Part 3

Looking at the environment and sector uses

Chapter 11

Linking land management to water planning: Estimating the water consumption of Spanish forests

Bárbara Willaarts
Water Observatory of the Botín Foundation;
CEIGRAM, Technical University of Madrid, Madrid, Spain

ABSTRACT: The role of vegetation in the partition of rainfall and the provision of water supply downstream have seldom been addressed in Spain's water planning, despite the fact that changes in the vegetation cover and land management have large hydrological implications. This chapter gives a first overview on what are the water requirements of major forest types across Spain, including woods, shrubs, agroecosystems and pastures. Likewise, it provides a preliminary accounting on how droughts and changes in the forest cover modify the evapotranspiration rates, and the likely impacts on streamflow availability. Our results suggest that forests consume the largest fraction of annual rainfall in Spain, above agriculture, and that changes in land use have a greater impact compared to droughts on runoff reduction downstream.

Keywords: Forest evapotranspiration; Forest expansion; Land abandonment; Integrated land and water resources management

1 INTRODUCTION

Land use and land cover play a crucial role in the partition of rainfall and the provision of blue water for downstream users in catchments. The number of studies addressing the hydrological implications linked to land conversions has grown significantly over the last years, particularly in humid regions (Gordon *et al.*, 2005; Jackson *et al.*, 2005; Scanlon *et al.*, 2007; Trabucco *et al.*, 2008). These driven changes on the water cycle have been argued to rival or even surpass those ascribed to climate change (Vörösmarty *et al.*, 2000).

In semi-arid countries like Spain research on the links between land use and water is still scarce (Gallart & Llorens, 2003; Gallart *et al.*, 2011; Willaarts *et al.*, 2012). This knowledge gap is paradoxical bearing in mind that forest area has increased approximately 1.5 Mha [Mha = million hectares = 10^6 ha] in the last two decades, and over 30% of this augmentation is concentrated in some of the most water-stressed provinces along the Mediterranean arc (MAGRAMA, 2012a; 2012b). This forest expansion largely responds to the increase of afforestation and rural abandonment processes taking place on previous agricultural fields (Hill *et al*., 2008; Lasanta *et al*., 2009).

Alongside with the changes in the forest area, a significant reduction in runoff has been observed in different catchments across Spain over the last decades (Beguería *et al*., 2003; Otero *et al*., 2010; Lorenzo-Lacruz *et al*., 2012). Most of these studies agree that climate change, and particularly the reduction in precipitation observed during the second half of the 20th century, is a major driver of streamflow reduction. However, these studies also conclude that observed decreases cannot be explained by climatic factors alone.

The reasons why water planning in Spain has – so far – disregarded the potential impacts on water availability resulting from land conversions, and particularly from changes in the forest cover, might be diverse. On one hand, knowledge of forest water requirements is scarce, as oppose to the extensive research carried out within agriculture, probably because commercial forestry in Spain represents a small economic sector (less than 3% of the GDP) and it is mainly concentrated in water-abundant basins of northern Spain with few water conflicts. On the other hand, conventional approaches to water planning have mostly focused on managing the demand side, securing blue water availability by adopting structural approaches and constructing dams and large infrastructures. Only recently, the tight nexus existing between land and water is becoming more understood; and the fact that managing water in relation to land might not alleviate the high blue water demand among competing users, but it can contribute to optimizing the supply of blue water. Foremost, because the largest fraction of the annual rainfall (over 80%) in semiarid regions like Spain turns into soil moisture, and the way we manage this green water can make a difference in the fraction of available runoff downstream.

Managing water in connection with land requires a deep understanding about the relationship existing between landscape structure and rainfall partition. Usually, forests with a thick vegetation cover and well developed soils have a larger soil water holding capacity; thus, the largest fraction of annual rainfall is evapotranspired. On the contrary, short grass vegetation like pastures, have less access to soil moisture and generate larger flows of runoff. Nevertheless, rainfall partition varies greatly across landscapes, depending on the type of vegetation cover, land management, climate and soil characteristics.

The European Water Framework Directive (WFD) has made a huge effort in order to adopt a broader perspective in relation to water management, by trying to conciliate the use of blue water by different stakeholders with the protection of aquatic systems, in an attempt to reverse and prevent their further deterioration. However, the WFD still needs to further expand its approach, since it has poorly addressed the interrelations between land and water-related processes. Accordingly, the main goal of this chapter is to provide a first estimation of what are the water requirements (evapotranspiration rates) of major forest types, including woods, pastures, agroecosystems (mainly *dehesas*) and shrubs across the national territory. A further objective is to assess how droughts and changes in the forest cover could be altering forest evapotranspiration and consequently streamflow availability. Gaining understanding on this front can help to lay the foundations for moving towards an *Integrated Water and Land Resources Management* (IWLRM) approach (Falkenmark & Rockström, 2004) in Spain.

2 DATA AND METHODS

The water requirements of Spanish forests were estimated following Zhang *et al.* (2001), who argue that forests evapotranspiration is controlled by climate but also by the capacity of the different species to pump water from the unsaturated zone. This capacity depends, among other factors, on the physiological conditions of the plant species and their root depth. Using experimental data from over 300 studies, Zhang and colleagues found a semi-empirical relationship to estimate annual forest water consumption, expressed as:

$$\frac{ET_i}{PP_i} = \left(\frac{1 + w_i \times \frac{E_{oi}}{PP_i}}{(1 + w_i \times \frac{E_{oi}}{PP_i}) + (\frac{PP_i}{E_{oi}})} \right) \tag{1}$$

where *ET* represents the annual evapotranspiration rate of forest *i* (mm); *PP* and E_o are respectively, the annual rainfall and potential evapotranspiration of the area where forest *i* grows (mm); and *w* is an adimensional indicator called *water availability coefficient*, equivalent to the crop water coefficient, whose value varies from species to species depending on its physiology and plant architecture.

To estimate *w* for Spanish forests, we conducted a literature review on experimental studies where actual evapotranspiration rates were measured for different forest types across Spain and/or in areas with similar climate conditions (see Table 1). Based on this information, we used Equation (1) to estimate the *w* parameter for the different forest types present in Spain.

Information regarding Spanish forest area and species composition was obtained from the *Forest National Inventory* (FNI) (MAGRAMA, 2012a). Specifically, we used the data provided by the third FNI, which represents the most updated source of information on forest status in Spain (period 1996–2006), to quantify the actual rate of forest water evapotranspiration.

To account for the variations that changes in the forest cover over the last years could have had in the water balance of forests, we used the information of the second FNI to estimate the forest evapotranspiration for time period 1986–1996. Variations in forests' water consumption observed across both periods (period 1986–1996 against 1997–2007) were quantified and described at provincial scale.

Annual *ET* for each forest type was calculated using mean annual values of *PP* and E_o obtained from the Integrated Water Information System (*Sistema Integrado de Información del Agua*, SIA) for the time period 1980–2008. We used mean values instead of year to year data because we wanted to isolate at first the effect of climate variability on the forest water accounting. In doing so, changes in the water consumption observed across time will be due to changes in the coverage and area surface of forest and not due to the intrinsic variability of the Mediterranean climate. Additionally, in order to estimate the impacts of droughts on water availability downstream, we also estimated the actual forest's water consumption using the E_o and *PP* annual values of a particularly dry year (2005).

Table 1 Data sources used to estimate the water availability coefficient (*w*) for the most representative vegetation species found in Spain. Precpitation (PP), Potential evapotranspiration (Eo) and actual evapotranspiration (ET) represent mean annual values and (standard deviation) from the different observations recorded for each species.

Forest species	*Number of observations*	*Year of measurement*	*PP (mm/year)*	E_o *(mm/year)*	*ET (mm/year)*	*Source*	*Region – Country*
Fagus sylvatica	3	2000, 2001	817 (54)	528 (14)	509 (9)	Fernández *et al.* (2006); Dalsgaard *et al.* (2011)	Galicia (Spain); Denmark
Pinus halepensis	2	1997	454 (0.1)	1,160	332 (37)	Bellot *et al.* (2001)	Alicante (Spain)
Pinus nigra	1	1989	650	1,209	559	Domingo *et al.* (1994)	Almería (Spain)
Pinus pinea	2	1961–1990	796 (47)	894 (35)	451 (100)	Willaarts (2010)	Seville (Spain)
Pinus ssp	3	1961–1990	544 (131)	678 (231)	277 (149)	Willaarts (2010)	Seville (Spain)
Pinus sylvestris	2	2005	682 (188)	654 (63)	328 (8)	Vincke & Thery (2008)	Belgium
Quercus robur/Q. petraea	1	1989	965	665	588	Frank & Inouye (1994)	Central Europe
Quercus pyrenaical/ Q. pubescens	2	1991–1993	932 (218)	968 (22)	516 (13)	Moreno *et al.* (1996)	Salamanca (Spain)
Quercus ilex	11	1961–1999	596 (155)	942 (54)	515 (79)	Piñol *et al.* (1999); Joffrey & Rambal (1993); Willaarts (2010)	Seville and Barcelona (Spain)
Quercus robur	3	1992–1994	914 (53)	510 (66)	447 (18)	Frank & Inouye (1994)	Denmark
Quercus suber/Q. ilex/Q. faginea	5	2000–2007	579 (178)	782 (17)	482 (45)	Pons (2009)	Valencia (Spain)
Abies Alba	16	2001–2002	946 (203)	607 (46)	560 (65)	Vilhar *et al.* (2005)	Slovenia
Dehesas with shrubs (Quercus ssp)	1	1961–1990	910 (86)	851 (51)	512 (136)	Willaarts (2010)	Seville (Spain)
Dehesas (Quercus ssp)	1	1961–1990	895 (108)	882 (60)	478 (102)	Willaarts (2010)	Seville (Spain)
Eucalyptus spp.	4	1961–1990	1,364 (405)	1,035 (141)	839 (177)	Van Lill *et al.* (1980); Bosch & Hewlett (1982); Fernández *et al.* (2006); Jiménez *et al.* (2007)	South Africa; Australia; Galicia and Seville (Spain)
Mediterranean shrubs (*Quercus coccifera; Pistacia Lentiscus; Erica multiflora; Stipa tenacissima*)	4	1961–2001	695 (246)	866 (194)	384 (159)	Lewis (1968); Bellot *et al.* (2001); Willaarts (2010)	USA; Alicante and Seville (Spain)
Pastures	3	1984–1986, 1997	699 (174)	966 (81)	430 (90)	Joffrey & Rambal (1993); Bellot *et al.* (2001); Willaarts (2010)	Seville and Alicante (Spain)

3 RESULTS

3.1 Forest water requirements

Table 2 summarizes the water availability coefficients (w) obtained for the major forest species found in Spain. Overall tree species have a greater w compared to shrubs, *dehesas* and pastures. This is mainly because trees and shrubs have greater amount of biomass stored per unit of space and larger root systems than pastures, which increases their water demand and access. The range of w values estimated for Spanish forests are in agreement with those obtained by Zhang *et al*. (2001) for forest and pastures elsewhere.

Figure 1 describes the implication different w coefficients have in terms of water consumption for three main typologies of forests types. In the most humid regions of Spain (aridity index close to 1), *Quercus* forests, *dehesas* and pastures have similar evapotranspiration rates (*ET/PP*). Foremost, because under these climatic conditions radiation as oppose to precipitation is the limiting factor influencing evapotranspiration. However, as we move in to the warmer and drier south of Spain, precipitation becomes the limiting factor. In these regions, the *ET/PP* ratio (covering other factors such as soil properties or topography constant) will be determined by the capacity each forest type has to access water (w). For instance, in areas where the aridity index is close to 2.5 (e.g. Valencia), *Quercus ilex* consumes approximately 90% of the total annual precipitation. However, under the same climate conditions, pastures evapotranspire only 60% of the annual rainfall.

Table 2 Water availability coefficients (w) obtained for different forest types and species found in Spain.

Vegetation type	*Composition*	*w*
Forest	*Fagus sylvatica*	2.4
	Abies alba	2.0
	Quercus suber/Quercus faginea	2.0
	Quercus ilex	1.9
	Quercus robur/Quercus petraea	1.8
	Quercus pyrenaica/Quercus pubescens	
	Eucalyptus spp.	1.5
	Pinus halepensis	1.2
	Pinus nigra	
	Pinus pinea	
	Pinus ssp	
	Pinus sylvestris	
Shrubs	Mediterranean (*Quercus coccifera; Pistacia Lentiscus; Erica multiflora; Stipa tenacissima*)	0.7
Dehesa (Agroecosystems)	*Quercus ssp* with annual pastures and Mediterranean shrubs	0.4
	Quercus ssp with annual pastures	0.3
Pastures	Annual	0.1

Source: Own elaboration.

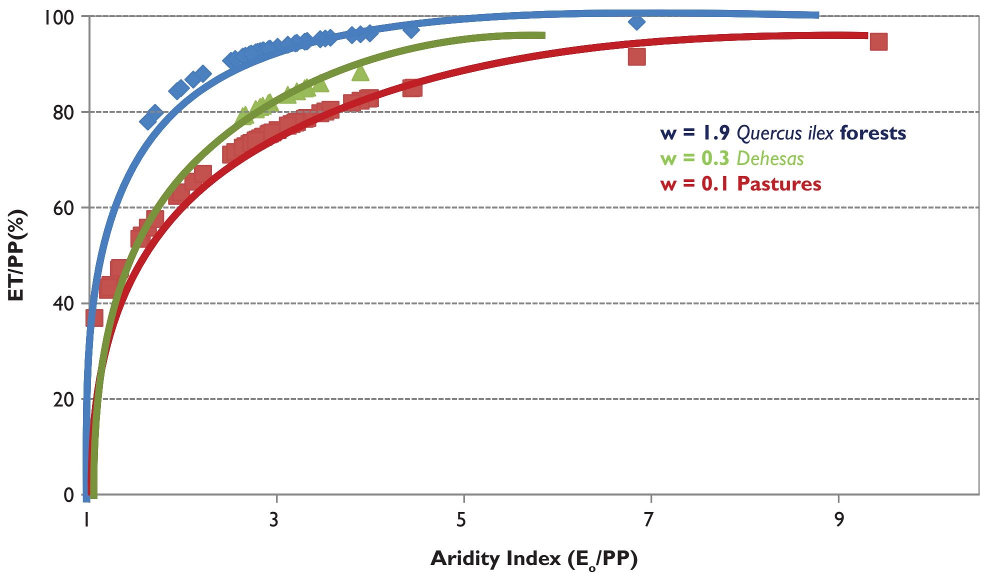

Figure 1 Mean annual evapotranspiration rates (expressed as % of annual rainfall) of three representative Spanish vegetation types. Observations refer to the *ET/PP* ratio calculated for the different Spanish provinces where each one of the three vegetation types grow. (Source: Own elaboration).

Table 3 summarizes the mean annual evapotranspiration rates of Spanish forests at present. Conifer, broadleaf, afforested and mixed forests consume together almost 75,000 hm^3 [hm^3 = cubic hectometre = million m^3 = 10^6 m^3], which represents 24% of the Spanish mean annual precipitation (approximately 318,000 hm^3). Pastures are the second largest water consumers (32,000 hm^3/year) as they occupy almost 9 Mha. Shrubs and *dehesas* occupy around 3.7 Mha and consume approximately 16,000 hm^3, 13% of the national forest consumption.

Tree species have also different average water requirements (Table 3). Non-native species such as *Eucalyptus ssp*, frequently used in commercial and afforestation programs, evapotranspire larger amounts of water (over 5,400 m^3/ha/year) compared to native *Quercus* or *Pinus* species, which consume less than 5,000 m^3/ha/year. These results have large implications from a water planning perspective, especially in water-scarce areas within Spain, where several reforestation programs are being subsidized in previously used rain-fed agricultural areas as a climate change mitigation measure. Such afforestation programs have often been regarded as a cost-effective way to simultaneously sequester carbon, increase wood and paper supplies and diversify rural incomes, especially in the developing world (Vertessy, 2001). However, in the Spanish context these reforestation programs might contribute to sequester CO_2 emissions, but large scale programs undertaken with non-native species might have important trade-offs in terms of water availability downstream.

Climate is a major driver of forest's distribution across Spain. Forest species extending along the Mediterranean arc of Spain (e.g. *Quercus ilex*, *Q. faginea*, *Q. suber* or *Pinus halepensis*) are well adapted to dry conditions and therefore have smaller aver-

Table 3 National accounting of water consumed by Spanish forest types. Species composition and actual surface area was obtained from the third FNI (MAGRAMA, 2012a).

Vegetation type	*Composition*	*Mha*	*m³/ha/year*	*SD*[1]	*hm³/year*
Conifer forest	*Pinus halepensis*	1.9	4,370	756	7,949
	Pinus pinaster	1.2	4,581	761	5,708
	Pinus sylvestris	1.0	4,728	759	4,726
	Pinus nigra	0.7	4,461	801	2,916
	Pinus pinea	0.4	4,497	473	1,624
	Pinus ssp	1.3	4,685	873	6,012
	Abies & Juniperus ssp	0.4	4,846	690	1,879
Afforestation	*Pinus ssp*	0.1	4,451	1,218	238
	Eucaliptus ssp	0.6	5,480	750	3,155
Broadleaf forest	*Quercus ilex*	2.6	4,847	738	12,683
	Quercus pyrenaica	0.7	5,076	753	3,564
	Fagus sylvatica	0.4	6,044	718	2,747
	Quercus suber	0.3	5,602	448	1,688
	Quercus robur	0.2	5,870	620	1,080
	Quercus faginea	0.2	4,721	787	687
	Other broadleaf species	1.1	4,938	957	6,119
Dehesas (Agroecosystems)	*Quercus ssp*	2.4	4,175	479	10.225
Mixed forest	*Quercus & Pinus ssp*	0.7	4,695	883	3,338
	Pinus & broadleaf *ssp*	0.4	5,218	1,131	2,093
	Mix of broadleaf *ssp*	<0.1	5,569	676	207
Shrubs	Shrubs	1.3	4,307	728	5,495
Pastures	Pastures	8.9	3,693	604	32,105
TOTAL		**27.5**			**122,604**

Source: Own elaboration.

[1] SD = standard deviation; [hm³ = cubic hectometre = million m³ = 10^6 m³].

age evapotranspiration rates (~4,800 m³/ha/year) compared to typical Atlantic species (e.g. *Fagus sylvatica*, *Quercus robur*, *Q. pyrenaica* or *Abies ssp*), which consume over 5,400 m³/ha/year. *Dehesas*, pastures and shrubs have lower water requirements as their biomass content is smaller (≤4,000 m³/ha/year).

From a hydrological perspective, the differences found across species water requirements have important implications. The presence of Atlantic forests with high water requirements in the northern basins does not necessarily have negative implications from a water availability perspective. These basins are water abundant and reducing their forest cover could have rather worse than positive impacts. Foremost, because these forests play a critical role regulating the baseflow and surface runoff within catchments and the removal of forest cover will disrupt this regulating process, increasing the risk of floods. Mediterranean forests perform similar ecological functions, but they extend in basins where competition for water is much higher. In this part of Spain as in other Mediterranean areas of southern Europe there is a growing problem of land abandonment (Lasanta *et al*., 2009). Official statistics have reported a decrease in the agricultural area of 1.5 Mha since the mid 1990s (MAGRAMA, 2012b).

This reduction is mainly related to the low productivity of much of this agricultural land, which has either been converted into other uses (e.g. urban) or abandoned. This process of land abandonment entails important hydrological implications as it encompasses an increase in the vegetation cover (mainly serial shrubs and forest regrowth), which augments the vegetation water demand and reduces water availability downstream (Otero *et al*., 2010; Willaarts *et al*., 2012). From an ecological perspective no real positive effects result from the abandonment and homogenization of the agrarian Mediterranean landscape, as it increases the risks of fires, reduces the biological diversity and lowers the efficiency of forests as carbon sinks as they age, particularly in *dehesas*.

As Table 3 shows, Spanish forests currently evapotranspire approximately 122,000 hm^3/year. Agriculture alone consumes around 30,000–33,000 hm^3 (see Figure 1, Chapter 6), evidencing that forests consume the largest amount of annual rainfall in Spain. This is not to say that forest cover should be reduced to increase water availability downstream. On the contrary, forests play a critical role regulating the water cycle in catchments and supplying multiple ecosystem services, e.g. by preventing floods and regulating the micro and meso-climate. However, these results provide evidence of the importance of placing forest and land management at the core of hydrological planning. Even though much of the water conflicts in water stress basins are frequently caused by poor demand management (e.g. over-allocation of water rights, low efficiency, etc.), managing forests (e.g. by preventing shrub encroachment and forest aging, and maintaining a proper forest cover) can be part of the solution in water stress basins, since it might contribute to optimize the supply of water for downstream uses. The former results also raise an important issue: the existing trade-offs between climate change mitigation options (e.g. afforestation programmes) and water supply optimization options in catchments.

3.2 Changes in forest water consumption under dry conditions

Table 4 summarizes the estimated changes in forest water consumption in a dry year. Under dry conditions like those experienced in Spain in 2005, forest evapotranspiration at national level was estimated to be 20,000 hm^3 lower than under mean climatic conditions. However, the ratio of forest water evapotranspiration to precipitation increased by 3%, which means an equivalent reduction in runoff availability. This cutback mainly occurs because most of the scarce rainfall infiltrated in soils beneath forests is used for the most part to satisfy the demand of the stressed vegetation cover and only a small fraction during the wetter months exceeds the soil's field capacity, feeding rivers and aquifers.

From the water planning perspective the previous results have great implications for securing blue water availability (see Figure 2). Under dry conditions the largest reduction in blue water availability resulting from greater forest water consumption occurs in arid and semi-arid regions with an aridity index closer to 2 (e.g. Extremadura, Castille-La Mancha and Andalusia). These results evidenced that impacts on water availability under dry conditions without proper forest management are greater in the naturally water-scarcer regions.

Table 4 Annual national forest water consumption (hm^3) under dry and mean average climatic conditions.

	Mean condition (period 1980–2008)	*Dry year (2005)*
Forest evapotranspiration (*ET*)	122,604	99,251
Precipitation (*PP*)	318,124	237,156
ET/PP (%)	39	42

Source: Own elaboration.

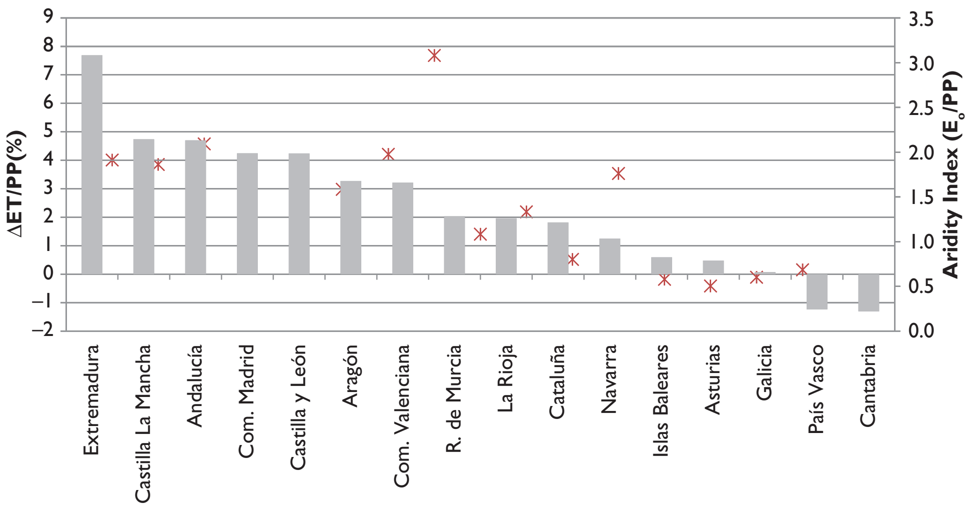

Figure 2 Changes in the ratio of annual forest evapotranspiration (ET/PP) comparing mean (1980–2008) and dry annual conditions (year 2005) (grey bars). The aridity index (red dots) represents the mean annual ratio of E_o to PP for the time period 1980–2000. (Source: Own elaboration).

3.3 Changes in forest water consumption due to land cover changes

According to the data provided by the second and third FNI, between 1986 and 2006 the forest area in Spain increased approximately by 1.5 Mha (Table 5). Such forest expansion has augmented forest's annual ET by almost 10,500 hm^3. If mean annual rainfall in Spain is around 318,000 hm^3, the percentage of precipitation annually consumed by Spanish forests has increased from 35 to 39%.

The largest increases in forest cover and water consumption have occurred mainly in the southern half of the country, in the regions of Extremadura, Andalusia and Castille-La Mancha (see Figure 3). Important increases of the forest water consumption have occurred also in the northern regions of Asturias and Galicia, where large commercial forest programmes are well established. Overall, it is noteworthy that almost 50% of the observed increase in the water consumed by forests has taken place in arid and semi-arid provinces (aridity index > 2.5).

Table 5 Changes in forest water consumption between 1996 and 2007.

Vegetation type	*Area 1996 (Mha)*	*Area 2007 (Mha)*	*Water requirements (m^3/ha/year)*	*ET 1996 (hm^3/year)*	*ET 2006 (hm^3/year)*
Forests	9.8	14.9	5,074	49,882	74,779
Dehesas	2.3	2.4	4,175	9,511	10,225
Shrubs	2.1	1.3	4,307	9,047	5,495
Pastures	11.8	8.9	3,693	43,482	32,105
Total	**26.0**	**27.5**		**111,922**	**122,604**

Source: Own elaboration.

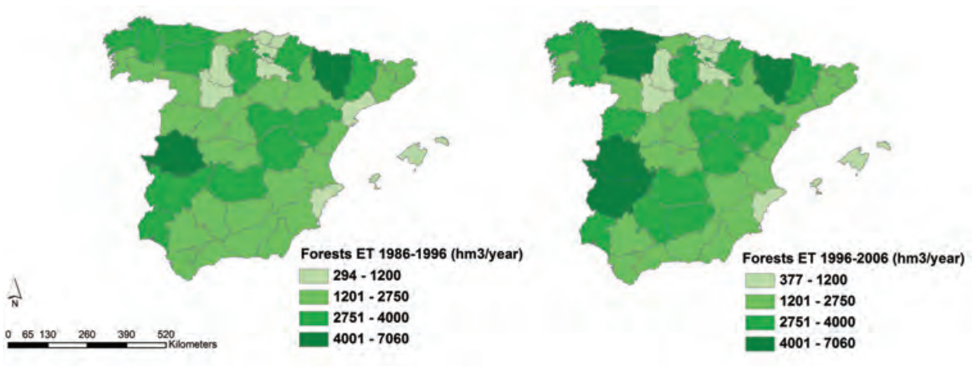

Figure 3 Trends in annual forest's ET (hm^3) in Spain during the last three decades. (Source: Own elaboration).

Despite the importance of these figures, the former results need to be interpreted with caution as the uncertainty surrounding the changes in forest surface area in Spain during the last 30 years is very high. Other official land use data sources like the Corine Land Cover Project (EEA, 1990; 2005) or the Crops and Land Use map created by the Ministry of Agriculture (*Mapa de Cultivos y Aprovechamientos*) (MAGRAMA, 2012b) report different land use and land cover trends compared to the FNI datasets. A detailed and contrasted assessment between the different land use sources needs to be carried out to obtain a better and clearer picture of what has really happened within the Spanish territory in terms of land use and land cover flows over recent decades.

4 CONCLUSIONS

Forests consume the largest amount of annual rainfall in Spain, above agriculture, and this highlights the crucial role they play in the water balance. Currently, Spanish forests evapotranspire 39% of the annual incoming rainfall, although during droughts this ratio can rise up to 42%. This increase in water consumption implies an equivalent reduction in runoff availability downstream. But above climate, land use changes and particularly the increase of forest cover linked to land abandonment and afforestation programmes seem to have a greater impact on water resources in Spain, reducing blue water availability by up to 4% annually. The magnitude of these reductions is especially relevant in the most water-stressed regions. Nevertheless, a contrasted assessment is needed to ascertain the real scale of land use and land cover changes across Spain to accurately judge the impacts of changes in forests area on water resources. Even though efforts to use water more efficiently need to be placed on managing the demand better, integrating land and forest management into water planning might be a cost-effective solution to optimize the supply of water in catchments. Such realization questions the potential negative *co-effects* of afforestation programs, currently being undertaken as a climate change mitigation option, from a water perspective.

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