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Establishment of a hydrological model in a subbasin of the Sabor river

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ABSTRACT

Land cover changes have consequences on hydrological processes of a basin through changes in evapotranspiration and surface and subsurface water movements in the landscape. Concern in the Mediterranean region has grown recently due to the prospects of a reduction in precipitation and the occurrence of large periods of drought potentially affecting human communities and biodiversity. This research consisted in the implementation of a hydrological model in the Upper Sabor river catchment, Northeastern Portugal, to evaluate the impacts of land cover change on hydrological processes, namely water yield. This catchment was chosen to represent landscape composition and configuration in a changing mountain area of the region where types and rates of land use change are known in detail for the last 50 years. SWAT (Soil and Water Assessment Tool) was the model chosen to address the research question. The implementation of SWAT consisted in data gathering, preparation and database development: elevation, land use/land cover, weather, soils and land management practices. Model validation was done considering data on streamflow between 1973 and 2008. Monthly average results have shown that water yield in the watershed depended on proportions of land cover in the landscape. From the scenarios tested through simulation, we can highlight that replacing agriculture by shrublands increased evatpotranspiration and decreased water yield. On the other hand, a considerable augment in water yield was registered when pastures became the dominant land use class. Scenarios with the largest occupations in agriculture or pastures, were the least evapotranspirative. Responses from land cover classes varied over the year.

RESUMO

Alterações do uso do solo produzem efeitos nos processos hidrológicos de uma bacia através de alterações na evapotranspiração e no fluxo de água superficial e subterrânea na paisagem. Na região mediterrânica têm aumentado as preocupações devido a previsões de redução da precipitação e à ocorrência de períodos de seca prolongados, potencialmente afectando as comunidades humanas e a biodiversidade. Este trabalho consistiu na implementação de um modelo hidrológico na parte superior da bacia do rio Sabor, no nordeste de Portugal, para avaliar os impactos de alterações do uso do solo em processos hidrológicos, nomeadamente no caudal produzido. Esta bacia foi escolhida por representar uma paisagem de montanha em mudança numa região onde os tipos e taxas de alteração do uso do solo são conhecidos em detalhe nos últimos 50 anos. O SWAT (Soil and Water Assessment Tool) foi o modelo seleccionado para responder aos propósitos do trabalho. A implementação do modelo SWAT consistiu na recolha, preparação e desenvolvimento de uma base de dados com informação topográfica, de ocupação e uso do solo, meteorológica, dos tipos de solo e das práticas de gestão. A validação do modelo baseou-se em dados de caudal entre 1973 e 2008. Os resultados, em médias mensais, mostraram que a água produzida na bacia depende da cobertura do solo. Dos cenários testados, pode-se salientar que a substituição de área agrícola por área de matos faz aumentar a evapotranspiração e diminuir o caudal. Por outro lado, foi registado um aumento considerável do caudal quando na área, as áreas de pastagens passaram a ser dominantes. Os cenários com maior área agrícola ou de pastagem, foram os que apresentaram menor evapotranspiração. As respostas das classes de uso do solo variam ao logo do ano.

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c.	*circa*, around
e.g.	*exampli gratia*, for example
et al.	*et alli, et aliae*, and others
etc.	*et cetera*, and so on, and so forth
i.e.	*id est*, that is

1. INTRODUCTION

Hydrological processes are highly related to the vegetation that covers the surface. Changes in the land cover, such as afforestation or deforestation and agriculture abandonment, can have strong effects on these processes, and consequently on the water balance of a watershed. Therefore, it is of great importance the understanding of the relationship between land cover, land cover change and their impacts on the basin hydrology, in order to be able to predict the consequences of different landscape scenarios. To contribute to that necessary knowledge, we decided to implement a hydrological model in the Upper Sabor River catchment, northeastern Portugal, to describe and predict hydrological processes and to evaluate the effects of land cover change on these processes at the basin scale, namely water yield, for the 1973-2008 period. This catchment was chosen to represent landscape composition and configuration in a changing mountain area of the Mediterranean region where types and rates of land use change are known in detail for the last 50 years (Azevedo *et al*., 2011).

2. LITERATURE REVIEW

The water yield of a watershed is determined by both groundwater bodies and surface runoff (Nosetto *et al.*, 2011), which is largely controlled by land cover either by forest and agriculture activities or by urban development (Fox *et al.*, 2012). The overall consequences of land cover changes on surface runoff still are not always taken into account by land managers (Fox *et al.*, 2012).

Land use / land cover change and hydrological processes

Several factors contribute to the hydrological balance of a basin such as the precipitation pattern, underground water, soil type and soil cover (Zhang *et al*., 1999). In this context, vegetation plays an important role on the partitioning of the precipitation, dividing it between wet (*i.e.* runoff and deep drainage) and dry (evapotranspiration) water fluxes (Nosetto *et al*., 2011). Consequently, changes in the land cover produce effects on the hydrological processes above and on the extent of the areas contributing to runoff (García-Ruiz and Lana-Renault, 2011). Another important variable in water balance is soil type. Land abandonment, as discussed hereinafter is an important land change driver and it is highly correlated to marginal soils (mainly regosols and lithosols) with respect to water holding capacity, as highlighted by Sluiter and De Jong (2007).

Land abandonment

Agriculture land abandonment of European rural areas during de 20th century, particularly since the end of the 2nd World War, was an important phenomenon that occurred mostly in areas located in mountainous and semiarid environments (García-Ruiz and Lana-Renault, 2011**;** MacDonald *et al*., 2000). The most obvious consequence, was the transformation of the landscape that registered a spread of natural vegetation, both forest and shrubs (Taillefumier and Piégay, 2003; Poyatos *et al*., 2003) that when unmanaged, led to a dramatic increase in wildfires (Nunes *et al*., 2010) followed by more surface runoff.

Land abandonment affected severely Portugal (Van Doorn and Bakker, 2007; Nunes *et al*., 2010; Azevedo *et al*., 2011), Spain (Díaz *et al*., 2007; Lasanta *et* *al*., 2000) and other Mediterranean countries (MacDonald *et al*., 2000; Koulouri and Giourga, 2007; Cernusca *et al*., 1996). Population migrations to the cities and countries like France or Germany (Nunes *et al*., 2010), low productivity of some of the rural areas (Duarte *et al*., 2008) along with their physical constraints and poorly skilled and aged farmers of their small sized lands (MacDonald *et al*., 2000), the Common Agricultural Policy (CAP) (Lasanta *et al*., 2000; Boellstorff and Benito, 2005), national political decisions and regional, national, and international market interests, were some of the reasons that contributed to this historical fact which had a great impact on farmland abandonment (García-Ruiz and Lana-Renault, 2011). Large land cover changes also occurred in several countries around the world such as those reported by Paruelo *et al*. (2006), Leblanc *et al*. (2008) and Schofield (1992).

Agriculture land abandonment in the last two decades of the 20th century, mostly cereal crops, resulted largely from CAP implementation, which encouraged farmers to spot cultivating their land through the payment of subsides (García-Ruiz and Lana-Renault, 2011; Nunes *et al*., 2010). Due to this political change, the landscape structure suffered a severe transformation characterised by an increase in semi-natural vegetation elements, mainly forest and shrublands (MacDonald *et al*., 2000; Poyatos *et al*., 2003) affecting numerous landscape processes including fire which increased dramatically in these landscapes (García-Ruiz and Lana-Renault, 2011).

Hydrological processes have also been strongly impacted by land use change. All over the world, several studies have been made in order to measure and analyse the impact of land cover changes on catchment hydrology (*e.g*., Schofield, 1992; Casermeiro *et al*., 2004; Leblanc *et al*., 2008; García-Ruiz and Lana-Renault, 2011; Nosetto *et al*., 2011; Fox *et al*., 2012). Different covers and cover changes lead to distinct hydrological results. Afforestation and deforestation have opposed results on water yield, like Fohrer *et al*. (2001) and Brown *et al*. (2005) observed in catchments with a wide range of areas. Nosetto *et al*. (2011) highlight that stronger effects result from tree-herbaceous transitions, pointing the South America example where soybean is taking over new areas at high rates, like in Argentina and Uruguay (Paruelo *et al*., 2006), with great impacts on the water balance.

Land cover impacts on evapotranspiration rates have also been observed. In their Central Argentina study, Nosetto *et al*. (2011) calculated predictive annual evapotranspiration amounts for different land covers: 785 mm for tree plantations, 764 mm for dry forests, 562 mm for grasslands, 533 mm for wheat/soybean double crop system and 423 mm (yearly values) for single crop soybean. As a consequence of reducing the evapotranspiration rate through the replacement of forest areas by agriculture crops, groundwater recharge and water-table levels increased in Australia (Schofield, 1992) and southwest Niger (Leblanc *et al*., 2008). As expected, the opposite was observed by several authors (Heuperman, 1999; Farley *et al*., 2005; Nosetto *et al*., 2005), where afforestation of grasslands and shrublands resulted in increased evapotranspiration and reduced water yields.

The Mediterranean region, due to the large landscape transformation observed over the millennia and the particularity of its climate, namely the annual temperature/precipitation combination, which makes plant colonization and growth difficult (García-Ruiz and Lana-Renault, 2011), has also been object of land cover changes studies (Llorens *et al*., 1992; Cerdà, 1997; Lasanta *et al*., 2000; Piégay *et al*., 2004; Cammeraat *et al*., 2005; Koulouri and Giourga, 2007; Lesschen *et al*., 2007; Díaz *et al*., 2007; Lesschen *et al*., 2008; Bakker *et al*., 2008; López-Moreno *et al*., 2008; Seeger and Ries, 2008; Nunes *et al*., 2010).

To assess the impacts of land cover changes different approaches can be followed, like statistics methods or controlled experimental manipulations on land surface along with hydrologic readings (DeFries and Eshleman, 2004), but for this work we chose a hydrological modelling approach, which is widely used nowadays, comprising many advantages, such as the possibility of simulating long periods of time, the creation of future management scenarios predicting the consequences of different land cover changes with a reduction on costs and on time consumption (*e.g.*, no data collecting needed), and it can be applied to a wide variety of catchments. Several hydrological models are available, like the HYLUC (Hydrological Land Use Change) used by Delgado *et al*. (2010) or the

MIKE SHE (Système Hydrologique Européen) used in El-Nasr *et al*. (2005) work, but SWAT was the chosen one.

The SWAT model

Thirty years of non-point source modelling by the United States Department of Agriculture – Agriculture Research Service, resulted in the development of the Soil and Water Assessment Tool (SWAT) model (Neitsch *et al*., 2011). This model aggregates several earlier developed smaller components, namely (1) a pesticide component called Chemicals, Runoff and Erosion from Agricultural Management Systems (CREAMS) model, (2) a daily rainfall hydrology component called Groundwater Loading Effects on Agricultural Management Systems (GLEAMS) model, and (3) a crop growth component first called Erosion Productivity Impact Calculator model, later renamed Environmental Impact Policy Climate (EPIC) model (Gassman *et al*., 2007). These smaller parts were first directly aggregated into the Simulator for Water Resources in Rural Basins (SWRRB) model, capable of simulating management impacts on water and sediment movement for ungauged rural basins, which in turn was later upgraded into the current SWAT model (Neitsch *et al*., 2011).

SWAT has been used in hundreds of studies worldwide (*e.g*., Francos *et al*., 2001; Ouessar *et al*., 2009; Nie *et al*., 2011; Cai *et al*., 2011; Nunes *et al*., 2011) and proven to be an efficient tool in assessing water resources at a wide range of scales and environmental conditions (Gassman *et al*., 2007). It is physically based, computes readily available data (*e.g.* weather, soil, vegetation, land management practices), and allows the study of short to long-term impacts, processing data on a continuous time mode (Neitsch *et al*., 2011). In order to properly simulate hydrologic processes in a watershed, this basin-scale model allows the partitioning of the area in several subbasins which in turn can be subdivided into several variable sized hydrologic response units (HRUs) that consist of homogeneous land use, management, and soil characteristics (Gassman *et al*., 2007). At first, these homogeneous areas could only be defined at the subbasin level, and only later they were incorporated into the SWAT model as part of the Hydrologic Unit Model for the United States (HUMUS) project, increasing predictions accuracy (Arnold *et al*., 2011).

Whereas subbasins are spatially related to each other, depending on the geographic position they occupy in the watershed, HRUs are not, each representing the total area that a particular land use, management and soil characteristics occupies in a subbasin, gathering scattered land pieces, and no spatial interactions exist between HRUs (Arnold *et al*., 2011). This way, and before being routed through the water channels, the total of loadings (*e.g*. sediment, nutrients, etc.) from a subbasin is calculated as the sum of the loadings of all the HRUs of the basin (Arnold *et al*., 2011).

Independently of the focus of the study, water balance is the driver of all processes taking place in the watershed (Neitsch *et al*., 2011). SWAT is a continuous-time model that can process information on a daily time basis, and in each hydrologic cycle simulated, SWAT processes data on a two-phase approach: (1) a land phase that controls, in each subbasin, the amount of water, sediment and other loadings, and (2) a routing phase to control their movement through the channel network to the outlet (Neitsch *et al*., 2011).

The first phase simulates land hydrology, using the water balance equation

$$SW_t = SW_0 + \sum_{day=1}^{t} (R_{day} - Q_{day} - ET_{day} - P_{day} - QR_{day})$$

where t is the simulation period, SW_t is the soil water content after the simulation period, SW_0 is the soil water content at the beginning of the simulation period, and R_{day}, Q_{day}, ET_{day}, P_{day} and QR_{day} are daily values (in mm) for precipitation, runoff, evapotranspiration, percolation and return flow, respectively (Neitsch *et al*., 2011). Better accuracy is achieved with the subdivision of the watershed in smaller homogeneous units: evapotranspiration depends on each land use and soil, and total runoff for the watershed is obtained after calculating and routing each HRU contribution (Neitsch *et al*., 2011). Surface runoff volume is calculated based either on the SCS (Soil Conservation Service) curve number method or on the Green & Ampt infiltration method (Gassman *et al*., 2007; Neitsch *et al*., 2011).

The second phase simulates the channel hydrology, where the loadings calculated earlier are routed through the stream network of the basin (Neitsch *et al*., 2011).

In spite of some limitations such as (1) the spatial detail that is required for an accurate simulation or (2) the lack of enough monitoring data, SWAT model is very versatile and can be used to integrate multiple environmental processes and be used to support watershed management decisions (Gassman *et al*., 2007). For all the advantages of the model mentioned before, SWAT was chosen to address the research question of this study, which is to assess the effects of land use changes on the catchment outflow.

3. MATERIALS AND METHODS

Study area

The Sabor river is a tributary of the Douro river, with headwaters in Spain close to the Portuguese border. The entire Sabor river basin is around 3868 km^2 in size, but in this work we are only focused on its upper basin that drains an area of *c*. 396 km^2 (Figure 1).

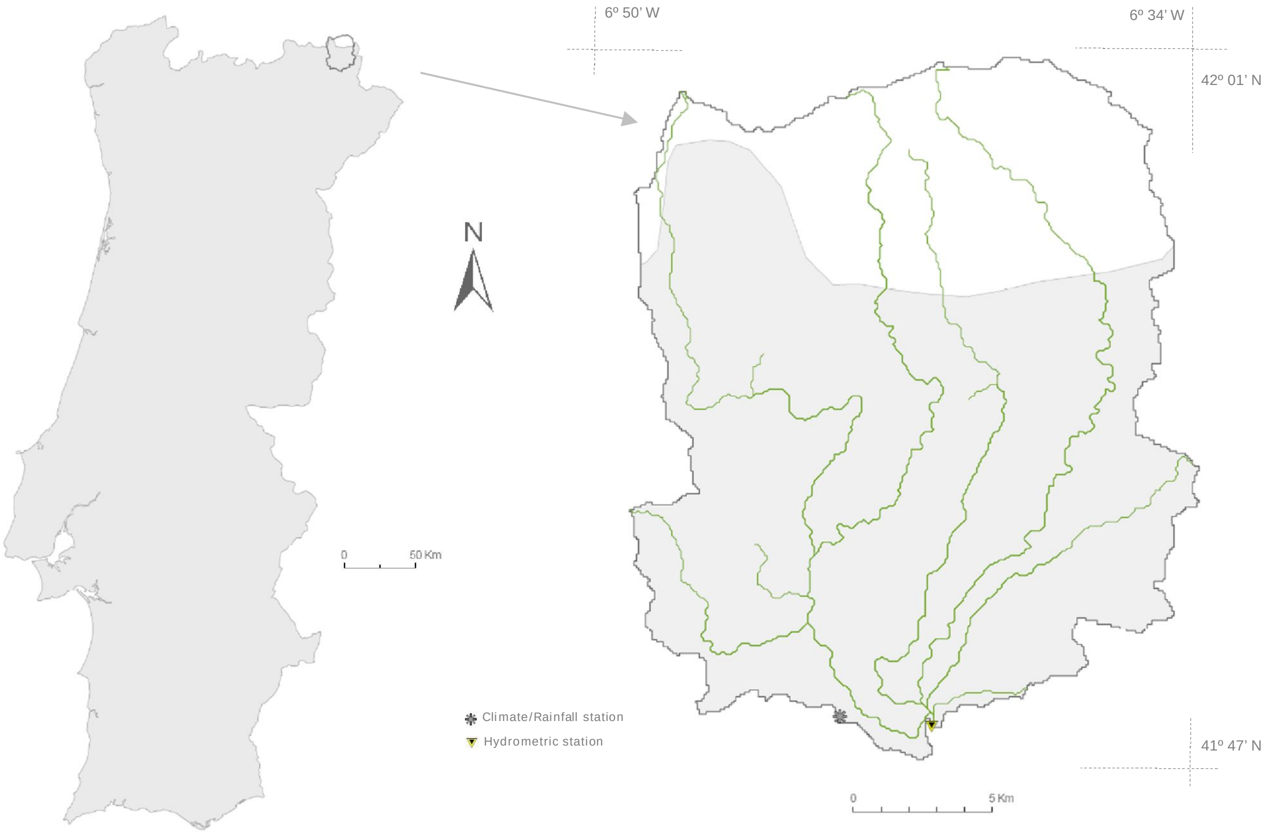

Figure 1 – Study area (Upper Sabor river catchment).

The basin of this study is located mostly in a mountainous area of Serra de Montesinho, part of the Montesinho Natural Park, northeast of Portugal, including also a small area (26%) located in Spain (Figure 1). It flows for approximately 40kms within the study area, descending from an upstream altitude of 1565m down to 508m. Based on the data collected for the model, the annual average precipitation for the study period was 726.0mm. Both precipitation and temperature annual patterns are shown in Figure 2.

Slopes are steep (above 10%) in 69.4% of the area, its geology is granitic in the upper regions and schist in the lower areas (Soares da Silva, 1982). Soils are mainly Humic cambisols (65.29%) and Umbric leptosols (34.71%).

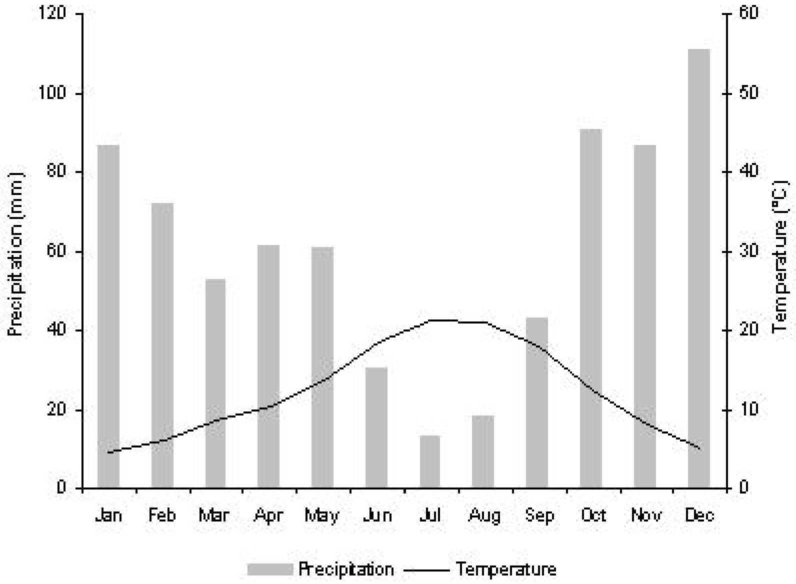

Figure 2 – Rainfall and temperature annual patterns for the study period (monthly average values).

Data

All data was first collected from several sources, subsequently prepared in the ArcGIS Geographic Information System, version 9.3.1, and later loaded and processed in ArcSWAT interface.

Land cover data used in this work was obtained from the Corine Land Cover 2000 (CLC2000) project (EEA, 2012) with a 100m resolution. Considering the Corine land cover classification, the occupation observed in the study area is mostly of forest and scrubland (69.0%) and rainfed agriculture (30.0%) classes, leaving only 0.9% to urban occupation and 0.1% to water bodies (correspondent to the Serra Serrada dam). These land use values were later changed and adjusted according to SWAT HRU creation.

Soil data for the Spanish side of the study basin was extracted from the Food and Agriculture Organization of the United Nations (FAO-UN) 1:5,000,000

Digital Soil Map of The World (FAO-UN, 2003). From the Portuguese side, soil data source was the Portuguese Environmental Agency web atlas (IA, 2012) with a scale of 1:1,000,000.

The catchment topography was mapped based on the Shuttle Radar Topography Mission (SRTM) data with a 90m resolution (Jarvis *et al*., 2008).

Daily discharge readings from the Gimonde gauge station, without significant gaps for the 1973-2004 period, were obtained from the Portuguese National Water Resources Database System (SNIRH, 2011).

Climate daily data was provided by different sources. Precipitation and temperature (minimum and maximum) were obtained from the European Climate Assessment & Dataset database (ECA&D, 2012), dew point and wind speed data from the United States National Climate Data Center (NCDC, 2012), and radiation data from the World Radiation Data Center (WRDC, 2012) database. A weather station located in Bragança was found to be useful for this study, in spite of some data gaps for the 35 hydrological years of the study period (1973-2008).

Data processing

All the spatial data collected was converted into SWAT compatible formats. Soil classes were configured using global parameters according to soil suborder estimated by Nunes *et al*. (2008) from global soil texture databases. Due to the imperviousness characteristics of both the granite and schist bedrock, the SWAT configuration wasn’t much distinguished on groundwater parameters. Land cover codes were reclassified into the following vegetation cover classes: forests, transitional woodland/shrubs, rainfed agriculture, Mediterranean shrublands, low density urban areas and water bodies. Vegetation species were assigned to each vegetation cover according to more detailed information from the Portuguese area of the basin (IPB, 2007), given that CLC2000 classes were sub-divided:

- forests: 15% oaks, 50% maritime pines, 35% shrublands;
- transitional woodland/scrub: 30% maritime pines, 70% shrublands;

- rainfed agriculture: 60% winter cereal, 40% shrublands.

Parameters for oaks, maritime pines and winter cereal were taken directed from the model database; for shrublands were parameterized following Nunes *et al*. (2008). This reclassification highlighted the importance of shrublands even in other land covers.

Subbasins

The catchment area was divided into 10 subbasins. It was thoughtfully divided according to the spatial distribution of soil and land cover classes, and especially to the Sabor river tributaries in the catchment area.

HRU creation

Several combinations of land use, soil and slope class thresholds were tested. According to each combination, SWAT subdivided each subbasin into several HRUs. In order to reduce model complexity and improve understanding of the model processes, a 500 ha threshold for all classes was chosen. The catchment area was therefore divided into a total number of 61 HRUs. As a consequence of the HRU creation configuration choices, including the sub-division of land-uses in the several vegetation classes detailed above, and the fact that SWAT integrates HRUs under the threshold in the dominant nearby HRUs, the original land cover classification differs from the classification used by SWAT (Table 1). However, this can mostly be attributed to the shift from a land-use based classification to a vegetation type-based classification. As a result, the area occupied by each SWAT vegetation type, represents the sum of the areas it occupied within each of the original land uses classes (Table 1).

Model calibration and validation

As simulations were being processed, some choices were made with respect to the input data used. It was decided that the radiation data collected was not useful for the model, and it was not considered. Thus, we let SWAT calculate it.

Table 1 – Land cover classes before and after HRU creation.

Original landcover			**SWAT landcover**		
Land use class	**Vegetation**	**Occupation (%)**	**Land use class**	**Vegetation**	**Occupation (%)**
Forest	Oak (15%) Maritime pine (50%) Shrubland (35%)	13.2	Forest	Oak	1.2
Transitional woodland/shrub	Maritime pine (30%) Shrubland (70%)	21.4	Transitional	Maritime pine	10.3
Mediterranean shrubland	Shrubland (100%)	34.4	Shrubland	Shrubland	67.5
Rainfed agriculture	Winter cereal (60%) Shrubland (40%)	30.0	Agriculture	Winter cereal	21.0
Urban areas		0.9			0.0
Water bodies		0.1			0.0

We chose to establish “elevation bands” by adjusting both precipitation and temperature according to altitude differences with the Bragança meteorological station, using a precipitation lapse gradient of 536.1 mm/km (calculated using the rainfall maps from Nicolau, 2002) and a temperature lapse gradient of -4.7ºC/km (João Pedro Nunes, Universidade de Aveiro, personal communication) for each subbasin of the catchment. Since Bragança is in a lower altitude relatively to most of the catchment, rainfall was generally increased and temperature generally decreased. This was done to improve the model accuracy, and the application of this method resulted in better results.

To calibrate the model, some sensitive parameters (summarized in Table 2) were manually changed and the results were validated against the observed outflow values. The calibrated parameters were (1) the fraction of percolation from the root zone which recharges the deep aquifer (RCHRG_DP), (2) the index of groundwater flow response to changes in recharge (ALPHA_BF), (3) the groundwater delay time (GW_DELAY), (4) the minimum temperature for plant growth (T_BASE), (5) the potential evapotranspiration method (IPET), (6) the available water capacity of each soil layer (SOL_AWC) and (7) a runoff curve number (CN2) which is a function of the soil's permeability, land use and antecedent soil water conditions (Neitsch *et al*., 2011). Several combinations were tested and the one that gave the best results was selected.

Table 2 – Calibrated parameters.

<table>
<tr><th colspan="2"></th><th>Starting value</th><th colspan="4">Calibration value</th></tr>
<tr><td colspan="7">Groundwater parameters</td></tr>
<tr><td colspan="2">(1) RCHRG_DP</td><td>0.05</td><td colspan="4">0</td></tr>
<tr><td colspan="2">(2) ALPHA_BF (days)</td><td>0.048</td><td colspan="4">0.3</td></tr>
<tr><td colspan="2">(3) GW_DELAY</td><td>31</td><td colspan="4">1</td></tr>
<tr><td colspan="7">Vegetation parameters</td></tr>
<tr><td colspan="3">(4) T_BASE (ºC)</td><td>T*</td><td>S*</td><td>A*</td><td>F*</td></tr>
<tr><td colspan="3">→ All land use classes</td><td>9</td><td>13</td><td>0</td><td>10</td></tr>
<tr><td colspan="7">Soil water balance parameters</td></tr>
<tr><td colspan="2">(5) IPET</td><td colspan="5">Penman-Monteith</td></tr>
<tr><td colspan="2">(6) SOL_AWC (mm H_2O/ mm soil)</td><td></td><td colspan="4"></td></tr>
<tr><td rowspan="2">Humic cambisols</td><td>0-300 mm</td><td>0.18</td><td colspan="4">0.14</td></tr>
<tr><td>301-1200 mm</td><td>0.14</td><td colspan="4">0.10</td></tr>
<tr><td>Umbric leptosols</td><td>0-480 mm</td><td>0.15</td><td colspan="4">0.10</td></tr>
<tr><td colspan="3">(7) CN2</td><td>T*</td><td>S*</td><td>A*</td><td>F*</td></tr>
<tr><td colspan="3">→ All slopes, Humic cambisols</td><td>55</td><td>56</td><td>73</td><td>66</td></tr>
<tr><td colspan="3">→ All slopes, Umbric leptosols</td><td>77</td><td>77</td><td>**</td><td>83</td></tr>
</table>

* T=Transitional; S=Shrubland; A=Rainfed Agriculture; F=Deciduous Forest.

** not existent in the study area.

The final SWAT model for the catchment outflow was substantiated by some statistic metrics: (1) the coefficient of determination (r^2), (2) the Bias calculation, which measures the average tendency of the simulated values to be larger or smaller than the observed data (Moriasi *et al*., 2007), (3) the residual variance estimated by Root Mean Square Error (RMSE) and (4) the Nash-Sutcliffe Efficiency (NSE) index, a normalized statistic that determines the relative magnitude of the residual variance ("noise") compared to the measured data variance ("information") (Moriasi *et al*., 2007).

Land cover change scenarios

The current land use / land cover in the basin was considered as the reference scenario (Scn-0) for this study. After the calibration three other scenarios were established (Table 3): Scn-2 an agricultural land abandonment situation, where all agriculture areas of the catchment are set to be occupied by shrublands (expansion to a total of 88.5%); Scn-3 an agriculture area expansion, obtained by expanding agriculture to the shrublands in lowest slope (<10%) areas that were occupying 12.5%, and Scn-4, a pastureland scenario where all shrubs and transitional woodland/shrub areas located in the steepest slopes were replaced by pastures (65.3%). For Scn-4 the SWAT parametrization winter pasture was used directly. Table 3 does not discriminate land cover classes per slope.

Table 3 – Proportion of land cover classes in the four scenarios tested.

Land cover	**Scn-0**	**Scn-2**	**Scn-3**	**Scn-4**
Agriculture	21.0%		33.5%	33.5%
Shrubland	67.5%	88.5%	55.0%	
Transitional	10.3%	10.3%	10.3%	
Forest	1.2%	1.2%	1.2%	1.2%
Pastures				65.3%

Simulations

The simulations of the water yield at the Gimonde outlet were processed on a daily time-step basis, for the whole 1973-2008 period. The research questions discussed in this study were supported by evapotranspiration and water yield monthly averaged results for the 35 years, for each scenario and land use.

4. RESULTS AND DISCUSSION

Implementation of SWAT in the upper Sabor basin

The main goal was to define a robust hydrological model for the area, which was achieved and validated against the existent real daily outflow values for the study period. Statistic results confirmed it by a coefficient of determination (r^2) of 0.65, which is considered “satisfactory” when ranging between 0.36 and 0.75 according to Motovilov *et al*. (1999) and also by a NSE model efficiency index of 0.65 which is considered “good” by to Nash and Sutcliffe (1970): NSE below 0 means that the model performs worse than using the average streamflow for prediction and when ranging between 0 and 1, indicates model performance above using average streamflow, with better values closer to 1. The maximum NSE is equal to r^2 (Nash and Sutcliffe, 1970), and therefore an NSE index close to r^2 can be considered good if r^2 is also considered good. By comparing predictions and observations on an average level for the whole simulated period, we obtained a Bias of 0.12 m^3/s which represents a relative difference of 1.8% between both (Janssen and Heuberger, 1995). Comparing them on an individual level, the RMSE measured the model with 8.62 m^3/s, less than the standard deviation of observations (14.51 m^3/s), also an indicator of good model performance (Janssen and Heuberger, 1995).

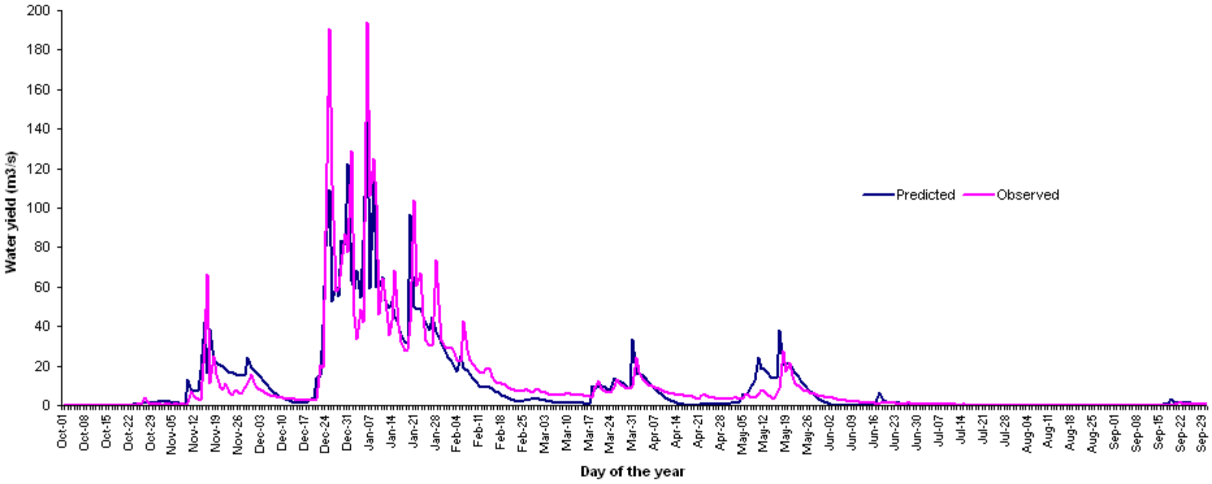

Figure 3 - Predictive and observed water yield during the 1995/1996 hydrological year.

From Figure 3 we can observe a regular hydrological year on a daily basis: water yield begins to become relevant in the autumn, reaching its highest values during winter, and decreasing until summer season arrives. We can see that the model predicts higher water yield in the autumn but in compensates in winter months with the predictions below the observed values. Figure 4, shows the water yield in a monthly sequence for the whole period with observed data (1973-2004), and we can see that the same pattern is repeated every year as well as the predictions deviations. The difficulty of the model to respond on time and not sooner, to the autumn precipitation, could be partly solved with a more accurate and detailed SWAT configuration of soil and vegetation properties. However, Figure 4 shows that the model was able to reasonably simulate the seasonal patterns of streamflow, as well as the difference in streamflow between wet and dry years.

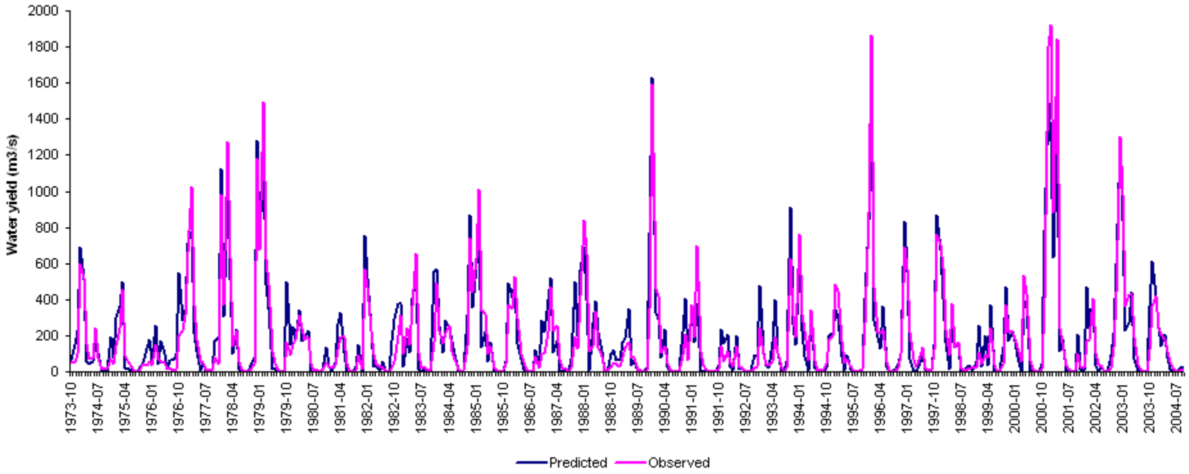

Figure 4 – Predictive and observed water yield for the 1973-2004 period (monthly sequence).

Effect of land use change on water yield

All land cover scenarios produced changes on the catchment evapotranspiration and water yield values. Scenarios Scn-0, Scn-2 and Scn-3 showed a clear association to agriculture/shrubland land cover: evapotranspiration decreased as crops were replaced by shrubs, 3.6% from Scn-2 to Scn-3 (Table 4). Conversely, water yield increased slightly as shrub area was successively replaced by crops, varying 1.8% from Scn-3 to Scn-2.

Scn-4 scenario (65.3% pastureland) produced the highest annual outflow at Gimonde outlet, 12.2% above the current scenario (Table 5). This pastureland dominating landscape also differed greatly from all other scenarios, by reducing evapotranspiration on 23.4% from the current composition.

Table 4 - Average annual evapotranspiration simulated for scenarios Scn-0 to Scn-4. Variation expressed in percentage of evapotranspiration for the reference Scn-0 scenario.

	Evapotranspiration - average annual (mm)	**Variation to Scn-0 (%)**
Scn-0	271.4	
Scn-2	278.0	2.4
Scn-3	268.1	-1.2
Scn-4	207.9	-23.4

In all cases, over the year we observed (Figure 5) a gradual increase in evapotranspiration on the first six months, and a decrease during the rest of the year.

Table 5 - Average annual water yield simulated for scenarios Scn-0 to Scn-4. Variation expressed in percentage of water yield for the reference Scn-0 scenario.

	Water Yield – average annual (mm)	**Variation to Scn-0 (%)**
Scn-0	505.8	
Scn-2	499.6	-1.2
Scn-3	508.9	0.6
Scn-4	567.3	12.2

The inflection point is reached at the beginning of the summer for all scenarios as would be expected from the combination between higher potential evapotranspiration demands, and the depletion of soil water to satisfy these demands. There are differences between the scenarios, especially noticeable for the pasture landscape (Scn-4) where evapotranspiration starts decreasing one month earlier and is significantly less than for other scenarios during the summer season. The largest agriculture area scenario (Scn-3) registered the highest values in both July and August, at summer peak.

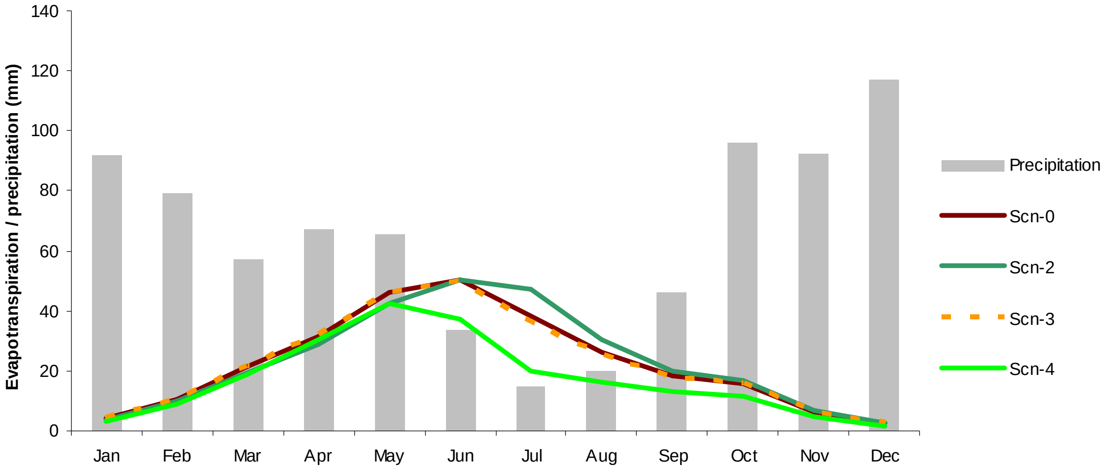

Figure 5 – Watershed evapotranspiration (average monthly values).

The water yield pattern followed approximately the annual precipitation pattern (Figure 6). It decreased from January to August with all scenarios overlapping during this period. Until the end of the year, water yield increased, reaching the highest values in December. In this second period we can observe that the pastureland scenario (Scn-4) registered the largest increase of all, mainly in October, having thus the largest water yield of all scenarios. This is due to the drying out of the herbaceous vegetation during the summer season in which evapotranspiration is reduced, therefore leading to a smaller depletion of soil water storages; consequently at the start of the wet season in October, soils are wetter and rainfall leads to higher water yield, while in other scenarios the drier soils require a higher period of soil water recharge. The largest agriculture area landscape (Scn-3) produces slightly less water than those (Scn-0 and Scn-2) that have more shrub area. It is also important to remark that August values did not go beyond 2 mm, meaning that water yield was close to zero. On the other hand, all scenarios overcame 100 mm / month in winter time.

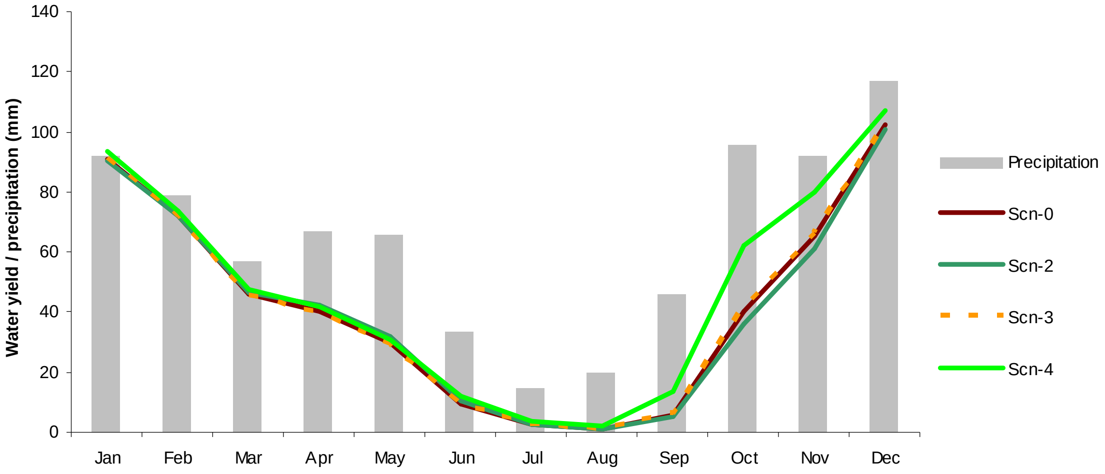

Figure 6 – Watershed water yield (average monthly values)

Individually, each scenario followed the overall evapotranspiration and water yield patterns described above. However, distinct land cover patterns provided differences for each situation and can be analyzed in more detail.

An overall overview of land cover behaviour for all scenarios, tells us that agriculture and pasture land covers reached the highest evapotranspiration values sooner, in May, after a marked and linear rise since January, mostly during the whole spring season (Figure 7). This pattern is justified by the fact that annual vegetation ends the growing phase at the end of the spring, when crops are harvested and pastures end their cycle. The large decrease (all around 60%) registered by agriculture land cover class in all scenarios, is thus explained. Agriculture has higher values than pastures due to higher growth and especially higher leaf coverage. Shrubs reach their highest evapotranspiration values one month later, and both forest and transitional areas, only in July. These land use classes correspond to permanent vegetation, with a slightly longer growing period, continuing to evapotranspirate afterwards although at lower levels.

Water yield showed an annual V pattern for all land uses, with the lowest values reached in August, at the height of the summer. All year around, both hardwood forest and transitional areas are the most yielding classes. Pastures show similar values after summer season but are less productive until then, although shrubs and agriculture yield even less water. As crops grow more than pastures, they also use more water. Since summer season, shrubs register the lowest values.

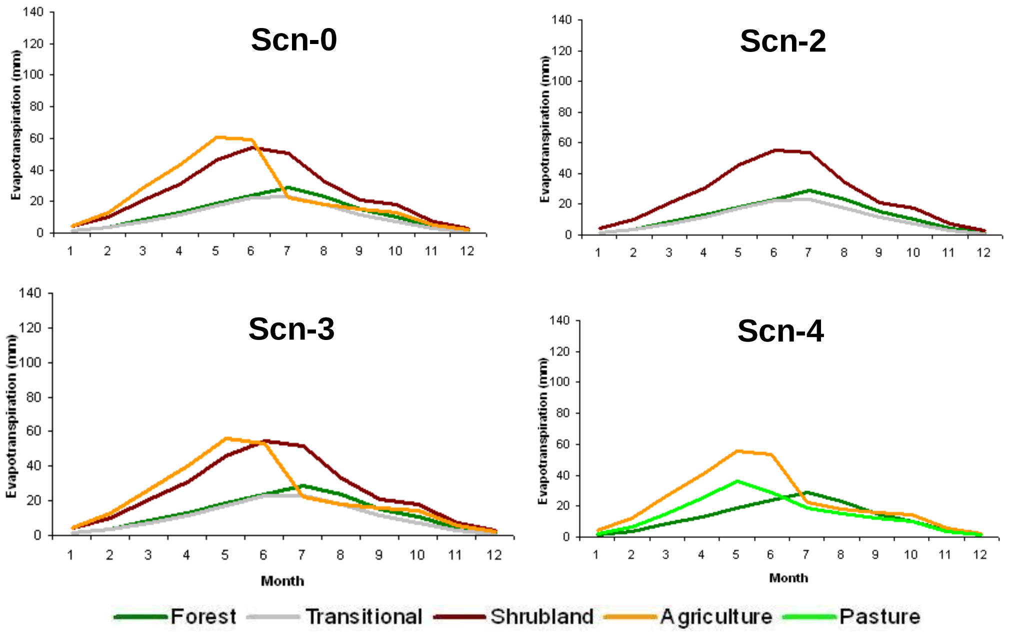

Figure 7 – Average monthly evapotranspiration by land-cover class for scenarios Scn-0 to Scn-4 in the Upper Sabor watershed.

The difference between Scn-0 (reference) and Scn-3 scenarios is 12.5% (Table 1) in shrubland area changed to agriculture. In spite of this, the evapotranspiration and water yield results from these two scenarios, have practically no changes and observed values overlap (Figures 3 and 4). With regard to water yield, and as explained above, agriculture areas are the least productive during the decreasing period of the year, but after the inflection point, in summer, shrubs are those that yield less water. Forest and transitional areas are the land uses with higher water yield all year around (Figure 8).

The second scenario (Scn-2) has no agriculture occupation. Most of the year, shrub areas evapotranspirate more than forest and transitional land uses together, mainly in May and June (Figure 7). Inversely, it outflows considerably less water than the other two land cover classes, which overlap monthly values throughout the year (Figure 8).

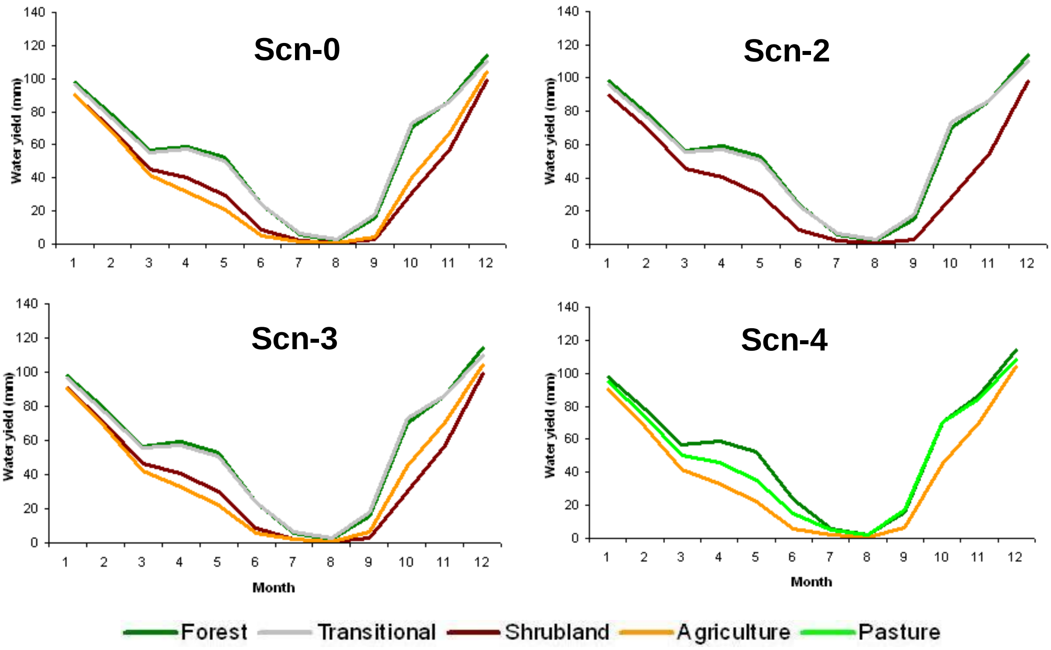

Figure 8 – Average monthly water yield by land-cover class for scenarios Scn-0 to Scn-4 in the Upper Sabor watershed.

Pasture landscape scenario (Scn-4) results were not as straightforward as the previous. In this case, agriculture areas evapotranspirate much more until June, reaching the highest value in May and registering a 58.7% decrease in August, keeping low values the rest of the year although always above the registered in pasturelands (Figure 7). Forest is the less evapotranspirative land cover class except between July and September when it slightly overcame the other classes. Analysing the water outflow (Figure 8), agriculture is by far the least yielding class of the scenario, mainly during spring and autumn seasons. Forest cover overcomes the other uses until July, and is overlapped by pasture since then.

Scn-2 was the scenario showing the lowest outflow (Table 5). As shrubland was successively replaced by agriculture, first, and pastureland, later, the outflow increased (13.4% for Scn-4) (Figure 6). Differences were not, however, very high. They were mostly focused on the autumn season, at the start of the soil wetting-up period, due to different soil water uses in the summer.

From these observations, we can register a pattern for all land use classes. In fact, each of them shows a similar pattern in all scenarios which allows us to infer that the water yield differences registered between scenarios is due to the different land use class combinations.

An important remark is relative to the fact that the pasture scenario (Scn-4) has a six months period, during summer and autumn seasons, where the outflow exceeds in more than 25% the obtained for the other scenarios, specially comparing with Scn-2 which has more shrubland area. In fact, in August and September the increase overcomes 125%. This can be an important detail that can help taking management decisions. It was already expected that the replacement of shrub and transitional vegetation either by crops or by pastures would increase surface runoff and thus, the catchment outflow. Nosetto *et al*. (2011) reported the largest hydrological changes on woody-herbaceous transitions. It is an expected result due to the greater amount of surface water that wasn't intercepted nor retained by the vegetation that covers the basin. This conclusion is opposite from our results, and it can be explained by the fact that evapotranspiration values calculated by SWAT for forest and transitional land use classes are probably underestimated, and this isn't obvious from our simulations because they just occupy a small area (<12%) of the basin. Woodland and scrub are, in fact, better for maintaining good soil properties and thus reducing surface runoff (Nunes *et al*., 2010). An example comes from the Catalan Pre-Pyrenees where a grassland area afforested with pine tree, resulted in a 18% runoff reduction (Poyatos *et al*., 2003).

The largest shrubland cover scenario (Scn-2) can be a realistic possibility in the near future, particularly in the Mediterranean region. Studies have been reporting, for several years now, positive correlations between increasing forest and shrub areas and recurrent wildfires (Moreira *et al*., 2001; Azevedo *et al*., 2011) but also between wildfires and both burned area and drought events (Dimitrakopoulos *et al*., 2011). At the same time, equilibrium between available resources and water demand is becoming critical with the current climatic and land cover change trends (López-Moreno *et al*., 2008).

5. CONCLUSIONS

In this research a valid hydrological model for the upper Sabor river watershed was implemented, which seemed useful in estimating the effects of land use change on water yield. The results show that the pastureland scenario (Scn-4) was the one responsible for higher water yields mainly after August. When comparing land use classes, forest and transitional land use classes yielded more water, and agriculture and shrublands are the less productive ones. Important differences on evapotranspiration values were only observed more clearly after May, and showed that the scenario most largely occupied by shrubs (Scn-2) is the most evapotranspirative and that Scn-4 scenario (mostly pastures) is the less one. In terms of evapotranspiration the land cover classes that presented higher evapotranspiration were agriculture until the summer season, and shrubs afterwards.

6. FINAL REMARKS

Improvements need to be incorporated to the model in the near future particularly in terms of parameterization of land-use classes with emphasis for water uptake per vegetation class. Shrubland and forest covers, for example, although not much different from a basin water yield perspective, are distinct enough in a way that can be taken as different management options. In this work, the SWAT configuration was not sufficiently detailed to distinguish among them, but it would have been very useful in defining an afforestation scenario which wasn't considered due to this difficulty. Another type of improvement to be made, is to define in more detail soil characteristics (*i.e.* texture, hydrological properties, humidity) as well as vegetation parameters adjusted for the study area based on MODIS (Moderate Resolution Imaging Spectroradiometer) satellite imagery and indices such as NDVI (Normalized Difference Vegetation Index) (Carroll *et al*., 2004) that can be used on plant growth studies. As a result, and in spite of a good watershed water yield representation, the model requires tuning at higher resolution using more detailed information.

It would have also been useful if other hydrological and climatic stations within the basin limits had more observations data, allowing a better validation and calibration of the model, which was thus more limited.

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