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Evaluation of the AnnAGNPS model for predicting runoff and sediment yield in a small Mediterranean agricultural watershed in Navarre (Spain)

Y. Chahor[a,*], J. Casalí[a], R. Giménez[a], R.L. Bingner[b], M.A. Campo[a], M. Goñi[a]

[a] Department of Projects and Rural Engineering, Public University of Navarre, Campus de Arrosadía s/n, 31006 Pamplona, Navarre, Spain
[b] USDA-ARS National Sedimentation Laboratory, 598 McElroy Drive, Oxford, MS 38655, USA

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ABSTRACT

AnnAGNPS (Annualized Agricultural Non-Point Source Pollution Model) is a computer model developed to predict non-point source pollutant loadings within agricultural watersheds. It contains a daily time step distributed parameter continuous simulation surface runoff model designed to assist with determining Best Management Practices (BMPs), the setting of Total Maximum Daily Loads (TMDLs), and for risk and cost/benefit analyses. The purpose of this study was to evaluate the capabilities of the model to simulate runoff and sediment loads in a small Mediterranean agricultural watershed (207 ha) located in the region of Navarre (Spain) using nine years of continuous data monitoring. Data for the first five years (2003–2007) were used for calibration and the remaining four years (2008–2011) for validation. No significant channel erosion nor in-stream structures were identified within this small and homogeneous watershed. Thus the set of models for analysing stream networks and corridors were not considered in this study. Firstly, AnnAGNPS was calibrated for runoff by modifying Curve Number values for different stages of the main crops. Results showed that the model satisfactory simulated surface runoff at monthly, seasonal and annual scales both in calibration and in validation processes. A Differential Sensitivity Analysis (DSA) was carried out to evaluate the sensitivity of eight input parameters for sediment load prediction. Based on DSA results, the AnnAGNPS model was calibrated for sediment load simulation. The model was capable of simulating the sediment load at an annual scale with a difference of less than 1% for calibration and 7% for validation. However, the results at monthly and seasonal scale were less precise. The use of stream networks and corridors models, already inserted in the system of computer models that make up AnnAGNPS, seem to be necessary for a more precise explanation of sediment yields and loads at monthly and seasonal scales, even for small watersheds.

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1. Introduction

Agricultural activities are some of the main factors causing soil and water degradation in agricultural areas. Excessive loads of nutrients (e.g. nitrate, phosphorus) and sediments from non-point source pollution and soil erosion recorded at the outlet of agricultural watersheds have been reported (Schaffner et al., 2011). Additionally, excessive amounts of sediment in runoff water cause degradation of drinking water quality, siltation of reservoirs and pollution of aquatic ecosystems. Soil erosion is a common phenomenon in Navarre's agricultural lands, where sheet and rill (Casalí et al., 2008, 2009, 2010), gully (Casalí et al., 1999a; De Santisteban et al., 2006; Giménez et al., 2009) and channel erosion (Casalí et al., 1999b; Campo et al., 2007) are frequently observed (Donézar et al., 1990a,b). For that reason, four experimental watersheds with contrasting land uses located in the region of Navarre, and maintained by the local government, have been monitored and studied since 1996 or 2001 onwards in order to assess the environmental impact of agrarian activities and to identify and implement environmentally sound land management practices.

Each watershed contains one automatic weather station, several non-recording daily rainfall gauges distributed throughout the watershed, and one hydrological station, where water discharge, turbidity and water quality parameters are measured. Detailed descriptions and general characterizations of the hydrological and erosive behaviour of three of these watersheds have been published (Casalí et al., 2008, 2010), where, among other remarkable results, the irregular behaviour of this region' climate and, thus, watershed response, was highlighted.

Some hydrological watershed models are able to successfully simulate natural processes of runoff, sediments, nutrients and chemicals, but only after their calibration, which is in turn based

* Corresponding author. Tel.: +34 948 16 9843; fax: +34 948 16 9148.
E-mail address: ychahor@yahoo.com (Y. Chahor).

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on reliable datasets. Moreover, some of those models permit the evaluation of the impact of human activities (e.g. agricultural practices) under different conditions. In fact, models can help to select suitable land uses and the best management practices to reduce the damaging effects of agricultural practices on the environment. A detailed review of several erosion and sediment transport models can be found in Borah and Bera (2003).

Various studies worldwide have evaluated the ability of AnnAGNPS model (Bingner et al., 2012) to predict runoff and sediment loads under different climate conditions and land uses (Table 1). These studies have utilized watershed with areas ranging from 0.1 to 130 km^2 and for short time periods (24 months on average) except Das et al. (2008), who assessed the AnnAGNPS model for 120 months. However, few efforts have been made hitherto to evaluate AnnAGNPS under Mediterranean conditions (Gastesi et al., 2006; Licciardello et al., 2007; Taguas et al., 2009).

The purpose of this study was, therefore, to test the suitability of the AnnAGNPS model for simulating direct runoff and sediment loads in a small Mediterranean, grain-sown watershed for a long term time period (9 years). This work is a continuation of two papers (Casalí et al., 2008, 2010) studying the hydrological response of agricultural watersheds, but this is a first approach focused on the applicability of models for simulating the behaviour observed.

2. Materials and methods

2.1. AnnAGNPS model description

AnnAGNPS (Bingner et al., 2012) is a distributed-parameter, continuous-simulation, watershed-scale model based originally on the single-event model AGNPS (Young et al., 1989). The USDA Agricultural Research Service (ARS) and the Natural Resources Conservation Service (NRCS) developed the original AGNPS and AnnAGNPS to evaluate the impacts of agricultural non-point source pollution on water quality and the environment (Young et al., 1989). AnnAGNPS simulates runoff, sediment, nutrient and pesticide loads, exiting from agricultural areas through drainage streams. AnnAGNPS consists of a system of computer models developed to predict non-point source pollutant loadings within agricultural watersheds. It contains a continuous simulation surface runoff model designed to assist with determining Best Management Practices (BMPs), the setting of Total Maximum Daily Loads (TMDLs), and for risk and cost/benefit analyses.

The set of computer programs consist of: (1) input generation and editing as well as associated databases; (2) the "annualized" science and technology pollutant loading model for agricultural-related watersheds (AnnAGNPS); (3) output reformatting and analysis; and (4) the integration of more comprehensive routines (CCHE1D) for the stream network processes; (5) a stream corridor model (CONCEPTS); (6) an instream water temperature model (SNTEMP); and (7) several related salmonid models (SIDO, Fry Emergence, Salmonid Total Life Stage, and Salmonid Economics). Not all of the models are electronically linked but there are paths of common input/output that, with the use of standard text editors, can be linked. No significant channel erosion nor in-stream structures were identified within this small and homogeneous watershed. Thus, the sets of models for analysing stream networks and corridors were not considered in this study. The SNTEMP and the salmonid models were not used either.

In AnnAGNPS, the analyzed watershed can be divided into many small, homogeneous (in terms of soil type, land use and land management) drainage areas called *cells*. They are connected to each other defining a network of channels and reaches, where water, sediment and nutrients are transported. Cells and reaches and their topographic properties can be estimated using additional modelling components supporting the development of AnnAGNPS input parameters, such as TOPAGNPS (Topographic Parameterization program used for AGNPS) and AGFLOW (Agricultural watershed Flownet generation program) programmes (Bingner et al., 1997; Bingner and Theurer, 2001; Garbrecht and Martz, 2004).

The SCS Curve Number (CN) technique (USDA, 1972) is used within AnnAGNPS as part of the determination of runoff, which is in fact the same technique utilized in many other hydrologic models such as SWRRB and EPIC models (Williams et al., 1985, 1982).

The Revised Universal Soil Loss Equation (RUSLE) (Renard et al., 1996) is used to estimate the daily sheet and rill erosion of the area whenever a runoff event occurs as a consequence of rainfall, irrigation, or snowmelt. In addition, the Hydro-geomorphic Universal Soil Loss Equation (HUSLE) is used to simulate sediment delivery to the stream (Theurer and Clarke, 1991).

The input data required by the AnnAGNPS model are of two major types. The first one is a daily climate record formed by daily precipitation, air temperature (maximum and minimum), sky cover or solar radiation, dew point temperature, wind direction and speed, etc. The second one comprises a description of the physical characteristics and management of a watershed such as morphological parameters, soil, crops and agricultural practices. Moreover, the output parameters are available at daily, monthly and annual scales.

2.2. Study area

The studied watershed named Latxaga is located in the East of Navarre (Spain), 22 km away from Pamplona, (chief city of Navarre). It covers 207 ha. The geographical coordinates of the watershed outlet are 42°47′7.5″ N and 1°26′11.4″ W; at 503 m height (Fig. 1). The watershed elevation is between 504 m and 639 m, with slopes from 7% to 30%. The watershed is drained by a 5.38 km stream characterized by dense riparian vegetation. The climate is humid Sub-Mediterranean, with a mean annual rainfall of 800 mm and an annual average temperature of 12 °C. The geological materials are composed of clay marls and Pamplona grey marls. The dominant soils according to USDA Soil Taxonomy Classification (1998) are *Paralitic Xerorthent* (covering 43% of the total area) located on eroded hill slopes, and *Fluventic Haploxerept* (36% of the total area) located on swales and hill slopes (Table 2).

The entire watershed is usually cultivated with winter cereals, i.e. wheat (*Triticum* spp.) and barley (*Hordeum vulgare* L.), (Casalí et al., 2008), with a production of around 3500–4000 kg ha^{-1}. Soil preparation is based on conventional tillage, which is normally carried out following the contour lines (Table 3).

2.3. Data acquisition

2.3.1. Climate data

The AnnAGNPS model requires a climate file that describes daily climate data. The time span of data acquisition was nine years, from January 2003 to the end of 2011. Most of the climate data have been recorded from the Beortegi climate station (42°47′51.8″ N and 1°26′5.2″ W; at 580 m height). Additionally, three climate parameters, i.e. dew point temperature, maximum 24-h precipitation with a two year return period and global storm type were estimated using the following procedures.

The dew point temperature was calculated from the relative humidity and the mean air temperature using the inverse of Tetens's equation (Chow et al., 1988), optimized for dew points in the range −35 to 50 °C.

Due to the lack of sufficient precipitation records from the Beortegi station, the maximum 24-h precipitation with a two-year return period was estimated as an average value of another two stations (Pamplona-Observatorio and Ustés stations), which

Table 1
Different studies where AnnAGNPS model was evaluated. In cases where both calibration and validation were carried out only the latter test is indicated.

Authors	Location	Climate	Area (km^2)	Land use	Analyzed variables	Study period (months)	Calibrated parameters	Time scale of evaluation	Observations
Yuan et al. (2001)	Mississippi Delta (The Deep Hollow lake watershed)	Humid subtropical	0.1	Cotton and soybeans	Runoff and sediments	36	None	Event and monthly	AnnAGNPS successfully predicted runoff for individual event (R^2 = 0.9) but less satisfactory at monthly scale (statistical index not given). Predicted sediment yield at event and monthly scales had R^2 of 0.5 and 0.7, respectively.
Baginska et al. (2003)[a]	90 km North west of Sydney Australia (Currency Creek watershed)	Temperate	2.5	Crop land and pasture	Runoff and nutrients (N, P)	21	CN (Curve Number)	Event	AnnAGNPS simulated satisfactory flow events (E = 0.82).
Shrestha et al. (2006)	Siwalik Hills of Nepal (Masrang Khola watershed)	Subtropical	1.3	Forest, maize, rice, bush forest and grazing land	Runoff and sediments	15	CN, Manning's n, values of sheet and concentrated flows	Event	AnnANGPS predicted runoff volume within range of acceptable accuracy (R^2 = 0.91) and sediment yield in the range of moderate accuracy (R^2 = 0.59)
Licciardello et al. (2007)	East of Sicily Italy (Cannata watershed)	Mediterranean	1.3	Pasture and cropland	Runoff and sediments	84	CN, surface long term random roughness and Manning's n	Event, monthly, yearly	AnnAGNPS showed satisfactory capability in simulating surface runoff at event (R^2 = 0.87, E = 0.83), monthly (R^2 = 0.93, E = 0.85) and annual (R^2 = 0.99, E = 0.62) scales. For sediment yield good model efficiency were founded for 24 events (R^2 = 0.84, E = 0.79).
Polyakov et al. (2007)	Kauai Island Hawaii (Hanalei River basin)	Tropical	48	Shrub and evergreen forest	Runoff and sediments	24	CN	Daily and monthly	Monthly runoff volumes predicted by AnnAGNPS compared well with the measured data (R^2 = 0.90). Prediction of daily runoff was less accurate (R^2 = 0.55). Predicted and observed sediment yield on a daily basis was poorly correlated (R^2 = 0.5, E = 0.43) but more accurate at monthly basis (R^2 = 0.85).

Table 1 (*Continued*)

Authors	Location	Climate	Area (km^2)	Land use	Analyzed variables	Study period (months)	Calibrated parameters	Time scale of evaluation	Observations
Sarangi et al. (2007)	British West Indies (St. Lucia Watershed)	Tropical	0.12	Cropland	Runoff and sediment	19	CN, root mass and crop residue	Event	Predicted runoff in agricultural and forested watersheds resulted in $C_{P,A}$[b] values of 0.028 and 0.23, respectively, while sediment loss simulation was less accurate ($C_{P,A}$ = 0.341).
Shamshad et al. (2008)	Malaysia (River Kuala Tasik Watershed)	Tropical	125	Cropland and forest	Runoff, sediment and nutrients (N, P)	25	CN, root mass and canopy cover	Event	Runoff was predicted "well" (R^2 = 0.9 and E = 0.70), sediment prediction was "reasonable" (R^2 = 0.66 and E = 0.49).
Das et al. (2008)	Canada – Ontario (Canagagigue Creek)	Humid continental	53	Cropland	Runoff and sediment	120	CN, soil bulk density, hydraulic conductivity, tile depth, soil erodibility (K) factor, RUSLE C and RUSLE P	Event, monthly and yearly	AnnAGNPS performed well in predicting runoff at event and monthly scales (E = 0.50 and E = 0.69, respectively). Observed and simulated annual runoff ranged from −18% to 20%. Monthly sediment yield was over estimated by 28% (E = 0.35).
Yuan et al. (2008)	Mississippi Delta (Beasley Lake watershed)	Humid subtropical	0.07	Cotton, soybean and corn	Runoff and sediment	60	None	Event	The model demonstrated satisfactory capability in simulating runoff (E = 0.81) and sediment yield (E = 0.54).
Parajuli et al. (2009)	South central Kansas (Red Rock creek and Goose creek watersheds)	Humid subtropical	136	Cropland	Runoff and sediment and total phosphorus	45	CN, RUSLE C factor	Monthly	The model provided from faire to very good model efficiency for simulating surface runoff (R^2 = 0.5) and sediment yield (R^2 = 0.62)
Taguas et al. (2009)[a]	Cadiz – Spain (Setenil watershed)	Mediterranean	0.07	Olive orchard	Runoff and sediment	24	CN, RUSLE C factor	Event, monthly	The results confirmed the applicability of AnnAGNPS to predict runoff (E = 0.66/R^2 = 0.69; E = 0.95/R^2 = 0.96) and sediment yield (E = 061/R^2 = 0.62; E = 0.6/R^2 = 0.70) respectively at event and monthly scales.

[a] Only calibration.
[b] $C_{P,A}$, Coefficient of prediction.

Table 2
Classification of the main soils present in Laxtaga watershed as well as information required by AnnAGNPS for each soil layer. Only data of the upper horizons (10–20 cm depth) are shown.

Classification (USDA SOIL Taxonomy, 1998)	Geomorphology	Upper horizon texture (USDA)	Sand (%)	Silt (%)	Clay (%)	Organic matter (%)	[a] Wilting point (% Vol)	[b] Field capacity (% Vol)	Saturation (% Vol)	Saturated hydraulic conductivity (mm/h)	Bulk density (g/cm^3)	Hydrologic soil group
Fluventic Xerochrept	Swales	Loam-clay-silty	16.8	47.2	36.0	1.9	22.0	34.7	48.9	3.8	1.35	C
Fluventic Xerochrept	Accumulation hillslope	Loam-clay-silty	20.7	42.0	37.2	1.8	22.6	37.4	48.4	3.4	1.37	C
Fluventic Xerochrept	Swales	Loam-silty	24.8	46.8	28.4	1.8	17.7	33.5	46.6	6.1	1.42	B
Fluventic Xerochrept	Accumulation hillslope	Loam-clay-silty	23.4	41.3	35.3	1.4	21.4	36.2	47.1	3.4	1.40	C
Paralithic Xerorthent	Erosion hillslope	Loam-clay-silty	22.9	42.6	34.4	1.3	20.8	35.8	46.7	3.4	1.41	C
Paralithic Xerorthent	Erosion hillslope	Loam-clay-silty	19.3	46.6	34.0	1.1	20.7	36.1	46.7	3.2	1.41	C
Typic Xerorthent	Erosion hillslope	Loam-clay-silty	22.7	42.9	34.3	1.7	20.9	36	47.5	3.9	1.39	C
Typic Xerorthent	Erosion hillslope (gentele)	Loam-clay-silty	22.6	42.3	35.1	1.8	21.5	36.4	47.8	3.8	1.38	C

[a] Wilting point, water content at 1500 kPa.
[b] Field capacity, water content at 33 kPa.

are situated roughly under the same climate type (humid Sub-Mediterranean). Thus, the maximum 24 h precipitation with a two year return period value was 54.7 mm (Ministerio de Agricultura, Pesca y Alimentación, 1986).

The global storm type was determined by comparing the rainfall distribution of Beortegi to the rainfall distribution of USA included in AnnAGNPS. The USA region that most closely resembled the local annual rainfall distribution pattern corresponds to the West Coast, both Seattle (Washington) and San Francisco (California). The global storm type selected was thus the "Ia".

2.3.2. Topography data

A Digital Elevation Model (DEM) (5 m × 5 m) of the watershed was acquired from the Department of Rural Development, Environment and Local Administration of the Government of Navarre. It was used to obtain the necessary input data for running the TOPAGNPS program. More precisely, the DEM was used (i) to identify and measure topographic features, (ii) to define surface drainage channels, (iii) to subdivide watersheds on cells along drainage divides and (iv) to calculate representative cell parameters, including cell area, slope and length. The size of the cells depends on the values of the Critical Source Area (CSA) and Minimum Source Channel Length (MSCL). The CSA is defined as the minimum upstream drainage area above which a source channel is initiated and maintained; while the MSCL is the minimum acceptable length of the cell swale for the source channel to exist. Different combinations of CSA/MSCL values were tried until obtaining a realistic representation of the main drainage system and of the land use of the Laxtaga watershed. Visual comparisons between a real land use map and the watershed division were made by using TOPAGNPS program. Finally, values of 4 ha and 100 m were defined for CSA and MSCL, respectively. These values led to dividing the watershed into 43 cells and 17 reaches (Fig. 2).

2.3.3. Soil data

For each soil type, the model requires specific data of all the different soil layers up to the impervious layer (i.e., for the entire solum). However, and for the sake of simplicity, only the dataset regarding top soils is shown (Table 2). However, the model was also provided with similar information on the different soil sublayers.

Soil maps (Fig. 3A) and physical and chemical soil characteristics were obtained from the Department of Rural Development, Environment and Local Administration of the Government of Navarre (Gobierno de Navarra, 2001). Moreover, the soil erodibility factor (K) was determined following Wischmeier and Smith (1978). Also, the wilting point, field capacity, saturated hydraulic conductivity and bulk density of the different soil layers were computed by the Soil Water Characteristics Hydraulic Properties Calculator developed by USDA-ARS and the Washington State University (Saxton and Rawls, 2006).

2.3.4. Land use data

Most of the watershed (approximately 90% of the total area) is occupied by cereals: wheat and barley, while the remaining area is devoted to legumes (*Vicia faba* L. and *Pisum sativum* L.), sunflower (*Helianthus annuus* L.) and, finally, a minimum part of the land lies fallow. It should be noted that plots given over to the minor uses cited above may change from year to year without following a strict crop rotation. The information concerning the management schedule (Table 3) was obtained by interviewing local farmers.

A land use map containing plot delimitations was provided by the Department of Agriculture, Livestock and Food of the Government of Navarre (Fig. 3B). Although in Fig. 3B the different crops (and fallow) are merged for simplicity into the single class "Agricultural lands", they were discriminated and taken into account separately when running the model.

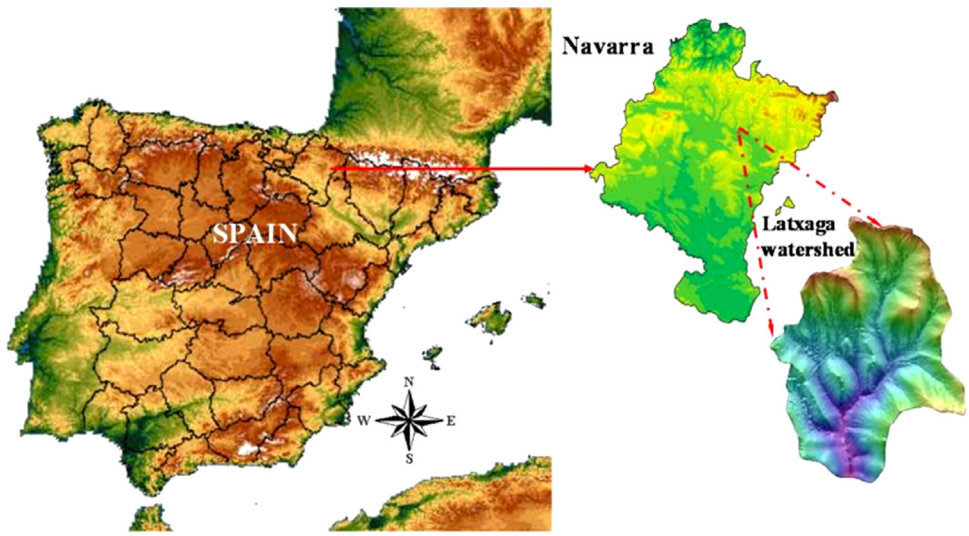

Fig. 1. Latxaga watershed location.

Table 3
Schedule of annual cultivation and agricultural practices normally followed in Latxaga watershed.

Land use	Date	Operation	Observation
Wheat and barley	15 September	Tillage	Moldboard (25 cm)
	20 September	Smoothing	Harrow
	10 October	Fertilization	Phosphate (200 kg ha^{-1})
	15 October	Seeding	Combined seeding machine (90–100 kg ha^{-1})
	15 January	Fertilization	Urea 210 kg ha^{-1}
	15 February	Weeding	Mesosulfuron-methyl *Atlantis*® (400 g ha^{-1})
	15 March	Fertilization	Urea 250 kg ha^{-1}
	1 July	Grain harvesting	4500–5000 kg ha^{-1}
	2 July	Straw packaging	
Bean (*Vicia faba*)	15 September	Tillage	Moldboard (25 cm)
	20 September	Smoothing	Harrow
	21 September	Seeding	Combined Seeding machine (220 kg ha^{-1})
	15 February	Weeding	Fluazifop-p-butil (ester) *Fosilade*® (1 L ha^{-1})
	1 July	Grain harvesting	2000–2500 kg ha^{-1}
Pea (*Pisum sativum*)	15 September	Tillage	Moldboard (25 cm)
	20 September	Smoothing	Harrow
	1 December	Seeding	Combined seeding machine 220 kgha^{-1}
	3 December	Weeding	Imazethapyr, ammonium salt *Poursuit*® (1.5 L ha^{-1})
	1 July	Grain harvesting	2000 kg ha^{-1}
Sunflower	20 September	Tillage	Moldboard (25 cm)
	15 March	Smoothing	Harrow
	1 May	Seeding	Precision seeder (300 g ha^{-1})
	3 May	Weeding	Fluorocloridona *Racer 25*® (2 L ha^{-1})
	15 May	Fertilization	15% N, 15% P_2O_5, 15% K_2O (270 kg ha^{-1})
	15 July	Grain harvesting	2500 kg ha^{-1}
	17 July	Straw packaging	
Fallow	15 May	Tillage	Moldboard (25 cm)

Curve Number values proposed by the SCS (1986) were initially assigned to each land use (Table 4).

2.3.5. Hydrology and sediment load data

The watershed outlet was equipped with a hydrology station containing a water level sensor model 6531 (UNIDATA, Australia, Willetton), which allowed one to measure total discharge calculated from water level. To determine sediment yield and water quality, an automatic sampler ISCO 6712 (Teledyne Isco, Lincoln, NE, USA) collecting samples every 6 h was used. Water samples (sediment concentration and dissolved nitrate and phosphate, sulphate, carbonate, potassium, calcium, magnesium and sodium) were analyzed following the standard methods for water quality parameters at the Department of Rural Development and Environment and Local Administration of the Government of Navarre.

Table 4
Initial Curve Number (CN).

Cover descriptions	Curve Numbers for hydrologic soil groups			
	Initial values		Final values	
	B	C	B	C
Bare soil	86	91	43	45
Small grain	75	83	60	66
Fallow	83	88	33	35
Row crop	78	83	62	66
Grassland	67	77	No change	
Residential districts	75	83	No change	

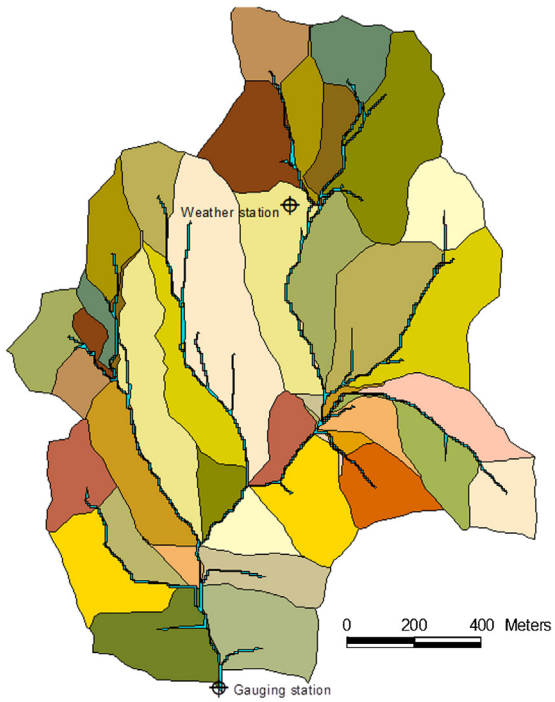

Fig. 2. Latxaga watershed with subwatershed (cells) division and stream channels.

Chemical analysis was performed using UV–vis spectrometry and liquid chromatography coupled with a conductivity detector. The four samples collected each day were mixed together prior to analysis in order to provide a representative daily average sample for determining sediment and nutrient concentrations according to Isidoro et al. (2003). Since AnnAGNPS does not simulate base-flow, in order to compare predicted runoff with measured runoff, the base flow was previously separated from measured runoff using a digital filtering of hydrographs proposed by Eckhardt (2005).

2.4. AnnAGNPS model evaluation

It is recommended that calibration and validation are carried out in two separated periods of time (with not necessary the same number of years each). In addition, Gan et al. (1997), Kim et al. (2007) and Vázquez et al. (2008) state that selected calibration and validation periods should be representative of a wide range of precipitation. Such variability is considered necessary for a rigorous and comprehensive model evaluation.

In this study, the model was calibrated for runoff volume and sediment load using five years of observed data, from 2003 to 2007; whereas the period between 2008 and 2011 was used for the validation. Moreover, 2006–2007 and 2008–2009 were relatively wet years while 2004–2005 and 2010–2011 were relatively dry ones. Three consecutive years of climate data were used as "warm-up" period.

In the other hand, and according to Donigian (2002), hydrological model calibration is a hierarchical process beginning with calibration of runoff and stream flow, followed by calibration of sediment load. This was then the order followed in this study. Calibration was carried out at monthly, seasonal and annual scale.

2.4.1. Runoff evaluation

Most of the worldwide studies evaluating AnnAGNPS (Yuan et al., 2001; Baginska et al., 2003; Shrestha et al., 2006; Licciardello et al., 2007; Polyakov et al., 2007; Shamshad et al., 2008; Das et al., 2008; Parajuli et al., 2009; Taguas et al., 2009) show CN as the most sensitive input parameter to surface runoff prediction. In

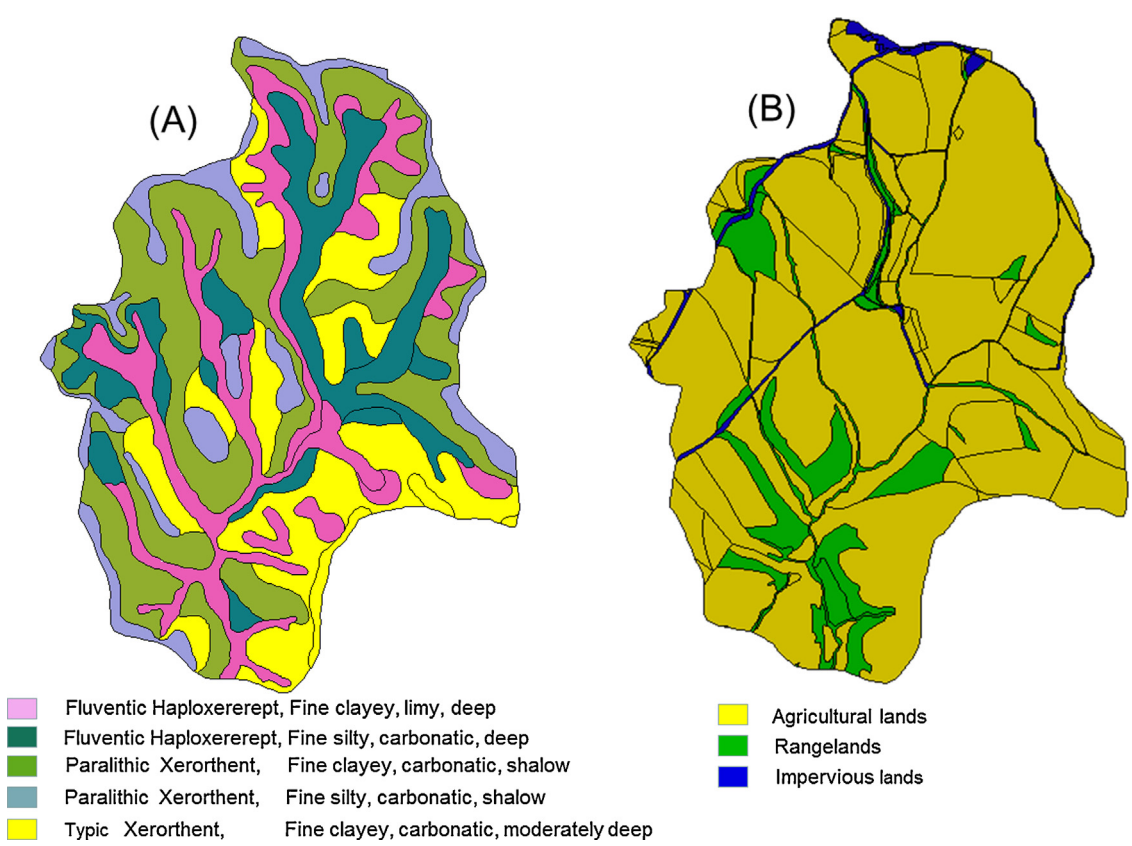

Fig. 3. Soil (A) and land use (B) maps.

agreement with that, Table 1 shows that in most of the therein cited studies AnnAGNPS was successfully calibrated for surface runoff simulation by, precisely, adjusting CN values. Therefore, in this study, the runoff calibration process was also performed by modifying values of this parameter. A sensitivity analysis was not considered necessary as it was for the following sediment calibration (see below). A sensitivity analysis is an instrument for the assessment of the input parameters with respect to their impact on model output.

2.4.2. Sediment load. Sensitivity analysis

Most authors who studied prediction of sediment by using AnnAGNPS (Tsou and Zhan, 2004; Shrestha et al., 2006; Licciardello et al., 2007; Sarangi et al., 2007; Shamshad et al., 2008; Das et al., 2008; Parajuli et al., 2009) carried out model calibration by adjusting different AnnAGNPS input parameters without a previous sensitivity analysis. For instance, Licciardello et al. (2007) carried out calibration by modifying the surface random roughness and sheet and concentrated flow Manning's roughness coefficients. They concluded that model response was remarkably more sensitive to random roughness than to Manning's coefficients adjustment. Similarly, Shrestha et al. (2006) calibrated the model by modifying the surface roughness. Parajuli et al. (2009) calibrated AnnAGNPS for sediment yield by adjusting the crop cover management factor (RUSLE-C) as well as the support practice factor RUSLE-P. Shamshad et al. (2008) and Sarangi et al. (2007) carried out calibration by adjusting root mass, crop residue and canopy cover.

By contrast, Das et al. (2008) carried out a sensitive analysis before calibration including various input parameters. Das' et al. results showed that generated sediment yield was sensitive to soil erodibility factor (K), RUSLE-C and RUSLE-P which are the crop management factor and the erosion-control practice factor of the RUSLE equation respectively. They also concluded that Manning's roughness factor had significant impacts on runoff peaks and sediment loads.

In this study a sensitivity analysis was considered necessary and then carried out before calibration for sediment prediction. Among the different sensitivity analysis methods, the Differential Sensitivity Analysis (DSA) was used (Hamby, 1994; Lenhart et al., 2002; Frey et al., 2003; Das et al., 2008). The DSA method was selected for its simplicity and low-need computational time compared to other statistical sensitivity analysis methods. The DSA is calculated at one or more points in the parameter space of an input, keeping other inputs fixed.

Based on the studies mentioned above, eight input parameters were selected to assess the model sensitivity in predicting sediment load. They were: random roughness, Manning's sheet and reach coefficients, remaining residue cover, canopy cover, root mass, rainfall height and the RUSLE-P factor.

The DSA sensitivity analysis was applied to the eight parameters through variation of the initial value (Δx) by a fixed percentage of $\Delta x = \pm 10\%$ (Lenhart et al., 2002), whereas the other parameters remained constant. The model was then run for the 5 years of the calibration, i.e., 2003–2007. The annual average of sediment load was used to quantify the degree of sensitivity with respect to the input parameter variations.

To classify input parameters according to their sensitivity, the sensitivity index, I (Lenhart et al., 2002) was computed as follows:

$$I = \frac{(y_2 - y_1)/y_0}{2\Delta x/x_0} \quad (1)$$

The model output y_0 is calculated with an initial value x_0 of the parameter x. This initial parameter value is varied by $\pm\Delta x$ yielding $x_1 = x_0 - \Delta x$ and $x_2 = x_0 + \Delta x$ with corresponding values y_1 and y_2. The x_0 are either default values given by the model or obtained from USDA's handbooks.

The sign of the index shows if the model reacts co-directionally (+) or counter-directionally (−) to the input parameter change. A value of I near zero indicates that the output is not sensitive to the parameter under study, whereas a value of I significantly different from zero shows high degree of sensitivity. Sensitivity Index is ranked into four values (Lenhart et al., 2002) as follows: less than 0.05: small to negligible sensitivity; 0.05–0.2: medium sensitivity; 0.2–1.0: high sensitivity; more than 1: very high sensitivity.

Sediment load calibration was carried out using alternately input parameters in decreasing order of sensitivity. Each input parameters were alternately changed – within realistic values – in an amount equal to 5% of its original value, until reaching the best possible match between observed and predicted sediment load values.

Observed and simulated sediment load were compared at monthly, seasonal and annual time scales.

2.5. Model performance assessment

Qualitative and quantitative approaches were used to assess the model performance in predicting runoff and sediment load during calibration and validation phases. This evaluation was made at monthly, seasonal and annual time scales. The qualitative approach consisted of a visual graphic comparison of observed and predicted values, whereas, for the quantitative procedure statistical criteria were used. They were, Nash–Sutcliffe efficiency coefficient E (Eq. (2)), modified Nash–Sutcliffe efficiency coefficient E_1 (Eq. (3)) and percent bias PBIAS (Eq. (4)).

2.5.1. Nash-Sutcliffe efficiency E

The coefficient of efficiency, proposed by Nash and Sutcliffe (1970) is calculated as:

$$E = 1 - \frac{\sum_{i=1}^{n}(O_i - S_i)^2}{\sum_{i=1}^{n}(O_i - O)^2} \quad (2)$$

n: number of observations;
O_i: observed data;
S_i: simulated data;
O: mean of observed data;
S: mean of simulated data.

The Nash–Sutcliffe efficiency is a normalized statistic that determines the relative magnitude of the residual variance ("noise") compared to the measured data variance ("information") (Nash and Sutcliffe, 1970). The coefficient E indicates how well the plotting of observed versus simulated data fits the 1:1 line. E is dimensionless and ranges from minus infinity to 1; $E = 1$ is considered as a perfect fit and $E < 0$ indicates that the mean value of the observed data is a better predictor than the model.

The Nash–Sutcliffe efficiency coefficient has been widely used to evaluate the performance of hydrological models in simulating flow and sediments (Moriasi et al., 2007). Van Liew et al. (2003) proposed results as being highly satisfactory for an E value equal or larger than 0.75, satisfactory between 0.36 and 0.75 and unsatisfactory for E smaller than 0.36.

It should be noted that this coefficient is very sensitive to extreme values (Legates and Mc Cabe, 1999) since the difference between observed and simulated data values is raised to the second power. To avoid this, Legates and Mc Cabe (1999) and Krause et al. (2005) suggested adjusting E to reduce the effect of squared terms

by rewriting a more generic form of the coefficient of efficiency as follows:

$$E_1 = 1 - \frac{\sum_{i=1}^{n} \left|O_i - S)\right|}{\sum_{i=1}^{n} \left|O_i - O)\right|} \quad (3)$$

The adjusted E with the desired properties (not inflated by squared values) is E_1.

Krause et al. (2005) reported that, in general, E_1 has a lower value than E. In addition, Licciardello et al. (2007) considered values of E_1 of between 0.51 and 0.71 as demonstrating a satisfactory model efficiency.

2.5.2. Percent bias PBIAS

Eq. (4) is a measure of the average tendency of the simulated values to be larger or smaller than the observed values. The optimal PBIAS value is 0. Moreover, a positive value indicates a model bias towards underestimation, whereas a negative value indicates a bias towards overestimation (Gupta et al., 1999). Model efficiencies were classified by Moriasi et al. (2007) and Parajuli et al. (2009) as being very good for $\pm 11 \leq \text{PBIAS} \leq \pm 15$ for runoff prediction and $\pm 16 \leq \text{PBIAS} \leq \pm 30$ for sediment prediction.

$$\text{PBIAS} = 1 - \frac{\sum_{i=1}^{n} (O_i - S_i) \times 100}{\sum_{i=1}^{n} O_i} \quad (4)$$

3. Results and discussion

3.1. Runoff calibration

The model was run using five curve number categories proposed by the SCS (1986) (Table 4), with "CN-grassland" representing grassland and shrubs within the watershed and the "CN residential districts" illustrating the CN values of the area occupied by the Beortegui village. For the crops, three types of CN were used throughout one crop cycle year: the CN "bare soil" was used for crop land after tillage; the CN "small grain" was used when the crops (cereal and legumes) were installed. The CN for fallow with crop residue cover was used after grain harvesting, while crop residues remained over the soil (Table 4). As a result, the model simulation generated an annual average runoff of 158 mm/year, which was nearly three times higher than the observed value (58.2 mm). At a monthly time step, runoff overestimation was observed during the whole period with Nash coefficient and PBIAS presenting a poor result ($E = -1.52$ and PBIAS = −164). A similar overestimation tendency was reported by Polyakov et al. (2007) in a 4800-ha watershed located on the island of Kauai, Hawaii. They observed that, during the preliminary model simulations, the model overpredicted runoff amounts and runoff event frequency (Table 1).

In order to improve the match between the observed and the simulated surface runoff amounts, it was decided to reduce the CN values related to the crop cycle. AnnAGNPS was run several times using decreasing values of CN each time, and then the statistical analysis was remade. The best results were obtained decreasing the CN values of bare soil, small grain and fallow by 20%, 20% and 50%, respectively. The annual average simulated runoff was then 62.5 mm/year and $E = 0.54$ and $E = 0.49$, respectively, for monthly and seasonal time scales. It should be reported that "CN-grassland" and "CN residential districts" were decreased during the calibration but without any clear effect on simulating surface runoff. This is probably due to their small area within the catchment, which does not produce large amounts of runoff compared to the rest of area. This first calibration clearly improved the model response. However, the model still tended to overestimate surface runoff during summer and autumn seasons, while in winter and spring the runoff was underestimated. It can be due to a lack of describing seasonally variable SCS CN's in the input parameters. Therefore, a new calibration was performed.

Table 5
Estimated statistical parameters of model performance for calibration and validation.

	Calibration				Validation			
	E	E_1	PBIAS	R^2	E	E_1	PBIAS	R^2
Monthly scale								
Runoff	0.75	0.58	−2.65	0.79	0.69	0.58	−11.75	0.82
Sediment	0.13	0.2	−0.06	0.20	−0.05	0.14	−2.3	0.13
Seasonal scale								
Runoff	0.79	0.6	−2.38	0.81	0.94	0.75	−11.01	0.81
Sediment	0.26	0.23	7.4	0.30	−0.04	0.21	−7.1	0.11
Annual scale								
Runoff	0.63	0.4	−2.65	0.78	0.37	0.35	−11.75	0.69
Sediment	0.46	0.3	−0.06	0.46	−0.73	0.34	−7.16	0.03

To adjust the underestimation of surface runoff during winter, it was decided to introduce new CN values for this season. The initial CN value chosen for this period was "row crop" (Table 4) representing the crop stage throughout the winter. The results obtained after the introduction of new CN values were acceptable in terms of prediction of surface runoff during winter. However, during spring, the runoff was overestimated by 37%, which led us to introduce another CN value for spring to correct this overestimation.

The spring CN value was determined by decreasing the "row crop" CN value by 20%. An even better performance was obtained by also decreasing the CN values of "bare soil" and "fallow CN", respectively, by 50% and 60% (Table 4).

Thus, a noticeable improvement in the model prediction was obtained, with less than 1% of difference between simulated and observed average annual runoff and with, for instance, $E_m = 0.75$ and $E_s = 0.79$, respectively, for monthly (m) and seasonal (s) time scales as well as $E_{1m} = 0.58$, $E_{1s} = 0.60$ and $\text{PBIAS}_m = -2.65$, $\text{PBIAS}_s = -2.38$ (Table 5). According to Moriasi et al. (2007) and Parajuli et al. (2009) the results obtained after AnnAGNPS model calibration can be considered as being satisfactory (Fig. 4).

Nevertheless, a slight over-prediction of runoff still persisted especially in the dry summer season and at the beginning of autumn (Fig. 5). For instance, despite the low values given to CN, the model predicted some runoff – especially for major precipitation events – although no runoff was recorded in the outlet gauge station. In our opinion, this over-prediction is due to the soil conditions (very dry) in this period with soil possibly having macropores which promote water infiltration instead of runoff. This over-prediction can be observed, for example, in September 2006 and June 2007 (data not shown), when the precipitation was, respectively, 234 mm and 93 mm, which generated a simulated surface runoff 79% and 89% higher than measured surface runoff, respectively. The rainfall was 53% and 58% higher than the average precipitation for the same months. Furthermore, at the annual scale, the difference between simulated and observed surface amounts was about 2.5% with an average of 61.4 mm and 59.8 mm, respectively.

3.2. Runoff validation

Like calibration results for validation at monthly and seasonal time scales can be considered as satisfactory (Table 5) (Figs. 6 and 7). Moreover, at an annual scale, the difference between simulated and observed surface amounts was only about 10.5% with an average of 51.7 mm and 46.3 mm, respectively. These results confirm the ability of the model to predict surface runoff after calibration.

The accuracy of our simulations is roughly similar to that found in the literature for watersheds of approximately the same size (e.g.,

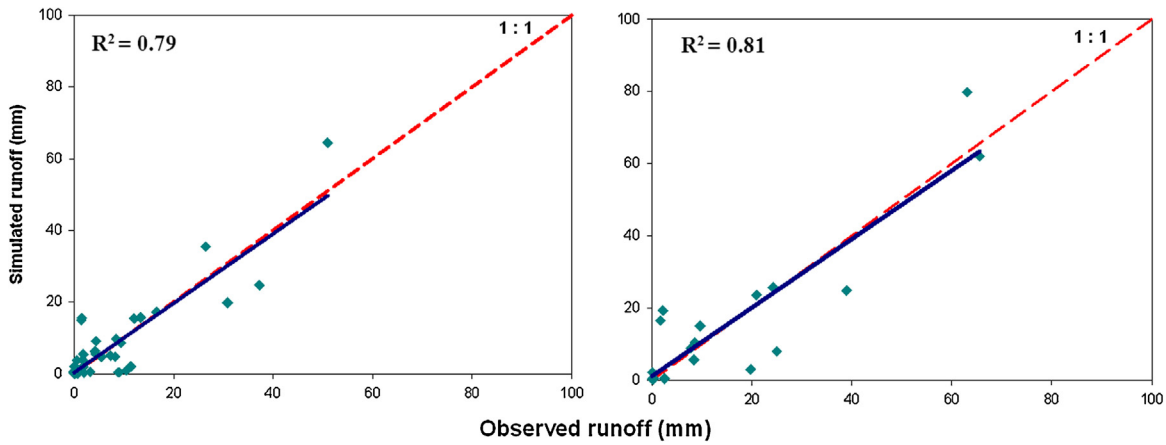

Fig. 4. Comparison between observed and simulated surface runoff at monthly (left) and seasonal (right) scales for calibration process.

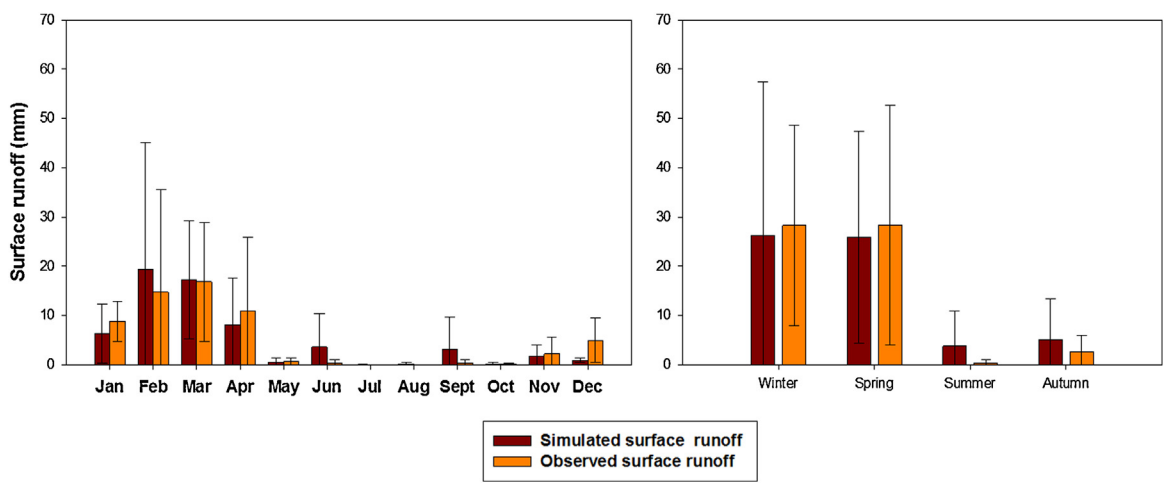

Fig. 5. Comparison of the simulated and observed monthly (left) seasonal (right) average surface runoff for the calibration.

Licciardello et al., 2007; Table 1). Moreover, 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 (cf. Taguas et al., 2009 and Parajuli et al., 2009; Table 1). This could be partly explained by the homogeneous hydrological and climate conditions expected in a small watershed, which simplify model simulation.

Thorough evaluations of AnnAGNPS at an annual scale are somewhat scarce in the literature, e.g. Licciardello et al. (2007). The latter authors managed to obtain – at an annual scale – a more successful simulation in a similar (Mediterranean) but smaller watershed than Latxaga (Table 1). This agrees with the alleged tendency between the watershed size and the simulation accuracy mentioned above.

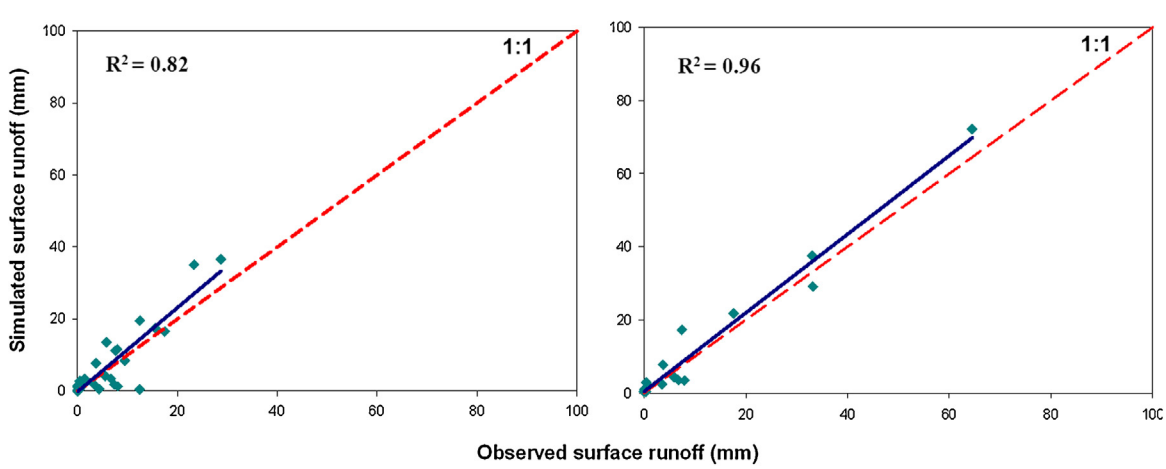

Fig. 6. Comparison between observed and simulated surface runoff at monthly (left) and seasonal (right) scales for validation.

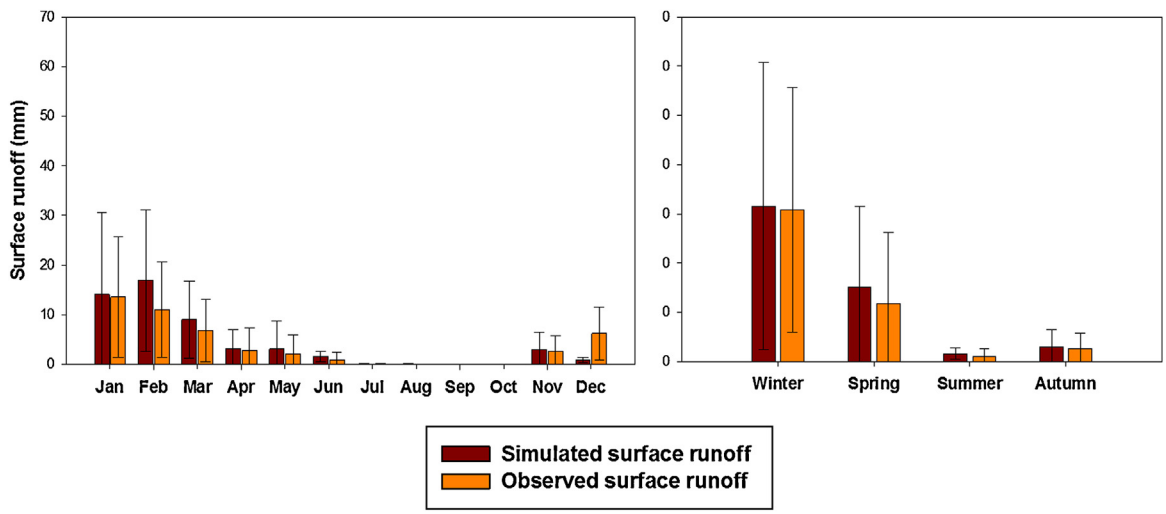

Fig. 7. Comparison of the simulated and observed monthly (left) seasonal (right) average surface runoff for the validation.

3.3. Sediment load

3.3.1. Sensitivity analysis

Most of the input parameters had a linear effect on sediment load prediction except for Manning's sheet and reach coefficients (Fig. 8). In addition, sediment load model output had a negative correlation with most of the input parameters selected, while RUSLE-P factor had a positive correlation. As defined by Renard et al. (1996), the RUSLE-P factor is the ratio of soil loss with specific support practice to the corresponding loss upslope and downslope tillage (e.g., the effect of contour tillage on soil erosion by runoff).

According to Lenhart et al. (2002), only RUSLE-P and canopy cover can be classified as high sensitive parameters and the remaining six parameters as medium sensitive ones. However, it was noted that within the last category (i.e., medium) there was a wide range of variation in the sensitivity index, with a value of 1 for canopy cover, which is three times higher than that for Manning's sheet coefficient (Table 6).

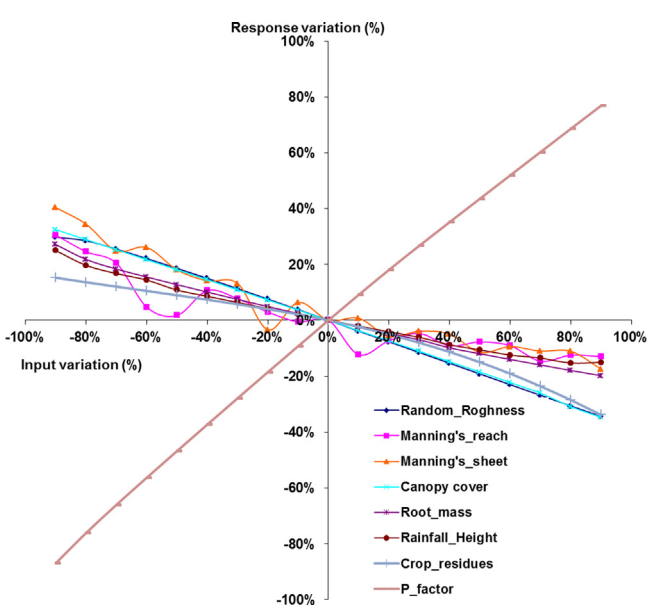

Fig. 8. The sensitivity of sediment load to the eight selected input parameters.

3.3.2. Sediment load calibration

First, calibration was carried out by adjusting the RUSLE-P factor which is the most sensitive input parameter. Wischmeier and Smith (1978) and Renard et al. (1996) reported that the contour RUSLE-P factor can have a value of between 0.4 and 0.6 in watershed conditions under different slope percentages with contour tillage and non existence of gullies or rills. As reported by Casalí et al. (2008) from field observation at Latxaga watershed no gullies/rills have been observed; this lead us to assign a P factor value within the interval already mentioned; the best results were obtained for 0.5. As a result, sediment load was reduced by 58%, though, some overestimation still persisted at 30% of annual average.

Next, random roughness was varied; followed by canopy cover, root mass, rainfall height, remaining residue cover, Manning's sheet coefficient and reach coefficient. The best results were obtained by increasing the input data as follows: random roughness coefficient by 10%, canopy cover, root mass and rainfall height by 20%, remaining residue cover by 20%, Manning's sheet by 25% and reach coefficient by 30%.

The increment in random roughness and in Manning's sheet and reach coefficients led to a decrease in transport capacity and runoff detachment. A high value was given to Manning's reach coefficient due to the nature of the stream network within Latxaga watershed characterized by very dense riparian vegetation during the whole year, especially towards the outlet where sedimentation is frequent.

Increasing canopy cover and rainfall height increases the effectiveness of vegetation in reducing the energy of rainfall striking the soil's surface. In addition, vegetation affects erosion by reducing the transport capacity of runoff (Foster, 1982).

After that, sediment load prediction was improved at an annual scale. The annual average amounts were 341.5 kg/ha/year and 341.3 kg/ha/year for simulated and measured sediment load,

Table 6
Sensitivity classification of AnnAGNPS sediment load to input parameters variation.

Input parameters	Sensitivity index (I)
Manning's reach coefficient	−0.07
Rainfall height	−0.10
Manning's sheet coefficient	−0.11
Root mass	−0.12
Random roughness	−0.18
Crop residues	−0.19
Canopy cover	−0.22
RUSLE P factor	0.45

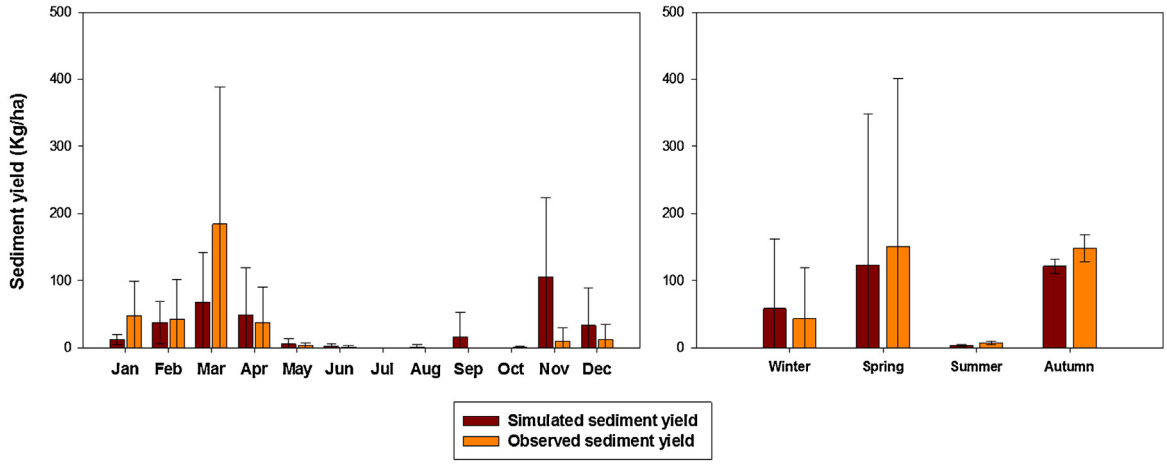

Fig. 9. Comparison of the simulated and observed monthly (left) seasonal (right) average sediment load for calibration.

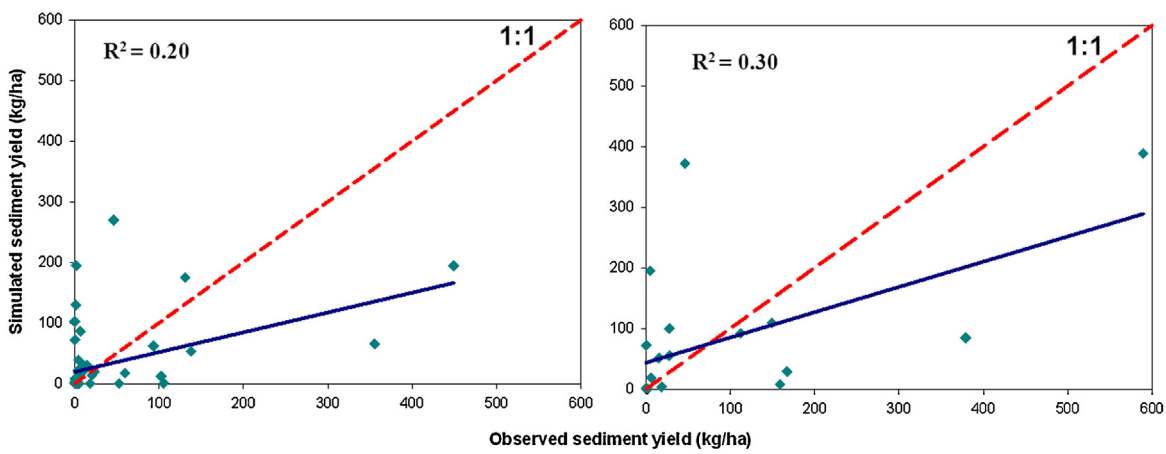

Fig. 10. Comparison between observed and simulated sediment load at monthly (left) and seasonal (right) scales for calibration.

respectively (which corresponds to a 0.06% of difference between observed and simulated sediment load). However, comparison between predicted and observed sediment load on a monthly and seasonal basis showed a low correlation (Table 5 and Figs. 9 and 10). Then, the results obtained after calibration can be considered as being unsatisfactory at monthly and seasonal scales. The model tends to overestimate sediment load during autumn and underestimate it during winter and spring.

The use of stream networks and corridors models (CCHE1D and CONCEPTS), already inserted in the system of computer models that make up AnnAGNPS, and that include more detailed science for the channel hydraulics, morphology, and transport of sediments, seem to be necessary for a more precise explanation of sediment yields and loads at event, seasonal and monthly scales, even for small watersheds. For that purpose, a more detailed topographic representation of the watershed, and mainly of channel slopes, would be required. Moreover, a thorough field inspection and survey within the watershed would help to better understand the processes behind sediment generation and, hence, lead to the correct choice of some auxiliary models.

3.3.3. Sediment load validation

The model was not able to satisfactorily reproduce observed records at monthly and seasonal time scales (Table 5 and Figs. 11 and 12). At annual scale, the model performed much better with only 7.1% of difference between the observed and simulated sediment load; the annual averages were 338.4 and 315.8 kg/ha/year for the simulated and observed sediment load, respectively. These large discrepancies in the model performance depending on the time scale considered might be explained as follows. At a small time scale (e.g. monthly) a noticeable mismatch was frequently observed between the amounts of sediment reaching the outlet with the corresponding runoff. This may be due, for instance, to the relatively easy re-entry of previously deposited sediment into streams. This would obviously lead to some failure in the model simulation at a short time scale. But, sooner or later, sediment reaches the watershed outlet so that in a context of an annual balance, sediment and runoff figures finally roughly matched. However, this better performance of the model at an annual scale is not reflected in the corresponding statistical indexes (Table 5) possibly because of the limited number of years used in the analysis. In fact, existing evaluations of the model prediction capability of annual sediment production are even fewer than those regarding annual runoff prediction (e.g., Das et al., 2008; Table 1). Furthermore these works are normally limited to showing proportional – numerical or graphical – differences between observed and simulated values without a statistical analysis (e.g., Das et al., 2008).

Regarding evaluation of sediment simulation at a monthly scale, the results shown in the literature are varied but, in general, better than those obtained in the present work (Table 1) perhaps because the model overlooked some important (in-stream) processes that occurred in the watershed. This reinforces our former hypothesis about the necessity to use stream network and corridor models.

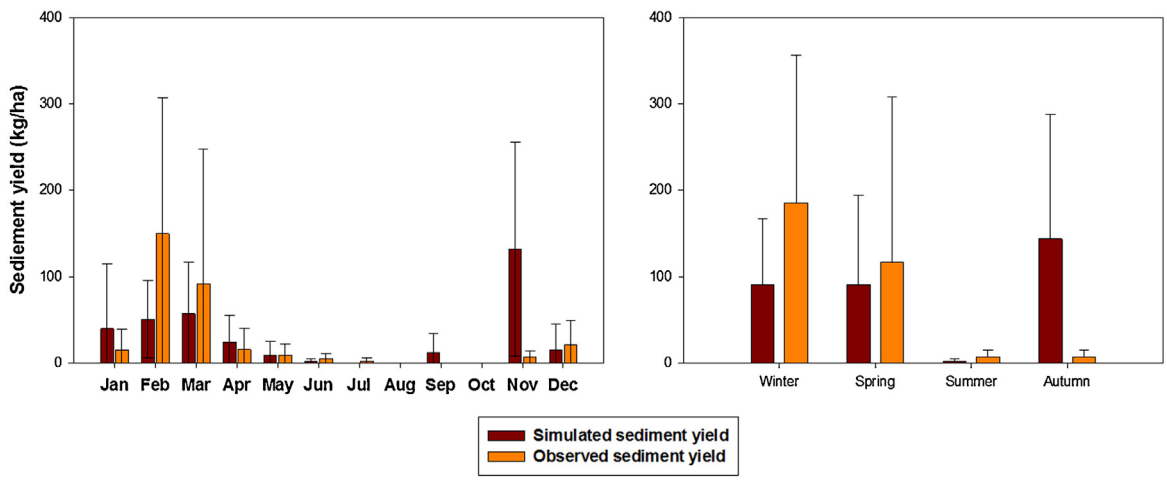

Fig. 11. Comparison of the simulated and observed monthly (left) seasonal (right) average sediment load for validation.

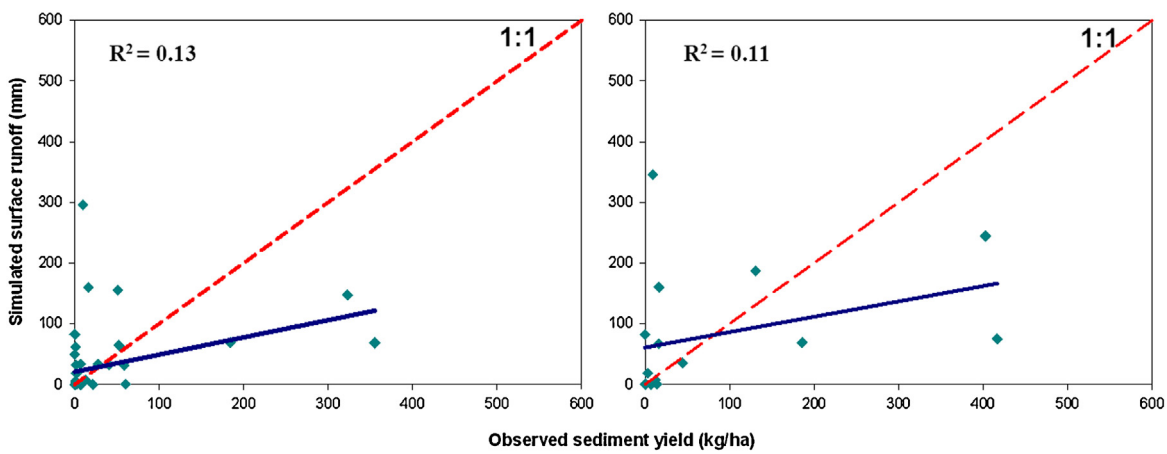

Fig. 12. Comparison between observed and simulated sediment load at monthly (left) and seasonal (right) scales for validation.

4. Conclusions

The AnnAGNPS model was evaluated for assessing its capability for predicting surface runoff and sediment load in a small Mediterranean agricultural watershed called "Latxaga" in the central part of Navarre using recorded data from January 2003 to December 2011.

AnnAGNPS showed an adequate capability in simulating surface runoff after calibration. This consisted of adjusting the initial CN values, as well as adding new CN values during winter and spring. Thus, a noticeable improvement in surface runoff prediction was obtained at monthly and seasonal time scales after calibration and also for validation, with values of performance assessment indicators such as Nash–Sutcliffe efficiency: $E_m = 0.75$, $E_s = 0.79$ for calibration and $E_m = 0.69$, $E_s = 0.94$ for validation at monthly and seasonal scales, respectively.

Concerning sediment load, a sensitivity analysis was carried out to evaluate the sensitivity of sediment prediction to a change in eight input parameters. AnnAGNPS was more sensitive to RUSLE-P factor, canopy cover, residue cover and random roughness coefficient followed by root mass, Manning's sheet coefficient, and, finally, rainfall height and Manning's reach coefficient.

AnnAGNPS was then calibrated based on sensitivity analysis results by adjusting the selected input data parameters. Successful results were only obtained at the annual scale. The model was capable of predicting the total sediment loads with a difference of less than 1% between measured and simulated values after calibration, and with a difference of 7% for validation.

The model response can be considered as satisfactory for determining Best Management Practices (BMPs), and for risk and cost/benefit analyses. The use of stream networks and corridors models, already inserted in the system of computer models that make up AnnAGNPS, and that include more detailed science for the channel hydraulics, morphology, and transport of sediments, seem to be necessary for a more precise explanation of sediment yields and loads at event, seasonal and monthly scales, even for small watersheds.

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