Effectiveness of alternative management scenarios on the sediment load in a Mediterranean agricultural watershed

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Abstract

The Annualised Agricultural Non-point Source model was used to evaluate the effectiveness of different management practices to control the soil erosion and sediment load in the Carapelle watershed, a Mediterranean medium-size watershed (506 km^2) located in Apulia, Southern Italy. The model was previously calibrated and validated using five years of runoff and sediment load data measured at a monitoring station located at Ordona - Ponte dei Sauri Bridge. A total of 36 events were used to estimate the performance of the model during the period 2007-2011. The model performed well in predicting runoff, as the high values of the coefficients of efficiency and determination during the validation process showed. The peak flows predictions were satisfactory especially for the high flow events; the prediction capability of sediment load was good, even if a slight over-estimation was observed. Simulations of alternative management practices show that converting the most eroding cropland cells (13.5% of the catchment area) to no tillage would reduce soil erosion by 30%, while converting them to grass or forest would reduce soil erosion by 36.5% in both cases. A crop rotation of wheat and a forage crop can also provide an effective way for soil erosion control as it reduces erosion by 69%. Those results can provide a good comparative analysis for conservation planners to choose the best scenarios to be adopted in the watershed to achieve goals in terms of soil conservation and water quality.

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Introduction

Soil erosion can lead to reduction of soil fertility, loss of nutrients, and declines of crop yields in farmlands, and can trigger the degradation of the soils and the land (Leh *et al*., 2013). In a review of mechanised agricultural systems in which wheat, corn, soybean and barley were planted, Bakker *et al*. (2004, 2005) found that on average, soil erosion reduced crop productivity by about 4% for each 10 cm of soil lost. In recent years, it is widely recognised that more site-specific approaches are needed to assess variations in erosion susceptibility in order to select the most suitable land management method (Pandey *et al*., 2008).

Structural and non structural measures to control negative impacts of runoff and erosion processes can be properly addressed through reliable prediction models. Although there has been considerable effort, additional work is needed to assess and improve the reliability of available prediction models in different environmental contexts. Reliable prediction models can help to select the most practical and effective tools in reducing erosion problems and developing appropriate land use planning (Licciardello *et al*., 2007; Haregeweyn *et al*., 2013). Numerous watershed models with various capabilities and degrees of complexity are available such as the Annualised Agricultural Non-point Source (AnnAGNPS) (Bingner and Theurer, 2005), WEPP (Flanagan *et al*., 2012), SWAT (Arnold *et al*., 1998). Thanks to their ability in predicting the watershed response to rainfall and other inputs, such models are largely used as tools for developing management strategies to reduce the effects of non-point source pollution on water quality (Borah *et al*., 2006).

AnnAGNPS has been implemented to assess runoff and water quality as well as sediment yield in small to large watersheds under different environmental conditions. Assessments of model performance, frequently coupled with calibration/validation trials in monitored watersheds ranging from 32 ha to 2500 km^2, have recently been published (Licciardello *et al*., 2007; Yuan *et al*., 2008; Parajuli *et al*., 2009; Zema *et al*., 2010). Different studies have been conducted using AnnAGNPS at the watershed scale in semi-arid environments (Licciardello *et al*., 2007; Taguas *et al*., 2012; Bisantino *et al.*, 2013; Chahor *et al.*, 2014). With particular reference to the Mediterranean environment, soil erosion in Southern Italy small watersheds characterised by ephemeral streams (Morgagni *et al*., 1993; Licciardello and Zimbone, 2002; Bisantino *et al*., 2013) was successfully predicted.

In order to estimate erosion and sediment transport processes in semi-arid environments the AnnAGNPS model was applied in the Carapelle watershed (Southern Italy). The model structure is suitable as it contains both empirical and quasi-physically based algorithms, it is fully distributed with land surface runoff and sediment processes modelled for the individual AnnAGNPS cell and the output is routed to the catchment outlet. The data requirements and computational complexity of the AnnAGNPS allow the model to be used as a tool for watershed management planning (Bisantino *et al.*, 2013).

The AnnAGNPS model was developed to analyse and provide estimates of runoff with primary emphasis upon sediment and nutrients transport from agricultural watersheds and to compare the effects of various conservation alternatives. Simulations under various combinations of different scenarios of land and water management can provide comparative analysis of different options and prove to be very useful as a guide to what best management practices (BMPs) can be adopted to minimise pollution from point and nonpoint sources (Shrestha *et al.*, 2006). BMPs are structural and non-structural approaches used to reduce pollutant loads in watersheds draining both urban and rural areas. The Soil and Water Conservation Society (SWCS) defines a BMP as a practice or combination of practices that are determined by a state or designated area-wide planning agency to be the most effective and practicable (including technological, economic and institutional considerations) means of controlling point and nonpoint source pollutants at levels compatible with environmental quality goals (Evans and Corradini, 2001). An important management practice is the no-till farming. No-till farming, due to an associated increase in surface residue and reduction in surface runoff, has been recommended as a best management practice to reduce soil erosion. Surface residues affect erosion by decreasing the soil surface area susceptible to raindrop impact, reducing the velocity of runoff and hence its transport capacity, and by creating mini-ponds that result in deposition behind clumps of residue (Fu *et al.*, 2006). Another conservation practice is the crop rotation (often called conservation crop rotation) that is defined as the use of different crops in a specified sequence on the same farm field. There are several reasons for using crop rotations, although the primary one is to reduce soil erosion, thereby reducing the quantities of sediment and sediment-bound pollutants such as nitrogen, phosphorus and pesticides (Evans and Corradini, 2001). Vegetation plays a critical role for soil conservation. Early research on the hydrologic impacts of vegetation management practices began in the 1910s was expanded into the 1930s and 1940s, and continued in the 1980s to further evaluate the effects of vegetation manipulations on the basin's water resources and other uses (Zou *et al.*, 2010). The impact of vegetation on the system is great. Vegetation produces an erosion-resistant peat layer, stabilises channel banks and slows down the water flow. Regarding flow resistance, vegetation increases roughness so reduces flow conveyance (Wolman and Gerson, 1978). The vegetation could retain 30%-70% of the deposited sediments. The ability of vegetation to entrap and retain sediment is related to the length and cross-sectional area of the vegetation (Thornton *et al.*, 1997). Vegetation also stimulates aggradation of bed load material on the channel bottom, and contributes to avulsion by blocking the channels (Gradzinski *et al.*, 2003).

The objective of this paper is to evaluate the effectiveness of alternative BMPs scenarios, and their impact on soil erosion, sediment load and sediment yield at the watershed scale. To reach this aim the AnnAGNPS model (V 5.0) was implemented in a middle sized Mediterranean watershed located in Southern Italy. The prediction capability of the model was previously estimated using a five years database. A continuous simulation process of runoff and sediment load has been carried out comparing the simulation outputs to the corresponding observed data measured during the period 2007-2011. The calibration process for the model parameters that have a large impact on the prediction capacity of the model has been performed at the event scale utilizing the events recorded in the period 2007-2008, then the validation process to evaluate the model performance using the events recorded in the period 2009-2011.

Materials and methods

Study area

The Carapelle torrent is one of the main streams that furrow the Tavoliere Plain of Apulia region (Southern Italy), between the Ofanto River and the promontory of Gargano (Figure 1; Table 1). Its flow regime is torrential as flood events are associated with intense rainfalls. Suspended sediment transport, mainly constituted by fine particles (Gentile *et al.*, 2010), is mostly concentrated during floods. The soils in the watershed predominantly belong to the Entisols type, with low organic matter content, natural fertility and water holding capacity. The areas with low slopes are occupied by cereal cultivation and olive orchards, while in the high steep slopes deciduous oaks, hardwoods (*Quercus pubescens* and *Quercus cerris*), and pasture conditions are present. The climate is typically Mediterranean, with rainfalls ranging from 450 to 800 mm/year and average temperatures from 10 to 16°C.

AnnAGNPS model description

The Annualised Agricultural Nonpoint Source Pollution model (Theurer and Cronshey, 1998; Bingner and Theurer, 2005; USDA-ARS, 2006) was developed by the USDA Agricultural Research Service (ARS) and Natural Resources Conservation Service (NRCS) to predict sediment and chemical delivery from un-gauged agricultural watersheds up to 300,000 ha (Bosch *et al.*, 2001). AnnAGNPS is a continuous watershed simulation, batch-process computer program where runoff, sediment, nutrients and pesticides are routed from their origins in upland subareas (cells) through a channel network to the outlet of the watershed (Bingner and Theurer, 2005). The climatic data requirements for simulations include daily maximum and minimum temperature, precipitation, average daily dew point temperature and wind speed and sky AnnAGNPS utilises the generation of weather elements for multiple applications climate generation model (Hanson and Johnson, 1998) to generate daily precipitation, maximum and minimum temperature, wind speed, and solar radiation. AnnAGNPS users also have the option to input measured climate data by uploading the data into the input editor.

AnnAGNPS hydrology is based on basic hydrologic principles during the daily time steps (Bingner and Theurer, 2005). The hydrologic processes simulated in the model include interception, evaporation, surface runoff, evapotranspiration, subsurface lateral flow and subsurface drainage (Yuan *et al.*, 2006b). In AnnAGNPS, runoff is predicted using the SCS curve number technique (USDA-SCS, 1986), and sheet and rill erosion are predicted with the revised universal soil loss equation (RUSLE) (Renard *et al.*, 1997). Soil moisture balance is calculated on a sub-daily time step using a simple constant-time step procedure for both the tillage and below tillage composite soil layers (Bingner and Theurer, 2005). Sediment transport in channels is computed using a modified Einstein equation, and the Bagnold (1966) equation is used to estimate sediment transport capacity of the flow (Bingner and Theurer, 2005). AnnAGNPS utilises the hydro-geomorphic universal soil loss equation model (Theurer and Clarke, 1991) to determine sediment delivery ratios of total sediment to the stream network.

Monitoring stream flow and suspended sediments

A monitoring station located at the Ordona old bridge has been established to continuously monitor the stream flow and suspended sediment load (Figure 1). An ultrasound stage meter and a stage recorder are in operation to monitor stream flow. Runoff is determined by converting the record of water levels into a record of flows using the experimental stage-discharge rating curve given by the National Hydrografic Service. An infrared optic probe (Hach-Lange SOLITAX Hsline) is used to monitor suspended sediments concentration (SSC), by coupling backscattering and nephelometric photodetectors.

Gentile *et al*. (2010) tested the probe in the laboratory in order to evaluate the functional capacity of the instrument and to assess the effects of the different grain size and solid fractions on measurements. The instrument was field calibrated during the flood events of 2007-2009 to evaluate the efficacy of the housing system, to identify a calibration curve of the instrument for the specific torrent and to assess the type of the relationship between the SSC measured by the instrument and the gravimetric SSC. The SSC of all samples was measured using the gravimetric method and compared with the data observed by the optical sensor.

Thirty-six events observed during 2007-2011 (Figure 2) were used for the application of the AnnAGNPS model. This number does not include all runoff and sediment loads that occurred in the watershed, as some storm events were not sampled due to equipment malfunctions or temporary lack of power to the sensor, caused by the solar panels. In general, the small number of flood events during the rainy season is a characteristic of Mediterranean watersheds (Bisantino *et al*., 2011).

Since base flow is not considered within AnnAGNPS, the surface runoff separation from baseflow was performed using the filtering algorithm developed by Eckhardt (2005). Baseflow separation is required in numerous widely used hydrological and erosive models and must be considered in monthly models (Mouelhi *et al*., 2006). The filtering algorithm has the following equation:

$$b_k = \frac{(1 - BFI_{\max})ab_{k-1} + (1-a)BFI_{\max}Q_t}{1 - aBFI_{\max}} \qquad (1)$$

where:
b_k is the base flow at time step k;
b_{k-1} is the base flow at the previous time step;
Q_i is the measured total flow;
BFI_{max} is a constant that can be interpreted as the maximum value of long term ratio of base flow to total stream flow;
a is the recession constant. The filter parameter a and BFI_{max} were calculated using the hydrograph recession curve analysis and the optimisation module developed by Kyoung *et al*. (2010).

Input data preparation

Topography

The topography of the study area was determined using a digital elevation map with resolution equal to 90 m, provided by the shuttle radar topographic mission project carried out by the National Aeronautics and Space Administration (NASA) and the National Geospatial-Intelligence Agency (NGA).

The watershed was modelled using the TOPAZ-based (Garbrecht and Martz, 1995) TopAGNPS program within the AnnAGNPS ArcView interface version 3.2 with a critical source area of 50 ha and minimum source channel length of 250 m. This delineation resulted in a total of 1006 cells and 416 reaches.

Land use and field management

Land use data are based on the 1:100,000 CORINE Land Cover data set (CLC2000). The accuracy of the data set has been validated in other studies by comparing images with ground based photography and field surveys (EEA, 2006). Based on the CLC2000 dataset, land uses were grouped in six main classes: cropland (winter wheat and olive-groves),

Table 1. Main characteristics of the Carapelle watershed, mouth at Ordona Bridge.

Parameter	Unit	Value
Watershed area	km^2	506.2
Maximum altitude	m asl	1075.0
Average altitude	m asl	466.0
Minimum altitude	m asl	120.0
Main channel length	km	52.2
Main channel slope	%	1.8
Mean watershed slope	%	8.2
Time of concentration	hour	10

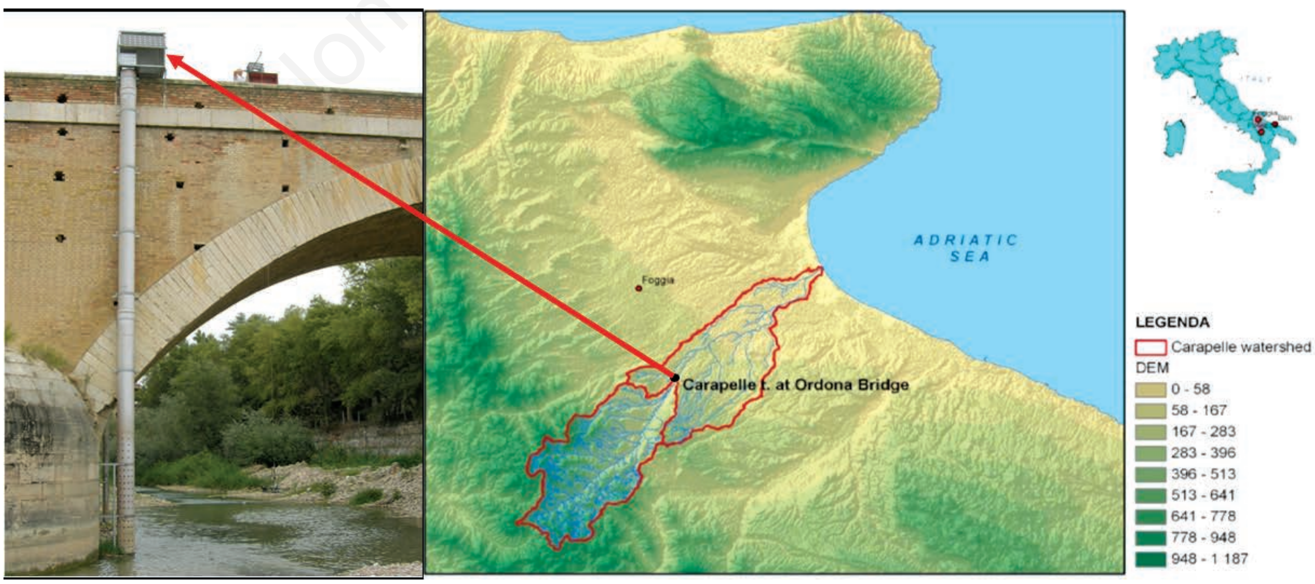

Figure 1. The stream flow and sediment load monitoring station and its location in the Carapelle watershed.

rangeland, forest, urban, fallow and pasture. Figure 3 reports the land use and the soil texture classes maps with the surface area covered by each land use and soil texture. The CORINE data set only distinguishes between arable land and agricultural or non-agricultural land use types, therefore information on crop growth and cropping methods were needed. In particular the crop data and management information required by the model include the units harvested, surface and subsurface decomposition, crop residue, root mass, canopy cover, management scheduling and agricultural operations.

The winter wheat crop parameters were based on RUSLE guidelines and internal databases (Renard *et al*., 1997) while four management practices were assigned to represent the local conditions of the watershed. Planting operations occurred in September and harvesting operations occurred in June. After harvest, the land is prepared with other management practices (tillage, semi-deep drill). The tillage effects are linked to the management of crop residues, control of competing vege-

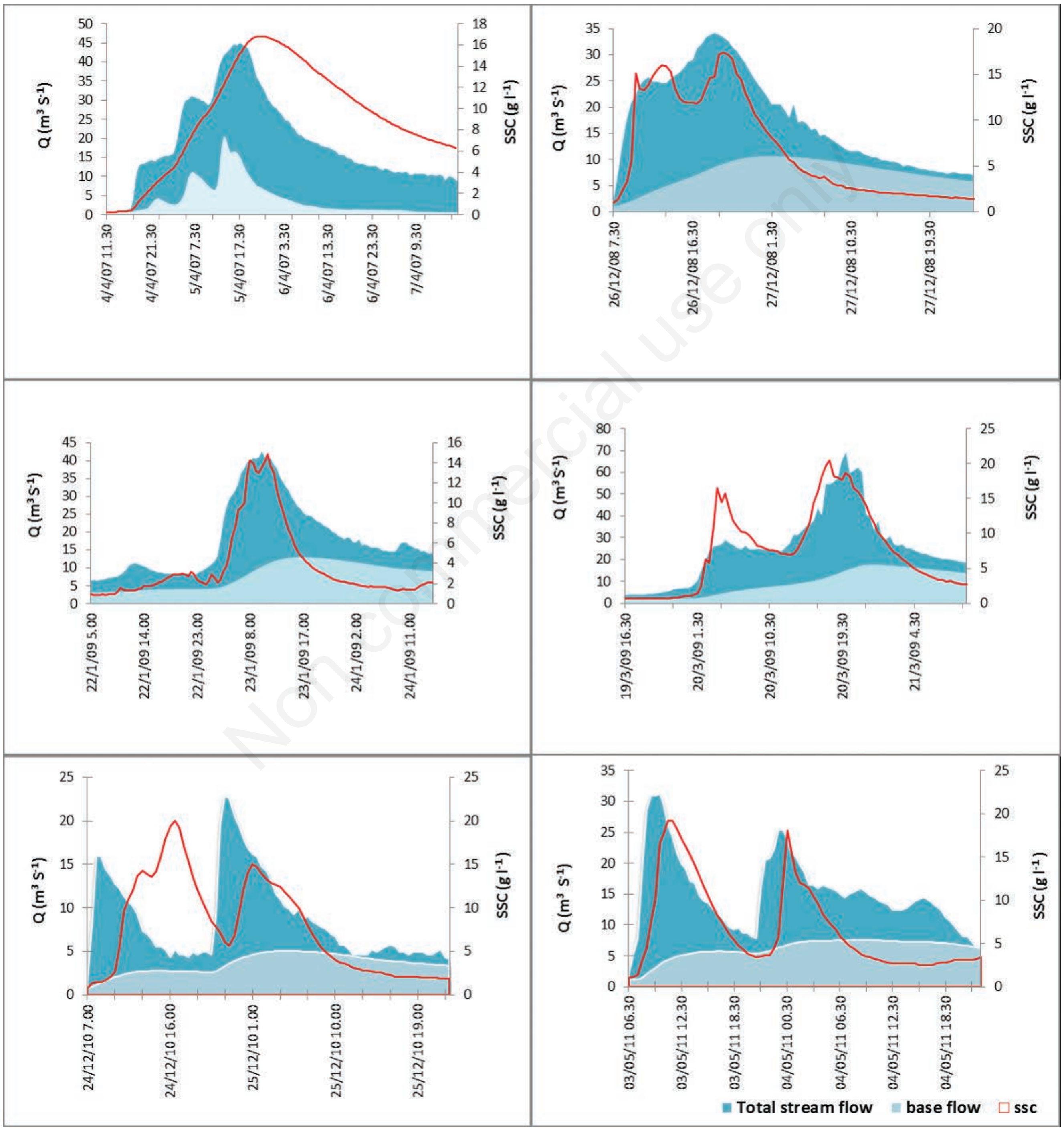

Figure 2. Measured stream flow, suspended sediments and calculated baseflow for some flow events registered during the period 2007-2011.

tation, incorporation of amendments, preparation of the seedbed and, in semi-arid zones, moisture conservation. The management operation data, including tillage and fertiliser application were scheduled as shown in Table 2. For the olive, a new database was created in which the root density, the estimated percent areal coverage of the crop canopy and the average rainfall drop height were assumed to remain constant respectively at 30,000 kg ha^{-1}, 50 % and 1 m (Galvagni *et al*. 2006). Single non-cropland databases were assigned to rangeland, forest, urban, fallow and pasture field types. The crop management factor C for each period was calculated by the model based on land use, canopy cover, surface cover, surface roughness and soil moisture conditions. The P factor was set to 1 since no significant management operations were implemented to reduce soil erosion.

Soil properties

Soil parameters such as the textural classes, saturated hydraulic conductivity and soil depths were extracted from the project Agro-eco-

Table 2. Management scheduling for cropland.

Event date	Management scheduling
Winter wheat	
06/01	Harvest grain
09/01	Tillage
09/20	Begin crop growth
12/15	Semi-deep drill
Olive grove	
01/01	Organic fertiliser application
04/01	Tillage operation
06/01	Shallow tillage operation
08/01	Shallow tillage operation
11/01	Harvest
12/01	Organic fertiliser application

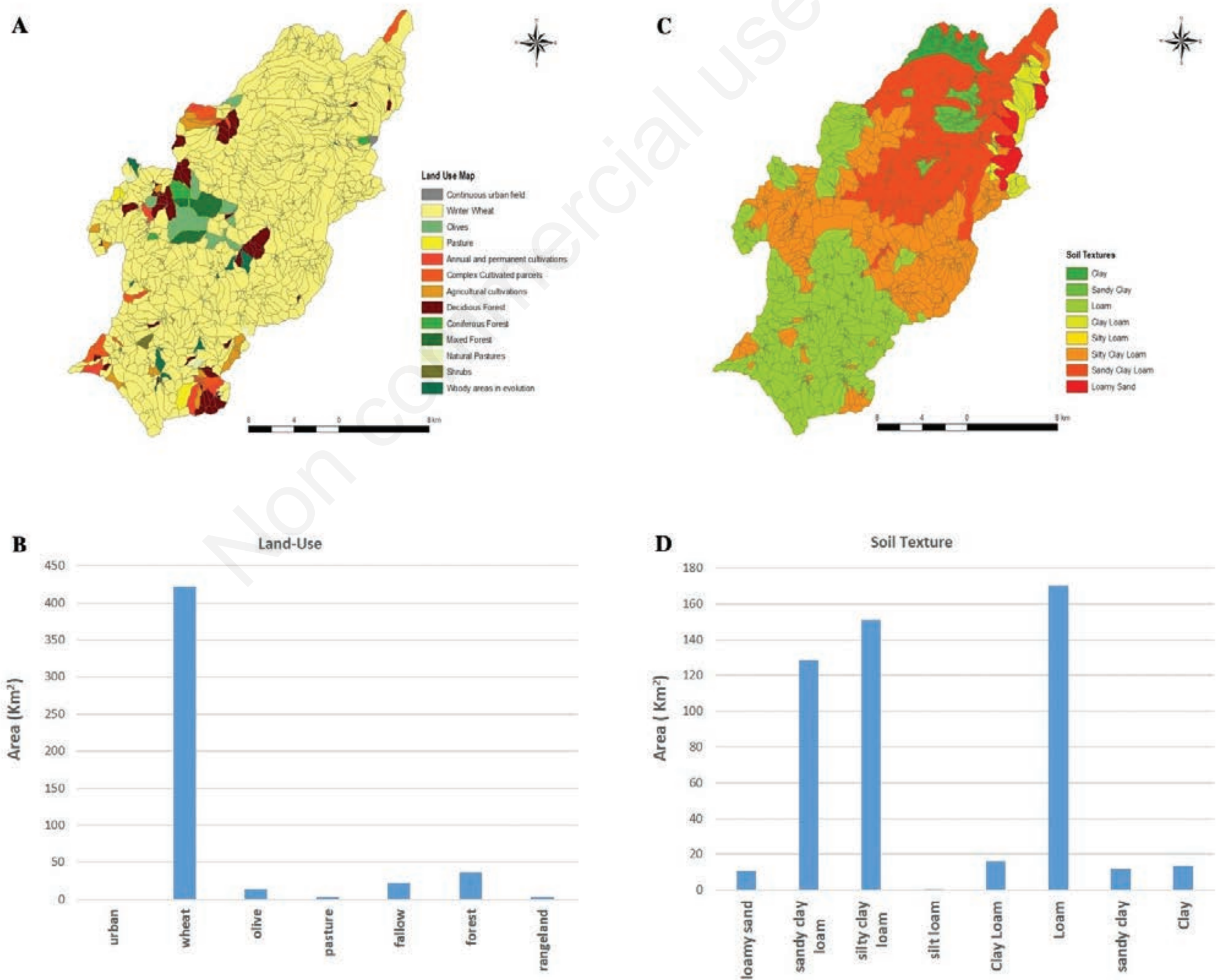

Figure 3. (A) and (B) are the land use map and the surface area covered by each land use; (C) and (D) are the soil texture classes and the surface area covered by each soil texture.

logical Characterisation of the Apulia Region named ACLA2 (scale 1:100,000), a project financed by the Apulia region for the agro-ecological characterisation of the region based on field observations, laboratory tests, and the interpretation of aerial photos and satellite images (Caliandro *et al*., 2005).

The soil depth is considered as the portion of soil that allows the development of functional and organic roots, where the term *functional* refers to soil moisture dynamics while *organic* considers the interactions involved in the organic matter production (Caliandro *et al*., 2005). On the basis of the United States Department of Agriculture soil textural classes the mean percentages by weight of sand, clay and silt, were assigned to each textural class. The percentage of organic matter was derived from the project Octop of the European Soil Data Centre (ESDAC, 2003).

In the Carapelle watershed soils have weak or no diagnostic subsurface layers and are generally well drained. In the root zone (h<110 cm), saturated hydraulic conductivity can be assumed to have high values (k_{sat}>3.6 cm/h), but the drainage can be restricted below the root zone (k_{sat}<0.036 cm/h). The average soil hydraulic properties, water content at wilting point Wp, field capacity Fc, and saturated hydraulic conductivity ks, were calculated for each soil type (Table 3) using the Saxton and Rawls (2006) pedotransfer functions. The RUSLE soil erodibility factor *K*, was estimated using the Lal and Elliot (1994) equation. Eight types of soils were identified and the average erodibility factors were calculated (Table 3). Based on each land use (cropland, fallow, rangeland, forest, pasture, urban) and hydrologic soil group (A, B, C, D) the initial curve numbers were defined (Table 4).

Climate

Meteorological data such as daily maximum temperature, daily minimum temperature, daily precipitation, daily sky cover, daily wind speed and daily dew point temperature were used as the input climate data for the simulations. The spatial distribution of climatic data were assessed using the Thiessen weighting procedure related to the eight rain gauges located in the watershed or in the surrounding area.

The rainfall erosivity factor R was estimated considering the mean monthly precipitation of the period 1979-1999, according to Ferro *et al*. (1999), resulting in 960.70 MJ mm ha^{-1}year^{-1} (Bisantino *et al*., 2013).

Model calibration and validation

Both the hydrological and erosion components of AnnAGNPS were calibrated/validated in a logical order taking into account a previous sensitivity analysis performed by Bisantino *et al.* (2013) for the most meaningful parameters of the model [R, K, C and P factors of USLE equation, curve number (CN) and Manning's roughness coefficient]. The parameter calibration order used was first surface runoff, then peak flow and finally sediment load. Input parameters affecting surface runoff and peak flow were first calibrated because of their influence on the other output.

The calibration/validation process of runoff was carried out by modifying the initial values of CN, which represent a key factor in obtaining accurate prediction of runoff and sediment load (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). For the calibration of peak flows and sediment loads, both 24 h rainfall distributions (types I and Ia) typical of a Pacific maritime climate with wet winters and dry summers outlined by the Natural Resource Conservation Service (NRCS) and described by SCS (1972) were considered. Based on the analysis of observed rainfall events at different rain gauges performed by Bisantino *et al.* (2013) it was found that both storm types well represent the meteorological conditions of Mediterranean zones. The storm type *I* was found to give better predictions of peak discharge during simulations.

The sediment loads were evaluated at the event scale by adjusting the sheet flow Manning's roughness coefficient for each cell. With sheet flow, the friction value (Manning's *n*) is an effective roughness coefficient that includes the effect of raindrop impact, drag over the plane surface; obstacles such as litter, crop ridges and rocks, and erosion and transportation of sediment (SCS, 1986).

The observed flood events have runoff volumes ranging from 0.2 to 8.6 mm (94,593 to 4,336,938 m^3), peak discharges between 1.6 and 73.6 m^3/s and sediment loads between 202 to 103,216 t (0.4 to 204 g m^{-2}). The years considered (2007-2011) had precipitation rates ranging from 544.0 mm in 2007 to 873 mm in 2010.

Model performance assessment

The model performance was evaluated at the event scale by qualitative and quantitative approaches. The qualitative approach consisted of visually comparing observed and simulated values. For a quantitative evaluation, a range of both summary and difference measures were used. The summary measures utilised were the mean and standard deviation of both observed and simulated values. For difference measures five evaluation criteria were used to evaluate the model performance: the coefficient of determination (R^2), the Nash-Sutcliffe coefficient of efficiency (NSE), the Willmott index of agreement (W), the coefficient of residual mass (CRM), and the root mean square error (RMSE). The coefficient of determination R^2 describes the proportion of the total variance in the observed data that can be explained by the model. R^2 is an insufficient and often misleading evaluation criterion as large values of R^2 can be obtained even when the model-simulated values differ considerably in magnitude. The Nash and Sutcliffe (1970) NSE was also used to assess the model efficiency (Table 5). In particular, some authors discussed that NSE is more sensitive to extreme values (Legates and McCabe, 1999; Krause *et al*., 2005). Willmott (1982) sought to overcome the insensitivity of correlation-based measures to differences in the observed and model-simulated means and variances by developing the index of agreement. CRM was used to indicate a

Table 3. Soil properties for each textural class.

Soil structure	K factor (t h MJ^{-1} mm^{-1})	Wp (%)	Fc (%)	ks (mm h^{-1})
Clay	0.035	0.3	0.42	4.5
Sandy clay	0.034	0.26	0.37	14.89
Loam	0.043	0.11	0.24	12.7
Clay loam	0.03	0.2	0.34	2.02
Silty-loam	0.044	0.1	0.27	9.88
Silty-clay-loam	0.043	0.18	0.37	4.59
Sandy-clay-loam	0.033	0.17	0.26	4.83
Sandy-loam	0.006	0.2	0.1	32.92

Table 4. Initial curve number values.

Cover type	Initial curve numbers for hydrologic soil groups			
	A	B	C	D
Cropland	72	81	88	91
Fallow	76	85	90	93
Rangeland	35	56	70	77
Forest	43	65	76	82
Pasture	49	69	79	84
Urban	89	92	94	95

prevalent model over- or underestimation of the observed values (Loague and Green, 1991). The values considered optimal for these criteria were one for R^2, *NSE* and *W* and zero for *CRM*. According to common practice, simulation results are considered good for values of NSE greater than or equal to 0.75, satisfactory for values of NSE between 0.75 and 0.36, and unsatisfactory for values below 0.36 (Van Liew and Garbrecht, 2003; Moriasi *et al*., 2007). Finally, the RMSE describes the difference between the observed and simulated values in the unit of the variable, and it ranges from zero to ∞, where zero indicates that there is no difference between model simulations and field observations. To quantify the model accuracy in simulating runoff, peak discharge and sediment load, AnnAGNPS was applied to simulate the entire period 2007-2009. The estimation efficiency was evaluated as relative error (RE). The RE is the ratio of the total difference between simulated and observed values versus the total observed value. It ranges from minus one to ∞ while zero indicates that there is no difference between model simulation and field observation. The smaller the absolute value of a RE, the better performance of the model is:

$$RE = \frac{|P-O|}{O} \qquad (2)$$

where P is the predicted value and O is the observed value.

The relative error was used to solve the problems of significance and units, as it is the ratio between the absolute error and the absolute value of the correct value.

Management practices

The management practices have an important role when applied as a plan of soil and water conservation. The aim of the simulation was to understand the entity of the soil erosion and sediment load reduction at a watershed scale in a Mediterranean environment when applying agricultural or environmental measures of soil erosion control.

Several different management practices were modelled in the AnnAGNPS model as means to reduce soil erosion and sediment load from the watershed. Those management practices could be a good starting point to design a combination of agricultural and environmental measures that can have a good impact on the reduction of sediment load from the watershed. Such a process, that should be carefully carried out to take into account the real conditions of the watershed in terms of physical, environmental, agricultural and socio-economic features, could drive to the definition of the so-called BMP. To evaluate the effectiveness of BMPs on sediment load, several alternative scenarios, shown in Table 6, were compared with the baseline existing condition, previously described in Table 2. The scenarios are based on those suggested by the Rural Development Plan of Apulia Region (period 2007-2013), imple-

Table 5. Coefficients and difference measures for model evaluation and their range of variability.

Coefficient	Equation	Range of variability
Coefficient of efficiency (Nash and Sutcliffe, 1970)	$NSE = 1 - \frac{\sum_{i=1}^{n}(O_i - P_i)^2}{\sum_{i=1}^{n}(O_i - \bar{O})^2}$	−∞ to 1
Willmott index (1982)	$W = 1 - \frac{\sum_{i=1}^{n}(O_i - P_i)^2}{\sum_{i=1}^{n}(\lvert P_i - \bar{O}\rvert + \lvert O_i - \bar{O}\rvert)^2}$	0 to 1
Coefficient of determination R^2	$r^2 = \left(\frac{\sum_{i=1}^{n}(O_i - \bar{O})(P_i - \bar{P})}{\sqrt{\sum_{i=1}^{n}(O_i - \bar{O})^2}\sqrt{\sum_{i=1}^{n}(P_i - \bar{P})}}\right)^2$	0 to 1
Coefficient of residual mass (Loague and Green, 1991)	$CRM = \left(\frac{\sum_{i=1}^{n}O_i - \sum_{i=1}^{n}P_i}{\sum_{i=1}^{n}O_i}\right)$	−∞ to ∞
Root mean square error	$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(O_i - P_i)^2}$	0 to ∞

mented on the basis of the agricultural policy of the European Union. To study the effect of land use change on the erosion process, and subsequently on the load arriving to the outlet, the cropland area or parts of it, was substituted by grass, as reported in scenarios D, E, and F. Similarly, the effect resulted from substituting the cropland area or parts of it with forestland, was studied in scenarios J, K, and L. In scenario M, a crop rotation of wheat and alfalfa, as a forage crop, was considered, with four years of wheat and one year of alfalfa; this rotation was chosen because it is used by some farmers in the watershed as a way to control soil erosion, as evidenced during field investigations.

Results and discussion

Calibration and validation

The model performance was calibrated at the event scale utilising 11 observed erosive events registered during the period 2007-2008 as done by Bisantino *et al*. (2013). The validation has been carried out on 25 events spanning from 2009 to 2011, including the 8 events recorded in 2009 and used by Bisantino *et al*. (2013). In un-calibrated mode, the model tends to over-predict the runoff volumes, so the initial CNs were properly decreased to get runoff results closer to the observed ones. The same results were found in semi-arid conditions by Licciardello *et al*. (2007). At the end of calibration, runoff depths were in general slightly over predicted (see the negative value of the CRM coefficient in Table 7). The mean value and the standard deviation of the simulated runoff depths were close to the observed corresponding values, with a difference equal approximately to 10 and 2% respectively. The coefficient of determination and the Nash-Sutcliff efficiency factor achieved after the runoff calibration were good (Table 7). Similar results were found at the event scale by other authors like Yuan *et al*. (2001), Shrestha *et al*. (2006) and Shamshad *et al*. (2008).

After calibration, the mean predicted value of peak flow was 14% different from the mean observed value, however, the difference between predicted and simulated values raises for the standard deviation to be more than 40% (Table 7). High efficiency is shown by the coefficient of determination R^2 value (R^2=0.81), while other statistical indexes (NSE and RMSE) show a satisfactory prediction (Table 7). Other authors (Zema *et al*., 2010; Shrestha *et al*., 2006; Licciardello *et al*., 2007) found

Table 6. Results of the simulations using different scenarios.

Scenario	Description of scenario	Erosion (Mg ha^{-1} yr^{-1})	Yield (Mg ha^{-1} yr^{-1})	Load (Mg ha^{-1} yr^{-1})
B	Base scenario (current conditions)	0.629	0.296	0.206
D	All cropland areas converted into grass	0.065	0.025	0.018
E	2.5% of cropland areas converted into grass	0.577	0.275	0.194
F	13.5% of cropland areas converted into grass	0.400	0.194	0.131
J	All cropland areas converted to forestland	0.065	0.025	0.019
K	2.5% of cropland areas converted to forest	0.578	0.275	0.192
L	13.5% of cropland areas converted to forest	0.399	0.194	0.138
M	Crop rotation (4 yr wheat_1 yr alfalfa)	0.196	0.091	0.070

Table 7. Statistics concerning the AnnAGNPS calibration and validation in the Carapelle watershed.

	Mean	SD	NSE	R^2	CRM	RMSE	W
Calibration							
Runoff (mm)							
Observed	1.5	1.9	-	-	-	-	-
Default simulation	2.1	2.4	0.38	0.65	–0.42	1.4	0.88
Calibrated model	1.7	1.9	0.76	0.78	–0.1	0.91	0.93
Peak flow (m^3/s)							
Observed	16	14	-	-	-	-	-
Default simulation	27	31	–1.4	0.86	–0.75	21	0.78
Calibrated model	18	20	0.54	0.81	–0.14	9.2	0.92
Sediment load (kg/m^2)							
Observed	0.018	0.025	-	-	-	-	-
Default simulation	0.037	0.044	–0.81	0.62	–1.04	0.33	0.77
Calibrated model	0.024	0.028	0.67	0.74	–0.35	0.01	0.92
Validation							
Runoff (mm)							
Observed	2.56	2.22	-	-	-	-	-
Simulated	2.28	2.18	0.81	0.82	0.11	0.99	0.95
Peak flow (m^3/s)							
Observed	29	18	-	-	-	-	-
Simulated	26	22	0.69	0.82	0.11	10.2	0.93
Sediment load (kg/m^2)							
Observed	0.036	0.05	-	-	-	-	-
Simulated	0.038	0.04	0.86	0.86	–0.06	0.02	0.96

SD, standard deviation; NSE, Nash-Sutcliffe coefficient of efficiency; R^2, coefficient of determination; CRM, coefficient of residual mass; RMSE, root mean square error; W, Willmott index of agreement.

that the model unsatisfactory predicted peak flows.

To calibrate the sediment load, sheet flow Manning's *n* roughness coefficient of each cell was modified starting from the initial values taken from TR55 (SCS, 1986). For forest and rangeland, Manning's *n* values respectively equal to 0.8 and 0.13 were set, while for urban areas, cropland and pasture the initial value of 0.15 was considered. Increasing the value of MN for the different land uses and especially for the cropland (wheat) and urban areas, the tendency of the model to overestimate the suspended sediment load that is clear in the un-calibrated mode was reduced (see the CRM values before calibration in default simulation and after calibration in (Table 7). Generally, a good correlation between observed and simulated data was obtained, as reported by the Nash Sutcliffe efficiency index and the coefficient of determination R^2; the value of the root mean square error was close to zero, showing a good model efficiency in predicting sediment load. As for validation, the results were excellent in the simulation of runoff volumes (Table 7), and satisfactory in modelling peak discharges, as witnessed by RMSE, NSE, and R^2 values.

Figure 4 reports the visual comparison between simulated and observed data for the entire period (thirty-six events). As expected using the calibrated SCS-CNs, the model prediction is good for runoff and sediment load and satisfactory for peak discharge.

After the validation process, it was observed, comparing the statistical indexes, that the model prediction was better in the validation than in the calibration process. To better understand this result, the RE was calculated for two groups of events and represented on a box plot (Figure 5). The first group (26 events) has peak discharges $Q_p \leq 30$ m^3 s^{-1} and is representative of low flow events, as previously stated by Gentile *et al*. (2010) in the same watershed; the second group (10 events) has peak discharges $30 < Q_p \leq 73.6$ m^3 s^{-1} and is representative of high flow events. A difference in the RE values between the two groups was observed, showing that the model better predicts sediment load for high intensive events and that a larger scatter between simulated and observed sediment load values exists for low flow events. The same behaviour was observed for peak flows.

As the number of high flow events included in the validation process (25 events, 3 years) is greater than those included in the calibration (11 events, 2 years), this could be the reason why the model performs better in validation than in calibration.

Effectiveness of alternative management practices

AnnAGNPS model produces the amount of soil erosion generated from each user-specified computational area in the watershed, as shown in the map reported in Figure 6. The map is very useful to identify the highest sediment producing cells that can be first targeted to get better and effective results in erosion and load reduction. Based on the soil erosion map, the watershed was classified into three erosion classes. The cells that produce more than 2.5 Mg ha^{-1}yr^{-1} of sediments, that account for 2.5% of the total watershed area were targeted in scenarios E and K; the cells that produce soil erosion greater than 1.2 Mg ha^{-1}yr^{-1} that accounts for 13.5% of the watershed, were targeted in scenarios F and L. A similar approach was followed by Yuan *et al*. (2006a) in the case of the *Bayou Lafourche* watershed, where the areas producing more than 3.7 Mg ha^{-1}yr^{-1} of sediments and those that produced more than 1.1 Mg ha^{-1}yr^{-1} were identified.

In Table 6 the average annual soil erosion, sediment yield and sediment load are reported, with reference to the different management practices that were implemented. The soil erosion refers to the amount of soil detached from the landscape; the sediment yield refers to the amount of sediment that moves through the landscape and reaches the channel; the sediment load refers to the amount of sediment that moves through the stream channels and reaches the watershed outlet,

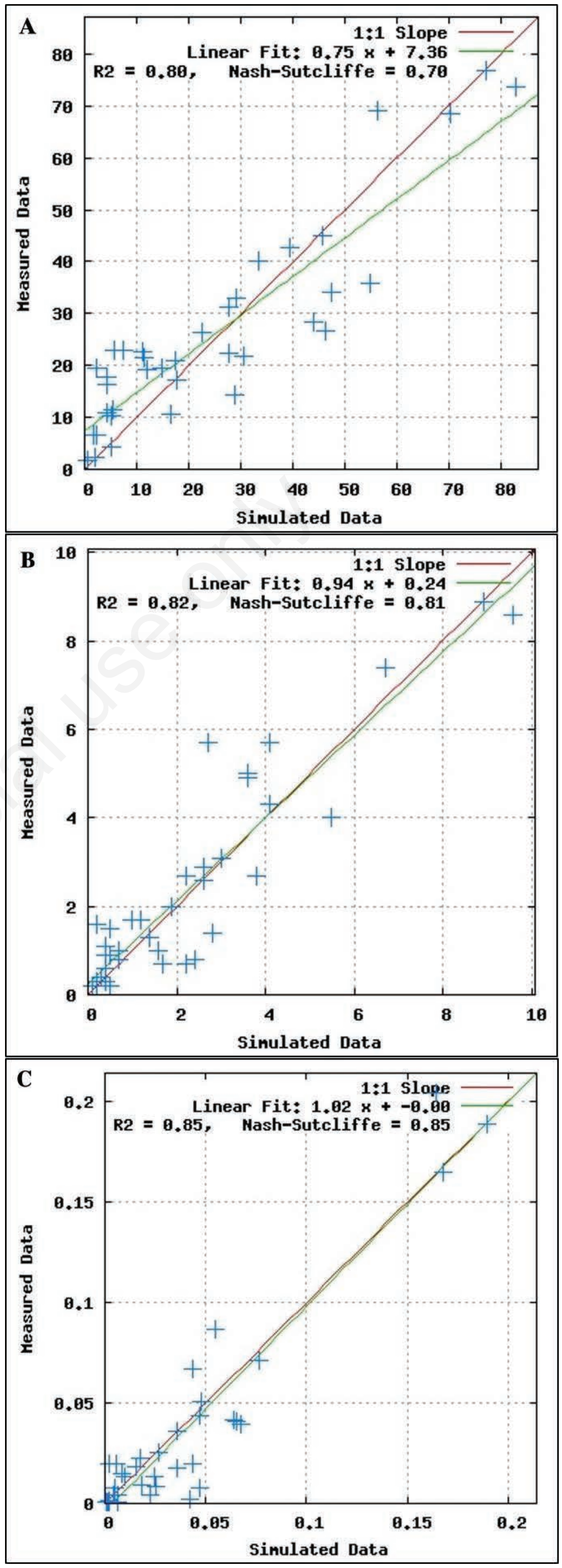

Figure 4. Comparison of 36 observed and simulated events: (A) peak flow (m^{3}s^{-1}), (B) runoff (mm) and (C) sediment load (kg m^{-2}) in the Carapelle watershed.

as reported by Yuan *et al*. (2006a). The values shown in Table 6 are average annual values over 5 years of simulations (period 2007-2011). Scenario B represents the current conditions of the watershed and resulted in an annual average erosion over the entire watershed equal 0.63 Mg ha^{-1}yr^{-1}. Simulations of different management scenarios were compared with the case that represents the existing conditions (scenario B). The effect of land use changes was evaluated by converting different cropland areas to grassland as in scenarios D, E, and F. Scenario D, in which all cropland is substituted with grass, can be considered as a reference for the evaluation of this practice. Implementing the scenario E, in which 2.5% of the cropland area is substituted with grass, gives origin to 8.5% reduction in soil erosion, while implementing scenario F (substitution of 13.5% of the cropland area) reduced soil erosion by 36.5%, which leads in turn to sediment yield and sediment load reductions by 34.5 and 36%, respectively. A total cover with grass (100%, scenario D) reduced soil erosion by 90% and sediment load by 91%. These results account for the optimum role of grass in covering the soil during severe storms in addition to its role in retaining the sediment in sight before being transported to the reaches and hence to the outlet. These results are in agreement with those found by Yuan *et al*. (2006a), obtained applying 100% grass instead of cropland that showed a reduction in soil erosion by 98% and in sediment load by 97%. The Authors also found that it was more realistic and economically feasible converting different percentages of high eroding areas to grassland. In their study they implemented a scenario in which 16.6% of the highest eroding cropland was converted to grass and another one in which 25.2% of the highest eroding cropland was converted to grass, which reduced the soil erosion by 72 and 86% respectively and sediment load by 65 and 80%. In a different study performed in the Fort Cobb reservoir in Central Oklahoma (787 km^2), Garbrecht and Starks (2009) found that converting 20% of the most erosion-prone cropland to grassland reduced the overall sediment load from cropland channels by more than 20%. Using the same concept of converting cropland into another type of land use, another management practice was considered, that is converting different percentages of cropland into forestland (scenarios J, K, and L). The scenario J, in which all the cropland areas are substituted with forest, is used here as a reference value. Soil erosion was reduced by 90%, this result being in agreement with the findings of Yuan *et al*. (2006a) that achieved a 99% reduction in soil erosion and 97% reduction in sediment load when all cropland area was substituted with forestland. In scenarios K and L, in which only 2.5 % and 13% of cropland areas were converted to forest, a sediment load reduction equal to 8 and 36.5% respectively was achieved (Figure 7). In a similar study Tian *et al*. (2010) converting all cropland to forestland in the Heigou River watershed in China, reduced sediment yield by 96.8%, while converting only cropland with slope more than 25° to forest and cropland areas with slopes more than 10° reduced the sediment yield in the watershed by 56.8 and 82.8% respectively.

A crop rotation of wheat and alfalfa (scenario M), composed of four years of wheat and one year of alfalfa, is recommended and followed by some farmers and landowners in the watershed to control soil erosion. It leads to a reduction in soil erosion equal to 70%, which results in a sediment yield and sediment load reduction equal to 69.5 and 66%, respectively. Shi *et al*. (2004) found that the improvements resulting from crop rotations practices have the potential to reduce the area with soil loss >soil loss tolerance for economic planning (that was set equal to 10 Mg ha^{-1}yr^{-1}) to approximately 9% of the watershed area.

Most of the systems considered in this study have a reasonable chance of being implemented if financial incentive programs exist or could be developed. On the other hand, some scenarios considered in this study (such as converting 100% of the cropland areas to 100% grass or 100% forest) cannot be realistically implemented, but have been useful as benchmarks to evaluate the effects of the other options.

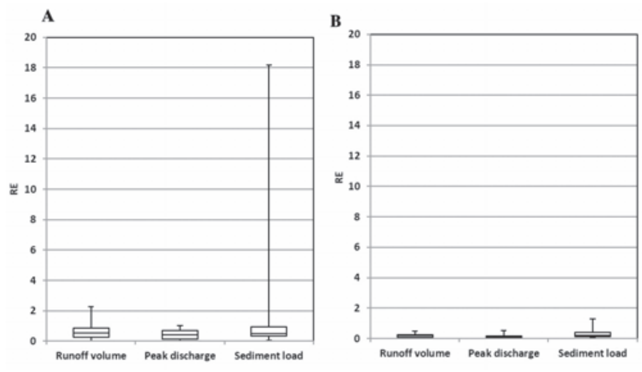

Figure 5. Average relative error (RE) for low flow events (A) and high flow events (B).

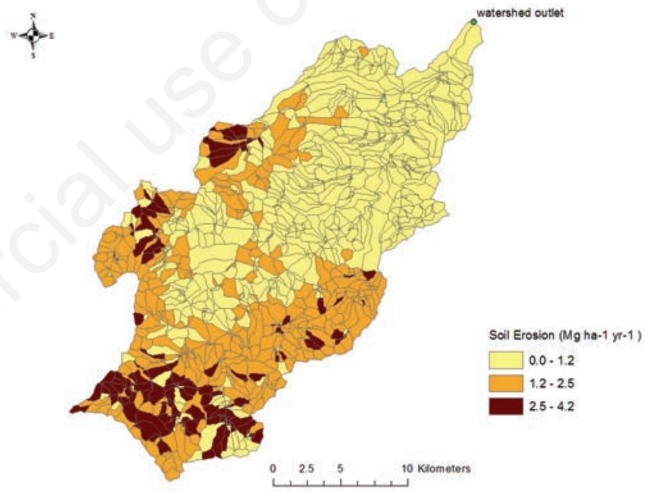

Figure 6. Soil erosion map.

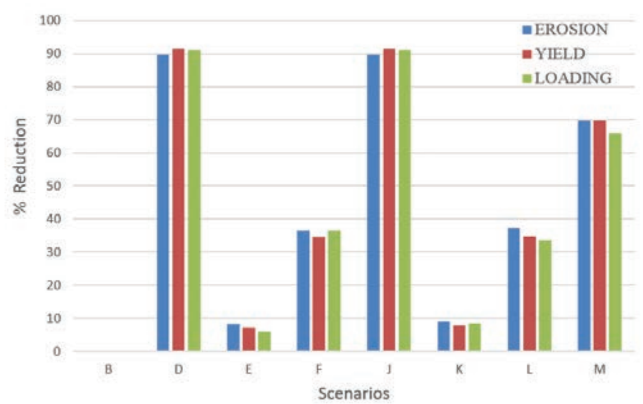

Figure 7. Soil erosion, sediment yield and sediment load reduction using alternative scenarios.

Conclusions

The AnnAGNPS model performed well in predicting runoff and sediment load on the event basis in calibration and validation, while its performance was satisfactory for peak discharge. Generally, the model showed a tendency to better predict high flow events while a greater scatter was found between observed and predicted values in case of low flow events. When applied to the identification of BMPs, the model showed the best practices to be the full conversion of cropland areas to grass or forestland, even though these scenarios cannot be considered realistic for economic reasons. A crop rotation of wheat and a forage crop can also provide an effective way for erosion control as it reduces erosion by 69%. Using the AnnAGNPS model to identify critical areas that produce high amounts of soil erosion and simulating the conversion of the most eroding 13.5% cells to grass or forest, a 36.5% erosion decrease was observed in both cases. Further analysis could be implemented to test scenarios combining two or more different management practices and taking into account those encouraged by regional incentives for the farmers.

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