

LAND USE/COVER CHANGES AND WATER RESOURCE IMPLICATIONS IN SPAIN A PRELIMINARY OUTLINE

ABSTRACT

Since the middle of the XX century, the main land use and cover change in Spanish mountain areas has been afforestation subsequent to land abandonment, both spontaneous and supported by Spanish and European policies. Changes in land cover are more difficult to assess than land use ones, the more reliable information being provided by the two successive assessments of the 'Inventario Forestal Nacional' (National Forest Inventory). This information reveals an important increase in trees canopy cover in all the regions eventhough forest surface shows a rather decreasing trend. There are many evidences of water resources diminution in different parts of Spain for the period 1921-99, representing in average a 0.4% per year. This diminution has been claimed to be the result of first the increasing irrigation, and second the climate variability. Indeed, the observed reduction in discharge may be partly explained by the increment of the irrigation surface in downstream areas, but there is also a significant reduction of discharges in the headwater areas that can not be explained only considering climate variability.

The causal links between land cover and water yield changes have been largely demonstrated at the experimental catchment scale, nevertheless there is a need to provide evidences of these links at the operational scale. The above reported changes occurred in Spain in the last 50 years provide excellent opportunities for such studies.

LAND USE AND COVER CHANGES IN SPAIN DURING THE 20 CENTURY

Wide headwater areas in Spain suffered during the first three fourth parts of the 20 century the abandonment of farming and stockbreeding activities, linked to the loss of about 80% of the population (Lasanta, 1990). This process allowed the increase of forested areas, both spontaneous and promoted by Spanish and EU Policies. In the period 1940-1982, nearly 3.2 million hectares were afforested in Spain, although the failure of some of the works as well as wildfires compensated most of this effort (Ortigosa, 1990). Subsequently, following UE directives, more than 400.000 ha have been reforested during the period 1994-98 (DGCONA, 2000). In the near future, national governments may be promoting the afforestation as a measure to counterbalance CO₂ emissions, following the directions of the Kyoto protocol.

The assessment of land use changes reported by FAO (1990-1998) demonstrates an increase of forest and woodland area of 23% (6% of the total area of Spain) during the period 1961-1998 (Figure 1). The increase of forest area was mainly produced at the expense of pasture area until 1985 and at the expense of the agricultural area afterwards, this change may be attributed to the incorporation of Spain in the European Union.

Nevertheless, this information gives an idea about the administrative changes rather than an assessment of land cover. The more detailed information on forest cover is provided by the first and second Forest Inventories (MA, 1968-1974; MAPA, 1990-1997) which, although were not synchronous for all the regions, give an idea of the changes in 20 years, between 1970 and 1990. A summary of the inventories (Figure 2) shows that the forest area was stable in the more humid autonomous regions, whereas it suffered relevant changes in the drier ones (Extremadura, Murcia). The overall forest area decreased in 9% of the total country area. On the other hand, the canopy cover fraction suffered an increase in all the Autonomous regions, with a mean change from 0.38 to 0.55. This change must be considered as the result of the closure of clearings and vegetative growth of young forests recently overgrown or planted on former pasture and crop areas.

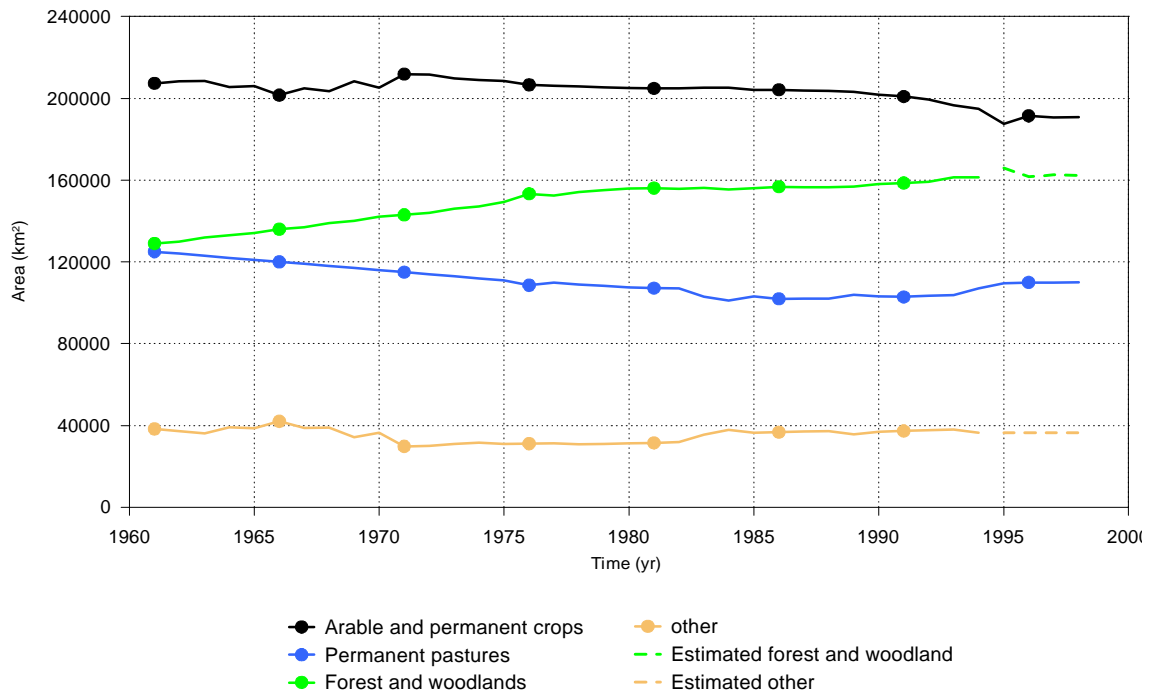


Figure 1 - Evolution of land use - land cover in Spain for the period 1961-1998 (FAO, 1990-98)

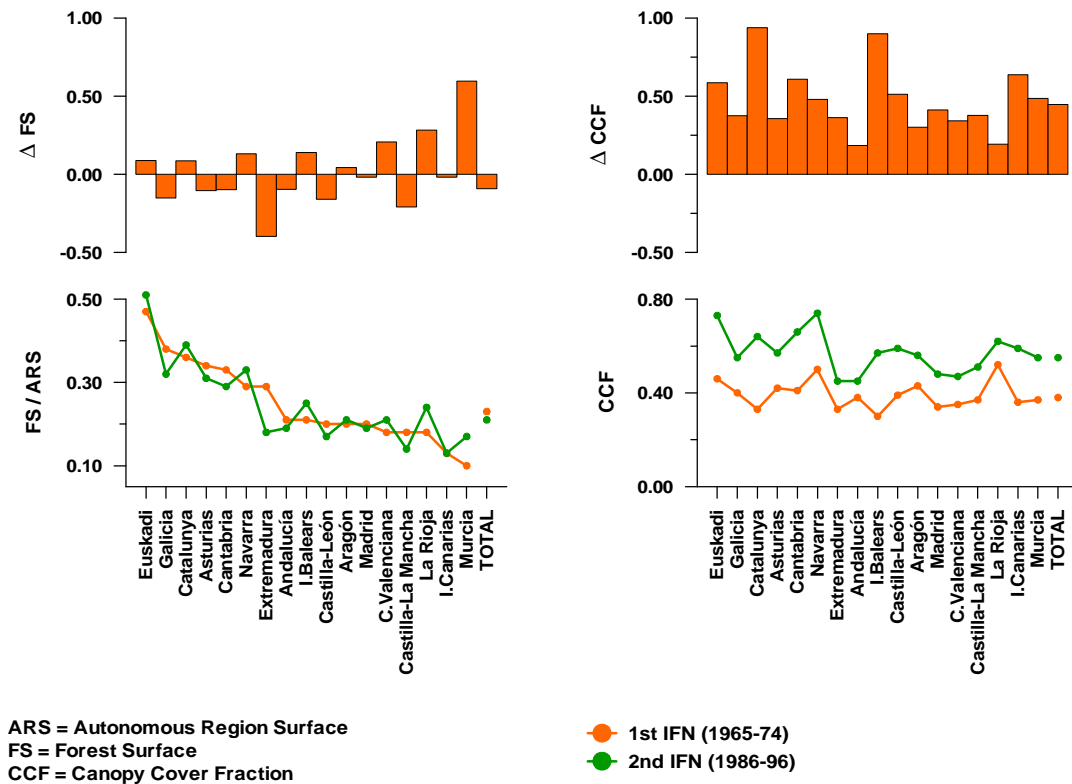


Figure 2 - Differences in Forest Surface and Canopy Cover Fraction between the 1st and 2nd "Inventario Forestal Nacional" (National forest inventories)

The relevance of land cover changes must be considered as the change in both forest area and canopy cover fraction. The product between forest area and canopy cover fraction (i.e., a measure of the area fully covered by the forest canopy) increased between the two inventories in 1,411,300 ha (2.8% of the whole country surface). If this increase is divided by the canopy cover fraction obtained in the first inventory, the changes, expressed in terms of unchanging cover fraction, would represent an increase of 3,713,950ha (7.3% of the whole surface).

TEMPORAL EVOLUTION OF WATER RESOURCES IN SPAIN

Most of the historical records of river discharges in Spain begun by 1940. Nowadays, after more than 50 years, decreasing trends of annual discharges have been observed by several authors in most of the flow records (Batalla et al., 1992; Vieira and Tavares, 1996; Prieto, 1996; MIMAM, 1998; MIMAM, 2000). The cause of these decreasing trends in flow have been attributed first to the increase in water abstractions, mainly for irrigation, and second to the climatic variability.

A sample of the more relevant decreasing trends are shown on the Figs. 3 to 5. The record of the river Duero at Miranda (Figure 3) shows a decrease of 5,450 hm³ a⁻¹ (59% of the mean flow) in the 62 years of the analysed period; the slope of the linear regression is significant at the 0.01 level in spite of the high inter-annual irregularity of the flow.

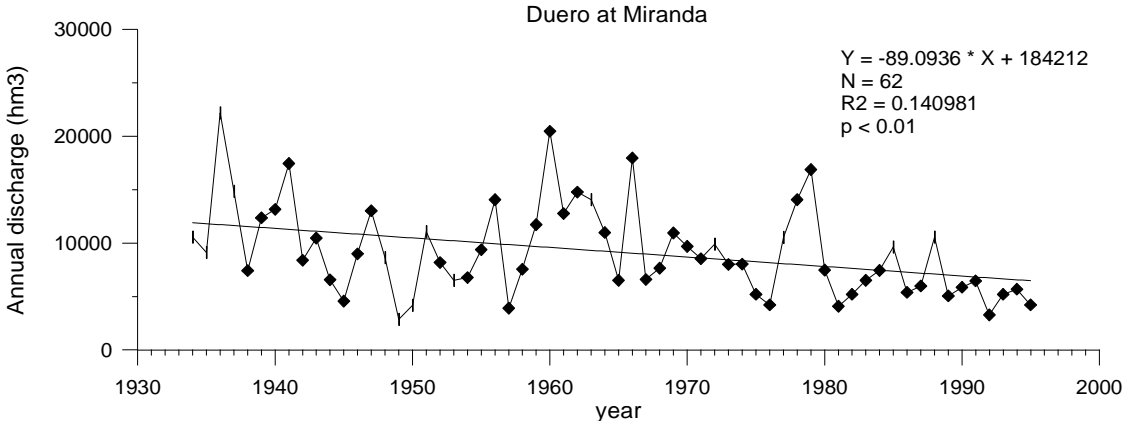


Figure 3 - Annual discharge observed in the Duero river at Miranda (data from Vieira and Tavares, 1996)

The annual flow record of the river Ebro at Tortosa (Figure 4) has been recently revised for the Spanish hydrological plan (MIMAM, 2000). The revised record has an increased temporal stability compared with the original record, but it still shows a decrease of 5760 hm³ a⁻¹ (58.2% of the mean flow) for the 57 years of the analysed period. As in the case of the former record, the slope of the linear regression is significant at the 0.01 level in spite of the high variability of the annual values.

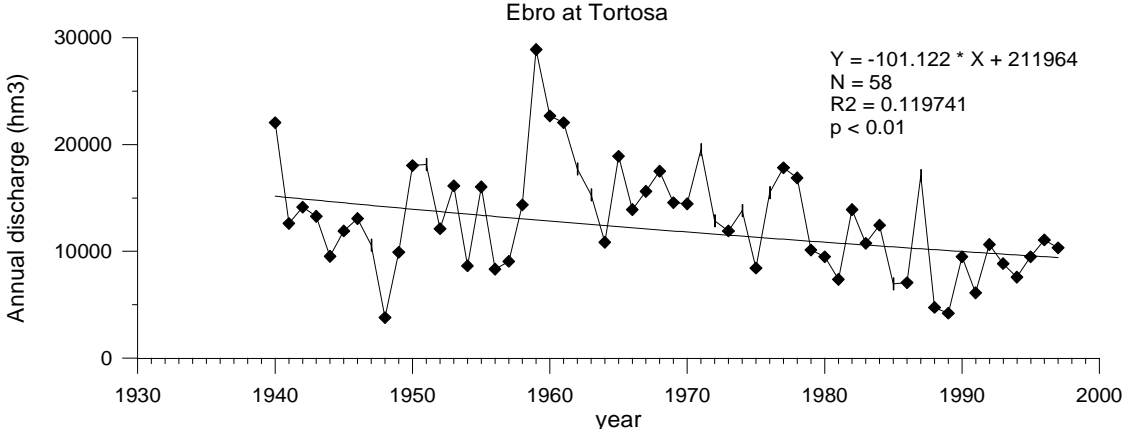


Figure 4 - Annual discharge observed in the Ebro river at Tortosa (data from MIMAM, 2000)

Finally, the flow record of the Tagus river at the inlet of the Tajo-Segura transfer is shown on the Figure 5. This is a much smaller catchment but is analysed here because there has been no relevant increase of water use in the catchment and also because it provides water to the main water infrastructure for water management in Spain. The record between 1912 and 1970 does not show any significant trend, but from 1940 to 1996 a decrease of $687 \text{ hm}^3 \text{ a}^{-1}$ (58% of the mean flow) is observed, the slope of the linear regression being significant at the 0.01 level. It is important to mention that the Tajo-Segura transfer since its setup in 1979 until 1997 was able to transfer only a mean of $263 \text{ hm}^3 \text{ a}^{-1}$, whereas it was designed for $600 \text{ hm}^3 \text{ a}^{-1}$ (MIMAM, 1998).

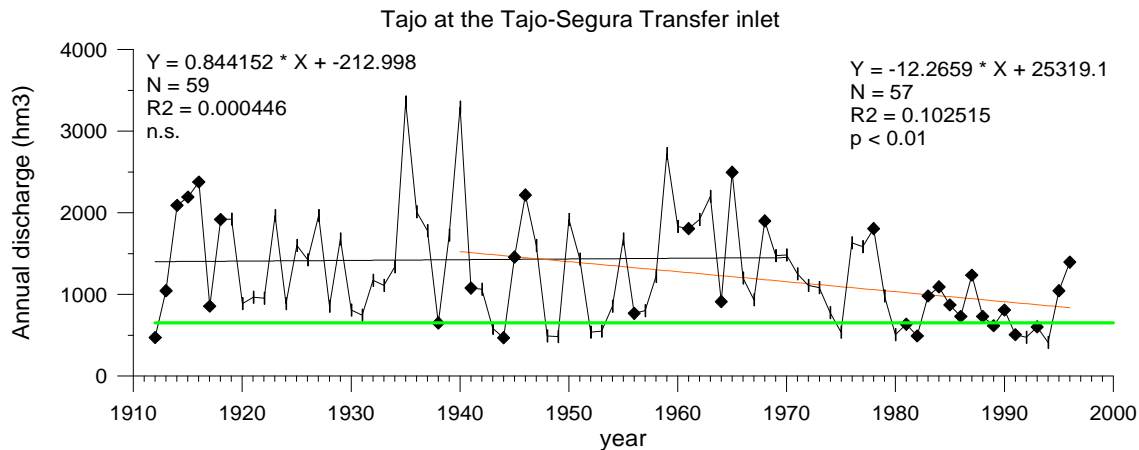


Figure 5 - Annual discharge observed in the Tagus river at the Tajo-Segura transfer inlet (data from MIMAM, 1998). The thick grey line represents the demand of this infrastructure

The importance of these changes in the whole water resources in Spain has been attempted by Prieto (1966) using the records of a set of rivers representative of the several hydrological regions. This assessment suggests that the decrease represents about 33.7% of the mean flow in the period 1921-1995.

LINKING CHANGES IN LAND COVER WITH TRENDS IN WATER RESOURCES

The Figure 6 represents the analysis of the changes in water balance of the Ebro river at Tortosa. The upper part shows the observed flow as well as the flow simulated by MIMAM (2000) with a precipitation-runoff conceptual distributed model (Ruiz-García, 1999) which takes into account the evapotranspiration demand. The temporal trend of the simulated flow is not significant but represents a decrease of $2,140 \text{ hm}^3 \text{ a}^{-1}$ (16.6% of the mean flow) than must be taken into account in the analysis. In the lower part, the evolution of water consumption for irrigation has been assessed from the increase of irrigated areas estimated by MIMAM (2000) and the specific water consumption for crop irrigation (440 mm a^{-1}) assessed by Casterad and Herrero (1996). The water consumed by other kinds of uses was considered less than the return from irrigation. The temporal evolution of residuals (simulated flow minus observed flow minus water consumption) represented a decrease of water flow of $2,220 \text{ hm}^3 \text{ a}^{-1}$ (17.2% of the mean flow) for the studied period, and the slope of the linear regression was significant at the 0.01 level. The significant decrease of water flow not explained after the consideration of both the variability of climate and the evolution in water abstraction is to be considered the result of the increase of water consumption by the vegetation in the headwaters. Indeed, most of the records of the tributaries of the Ebro show decreasing trends at gauging points located before the derivations for irrigation (Gracia, 2000).

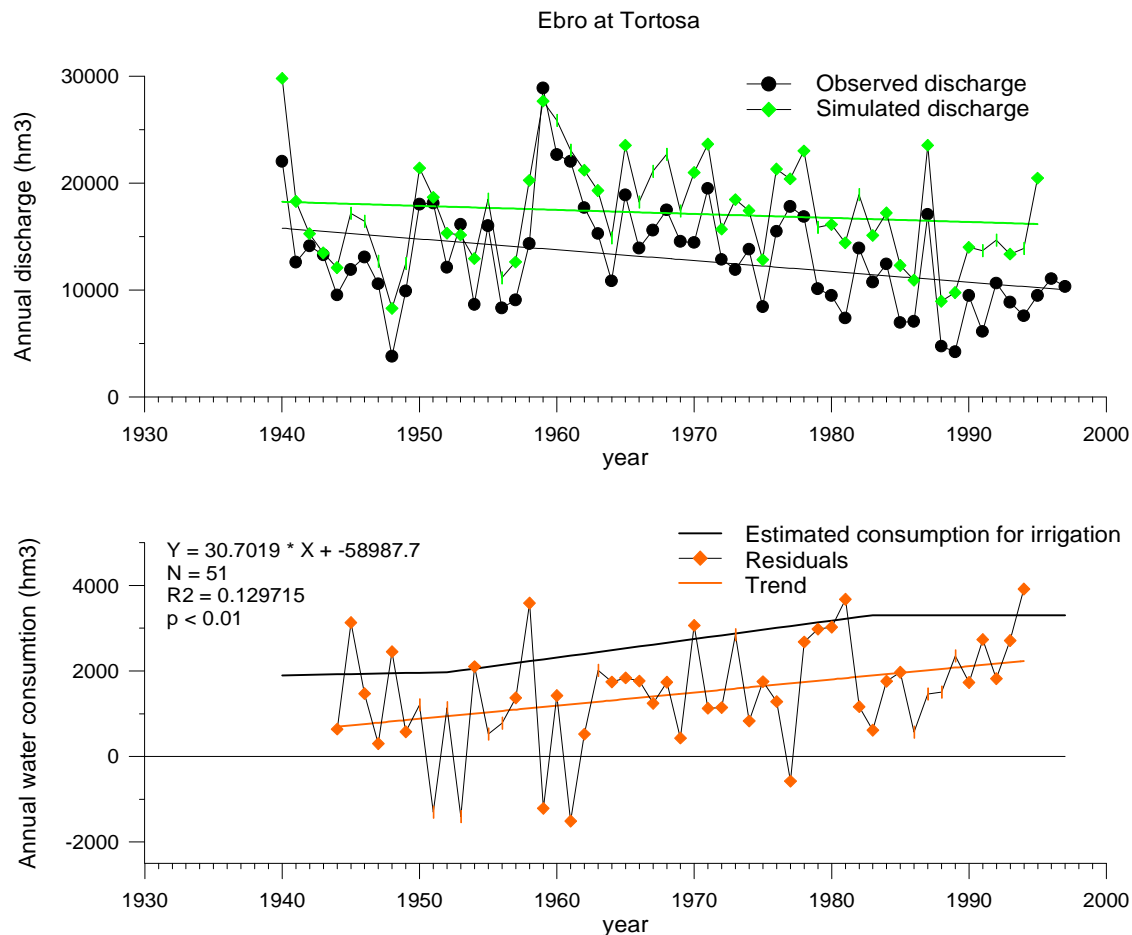


Figure 6 - Above: flow observed and simulated with a precipitation - runoff model in the Ebro river at Tortosa (both since MIMAM, 2000)
Below: estimated water consumption for irrigation and residuals (see text)

The same type of analysis has been then performed in a simplified manner for the records of Figures 3 and 5, as well as the Ebro at Palazuelos and Duero at Carrascal using data from Prieto (1996), the results being summarised on the Tab. 1. There are only relevant changes in water abstractions from the Duero river at both locations, where the amount of water consumed has been estimated by applying a specific water consumption of 440 mm a⁻¹ (Casterad and Herrero, 1998) to the new irrigated area (assuming an increase during the period of record of 55% of the present irrigated area assessed by MIMAM, 2000). The changes in flow due to precipitation variation have been obtained from Prieto (1996) for the Duero at Carrascal, from Mestre (1996) for the Duero at Miranda and Ebro at Palazuelos, and from MIMAM (1998) for the Tagus catchment.

river and location	period	flow	gross decrease		consumption		precipitation		residual	
	years	hm ³ a ⁻¹	hm ³ a ⁻¹	%	hm ³ a ⁻¹	%	hm ³ a ⁻¹	%	hm ³ a ⁻¹	%
Duero at Carrascal	1921-95	4440	1770	39.8	658	14.8	338	7.6	774	17.4
Duero at Miranda	1934-96	9190	5450	59.3	1080	11.8	1630	17.7	2740	29.8
Ebro at Palazuelos	1915-95	1670	619	37.1	-	-	112	6.7	507	30.4
Ebro at Tortosa	1940-97	12900	5760	44.7	1410	10.9	2140	16.6	2220	17.2
Tajo at T-S transfer	1940-96	1180	687	58.2	-	-	145	11.4	542	45.9

Table 1 - Breakdown of temporal changes in flow for a sample of rivers

The fact that catchments without relevant change in water consumption showed the higher range in residuals indicates that the consumption of water was not greatly underestimated in the other catchments. This preliminary assessment suggests that the residuals, i.e. the flow loss due to changes in the behaviour of

headwaters, were more important than the flow loss due to either rainfall variability and increase of water consumption.

A number of experiments conducted over the world demonstrated that the decrease of forest cover in a catchment implies an increase of water yield from it and, conversely, the establishment of a forest cover implies a decrease of water yield (Bosch and Hewlett, 1982; Sahin and Hall, 1996).

The residuals from the Table 1 have been expressed in terms of runoff depth loss for a 20-year period (assuming a linear change throughout the analysed period), and then compared with the respective increase of forest surface in terms of the canopy cover fraction in the first Forest Inventory. The results are shown on the Figure 7 together with other results obtained elsewhere for easier comparison. In this graph, the points with negative values in both coordinates (decreases in yield following augmentation in cover) are located together with points with both positive variables.

This graph shows that the results obtained in this study are coherent with the results obtained elsewhere, although four of the cases suffered changes in forest cover smaller than or similar to the small range reported in the literature. Furthermore, the size of the studied catchments are bigger than the cases reported in the literature.

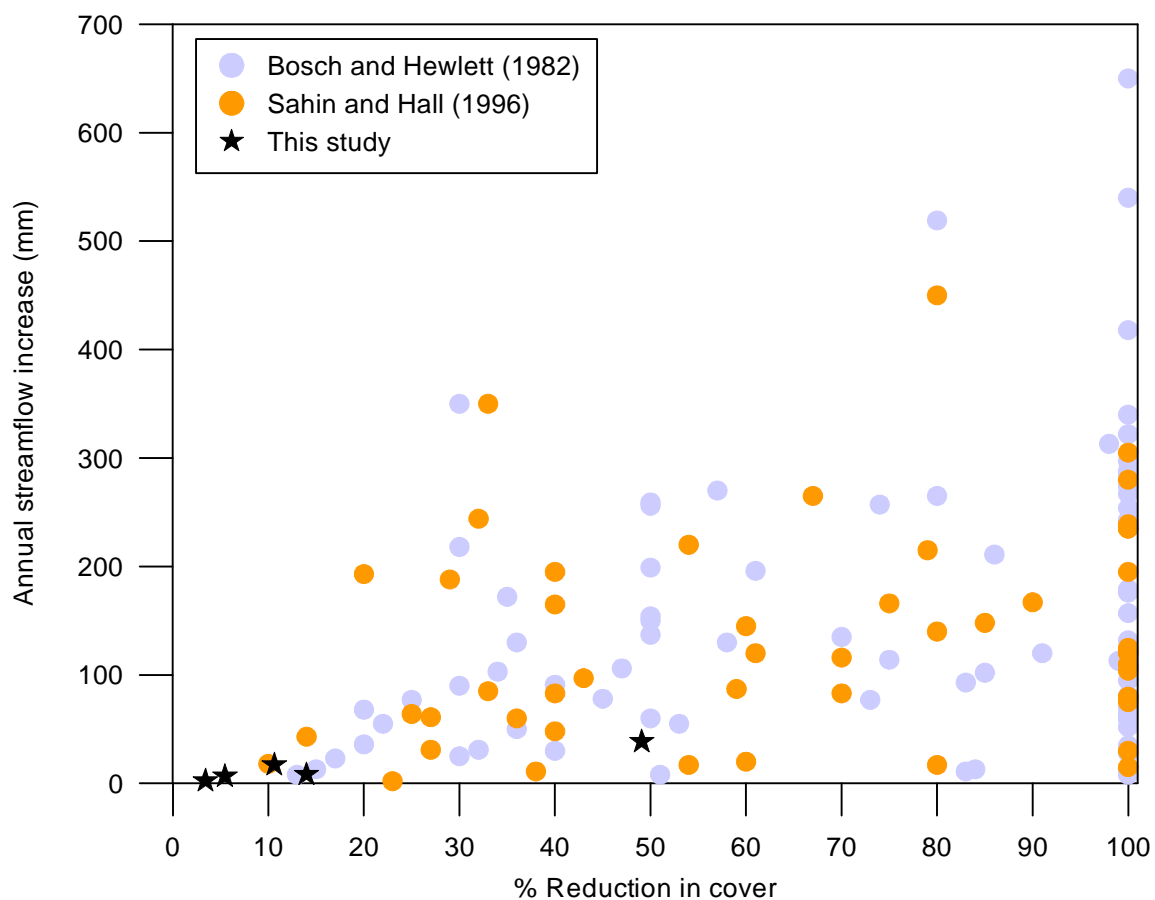


Figure 7 - Relationships between changes in forest cover and water yield in the examples of Tab. 1, compared with cases reported elsewhere. (Stars have negative values in both coordinate variables)

CONCLUSIONS

Important changes in land cover in the headwater areas of Spain have occurred in the last 60 years, as a consequence of rural abandonment and environmental and agricultural policies. As afforestation is a slow process, for analysing land cover change it is necessary to consider not only the variation of forested areas extension, but also changes in canopy cover fraction. Detailed information available for analysing land cover change in Spain has a short time coverage (only 20 years).

Precipitation-runoff relationships are not stationary in most of Spanish catchments. Flow decrease is not only due to water abstractions for irrigation but mainly to the behaviour of headwaters, attributable to the

increase in forest land cover.

The hydrological consequences of these land use changes in headwaters seem therefore more important than precipitation trends and increase of water abstractions. Furthermore, these changes are already observable and are therefore more realistic than the predictable reduction of flow due to climatic change.

The preliminary results obtained suggest that the relationship between land cover change and flow decrease falls within the range reported in the literature, but the present case is related to larger catchments, analyses the afforestation process and includes smaller modifications of land cover.

More attention is therefore to be paid to both land cover changes in the headwaters and precipitation-rainfall relationships. In this study, large catchments have been studied in a preliminary manner in order to assess the economic and strategical impact of these changes. Nevertheless, the studies of scientific and applied value must be conducted in smaller catchments in order to consider more detailed characteristics of vegetation (density, type of trees, leaf area index...) and hydrometeorology (range of precipitation, role of snow, seasonal patterns...). The results of these studies would be of great value to assess the hydrological impact of land cover changes in the future or in other locations, to test and validate hydrological models, as well as to design hydrologically sound land management strategies to mitigate the effects of climate change.

Acknowledgements

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