento and InVEST models.

Sacramento model		**InVEST model**	
Inputs	***Outputs***	***Inputs***	***Outputs***
Precipitation	Snow retention	Precipitation	Water yield (surface, subsurface and groundwater flow)
Temperature	Evaporation	Evapotranspiration	
Evaporation	Surface flow	Land use/land cover	
	Groundwater flow	Plant available water content	
		Evapotranspiration coefficient	
		Root depth	
		Effective soil depth	
		Zhang coefficient	

Table 5

Comparison between base and future scenarios of rainfall, actual evapotranspiration, water yield and drinking water supply in Francolí river basin**.**

Time span	**Scenario**	**Rainfall**	**Rainfall reduction**	**Actual evapotranspiration**	**AET reduction**	**Water yield**	**Water yield reduction**	**Drinking water supply**	**Drinking water supply reduction**
		mm · yr^{-1}	%	mm · yr^{-1}	%	$hm^3 \cdot yr^{-1}$	%	$hm^3 \cdot yr^{-1}$	%
1971-2000	Base	565.42	-	416.67	-	47.77	-	41.86	-
2011-2040	A2	528.66	6.5	404.59	2.9	37.81	21	31.90	24
2041-2070	A2	535.45	5.3	416.92	-0.06	36.09	24.5	30.18	28
2071-2100	A2	484.56	14.3	396.29	4.89	26.81	44	20.90	50
2011-2040	B1	555.80	1.7	418.7	-0.49	41.83	12.5	34.92	14
2041-2070	B1	548.09	3.06	427.06	-2.49	42.20	11.5	36.29	13
2071-2100	B1	511.7	9.5	406.85	2.36	31.86	33	25.95	38