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# EVALUATION OF RUNOFF, PEAK FLOW AND SEDIMENT YIELD FOR EVENTS SIMULATED BY THE ANNAGNPS MODEL IN A BELGIAN AGRICULTURAL WATERSHED†

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## ABSTRACT

The AnnAGNPS model, widely utilized as a practical tool for addressing erosion problems and land use planning, was implemented in a small agricultural watershed located in central Belgium, to assess its prediction capacity of runoff, peak flow and sediment yield in humid temperate conditions. Model performance was evaluated at the event scale by using a database reporting hydrological, geomorphologic and land use data collected during a 2-year period. Seventeen events were modelled and compared with the corresponding observations at the watershed outlet.

The model performed well in predicting the largest runoff volumes, as shown by the high values achieved for the coefficients of efficiency ($E = 0{\cdot}89$) and determination ($r^2 = 0{\cdot}92$). However, some events resulted in zero runoff simulation. The prediction capability for peak flow and sediment yield was poor ($E = 0{\cdot}35$ and $0{\cdot}16$, respectively). This inaccuracy can have several causes: the internal model deficiencies may be due to the incomplete representation of watershed complex processes, while external problems may be related to the conditions within the modelled watershed and the quality of recorded data.

On the whole the AnnAGNPS model may be considered as being suitable to simulate the significant runoff events in the experimental watershed. However, the model may be seen as better suited for comparative assessments of alternative management and policy scenarios and for gross estimation of nutrient loads rather than the precise prediction of a single event, consequently helping in the prediction of land degradation problems in the experimented conditions. Copyright © 2010 John Wiley & Sons, Ltd.

KEY WORDS: AnnAGNPS; Belgium; hydrological models; peak flow; runoff volume; SCS curve number; sediment yield

## INTRODUCTION

Soil erosion leads to significant land degradation. In recent years it is widely recognized that more site-specific approaches are needed to assess variations in erosion susceptibility in order to select the most suitable land management method (Adinarayana *et al*., 1998; Shrestha *et al*., 2006). 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). 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 agronomic and agricultural 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 a distributed model 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) which is now widely applied around the world (Licciardello and Zimbone, 2002; Haregeweyn and Yohannes, 2003; Hassen *et al*., 2004; Leòn *et al*., 2004), have been updated through the continuous simulation modelling of physical processes governing routing of water, sediment and pollutants associated with runoff events (Baginska *et al*., 2003). AnnAGNPS can be used to predict runoff, erosion as well as

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nutrient and chemical transport export from a watershed. 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 minimize pollution from point and nonpoint sources (Shrestha *et al*., 2006).

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. Suttles *et al*. (2003) achieved poor AnnAGNPS predictions of sediment and nutrient loads in a Georgia watershed, covered by both extensive forest and riparian conditions and attributed this to the defective data input used with the model. 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 AnnAGNPS applications to a small Mississippi watershed, Yuan *et al*. (2001, 2005) demonstrated that 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 tests carried out by Baginska *et al*. (2003) in a small Australian watershed, mainly covered by farming and residential land uses, acceptable model predictions ($E = 0{\cdot}82$) were assessed for runoff at event scale after the calibration of hydrological parameters.

More recently Shrestha *et al*. (2006) implemented AnnAGNPS at a small Nepalese watershed, mainly forested and cultivated, showing the need of calibration for satisfactory runoff predictions. Despite the calibration process, peak flow and sediment yield evaluation resulted in a much lower accuracy. 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 (Polyakov *et al*., 2007). Calibration/validation tests in two small watersheds (agricultural and forested, respectively) in S. Lucia Island (British West Indies) suggested that AnnAGNPS could be used under the conditions tested (Sarangi *et al*., 2007). AnnAGNPS was also implemented in a Sicilian agricultural watershed, generally showing a good prediction capability for runoff and sediment yield events but at the same time showing a lower accuracy in peak flow simulation in semi-arid climatic conditions (Licciardello *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 Kliment *et al*. (2008) showed that the model was not suitable for continuous simulation in large river basins with a high proportion of subsurface runoff. Finally, in a 6309-ha watershed in Malaysia (tropical region which sometimes experiences heavy rainfall) runoff was well predicted while sediment load simulations were of moderate accuracy (Shamshad *et al*., 2008).

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. This paper aims at evaluating AnnAGNPS prediction capabilities for runoff and sediment yield in such conditions utilizing a 2-year database collected at a small agricultural watershed located in central Belgium. Our study differs from most others in that no calibration processes were undertaken: therefore the errors related to model parameterization and hydrological processes modelling are expected to be not compensated by the calibration process. By doing so, we were able to investigate to what extent AnnAGNPS may be expected to provide usable results in conditions outside of research watersheds, where the necessary data for model calibration and validation are not available.

## MATERIALS AND METHODS

### *Brief Description of AnnAGNPS*

AnnAGNPS (Geter and Theurer, 1998; Bingner and Theurer, 2001) 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

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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 (Hydro-geomorphic 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 (Yuan *et al*., 2005). 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).

### *Characteristics of the Ganspoel Watershed*

The model AnnAGNPS (version 4·0) was implemented in continuous simulation using a database reporting hydrological, geomorphologic and land uses data collected at a small watershed (Ganspoel, 50°48'N, 4°35'E) located in central Belgium. The following information concerning the database was drawn from the works by Steegen *et al*., 2001 and Van Oost *et al*., 2005, in which further details can be found.

The watershed covers 115 ha between 60 m and 100 m a.s.l. with an average slope of about 10 per cent, but which can locally exceed 25 per cent. A dense network of dry channels characterizes the area (Figure 1).

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. Top soils have a very high silt content (70–80 per cent) and a moderate clay content (7–15 per cent) (Van Oost *et al*., 2005).

The watershed land use is mainly agricultural. Forested (5 per cent) and pasture (4 per cent) zones cover the steep slopes as well as some of the thalweg areas. A built-up zone is located in north-western part of the Ganspoel watershed and represents 9 per cent of its area (Steegen *et al*., 2001). The main crops are wheat, maize, sugar beet and potato with an average field size of 1·9 ha. The general crop rotation consists of winter cereals followed by a root crop (beet or potatoes) or maize. Typically one or two chisel plough operations (0·20-m depth) and one harrow operation (0·10-m depth) follow one tillage mouldboard plough operation (0·25-m depth) between each crop.

The climate of this area 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 $y^{-1}$ 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.

Figure 1. Aerial view of the Ganspoel watershed (Belgium). This figure is available in colour online at wileyonlinelibrary.com

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*The Hydrological Database*

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 watershed outlet. The rainfall events were recorded by a tipping-bucket rain gauge (logging interval equal to 1 min with 0·5-mm tips).

Water depths were continuously measured with a time interval of 2 min and an accuracy of 2 mm by a San Dimas flume (Wilm and Storey, 1944) equipped with a flowmeter (ISCO-4220, ISCO, Lincoln, NE, USA), 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 (ISCO-6700) with a flow-proportional sampling rate (every 30 $m^3$ runoff), was determined by oven-drying every sample at 105°C for 24 h.

Seventeen runoff events, corresponding to rainfall depths in the range 5·5–57·5 mm, were adequately sampled (Table I). 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 2–604 kg $ha^{-1}$ (Table I). Ten other events were not taken into account because of inadequate sampling (see Van Oost *et al.*, 2005, for more details).

*AnnAGNPS Implementation in the Ganspoel Watershed*

A high precision Digital Elevation Model (DEM) of the watershed with a 5 m-resolution was created by Van Oost *et al.* (2005). Field boundaries, roads and built-up areas were mapped using a GPS. The watershed discretization into homogeneous drainage areas ('cells') and the hydrographic network segmentation into channels ('reaches') were performed using the GIS interface incorporated into AnnAGNPS (Figure 2). 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. In order to optimize the reproduction of the watershed morphology a CSA (Critical Source Area) of 0·5 ha (default 5 ha) and a MSCL (Minimum Source Channel Length) of 50 m (default 100 m) were used, resulting in 155 cells (ranging from 0·03 to 4·40 ha) and 65 reaches.

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

| Event | Rainfall | | Runoff volume | | Runoff coefficient (per cent) | Peak flow ($m^3 s^{-1}$) | Sediment yield | |
|---|---|---|---|---|---|---|---|---|
| | Depth (mm) | Duration (h) | ($m^3$) | (mm) | | | ($10^3$ kg) | (kg $ha^{-1}$) |
| 19/05/1997 | 8·0 | 0·4 | 252 | 0·22 | 2·8 | 0·103 | 8·2 | 70·1 |
| 21/05/1997 | 6·5 | 8·4 | 155 | 0·13 | 2·0 | 0·056 | 2·7 | 23·3 |
| 11/07/1997 | 13·0 | 0·6 | 2307 | 1·97 | 15·2 | 0·862 | 40·9 | 349·7 |
| 14/07/1997 | 5·5 | 0·6 | 428 | 0·37 | 6·7 | 0·181 | 4·4 | 37·6 |
| 17-18/07/1997 | 21·5 | 8·4 | 404 | 0·35 | 1·6 | 0·050 | 3·6 | 30·8 |
| 25/12/1997 | 6·5 | 1·0 | 106 | 0·09 | 1·4 | 0·043 | 0·2 | 2·1 |
| 05/01/1998 | 8·0 | 4·2 | 270 | 0·23 | 2·9 | 0·051 | 0·5 | 4·5 |
| 28/04/1998 | 11·0 | 1·4 | 164 | 0·14 | 1·3 | 0·037 | 0·2 | 1·8 |
| 05/06/1998* | 10·5 | 3·3 | 2 | 0·002 | 0·02 | 0·003 | — | — |
| 06/06/1998* | 29·5 | 32·8 | 15303 | 13·08 | 44·3 | 1·827 | — | — |
| 11/06/1998* | 16·5 | 21·4 | 4309 | 3·68 | 22·3 | 0·389 | — | — |
| 22/08/1998* | 36·5 | 47·2 | 1087 | 0·93 | 2·5 | 0·046 | — | — |
| 26/08/1998 | 5·5 | 8·4 | 451 | 0·39 | 7·1 | 0·064 | 1·9 | 16·2 |
| 08-09/09/1998 | 24·5 | 1·5 | 530 | 0·45 | 1·8 | 0·067 | 1·3 | 11·1 |
| 13-14/09/1998 | 57·5 | 19·1 | 10361 | 8·86 | 15·4 | 1·017 | 66·1 | 565·2 |
| 31/10-01/11/1998 | 25·0 | 19·3 | 1957 | 1·67 | 6·7 | 0·064 | 6·9 | 58·9 |
| 14/11/1998 | 15·5 | 14·4 | 834 | 0·71 | 4·6 | 0·032 | 0·7 | 6·1 |
| 29/11/1998 | 18·5 | 19·9 | 653 | 0·56 | 3·0 | 0·025 | 1·4 | 12·0 |
| 07/12/1998* | 7·0 | 60·8 | 1090 | 0·93 | 13·3 | 0·026 | — | — |
| 19/12/1998* | 4·5 | 5·7 | 318 | 0·27 | 6·0 | 0·033 | — | — |
| 07/01/1998* | 28·0 | 51·5 | 2110 | 1·80 | 6·4 | 0·061 | — | — |
| 16-17/01/1999 | 14·5 | 21·0 | 1101 | 0·94 | 6·5 | 0·033 | 2·6 | 21·8 |
| 25/01/1999* | 21·5 | 49·5 | 1878 | 1·61 | 7·5 | 0·788 | — | — |
| 28/01/1999 | 8·0 | 3·8 | 827 | 0·71 | 8·9 | 0·046 | 3·0 | 25·6 |
| 07/02/1999 | 6·5 | 12·0 | 354 | 0·30 | 4·6 | 0·029 | 0·5 | 4·7 |
| 21/02/1999* | 8·0 | 49·5 | 2763 | 2·36 | 29·5 | 0·768 | — | — |
| 01/03/1999* | 6·0 | 8·1 | 1510 | 1·29 | 21·5 | 0·777 | — | — |

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

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Figure 2. Layout of the Ganspoel watershed discretization by the AnnAGNPS model. This figure is available in colour online at wileyonlinelibrary.com

As no meteorological information (except for rainfall data) was provided in the database, climatic data (daily values of maximum and minimum air temperature and wind velocity) were collected at the nearest meteorological station (Bruxelles, 50°54'N, 4°30'E, about 13 km far from the Ganspoel watershed outlet). Solar radiation was evaluated by the Hargreaves' formula, while daily values of dew point temperature were calculated on the basis of air temperature and relative humidity. In order to allow the model to adjust the initial soil water storage terms, the meteorological data from January 1996 to April 1997 were appended to the beginning of the dataset. The initial values of CN, unique throughout the whole simulation period, were derived following the indications reported in the standard procedure set by the USDA Soil Conservation Service (USDA-SCS, 1972) (Table II).

Table III shows the values or range of the RUSLE parameters as calculated for the Ganspoel watershed. The average annual rainfall factor (R), its cumulative percentages for 24 series of 15-day periods in a year (Figure 3a), and the soil erodibility factor (K) were determined according to the Wischmeier and Smith (1978) guidelines, the latter on the basis of a field survey of soil hydrological characteristics (Steegen *et al*., 2001; Van Oost *et al*., 2005). Values for soil physical parameters required by AnnAGNPS, e.g. wilting point and field capacity of the soil, were not available from the dataset and were therefore derived using a pedo-transfer function (Saxton *et al*., 1986).

Table III. Values or range of the RUSLE parameters set at the Ganspoel watershed, Belgium

| RUSLE factor | Value or range |
|---|---|
| R (MJ mm ha$^{-1}$ h$^{-1}$ y$^{-1}$) | 1496 |
| K ($10^3$ kg ha$^{-1}$ per R-factor unit) | 0·062 |
| LS (-) | 0·097–2·290 |
| C (-) | |
| Cropland | 0·00002–0·269 |
| Rangeland | 0·0074 |
| P (-) | 1 |

Table II. Input parameters for implementation of the AnnAGNPS model at the Ganspoel watershed, Belgium

| Parameter | Land use | Values or range |
|---|---|---|
| Soil data | | |
| Average sand content (per cent) | | 14 |
| Average silt content (per cent) | | 75 |
| Average clay content (per cent) | | 11 |
| Field capacity (m m$^{-1}$) | | 0·38 |
| Wilting point (m m$^{-1}$) | | 0·18 |
| Saturated hydraulic conductivity (mm h$^{-1}$) | Cropland | 77·7–205·1 |
| | Forested, meadow and fallow zones | 25·3–125·1 |
| | Urban zones | 0·001 |
| Hydrological submodel | | |
| Initial curve number (CN) | Cropland + urban zones | 81[a]; 84[b] |
| | Forested, meadow and fallow zones | 71[a]; 78[b] |
| Synthetic 24-h rainfall distribution type | | II |
| Erosive submodel | | |
| Sheet flow Manning's roughness coefficient (m$^{-1/3}$ s) | All | 0·15[c] |
| Conc. flow Manning's roughness coefficient (m$^{-1/3}$ s) | | 0·04[c] |
| Surface long-term random roughness coefficient (mm) | | 16 |

[a]Hydrologic group B.
[b]Hydrologic group D.
[c]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).

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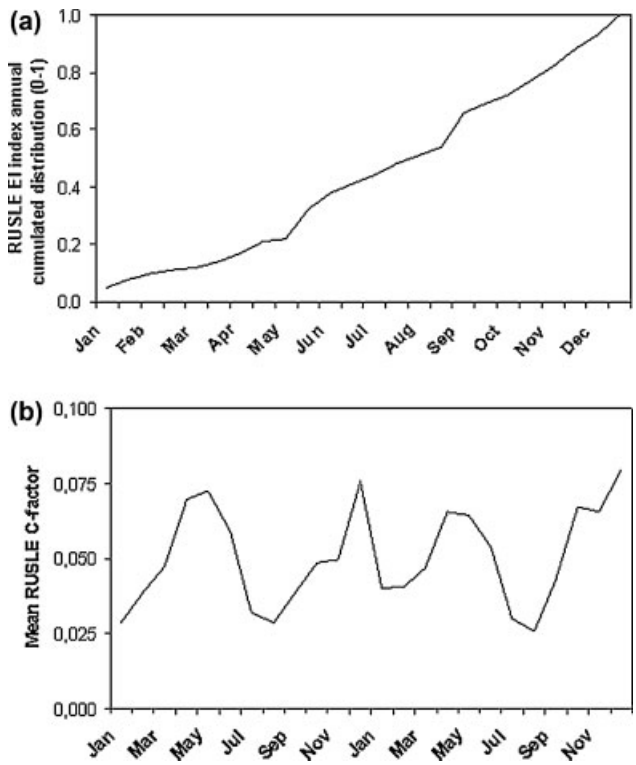


Figure 3. Monthly values of annual cumulated distribution for RUSLE EI index (a) and C-factors (values averaged between the cropland cells), (b) along the simulation period by AnnAGNPS model in Ganspoel watershed (Belgium).

The whole watershed was modelled assuming a unique soil type (silt loam) with a uniform soil profile (up to a depth of 1 m). 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 soil saturated hydraulic conductivity $K_{sat}$ (one for each soil land use surveyed into the watershed) were input to the model. These values were derived from the Ganspoel database as well as from the LISEM Limburg database, as these data were collected on very similar soils (Takken *et al*., 1999; Nearing *et al*., 2005).

Soil surface parameters (e.g. vegetation cover and roughness) were collected during 20 surveys carried out between November 1996 and February 1999. 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, surface cover, surface roughness and soil moisture condition) (AnnAGNPS, 2001; Bingner and Theurer, 2005) (Figure 3b). Initial values for random roughness and vegetation coverage were derived from the Ganspoel database surveys. The practice factor (P) was always set to 1, due to the absence of significant protection measures in the watershed (Table III).

### *Model Performance Assessment*

Model performance was evaluated at the event scale 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 IV).

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 IV). In particular, $E$ is more sensitive to extreme values, while $E_1$ is better suited to significant over- or underprediction by reducing the effect of squared terms (Legates and McCabe, 1999; Krause *et al*., 2005). As suggested by the same authors, $E$ and $E_1$ were integrated with the Root Mean Square Error (RMSE), 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 IV). 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).

## RESULTS

Runoff depths were in general underpredicted (see the positive value of the CRM coefficient). The accuracy achieved for the prediction of the largest event (13-14/09/1998) gave a coefficient of determination exceeding 0·90 (Figure 4a) and a model efficiency ($E$) of 0·89 for runoff depth (Table V). The mean and standard deviation of simulated runoff volume depths were close to the corresponding observed values with differences lower than 12 and 16 per cent. When the events simulated as zero runoff were excluded from the analysis, the values for $r^2$ and $E$ became 0·98 and 0·97, respectively.

Similarly high values for the coefficient of determination were found for runoff simulations by AnnAGNPS at the

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Table IV. Coefficients and difference measures and their range of variability for the AnnAGNPS model evaluation at the Ganspoel watershed, Belgium

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

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

event scale by Yuan *et al*. (2001), Shrestha *et al*. (2006) and Shamshad *et al*. (2008). Sarangi *et al*. (2007) obtained similar values for the coefficient of determination and model efficiency when applying AnnAGNPS in an agricultural watershed of S. Lucia Island. However, in these studies AnnAGNPS was calibrated before a validation was carried out.

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 4b). Even though statistics of observed and predicted values were of the same order of magnitude (Table V), the low values achieved by the coefficients of efficiency ($E$ and $E_1$ lower than 0·35) and conversely the high RMSE (163 per cent of observed mean, Table V) 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; Licciardello *et al*., 2007).

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 VI; Figure 4c). Coefficients of efficiency ($E$ and $E_1$) were close to zero and the coefficient of determination did not exceed 0·60 (Table V). Those results were in accordance of what found by Yuan *et al*. (2001), Shrestha *et al*. (2006), Polyakov *et al*. (2007) and Shamshad *et al*. (2008) in sediment yield modelling by AnnAGNPS.

## DISCUSSION

The AnnAGNPS model implementation at Ganspoel watershed provided a generally good capability to simulate the greatest runoff event, 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 modelling is possible without calibration provided that sufficiently detailed input data are available. The database 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 (Refsgaard, 1997; Eckhardt and Arnold, 2001; Kavetski *et al*., 2006; Beven, 2006). A possible reason for this is that in many cases the available input data are much less detailed than those available for the Ganspoel watersheds in terms of soil surface characteristics and soil cover. 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 within the hydrological database utilized for the AnnAGNPS model implementation at the experimental watershed 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,

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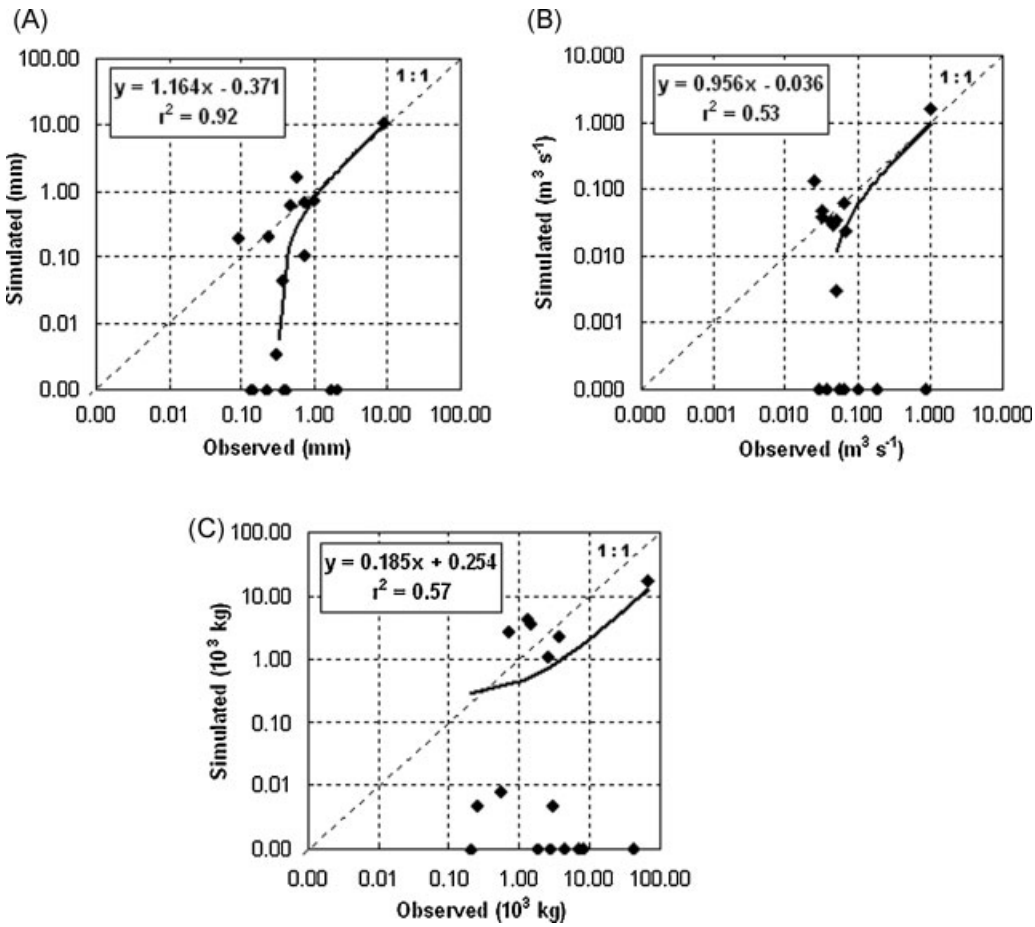


Figure 4. Comparison of 17 observed and simulated (by AnnAGNPS) events in the Ganspoel watershed, Belgium: (a) runoff, (b) peak runoff rate and (c) sediment yield (values are in logarithmic scale).

achieving a mean deviation between simulations and observations of about 50 per cent.

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;

Table V. Statistics concerning the AnnAGNPS simulations of 17 events at the Ganspoel watershed, Belgium

| Values | Mean (mm) | *SD* (mm) | $r^2$ | *E* | $E_1$ | RMSE (mm) | CRM |
|---|---|---|---|---|---|---|---|
| | | | Runoff | | | | |
| Observed | 1·04 | 2·26 | — | — | — | — | — |
| Simulated | 0·87 | 2·53 | 0·92 | 0·89 | 0·59 | 0·73 | 0·16 |
| | | | Peak flow | | | | |
| Values | Mean ($m^3 s^{-1}$) | *SD* ($m^3 s^{-1}$) | $r^2$ | *E* | $E_1$ | RMSE ($m^3 s^{-1}$) | CRM |
| Observed | 0·16 | 0·30 | — | — | — | — | — |
| Simulated | 0·12 | 0·39 | 0·53 | 0·35 | 0·19 | 0·26 | 0·27 |
| | | | Sediment yield | | | | |
| Values | Mean ($10^3$ kg) | *SD* ($10^3$ kg) | $r^2$ | *E* | $E_1$ | RMSE ($10^3$ kg) | CRM |
| Observed | 8·54 | 17·65 | — | — | — | — | — |
| Simulated | 1·84 | 4·31 | 0·57 | 0·16 | 0·29 | 15·71 | 0·78 |

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

| Date | Rainfall (mm) | Runoff volume | | Peak flow | | Sediment yield | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Obs. | Sim. | Obs. | Sim. | Observed | | Simulated | |
| | | (mm) | | ($m^3 s^{-1}$) | | ($10^3$ kg) | (kg ha$^{-1}$) | ($10^3$ kg) | (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 |

Baginska *et al*., 2003; Licciardello *et al*., 2007) and setting up pre-run before the first event simulated (which is important for initial soil moisture setup).

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-I (AMC-I) based on the NRCS criteria, minimizing 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 (Licciardello *et al*., 2007; Polyakov *et al*., 2007; Sarangi *et al*., 2007).

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 further improve the coefficients of efficiency ($E$ and $E_1$) and determination ($r^2$) for runoff volume model prediction capability at the experimental watershed.

Peak flow prediction capability shown by the AnnAGNPS model was basically poor. 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 are not suitable for the study area, leading to a severe underestimation of rainfall intensities and hence peak flows runoff rates, a fact also noted in other studies (Shrestha *et al*., 2006; Licciardello *et al*., 2007). A prediction method that takes into account the actual patterns of rainfall intensity would be expected to provide better accuracy in peak flow estimations.

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 it 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 runoff.

However, another factor that, despite the fact that the Ganspoel database is quite detailed, the limited availability of input parameters may also play a role. 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 (Licciardello *et al*., 2007). As values for these parameters were not all available in the Ganspoel dataset data from the literature had to be used in some cases.

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

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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 modelling 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 discretization 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.

## CONCLUSIONS

Watershed prediction models are considered a cost-effective and time-efficient method for the assessment of pollutant loads, simulation of watershed processes in order to single out the most suitable management practice in conservation planning. The widely spread AnnAGNPS model was used to simulate single events (17 observations in the period from May 1997 to February 1999) in an agricultural watershed located in central Belgium in order to evaluate model prediction capability in humid continental conditions.

The AnnAGNPS model was found to perform well in simulating the highest runoff volumes, without any a priori calibration; the other runoff events were instead underpredicted, presumably because of model's difficulties to adjust CN values during the continuous simulation of the soil moisture conditions, which provided, in some cases, too low or no predicted runoff, as also found by other Authors.

However, prediction accuracy was low for peak flow and sediment yield predictions: both peak runoff and sediment yield were strongly underestimated. Several reasons may be responsible for the poor model performance. On the whole, our study confirms that, even when a relatively detailed dataset is available, the application of process-based models has to be done with care. While moderate to good results were obtained with respect to total runoff prediction, predictions for peak runoff and sediment yield were poor at best. Thus, even in conditions where detailed data are available, calibration remains a prerequisite for the successful application of a process-based erosion model (Refsgaard, 1997; Eckhardt and Arnold, 2001; Beven, 2006; Kavetski *et al*., 2006). Sensitivity analysis should be performed in the future study so that important parameters to affect runoff, peak flow and sediment yield would be found. Adjusting parameters in the suitable range is expected to give better simulation results.

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