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Chapter 1

Prediction of Surface Runoff and Soil Erosion at Watershed Scale: Analysis of the AnnAGNPS Model in Different Environmental Conditions

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Additional information is available at the end of the chapter

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1. Introduction

Negative effects of surface runoff and soil erosion in watersheds can be controlled and mitigated through hydrological models. Moreover, they are suitable to simulate various combinations of different scenarios of land and water management in a watershed and therefore they are useful for comparative analysis of different options and as a guide to what Best Management Practices (BMPs) can be adopted to minimize pollution from point and non-point sources (Shrestha et al., 2006).

Continuous simulation models (e.g. AnnAGNPS, WEPP, SWAT, etc.) provide great advantages over event-based models as they allow watersheds and their response to be studied over a longer time period in an integrated way. Nowadays, several continuous watershed-scale erosion models are available: however, relatively little validation of their performance under varying climatic and land use conditions has been carried out. The latter is an essential step before a model can be reliably applied.

The AnnAGNPS (Annualized Agricultural Non-Point Source) model (Geter and Theurer, 1998; Bingner and Theurer, 2001) is among the distributed models developed to evaluate the continuous hydrologic and water quality responses of watersheds. Many major hydrologic concepts of the single-event AGNPS model (Young et al., 1987) have been updated through the continuous simulation modeling of watershed physical processes (Baginska et al., 2003).

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AnnAGNPS has been implemented to assess runoff water amount and quality as well as sediment yield in small to large monitored watersheds (ranging from 0.32 to 2500 km^2) under different environmental conditions. Such applications were frequently coupled with calibration/validation trials. Poor AnnAGNPS predictions of sediment and nutrient loads were achieved in a Georgia watershed, covered by both extensive forest and riparian conditions and attributed this to the defective data input used with the model (Suttles et al., 2003). Moderate accuracy in model simulation of phosphorous and nitrogen processes was also highlighted by model applications in two small watersheds located in the Mississippi Delta (Yuan et al., 2005) and in the Sydney region (Baginska et al., 2003). The capability of the model (coupled to the BATHTUB eutrophication reservoirs model) in simulating nutrients load variations in response to land use changes in a Kansas large reservoir was pointed out by Wang et al. (2005).

In applications to a small Mississippi watershed reported by Yuan et al. (2001, 2005), AnnAGNPS adequately predicted long-term monthly and annual runoff and sediment yield and predicted and observed runoff from individual events were reasonably close, achieving coefficients of determination r^2 and efficiency E (Nash and Sutcliffe, 1970) equal to 0.94 and 0.91 respectively). In a small Australian watershed, mainly covered by farming and residential land uses, acceptable model predictions (E = 0.82) were assessed for runoff at event scale after the calibration of hydrological parameters Baginska et al. (2003).

More recently AnnAGNPS was implemented at a small Nepalese watershed, mainly forested and cultivated, where the need of calibration for satisfactory runoff predictions was shown. Despite the calibration process, peak flow and sediment yield evaluation resulted in a much lower accuracy (Shrestha et al., 2006). The prediction performance of AnnAGNPS in a 48-km^2 watershed located in Kauai Island (Hawaii, USA) was considered good for monthly runoff predictions and poor on a daily basis (Poliakov et al., 2007). Calibration/validation tests in two small watersheds in S. Lucia Island (British West Indies) (agricultural and forested respectively) suggested that AnnAGNPS could be used under the conditions tested tested (Sarangi et al., 2007). In an agricultural river basin (374 km^2) of Czech Republic suspended load following short duration intensive rainfall events was accurately predicted by the AnnAGNPS model; there the model was not suitable for continuous simulation in large river basins with a high proportion of subsurface runoff (Kliment et al., 2008). In a 63-km^2 watershed in Malaysia (tropical region which sometimes experiences heavy rainfall runoff) was well predicted while results with respect to sediment load were moderate (Shamshad et al., 2008).

Some applications in Spanish catchments covered by olive orchards showed the sensitivity of AnnAGNPS to different temporal scales in modeling runoff and sediment yield under different management systems (Aguilar and Polo, 2005) and the model applicability to predict runoff and sediment at event and monthly scales after calibration (Taguas et al., 2009). A calibration/validation exercise using a 10-year hydrological database in 53-km^2 watershed in Ontario (Canada) highlighted that adjustments of the monthly curve number values and of the RUSLE parameters are relevant to improve the hydrology and sediment components of AnnAGNPS, especially during winter and early spring periods (Das et al., 2009). A good model performance was obtained in terms of runoff and erosion prediction after calibration/

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validation processes in a 136-km^2 agricultural watershed in south-central Kansas; total phosphorus predictions were instead good only for the calibration period (Parajuli et al., 2009). Finally, a poor model performance in simulating agricultural pollution by nitrogen, phosphorus and sediment was obtained in a 16.97-km^2 watershed located in North Dakota (USA), mainly due to the large size of the study area and the high variability in land use and management practices (Lyndon et al., 2010).

Thus, the results of AnnAGNPS evaluations that have hitherto been carried out are generally promising. At the same time it can be noticed that model performance is variable and the boundary conditions under which the model may be successfully used for runoff and sediment yield prediction have not been well defined.

2. Aim of the work

In order to consolidate use of the AnnAGNPS model in different climatic and geomorphologic conditions, this investigation has verified model prediction capability of surface runoff, peak flow and sediment yield in two small European watersheds under climate conditions typical of the semi-arid (Cannata watershed, southern Italy) and humid-temperate (Ganspoel watershed, central Belgium) environments respectively. Through this work we have investigated to what extent AnnAGNPS may be expected to provide usable results in environmental conditions outside of research watersheds, where sometimes the necessary data for model calibration and validation are not available.

3. The AnnAGNPS model

AnnAGNPS is a distributed parameter, physically based, continuous simulation, daily time step model, developed initially in 1998 through a partnering project between the USDA Agricultural Research Service (ARS) and the Natural Resources Conservation Service (NRCS). The model simulates runoff, sediment, nutrients and pesticides leaving the land surface and shallow subsurface and transported through the channel system to the watershed outlet, with output available on an event, monthly and annual scale. Required inputs for model implementation include climate data, watershed physical information, as well as crop and other land uses as well as irrigation management data.

Because of the continuous nature of AnnAGNPS, climate information, which includes daily precipitation, maximum and minimum temperatures, dew point temperatures, sky cover and wind speed, is necessary to take into account temporal weather variations. The spatial variability of soils, land use, topography and climatic conditions can be accounted for by dividing the watershed into user-specified homogeneous drainage areas. The basic components of the model include hydrology, sedimentation and chemical transport.

The SCS curve number technique (USDA-SCS, 1972) is used within the AnnAGNPS hydrologic submodel to determine the surface runoff on the basis of a continuous soil moisture balance. AnnAGNPS only requires initial values of curve number (CN) for antecedent moisture condition AMC-II, because the model updates the hydrologic soil conditions on the basis of the daily soil moisture balance and according to the crop cycle.

The peak flow is determined using the extended TR-55 method (Cronshey and Theurer, 1998). This method is a modification of the original NCRS-TR-55 technology (USDA-NRCS, 1986), which is considered as a robust empirical approach suitable for wide variety of conditions including those where input data might be limited as in the experimental watershed (Polyakov et al., 2007).

The AnnAGNPS erosion component simulates storm events on a daily basis for sheet and rill erosion based on the RUSLE method (Revised Universal Soil Loss Equation, version 1.5, Renard et al., 1997). The HUSLE (Hydrogeomorphic Universal Soil Loss Equation, Theurer and Clarke, 1991) is used to simulate the total sediment volume delivered from the field to the channel after sediment deposition.

The sediment routing component simulates sheet and rill sediment deposition in five particle size classes (clay, silt, sand and small and large aggregates) on the basis of density and fall velocity of the particles and then routes sediment separately through the channel network to the watershed outlet as a function of sediment transport capacity (calculated by the Bagnold equation; Bagnold, 1966). A key assumption is that the aggregates break up into their primary particles once they enter the stream channel.

For the chemical component of the model, dissolved and adsorbed sediment predictions are assessed for each cell by a mass balance approach. Algorithms for nutrient (nitrogen, phosphorous and organic carbon) and pesticide dynamics are largely similar to the EPIC (Williams et al., 1984) and GLEAMS (Leonard et al., 1987) models.

More details on the theoretical background of AnnAGNPS are reported by Bingner and Theurer (2005).

4. Description of the Experimental Watersheds

The input data utilised for AnnAGNPS implementation in the Cannata watershed was collected during a proper monitoring campaign providing topographic, soil and land use data as well as 7-year hydrological observations.

For model verification in the Ganspoel watershed the input database was drawn from the works by Steegen et al., 2001 and Van Oost et al., 2005. Compared to the Cannata watershed, this experimental database reported less geomorphological information; moreover, the hydrological observations were related only to a 2-year period: thus this study case represents a typical “data-poor environment” (Merritt et al., 2003).

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4.1. Cannata watershed

4.1.1. Geomorphological information

The Cannata watershed, located in eastern Sicily, southern Italy (outlet coordinates 37 53'N, 14 46'E), is a mountainous tributary, ephemeral in flow, of the Flascio River (Figure 1).

The watershed covers about 1.3 km^2 between 903 m and 1270 m above mean sea level with an average land slope of 21%. The longest channel pathway is about 2.4 km, with an average slope of about 12% (Figure 2). The Kirpich concentration time is 0.29 h.



Figure 1. View of the Cannata watershed in proximity of its outlet.

In a survey conducted at the start of experimental campaign, five different soil textures (clay, loam, loam-clay, loam-sand and loam-sand-clay) were recognized on 57 topsoil samples; clay-loam (USDA classification) resulted as the dominant texture. The soil saturated hydraulic conductivity, measured by a Guelph permeameter, resulted in the range 0.2 to 17.6 mm h^{-1}.

Continuous monitoring of land use has highlighted the prevalence of pasture areas (ranging between 87% and 92% of the watershed area) with different vegetation complexes (up to 15 species) and ground covers. Four soil cover situations can be distinguished: a high-density herbaceous vegetation (eventually subjected to tillage operations), a medium-density herbaceous vegetation, sparse shrubs and cultivated winter wheat with a wheat-fallow rotation. More detailed information about the watershed characteristics and the monitoring equipment were reported previously (Licciardello and Zimbone, 2002).

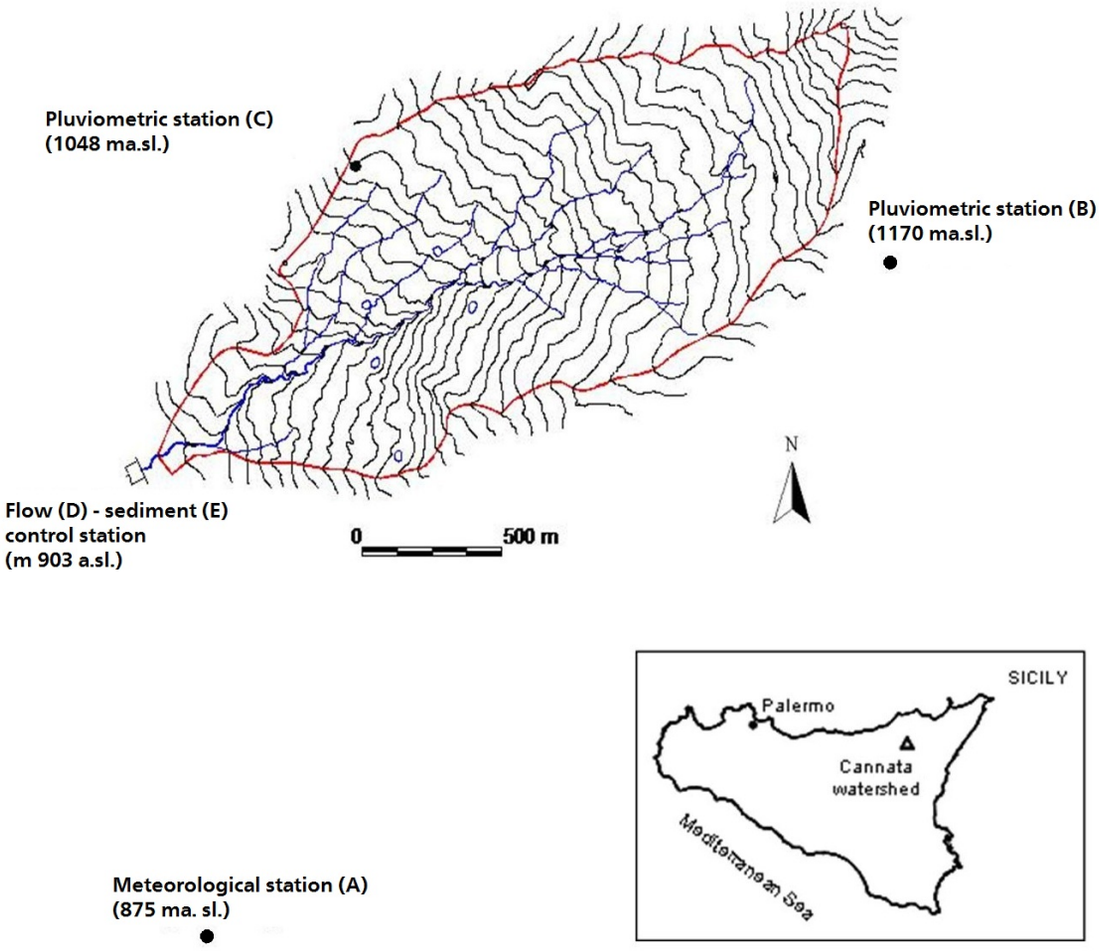


Figure 2. Location, contour map and hydrographic network of the Cannata watershed.

4.1.2. The hydrological database

In the monitoring period of 1996 to 2003 the hydrological observations were collected utilising the following equipment (Figure 2): a meteorological station (A, located outside of the watershed) recording rainfall, air temperature, wind, solar radiation and pan evaporation; two pluviometric stations (B and C); and a hydrometrograph (D) connected to a runoff water automatic sampler (E) for the measurement of sediment concentration in the flow.

In the observation period yearly rainfall between 541 and 846 mm (mainly concentrated from September to March) was recorded at the station A, with a mean and standard deviation (SD) of 662 and 134 mm respectively. The corresponding yearly runoff was in the range 30.7 to 365.8 mm, with a mean of 105.3 mm and SD of 100 mm. The coefficient of yearly runoff, calculated as the ratio between total runoff and total rainfall as recorded by station A, varied between 5% and 41%, with a mean and SD of 15% and 75% respectively. Occasional high differences in recorded rainfall events between the three gauges were found; as expected, rainfall spatial variability decreased on a monthly and yearly basis.

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At event scale, rainfall depths over 6.8 mm gave runoff volumes higher than 1 mm; the maximum runoff volume and discharge recorded in the observation period were 159.6 mm and 3.4 m^3 s^{-1} (2.6 l s^{-1} km^{-2}) respectively. Twenty-four erosive events were sampled with a suspended sediment concentration between 0.1 and 9.2 g l^{-1}; the maximum event sediment yield (estimated on the basis of runoff volume and suspended sediment concentration in the flow) was 283 Mg (2168.4 kg ha^{-1}).

4.2. Ganspoel watershed

4.2.1. Geomorphological information

The Ganspoel watershed (outlet coordinates 50 48'N, 4 35'E), located in central Belgium, covers 1.15 km^2 between 60 m and 100 m a.s.l. with an average slope of about 10%, but which can locally exceed 25%. A dense network of dry channels characterizes the area (Figure 3). The topography of the area is formed in sandy deposits overlain by a loess layer that was deposited during the latest glacial period. Soils are therefore dominantly loess-derived luvisols, with their physical parameters related much more to land use than to soil texture (Van Oost et al., 2005).

Top soils have a very high silt percentage (on the average 75%) and moderate clay and sand content (on the average 11% and 14% respectively) (Van Oost et al., 2005).

The watershed land use is mainly agricultural. Forested (5%) and pasture (4%) zones cover the steep slopes as well as some of the thalweg areas. A built-up zone is located in northwestern part of the Ganspoel watershed and represents 9% of its area (Steegen et al., 2001). The main

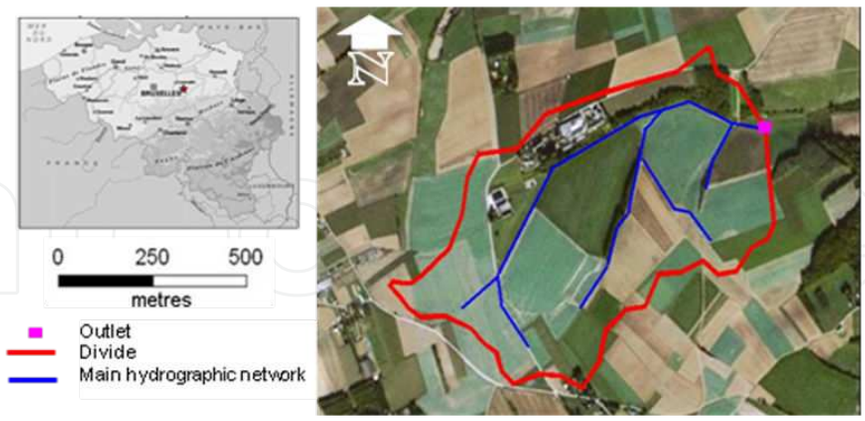


Figure 3. Location and aerial view of the Ganspoel watershed.

4.2.2. The hydrological database

The climate of central Belgium shows relatively cool summers and mild winters resulting in an average annual temperature of 11 C. Annual precipitation varies normally between 700

and 800 mm year^{-1} and is well distributed over the year. High intensity rainfall events occur mainly in spring and summer: such thunderstorms may reach peak rainfall intensities of ca. 70 mm h^{-1} while total rainfall amounts may amount to 40 mm, exceeding rarely 60 mm.

The hydrological database was collected during a recording period of about 2 years (May 1997-February 1999). The rainfall and flow/sediment measurement station was located at the outlet of the watershed. The rainfall events were recorded by a tipping-bucket rain gauge (logging interval equal to 1 minute with 0.5-mm tips). Water depths were continuously measured with a time interval of 2 minutes and an accuracy of 2 mm by a San Dimas flume equipped with a flowmeter, using a submerged probe level sensor. Water discharge was then calculated by a constant relationship between water depth and discharge. The suspended sediment concentration, measured by an automated water sampler which a flow-proportional sampling rate (every 30 m^3 runoff), was determined by oven-drying every sample at 105 C for 24 hours.

Seventeen runoff events, corresponding to rainfall depths in the range 5.5-57.5 mm, were adequately sampled (Table 1). The sampled events concerned generally low runoff volumes (15 with runoff depths lower than 2 mm), but the most intense event (13-14 September 1998) produced a runoff volume of 9.5 mm. Event-based sediment yields were in the range 2 to 604 kg ha^{-1} (Table 1). Ten other events were not taken into account because of inadequate sampling.

Event	Rainfall		Runoff volume	Runoff coefficient	Peak flow	Sediment yield	
	depth (mm)	duration (h)	(mm)	(%)	(m^3 s^{-1})	(Mg)	(kg ha^{-1})
19/05/1997	8.0	0.4	0.22	2.8	0.103	8.2	70.1
21/05/1997	6.5	8.4	0.13	2.0	0.056	2.7	23.3
11/07/1997	13.0	0.6	1.97	15.2	0.862	40.9	349.7
14/07/1997	5.5	0.6	0.37	6.7	0.181	4.4	37.6
17-18/07/1997	21.5	8.4	0.35	1.6	0.050	3.6	30.8
25/12/1997	6.5	1.0	0.09	1.4	0.043	0.2	2.1
05/01/1998	8.0	4.2	0.23	2.9	0.051	0.5	4.5
28/04/1998	11.0	1.4	0.14	1.3	0.037	0.2	1.8
05/06/1998*	10.5	3.3	0.002	0.02	0.003	-	-
06/06/1998*	29.5	32.8	13.08	44.3	1.827	-	-
11/06/1998*	16.5	21.4	3.68	22.3	0.389	-	-
22/08/1998*	36.5	47.2	0.93	2.5	0.046	-	-
26/08/1998	5.5	8.4	0.39	7.1	0.064	1.9	16.2
08-09/09/1998	24.5	1.5	0.45	1.8	0.067	1.3	11.1
13-14/09/1998	57.5	19.1	8.86	15.4	1.017	66.1	565.2

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Event	Rainfall		Runoff volume	Runoff coefficient	Peak flow	Sediment yield	
	depth (mm)	duration (h)	(mm)	(%)	($m^3 s^{-1}$)	(Mg)	(kg ha^{-1})
31/10-01/11/1998	25.0	19.3	1.67	6.7	0.064	6.9	58.9
14/11/1998	15.5	14.4	0.71	4.6	0.032	0.7	6.1
29/11/1998	18.5	19.9	0.56	3.0	0.025	1.4	12.0
07/12/1998*	7.0	60.8	0.93	13.3	0.026	-	-
19/12/1998*	4.5	5.7	0.27	6.0	0.033	-	-
07/01/1998*	28.0	51.5	1.80	6.4	0.061	-	-
16-17/01/1999	14.5	21.0	0.94	6.5	0.033	2.6	21.8
25/01/1999*	21.5	49.5	1.61	7.5	0.788	-	-
28/01/1999	8.0	3.8	0.71	8.9	0.046	3.0	25.6
07/02/1999	6.5	12.0	0.30	4.6	0.029	0.5	4.7
21/02/1999*	8.0	49.5	2.36	29.5	0.768	-	-
01/03/1999*	6.0	8.1	1.29	21.5	0.777	-	-

* Event not taken into account, because of inadequate sampling (see Van Oost et al., 2005 for more details).

Table 1. Main characteristics of the observed events used for the AnnAGNPS model implementation at the Ganspoel watershed (Ganspoel database, 2007).

5. Model implementation

The watershed discretization into homogeneous drainage areas ("cells") and the hydrographic network segmentation into channels ("reaches") were performed for both watersheds using the GIS interface incorporated into AnnAGNPS.

The geometry and the density of the drainage network were modeled by setting the Critical Source Area (CSA) to 1.25 ha and the Minimum Source Channel Length (MSCL) to 100 m for the Cannata watershed, which allowed a suitable representation of the same watershed in a previous study (Licciardello et al., 2006). Such values were decreased to 0.5 ha and 50 m respectively for the Ganspoel watershed, because of its higher land use heterogeneity (Nearing et al., 2005). The Cannata watershed resulted in 78 cells and 32 reaches (Figure 4a), while the Ganspoel watershed in 155 cells and 65 reaches (Figure 4b).

The elevation GIS layer was arranged by digitizing contour lines every 2 m on a 5-m resolution DEM; land use and soil input data were derived from 25-m resolution GIS maps. The morphologic parameters (i.e., cell slope length and steepness) as well as the dominant land uses and soil types were directly associated with each drainage area by means of the GIS interface.

Meteorological and pluviometric input data were properly arranged by the AnnGNPS weather subroutines. For the Cannata watershed daily values of maximum and minimum air temperatures, relative humidity, solar radiation and wind velocity were measured at the meteorological station within the watershed. Daily rainfall input data were derived from records provided by the three working rain gauges in the different periods and input to each drainage area by applying the Thiessen polygon method, except when only the rainfall recorded at a single station was available (Figure 2). For the Ganspoel watershed, as no meteorological information (except for rainfalls) was provided in the database, air temperature, relative humidity and wind velocity data were collected at the nearest meteorological station (Bruxelles, 50 54'N, 4 30'E, about 13 km far from the watershed outlet). Solar radiation was evaluated by the Hargreaves' formula. For both watersheds daily values of dew point temperature were calculated on the basis of air temperature and humidity.



Figure 4. Layouts of the Cannata (left) and Ganspoel (right) watershed discretisation by the AnnAGNPS model.

To allow the model to adjust the initial soil water storage terms, the first two years were appended to the beginning of the precipitation and meteorological dataset. The initial values of CN, unique throughout the whole simulation period, were initially derived from the standard procedure set by the USDA Soil Conservation Service (Table 2).

Table 3 shows the values or range of the RUSLE parameters set utilised by the erosive submodel. The average annual rainfall factor (R), its cumulative percentages for 24 series of 15-day periods in a year and the soil erodibility factor (K) were determined according to guidelines by Wischmeier and Smith (1978), the latter on the basis of a field survey of soil hydrological characteristics (Indelicato, 1997; Steegen et al., 2001; Van Oost et al., 2005).

In the Cannata watershed, for each of the five soil textures, a uniform soil profile was modeled up to 1500 mm by averaging the required physical characteristics from the field samples. Soil wilting point and field capacity were derived from the experimental dataset. The whole Ganspoel watershed was modelled assuming a unique soil type (silt loam) up to a depth of 1000 mm. Values of soil wilting point and field capacity, not available from the Ganspoel dataset, were estimated by a pedo-transfer function (Saxton et al., 1986). The values of the soil saturated hydraulic conductivity (K_{sat}, in the range 0.001-205 mm h^{-1}) was derived from the LISEM Limburg database, as these data were collected on very sim-

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ilar soils (Takken et al., 1999; Nearing et al., 2005). Given that, as above mentioned, soil physical parameters were much more related to land use than to soil texture (Van Oost et al., 2005), six different values of K_{sat} (one for each soil land use surveyed into the watershed) were input to the model.

Parameter	Cannata			Ganspoel	
	Land use	Value default model	Value after calibration	Land use	Value
HYDROLOGICAL SUBMODEL					
Initial curve number (CN)	Cropland	81[C]; 84[D]	75[C]; 78[D]	Cropland + urban zones	81[B]; 84[D]
	Pasture	79[C]; 84[D]	72[C]; 78[D]	Forested, meadow and fallow zones	71[B]; 78[D]
Synthetic 24-h rainfall distribution type	All	I	Ia	All	II
EROSIVE SUBMODEL					
Sheet flow Manning's roughness coefficient ($m^{-1/3}$ s)	Pasture	0.13*	0.1*	All	0.15*
	Cropland	0.125*	0.1*		
Concentrated flow Manning's roughness coefficient ($m^{-1/3}$ s)	Pasture	0.13*	0.1*		0.04*
	Cropland	0.125*	0.1*		
Surface long-term random roughness coefficient (mm)	Pasture +cropland	32	15		16

(1) The hydrologic groups are reported in brackets
(*) According to the indications in the AGNPS user manual (Young et al., 1994) integrated with those provided by the user manual of the EUROSEM model (Morgan et al., 1998).

Table 2. Input parameters subject to calibration process of the AnnAGNPS model in the experimental watersheds.

For both waterheds vegetation cover and soil random roughness data were collected during the whole monitoring period.

Management information (crop types and rotation as well as agricultural operations) was entered in the plant/management files and modelled using the RUSLE database guidelines and database. For the crop cultivations it was necessary to modify some default parameter values such as crop planting and harvest dates as well as type and dates of agricultural operations.

The C factor was directly calculated by the model as an annual value for non-cropland and as a series of twenty-four 15-day values per year for cropland (based on prior land use, sur-

face cover, surface roughness and soil moisture condition (AnnAGNPS, 2001; Bingner and Theurer, 2005). The practice factor (P) was always set to 1, due to the absence of significant protection measures in the watershed (Table 3).

RUSLE factor		Value or range	
		Cannata	Ganspoel
R (MJ mm ha^{-1} h^{-1} $year^{-1}$)		1040	1496
(Mg ha^{-1} per R-factor unit)		0.39 to 0.53	0.06
LS (-)		1.72 to 4.94	0.10 to 2.29
C (-)	Cropland[a]	0.0002 to 0.042[b]; 0.0001 to 0.043[c]	0.00002 to 0.269
	Rangeland[d]	0.016[b]; 0.029[c]	0.0074
P (-)		1	

[a] Series of twenty-four 15-day period values per year (AnnAGNPS, 2001)
[b] Before calibration
[c] After calibration and for validation
[d] Annual value (AnnAGNPS, 2001).

Table 3. Values or range of the RUSLE parameters set at the experimental watersheds for the evaluation of the AnnAGNPS model.

5.1. Hydrological simulation

After processing the input parameters of the hydrological and erosive sub-models (respectively requiring the determination of the initial Curve Numbers for the USDA SCS-CN model and the calculation of the RUSLE model factors), daily values of surface runoff, peak flow and sediment yield were continuously simulated at the outlet of both watersheds by AnnAGNPS (version 3.2).

Considering that baseflow is not considered by AnnAGNPS, the surface runoff separation from baseflow was performed by the traditional manual linear method applied to observed stream flow data. Based on studies by Arnold et al. (1995) as well as Arnold and Allen (1999), these results match reasonably well with those obtained through an automated digital filter; the differences in the surface runoff component extracted by the two methods are up to 20% at yearly scale.

5.1.1. Cannata watershed

Both the hydrological and erosion components of AnnAGNPS were calibrated/validated separating the calibration and validation periods by the split-sample technique. The calibration/validation process was carried out by modifying the initial values of CN, which represent a key factor in obtaining accurate prediction of runoff and sediment yield (Yuan

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et al., 2001; Shrestha et al., 2006); and the most important input parameter to which the runoff is sensitive (Yuan et al., 2001; Baginska et al., 2003), besides soil (field capacity, wilting point and saturated hydraulic conductivity) as well as climate parameters (precipitation, temperature and interception).

In order to calibrate/validate the peak flows and the sediment yields, both 24-h rainfall distributions typical of a Pacific maritime climate (types I and Ia) with wet winter and dry summers (USDA-NCRS, 1986) derived by the extended TR-55 method database were used. The sediment yields were evaluated at event scale by adjusting the surface long-term random roughness coefficient (which affects the RUSLE C-factor) as well as the sheet and concentrated flow Manning's roughness coefficients (Table 3).

5.1.2. Ganspoel watershed

For simulation of surface runoff, peak flow and sediment yield events, the AnnAGNPS model run with default input parameters (Table 3). No calibration/validation processes were undertaken.

6. Model evaluation

In both the experimental watersheds surface runoff volumes and sediment yields were evaluated at the event scale; in the Cannata watershed the analysis of surface runoff was extended to the monthly and annual scale.

Model performance was assessed by qualitative and quantitative approaches. The qualitative procedure consisted of visually comparing observed and simulated values. For quantitative evaluation a range of both summary and difference measures were used (Table 4).

The summary measures utilized were the mean and standard deviation of both observed and simulated values. Given that coefficient of determination, r^2, is an insufficient and often misleading evaluation criterion, the Nash and Sutcliffe (1970) coefficient of efficiency (E) and its modified form (E_1) were also used to assess model efficiency (Table 4). In particular, E is more sensitive to extreme values, while E_1 is better suited to significant over- or underprediction by reducing the effect of squared terms (Krause et al, 2005). As suggested by the same authors, E and E_1 were integrated with the Root Mean Square Error (RMSE), which describes the difference between the observed values and the model predictions in the unit of the variable. Finally, the Coefficient of Residual Mass (CRM) was used to indicate a prevalent model over- or underestimation of the observed values (Loague and Green, 1991).

The values considered to be optimal for these criteria were 1 for r^2, E and E_1 and 0 for RMSE and CRM (Table 4). According to common practice, simulation results are considered good for values of E greater than or equal to 0.75, satisfactory for values of E between 0.75 and 0.36 and unsatisfactory for values below 0.36 (Van Liew and Garbrecht, 2003).

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

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

Table 4. Coefficients and difference measures for model evaluation and their range of variability.

7. Results and discussion

7.1. Cannata watershed

7.1.1. Calibration test

The observed runoff volumes from October 1996 to December 2000 at the watershed outlet were used for model calibration at monthly and event scales; annual model performance was evaluated by utilizing observations from the years 1997 to 2000. In trying to approximate the mean and SD values of the observed runoff, the initial CNs were properly decreased both in rangeland and in cropland areas (Table 3). Table 5 shows the values of the chosen difference measures obtained for runoff at annual, monthly and event scales before and after calibration.

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Values	Mean (mm)	Std. Dev. (mm)	r^2	E	E_1	RMSE (mm)	CRM
Calibration test							
Annual scale (1997 to 2000)							
Observed	78.54	40.25					
Predicted[a]	107.05	43.05	0.59	-0.13	-0.10	38.19	-0.40
Predicted [b]	77.17	39.81	0.72	0.70	0.53	6.30	0
Monthly scale (Oct. 1996 to Dec. 2000)							
Observed	7.71	15.91					
Predicted [a]	10.79	19.50	0.75	0.59	0.48	10.15	-0.40
Predicted [b]	7.70	15.98	0.78	0.77	0.61	7.61	0
Event scale (Oct. 1996 to Dec. 2000)							
Observed	0.25	2.42					
Predicted [a]	0.36	2.79	0.83	0.76	0.52	1.18	-0.40
Predicted [b]	0.25	2.36	0.85	0.84	0.64	0.96	0
Validation test							
Annual scale (Jan. 2001 to Dec. 2003)							
Observed	158.74	145.05					
Predicted [b]	108.38	80.79	0.99	0.62	0.54	72.74	0.32
Monthly scale (Jan. 2001 to Dec. 2003)							
Observed	13.23	34.43					
Predicted [b]	9.03	24.20	0.93	0.85	0.66	13.27	0.32
Event scale (Jan. 2001 to Dec. 2003)							
Observed	0.43	5.37					
Predicted[b]	0.30	4.00	0.87	0.83	0.58	2.21	0.32

[a] Default simulation
[b] Calibrated model.

Table 5. Values of the coefficients, summary and difference measures applied to runoff volumes at different time scales for calibration and validation tests at the Cannata watershed.

The simulated total runoff volume for the period of October 1996 to December 2000 (405.72 mm) was only slightly higher than the observed value (393.23 mm), showing a runoff prediction capability for long periods, which was also detected by other Authors (Yuan et al., 2001). The improvement in the annual runoff volume predictions after the calibration is due to the reduction of the cumulated volume overprediction relative to events with smaller runoff (Figure 5). In some cases, at the beginning of the wet season, runoff was generated by AnnAGNPS but not observed (Figure 6). This was probably due to the peculiarity of the hydrological processes governing runoff formation in Mediterranean regions, depending not only on catchment characteristics but also on antecedent hydrological conditions and characteristics of the rainfall events, with low runoff coefficients as a result of short-duration, high-intensity convective storms over dry soils (Latron et al., 2003).

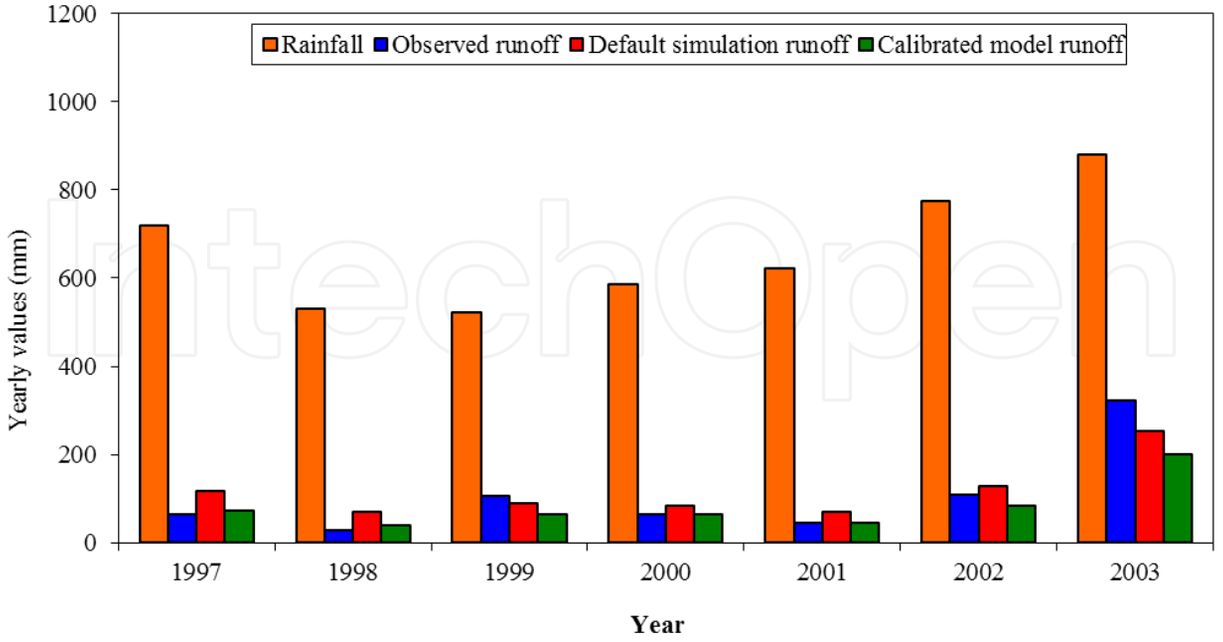


Figure 5. Comparison between observed and simulated (using default and calibrated parameters) yearly runoff volume for the years 1997 to 2003 at the Cannata watershed.

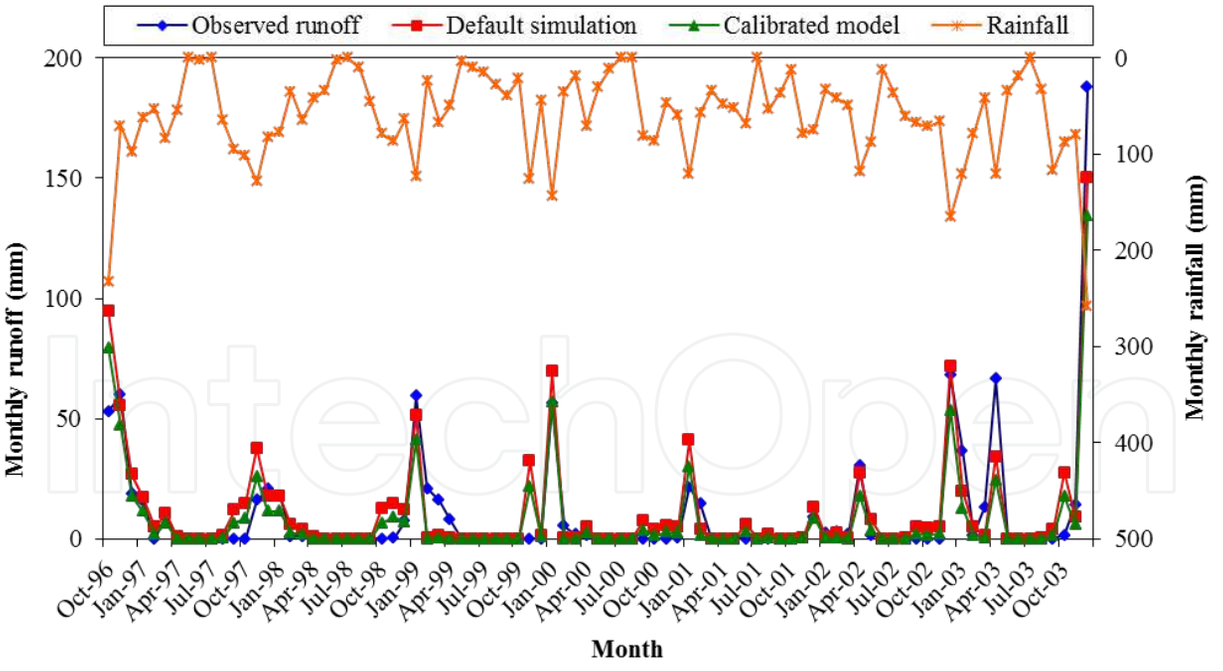


Figure 6. Comparison between observed and simulated (using default and calibrated parameters) monthly runoff volume for the whole period at the Cannata watershed.

The goodness of fit between observed and simulated runoff volumes (Figure 7) was also confirmed at the event scale by the summary measures as well as by the satisfactory values

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of E_1 and the low RMSE and CRM (Table 5). A similar value of E was found in the model calibration test reported by Baginska et al. (2003).

The apparent best results achieved for monthly and event-scale runoff volume predictions with respect to annual values may depend on the fact that the simulation period only represents a few years of data (four years and three years for the calibration and validation periods, respectively), while monthly and event-scale simulations provide more data for the statistics. Moreover, in Table 5, results of simulations related to the period of October to December 1996, which was very well simulated by the model, are not reported.

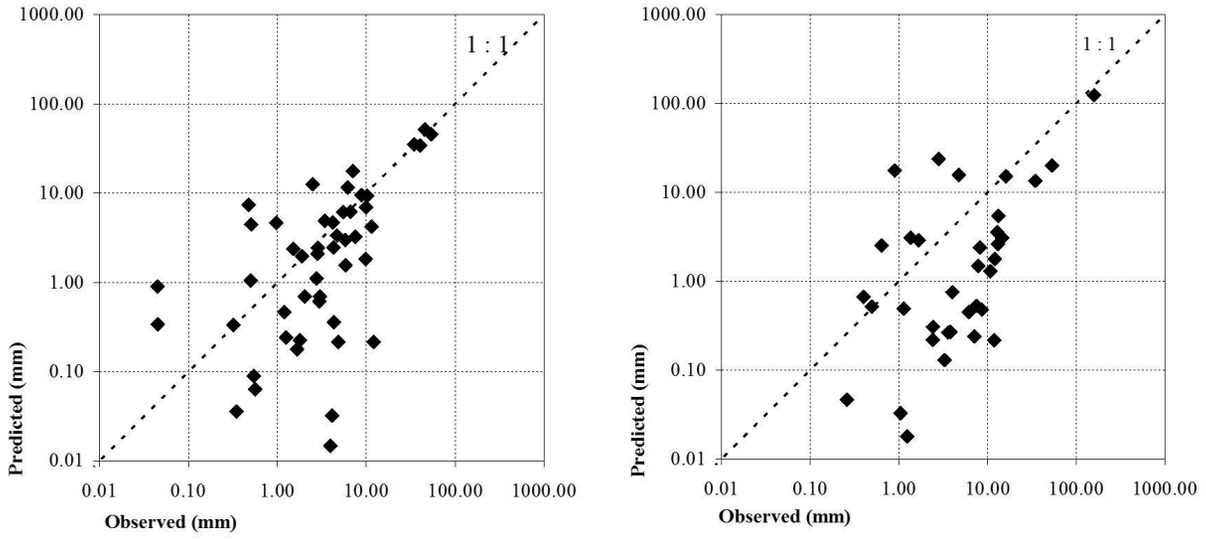


Figure 7. Comparison between observed and simulated runoff at event scale for (left) calibration and (right) validation tests at the Cannata watershed.

As expected, the coefficient E_1 is less sensitive to peaks (Krause et al., 2005) and was generally lower than E, but nevertheless satisfactory after the calibration process.

Adjustments of minimum and maximum interception evaporation (the portion of precipitation that neither runs off nor infiltrates) within the lower and upper default bounds assumed by AnnAGNPS for daily pluviometric and meteorological data did not improve the model prediction capability.

Peak flow predictions were closer to the observed values when the type Ia synthetic 24-h rainfall distribution (less intense than type I) was used. The overall model performance was satisfactory for less intense events, as shown by the E_1 coefficient (Table 6).

High values of the coefficient of determination and model efficiency (E and E_1) were found for the suspended sediment yield events observed from October 1996 to December 2000 (Figure 8) when the AnnAGNPS erosive submodel was calibrated (Table 7). By decreasing the surface long-term random roughness coefficient as well as the sheet and concentrated flow Manning's roughness coefficients for both rangeland and cropland areas, the tendency to underprediction was substantially reduced. The model response was remarkably more

sensitive to the random roughness (more than 95% of the model efficiency improvement) than the Manning's coefficients adjustments (Table 3).

Values	Mean ($m^3 s^{-1}$)	Std. Dev. ($m^3 s^{-1}$)	r^2	E	E_1	RMSE ($m^3 s^{-1}$)	CRM
Calibration test (Oct. 1996 to Dec. 2000)							
Observed	0.02	0.11					
Predicted [a]	0.03	0.33	0.57	-4.04	0.05	0.26	-1.12
Predicted [b]	0.01	0.14	0.56	0.34	0.52	0.09	0.14
Validation test (Jan. 2001 to Dec. 2003)							
Observed	0.02	0.14					
Predicted [b]	0.02	0.23	0.66	0.05	0.51	0.14	0.11

[a] Default simulation
[b] Calibrated model.

Table 6. Values of the coefficients, summary and difference measures applied to peak flow at event scale for calibration and validation tests at the Cannata watershed.

Peak flow and sediment yield predictions were only slightly sensitive to the calibration of the hydrological submodel; the model efficiency in sediment yield prediction did not increase by adjusting either the Manning's roughness coefficient for channels or the ratio of rill to inter-rill erosion for bare soil.

Values	Mean (Mg)	Std. Dev. (Mg)	r^2	E	E_1	RMSE (Mg)	CRM
Calibration test (Oct. 1996 to Dec. 2000)							
Observed	23.31	28.30	--	--	--	--	--
Predicted [a]	11.00	16.46	0.84	0.51	0.49	18.52	0.53
Predicted [b]	17.16	25.74	0.84	0.79	0.71	12.27	0.26
Validation test (Jan. 2001 to Dec. 2003)							
Observed	26.17	69.13	--	--	--	--	--
Predicted [b]	32.14	81.62	0.92	0.87	0.55	24.34	-0.23

[a] Default simulation
[b] Calibrated model.

Table 7. Values of the coefficients, summary and difference measures applied to sediment yield at event scale for calibration and validation tests at the Cannata watershed.

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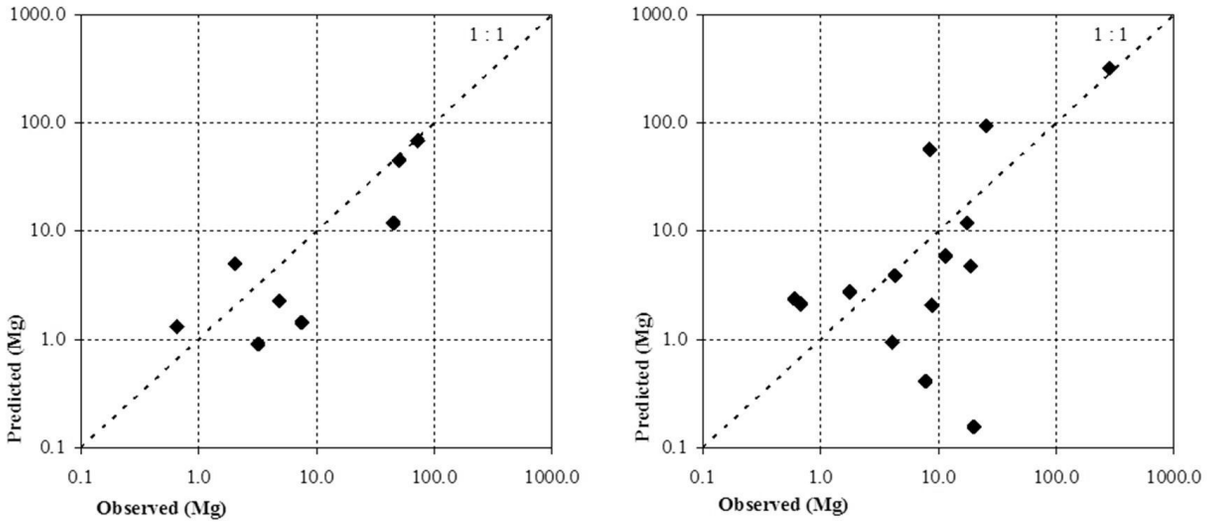


Figure 8. Comparison between observed and simulated sediment yield at event scale for (left) calibration and (right) validation tests at the Cannata watershed.

7.1.2. Validation test

The performance of the calibrated model was evaluated for the period of January 2001 to December 2003 in terms of runoff, peak flow and sediment yield.

AnnAGNPS runoff volume predictions confirmed the satisfactory model performance both at the event and annual scales and the good performance at the monthly aggregated values (Table 5). However, an underprediction was highlighted by the difference in summary measures and the values of RMSE and CRM. This tendency was mainly due to underestimation of the more significant events (Figure 7), as also found in the tests performed by Yuan et al. (2001).

The poor performance of the model in predicting extreme peak flows was confirmed in the validation period. The overall model prediction capability was unsatisfactory (Table 6), as shown by the poor value of the coefficient of efficiency (E = 0.05). A high overprediction (over 105%) for the most significant event, which occurred on 12 December 2003, is also noted.

A satisfactory model efficiency (E_1 = 0.55) and a very high coefficient of determination (r^2 > 0.90) were also found for the suspended sediment yield events observed in the period of 2001 to 2003 (Table 7 and Figure 8). The satisfactory value achieved for the Nash and Sutcliffe coefficient (E = 0.87) was mainly due to the successful performance of the model for large rainfall events, in particular for the highest sediment yield, which occurred on 12 December 2003.

7.2. Ganspoel watershed

Runoff depths were in general underpredicted (see the positive value of the CRM coefficient in Table 8). The accuracy achieved for the prediction of the largest event (13-14/09/1998) gave a coefficient of determination exceeding 0.90 (Figure 9) and a model efficiency (E) of 0.89 for runoff depth (Table 8). The mean and standard deviation of simulated runoff vol-

ume depths were close to the corresponding observed values with differences lower than 12% and 16%. When the events for which zero runoff was simulated events were excluded from the analysis, the values for r^2 and E become 0.98 and 0.97 respectively. Similarly high values for the coefficient of determination were found for runoff simulations by AnnAGNPS at the event scale by Yuan et al. (2001), Shrestha et al. (2006) and Shamshad et al. (2008) and for the coefficient of determination and model efficiency by Sarangi et al. (2007). However, in these studies AnnAGNPS was calibrated before a validation was carried out.

From such outcomes it can be remarked that the AnnAGNPS model provided a generally good capability to simulate the greatest runoff event in the Ganspoel watershed, as shown by the high coefficients of efficiency (E and E_1) and determination (r^2) achieved without any a priori calibration. The latter is an important observation as it shows that, at least for significant events, adequate runoff modeling is possible without calibration provided that sufficiently detailed input data are available. The latter should not only contain land use, but also surface characteristics and soil roughness as these are important controls on runoff production. This result contrasts somewhat with that of many other studies, where the need for appropriate calibration is stressed (e.g. Refsgaard, 1997; Beven, 2006). A possible reason for this is that in many cases the available input data are less detailed than those available for the Ganspoel watersheds in terms of soil surface characteristics and coverage. The latter are important controls on runoff generation: if such data are not available, model predictions cannot be expected to be accurate without prior calibration.

The majority of the observations available in the hydrological database was of low magnitude (14 out of 17 with runoff depths lower than 1 mm); for them the model simulation accuracy was basically less accurate, achieving a mean deviation between simulations and observations of about 50%. Moreover, seven events (five of them concentrated at the end of relatively dry periods and generated by storms with a depth up to 13 mm) resulted in zero runoff simulation, even tuning the values of the initial CNs or saturated hydraulic conductivity (which represent the most important input parameters to which the runoff is sensitive (Yuan et al., 2001; Baginska et al., 2003) and setting up pre-run before the first event simulated (which is important for initial soil moisture). The AnnAGNPS model, calculating daily and sub-daily water budgets using NRCS TR-55 method coming from the SWRRB and EPIC models (Williams et al, 1984; USDA-NRCS, 1986), presumably would have adjusted the CNs to antecedent moisture condition AMC-I based on the NRCS criteria, minimising the effect of varying the CNs (Sarangi et al., 2007). The climatic characteristics of the studied watershed caused the model to produce unrealistic CN values during its initialization and, as a result, too low or no predicted runoff, as also found in various experimental applications in different climatic conditions (Polyakov et al., 2007; Sarangi et al., 2007).

Even in the Ganspoel watershed adjustments of minimum and maximum interception, as operated for model's implementation at the Cannata watershed, did not further improve the coefficients E, E_1 and r^2 calculated for runoff volume prediction.

The AnnAGNPS model provided the highest accuracy in peak flow predictions when the type "II" synthetic 24-h rainfall distribution (typical of continental climate, with cold winter and warm summer) was set in simulation tests (Figure 9). Even though statistics of observed

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and predicted values were of the same order of magnitude (Table 8), the low values achieved by the coefficients of efficiency (E and E_1 lower than 0.35) and conversely the high RMSE (163% of observed mean, Table 8) utilized for model evaluation confirmed the unsatisfactory prediction capability of the model for peak flow, also found elsewhere in different model tests (Shrestha et al., 2006). The model uses the extended TR-55 methods through synthetic 24-h rainfall distributions to calculate the peak flow (Cronshey and Theurer, 1998). Apparently, the latter method results is not suitable for the study area, leading to a severe underestimation of rainfall intensities and hence peak flows, a fact also noted by Shrestha et al. (2006). A prediction method that takes into account the actual patterns of rainfall intensity would be expected to provide better accuracy in peak flow estimations.

Runoff							
Values	**Mean (mm)**	**Std. Dev. (mm)**	**r^2**	**E**	**E_1**	**RMSE (mm)**	**CRM**
Observed	1.04	2.26	-	-	-	-	-
Predicted	0.87	2.53	0.92	0.89	0.59	0.73	0.16
Peak flow							
	Mean ($m^3 s^{-1}$)	**Std. Dev. ($m^3 s^{-1}$)**	**r^2**	**E**	**E_1**	**RMSE ($m^3 s^{-1}$)**	**CRM**
Observed	0.16	0.30	-	-	-	-	-
Predicted	0.12	0.39	0.53	0.35	0.19	0.26	0.27
Sediment yield							
	Mean (Mg)	**Std. Dev. (Mg)**	**r^2**	**E**	**E_1**	**RMSE (Mg)**	**CRM**
Observed	8.54	17.65	-	-	-	-	-
Predicted	1.84	4.31	0.57	0.16	0.29	15.71	0.78

Table 8. Statistics concerning the AnnAGNPS simulations of 17 events at the Ganspoel watershed.

Predicted sediment yields were strongly underestimated with respect to the observed values (up to one order of magnitude in three cases); the correlation between observed and predicted values was relatively low (Table 9; Figure 9). Coefficients of efficiency (E and E_1) were close to zero and the coefficient of determination did not exceed 0.60 (Table 8). Those results were in accordance of what reported by Yuan et al. (2001), Shrestha et al. (2006), Polyakov et al. (2007) and Shamshad et al. (2008) in sediment yield modeling by AnnAGNPS.

The model tendency to strongly underpredict peak flow is probably one of the main reasons for the underestimation of erosive events and, consequently, of sediment yield (also

shown by the separate comparison of deposition and erosion values for observed and simulated events, Van Oost et al., 2005), but is not the only one. Also in the case of a good estimation of the runoff volume and an overestimation of the peak flow (13-14/09/1998), the sediment yield was underestimated. Runoff alone is not adequate for erosion and sediment delivery predictions, but in the AnnAGNPS erosion sub-model it is used to estimate the delivery of the particle sizes of eroded sediment (simulated through the RUSLE model) based on runoff and peak flow.

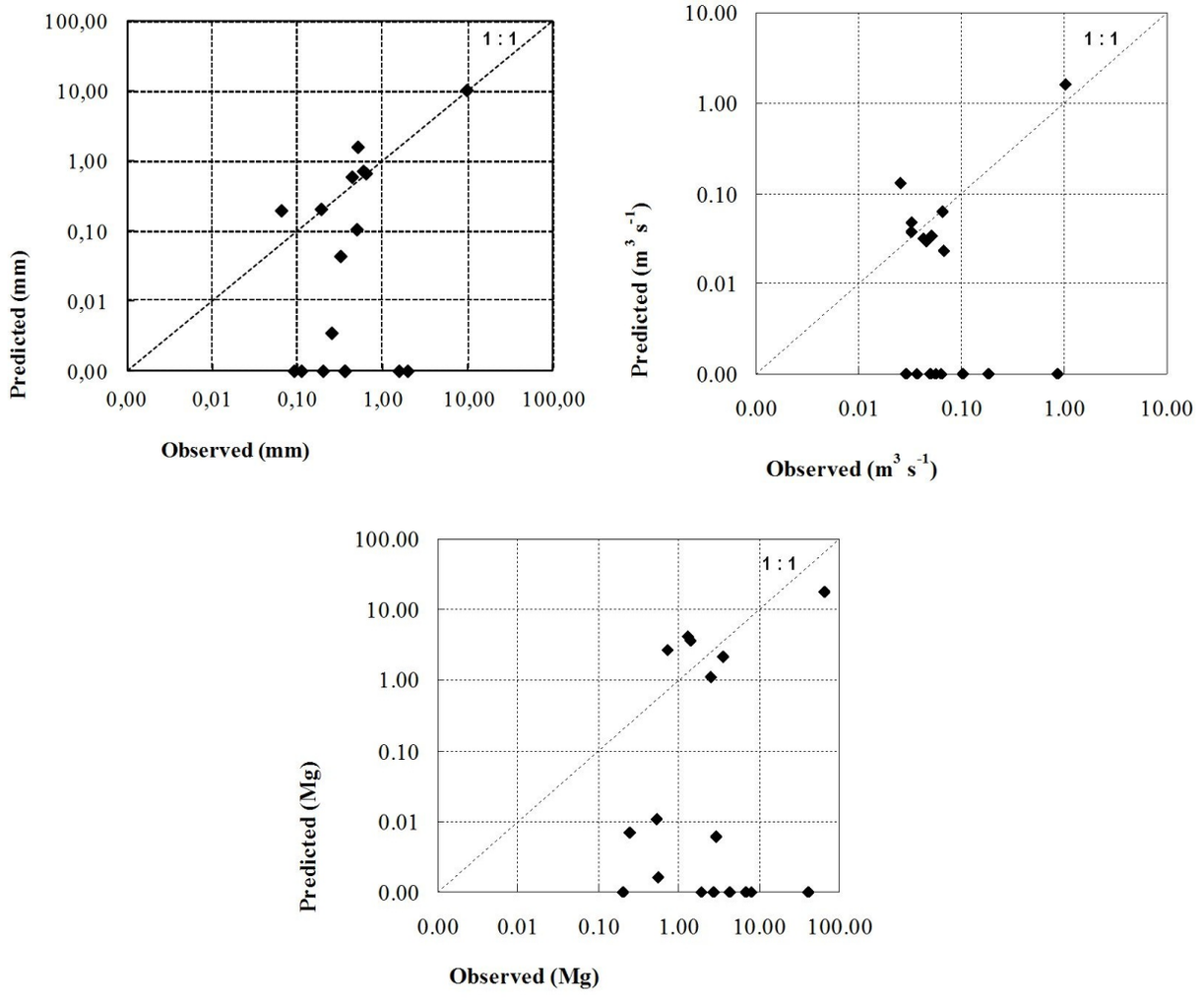


Figure 9. Comparison of 17 observed and simulated (by AnnAGNPS) events in the Ganspoel watershed, for runoff (upper left), peak flow (upper right) and sediment yield (bottom) (values are in logarithmic scale).

However, another factor that may also play a role in poor model simulations of erosion was the limited availability of input parameters. The AnnAGNPS model requires up to 100 unique parameters for runoff volume assessment and up to an additional 80 unique parameters for sediment yield prediction. As values for these parameters were not all available in the Ganspoel dataset data from the literature had to be used in some cases.

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Date	Rainfall	Runoff volume		Peak flow		Sediment yield			
		Obs.	Sim.	Obs.	Sim.	Observed		Simulated	
	(mm)	(mm)		($m^3 s^{-1}$)		(Mg)	(kg ha^{-1})	(Mg)	(kg ha^{-1})
19/05/1997	8.0	0.22	0	0.103	0	8.20	70.09	0	0
21/05/1997	6.5	0.13	0	0.056	0	2.73	23.32	0	0
11/07/1997	13.0	1.97	0	0.862	0	40.91	349.68	0	0
14/07/1997	5.5	0.37	0	0.181	0	4.40	37.63	0	0
17-18/07/1997	21.5	0.35	0.04	0.050	0.003	3.60	30.78	2.18	18.63
25/12/1997	6.5	0.09	0.20	0.043	0.032	0.25	2.11	0.01	0.09
05/01/1998	8.0	0.23	0.21	0.051	0.034	0.53	4.53	0.01	0.09
28/04/1998	11.0	0.14	0	0.037	0	0.21	1.76	0	0
26/08/1998	5.5	0.39	0	0.064	0	1.89	16.18	0	0
08-09/09/1998	24.5	0.45	0.60	0.067	0.023	1.30	11.09	4.17	35.64
13-14/09/1998	57.5	8.86	10.55	1.017	1.629	66.13	565.19	17.66	150.94
31/10-01/11/1998	25.0	1.67	0.01	0.064	0.062	6.89	58.92	0	0
14/11/1998	15.5	0.71	0.68	0.032	0.038	0.72	6.13	2.61	22.31
29/11/1998	18.5	0.56	1.62	0.025	0.129	1.40	12.01	3.51	30.00
16-17/01/1999	14.5	0.94	0.73	0.033	0.047	2.55	21.80	1.09	9.32
28/01/1999	8.0	0.71	0.11	0.046	0.029	2.99	25.57	0	0
07/02/1999	6.5	0.30	0	0.029	0	0.55	4.69	0	0

Table 9. Main characteristics of the observed events and simulations by the AnnAGNPS model at the Ganspoel watershed.

Moreover, the following factors can explain the low correlation between observed and predicted sediment yields:

- AnnAGNPS uses the RUSLE method as the erosion sub-model. RUSLE has been developed to deliver estimates of long-term average erosion rates rather than event-based simulations. For this reason, comparison of individual events may not agree as well as long-term annual values (Shrestha et al., 2006), even in the case of adequate prediction for the most intense runoff events, as achieved in our model tests;
- we deliberately opted to evaluated the AnnAGNPS model without prior validation in order to assess its performance in cases where no data for validation are available;
- the Ganspoel watershed contains more than 80 fields (roads, buildings, forest, grassed channels and several crops with differing planting and harvesting schedules), showing difficulties for modeling of interactions between physical processes (water evapotranspiration,

interception, infiltration and runoff as well as soil detachment and transport) and water and sediment routing associated with its complexity (Nearing et al., 2005; Licciardello et al., 2009). Probably, the scale of soil property measurements within the available geomorphological database does not correspond to the discretisation scale of the Ganspoel watershed (characterized by land use heterogeneity and crop schedule complexity, as mentioned above) performed by the GIS interface of the data-intensive AnnAGNPS model.

8. Conclusion

The implementation of the AnnAGNPS in two small agricultural watersheds (Cannata, southern Italy, and Ganspoel, central Belgium) provided interesting indications about model's prediction capability of surface runoff, peak flow and sediment yield and thus about its applicability in the experimental conditions.

The study case of the Cannata watershed has highlighted a good prediction capability of runoff and erosive events, particularly for the events of highest relative magnitude (higher than 15 mm and 100 kg ha^{-1} respectively); a good accuracy has been achieved also for monthly runoff volumes simulation. The over-estimation of runoff volumes at yearly scale has been limited by setting up the initial CNs in the calibration phase, with mean differences between observed and simulated yearly values lower than 20%. Peak flow predictions have been satisfactory only for the less intense events (lower than 0.3 m^3/s); the utilisation of the different synthetic hyetographs available for the hydrologic sub-model has not hallowed to eliminate the high overestimation of the most intense peak flows. On the whole, the results provided by the analysis of this study case encourage further efforts in order to verify the model transferability to the climatic conditions typical of the semi-arid Mediterranean environment.

The evaluation of AnnAGNPS in the Ganspoel watershed has highlighted a good prediction capability only for the most intense runoff events (higher than 1 mm) in absence of calibration. The prediction capability of peak flows and sediment yields have resulted instead unsatisfactory (as also highlighted by the low coefficients of efficiency): the poor model's sediment yield predictions reflect the unreliability of simulated values of peak flows, required as input by the erosive sub-model.

The influence of the limited availability of geomorphologic parameters (balanced by the estimation, even reasonable, of some input parameters) as well as of hydrological observations (which even has advised against realistic calibration processes) on the model performance can not be excluded.

However, the availability of proper climatic (allowing set-up of input meteorological data) and GIS sub-routines (helping to process available DEM and themes) together with the user-friendly graphical interfaces in the model software made easy in AnnAGNPS the input data processing. In spite of the large number of input parameters required (more than 100), as for the majority of continuous, physically-based and distributed models, we have remarked a basical easiness of model implementation at the Cannata watershed, thanks to the good

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availability of geomorphologic and hydrologic information within the experimental database as well as the easiness of finding/measuring the majority of input parameters (e.g. meteorological data, soil physical properties). Nevertheless, in some cases processing of simulated hydrologic variables resulted in a time consuming task, especially for surface runoff analysis at event scale.

The model performance could be further improved by optimising algorithms for water balance of soil (in order to improve the simulation of more realistic moisture conditions) or by utilising as input the observed rainfall patterns (at hourly or sub-hourly scales) instead of the synthetic hyetographs utilised at present by AnnAGNPS. Sensitivity analyses, which would allow a more precise estimation of the input parameters to which model response is more sensitive, would be advisable for a better model implementation.

Such improvements, together further research activities aiming at model verification in different environmental conditions, could enhance the model consolidation and stimulate its wider diffusion in professional activities for controlling surface runoff and soil erosion as well as planning mitigation countermeasures.

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