# EVALUATION OF SURFACE RUNOFF PREDICTION BY ANNAGNPS MODEL IN A LARGE MEDITERRANEAN WATERSHED COVERED BY OLIVE GROVES


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## SURFACE RUNOFF EVALUATION IN LARGE MEDITERRANEAN WATERSHED BY ANNAGNPS MODEL

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### Abstract

*The distributed parameter and continuous simulation AnnAGNPS model was implemented in the watershed Anzur (Spain) covered by olive groves, to assess its prediction capability of surface runoff at the large watershed scale in semi-arid conditions. A 5-year database reporting hydrological, geomorphological and land use characteristics of the watershed allowed model implementation. Almost 180 surface runoff events were modelled by AnnAGNPS and compared to the corresponding observations through statistical indexes and grouping the runoff events in order to evaluate the model at different temporal scales (event, monthly, and seasonal). AnnAGNPS evaluation showed that, in general, runoff was estimated by the default model with low accuracy at all the investigated time scales, likely as a result of a simple representation of spatial variability. Calibration (by reducing initial Curve Numbers (CN) of the olive groves) provided more accurate and satisfactory predictions of event, monthly and seasonal runoff volumes with a low effort in the parameterisation approach. The best model performance was achieved at the event scale. The runoff prediction reliability may be attributable to the AnnAGNPS inaccuracy in adjusting CN values during the continuous simulation of the soil moisture conditions, since estimations of daily evapotranspiration values are quite realistic.*

**Keywords:** *prediction model, AnnAGNPS, large watershed, runoff, olive crop, Mediterranean climate.*

### Introduction

One of the main environmental threats considered by experts and policymakers over the last few decades has been the impact of agriculture on the use of water (Foley *et al*., 2011; Abu Hammad and Tumeizi, 2012) and other environmental degradation processes directly associated such as soil erosion, particularly in fragile ecosystems (Bisaro *et al*., 2014; Gao *et al*., 2014), not only in the context of an increasing global population (Prokop and Poreba, 2012; Zhao *et al*., 2013; Leh *et al*., 2013) but also of the incertitude derived from climate change (Liu *et al*., 2014). High erosion rates are expected in agricultural regions where vines, almond and olive trees grow, due to the environmental restrictions of the climate, topography and unsuitable management practices (De Santiesteban *et al*., 2006). For example, over 95% of the world's olive oil is produced in the

Mediterranean Basin (FAOSTAT, 2012), where a high susceptibility to water and soil degradation is associated with its semi-arid regime, its hilly topography and difficult conditions of land use and management (Borrelli *et al*., 2013).

The study of soils naturally involves an interdisciplinary approach as a consequence of soils forming at the intersection of the atmosphere, biosphere, hydrosphere, and lithosphere (Brevik *et al.,* 2015). Water runoff and soil loss generation mechanisms have been studied in detail in semi-arid areas (Haile and Fetene, 2012) at the plot scale, where the understanding of the hydrological processes is still rather limited (García-Orenes *et al*., 2009; Cerdà *et al*., 2010). Subsequently, the results of these studies have varied and in some cases been contradictory, due to the influence a wide range of environmental scenarios and initial system conditions. Recently such studies have been further extended to the watershed scale, even though limited to small basins (e.g. Taguas *et al*., 2009; Gómez *et al*., 2014; Taguas and Gómez, 2015; Chahor *et al.,* 2014; Gastesi *et al*., 2006 Gabarrón-Galeote *et al*., 2013).

However there is scarce scientific information about the hydrological response of large olive grove watersheds despite the fact that olives are one of the main crops in Southern Europe. This is the case of Andalusia (Spain), where olive groves dominate its landscape, in a monoculture that covers approximately 15000 square kilometres, 17% of the total surface area of the region, and produces a third of the world's olive oil. In recent decades olive cultivation in Andalusia has been associated with severe risk of water and soil degradation (Gómez-Limón *et al*., 2011). In this context, a better understanding of the hydrological processes which are responsible for soil and water degradation would help territory planners and other stakeholders to arrange suitable countermeasures and optimize efficiency and cost of planned interventions (Brevik *et al.*, 2015).

Hydrological models can be utilised to limit land degradation problems linked to surface runoff and soil erosion (Borrelli *et al*., 2013). They are able to simulate watershed processes in a cost-effective and time-efficient way, helping land planners to identify the best practices for watershed management. In the last three decades several computer prediction models that vary in complexity and data input requirements have been developed to provide a better understanding of the hydrological system, sediment transport and associated pollutant loading of a basin. Nowadays the prediction of surface runoff typically involves the use of empirical models such as AnnAGNPS (Geter and Theurer, 1998; Bingner and Theurer, 2001), WEPP (Flanagan and Nearing, 1995), and SWAT (Arnold *et al*., 1998). Thus, the choice of the most appropriate model (in terms of time scale, application environment, complexity and ease of utilization) will depend on the intended use and the characteristics of the watershed under investigation (Borah and Bera, 2003).

AnnAGNPS (Annualized Agricultural Non Point Source) is a continuous simulation and distributed-parameter model utilised to evaluate surface runoff, soil erosion and pollutant transport in watersheds of extension ranging from 0.32 to 2500 $km^2$ under different environmental conditions (Bingner and Theurer, 2005; Shamshad *et al*., 2008). The results of the AnnAGNPS evaluations in monitored watersheds have generally been satisfying (Chahor *et al.,* 2014). For instance, AnnAGNPS has been used to model water balance and sediment load in small watersheds with olive groves (Taguas *et al*., 2009; 2012). AnnAGNPS was implemented in the semi-arid conditions of a Sicilian agricultural watershed, generally showing a good prediction capability for runoff and sediment yield events, but, at the same time, a lower accuracy in peak flow simulation (Licciardello *et al*., 2007). In watershed of Navarra Chahor *et al.* (2014) showed a satisfactory prediction capability of AnnAGNPS in surface runoff at monthly, seasonal and annual scales both in calibration and in validation processes. Additionally to Taguas et al. (2015), we are unaware of experiences of modelling large olive orchard watersheds (i.e. with extensions beyond the limits suggested by the developers), particularly on the temporal scale of event. Thus, more research, aimed at verifying the applicability of this model in these specific environmental scenarios, is needed in order to consolidate its use and better define the boundary conditions of its applicability.

This paper aims at evaluating the reliability, for different time scales, of the AnnAGNPS model for surface runoff prediction in a large watershed (Anzur river, Andalusia, Spain) whose main crop is olives. A complete modelling of the hydrological and erosive phenomena requires the use of different time scales due to their complexity. More specifically, we used a 5-year hydrological database of rainfall-runoff patterns collected in the watershed to assess event (also substantial storm), monthly and seasonal surface runoff. Model parameterization was described and presented to improve AnnAGNPS guidelines for olive grove land use.

## MATERIAL AND METHODS

### Geomorphologic and climatic characterization of the experimental basin

*Geomorphologic data*

The Anzur river flows through the Spanish region of Andalusia (Figure 1), being a tributary of the river Genil which itself is a tributary of the river Guadalquivir. The watershed covers 307.6 $km^2$ between 247 m and 1475 m above mean sea level with an average land slope of about 20%. The main stream is about 58.3 km from the source to the outlet (37°53′N, 04°46′W), with an average slope of about 12%.

According to the international standard taxonomic soil classification system of the International Union of Soil Sciences (IUSS), the main soils of the Anzur river have been classified as Calcic Cambisols associated with Calcaric Regosols (80%); other soils such as Chromic Luvisols, Calcaric Fluvisols and Rendzinas represent the remaining basin area.

The main land use is cropland (82.6% of the total basin area), mainly located on fertile plains and soils with high water retention capacity and easily arable. The main crop is olives which represents 77% of the area; the remaining area is rangelands (17%) and the urban areas (0.4%).

*Climatic data*

The study catchment presents a typically Mediterranean climate (type "BSk", according to Köppen's classification, 1936). The topographic diversity of the Guadalquivir river basin as well as the morphology of the mountainous zones located in the Northern and Southern Andalusia imply substantial differences between the lowest and the highest area in the catchment. In addition, the magnitude of the mean annual rainfall decreases from North-East to South-East following altitude patterns. Mean annual rainfall is close to 500 mm, while mean minimum and maximum temperatures are 10 and 30 °. The rainiest periods fall in November-December and February-March. In contrast, from June to September is a long, dry period with the lowest values of precipitation.

### Implementation and evaluation of the AnnAGNPS model in the Anzur watershed

*Model implementation procedure*

A Digital Elevation Model (DEM; Consejería de Medio Ambiente-Regional Environmental Council, 2014a), of the watershed with a 10 m-resolution was used to generate the topographical attributes. It was taken as the basis for the watershed discretization into homogeneous drainage areas ('cells') and the segmentation of the hydrographic network into channels ('reaches'), performed using the GIS interface incorporated into AnnAGNPS. The morphologic parameters (i.e. cell slope length and steepness) were directly calculated by TOPAZ (Topographic PArameteriZation), a subroutine which identifies and measures topographic features, defines surface drainage, subdivides watersheds along drainage divides, quantifies the drainage network and calculates representative subcatchment parameters from a DEM (Garbrecht and Martz, 1997). The dominant land use and soil types were associated with each drainage area by means of the model GIS interface.

In order to optimize the reproduction of the morphology of this large watershed and reduce calculation time and complexity, the default values of 8 ha and 100 m suggested by AnnAGNPS (2001) for CSA (Critical Source Area) and MSCL (Minimum Source Channel Length) parameters respectively were properly increased to 330 ha and 300 m (the highest values allowed by the AnnAGNPS software package); the Anzur watershed discretization resulted then in 143 cells (up to 958 ha) and 58 reaches.

Soil parameters were based on the information derived from CEBAS-CSIC (1971) and the Soil Map of Andalusia, prepared by REDIAM, Consejería de Medio Ambiente - Regional Environmental Council (2014b). Since the land use is dominated by olive groves, and in order to simplify the parameterisation, a unique and representative soil type, silty loam, corresponding to Calcaric Regosol with an uniform soil profile (up to a depth of 1 m), was assumed. For the same reason, only two land uses (cropland, i.e. olive groves, and urban areas, covering together 95% of the watershed surface) were taken into consideration (Table 2). The values for hydrological soil parameters required by AnnAGNPS (e.g. wilting point, field capacity and saturated hydraulic conductivity, $K_{sat}$) were calculated from soil texture data using Rawls' methodology (1991), while the related spatial data were prepared by using the Map of Soil Land Uses of Andalusia, prepared by REDIAM in 2012.

Daily rainfall data were derived from records provided by the rain gauges and applied to each drainage area by using Thiessen's polygon method (Thiessen, 1911). Rainfall and temperature data were collected during a 5-year observation period (January 2000 - March 2005) at the following measuring stations (managed by the Spanish Network of Meteorological Stations) available for the Anzur catchment: Rute-La Muralla (37° 24' N; 04°22' W); Rute Zambra (37°23' N; 04°22' W); and Puente Genil (37°21'N; 04°44'W). The other meteorological parameters needed by the climate sub-routine of AnnAGNPS (such as evapotranspiration and dew point temperatures) were obtained from the Santaella meteorological station (37°31'N; 4°51'W) located at 40 km from the basin perimeter. Daily flow data were obtained at Los Piedros gauging station (37º22'N; 4º36'W) for the same observation period (January 2000-March 2005). Meteorological and rainfall input data were properly ordered by the AnnGNPS climate subroutines (AnnAGNPS, 2001).

Baseflow is not evaluated by AnnAGNPS; consequently, following Licciardello *et al.* (2007), the surface runoff - baseflow separation was performed by the traditional manual linear method applied to observed stream flow data. Other studies (e.g. Arnold *et al.,* 1995; Arnold and Allen, 1999) show the proper matching between manual separated data and automated digital filter separated data; in our study the recorded differences in the surface runoff obtained by the two methods are lower than 11% at yearly scale.

To allow the model to adjust the initial soil water storage, the first two years (2000-2001) were appended to the beginning of the precipitation and meteorological data set (January 2000).

The initial values of Curve Numbers (CNs) of urban areas were derived following the indications reported in the standard procedure set by the USDA Soil Conservation Service (USDA-SCS, 1972; Table 1). Since similar data for olive groves are not included in the section "Management Information" of the AnnAGNPS database, the values of CNs reported for "orchard" were applied to the model.

*Model evaluation procedure*

The hydrological submodel of AnnAGNPS was initially run with default parameters and then calibrated taking into account the most sensitive inputs. The split-sample technique (Klemes, 1986) was used to evaluate the runoff volume predicted by the model in calibration and validation periods. Following the usual approach to continuous model evaluation (Neitsch *et al*., 2002), model accuracy in predicting runoff volume was assessed at the seasonal (four periods per year, i.e. three months for each season), monthly and event scales in the period January 2000 - March 2005. Evaluation at annual scale was not performed due the low number of observations (five years) available in the hydrological database. In order to take into account the long concentration time of the modelled watershed, the output values of runoff simulated by AnnGNPS, subsequent to a considered rainfall event were grouped into a single event.

Two separate approaches were adopted for model performance evaluation. A qualitative procedure consisted of visually comparing observed and simulated values. For a quantitative evaluation, a range of statistics (i.e. maximum, minimum, mean and standard deviation of both observed and simulated values) as well as other model evaluation criteria were used (Table 3).

Given that the coefficient of determination ($r^2$) is an insufficient and often misleading evaluation criterion (Licciardello *et al*., 2007; Zema *et al*., 2012), the Nash and Sutcliffe (1970) coefficient of efficiency (E) and its modified form ($E_1$, Willmott, 1982) were also used to assess model efficiency. In particular, E is more sensitive to extreme values, while $E_1$ is better suited to significant over- or underprediction by reducing the effect of squared terms (Legates and McCabe, 1999; Krause *et al*., 2005). As suggested by the same authors, E and $E_1$ were integrated with the Root Mean Square Error (RMSE) in the unit of the variable. Finally, the Coefficient of Residual Mass (CRM) was used to indicate a prevalent model over- or underestimation of the observed values (Loague and Green, 1991) (Table 3).

The values considered to be optimal for these criteria were 1 for $r^2$, E and $E_1$ and 0 for RMSE and CRM. According to common practice, simulation results are considered good for values of E greater than or equal to 0.70, satisfactory for values of E between 0.70 and 0.35 and unsatisfactory for values below 0.35 (Van Liew and Garbrecht, 2003).

The calibration process was carried out by modifying the initial values of CNs, trying to approximate the mean and standard deviation (SD) values of the observed runoff. Initial CNs were chosen as the calibration parameter, since CN represents a key factor in obtaining accurate prediction of runoff and sediment yield (Yuan *et al*., 2001; Shrestha *et al*., 2006) and the most important input parameter to which the runoff is sensitive (Yuan *et al*., 2001; Baginska *et al*., 2003), besides soil (field capacity, wilting point and saturated hydraulic conductivity) and climate parameters (precipitation, temperature and interception).

In a first calibration attempt, initial default CN (65) was replaced by a CN value of 80 taken from Romero *et al*. (2007), applied in Spanish olive groves with same edaphic and climatic environment, but obtained at the plot scale. Romero *et al*. (2007) provided the first values of CN determined for olive grove land use. Afterwards, the initial default CN (soil type B) was modified until the maximum model prediction capability was obtained (evaluated in terms of the E and $E_1$ indexes, see Table 3). Finally, erosion being one of the most negative effects of runoff (particularly under Mediterranean semi-arid conditions), a separate analysis of the runoff prediction capability by AnnAGNPS was performed on erosive rainfalls (i.e. rainfalls over 13 mm, according to Wischmeyer and Smith, 1978) from the experimental database.

## RESULTS AND DISCUSSION

*Hydrological observations*

During the 5-year observation period 178 rainfall events were observed. After spatial scaling using Thiessen's method, the mean event height was 1.5 mm with a very high variability; the maximum value recorded was 66.4 mm. On 75% of days no rainfall was recorded, while 2.4% of the events were higher than 15 mm. Fifty-eight rainfall events greater than 13 mm were sampled giving a maximum runoff value of 5.7 mm with a mean of 1.2 mm and standard deviation of 1.5 mm. On the monthly scale the recorded rainfalls were in the range 0-192 mm. Of the 65 monthly observations 40% were below 20 mm and only 13.8% were above 100 mm. The highest seasonal rainfall was recorded in winter 2001 (460 mm). In the dry seasons precipitation was very low with a maximum value of 23.3 mm recorded in summer 2002. On the annual scale rainfall was in the range 116-683 mm (mainly concentrated from October to March), with a mean and standard deviation of 511 and 209 mm, respectively.
The maximum event runoff volume and discharge were 2.7 mm and 9.9 $m^3 s^{-1}$ respectively; the mean runoff value was 0.1 mm. About 97% of the observed runoff was lower than 1 mm. The mean monthly runoff was 5.8 mm with a maximum value of 23.7 mm recorded in January 2001. In general, monthly runoff followed the same patterns as rainfalls (except for the year 2002-03 when the runoff trend was different from rainfalls), recording the highest cumulative runoff in the years with the highest precipitations (Figure 2). On the monthly scale, the winter season had the most rainfall and erosion; the lack of cover and the possible high soil moisture that derived from the autumn rainfall may cause serious soil loss which should be taken into account in planning the soil protection and management operations (Taguas *et al.*, 2009). As for rainfall, seasonal runoff was concentrated in the wet season (mainly in winter) with maximum value of 65.2 mm. On the annual scale, the cumulated runoff had a minimum of 10.1 mm (2001-2002) and a maximum of 99.4 mm (2000-01) with a mean value of 63.2 mm.
The highest and lowest value of runoff coefficients were observed for event and monthly scales respectively. The regression analysis between rainfall and runoff volumes shows a low correlation coefficient ($r^2 = 0.2$, $p < 0.05$) on the event scale. On the monthly scale, a higher determination coefficient ($r^2 = 0.4$, $p < 0.05$) than the values obtained on the event scale (despite a lower hydrological value number tending to increase the determination coefficient) provided an appreciable linear correlation between runoff and rainfall. Finally, the highest correlation rainfall-runoff was detected on the annual scale ($r^2 = 0.6$, $p < 0.05$).

*Evaluation of runoff prediction capability*

*Default model (before calibration procedure)*

Table 3 shows the statistics and the other quantitative indexes used for evaluation of runoff prediction capability by AnnAGNPS on the different time scales by default and calibrated model.
The runoff volumes observed at the outlet of the Anzur river were in general strongly overpredicted by the default model, as shown by the negative values of CRM. Low coefficients of regression were achieved, showing weak correlations between observed and predicted values (Figure 3a and Table 4); only the seasonal aggregation of runoff volumes gave a satisfactory coefficient of regression ($r^2 = 0.80$, $p < 0.001$).
Mean values of predicted runoff volumes were much higher than the corresponding event, seasonal, and monthly observations; not even the maximum values of the predicted runoff volumes (whose reliable predictions at the event scale are of crucial importance in the case of river control work design) were reliable, with errors of over 1000%.

As a consequence, the model efficiency was very low on all the analysed time scales, having coefficients of efficiency much lower than zero. However, the highest value was achieved on the seasonal scale (E = -0.18; $E_1$ = 0.17). The difficulty in runoff modelling seems to be more evident in reproducing the most intense events, shown by the lowest values (Table 4) achieved for the coefficient of efficiency (E), which is more sensitive than the modified form ($E_1$) to extreme values (Krause *et al*., 2005).

Taking into account a more precise spatial variability of the topography, by increasing the basin discretization up to the values of 8 ha for critical area (CSA) for the cell formation and 100 m for minimum length for the channel formation (MSCL), as suggested by the AnnAGNPS manual (2001), the model prediction accuracy did not improve compared to the simplified implementation; the large watershed surface covered by uniform cropland (in our case olive groves) and the low variability of soil type presumably induced a low sensitivity of AnnAGNPS to the higher discretization. Moreover, neither did increasing the soil depth from 0.2 to 5 metres - thus modifying the soil storage capacity - determine significant modifications of the model to simulate runoff; this was also observed in AnnAGNPS simulations in other watersheds made by Licciardello *et al.* (2007) and Zema *et al.* (2012) (data not shown), presumably due to the fact that the surplus of water stored into the soil profile turns into base flow, which is not modelled by AnnAGNPS.

*Calibrated model*

*Calibration period (2000-2002)*

A first attempt of calibration, using the initial CNs taken from Romero *et al.* (2007), did not produce a notable improvement of the model prediction capability, achieving for all the analyzed time scales remarkable differences between observed and simulated runoff volumes as well as a coefficient of efficiency (E) of -17.1 (data not shown). The impact of differences on spatial scale and the different algorithm used in AnnAGNPS, compared to the original CN-model, may explain the high deviations associated with the values of Romero's study.

In trying to maximise the model efficiency, the initial CN for cropland (olive groves) had to be noticeably reduced; the value which gave the best model prediction capability was 35 (Table 1). This calibrated CN value for cropland is extremely low and well below what it should be for this soil type: this might indicate that the model is compensating for its poor description of key processes with abnormal CN values. Also for urban land use (non crop) CN was decreased, but without any clear effect on simulation. This can be due to the small areas within the watershed, which does not produce large amounts of runoff, as observed also in the work of Chahor *et al.* (2014). The generation of unrealistic CN values during AnnAGNPS simulations has also been remarked in various experimental applications in different climatic conditions (Licciardello *et al.*, 2007; Polyakov *et al.*, 2007; Sarangi *et al.*, 2007; Zema *et al.*, 2012). However, model efficiency increases were not closely related to the corresponding decreases of the CN. This final attempt of calibration gave an improvement of the runoff prediction capability. After calibration the overprediction seen for the default model became a slight underprediction, as shown by the positive CRM coefficient for the calibrated model. Calibration generally gave runoff predictions closer to the corresponding observations on all the investigated time scales, even though the relative differences remained noticeable (Table 4 and Figures 4 and 5).

In general, the average values of the observed and simulated runoff volumes differed by about 60%. Calibration allowed the improvement of the simulations of the maximum runoff volumes, with differences between simulated and observed values not higher than 58% (up to 180% before calibration) for all the investigated time scales (Table 4).

On the event scale the correlation between observed and predicted values notably improved after calibration ($r^2$ = 0.61, $p < 0.001$ against 0.30, $p < 0.001$ for the default model) (Figure 2b and Table

4). On the monthly scale $r^2$ increased from 0.37 ($p < 0.001$) for the default model to 0.71 ($p < 0.001$). However, the patterns of the simulated runoff did not follow the observed values (data not shown). The highest coefficient of determination was achieved on the seasonal scale ($r^2 = 0.93$, $p < 0.001$ against a value of 0.80, $p > 0.001$ for the default model).

Calibration also notably increased model efficiencies (E and $E_1$), in most cases very poor for the default model. More specifically, E and $E_1$, thanks to calibration, became satisfactory for all the analysed time scales, with the highest values of 0.48 for E on the seasonal scale and of 0.49 for $E_1$ on the event scale (Table 4); also Bisantino *et al.* (2013) pointed out the good performance of the AnnAGNPS model in reproducing runoff volumes at the event scale both in calibration and in validation model in a watershed of Apulia (Southern Italy). In calibrating AnnAGNPS in microcatchments of Southern Spain, Taguas *et al.* (2009) reported better results on a monthly scale than on an event scale as a result of the sensitivity of the model to an appropriate selection of CN values for individual events. In an agricultural watershed of Sicily (Southern Italy) Licciardello *et al.* (2007) found a satisfactory capability in simulating surface runoff at annual scale, and good model performance was achieved at monthly and event scales after a reduction of the initial CNs; this indicates that the SCS curve number method was suitable for runoff predictions in those experimental conditions. Within two agricultural watersheds in the Navarre region of Spain Gastesi *et al.* (2006) noticed an error of -7% comparing 10-year observed and simulated runoff totals. In a watershed located in the same region Chahor *et al.* (2014) showed that the model satisfactory simulated surface runoff at monthly, seasonal and annual scales both in calibration and in validation processes.

Model performance did not improve by applying seasonal values of CNs (that is by setting up higher CNs in winter and lower values in summer), model efficiency being lower by 8% than the best values with a single CN for the entire simulation period.

Predictions of the 36 runoff events following rainfalls greater than 13 mm were not satisfactory when compared to the entire database of observed runoff events, the correlation being lower ($r^2 = 0.58$; $p < 0.001$) and the model efficiencies poor ($E = 0.25$ and $E_1 = 0.35$) (Table 4).

*Validation period (2003-2005)*

As mentioned above, the performance of the calibrated model was tested in the validation period. In general, the runoff volumes predicted by AnnAGNPS matched the corresponding observed values better than in the calibration period for both the event and monthly scales, while the accuracy was slightly lower at seasonal scale (Table 4). The underestimation of the runoff volumes was confirmed for all the investigated scales, as already noticed in the calibration phase, shown by the values of CRM (always higher than 0.58) and "a" (i.e. the slope of the regression line, always < 0). In greater detail, the differences between the observed and predicted mean runoff volumes were very similar to what was found in the calibration period (in both phases close to 60%) and the RMSEs were of the same order of magnitude (Table 4). Furthermore, the correlation between observed and predicted values was higher than in the calibration period and always appreciable ($r^2 > 0.7$, $p < 0.001$ at all the investigated time scales). The coefficient of efficiency of Nash and Sutcliffe (E) and its modified form ($E_1$) were higher than 0.40, except for the seasonal scale ($E = 0.36$ and $E_1 = 0.31$) (Table 4).

According to the criterion of Van Liew and Garbrecht (2003), runoff simulation provided by the AnnAGNPS model for the Anzur river can be considered just satisfactory for event, monthly and seasonal scales (E and $E_1$ higher than 0.35) both in the calibration and in validation period (Table 4); conversely, prediction of erosive events cannot be considered to be as satisfactory. The not optimal performance in modelling surface runoff by AnnAGNPS could be attributable to some factors. Firstly, modelling large watersheds can be difficult by AnnAGNPS; as a matter of facts, the area of the experimental watershed is beyond the limit suggested by model developers, whose morphological conditions affect their hydrological response. In other words, in order to take into account the long time of concentration (longer than a day) of the watershed, the modeller was forced to aggregate a number of runoff events, measured in the two or three days following the runoff event. There appears to be an inverse correlation between the watershed size and the success of the simulation; that is, the smaller the watershed the more satisfactory the model prediction seemed to be (Taguas *et al.*, 2009; Parajuli *et al.*, 2009; Chahor *et al.*, 2014). Furthermore, we found scarce information in guidelines for modelling Mediterranean crops, as olive, in the AnnAGNPS manual; this has required to draw the initial CN set from other studies (e.g. Romero *et al*. (2007) or, after calibration, extremely low values, which, as above discussed, could be considered as unrealistic. At present there are no experiences about AnnAGNPS application with abnormal CN values as well as no daily runoff grouping in singles event technique have been found in semiarid conditions.

Finally, as is well known, the reliability of surface runoff simulations by AnnAGNPS is directly linked to the accuracy of water loss predictions after rainfall, mainly infiltration and evapotranspiration. It seems that infiltration modelling in AnnAGNPS, performed by an empirical submodel based on prediction of soil moisture balance through a suitable set of CNs, suffers from some inaccuracy. This consideration is supported by the satisfactory predictions of daily evapotranspiration rates in the modelled watershed provided by AnnAGNPS. As a matter of fact, the comparison between the predicted evapotranspiration values and the corresponding observations, collected at the Santaella IAS-CSIC station (IAS-CSIC, 2012) for the year 2000 (Figure 5), gave good coefficients of determination and efficiency ($r^2 = 0.8$, $p < 0.001$ and $E = 0.6$), mainly for the highest values. This suggests that infiltration, that often represents the most important hydrological loss and could have negatively affected model simulations of surface runoff, was not predicted with as much accuracy as evapo-transpiration.



## CONCLUSIONS

This paper evaluated the applicability of the distributed-parameter and continuous-simulation AnnAGNPS model for simulating the hydrological response of a large watershed mainly covered by extensive olive groves in climatic conditions typical of the Mediterranean environment.

By utilizing a geomorphologic and hydrological database produced over a period of five years, the surface runoff at the watershed outlet was simulated and compared to the corresponding observations for the event, monthly and seasonal scales.

Simulation of the observed runoff events with model default parameters gave inaccurate results. However, thanks to the calibration process (performed by reducing initial CNs of the olive groves), the model allowed an appreciable accuracy in simulating surface runoff for all the examined time scales (particularly for the event scale), as highlighted by the satisfactory values of the statistics coefficients and other model evaluation criteria achieved for model quantitative evaluation.

Under these experimental conditions, acceptable results (depending on the time scale of analysis) can be achieved by a high simplification in modelling large watersheds (e.g. minimum discretization, homogenous soil texture, low number of land uses); this results in an advantage for model users (such as technicians, land use planners, etc.) which have to perform a simple calibration of initial CNs.

Moreover, in this study the calibrated CN values which maximised AnnAGNPS accuracy in predicting surface runoff are different from those experimental values obtained at plot scale in Spanish olive groves with same edaphic and climatic environment. The values achieved in this study at watershed scale could be included in the database of the AnnAGNPS model by the developers.

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## TABLES

Table 1. Values and source of input parameters for implementation of the AnnAGNPS model at the Anzur river, Andalusia, Spain.

| *Input data* | *Parameter/value* | | | *Source* |
|---|---|---|---|---|
| *Topography* | DEM 10 m x 10 m | | | Consejería de Medio Ambiente - Regional Environmental Council (2014) |
| | CSA = 330 ha; MSCL = 300 m (resulting in 143 cells and 58 reaches, which allowed the maximum simplification of watershed discretization) | | | AnnAGNPS (2001) |
| *Soil properties* | Sand (%) | 64 | | CEBAC-CSIC (1971); Soil Map of Andalusia (REDIAM, Consejería de Medio Ambiente- Regional Environmental Council, 2013) |
| | Silt (%) | 18 | | |
| | Clay (%) | 18 | | |
| | Bulk density (BD, kg $m^{-3}$) | 1500 | | |
| | Hydrological group (USDA, 1972) | B | | |
| | Field capacity (m $m^{-1}$) | 0.20 | | Rawls et al. (1991) |
| | Wilting point (m $m^{-1}$) | 0.09 | | |
| | Saturated hydraulic conductivity ($K_{sat}$, mm $h^{-1}$) | 30 | | |
| *Land uses* | Cropland, olive groves (82.7%)<br>Urban areas (16.4%) | | | Map of Soil Land Uses of Andalusia (REDIAM, Consejería de Medio Ambiente - Regional Environmental Council, 2012) |
| *Hydrological observations* | Rainfall and temperature data collected at the meteorological stations Rute-La Muralla, Rute Zambra and Puente Genil. Flow data measured at Los Piedros hydrometric station | | | Spanish Network of Meteorological Stations |
| | Meteorological data (wind velocity, evapotranspiration and dew point temperature) collected at Santaella station | | | IAS-CSIC, 2012 |
| *Initial curve numbers (CN)* | | ***Land use*** | | AnnAGNPS, (2001)<br>Romero et al. (2007) |
| | | *Crop* | *Non-crop* | |
| | *Default model* | 65 | 89 | |
| | *Calibrated model* | 35 | 89 | |

Table 2. Prevalent field management operations and related times in AnnAGNPS simulations of runoff volume at the Anzur river (Andalusia, Spain).

| *Land use* | *Operation* | *Time period* |
|---|---|---|
| Cropland (olive groves) | Tillage 1 | January – February |
| | Fertilization 1 | March |
| | Pruning | February – April |
| | Weeding | April- May |
| | Tillage 2 | April – May |
| | Harrowing | June – July |
| | Fertilization 2 | October – November |
| | Harvesting | November – January |
| Urban | -- | -- |

Table 3. Model evaluation criteria and their range of variability for the AnnAGNPS model evaluation at the Anzur river, Andalusia (Spain).

| Coefficient or measure | Equation | Range of variability |
|---|---|---|
| Coefficient of determination | $r^2 = \left[\frac{\sum_{i=1}^{n}(O_i - \overline{O})(P_i - \overline{P})}{\sqrt{\sum_{i=1}^{n}(O_i - \overline{O})^2}\sqrt{\sum_{i=1}^{n}(P_i - \overline{P})^2}}\right]^2$ | 0 to 1 |
| Coefficient of efficiency (Nash and Sutcliffe, 1970) | $E = 1 - \frac{\sum_{i=1}^{n}(O_i - P_i)^2}{\sum_{i=1}^{n}(O_i - \overline{O})^2}$ | -∞ to 1 |
| Modified coefficient of efficiency (Willmott, 1982) | $E_1 = 1 - \frac{\sum_{i=1}^{n}\lvert O_i - P_i\rvert}{\sum_{i=1}^{n}\lvert O_i - \overline{O}\rvert}$ | -∞ to 1 |
| Root mean square error | $\mathrm{RMSE} = \sqrt{\frac{\sum_{i=1}^{n}(P_i - O_i)^2}{n}}$ | 0 to ∞ |
| Coefficient of residual mass (Loague and Green, 1991) | $\mathrm{CRM} = \frac{\sum_{i=1}^{n}O_i - \sum_{i=1}^{n}P_i}{\sum_{i=1}^{n}O_i}$ | -∞ to ∞ |

n = number of observations.
$O_i$, $P_i$ = observed and predicted values at the time step i.
$\overline{O}$, $\overline{P}$ = mean of observed and predicted values.

Table 4. Statistics and model evaluation criteria concerning the observations and AnnAGNPS simulations of runoff volume at the Anzur river (Andalusia, Spain).

| | Number of observations/ simulations | $r^2$ | *a* | *E* | $E_1$ | *RMSE (mm)* | *CRM* | *Mean (mm)* | *Std. Dev. (mm)* | *Max (mm)* |
|---|---|---|---|---|---|---|---|---|---|---|
| **Calibration test** | | | | | | | | | | |
| Seasonal scale (Winter 2000 to Autumn 2002) | | | | | | | | | | |
| Observed | | -- | -- | -- | -- | -- | -- | 3.69 | 5.73 | 18.46 |
| Default model | 11 | 0.80 | 1.62 | -0.18 | 0.17 | 5.93 | -0.57 | 5.79 | 10.39 | 34.87 |
| Calibrated model | | 0.93 | 0.41 | 0.48 | 0.43 | 3.95 | 0.60 | 1.46 | 2.46 | 7.80 |
| Monthly scale (Jan. 2000 to Dec. 2002) | | | | | | | | | | |
| Observed | | -- | -- | -- | -- | -- | -- | 1.70 | 2.31 | 6.76 |
| Default model | 28 | 0.37 | 1.29 | -1.97 | -0.19 | 3.91 | -0.53 | 2.59 | 4.85 | 2.59 |
| Calibrated model | | 0.71 | 0.43 | 0.38 | 0.41 | 1.79 | 0.63 | 0.62 | 1.19 | 5.41 |
| Event scale (1 Jan. 2000 to 31 Dec. 2002) | | | | | | | | | | |
| Observed | | -- | -- | -- | -- | -- | -- | 0.47 | 1.01 | 5.22 |
| Default model | 102 | 0.30 | 1.20 | -2.39 | -0.08 | 1.86 | -0.53 | 0.71 | 2.21 | 14.78 |
| Calibrated model | | 0.61 | 0.36 | 0.43 | 0.49 | 0.76 | 0.64 | 0.17 | 0.48 | 3.25 |
| Erosive events (Jan. 2000 to Dec. 2002) | | | | | | | | | | |
| Observed | 36 | -- | -- | -- | -- | -- | -- | 1.13 | 1.45 | 5.22 |
| Calibrated model | | 0.58 | 0.37 | 0.24 | 0.35 | 1.25 | 0.65 | 0.39 | 0.70 | 3.25 |
| **Validation test** | | | | | | | | | | |
| Seasonal scale (Winter 2002 to Spring 2005) | | | | | | | | | | |
| Observed | 11 | -- | -- | -- | -- | -- | -- | 4.28 | 4.79 | 15.31 |
| Calibrated model | | 0.78 | 0.39 | 0.36 | 0.31 | 3.94 | 0.62 | 1.64 | 2.14 | 5.31 |
| Monthly scale (Jan. 2003 to May 2005) | | | | | | | | | | |
| Observed | 24 | -- | -- | -- | -- | -- | -- | 1.68 | 2.33 | 9.34 |
| Calibrated model | | 0.73 | 0.49 | 0.47 | 0.44 | 1.65 | 0.58 | 0.70 | 1.33 | 5.12 |
| Event scale (1 Jan. 2002 to 31 May 2005) | | | | | | | | | | |
| Observed | 76 | -- | -- | -- | -- | -- | -- | 0.53 | 1.17 | 5.74 |
| Calibrated model | | 0.72 | 1.30 | 0.62 | 0.57 | 0.72 | 0.58 | 0.22 | 0.77 | 5.09 |
| Erosive events (Jan. 2003 to Dec. 2005) | | | | | | | | | | |
| Observed | 21 | -- | -- | -- | -- | -- | -- | 1.63 | 1.71 | 5.74 |
| Calibrated model | | 0.70 | 0.63 | 0.45 | 0.40 | 1.34 | 0.60 | 0.65 | 1.30 | 5.09 |

**FIGURE CAPTIONS**

Figure 1. Map of the Anzur river (Andalusia, Spain) and the related meteorological stations.

Figure 2. Monthly rainfalls and runoff volumes measured at the Anzur river (Andalusia, Spain).

Figure 3. Comparison of the observed and simulated event runoff volumes in the Anzur river (Andalusia, Spain) for the default (a) and calibrated (b) AnnAGNPS model (values are in logarithmic scale).

Figure 4. Comparison between observed and simulated monthly runoff volumes in calibration (a) and validation (b) (using default and calibrated AnnAGNPS model) at the Anzur river (Andalusia, Spain).

Figure 5. Comparison between observed and simulated seasonal runoff volumes in calibration (a) and validation (b) (using default and calibrated AnnAGNPS model) at the Anzur river (Andalusia, Spain).

Figure 6. Comparison of the observed and simulated evapotranspiration volumes (ET) at the daily scale in the Anzur river (Andalusia, Spain) for the year 2000.

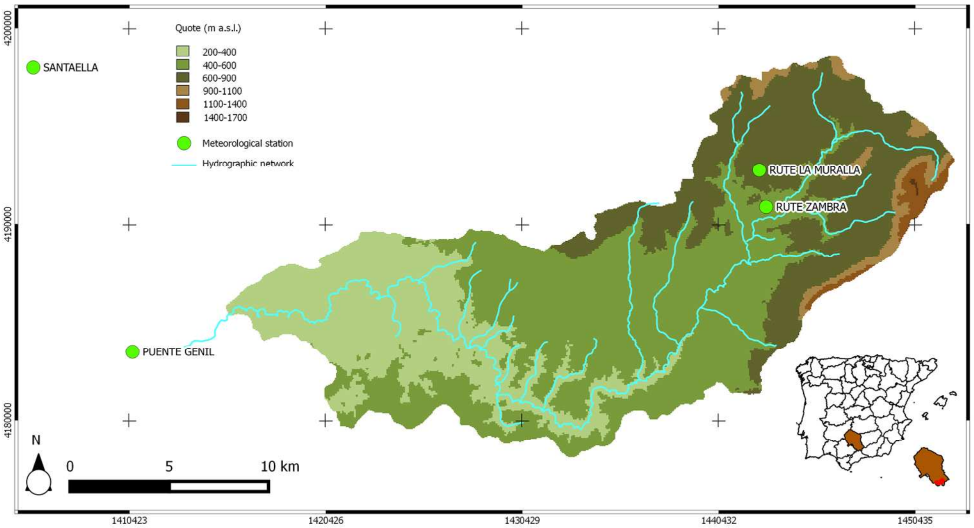


Figure 1. Map of the Anzur river (Andalusia, Spain) and the related meteorological stations.
296x162mm (200 x 200 DPI)

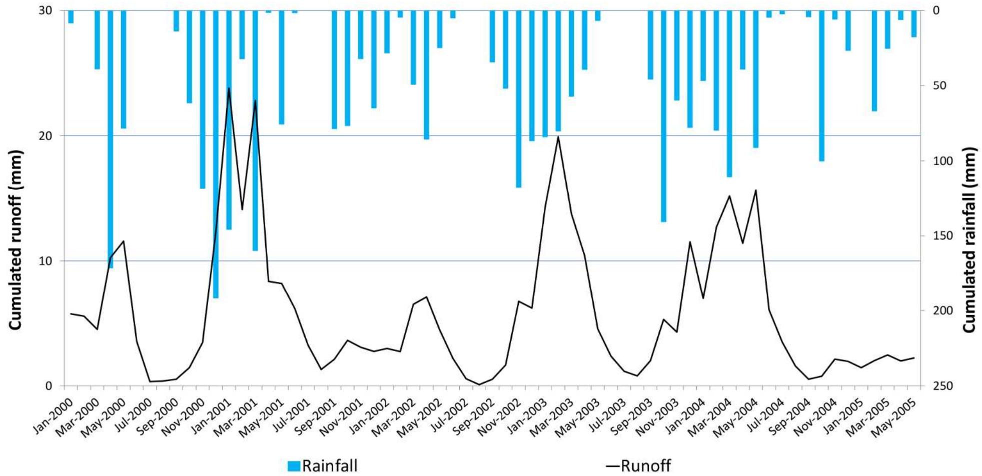


Figure 2. Monthly rainfalls and runoff volumes measured at the Anzur river (Andalusia, Spain).
173x89mm (300 x 300 DPI)

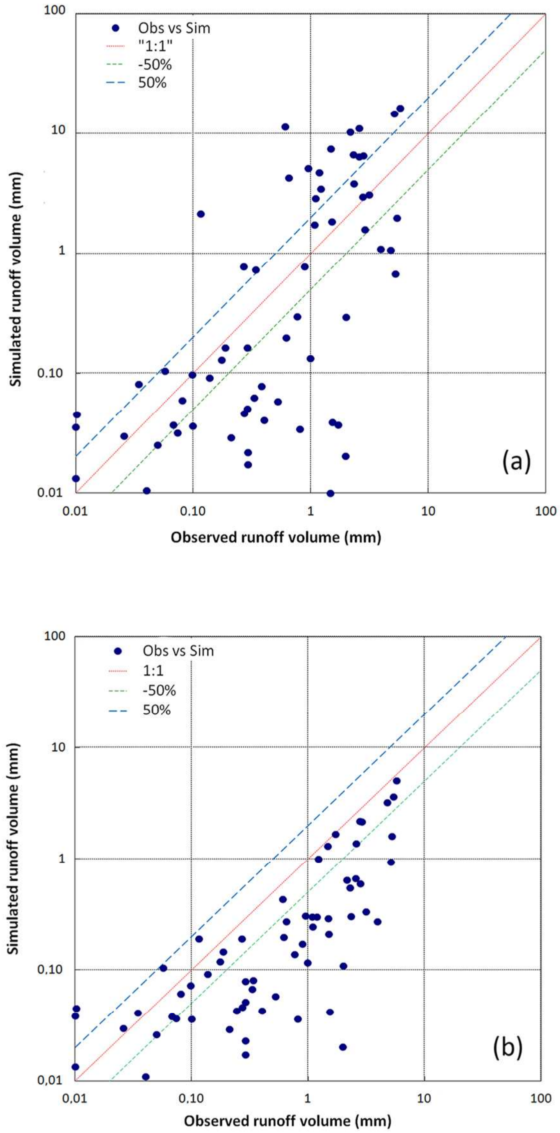


Figure 3. Comparison of the observed and simulated event runoff volumes in the Anzur river (Andalusia, Spain) for the default (a) and calibrated (b) AnnAGNPS model (values are in logarithmic scale).
153x272mm (200 x 200 DPI)

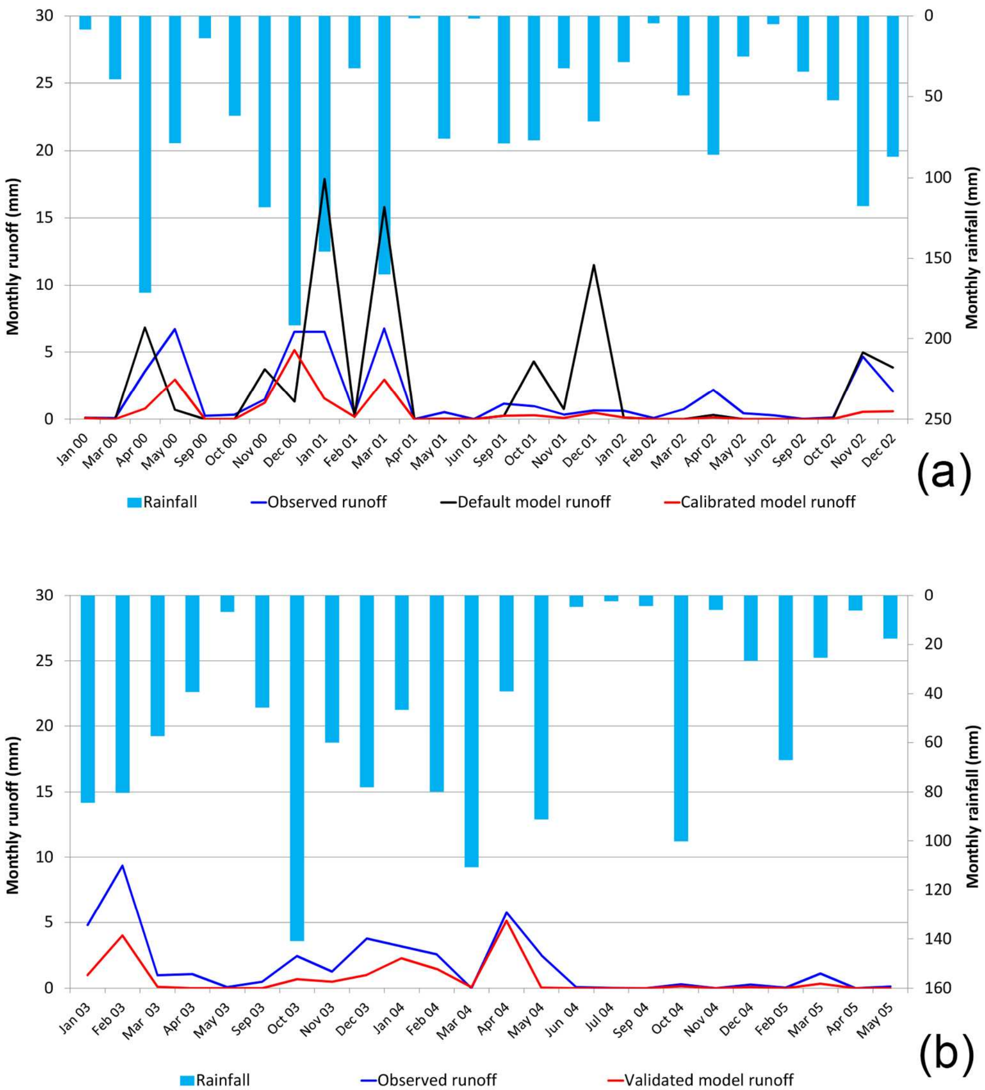


Figure 4. Comparison between observed and simulated monthly runoff volumes in calibration (a) and validation (b) (using default and calibrated AnnAGNPS model) at the Anzur river (Andalusia, Spain).
150x171mm (300 x 300 DPI)

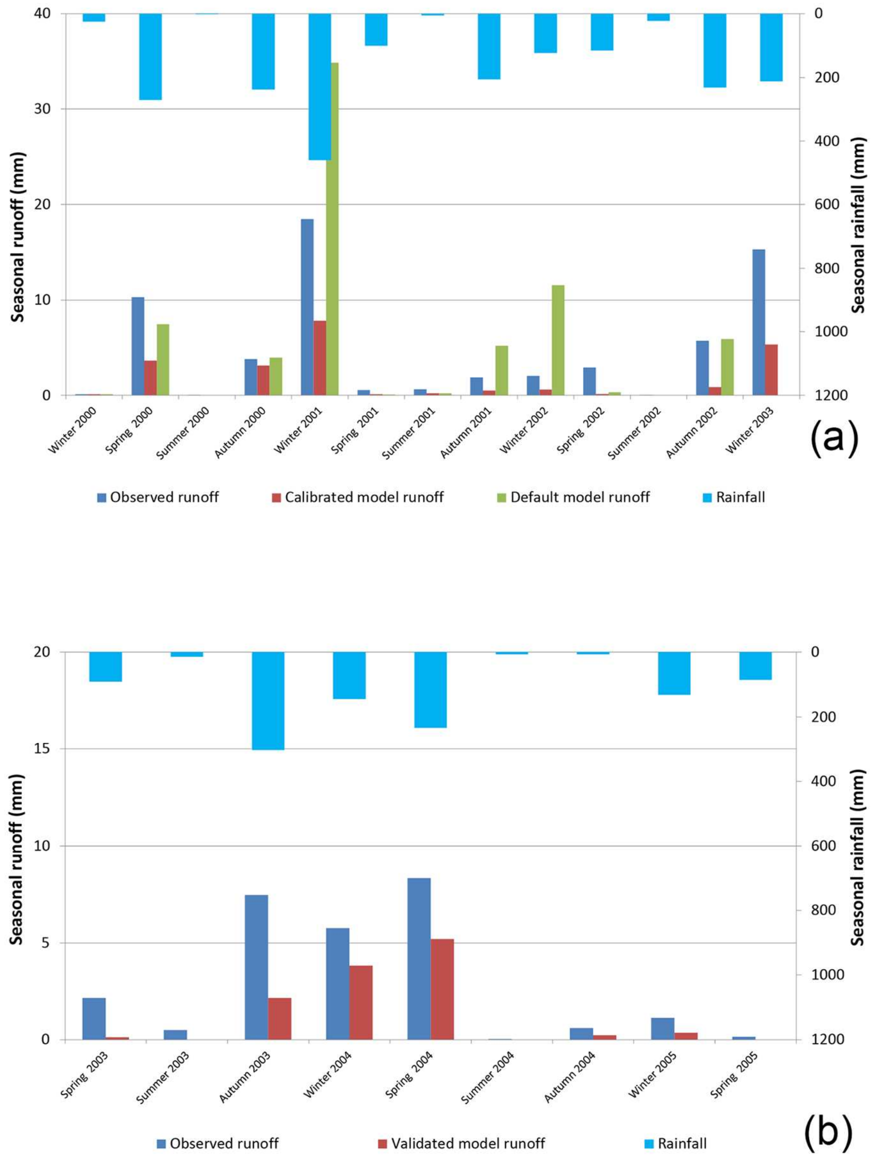


Figure 5. Comparison between observed and simulated seasonal runoff volumes in calibration (a) and validation (b) (using default and calibrated AnnAGNPS model) at the Anzur river (Andalusia, Spain).
153x205mm (250 x 250 DPI)

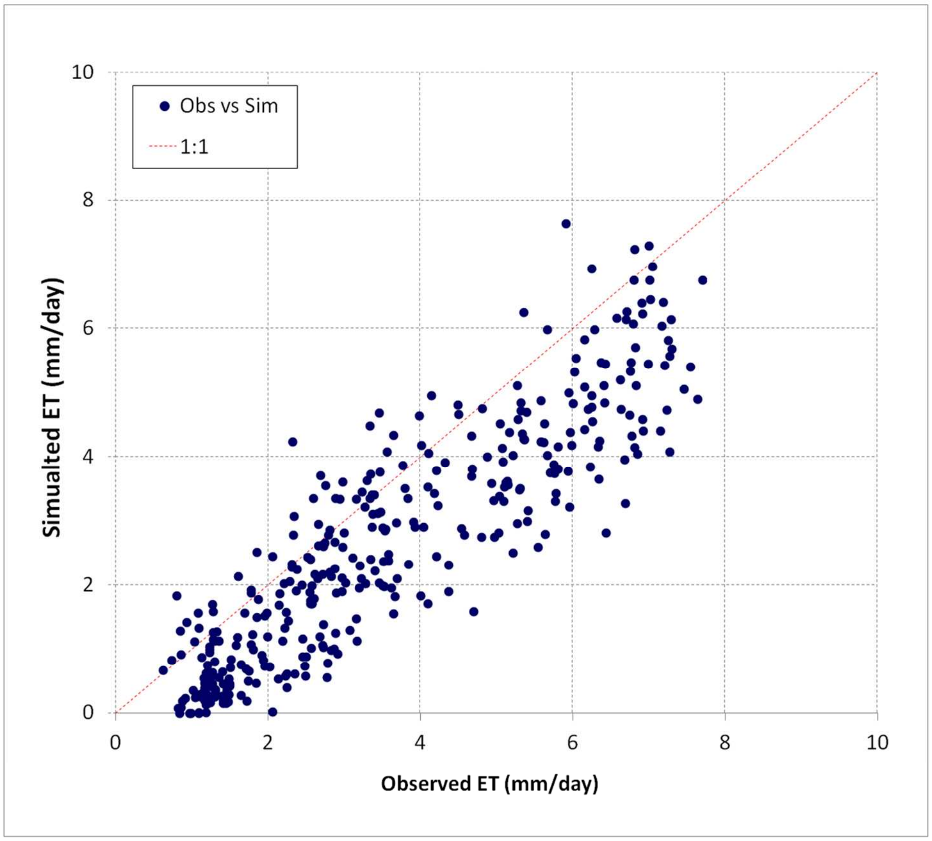


Figure 6. Comparison of the observed and simulated evapotranspiration volumes (ET) at the daily scale in the Anzur river (Andalusia, Spain) for the year 2000.
136x121mm (300 x 300 DPI)