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Evaluation of the WEPP Model in a Belgian Agricultural Watershed*

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Abstract: The physically based WEPP (Water Erosion Prediction Project) model was implemented in a small agricultural watershed located in central Belgium, called Ganspoel. The watershed, mainly agricultural and resulting in a smooth topography, covers about 115 ha in a landscape typical of large parts of central Europe. Seventeen runoff, peak flow and sediment yield events, collected during a 2-year monitoring period, were simulated by the model. Even though the runoff volume predictions were well correlated to the corresponding observations, WEPP prediction capability was generally unsatisfactory also when different set-up methods of the soil effective hydraulic conductivity were used. The poor performance achieved for runoff volume and peak flow simulations affected sediment yield predictions. The differences between observed and simulated values for runoff, peak flow and sediment yield events may depend on: i) the great number of small runoff and sediment yield events within the available database with which is associated large natural variation and which in many cases are not well reproduced by WEPP; ii) the lack of model calibration processes; iii) the scarceness of information about some important soil physical and hydrological parameters; iv) the land use heterogeneity and crop schedule complexity of the Ganspoel watershed.

Key words: Watershed modelling, WEPP, water runoff, peak flow, soil erosion.

1. Introduction

Estimation of runoff and sediment yield is necessary for developing watershed management plans involving soil and water conservation measures. Thus, research in hydrological modelling and related watershed planning issues form a strong component of the environmental activities [1]. In the case of soil erosion, which is becoming increasingly greater concern in the world due to its on-site and off-site impacts, computer simulation models have become important tools for the analysis of hill slope and watershed processes and their interactions and for the development and assessment of watershed management measures [2, 3]; adequate and reliable prediction models can be used to evaluate a variety of management scenarios without costly and lengthy field tests [4].

During the last decades many prediction models of empirical or conceptual nature have been developed for prediction of hydrological variables as water runoff, peak flow or sediment yield at hill slope, watershed or regional scales. Among them, continuous simulation

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** The contributions of the authors to this work can be considered equivalent.*

models provide great advantages over event-based models as they allow to study watersheds and their response over a longer time period in an integrated way.

Nowadays, for the many continuous watershed-scale erosion models available in the scientific literature, 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 WEPP (Water Erosion Prediction Project) model [5] is a physically based, distributed parameters, continuous simulation model, intended to represent the essential mechanisms controlling erosion including the complex interactions between various factors and their spatial and temporal variability [6]. WEPP has been developed by the USDA since late ’80 for application on cropland, rangeland, forestland and other managed lands [7]; the model is supposed to have a wide range of applicability [8] and therefore is able to reduce the need for extensive field experiments and calibrations [9].

WEPP has been tested and applied widely around the world and under varying climatic conditions: across the United States [10-12], in South America [3, 13], in Australia [14, 15], in Europe [16, 17], in Asia [1, 18] and in Africa [19, 20]. The model simulates runoff and sediment yield for different land use scenarios (e.g. rangelands, [21]; burnt scrub areas, [22]; irrigated croplands, [4, 23]; forest watersheds, [24]; construction sites, [25]; steep mountain regions, [26]); it has been implemented both at plot [4, 27, 28], at hill slope [29-31] and at watershed scale.

At watershed scale simulations of runoff and soil loss were conducted across the USA in 15 small watersheds (0.34 to 5.14 ha), producing very good results in terms of coefficient of determination [32]. Savabi [10] applied the model to a watershed of 330 ha with a coefficient of determination of 0.70 between measured and predicted results. In a small watershed (18.2 ha) the same author found tolerable differences between the annual runoff WEPP predictions and some of 32 years of observation and a maximum factor of underestimation and overestimation of about 0.5 and 3.5 respectively [11]. Model tests in Mediterranean watersheds showed significant differences between predictions and observations, mainly due to the seasonal effects (as cracking soils) [20] or the spatial variability in rainfalls [17], not currently well represented in WEPP. Accurate simulations of daily runoff and erosion were achieved by Pandey [1] in a small hilly watershed (2793 ha) under sub-humid tropical climatic conditions typical of Indian subcontinent. Calibration/validation trials in a 1.62 km^2 watershed of Southern China, mainly terraced and forested, provided satisfactory prediction capability for monthly values of runoff and sediment yield [18].

Nearing [33] investigated the sensitivity of WEPP and six other prediction models to precipitation and vegetation cover changes in a small agricultural watershed located in central Belgium, characterized by land use heterogeneity and crop schedule complexity.

Even though several studies were carried out using the WEPP model, from the above reported studies it is evident that WEPP 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; further refinement and additional testing of the model is still required for wide range of conditions and agricultural watersheds [1].

This paper aims at evaluating WEPP prediction capability for runoff, peak flow and sediment yield events in humid continental conditions, utilizing a two-year database collected at a small agricultural watershed located in central Belgium. In this study no calibration processes was undertaken, which otherwise can compensate the errors related to model parameterisation and hydrological processes modelling. By this way it has been drawn to what extent WEPP 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.

2. Materials and Methods

2.1 Brief Description of WEPP Model and Its Geospatial Interface (GeoWEPP)

WEPP is a physically based, distributed parameters, continuous simulation model which aims at predicting spatial and temporal distribution of net soil loss and deposition for a wide range of time periods and spatial scales. The WEPP hill slope version simulates water runoff and soil erosion along a single slope profile. The model watershed version is intended for use on small agricultural watersheds (less than 250 ha) [34], in which the sediment yield at the outlet is significantly influenced by hill slope and channel processes [1], even though tests of WEPP prediction capabilities have been conducted on watersheds greater in size than 100 km^2 [35].

The WEPP model is made up of several components, which take into account weather, winter hydrology, water balance, surface and subsurface hydrology, soil characteristics and management, plant growth, irrigation, hydraulics of overland flow, erosion processes and watershed channel hydrology [7].

Climate input data can be supplied through two subroutines: CLIGEN, an auxiliary stochastic climate generator [8] or BCDG (Breakpoint Climate Data Generator) [19]; the latter allows to use rainfall pattern for each rainfall and to take into account complex rainfalls with several intensity peaks [20].

The hydrological sub-model evaluates infiltration by using the Green-Ampt Mein-Larson model; runoff volume is routed over the land surface through an approximation of the kinematic wave model, which in continuous simulation model allows to assess peak discharge [36]. The WEPP model can run either using a time-invariant (K_{ec}) or a baseline soil effective hydraulic conductivity (K_b).

The plant growth sub-model, using EPIC [37] concepts of phenological crop development, assesses the impact of temporal changes in plant variables on the hydrologic and erosion processes: it simulates canopy cover, canopy height and root development as well as biomass production both for crops and rangeland plants.

Detachment, transport and deposition of sediment are simulated both in hill slope areas (i.e. overland flow) and channels area (i.e. concentrated flow). The movement of suspended sediment on rill, interrill and channel flow areas is based on a steady state erosion sub-model that solves a sediment continuity equation at peak runoff rate [36].

Soil erodibility is taken into account by three parameters: interrill erodibility (K_i), rill erodibility (K_r) and critical shear shear (τ_c). Soil resistance to detachment by raindrop impact determines K_i, while soil resistance to detachment by concentrated rill flow determines K_r. When shear stress exerted by flow exceeds τ_c, soil detachment begins [31].

A geospatial interface of the WEPP model (GeoWEPP) [38, 39] has been developed to automate slope, soil and management parameterisation. The GeoWEPP interface is based on an integrated software code of the topographic analysis tool TOPAZ [40]. TOPAZ uses two key parameters to operate channel delineation and characterizes its contributing areas: the Critical Source Area (CSA, the threshold area at which a permanent channel begins) and the Minimum Source Channel Length (MSCL, the minimum length of a channel segment). The version of GeoWEPP (release ArcX 2005.1) used in the present paper delineates a single representative hill slope for each contributing area with a single soil and land use along the entire hill slope.

2.2 Main Characteristics of the Experimental Watershed

The model (release in 2007) was implemented using a database reporting hydrological, morphological, soil type and land use data collected in a small watershed (50°48'N, 4°35'E) [41] located in central Belgium. The following information about the database is drawn from the works by Steegen [42] and Van Oost [43], in which further details can be found.

Fig. 1 Aerial view of the Ganspoel watershed, Belgium.

The watershed covers 115 ha between 60 m and 100 m a.s.l. with an average slope lower than 10%, but locally exceeding 25%. A dense network of dry valleys characterizes the area (Fig. 1).

The topography of the area is formed in sandy deposits overlain by a loess layer that was deposited during the latest glacial. 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 and a moderate clay content [43].

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 north-western part of the Ganspoel watershed and represents 9% of its area [41]. 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 ℃. 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.

2.3 The Hydrological Database

The hydrological database was collected during a recording period 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

Table 1 Main characteristics of the observed events used for WEPP implementation at the Ganspoel watershed, Belgium.

Event	Rainfall		Runoff volume		Runoff coefficient	Peak flow	Sediment yield	
	depth	duration						
	mm	h	m^3	mm	%	$m^3 \cdot s^{-1}$	10^3 kg	$kg \cdot ha^{-1}$
19/05/1997	8.0	0.4	252	0.22	2.9	0.103	8.2	70.1
21/05/1997	6.5	8.4	155	0.13	2.2	0.056	2.7	23.3
11/07/1997	13.0	0.6	2307	1.97	16.2	0.862	40.9	349.7
14/07/1997	5.5	0.6	428	0.37	7.1	0.181	4.4	37.6
17-18/07/1997	21.5	8.4	404	0.35	1.7	0.050	3.6	30.8
25/12/1997	6.5	1.0	106	0.09	1.5	0.043	0.2	2.1
05/01/1998	8.0	4.2	270	0.23	3.1	0.051	0.5	4.5
28/04/1998	11.0	1.4	164	0.14	1.4	0.037	0.2	1.8
26/08/1998	5.5	8.4	451	0.39	7.5	0.064	1.9	16.2
08-09/09/1998	24.5	1.5	530	0.45	2.0	0.067	1.3	11.1
13-14/09/1998	57.5	19.1	10361	8.86	16.5	1.017	66.1	565.2
31/10-01/11/1998	25.0	19.3	1957	1.67	7.2	0.064	6.9	58.9
14/11/1998	15.5	14.4	834	0.71	4.9	0.032	0.7	6.1
29/11/1998	18.5	19.9	653	0.56	3.2	0.025	1.4	12.0
16-17/01/1999	14.5	21.0	1101	0.94	6.9	0.033	2.6	21.8
28/01/1999	8.0	3.8	827	0.71	9.4	0.046	3.0	25.6
07/02/1999	6.5	12.0	354	0.30	5.0	0.029	0.5	4.7

equipped with a flowmeter (ISCO-4220), 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 ℃ 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 $kg \cdot ha^{-1}$ (Table 1). Ten other events were not taken into account because of inadequate sampling (see Ref. [42] for more details).

2.4 Model Parameterisation

2.4.1 Morphological Watershed Discretisation

In order to evaluate the WEPP capability of predicting runoff and erosive events, parameterisation was made as recommended in the WEPP User Summary [36].

The discretisation into sub-watersheds (groups of hill slopes) contributing to channels was carried out using GeoWEPP (Fig. 2). A high precision Digital Elevation Model (DEM) of the watershed with a 5 m-resolution was created using aerial photographs. Field boundaries, roads and built-up areas were mapped using a GPS.

Morphologic characteristics of each hill slope (i.e. length, width and slope) were automatically derived from the DEM following the procedure implemented in GeoWEPP. In order to optimize the reproduction of the watershed morphology, the CSA and the MSCL model's default values (5 ha and 100 m respectively) were properly decreased to 0.5 ha and 50 m, thus obtaining 155 hill slopes (0.1 to 4.2 ha) and 65 channels; about 20% of the modelled hill slopes was longer than 100 m (common recommended limit, [44]).

Land uses and soil types were overlaid to each sub-watershed through the GeoWEPP interface according to a majority criteria. All channels were treated as ditches with a section width always set to 1 m.

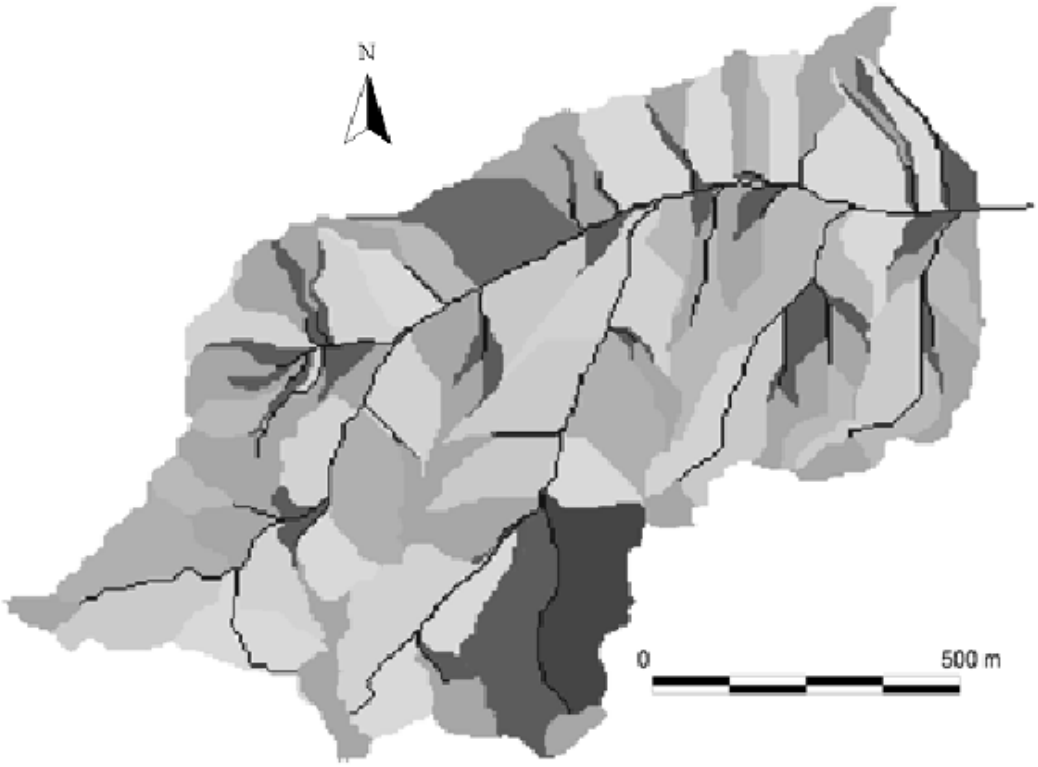


Fig. 2 Layout of Ganspoel watershed discretisation in sub-watersheds and channels by GeoWEPP.

2.4.2 Construction of Input Files

The Breakpoint Climate Data Generator (BCDG) was used to build the climate input file. As no meteorological information was provided with the available database, climatic data (daily values of maximum and minimum air temperature, relative humidity as well as wind velocity and direction) were collected at the nearest meteorological station (Bruxelles, 50°54'N, 4°30'E). 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.

The whole watershed was modelled on a unique soil type (silt loam); an uniform soil profile was assumed. Sand (14%), clay (11%) and silt (75%) soil contents as well as bulk density (1.4 $kg \cdot dm^{-3}$) were field or lab-measured. The Cation Exchange Capacity (CEC, 10 meq per 100 g) and the Organic Matter Content (OMC, 2.25%) were in the range reported in the WEPP User Summary [36] for silt loam soils; rock percentage was set to 2%.

Neither measurements of the soil effective hydraulic conductivity inputs (K_e), needed by the WEPP model, nor saturated hydraulic conductivity (K_{sat}) were available within the hydrological Ganspoel database; only values of K_{sat} compiled from databases of Leuven and Utrecht (using also data from the LISEM Limburg database, which is very similar) were reported [33, 41, 45]. The value of the soil albedo parameter was calculated by the Baumer's equation and set to 0.24 [36].

Six land uses were surveyed in the watershed (cereals, root crops, forest, meadow, fallow and urban areas). Soil surface parameters (e.g. soil surface crusting and roughness) and vegetation cover values were collected during 20 surveys carried out between November 1996 and February 1999. Information about the specific plants and the management practices were designated in the WEPP plant/management files and modelled using the model database. For the crop cultivations it was necessary to modify some parameters of the model's default database, including planting and harvest dates, types and dates of tillage,

Table 2 Input values of soil effective soil hydraulic conductivity (K_e, mm·h^{-1}) in WEPP implementation at the Ganspoel watershed, Belgium.

Land uses		Simulation series			
		I		II	III
		K_e internally calculated by WEPP		K_e = 50% K_{sat} (1)	K_e set as: f (Curve Number) for cropland (2) simulation series II for other land uses
Cropland	Cereals	2.8 (3)	1.6 (4)	38.8	13.6
	Root crops			102.6	9.5
	Forest			62.6	62.6
Rangeland	Meadow	20.6 (5)	1.0 (6)	26.1	26.1
	Fallow			12.7	12.7
Urban areas		20.6 (5)	1.0 (6)	10^{-4}	10^{-4}

(1) set according to the Ganspoel hydrological database
(2) according to Nearing [46]
(3) baseline effective hydraulic conductivity (WEPP User Summary, [36])
(4) time-invariant effective hydraulic conductivity (WEPP User Summary, [36])
(5) time-invariant effective hydraulic conductivity for plant community with rill cover lower than 45% (WEPP User Summary, [36]);
(6) time-invariant effective hydraulic conductivity for plant community with rill cover equal to or exceeding 45% (WEPP User Summary, [36]).

rotations as well as row width and distance between plants. The initial soil saturation level at the beginning of the simulation period (1st January 1997) was set to 0.9, as suggested in the WEPP User Summary [36].

2.4.3 Model Performance Evaluation Procedure

In order to evaluate the model performance, 17 rainfall events observed from May 1997 to February 1999 were modelled. The period from January to April 1997 was used to initialise soil conditions (i.e. the soil moisture).

Three simulation series were performed on a continuous basis using different sets of the soil effective hydraulic conductivity inputs (Table 2), to which model outputs have shown a high sensitivity in previous works [47, 48]. In simulation series I, the K_e values were internally calculated by WEPP based upon sand and clay content and CEC of the soil. In simulation series II the K_e values were assumed as 50% of K_{sat} [49]. Then, in simulation series III, K_e values for cropland were estimated based on the non-linear regression relationships between K_e and SCS-Curve Number [50] developed by Nearing [46] (Table 2). Given that, as above mentioned, the soil physical parameters were much more related to land use than to soil texture, six different values of K_{sat} (one for each soil land use) were input to the model.

Table 3 Input values of soil erodibility parameters in WEPP implementation at the Ganspoel watershed, Belgium.

	K_i/10^3 kg·s·m^{-4}	K_r/s·m^{-1}	τ_c/Pa
Cropland	5448	0.021	3.5
Rangeland	1214	3×10^{-4}	3.2

For the three simulations series the model adjusted automatically the baseline soil effective hydraulic conductivity (K_b) as a function of soil management and plant characteristics within the continuous simulation calculations [7]. The interrill erodibility (K_i), the rill erodibility (K_r) and the critical shear stress (τ_c) of soil were automatically calculated for the hill slopes by WEPP (Table 3).

Both the hydrological and erosion components of WEPP model were evaluated in logical order according to the input dependencies on each other. Runoff volume, peak flow as well as sediment yield predictions were assessed at event scale by using the 17 observed events of the Ganspoel hydrological database (Table 1).

Model performance was evaluated by qualitative and quantitative approaches. The qualitative procedure consisted of visually comparing the 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 coefficient of efficiency (E) of Nash and Sutcliffe [51] and its modified form (E_1) [52] 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 under-estimation by reducing the effect of squared terms [53, 54]. 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 under-estimation of the observed values [55, 56].

Table 4 Coefficients and difference measures and their range of variability for WEPP implementation at the Ganspoel watershed, Belgium.

Coefficient or measures	Equation	Range of variability
Coefficient of determination	$r^2 = \left[\frac{\sum_{i=1}^{n}(O_i-\bar{O})(P_i-\bar{P})}{\sqrt{\sum_{i=1}^{n}(O_i-\bar{O})^2}\sqrt{\sum_{i=1}^{n}(P_i-\bar{P})^2}}\right]^2$	0 to 1
Coefficient of efficiency [51]	$E = 1-\frac{\sum_{i=1}^{n}(O_i-P_i)^2}{\sum_{i=1}^{n}(O_i-\bar{O})^2}$	-∞ to 1
Modified coefficient of efficiency [52]	$E_1 = 1-\frac{\sum_{i=1}^{n}\lvert O_i-P_i\rvert}{\sum_{i=1}^{n}\lvert O_i-\bar{O}\rvert}$	-∞ to 1
Root mean square error	$\mathrm{RMSE} = \sqrt{\frac{\sum_{i=1}^{n}(P_i-O_i)^2}{n}}$	0 to ∞
Coefficient of residual mass [55, 56]	$\mathrm{CRM} = \frac{\sum_{i=1}^{n}O_i-\sum_{i=1}^{n}P_i}{\sum_{i=1}^{n}O_i}$	-∞ to ∞

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

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 [57].

3. Results

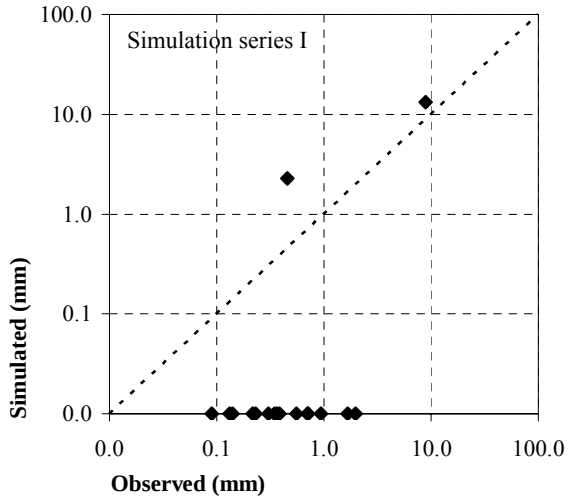
In all the simulation series the coefficient of regression was always close to 0.90 for runoff volume predictions (Table 5). The model efficiency E gave generally acceptable results, even though a relevant tendency to an underestimation of the observed events was found: for the simulation series I and II WEPP runoff volume predictions met the observations only for the most intense event (September 13-14, 1998). Fifteen events with observed runoff less than 2 mm were underestimated up to two orders of magnitude, simulated runoff being zero in many cases (Fig. 3).

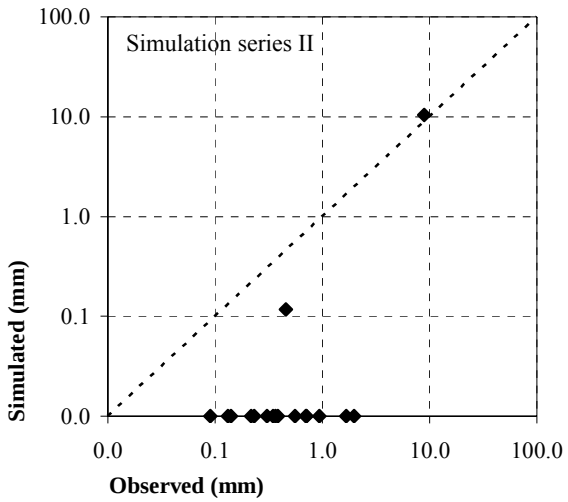
Setting up the values of K_e according to the relationship developed by Nearing [46] (simulation series III) let the simulated runoff volumes by WEPP to be closer to the observed values for most events (in particular from December 1997 to April 1998), even though the model efficiency slightly worsened with respect to simulation II. Three events (corresponding to rainfall depths lower than 6.5 mm) resulted in zero runoff simulations (Fig. 3). Also mean and standard deviation of simulated runoff volumes did never match the observed values (Table 5).

Model results did not improve either in the runs with time-invariant soil effective hydraulic conductivity values (K_{ec}) or estimating the effective hydraulic conductivity values (K_e) according to the procedure by Nearing [46] for fallow and cropped conditions. The regression analysis of observed versus simulated peak flow gave r^2 in the range 0.48 ÷ 0.56 with coefficients of model efficiency (E and E_1) always negative in all the simulation series (Table 5). Observed peak flows were modelled as zero values for most of the rainfall

Table 5 Statistics concerning the WEPP simulations of 17 events at the Ganspoel watershed, Belgium.

Runoff								
Values		Mean/mm	Std. Dev./mm	r^2	E	E_1	RMSE/mm	CRM
Observed		1.06	2.08					
	(I)	0.91	3.21	0.90	0.54	0.20	1.36	0.15
Simulated	(II)	0.62	2.52	0.94	0.83	0.43	0.84	0.42
	(III)	0.76	2.87	0.94	0.75	0.40	1.01	0.29
Peak flow								
Values		Mean/$m^3 \cdot s^{-1}$	Std. Dev./$m^3 \cdot s^{-1}$	r^2	E	E_1	RMSE/$m^3 \cdot s^{-1}$	CRM
Observed		0.162	0.296					
	(I)	0.301	1.052	0.53	-7.70	-0.81	0.847	-0.85
Simulated	(II)	0.209	0.844	0.55	-3.92	-0.32	0.637	-0.28
	(III)	0.241	0.869	0.56	-4.31	-0.32	0.662	-0.48
Sediment yield								
Values		Mean/10^3 kg	Std. Dev./10^3 kg	r^2	E	E_1	RMSE/10^3 kg	CRM
Observed		8.5	17.7					
	(I)	19.3	74.3	0.70	-11.08	-0.88	59.5	-1.26
Simulated	(II)	3.0	12.1	0.71	0.58	0.47	11.1	0.65
	(III)	18.6	76.1	0.71	-11.70	-0.81	61.0	-1.17





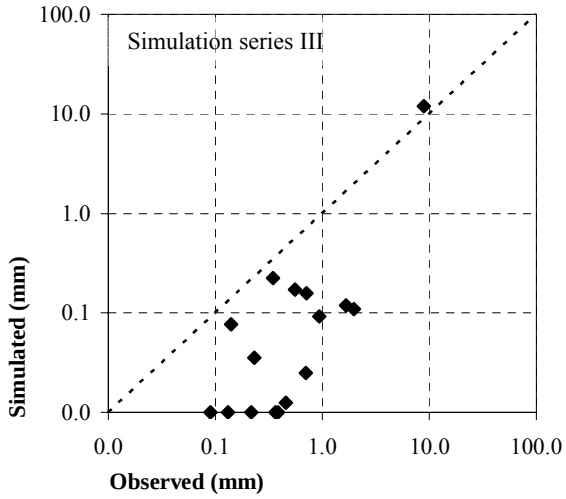


Fig. 3 Comparison between observed and simulated runoff volumes for WEPP implementation at event scale in the Ganspoel watershed, Belgium (values in logarithmic scale).

events in simulation series I and II; a relevant overprediction was observed in two and one case for simulation series I and II respectively. In simulation series III this model behaviour tended to disappear as no simulated peak flow was recorded only for five events (Fig. 4).

In all the simulation series model simulations gave r^2 always greater than 0.70; model efficiency, poor in the simulations series I and III, was instead satisfactory in

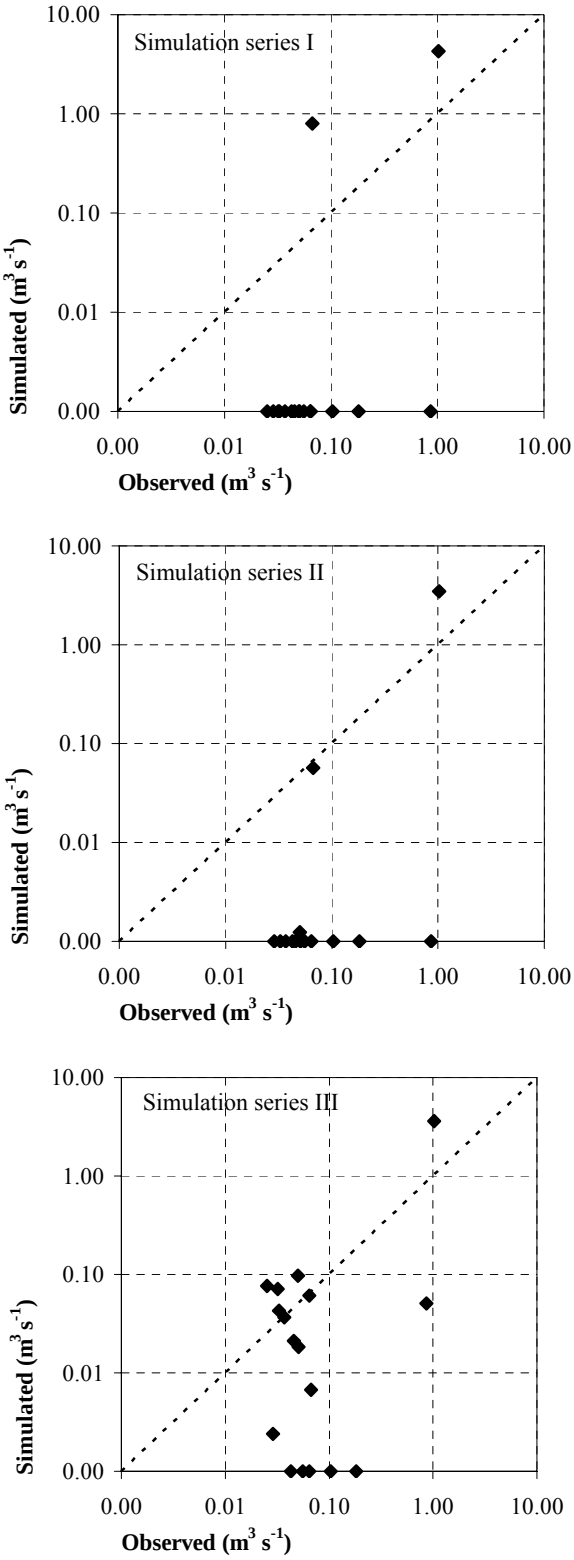


Fig. 4 Comparison between observed and simulated by WEPP peak flows for WEPP implementation at event scale in the Ganspoel watershed, Belgium (values in logarithmic scale).

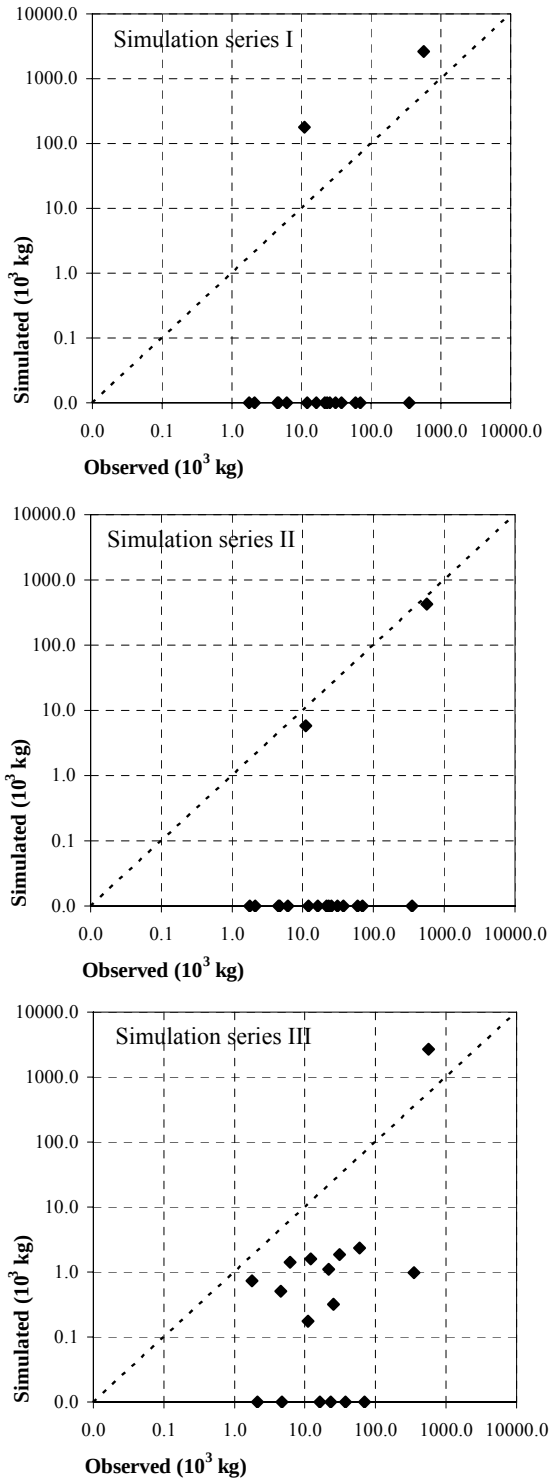


Fig. 5 Comparison between observed and simulated by WEPP sediment yields for WEPP implementation at event scale in the Ganspoel watershed, Belgium (values in logarithmic scale).

the simulation series II (Table 5), exclusively due the closeness of the sediment yield prediction to the

observed value for the most intense event (September 13-14, 1998). WEPP provided zero sediment yield for many observed events in the simulations series I and II; in simulation series III only three events was modelled as zero sediment yield (corresponding to zero runoff occurrence), even though the tendency to the relevant underestimation of the majority of the simulated events remained (Fig. 5).

It has to be noted that, Figs. 3, 4 and 5 show values in logarithmic scale in order to make easier the visual comparison, while the statistical parameters were computed on the data in decimal scale; the logarithmic scale representation makes differences in low values bigger and E values look lower than they are.

4. Discussion

The differences between observed and predicted values for runoff volume and peak flow provided by the WEPP model implementation in the experimental watershed may be reasonably explained as follows.

In this study the aythorsdeliberately opted to evaluated the WEPP model without prior calibration/validation processes, in order to assess its performance in cases where no data for validation are available; therefore the errors related to model parameterisation and hydrological processes modelling have not been compensated by an appropriate calibration process. This latter is considered in many cases necessary for adequate runoff modelling, as stressed in many other studies [58-61].

Even though some important input data which are important controls on runoff production (e.g. soil roughness and vegetal cover) are available for the Ganspoel watershed, the lack of other field-surveyed parameters, as the soil effective hydraulic conductivity (which is considered essential for accurate model predictions of runoff) [1, 18], definitely affected the WEPP model performance in runoff simulations.

The set of observations available in the database of the Ganspoel watershed was mainly made up of events of low magnitude (90% with runoff depths lower than 2 mm, Table 1), for which WEPP predictions may be generally unsatisfactory, as found by other authors: for example Soto and Díaz-Fierros [22], Gronsten and Lundekvam [31], Licciardello [17] and Konz [26] in different climatic, pedologic and land use highlighted the simulation of a no runoff occurrence with respect to events with low observed runoff volumes. According to Ref. [22] this model behaviour may depend on the runoff surface generation algorithm used in the WEPP model, which considers only Hortonian processes without runoff due to saturated flow: such runoff is common for low-intensity rainfall, as for many events simulated in the present study, where the infiltration capacity of the soil often exceeds mean rainfall intensity [62]. However, many tested models have difficulties in simulating low runoff. Chahinian [63] attributed this to the problems inherent in determining the soil moisture conditions before and during flood events, which do not account for soil moisture redistribution over the whole duration of a flood event [18].

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 [43]. It proves that an adequate runoff prediction is undoubtedly necessary for accurate erosion prediction.

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

(1) The above mentioned lack of calibration processes;

(2) The land use heterogeneity and crop schedule complexity of the Ganspoel watershed, which contains more than 80 fields roads, buildings, forest, grassed channels and several crops with differing planting and harvesting schedules; it may explain difficulties for modelling of interactions between processes and water and sediment routing associated with its heterogeneity

and complexity [33];

(3) The limited availability of some input parameters required by the WEPP model for runoff volume and sediment yield predictions may also play a role. As values for these parameters were not all available in the Ganspoel dataset, data from the literature had to be used in some cases.

Finally, numerous studies show the high variability associate with low values of runoff and soil loss in plots [64, 65]. Even if the natural variability of phenomena in plots can be different from small catchments, the coefficient of variation for replicated measurements, calculated for runoff and sediment yields events as function of their magnitude, can give an idea of the acceptable difference between observed and simulated values. In the present case, the coefficient of variation for runoff volumes, calculated by using the equation proposed by Gomez [64], ranges between 33% (associated with the highest event of 8.86 mm) and 150% (associated with the lowest event of 0.09 mm); the coefficient of variation for sediment yield rates, calculated by using the equation proposed by Nearing [65] is even higher (between 87% and 506%). Moreover, using the methodology proposed by Nearing [66] to calculate the goodness of the WEPP simulation considering the natural soil loss variability, the authors obtained that the amount of simulated values that fall within the expected range of the differences for two measured data points of the same population is between 71% (Simulation series III) and 88% (Simulation series I and II).

5. Conclusions

In this paper the WEPP model was used to simulate seventeen runoff, peak flow and sediment yield events (observed during a period about two years) in a small agricultural watershed located in central Belgium, in order to test the model capacity of predicting runoff and erosive events in humid continental conditions. Even though in the tests carried out the runoff volume predictions were well correlated to the corresponding observations, WEPP runoff prediction capability was generally unsatisfactory also when different set-up methods of the soil effective hydraulic conductivity were used.

The differences between observed and simulated runoff volumes and peak flow may basically depend on the lack of model calibration processes as well as the great number of small runoff events within the available database, which in many cases are not well reproduced by WEPP. In addition the lack of an essential parameter within the experimental database as the soil effective hydraulic conductivity negatively affected the WEPP model performance in runoff simulations.

Such a poor performance in runoff volume and peak flow simulations by WEPP at the Ganspoel watershed strongly influenced also sediment yield predictions, for which model efficiency was basically poor. Moreover the scarceness of information about some soil physical and hydrological parameters together with the land use heterogeneity and crop schedule complexity of the experimental watershed may worsen the WEPP model performance in sediment yield predictions.

On the whole, the above mentioned limitations of the available database and the high natural variability associated with the low values of runoff volumes and sediment yield events do not allow to exclude the possibility to simulate runoff and erosive events at small watersheds in humid continental conditions by WEPP. A more concrete attempt of calibration (and successive validation) of the hydrological sub-model (and consequently of the erosive subroutine) will be opportune, when a wider and more complete hydrological and geomorphologic database will be available.

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