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Using the modified agricultural non-point source pollution model in German watersheds

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Abstract

The modified agricultural non-point source pollution model (AGNPSm) was used in this study to predict runoff volume, peak flow rate, and sediment yield in three different watersheds in Germany. It is a distributed parameter soil erosion model which uses simple approaches to hydrological and sediment calculations. Simulations were carried out in the Glonn G1 (1.2 km^2), and Glonn G2 (1.6 km^2), and the Salzboede (81.7 km^2) watersheds in Germany. Runoff volume was predicted reliably in all three watersheds. Sediment yield predictions were excellent in the Glonn G1 and acceptable in the Glonn G2 watersheds. There were some uncertainties in the sediment yield calculations for the Salzboede watershed. This study shows that a less complex soil erosion model such as AGNPSm is able to produce reliable assessments of non-point source pollution for planning purposes. © 1999 Elsevier Science B.V. All rights reserved.

Keywords: AGNPSm; Soil erosion; Simulation; Non-point source pollution

1. Introduction

Many soil erosion models have been developed in recent decades. All soil erosion models have strengths and limitations because each was developed against the background of a particular philosophy, for different objectives, and for special site conditions. Model philosophies can be distinguished by the simplicity or complexity of a

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model. An increase in complexity means the replacement of empirical equations by physically-based equations and description of all processes, all dimensions, and all interactions between processes in a watershed. ‘All’ is a rather blurred term, and scientists define it differently for their models. For example, some models such as Hillflow (Bronstert, 1994) describe the infiltration process by looking at micropore and macropore flow separately and in a physically-based way. Other models do not distinguish between those two processes, and some lumped models use an empirical approach (e.g., the Curve Number Method) to describe infiltration (e.g., SWAT model of Arnold et al., 1994). More complex models are more sophisticated than less complex models, but this does not mean that the simulations produced by complex models are necessarily more reliable than the predictions obtained from less complex models. This hypothesis is supported by the studies of Loague and Freeze (1985), Goodrich (1990), Wilcox et al. (1990), Grayson et al. (1992), Diekkrueger et al. (1995). Furthermore, for different site conditions (land use, climate, soil, and topography) and at different scales, the dominant processes influencing sediment transport are not the same. Some soil erosion models were developed primarily for research purposes at a fine scale, whereas other models were developed for medium/macro scale use as planning tools.

The agricultural non-point source pollution model (AGNPS) of Young et al. (1987; 1994), and the modified agricultural non-point source pollution model (AGNPSm) version (Grunwald, 1997a,b) are distributed parameter soil erosion models, which use simple approaches for the calculation of event-based runoff volume, peak flow rate, and sediment yield. Both models are of limited complexity and use simple approaches for process description in a landscape. AGNPS and AGNPSm were developed for application in medium to large-sized watersheds to assess non-point source pollution. Key objectives included easy handling of the model, limited parameter input, and use as a decision support system for planning purposes.

The objective of the present study was to model event-based sediment yields using AGNPSm in three different watersheds in Germany. The study areas differed in size, land use, soil, and climate characteristics. Verification of the model simulations took place at the outlets of the particular watersheds investigated.

2. Area description

Two of the three watersheds in which simulation calculations were carried out are located in the Tertiary Uplands of Bavaria, Germany (Glonn G1 watershed [1.2 km^2] and Glonn G2 watershed [1.6 km^2]). The elevation varies between 511–550 m (G1) and 515–560 m (G2), and the average slope is 7% (G1) and 6% (G2). The soils are formed in glacial till material with some influence of loess resulting in loamy-sands, loam, and clay–loam soils. In the valley bottoms, gleyed soils are present. The total area in G1 covered by forest is 20.2%, while 79.8% is used as agricultural land, of which 30.9% is corn, 22.5% pasture/meadow, 32.7% grain, 7.3% potatoes, 5.2% forage fodder, and 1.4% waste land. Watershed G2 is dominated by forest (58.8%), while 41.2% is used as agricultural land, of which 60.2% is grain, 21.8% corn, 16.5% potatoes, and 1.5% pasture/meadow. The average annual precipitation for two adjacent stations was 830 mm (Mering) and 873 mm (Puch). The number of rainfall/runoff events used was 28 (G1) and 24 for (G2).

In addition, simulations were carried out for the Salzboede watershed, located in the Hilly Midlands of Germany. Parent materials are diabase, graywacke, slate, and shale. Weathered bedrock material is mixed with loess because of solifluction. The soils are predominantly loamy sands and loam to clay–loam soils mixed with loess. This watershed is 81.7 km^2 in size, with an elevation range of 190–564 m and an average slope of 9%. Land use consists of 46.0% forest, 21.5% pasture/meadow, and 23.5% arable land dominated by grain. The average annual precipitation is 786 mm. For model verification, 25 measured rainfall/runoff events were used (Rode, 1995).

3. Methods

Automation of the modeling process was achieved by programming an interface to link the spatial data and meteorological input data to the AGNPSm model. Spatial data (land use, soils, topography) were put into the SPANS (SPatial ANalysis System—Tydac, 1991) geographic information system (GIS). The interface enabled the event-based generation of input parameters for AGNPSm via primary and secondary derivation. With the aid of the adjunct DEDNM program (Garbrecht and Martz, 1993), the boundaries of each watershed, along with direction of flow and drainage network, were calculated for each watershed from the digital elevation data. The interface program is described in detail by Grunwald (1997a; b).

AGNPS uses the curve number method for the description of runoff volume (Soil Conservation Service—U.S. Department of Agriculture, 1972, 1985). Calculation of peak flow rate employs the equation of Smith and Williams (1980). Manning's equation is used to calculate runoff velocity. Soil loss is calculated by the modified universal soil loss equation (USLE) of Wischmeier and Smith (1978). Sediment transport capacity is calculated using the modified stream power equation of Bagnold (1966). Sediment transport is described in accordance with the stationary continuity equation of Foster et al. (1981) and Lane (1982).

The modifications to the AGNPS model incorporated into AGNPSm were made to make the model more applicable to German land use and climate conditions and to improve its performance. The modifications include the following:

- Replacement of the SCS curve number method by the method of Lutz (1984) for calculating runoff volume;
- Replacement of the USLE LS factor algorithm of Wischmeier and Smith (1978) by the algorithm of Moore and Burch (1986) based on stream power theory;
- Linkage of channel erosion by individual categories of particle size to runoff velocity;
- Replacement of uniform precipitation input by grid-based precipitation input.

The (Lutz, 1984) runoff method is similar to the SCS curve number method, but instead of one curve number parameter, it contains four parameters obtained by calibration. It was found in this study that the simulation of runoff volume was greatly improved using Lutz method instead of the curve number method. The Moore and Burch procedure for the LS factor is based on the concept of ‘partial watershed area’ and hence, is more realistic in terms of representing runoff generating processes. Linking channel erosion to runoff velocity gives a better description of erosion for each grid cell. Grid-based precipitation input was used to account for spatial variability in the rainfall.

The coefficient of efficiency (E) (Nash and Sutcliffe, 1970) was used as a measure of fit between actual and predicted data. E is given by:

$$E = \frac{\sum_{i=1}^{n}(m_i - \overline{m})^2 - \sum_{i=1}^{n}(p_i - m_i)^2}{\sum_{i=1}^{n}(m_i - \overline{m})^2} \quad i = 1,2,\ldots,n \tag{1}$$

where: m_i: measured variable, p_i: predicted variable, $\overline{m}$: arithmetic mean of m_i for all events $i = 1$ to n.

The calculation of E is a procedure which essentially is the sum of the deviations of the observations from a linear regression line with a slope of 1. If the measured variable is predicted exactly for all observations, E is 1. Low values of E show high deviations

Table 1
Summary of measured and predicted statistics (AGNPSm) for Glonn G1, Glonn G2, and Salzboede watersheds (validation results)

	Q_D [mm]		Q_p [l/s]		Sed [t]	
	Measured	Predicted	Measured	Predicted	Measured	Predicted
Glonn 1						
E [−]	0.96	0.96	0.84	0.84	0.90	0.90
Median	3.8	4.3	313	261	2.1	2.0
s.d.	13.4	11.6	170	210	4.9	4.1
n	18	18	18	18	28	28
Glonn 2						
E [−]	0.83	0.83	0.82	0.82	0.72	0.72
Median	2.0	2.8	76	62	3.0	3.1
s.d.	3.6	3.1	57	48	4.4	3.4
n	12	12	12	12	24	24
Salzboede						
E [−]	0.87	0.87	0.57	0.57	0.50	0.50
Median	8.6	8.7	8000	8100	16.2	76.4
s.d.	11.0	11.4	4640	6160	200.9	295.5
n	16	16	16	16	8	8

E: coefficient of efficiency (Nash and Sutcliffe, 1970).
s.d.: Standard deviation.
n: Number of rainfall/runoff events.
Q_D: runoff volume [mm] (Lutz method).
Q_p: peak flow rate [l/s].
Sed: sediment yield [t].

between measured and predicted values. If E is negative, predictions are very poor and average value of the output is a better estimate than the model prediction.

Field monitoring was carried out by the Bavarian Water Authority (1984) for the Glonn watersheds and by Rode (1995) for Salzboede watershed.

4. Results

Runoff volume and peak flow rate were calibrated in all three watersheds. Runoff volume was calibrated by using the Lutz calibration factors optimizing predicted to measured values using the coefficient of efficiency as a measure of best fit. To calibrate the peak flow rate, a calibration factor was integrated into the peak flow equation by Smith and Williams (1980). The coefficient of efficiency was also used here as a measure of best fit between predicted and measured values.

Simulation of the hydrological behavior of watershed G1 provided highly satisfactory results. A summary of the statistics for runoff volume, peak flow, and sediment yield predictions (validation results) is provided in Table 1. Runoff volumes calculated using the method of Lutz (1984) were characterized by a coefficient of efficiency (E) of 0.96 for 18 flood events (validation). The results for runoff volume calculations are shown in

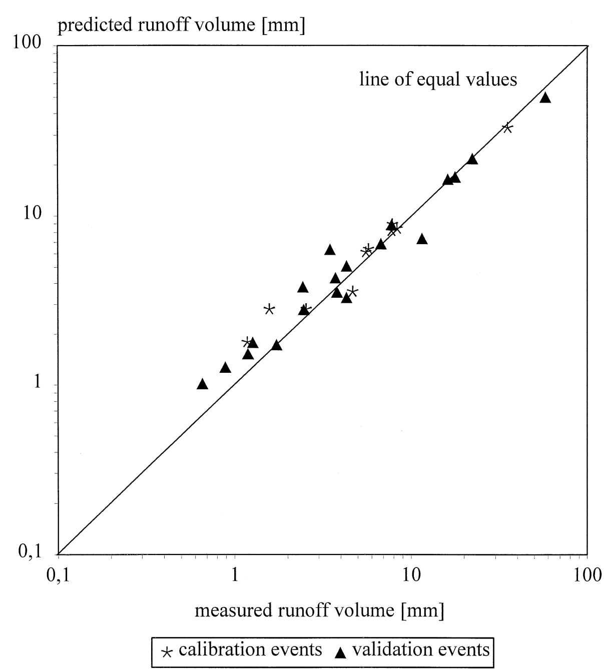

Fig. 1. Measured and predicted runoff volume—Glonn G1 watershed.

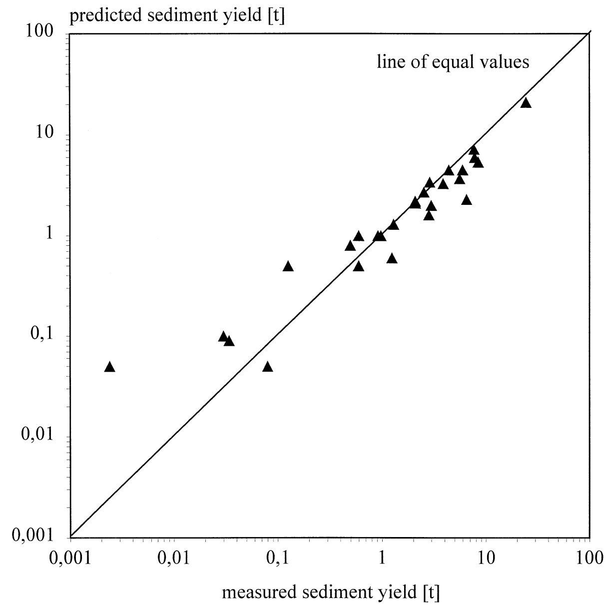

Fig. 2. Measured and predicted sediment yield—Glonn G1 watershed.

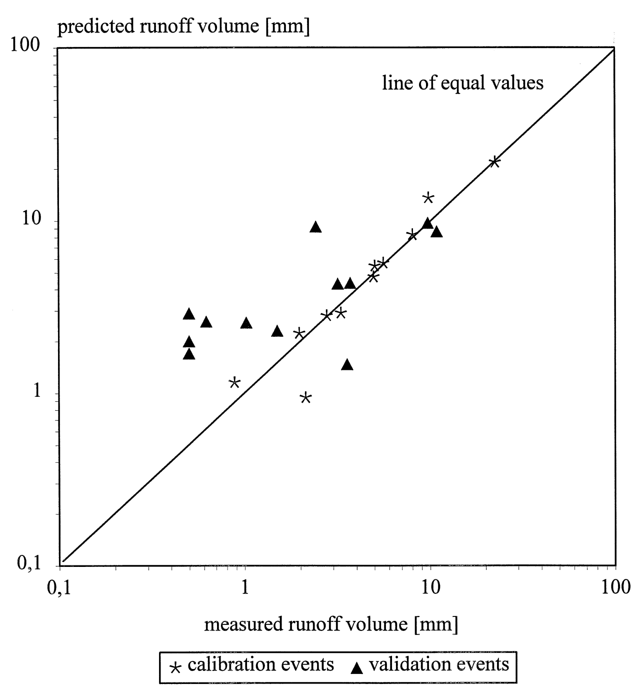

Fig. 3. Measured and predicted runoff volume—Glonn G2 watershed.

Fig. 4. Measured and predicted sediment yield—Glonn G2 watershed.

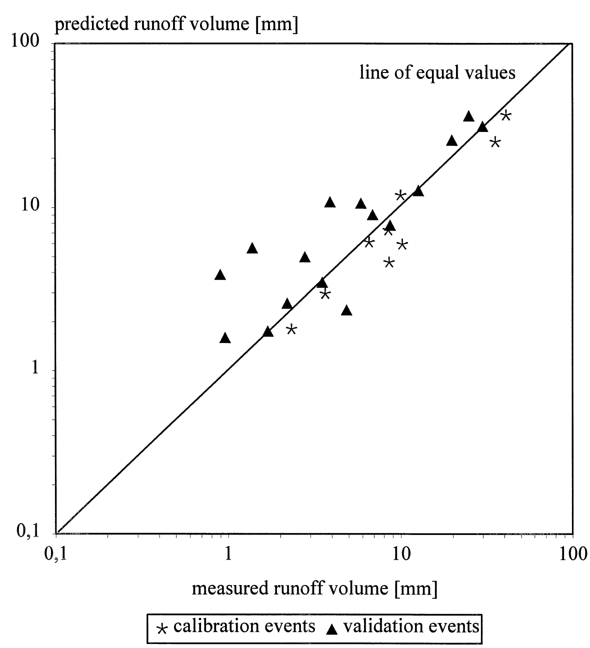

Fig. 5. Measured and predicted runoff volume—Salzboede watershed.

Fig. 1. In calibrating the Lutz method, 10 representative rainfall/runoff events out of a total of 28 were used. Fig. 1 shows that even for small events, the measured and predicted values are scattered near the 1:1 line. The difference between measured and predicted medians of 0.5 mm was very low. Peak flow yielded a coefficient of efficiency of 0.84, and the difference between measured and predicted medians of 52 l/s was acceptably low in watershed G1. In Fig. 2, the results for sediment yield from watershed G1 are shown. It should be stressed that no calibration of the sediment routine was carried out. The coefficient of efficiency was 0.90, and the deviation between measured and predicted medians was 0.08 t (Table 1). At the watershed outlet, no problems occurred in predicting sediment yield values that were very close to the measured values.

The validation results calculated for watershed G2 were similar to those obtained for watershed G1 (Table 1). Runoff volume was predicted with an E of 0.83, peak flow rate with an E of 0.82, and sediment yield with an E of 0.72. The difference in the medians between measured and predicted values were 0.8 for runoff volume 0.8 mm, 14 l/s for peak flow rate, and 0.1 t for sediment yield. Fig. 3 shows the predictions of AGNPSm for runoff volume and Fig. 4 for sediment yield in watershed G2.

In the Salzboede watershed, runoff volume yielded an E of 0.87 and an E for peak flow of 0.57 (validation results) (Table 1). Verification of the sediment routine was carried out on the basis of measurements for eight flood events. The E for sediment yield was 0.5, which is lower than for the smaller Glonn watersheds. Fig. 5 shows the predicted and measured values for runoff volume, whereas Fig. 6 shows results of the sediment yield predictions for the Salzboede watershed.

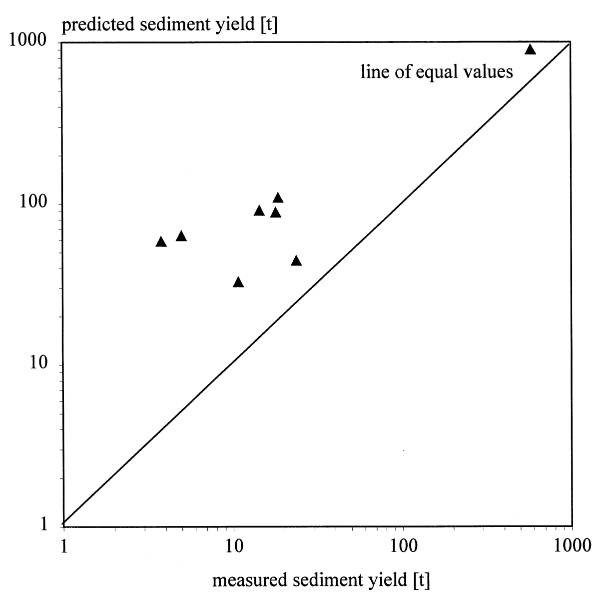

Fig. 6. Measured and predicted sediment yield—Salzboede watershed.

5. Conclusions

AGNPSm is not a very complex model but uses many empirical algorithms and the number of parameters needed is not very high. The complexity of the AGNPSm model seems to be sufficient to match predicted to measured values of runoff volume and sediment yield at the drainage outlet in the watersheds examined. The performance of AGNPSm was much more satisfactory than AGNPS, thus demonstrating the value of the modifications to the AGNPS model made in AGNPSm.

The predictive power of AGNPSm was robust in watersheds differing in size, land use, soil, and climate characteristics. There were no problems in predicting runoff volume in all three watersheds after calibration was undertaken. Sediment yield predictions were reliable for watersheds G1 and G2. The overprediction of sediment yield for smaller rainfall/runoff events is probably due to the use of Bagnold's equation for estimating sediment transport capacity. Anderson (1988) emphasizes that Bagnold's equation systematically overestimates sediment transport at low stages. This is because the equation fails to take into account enhanced energy losses through friction with the bed. However, it is more important to predict events with high sediment yield reliably because of their impact on the drainage system and the transport of attached nutrients into surface waters. This was undertaken using the sediment routine of the AGNPSm model. Higher deviations between measured and predicted sediment yields were found in the Salzboede watershed. One reason for the uncertainties in sediment yield predictions might be the size of the Salzboede watershed, such that simulation errors in transport processes accumulate to the drainage outlet of the watershed. Prediction errors are linked not only to model complexity but also to parametrization, which is highly dependent on data quality. Further research is necessary to transfer data-grid to model-grid information considering the spatial variability of parameters and to improve algorithms used in simulation models.

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