Soil Erosion and Sediment Redistribution in River Catchments

MEASUREMENT, MODELLING AND MANAGEMENT

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18 Runoff and Erosion Modelling by WEPP in an Experimental Mediterranean Watershed

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Introduction

In recent decades several simulation models have been developed to estimate and analyse the impact of water erosion at watershed scales (Renard *et al.*, 1982; Singh, 1995; Singh and Frevert, 2002), but more work is needed to test and improve their applicability and efficiency in environmental situations that differ from those where the models were developed (Goodrich and Simanton, 1995; Soto and Díaz-Fierros, 1998; Duiker *et al.*, 2001).

The Water Erosion Prediction Project (WEPP, Nearing *et al.*, 1989) is a physically based, distributed parameter model that has been widely applied around the world (Laflen *et al.*, 1994; Klik *et al.*, 1995; Liu *et al.*, 1997; Flanagan *et al.*, 1998; Hebel and Siegrist, 1998; Kincaid, 2002) to simulate the main physical processes related to infiltration, percolation, runoff and soil erosion phenomena at hillslope and watershed scales. A linkage between WEPP and geographical databases, called GeoWEPP, is under development to automate slope, soil and management parameterization (Renschler and Harbor, 2002; Renschler *et al.*, 2002).

Several tests of the WEPP model successfully conducted in the USA on both field experimental plots (Zhang *et al.*, 1996; Nearing and Nicks, 1997; Flanagan *et al.*, 1998; Tiwari *et al.*, 2000) and small watersheds (0.34–18.20 ha) (Savabi *et al.*, 1996; Liu *et al.*, 1997) have shown results comparable with those produced by other models (Tiwari *et al.*, 2000; Bhuyan *et al.*, 2002). Some efforts at model calibration at the plot scale in European conditions have produced acceptable results (Klik *et al.*, 1995; Hebel and Siegrist, 1998; Vlnasova *et al.*, 1998).

A few applications of WEPP have been carried out in Mediterranean conditions. Simulations of soil water content, runoff and erosion by WEPP for experimental plots in north-west Spain have shown reasonable agreement with observed values (Soto and Díaz-Fierros, 1998). An overestimation of interrill erodibility by the model was found for Mediterranean soils with stable aggregation in southern Spain (Duiker *et al.*, 2001). Results of comparison with measurements of deposited sediment in three Sicilian reservoirs with drainage watersheds of 115–570 km^2 (Santoro *et al.*, 2002) have shown that the greater the amount of eroded sediment, the smaller were the relative errors that resulted using the WEPP model.

In order to assess of the performance of erosion models in Mediterranean conditions, a monitoring programme in a small mountainous watershed was initiated in eastern Sicily (Italy) 7 years ago. In this paper the results of applications of WEPP to the monitored watershed model are analysed in order to draw conclusions on model implementation and performance in the experimental conditions studied.

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Materials and Methods

Main characteristics of the experimental watershed

The model was applied to data sets collected in eastern Sicily from a small mountainous watershed, called Cannata, which is a tributary, ephemeral in flow, of the Flascio River. The watershed (Fig. 18.1), covering about 130 ha, is equipped with the meteorological station A, recording rainfall, temperature, wind, solar radiation and pan evaporation, two additional rainfall gauges indicated by B and C, as well as a hydrometrograph connected to a runoff water automatic sampler (for the control of sediment concentration in the flow) (D and E).

Topsoil characteristics were investigated by a field survey at 57 sites within the watershed. Clay-loam (USDA classification) was the dominant texture (63% of spatially distributed samples). Guelph permeameter measurements yielded low to medium values of the saturated hydraulic conductivity (0.2–17.6 mm/h; $N = 57$; CV = 103%). Land use monitoring has highlighted the persisting prevalence of pasture areas (ranging between 87% and 92% of the watershed area) with different vegetation complexes (each grouping up to 15 species) and ground covers. In particular, four soil cover conditions 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 in a previous paper (Licciardello *et al.*, 2001).

Model parameterization

Morphological discretization of the watershed

GeoWEPP was used for the discretization of the watershed into a number of subwatersheds (groups of hillslopes) contributing to channels (Fig. 18.2). A Digital Terrain Model was arranged over a grid of 5 × 5 m cells using ARCVIEW 3.2 by digitizing 2-m elevation contour lines. The Critical Source Area (the threshold area at which a permanent channel begins) and the Minimum Source Channel Length (the minimum length of a channel segment) were set to 1.25 ha and 100 m, respectively, in order to optimize the reproduction of the watershed morphology.

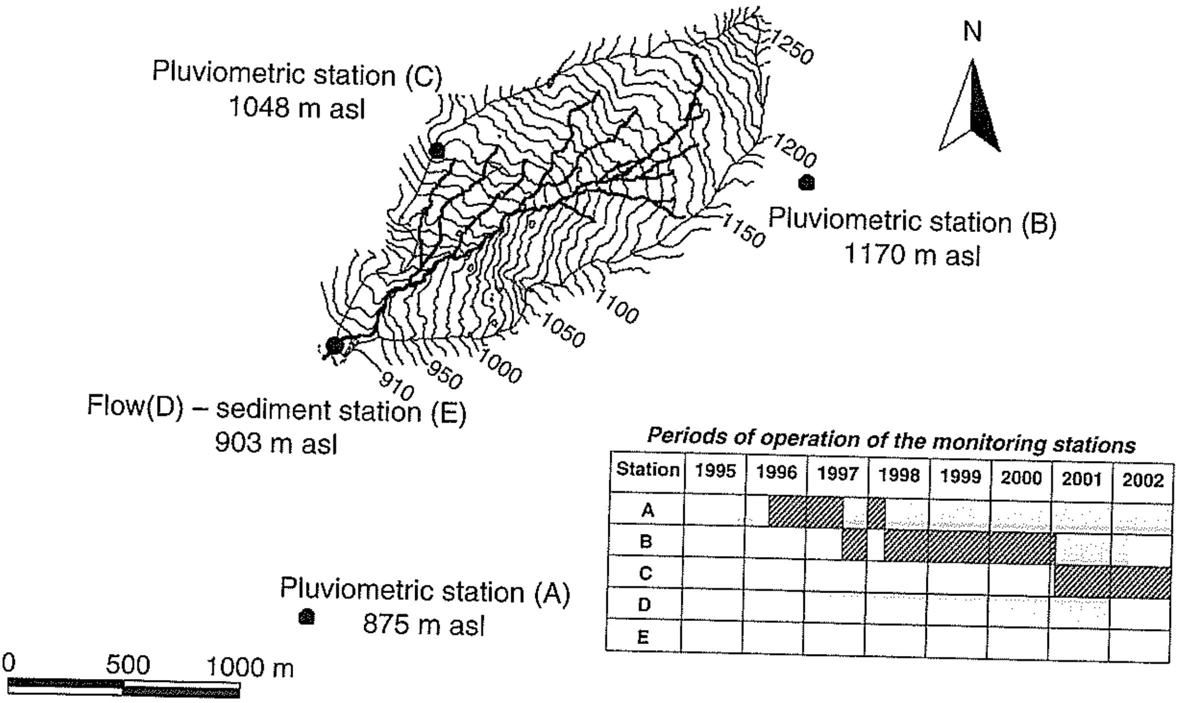

Fig. 18.1. Location and operating periods of the monitoring stations at Cannata watershed, Sicily.

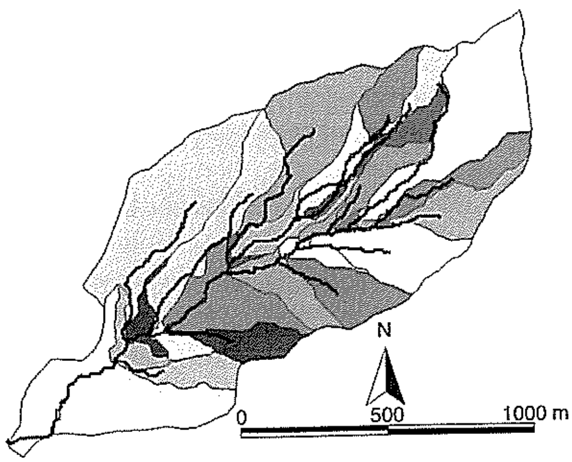

Fig. 18.2. Layout of subwatersheds and drainage network after GeoWEPP application to Cannata watershed.

This resulted in 27 subwatersheds (0.32–16.15 ha with two to three hillslopes), 68 hillslopes (0.01–11.49 ha) and 27 channels. Due to the morphology of the watershed, 30% of the obtained hillslopes were longer than 100 m (common recommended limit; Baffaut *et al.*, 1997).

The Watershed Project (i.e. the morphological schematization of the watershed for input to WEPP) was built through the WEPP Windows Interface using the morphological information on hillslopes and channel network taken from GeoWEPP. ARCVIEW 3.2 was used to overlay soil texture and land use of hillslopes in order to set the size and position of the Overland Flow Elements (OFEs) over each hillslope. Upper channels were treated as ditches, while lower channels were tested as ungraded channels. Twenty different types of OFEs, with a maximum number of ten in a single hillslope, were identified depending on land cover and soil texture combinations.

Construction of input files

The WEPP watershed version was applied on a continuous basis to the observation period from June 1996 to December 2002; the period June–October 1996 was used to train the model and build up initial soil moisture conditions. The Breakpoint Climate Data Generator (BPCDG, Zeleke *et al.*, 1999) was used to build the climate file. Climatic data (daily values of maximum and minimum air temperature, relative humidity, solar radiation and wind velocity and direction at 8:00 a.m. and 6:00 p.m.) were taken from meteorological station A; information on the rainfall pattern (depth and mean intensity in time definite range) were taken from the pluviometric station B in Fig. 18.1, which, based on previous rainfall–runoff data analysis, appeared more representative of true precipitation conditions. Daily values of dew point temperature were calculated on the basis of daily values of air temperature and relative humidity. Uniform soil profiles were assumed. For each of the five soil textures in the watershed, the data were derived by averaging the sand (particle diameter 0.1–2.0 mm), clay, very fine sand (particle diameter 0.05–0.1 mm), organic matter and rock content (particle diameter > 2 mm), cation exchange capacity (CEC), and bulk density from the 57 field samples (up to 36 for each type of soil). Three simulation series were performed using three different sets of the effective hydraulic conductivity inputs, K_e (Table 18.1), to which model outputs have shown a high sensitivity in previous work (Nearing *et al.*, 1990). Numerous attempts have been carried out to improve model simulations by setting the K_e values as a function of physical characteristics (Kidwell *et al.*, 1997; Kincaid, 2002), by a calibration of the runoff data (Hebel and Siegrist, 1998; Savabi, 2001), using measured infiltration data (Savabi, 2001) and by a non-linear regression relationship between K_e and SCS Curve Number (USDA, 1972) for fallow and cropped conditions (Nearing *et al.*, 1996).

In this study, in simulation series I, the K_e input 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 based on the median field saturated conductivity for each soil type (Bouwer, 1969), resulting in values in the range of 0.4–4.7 mm/h. In simulation series III, K_e values for cropland (1.9–5.8 mm/h) were estimated based on the relationship developed by Nearing *et al.* (1996). WEPP was run using both constant and internally adjusted by the model K_e values for the three simulations series. The interrill erodibility (K_i), the rill erodibility (K_r) and the critical hydraulic shear (τ_c), calculated for the hillslopes as recommended in the WEPP User Summary (Flanagan and Livingstone, 1995), were in the suggested range both for cropland and rangeland areas (Table 18.2).

Table 18.1. Set-up method of effective soil hydraulic conductivity (K_e) in the simulations by WEPP at Cannata watershed.

Simulation series			
I	II	III	
K_e internally calculated by WEPP based upon sand and clay content and CEC of the soil	K_e = 0.5 field saturated conductivity[a] measured by the Guelph permeameter	Rangeland K_e as in the simulation series II	Cropland $K_e = f$ (Curve Number)[b]

[a]As proposed by Bower (1969); [b]as proposed by Nearing *et al.* (1996).

Table 18.2. Interrill erodibility (K_i), rill erodibility (K_r) and critical hydraulic shear (τ_c) input values set according to the equations in the WEPP User Summary (Flanagan and Livingstone, 1995).

	K_i (10^3 kg/s/m^4)		K_r (10^{-3} s/m)		τ_c (N/m^2)	
Soil texture[a]	Rangeland	Cropland	Rangeland	Cropland	Rangeland	Cropland
Clay	796.18	3708.22	0.91	10.0	2.25	3.50
Loam	334.00	4293.62	0.36	4.0	0.49	3.57
Clay loam	603.70	4101.52	0.68	4.0	1.49	4.38
Sandy loam	228.21	4508.77	0.17	5.0	0.19	3.10
Sandy clay loam	276.99	4059.25	0.33	4.0	0.36	3.71

[a]USDA classification.

In the ungraded channels the critical hydraulic shear was set as a function of the stream bed material size, while the erodibility parameters were set to the default value in the WEPP database. For the ditches the default values are used for both parameters. The values for the soil albedo parameter (i.e. the fraction of the solar radiation which is reflected back to the atmosphere) were computed using the Baumer equation (Flanagan and Livingstone, 1995) and ranged between 0.08 and 0.22 for the loam and clay textures, respectively.

For each land use, information about the specific plants and the management practices were designated in the plant/management files. Some studies have reported the difficulty in representing complex plant ecosystems on rangelands (Laflen *et al.*, 1994) and the importance of spatial and temporal variation of vegetation for interrill erosion processes, particularly in semiarid conditions (Blackburn and Pierson, 1994). In this study, the different vegetation complexes have been represented using the plants (up to three) in the WEPP database that better fit the dominant species in the field. Thus the pasture areas of the watershed were modelled using fescue, bluegrass and big sagebrush (the last for the sparse shrubs) from the WEPP database for rangeland and lucerne from the database for cropland. For the crop cultivation, which ranged from 8% to 13% of the watershed area, it was necessary to modify several parameters of the model's default winter wheat database, including planting and harvest dates, type and dates of tillage, and crop rotations.

Furthermore, as the cropland area was characterized by broadcast sown wheat, it was necessary to modify the row width and the distance between plants. For the channels covered with vegetation (ditches), the total Manning roughness (n) coefficient was set as proposed by Knisel (1980) in the Chemicals, Runoff and Erosion from Agricultural Management Systems (CREAMS) manual. For the ungraded channels the default value of Manning's n was used.

Results and Discussion

Statistics of measured and simulated storm runoff depth are reported in Table 18.3 for the 50

Table 18.3. Storm runoff depth statistics for the observation period for the three simulation series performed by WEPP at Cannata watershed.

	Mean (mm)	Median (mm)	Minimum (mm)	Maximum (mm)	SD	r^2	E^a
Measured	7.8	4.0	1.0	54.0	11.1	–	–
Simulated							
I	1.3	0.0	0.0	3.0	3.7	0.20	–0.34
II	3.3	0.4	0.0	21.2	6.1	0.83	0.54
III	3.0	0.3	0.0	25.5	5.5	0.82	0.47

[a]Nash and Sutcliffe (1970).

Table 18.4. Measured and simulated annual runoff depth during the observation period in the Cannata watershed.

	Annual runoff depth (mm)					
	1997	1998	1999	2000	2001	2002
Measured[a]	62.9	30.7	104.4	65.5	37.5	83.7
Simulated						
I	12.4	3.7	4.7	1.0	8.3	2.8
II	73.8	45.6	44.1	40.6	43.7	53.6
III	68.0	42.2	40.0	34.1	40.3	49.1

[a]Rainfall depth recorded at station A.

Table 18.5. Measured and simulated runoff coefficients during the observation period in the Cannata watershed.

	Annual runoff coefficient (%)					
	1997	1998	1999	2000	2001	2002
Measured[a]	8.8	5.4	17.7	11.3	6.0	10.3
Simulated						
I	1.8	0.7	0.9	0.2	1.6	0.4
II	10.5	8.7	8.8	7.9	8.3	7.3
III	9.7	8.0	7.9	6.6	7.6	6.7

[a]Rainfall depth recorded at station A.

daily values of not less than 1 mm measured during the simulation period. These results were obtained for the computer runs with constant values. The results did not improve using values of K_e that were internally adjusted by the model. WEPP storm runoff depths were better correlated ($r^2 > 0.78$) to the measurements in simulation series II and III (Fig. 18.3), with coefficient of determination and standard error values similar to those found by Savabi *et al.* (1995). These results were also characterized by positive values of model efficiency (Nash and Sutcliffe, 1970). Storm runoff depth was underestimated for nine out of the ten events with runoff over 10 mm. An underestimation also resulted for the smallest events, runoff being zero in 40% of the cases (with a recorded precipitation of 5.2–24.8 mm). A similar behaviour for events with observed runoff depths less than 1 mm was reported by Soto and

Díaz-Fierros (1998). In the simulation series II and III there were more than 200 simulated events during the entire period of simulation. Consequently the annual runoff depth was underestimated between 36% and 62% for 3 of the 6 years (Table 18.4). The annual runoff coefficient values are shown in Table 18.5. These underestimations were similar to those reported by Savabi *et al.* (1996). The regression analysis of simulated vs observed peak runoff gave an r^2 of 0.63 for simulation series II and III (Fig. 18.3) with a model efficiency coefficient less than zero in both cases.

Statistics of storm sediment yields are reported in Table 18.6. High correlations between storm sediment yields were found for simulation series II ($r^2 = 0.92$) and III ($r^2 = 0.77$), but model efficiency coefficients were negative in both cases. Sediment yield in simulation series III was overestimated in seven out of 14 events because of high sediment concentrations in the generated overland flow (Table 18.7). Consequently, the cumulative sediment yield ($N = 14$ events) resulting from simulation series III and II was a factor of 2.3 and 3.2 greater, respectively, than the one estimated through field measurements (Table 18.7). Similar values were found by Liu *et al.* (1997) for the three Holly Springs watersheds (Mississippi, USA). The overestimation of erosion at sites with low erosion rates similar to Cannata, producing between 0.004 and 0.6 t/ha for an event, is supported by numerous examples in the literature (Liu *et al.*, 1997; Nearing, 1998, 2000; Nearing *et al.*, 1999; Tiwari *et al.*, 2000; Santoro *et al.*, 2002).

Ninety-five per cent of the average annual simulated sediment yield was produced from seven hillslopes covering approximately 32 ha, or 25% of the total area. This included the entire cultivated area of approximately 11 ha. The simulated sediment delivery ratio was 0.48 with a coefficient of variation of approximately 11%.

There are two factors that can explain the differences between the measured and predicted values of soil erosion. The first was related to the creation of excessively long slope lengths by GeoWEPP. WEPP overpredicts erosion when slope lengths exceed the recommended value of 100 m (Baffaut *et al.*, 1997). A second reason for the difference between measured and predicted erosion may be due

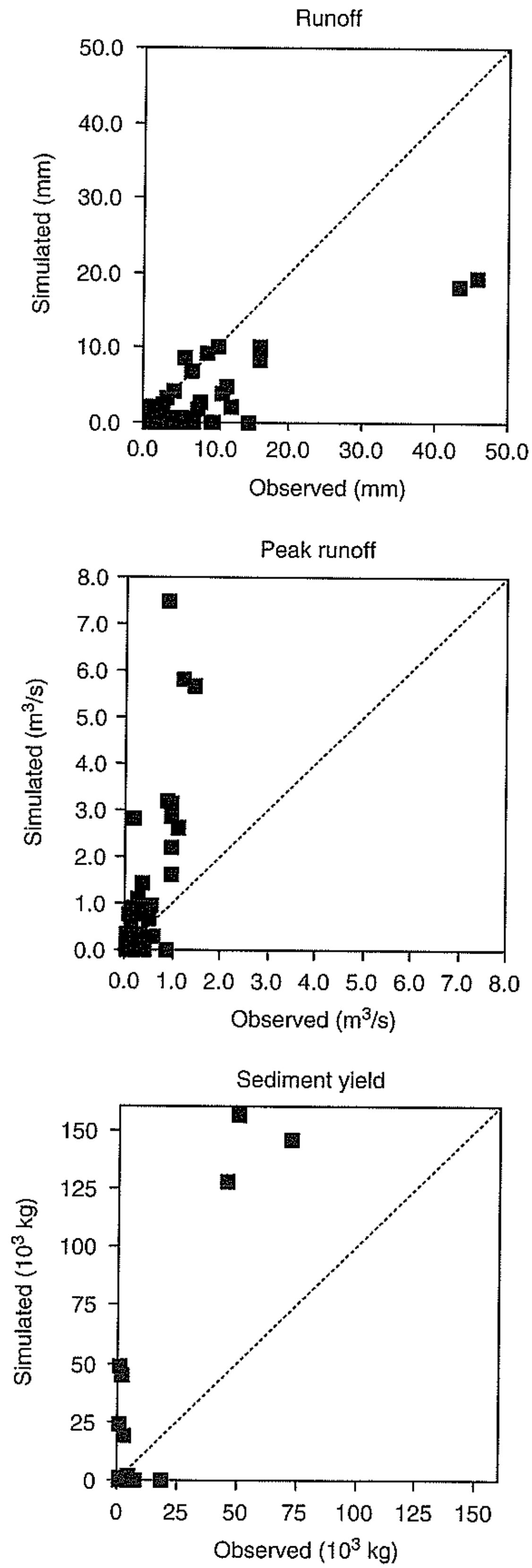

Fig. 18.3. Simulated (by WEPP) vs observed storm runoff ($N = 50$), peak runoff ($N = 45$) and sediment yield ($N = 14$) for simulation series III in the Cannata watershed.

Table 18.6. Storm sediment yield statistics for the observation period for the three simulation series performed by WEPP in the Cannata watershed.

	Mean (10^3 kg)	Median (10^3 kg)	Minimum (10^3 kg)	Maximum (10^3 kg)	SD (10^3 kg)	r^2	E^a
Measured	17.8	6.3	0.6	72.5	22.6	–	–
Simulated							
I	5.6	0.0	0.0	56.2	15.3	0.54	–0.1
II	57.4	15.4	0.0	287.6	89.7	0.92	–11.6
III	40.6	10.5	0.0	156.3	58.2	0.77	–3.1

[a]Nash and Sutcliffe (1970).

Table 18.7. Runoff volume, sediment yield and average sediment concentration for 14 events in the observation period at the Cannata watershed.

	Runoff volume D (10^3 m^3)	Cumulated sediment yield P (10^3 kg)	Average sediment concentration[a] P/D (g/l)
Measured	227.5	209.8	1.10
Simulated by WEPP			
I	7.9	79.0	9.96
II	75.5	681.0	9.02
III	68.9	457.9	6.64

[a]Computed as the ratio between cumulated sediment yield and cumulated runoff.

simply to natural variation in soil erosion at low rates (Nearing, 1998, 2000; Nearing *et al.*, 1999).

Conclusions

Predicted values of runoff were better correlated to the measurements of runoff in the simulation series with constant K_e values (during the whole period of simulation) set by the user. Storm runoff depth was generally underestimated for both large and small rainfall events. The annual runoff depth was underestimated for 3 of the 6 years. The results suggest possibilities of improvement for the WEPP and GeoWEPP models. The definition of excessively long slope lengths by GeoWEPP needs to be corrected, or alternatively, some modification of the WEPP model is needed to prevent the overprediction of erosion rates from these long slopes. Secondly, in semiarid conditions such as those in this study, spatial variability in rainfall is an important problem that is not currently represented in WEPP. This spatial variability is undoubtedly important in terms of accurate predictions of both runoff and sediment yield. Lastly, it was found time-consuming to generate data input files for the WEPP model because of a lack of model parameters related to the vegetation species typical of Mediterranean areas. None the less, in spite of the difficulties encountered and the limitations of the model, and given the relatively low rates of erosion (with which is associated large natural variation), the results were reasonable with discrepancies within the order of magnitude found in other studies (Liu *et al.*, 1997; Nearing, 1998, 2000; Nearing *et al.*, 1999; Tiwari *et al.*, 2000; Santoro *et al.*, 2002).

References

Baffaut, C., Nearing, M.A., Ascough II, J.C. and Liu, B.Y. (1997) The WEPP watershed model: II. Sensitivity analysis and discretization on small watersheds. *Transactions of the American Society of Agricultural Engineers* 40, 935–943.

Bhuyan, S.J., Kalita, P.K., Janssen, K.A. and Barnes, P.L. (2002) Soil loss predictions with three erosion simulation models. *Environmental Modelling and Software* 17, 137–146.

Blackburn, W.H. and Pierson, F.B. (1994) Sources of variation in interrill erosion on rangelands. In: Blackburn, W.H., Pierson, F.B. Jr, Schuman, G.E. and Zartman, R. (eds) *Variability in Rangeland Water Erosion Processes*. Soil Science Society of America, Madison, Wisconsin, pp. 1–10.

Bouwer, H. (1969) Infiltration of water into non-uniform soil. *Journal of Irrigation and Drainage Division ASCE* 95 (IR4), 451–462.

Duiker, S.W., Flanagan, D.C. and Lal, R. (2001) Erodibility and infiltration characteristics of five major soils of southwest Spain. *Catena* 45, 103–121.

Flanagan, D.C. and Livingstone, S.J. (1995) *USDA Water Erosion Prediction Project: User Summary*. NSERL Report 11. USDA-ARS National Soil Erosion Research Laboratory, West Lafayette, Indiana.

Flanagan, D.C., Laflen, J.M., Nearing, M.A. and Norton, L.D. (1998) The USDA Water Erosion Prediction Project (WEPP) Model. In: *Experience with Soil Erosion Models*. Universitat fur Bodenkultur Wien, Vienna, pp. 53–62.

Goodrich, D.C. and Simanton, J.R. (1995) Water research and management in semiarid environments. *Journal of Soil and Water Conservation* 50, 416–419.

Hebel, B. and Siegrist, S. (1998) Plot size application and validation of WEPP for Swiss conditions. In: *Experience with Soil Erosion Models*. Universität für Bodenkultur Wien, Vienna, pp. 149–160.

Kidwell, M.R., Weltz, M.A. and Guertin, D.P. (1997) Estimation of Green-Ampt effective hydraulic conductivity for rangelands. *Journal of Range Management* 50, 290–299.

Kincaid, D.C. (2002) The WEPP model for runoff and erosion prediction under sprinkler irrigation. *Transactions of the American Society of Agricultural Engineers* 45, 67–72.

Klik, A., Savabi, M.R., Norton, L.D. and Baumer, O. (1995) Application of WEPP hillslope model in Austria. *Proceeding of American Water Resources Association Conference*, 5–9 November 1995, Houston, Texas. American Water Resources Association, Middleburg, Virginia, pp. 313–322.

Knisel, W.G. (1980) *CREAMS: A Field-scale Model for Chemicals, Runoff, and Erosion from Agricultural Management Systems*. USDA Conservation Research Report 26. US Department of Agriculture, Washington, DC.

Laflen, J.M., Flanagan, D.C., Weltz, M.A., Stone, J.J. and Ascoug II, J.C. (1994) The WEPP model and its applicability for predicting erosion on rangelands. In: Blackburn, W.H., Pierson, F.B. Jr, Schuman, G.E. and Zartman, R. (eds) *Variability in Rangeland Water Erosion Processes*. Soil Science Society of America, Madison, Wisconsin, pp. 11–22.

Licciardello, F., Rizzo, N., Somma, F. and Zimbone, S.M. (2001) Runoff and soil erosion in a small Sicilian watershed. *Proceedings of International Symposium: Erosion Research for the 21st Century*, 3–5 January 2001, Honolulu, Hawaii, pp. 363–366.

Liu, B.Y., Nearing, M.A., Baffaut, C. and Ascough II, J.C. (1997) The WEPP Watershed Model. III. Comparison to measured data from small watershed. *Transactions of the American Society of Agricultural Engineers* 40, 945–952.

Nash, J.E. and Sutcliffe, J.V. (1970) River flow forecasting through conceptual models, 1. A discussion of principles. *Journal of Hydrology* 10, 282–290.

Nearing, M.A. (1998) Why soil erosion models over-predict small soil losses and under-predict large soil losses. *Catena* 32, 15–22.

Nearing, M.A. (2000) Evaluating soil erosion models using measured plot data: accounting for variability in the data. *Earth Surface Processes and Landforms* 25, 1035–1043.

Nearing, M.A. and Nicks, A.D. (1997) Evaluation of WEPP: hillslopes and small watersheds. In: Boardman, J. and Favis-Mortlock, D.T. (eds) *Global Change: Modelling Soil Erosion by Water*. NATO-ASI Global Change Series. Springer, Berlin, Germany, pp. 43–53.

Nearing, M.A., Foster, G.F., Lane, L.J. and Finker, S.C. (1989) A process-based soil erosion model for USDA-Water Erosion Prediction Project Technology. *Transactions of the American Society of Agricultural Engineers* 32, 1587–1593.

Nearing, M.A., Deer-Ascough, L. and Laflen, J.M. (1990) Sensitivity analysis of the WEPP hillslope profile erosion model. *Transactions of the American Society of Agricultural Engineers* 33, 839–849.
Nearing, M.A., Liu, B.Y., Risse, L.M. and Zhang, X. (1996) Curve numbers and Green-Ampt effective hydraulic conductivities. *Water Resources Bulletin-American Water Resources Association* 32, 125–136.
Nearing, M.A., Govers, G. and Norton, L.D. (1999) Variability in soil erosion data from replicated plots. *Soil Science Society of America Journal* 63, 1829–1835.
Renard, K.G., Rawls, W.J. and Fogel, M.M. (1982) Currently available models. In: Haan, C.T., Johnson, H.P. and Brakensiek, D.L. (eds) *Hydrologic Modelling of Small Watersheds*. American Society of Agricultural Engineers, St Joseph, Missouri, pp. 507–522.
Renschler, C.S. and Harbor, J. (2002) Soil erosion assessment tools from point to regional scales – the role of geomorphologists in land management research and implementation. *Geomorphology* 47, 189–209.
Renschler, C.S., Flanagan, D.C., Engel, B.A. and Frankenberger, J.R. (2002) GeoWEPP – the Geo-spatial interface for the Water Erosion Prediction Project. *Proceedings of the 95th Annual International Meeting of ASAE – XV World Congress of CIGR*, 28–31 July 2002, Chicago, Illinois. American Society of Agricultural Engineers, St Joseph, Missouri.
Santoro, V., Amore, E., Modica, C. and Nearing, M.A. (2002) Application of two soil erosion models to a large Sicilian basin. In: Rubio, J.L., Morgan, R.C.P., Asins, S. and Andreu, V. (eds) *Proceedings of III International Congress of European Society for Soil Conservation, Man and Soil at the III Millennium*. Geoforma, Valencia, Spain, pp. 1445–1458.
Savabi, M.R. (2001) Determining soil water characteristics for application of WEPP model in south Florida. *Transactions of the American Society of Agricultural Engineers* 44, 59–70.
Savabi, M.R., Flanagan, D.C., Hebel, B. and Engel, B.A. (1995) Application of WEPP and GIS-GRASS to a small watershed in Indiana. *Journal of Soil and Water Conservation* 50, 477–483.
Savabi, M.R., Klik, A., Grulich, K., Mitchell, J.K. and Nearing, M.A. (1996) Application of WEPP and GIS on small watershed in USA and Austria. In: Kovar, K. and Nachtnebel, H.P. (eds) *Proceedings of HydroGIS 96: Application of Geographic Information System in Hydrology and Water Resources Management*. IAHS Publication 235. IAHS Press, Wallingford, UK, pp. 469–476.
Singh, V.P. (1995) *Computer Models of Watershed Hydrology*. Water Resources Publications, Littleton, Colorado.
Singh, V.P. and Frevert, D.K. (2002) *Mathematical Models of Small Watershed Hydrology and Applications*. Water Resources Publications, Littleton, Colorado.
Soto, B. and Díaz-Fierros, F. (1998) Runoff and soil erosion from areas of burnt scrub: comparison of experimental results with those predicted by the WEPP model. *Catena* 31, 257–270.
Tiwari, A.K., Risse, L.M. and Nearing, M.A. (2000) Evaluation of WEPP and its comparison with USLE and RUSLE. *Transactions of the American Society of Agricultural Engineers* 43, 1129–1135.
USDA – Soil Conservation Service (1972) *National Engineering Handbook, Hydrology, Section 4*. USDA Soil Conservation Service, Washington, DC.
Vlnasova, K., Klik, A., Hebel, B. and Zarl, A. (1998) Validation and comparison of EUROSEM, SMODERP and WEPP hillslope models with measured data from erosion plots in Austria and the Czech Republic. In: *Experience with Soil Erosion Models*. Universität für Bodenkultur Wien, Vienna, pp. 287–293.
Zeleke, G., Winter, T. and Flanagan, D. (1999) BPCDG: Breakpoint Climate Data Generator for WEPP using observed climate standard weather data sets. http://topsoil.nserl.purdue.edu/nserlweb/weppmain/BPCDG.html
Zhang, X.C., Nearing, M.A., Risse, L.M. and McGregor, K.C. (1996) Evaluation of runoff and soil loss predictions using natural runoff plot data. *Transactions of the American Society of Agricultural Engineers* 39, 855–863.

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There can be little doubt that issues relating to soils and sediments are moving up the political agenda, and there is a growing realization that we need to collectively manage and protect both soil and water resources. In order to manage this delicate interface, attention is being increasingly directed towards holistic land–river management, demanding a greater appreciation of the interaction between soils and sediments. This book reviews the major achievements recently made in soil erosion and sediment redistribution research and management and identifies future requirements. It examines the developments made in three themes – measurement, modelling and management – and covers a variety of scales (in both time and space) and geographical locations. The book will be of interest to students, researchers and practitioners with an interest in soil science and geomorphology and in natural resource processes and management.

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