Water in Celtic Countries: Quantity, Quality and Climate Variability (Proceedings of the Fourth InterCeltic Colloquium on Hydrology and Management of Water Resources, Guimarães, Portugal, July 2005).
IAHS Publ. 310, 2007.

Water balance and observed flows in the Anllóns River basin (NW Spain)

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Abstract During 2001, 2002 and 2003, several streamflow measurement surveys were carried out in the Anllóns River basin, as well as an integral study of its hydrological characteristics that has provided an important understanding of its hydrological behaviour. The annual hydrographs for each hydrological year were obtained and their separation into the basic components: surface water and baseflow, were carried out. The baseflow component of streamflow was obtained by means of the HYSEP computer program (developed by USGS). The mean value of the groundwater recharge for the study period was 72% of the total streamflow of the river. At the same time, using the recorded precipitation and evapotranspiration values calculated with the data from the nearest meteorological stations, the soil water balance was calculated using the Thornthwaite and Mather methodology for each observed year. The results obtained have been compared with the observed data.

Key words actual evapotranspiration; groundwater component; hydrograph separation; observed flows; streamflow measurement; water balance

INTRODUCTION

The water balance has been defined as "the balance between the income of water from precipitation and snowmelt and the out flow of water by evapotranspiration, groundwater recharge and streamflow" (Dunne, 1978). Since 1944, the water balance has been used for computing seasonal and geographic patterns of irrigation demand, the prediction of streamflow and water-table elevations, the flux of water to lakes, etc. and it is also useful for predicting the effects of weather modification or changes of vegetation cover on the hydrological cycle. Obviously, the water balance is a valuable tool in the analysis of water problems in a region.

Given the complexity of the hydrological cycle, it is logical to suppose that the water balance parameters will be numerous, and the first problem is to obtain a good understanding of these factors. There are many different methods for calculating the water balance. In the present study, the selected method was a modified version of that introduced by Thornthwaite in the early 1940s. It calculates an annual water balance using monthly data.

The main objective of this study is to compare the results obtained by the water balance and the actual values of runoff observed in the Anllóns River basin.

Fig. 1 Anllóns River basin location.

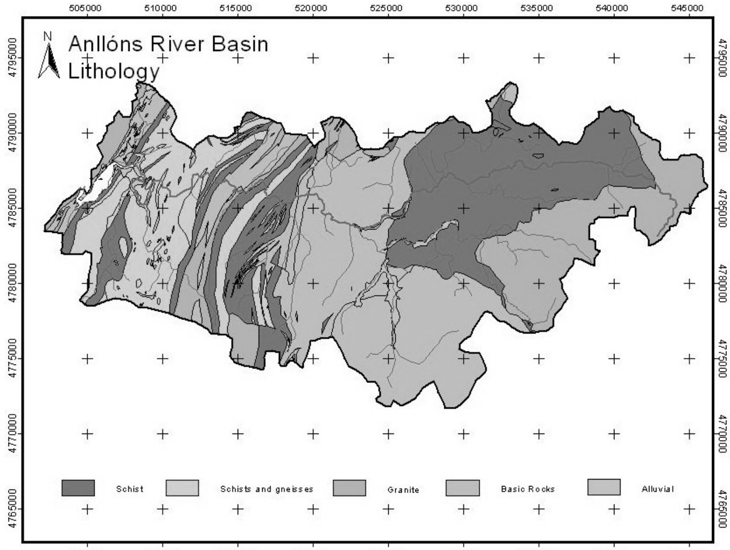

Fig. 2 Anllóns River basin lithology.

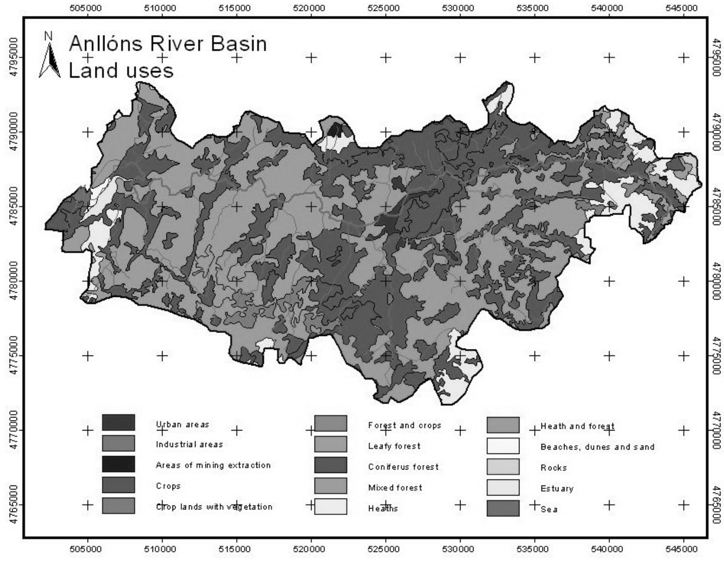

Fig. 3 Land use in the Anllóns River basin.

DESCRIPTION OF THE STUDY AREA

The group of river basins in Galicia (NW Spain), that flow into the Atlantic Ocean, with the exception of the Miño basin, is known as Galicia-Costa. This comprises a total of 21 basins covering an area of 9703.9 km^2, in which there are 17 hydrometric stations from which the flows draining an area of 5059.4 km^2 were recorded. The Anllóns basin (Fig. 1) is one of the most important of Galicia-Costa, and its river is one of the few flowing into the Atlantic Ocean in which the natural flow regime is preserved. The basin covers an area of 516 km^2, extending from the river source in the Coto de Pedrouzo to the mouth in the Ría de Corme e Laxe. The study area comprises a total of 450 km^2.

Along the 70 km of its length, the Anllóns crosses a series of zones of different, clearly distinguishable materials which lie in a transverse direction to the main river channel. Figure 2 shows a map of the predominant lithology in the basin. The lower area of the watershed is dominated by metamorphic rocks (schist and gneisses) whereas in the central area there is a wide range of basic rocks. Two-mica alkaline granites are present in a small area in the north and schists predominate in another zone that runs along almost all the upper strip of the catchment and which represents 71% of its total area. Finally, there is a zone of calco-alkaline granites in the most eastern area.

Forests, cultivated areas and grassland occupy most of the basin, whilst a small part is made up of urban areas (Fig. 3).

MATERIALS AND METHODS

Different methods were used depending on the aspects under study; the first part of the study involved the analysis and separation of the annual hydrographs to evaluate the groundwater component of streamflow; in the second, experimental part of the study, flows were measured at different times of the year and in different parts of the Anllóns basin; and in the last part the water balance was calculated. The techniques used are described briefly as follows.

Hydrograph separation

Groundwater component or baseflow is an important contributor for rivers and springs, particularly in wet regions. If we make an analysis of the observed streamflow hydrographs, an estimation of the surface runoff and the groundwater recharge in the catchment can be obtained. The surface runoff value can be considered very similar to the direct runoff necessary as an input parameter in the water balance estimation. The program used to analyse the annual hydrographs was the *HYSEP* (*Hydrograph Separation*) developed by the *United States Geological Survey* (*USGS*) (Ronal, 1996), and the separation method used by the program was the local-minimum method.

Flow measurement

Flow measurement at different points along the main stream channel and at different times of the year was carried out using *OTT C-20* and *OTT C-2* current meters and the analysis of the flows was made by the mid-section method (WMO, 1980; Herschy, 1999).

Water balance

The method selected to calculate the water balance was the Thornthwaite-Mather method (Dunne, 1978) and the evapotranspiration was calculated using the Penman formula. The meteorological values were obtained from the three nearest meteorological stations and the values obtained in previous studies (Díaz-Fierros, 1996). The parameters needed to apply this method are the monthly values of precipitation, evapotranspiration, the value of the direct runoff in the basin and the percentage of water available for runoff. It is also necessary to know the type of vegetation cover in the study area because the cropland coefficient has an important role in the water balance.

RESULTS AND DISCUSSION

During the years of observations, several streamflow measurement surveys in the Anllóns basin were made. Flows were recorded continuously in order to subsequently separate the components of the annual hydrographs. Figure 4 shows the results of the hydrograph separation for the observed hydrological years.

The precipitation and evapotranspiration recorded during the study period can be observed in Table 1. With the aim of obtaining a representative precipitation value for the whole basin, the precipitation values were interpolated using the Thiessen polygon method.

The values of direct runoff used were obtained by the observed hydrograph separation. Table 2 shows the monthly results obtained using that technique and the percentages corresponding to the total flow and monthly precipitation in the basin. As the calculations are made on an annual basis, it is assumed that there are no changes of soil moisture or groundwater storage over the year. The value adopted for the field capacity in the Anllóns river basin was 148 mm (Díaz-Fierros, 1996) and the monthly runoff as a percentage of water available for runoff selected (38%) was also obtained from Díaz-Fierros, 1996.

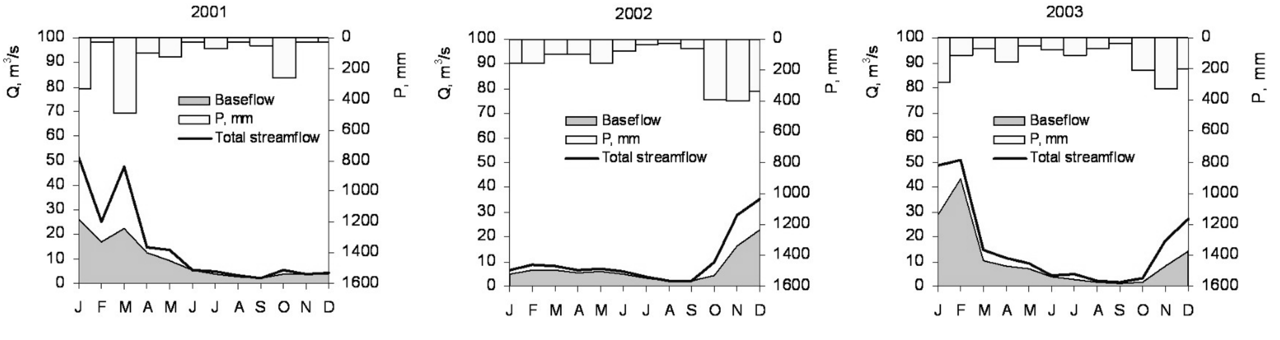

Fig. 4 Hydrograph separation for the observed hydrological years in the Anllóns River basin.

Table 1 Precipitation and potential evapotranspiration (mm) in the Anllóns River basin.

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
	Díaz-Fierros,1996	162	168	152	113	98	58	33	58	87	116	178	172	1395
P	2001	333	90	487	94	121	26	69	28	54	262	25	27	1554
	2002	152	158	97	93	157	79	31	25	57	395	400	340	1984
	2003	289	108	70	159	50	78	112	68	31	206	330	196	1697
ETP	2001	36	32	48	42	54	72	78	83	65	52	41	42	645
	2002	42	37	40	38	50	65	72	75	75	63	44	42	643
	2003	26	29	42	46	53	75	78	93	74	48	44	34	642

Table 2 Total runoff and surface runoff observed in the Anllóns River basin.

	Total runoff (mm)			Surface runoff (mm)			Surface runoff (% precipitation)		
	2001	2002	2003	2001	2002	2003	2001	2002	2003
Jan	307	38	288	152	8	119	46	6	41
Feb	139	49	282	44	14	41	49	9	38
Mar	284	47	86	150	10	26	31	10	37
Apr	84	37	65	13	6	18	13	6	11
May	80	41	55	24	7	12	20	5	24
Jun	31	35	26	0	6	6	0	8	8
Jul	29	21	30	6	2	14	9	8	12
Aug	19	15	12	3	1	3	9	3	4
Sep	14	13	8	2	1	1	3	1	3
Oct	33	58	19	9	20	9	3	5	4
Nov	23	166	105	1	43	59	4	11	18
Dec	25	210	160	3	61	75	10	18	38
Annual	1067	730	1137	405	180	382	25	7	20

The Anllóns River basin is located in the wet region of Spain and its mean annual precipitation is 1395 mm (Díaz-Fierros, 1996). The annual precipitation value observed for the study period was 370 mm greater than the historical average. Figure 5 shows the general form of the water balance in the Anllóns watershed for the observed years.

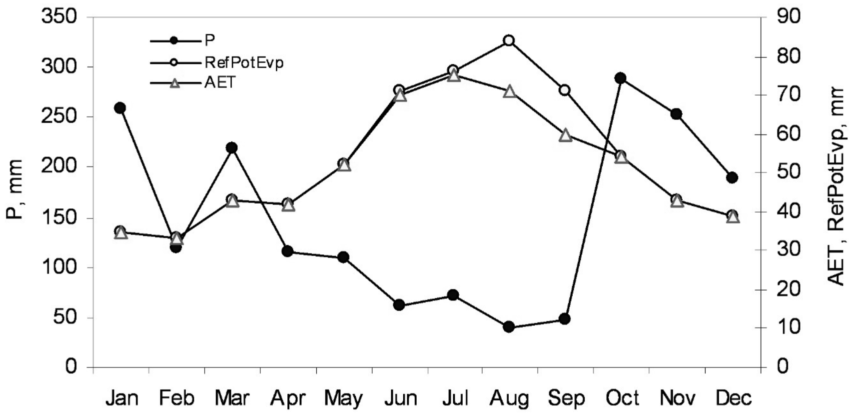

Fig. 5 Water balance for the three observed years in the Anllóns River basin.

From October until March the precipitation is greater than the evapotranspiration and there is a moisture surplus in the soil. Since the demand is smaller than the input, the groundwater resources and the surface streams are fed with this excess of water. However, in the dry months (from April to August) the evapotranspiration is greater than the precipitation, so this is a period of soil moisture deficit. Later on, in the month of October, when the rainy season starts, the rain feeds the soil moisture, and the new soil moisture surplus will feed the groundwater and the surface streams again.

The first year observed (2001) had a precipitation of 1554 mm and an observed runoff of 1067 mm (68% of the precipitation). The direct runoff in this period was 405 mm, i.e. a third of the total runoff. The temperatures oscillated between 9ºC in February and 18ºC in August, and the evapotranspiration was 605 mm. The highest value of evapotranspiration was registered in August, with the higher temperatures. The first three months of 2001 were very rainy (909 mm), almost twice as much as the average value for these three months determined from the historical data (Díaz-Fierros, 1996). In the following months, the behaviour of the precipitation was very different, there was a clear decrease, and the remaining precipitation (706 mm) was distributed over the rest of the year, 392 mm from April to September and only 313 mm from October to December. Comparing these values with the historical data, we can observe a clear deficit of precipitation for the autumnal months.

In 2002, the precipitation distribution was clearly different to that in 2001. The precipitation for January, February and March was 408 mm, i.e. 21% of the total precipitation for the year 2002 and the maximum value occurred in the last three months of the year (1135 mm) with 57% of the total rain. The precipitation recorded in the spring and summer was 441 mm. The year 2002 was the rainiest in the observed period but the shortage of precipitation for most 2001 and 2002 played an important role in the runoff generation. The maximum temperature value was recorded in August (17ºC) and the minimum in February (10ºC). The total evapotranspiration for 2002 was 643 mm, very similar to 2001.

The last year observed (2003) had a very similar behaviour, but the runoff generation was clearly different. In 2003, the annual precipitation was 1697 mm and October, November and December, were the rainiest months with 732 mm (41% of the total precipitation). The temperature values oscillated between the 8ºC in January and the 20ºC in August.

The water balance results show a good adjustment for the first observed year, with a coefficient of determination of 0.86. The second and third observed years present a slightly inferior correlation between the observed flows and the calculated ones, with values for the coefficients of determination of 0.73 and 0.72.

The first months of 2001 were especially wet, but the period between March and December had an important decrease of precipitation, which presents a clear effect in the results obtained in the water balance for the next year. The second year (2002) was clearly influenced by the shortage of precipitation recorded in the last months of 2001. This caused an outflow of the soil water and then a corresponding increase of the water retention by the soil in the following months, with significant precipitation that caused a clear decrease of the observed runoff in the watershed. This reasoning explains the worst agreement in the results for the second observed year. The results for the water balance are shown in Fig. 6.

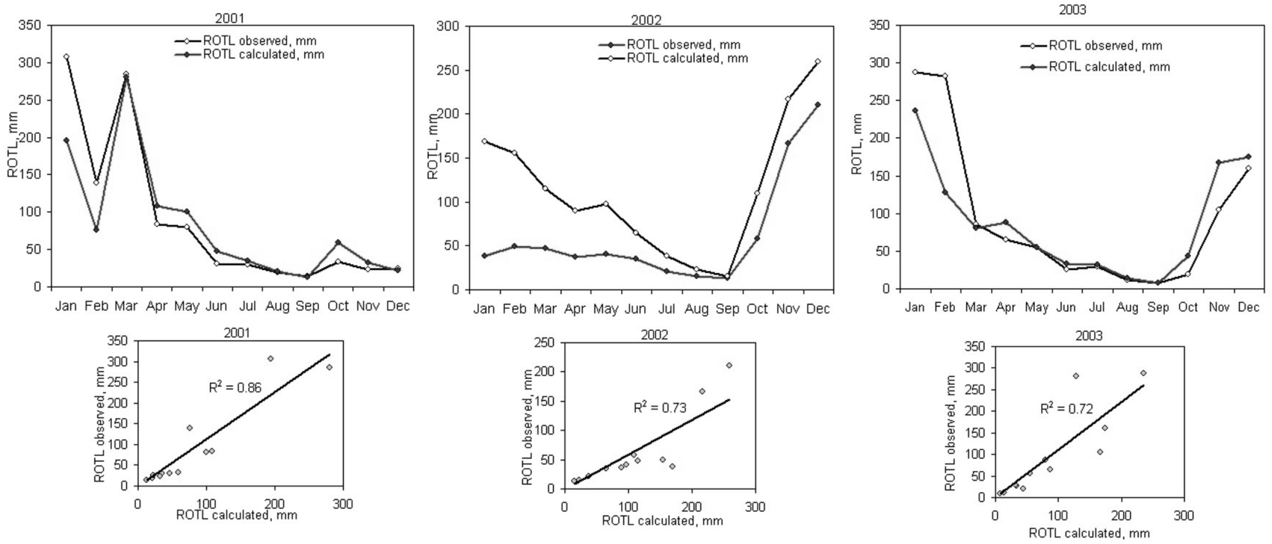

Fig. 6 Comparison between the ROTL observed and the ROTL calculated using the water balance model for each one of the years observed.

Figure 7 shows the results obtained with the water balance for the whole period and compares the total runoff observed in the catchment and the runoff calculated for the whole observed period. The scatter plot shows a relatively good agreement of the results obtained for the whole period of observations with a coefficient of determination of 0.89.

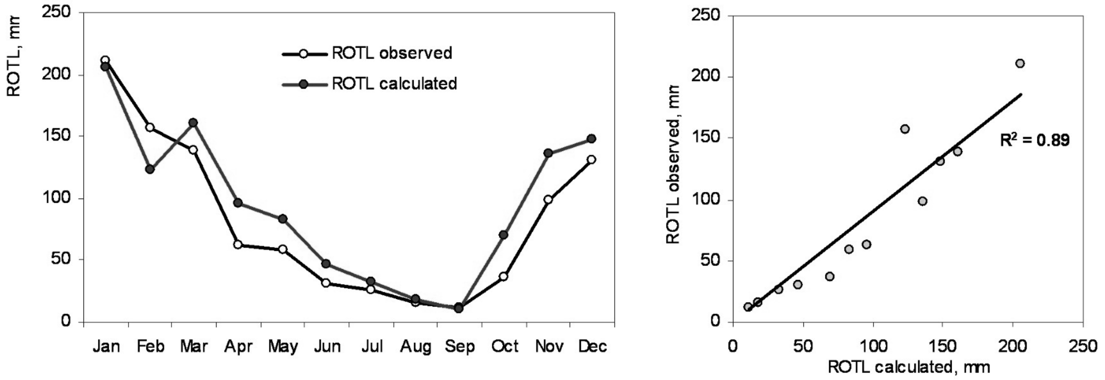

Fig. 7 Comparison between the ROTL (runoff including direct runoff) observed in the Anllóns River basin and the ROTL calculated using the water balance model for the three recorded years.

CONCLUSIONS

One of the main problems of water balance calculations in basins is the extrapolation of point-measured data to superficial characteristics. Basin precipitation was calculated as the weighted average based on data from the recording gauges. There are two main sources of error in the calculation of a basin water balance. The first relates to measurement or calculation of basic components of the water balance equation, the second source of errors results from variability of basin conditions of precipitation and evapotranspiration. The runoff is generally the most accurately measured water balance component.

The results showed the important influence of the capacity for retention of water by the basin. If we increase the water retention capacity of the basin, thus decreasing the water available for runoff (only 5%), we see that the adjustment of the results in the year 2002 is improved considerably; the coefficient of determination increases to 0.82.

In the analysis of the results it is necessary to highlight that the crop coefficient has remained constant and equal to one during all the seasons, so an improvement of the results may be possible by carrying out an appropriate adjustment of the value of this coefficient.

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