Influence of 7-year old *eucaliptus globulus* plantation in the low flow of a small basin

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Abstract In the hydrological year 1997/98 was made a plantation of Eucaliptus globulus, in a basin of 10.7 ha. Until the year 2003/04 was made a hydrological monitoring of the catchment with precipitation, temperature, solar radiation, and humidity measures. The flows were measured in continuous with a capacitive probe in a type "V" weir. For the seven observed years were determined the terms of the monthly water balance. The results show that at the present time, with 16 m of height of the trees (one half of their total growth time) the annual balance is not sensitive to the growth of the forest mass. However, the water balance for the dry season months (June, July, August and September), that define the low flow in the basin, shows a clear and sustained decrease with a descent in the flows that represents the 30% of the initial value.

Key words: Water balance, Forest hidrology, Eucaliptus plantation, Low flow

INTRODUCTION

Calder (1992), in his review of the influence of forest species on drainage from experimental watersheds, concluded that an increase in the area under fast-growing species like pine and eucalypt tends to reduce surface runoff by comparison with that seen from watersheds with mainly herbaceous cover. The typical magnitude of the reduction was reported to be about 40 mm per annum per 10% increase in forested area with respect to herb area. Slower-growing broadleaf trees also tend to reduce runoff, but only by about 10-25 mm per annum per 10% increase in forested area.

In Galicia, eucalypts (especially *Eucalyptus globulus*) have been widely planted since the 1950s, initially in response to the demand generated by two paper factories (at Pontevedra and Navia) that started up during this period. Eucalypt plantations rapidly became widespread throughout large areas of Galicia, and currently occupy about 300,000 hectares; eucalypt is the dominant tree species at altitudes below 400 m. Within the region, the eucalyptus has been the object of scientific and social controversy, particularly as regards possible negative effects on water resources and soil quality, and there have been a number of studies aimed at clarifying whether such effects occur (Díaz-Fierros *et al.* 1982; Perez Moreira 1992; Calvo de Anta 1992). As regards possible effects on water resources, there have been three main types of study: monitoring of soil water profiles, application of models for estimation of evapotranspiration, and monitoring of watershed-level water balance. The results of these studies suggest a) that transpiration from mature *E. globulus* stands may reach 1000-1200 mm per annum when soil water availability is sufficiently high; b) that the depth of the soil may be an important limiting factor, *i.e.* transpiration losses correlate positively with rooting depth; c) that watershed-level water balance does not differ significantly between *E. globulus* and *Pinus pinaster* stands; and d) that in summer transpiration losses from *Quercus robur* stands can be as high as from stands of the faster-growing plantation species.

In general, these studies have confirmed Calder's view that fast-growing plantation species tend to have basically negative effects on water resources. In any case a more detailed analysis of the effects of the different species on the different components of water balance can only be achieved by studying smaller and more homogeneous watersheds than have been studied to date. Here we present preliminary results of a study of an 11-hectare watershed almost entirely occupied by *Eucalyptus globulus*.

MATERIAL AND METHODS

General characteristics of the experimental watershed

The study was carried out in the "O Abelar" experimental watershed (area 10.7 ha), in the municipality of Abegondo (A Coruña Province), 8°21'15" N, 43°9'10" W. The geological substrate is schist of the Órdenes Complex. Soil texture is basically silty loam (sand 30%, silt

50%, clay 20%) throughout the watershed. Mean organic matter content is 9.5%, and pH in water 5.2.

Until June 1998, 58% of the watershed was under pasture and 37% under forage maize; the remaining 5% was riparian woodland. In June 1998, 60% of the watershed was planted with *E. globulus*, and in this date the remaining area was planted with this species, except for the riparian woodland and two small strips crossing the watershed, corresponding to high-tension power lines, as shown in Fig. 1.

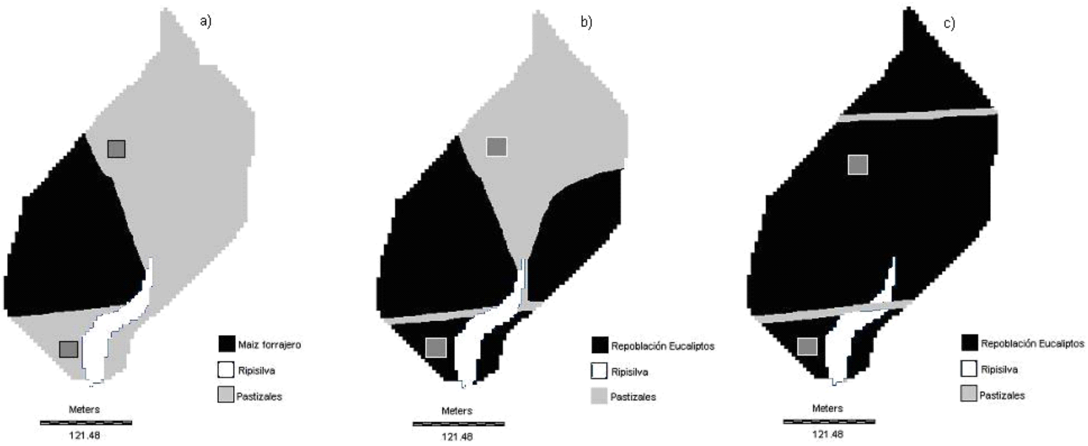

Fig. 1 Land-use maps of the O Abelar experimental watershed, up to June 1998 (a), from June 1998 to June 1999 (b), and from June 1999 to present (2005) (c). Squares indicate the positions of the two rain gauges.

RESULTS

Precipitation measurement

Precipitation was measured with two rain gauges, a totalizer gauge located in the upper part of the watershed, and an automatic gauge (0.2 mm intervals), situated in the lower part of the watershed. Daily data from the two gauges show very good correlation, despite the difference in altitude. We therefore used the data from the totalizer gauge only, except for short periods with technical problems, when we used daily medians of the automatic gauge readings.

The six hydrological years considered showed pronounced interannual variability: 2000/2001 was the rainiest of the last 30 years, with double the average rainfall (as recorded at the nearby Montaos station), and monthly rainfall in four months exceeding 450 mm; by contrast 2001/2002 was one of the driest years of this period, with total rainfall in the typically rainy months of November and December less than 100 mm; 2002/2003 was likewise especially rainy, so that only the three first years of the study can be considered reasonably normal. Rainfall during the dry period (June to September) expressed as a proportion of rainfall during the year as a whole was higher than the average in four years, and lower than the average only in the two wettest years, 2000/2001 and 2002/2003: in other words, the study period showed extreme among-year variation not only in total rainfall, but also in the seasonal pattern of rainfall. In all years except 2001/2002 there were more than 2 days with rainfall exceeding 50 mm, and in 2000/2001 there was one day with rainfall exceeding 100 mm. Daily rainfall data for the period 1997-2004 are shown in Fig. 2. Monthly and annual rainfall totals, and the rainiest day in each year, are shown for the calendar years 1997-2004 in Table 1.

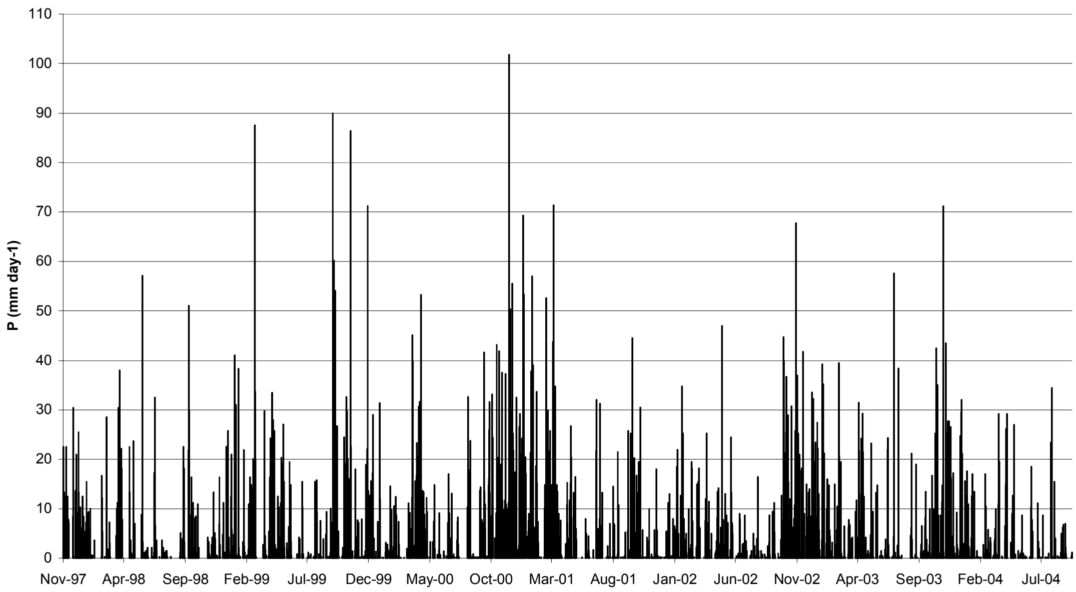

Fig. 2 Daily rainfall records for the O Abelar watershed over the period 1997-2004.

Table 1. Monthly and annual (calendar year) rainfall data for the O Abelar watershed over the period 1997-2004.Also shown is rainfall on the rainiest day in each year.

		1997	1998	1999	2000	2001	2002	2003	2004
January		87.90	125.25	194.26	61.00	466.23	127.50	284.00	166.30
February		28.90	38.91	87.86	90.40	129.00	157.75	135.25	45.00
March		0.00	68.10	25.79	32.40	517.12	83.00	94.50	58.80
April		24.40	303.20	234.99	438.48	93.20	77.60	216.75	138.80
March		170.60	88.09	178.45	100.32	129.25	165.50	68.25	80.00
June		133.90	73.26	50.16	22.56	23.75	82.00	89.60	50.25
July		21.10	71.74	30.70	70.03	129.00	32.50	114.00	26.85
August		51.70	2.43	83.30	91.34	73.00	32.75	37.20	93.50
September		5.10	173.58	350.21	112.36	67.50	55.00	40.90	34.60
October		99.10	87.70	209.82	254.70	252.25	329.25	233.75	283.60
November		222.40	73.56	168.48	458.64	30.25	392.25	300.50	35.40
December		165.80	125.86	249.84	497.48	52.50	312.00	225.40	98.60
Pmax day	P (mm)	35.80	57.15	89.98	101.81	71.40	67.75	71.25	34.50
	Date	25/05/1997	01/06/1998	18/09/1999	30/11/2000	20/03/2001	13/11/2002	15/11/2003	11-08-04
P total (mm)		1010.90	1231.69	2089.85	2229.72	1963.05	1847.10	1830.10	1146.20

Rainfall intensity was studied at the five-minute level (mm h^{-1}) over the period November 1997 to May 2000. The results of this analysis (Fig. 3) show that most rainfall events (> 80%) were low-intensity, *i.e.* < 4 mm h^{-1}, although within this 3-year period higher-intensity events (>12 mm h^{-1}, occasionally>24 mm h^{-1} or even 36 mm h^{-1}) sometimes occurred. High and very-high-intensity rainfall events are of course often strongly erosive.

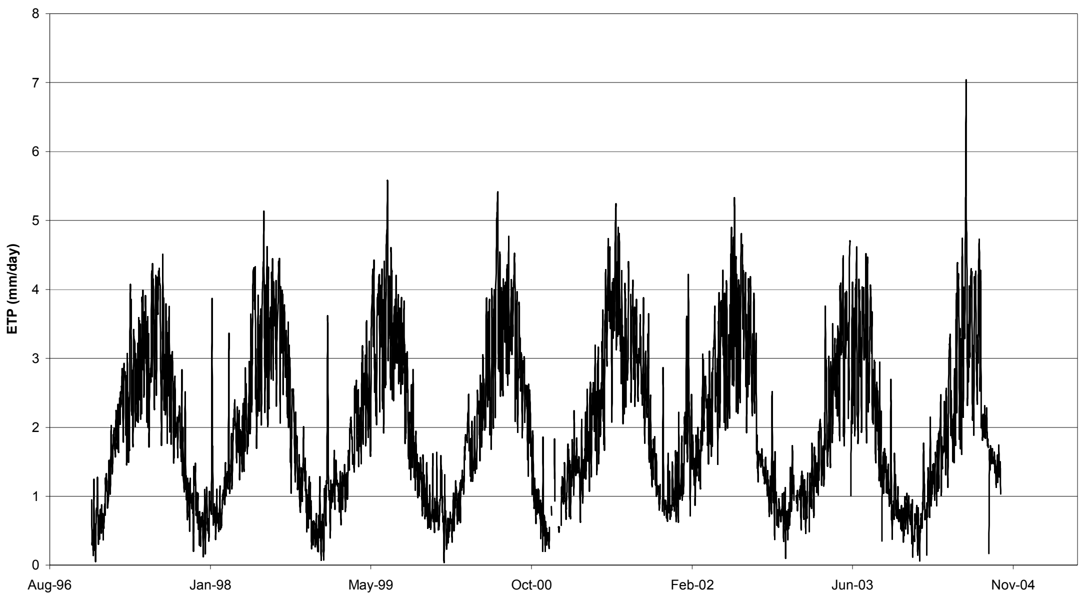

Fig. 3 Potential evapotranspiration (daily totals, mm) in the study area (Mabegondo weather station) over the period 1997/1998 to 2003/2004.

Table 2 shows the mean monthly rainfall data for the period 1961-1990 at the Montaos (climatological normal reference station), and for each hydrological year of study in the O

Abelar watershed. In addition, for each period (1961-90 at Montaos, or each year in O Abelar) this table shows the proportion of rainfall falling in the first part of the wet period (October-January), the second part of the wet period (February-May) and the dry period (June-September).

Table 2. Mean rainfall data for the Montaos weather station over the period 1961-1990, and for the O Abelar watershed in each year over the period 1997/1998 - 2002/2003. Also shown is the percentage of each year's total rainfall falling in the main seasons: the first part of the wet season (October - January inclusive), the second part of the wet season (February-May inclusive), and the dry season (June-September inclusive).

	Montaos	O Abelar						
	1961-1990	1997-1998	1998-1999	1999-2000	2000-2001	2001-2002	2002-2003	2003-2004
October	153	99.10	87.70	209.82	254.70	252.25	329.25	223.75
November	172	222.40	73.56	168.48	458.64	30.25	392.25	300.50
December	195	165.80	125.86	249.84	497.48	52.50	312.00	225.40
January	198	125.25	194.26	61.00	466.23	127.50	284.00	166.30
February	183	38.91	87.86	90.40	129.00	157.75	135.25	45.00
March	140	68.10	25.79	32.40	517.12	83.00	94.50	58.80
April	112	303.20	234.99	438.48	93.20	77.60	216.75	138.80
May	112	88.09	178.45	100.32	129.25	165.50	68.25	80.00
June	60	73.26	50.16	22.56	23.75	82.00	89.60	50.25
July	29	71.74	30.70	70.03	129.00	32.50	114.00	26.85
August	37	2.43	83.30	91.34	73.00	32.75	37.20	93.50
September	96	173.58	350.21	112.36	67.50	55.00	40.90	34.60
Wet 1 (%)	48	43	32	42	59	40	62	63
Wet 2 (%)	37	35	35	40	31	42	24	22
Dry (%)	15	22	34	18	10	18	13	14
Total	1487	1431.86	1522.84	1647.03	2838.87	1148.60	2113.95	1443.75

Evapotranspiration

Daily potential evapotranspiration was estimated with the Penman-FAO equation (Smith, 1990), using data from the nearby Mabegondo weather station, whose characteristics as regards evaporation are very similar to those of O Abelar. The results for the six years of study are shown in Fig. 3.

Despite the differences among the years of study, interannual variability in potential evapotranspiration was in general low, and much lower than interannual variability in rainfall. The minimum daily values (about 0.5 mm day^{-1}) were recorded during December and January, and the peak daily values (about 3-4 mm day^{-1}) on windy days in July. Daily fluctuation (*i.e.* the difference between each day's minimum and maximum value) was about 0.5-1.0 mm day^{-1} in the winter, and about 1.5-2.0 mm day^{-1} in the summer.

Monthly and annual potential evapotranspiration totals are listed in Table 3. As can be seen, the minimum monthly total was in all years rather less than 20 mm, and the maximum monthly total in all years close to 110 mm. The maximum annual total was 789 mm, for the hydrological year 2001/2002, and the minimum annual total 674 mm, for the hydrological year 2002/2003. In view of the scant interannual variability in this parameter, the mean for this six-year period, 728 mm, can be considered representative for this watershed.

Table 3. Monthly and annual totals of potential evapotranspiration in the study area.

	1997-1998	1998-1999	1999-2000	2000-2001	2001-2002	2002-2003	2003-2004
October	46.65	39.74	40.28	32.74	46.04	35.75	37.54
November	27.28	20.04	26.57	13.87	26.02	23.60	25.39
December	18.38	16.69	27.53	7.73	31.12	23.08	22.56
January	28.82	40.51	17.66	35.07	49.92	26.63	16.02
February	27.51	31.48	27.45	41.11	48.78	24.98	28.40
March	54.46	50.03	52.80	48.40	57.99	45.35	44.16
April	57.51	68.59	56.71	68.36	73.57	69.79	64.62
May	89.82	88.95	84.91	96.28	97.77	95.20	83.81
June	100.93	100.84	111.31	118.24	104.97	82.81	113.43
July	102.86	113.71	110.76	102.98	111.13	99.10	106.71
August	106.97	103.18	102.06	84.38	97.12	89.99	55.22
September	65.48	65.84	70.20	83.10	44.87	57.26	43.02
Total	726.67	739.60	728.23	732.27	789.29	673.54	640.88

Development of the eucalypt plantation

The eucalypt-planted area was divided into 5 zones, and in each zone we selected one tree considered representative of that zone, and 8 trees surrounding each "central" tree (n=9 trees per zone, 45 trees in total). We then measured the 150 cm height trunk diameter and height of each tree every 15 days over the first two years from planting, and subsequently once yearly. The results of this monitoring, summarized graphically in Fig. 4, indicate that both trunk diameter and height increased in basically linear fashion, in line with previous reports for this species in Galicia (Fernández, 1983) which have found that growth remains linear for about 10 years after planting. Our data indicate that O Abelar is a growth class-II site for eucalypt growth on the classification of Fernández (1983).

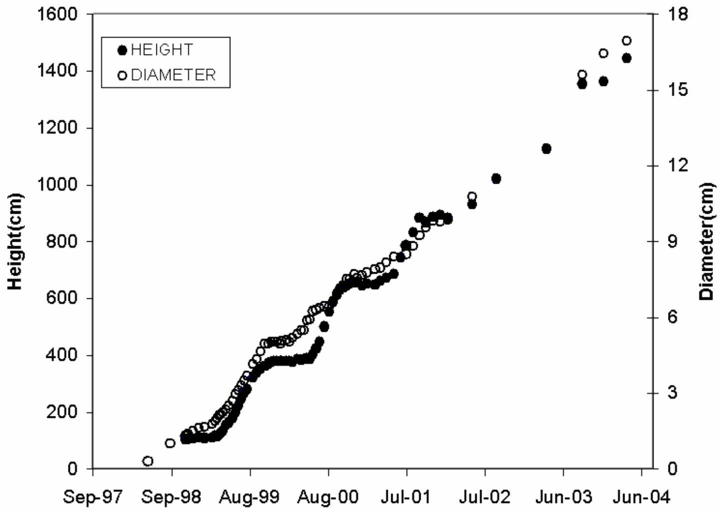

Fig 4. Growth of the eucalypt trees in the O Abelar watershed over the study period, showing chest-height diameter and height. Each value is the mean for 29 trees.

Despite the basically linear long-term growth, clear seasonal effects are also apparent, especially during the first few years, with growth occurring mainly during spring and summer.

Watershed streamflow data

The automatic streamflow monitoring system installed in the O Abelar watershed provided continuous data for the entire study period. The Parshall channel established initially had to be remodelled with a V-shaped outlet when dry season flow declined dramatically following the eucalyptus planting. Both before and after remodeling water level depth was monitored with a capacitative sensor. Daily mean streamflows (l s^{-1}) are shown in Fig. 5, and monthly mean streamflows in Table 4. Except for occasional gaps because of system malfunction, these data make up a good continuous record. As can be seen, flow showed marked temporal variability, dropping practically to zero during periods of low rainfall. High temporal variability is as expected given the small size of the watershed.

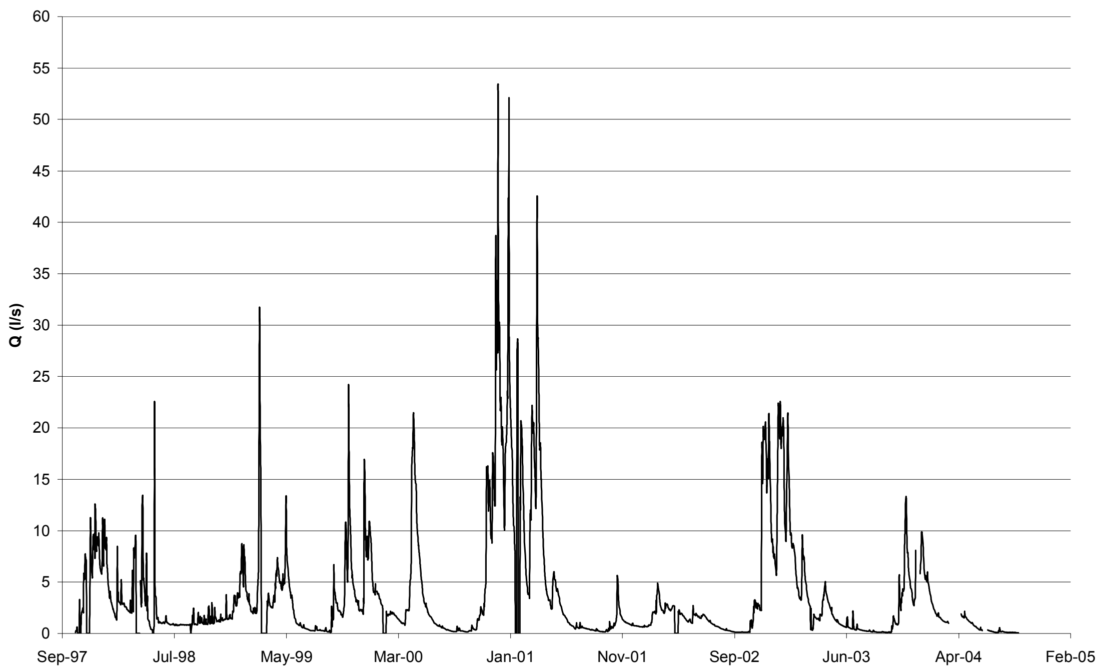

Fig. 5. Streamflow daily mean (l s^{-1}) data for the O Abelar watershed over the study period 1997-2004.

Table 4. Mean monthly and annual total streamflows (l s^{-1}) leaving the O Abelar watershed.

	1997	1998	1999	2000	2001	2002	2003	2004
January		7.29	5.04	4.36	21.66	1.12	15.43	6.84
February		2.9	2.71	1.95	10.02	2.9	5.72	2.88
March		2.64	10.23	1.37	19.34	2.55	3.89	1.26
April		6.09	4.05	8.48	5.92	1.67	1.98	No data
May		2.63	5.75	5.97	3.74	1.54	2.59	1.38
June		2.31	1.6	1.3	1.08	1.49	0.89	0.53
July		0.96	0.42	0.49	0.57	0.69	0.56	0.2
August		0.84	0.32	0.27	0.35	0.27	0.27	0.15
September		1.11	1.41	0.25	0.22	0.12	0.15	0.09
October	2.38	1.24	3.76	1.39	1.59	1.19	0.22	
November	3.17	1.43	6.91	12.89	1.11	11.47	2.66	
December	8.66	1.75	6.76	23.26	0.72	12.6	6.15	
Total	5.91	2.6	4.08	5.16	5.53	3.13	3.38	

The streamflow data for the six hydrological years considered do not show any clear trend, possibly as a result of the marked interannual variation in rainfall over the study period. In contrast, dry-season daily maximum flows show a declining trend over the study period (except for the hydrologically exceptional year 2001/2002), in line with the growth of the eucalypt plantation.

Discussion

The values of the different terms of the water balance equation for the study watershed are summarized in Table 5, considering both seasonal values (wet 1, wet 2, dry season) and annual totals for the 7 hydrological years of study. These values indicate that over the 7 years of the study, during which the he eucalypts planted over most of the study area grew to a mean height of 16 m, there was no clear trend in annual streamflow leaving the watershed. However, there was a clear decline in streamflow leaving the watershed during the dry season, from 3 years post-planting onwards: by 7 years post-planting, dry-season streamflow leaving the watershed had dropped to about 40% of the initial value. This declining trend is attributable to gradual depletion of soil moisture reserves by the growing plantation, with a consequent increase in actual evapotranspiration. Why no similar trend is observed in the wet season is more difficult to explain, since any depletion of soil moisture reserves would be expected to have an impact in the wet season too. More detailed ongoing analyses of the proportion of water returned to the atmosphere due to transpiration or interception (currently estimated at about 10%) may shed further light on the process of extraction of water from the soil, and on the role of different factors in this process.

Table 5. Seasonal water balance (mm) for the O Abelar watershed, over the period 1997-2004.

		October-January	February-May	June-September	Total
1997-1998	P.	612	498	321	1431
	Q	535	346	128	1009
	P-Q	77	152	193	422
1998-1999	P	482	527	514	1523
	Q	236	560	91	887
	P-Q	246	-33	423	636
1999-2000	P	689	660	296	1645
	Q	618	433	57	1108
	P-Q	71	227	239	537
2000-2001	P	1677	868	293	2838
	Q	1755	949	53	2757
	P-Q	-78	-81	240	81
2001-2002	P	462	484	202	1148
	Q	101	209	64	374
	P-Q	361	275	138	774
2002-2003	P	1317	514	282	2113
	Q	1266	342	46	1654
	P-Q	51	172	236	459
2003-2004	P	916	323	205	1444
	Q	419	162	25	607
	P-Q	497	160	180	837

In many cases, what is clear from Fig. 6 is that eucalypt plantations may have a clearly negative effect on dry-season water resources in Mediterranean climates.

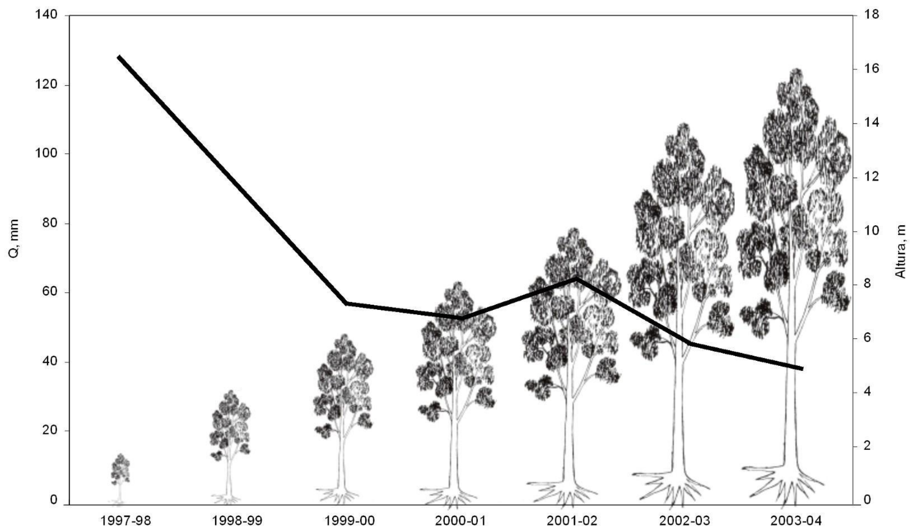

Fig. 6. Dry-season streamflows from the O Abelar watershed over the study period

REFERENCES

Calder, I.R. (2003) "Forest and water-Closing the gap between public and science perceptions".Stockholm Water Symposium. (http://www.siwi.org/waterweek2003)

Calvo de Anta, R. (1992) "El eucalipto en Galicia. Sus relaciones con el medio natural". University of Santiago de Compostela.

Calvo de Anta, R.M.; Paz González,A.; Díaz-Fierros Viqueira, F.(1979) "Nuevos datos sobre la influencia de la vegetación en la formación del suelo de Galicia". An. Edaf. Agrobiol. XXXVIII, 7-8(1151-1163).

Dafonte Dafonte, J.; González García, M.A.; Taboada Castro, M.T.; Paz González, A. (1998) "Avances sobre el estudio de la erosión hídrica. Variabilidad espacial de las propiedades generales del suelo en una cuenca agrícola". Jornadas Internacionales sobre Erosión Hídrica. A Coruña, II-XIII Junio (1998). Servicio de publicaciones de la Universidad de A Coruña.

Díaz-Fierros, F.; Calvo de Anta, R.; Paz González, A. (1982) "As especies forestais e os solos de Galicia". Sem. Estud. Galegos. Cuad. Área Cienc. Agrarias, 3,163 p.

FAO (1990) "Mapa Mundial de Suelos. Leyenda revisada". FAO-UNESC. Rome.

IGME. (1981) "Mapa Geológico Nacional. Hoja 70, Órdenes". Servicio de publicaciones del Ministerio de Industria y Energía.

Xunta de Galicia. (1986) "Avance do Segundo Inventario Forestal". Xunta de Galicia, Consellería de Agricultura.

Paz González, A. (1982) "Iniciación al estudio de las relaciones entre el agua del suelo y la evapotranspiración de cultivos y bosques en Galicia". Doctoral Thesis, University of Santiago de Compostela.

Pérez Moreira, R. (1992) "Ecoloxía forestal e ordenación do bosque". Edicións do Castro. Sada, A Coruña.

Soto González, B. (1996) "As Augas de Galicia. Balance Hídrico". Consello da Cultura Galega. Ponencia de Patrimonio Natural.

Thornthwaite, C.W.; Mather, J.R. (1955) "The Water Balance". Drexel Institute of Technology. Publications in Climatology. Volume VIII, number 1. Centerton, New Jersey. 1955.