AN AGNPS-BASED RUNOFF AND SEDIMENT YIELD MODEL FOR Two SMALL WATERSHEDS IN GERMANY

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ABSTRACT. *The event-based Agricultural Non-Point Source (AGNPS) pollution model is used extensively to simulate sud~ice runoff, sediment yield and nutrient transport in unmonitored watersheds. Investigation, that compare AGNPS predictions to measured data are rare. The objective of the present study was to compare surface runoff and sediment yield predictions from AGNPS water quality simulation model and modified versions to measured data. Shortcomings of the AGNPS model were examined. The study was carried out using 52 rainfall-runoff events, 22 for calibration and 30for validation, from two small watersheds (GI and G2) in Bavaria, Germany. Evaluation of model outputs was based on statistical comparisons between measured and predicted values fior each rainfall-runoff event. We compared three different surface runoff prediction methods: uncalibrated curve number (Q]), calibrated curve number (Q2), and Lutz (Q3). The modifications made to sediment yield calculations encompassed: (i) replacement of the Universal Soil Loss Equation LS fiactor algorithm (SI) by one based on stream power theory (S2), and (ii) linkage of channel erosion by individual categories of particle size to runoff velocity (S3). Measured median for surface runoff was under-predicted by 55.5% using Q1, overpredicted by 36.8% using Q2 and over-predicted by 13. 1 % using Q3 in G1. The largest coefficient of efficiency (E) was calculatedfor Q3 with 0.96 followed by 0.93 for Q2 and 0.25 for QJ in Gl. In G2, measured median for surface runoff was underpredicted by 80.0% using Q1, overpredicted by 45.0% using Q2, and overpredicted by 35.0% using Q3 in G2. Best performance in terms E was calculated by Q3 (0.83) followed by 0. 76 for Q2 and 0.24 for Q1 in G2. Median sediment yield measurement was underpredicted by 57.2% using S1, underpredicted by 47.6% using S2 and underpredicted by 4.8% using S3 in G1. The largest E was calculated with 0. 90 for S3 followed by 0.57for S2 and 0. 26 for S1 in G1. Measured median for sediment yield was underpredicted by 53.9% using S1, underpredicted by 38.5% using S2 and overpredicted by 3.3% using S3 in G2. E was largest with 0. 72 (S3) followed by 0.60 (S2) and 0.57 (SI) in G2. Results of this study illustrated that a calibration Qf CN and Lutz method for surface runoff calculations and the use of variant S3 for sediment yield calculations with AGNPS model showed the highest merit to match measurements with predictions at the drainage outlet.*

Key words. AGNPS, Non-point source pollution, Rainfall-runoff modeling, Calibration, Validation, Surface runQff, **Sediment yield.**

The event-based Agricultural Non-Point Source The"AGNPS) pollution model (Young et al., 1987, 1994) was designed to predict runoff volume, peak flow rate, sediment, and nutrient yield from medium to large-sized watersheds. The philosophy in developing AGNPS was to balance model complexity and model parameterization. A major objective was to describe major transport processes related to non-point source pollution within a landscape while using empirical and quasi-physically based algorithms. Basic model components include hydrology, sediment, and nutrient transport.

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Applications of the AGNPS water quality model are diverse. Feezor et al. (1989), Panuska et al. (1991), Vieux et al. (1993), and Grunwald (1997) investigated the effects of grid size selection through a sensitivity analysis of input. The study areas were discretized using different grid sizes, and the effects on hydrology, sediment, and nutrient components were analyzed. Model grid size was found to be the most important factor affecting sediment yield calculations. Fisher et al. (1997) analyzed the sensitivity of two distributed non-point source pollution models (AGNPS and ANSWERS) to the spatial arrangement of the landscape. This was a theoretical study in which the input spatial data were subjected to various degrees of spatially random mixing, such that the organized landscape became disorganized. The output values of the AGNPS model exhibited little or no sensitivity to the spatial distribution of most input data. Only infiltrationrelated inputs produced variations in sediment and nutrient yield output. Sensitivity analyses are intended to be theoretical in nature to study model behavior.

Hession et a]. (1989) linked the AGNPS model with the geographic information system (GIS) ARC/INFO and simulated effects of several best management practices assuming average input values. Linkage of the AGNPS model to a GIS was also presented by Needham et al.

(1989), Olivieri et al. (1991), and Tim et al. (1994). In those studies, the emphasis was on data handling and automation of the modeling process rather than model validation.

Use of the AGNPS model in decision support systems is widespread. Young et al. (1989) presented a study where several management practices were compared using the AGNPS model. Prato et al. (1990) used the AGNPS model to calculate the reduction potential for erosion using several conservation practices. Tim et al. (1992) and Rode et al. (1995) used AGNPS to simulate several scenarios to compare land use and tillage practices and their impact on non-point source pollution. Grunwald et al. (1997) compared several conservation management practices that were being subsidized by a program supported by the European Union (MEKA-Progyam).

Validation of the AGNPS model using measured data is scarce. Panuska et al. (1991) used five rainfall-runoff events for the validation of the AGNPS model. They concluded that sediment yield calculations were highly dependent on the quality of the peak flow calculations of the model. The predicted sediment yield values ranged from a maximum underprediction of 60% to a maximum overprediction of 1.4% compared to measured sediment yield values. Engel et al. (1993) compared the AGNPS, ANSWERS, and SWAT models using four rainfaH-runoff events. AGNPS and ANSWERS showed the best results when compared to measured values. Mitchell et al. (1993) used AGNPS to compare simulated and measured values for 50 rainfall-runoff events. The deviations between the arithmetic mean of measured and simulated values were 6.3 turn for runoff volume, 0.09 m3/s for peak flow rate, and 1.65 t for sediment yield. Srinivasan et al. (1994) compared 13 measured and simulated rainfall-runoff events using AGNPS. The simulated runoff volume was underestimated for all events.

Because the AGNPS model uses many empirical and quasi-physically based algorithms, the issue of applicability in unmonitored watersheds has to be addressed. If there are no measured values for surface runoff, peak flow rate, and sediment yield, no calibration and validation of the model can be carried out. In such cases, the uncertainty in model simulations is high. In studies by Prato et aL (1990), Young et al. (1989), Tim et al. (1992), and Rode et al. (1995), the AGNPS model was used in decision support studies where different land uses, tillage practices or conservation management techniques were simulated; however, no model validation was presented. Management recommendations given in those studies run the risk to prove wrong. In the studies by Panuska et al. (1991), Engel et al. (1993), and Srinivasan et al. (1994) 5, 4, and 13 raiDfall-runoff events, respectively, were used to compare predicted to measured values. Because of the small sample size, it is difficult to assess model behavior. Rainfall-runoff events with high recurrence intervals may or may not be included within the total data set. No information about recurrence intervals was given in those articles.

The objective of the present study was to compare surface runoff and sediment yield predictions from AGNPS water quality simulation model and modified versions to measured data collected at the drainage outlet. Shortcomings of the AGNPS model were examined.

THE AGNPS MODEL

AGNPS Version 5.0 was developed by Young et al. (1987, 1994). A comprehensive description of all routines used in AGNPS can be found in the AGNPS manual (Young et al., 1987). AGNPS calculates surface runoff for each garid-cell separately using the SCS Curve Number (CN) method (SCS-USDA, 1972, 1985). The key parameter in this method is the curve number, which is dependent on land use, soil type, and hydrologic condition. Surface runoff calculated in each grid cell is routed through the watershed based on flow directions from one grid cell to the next until it reaches the drainage outlet. There is no groundwater routine in AGNPS. 'Me model focuses on predictions of surface water flow and sediment yield for single precipitation events only. For each grid-cell, peak flow rate is calculated by the Smith algorithm (Smith et al., 1980). For each increment of the hydrograph, channel flow is calculated using channel width, channel depth, and flow velocity assuming a triangular cross-sectional area.

Soil loss is calculated by a modified Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978) that includes the energy-intensity value and a slope shape factor. Sediment discharge is calcuiated by the steady state continuity equation of Foster et al. (198 1) and Lane (1982). Based on the Einstein approach (1950), each soil particle class (five classes are considered) is calculated separately. The effective sediment transport capacity is calculated using modified Bagnold equation (Bagnold, 1966). In AGNPS, sediment yield calculations depend on soils (soil crodibility factor, USLE), topography (slope-length factor, slope-steepness factor, slope shape factor, USLE), land use and management (conservation factor and support practice factor, USLE), discharge and sediment yield flowing into the grid-cell, erosion and deposition within the grid-cell, and sediment transport capacity, which determines the sediment rate flowing, out of the grid-cell.

MODIFICATIONS TO THE AGNPS MODEL

In an attempt to improve simulations the following modifications were integrated into the AGNPS source code:

- Replacement of the SCS curve number method by the Lutz method (1984) for calculating runoff volume.
- Replacement of the Universal Soil Loss Equation LS factor 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.

Reasons why these modifications were thought to improve simulations are discussed below.

RUNOFF CALCULATIONS

Lutz (1984) published a runoff calculation method similar in concept to the CN method. He used 981 rainfallrunoff events in 75 watersheds within Germany for the development of a regionalized method for surface runoff calculation.

Soil data and land use were used to derive maximum discharge values (C-values) for each homogeneous area within a watershed. C-values are calculated based on a combination of soil type (hydrological soil groups A-D), land use data, average antecedent soil moisture condition (11), and an extreme rainfall event of 250 mm. These values based on the watershed characteristics correspond to curve numbers. Calculation of the surface runoff by Lutz (1984) is given by:

$$Ia = 0.03 \times S \qquad (1)$$

$$S = 25.4 \times \left(\frac{10}{C} - 10\right) \qquad (2)$$

$$a = Cl \times e^{(-C2/WZ)} \times e^{(-C3/Q_B)} \times e^{(-C4 \times D)} \qquad (3)$$

$$Q_D = (P - Ia) \times C + \frac{C}{A}\left[e^{-a(P-a)} - 1\right] \qquad (4)$$

where

- Ia = initial abstraction (mm)
- S = potential maximum retention (mm)
- C = maximum discharge value (-)
- a = factor of proportionality (1 mm^{-1})
- C1, C2, C3, C4 = weighting parameters for optimization (calibration factors)
- WZ = week value (-)
- Q_B = baseflow (l s^{-1} km^{-2})
- D = duration of precipitation (h)
- Q_D = surface runoff (mm)
- P = precipitation (mm)

Initial abstraction (Ia) (eq. 1) is calculated by multiplying S with a factor of 0.03, which is similar to the CN method where S is multiplied with a factor of 0.2. The Lutz method computes smaller initial abstraction values and larger surface runoff when compared to CN method.

The week value (WZ) represents a simplified crop growth factor, varying during the year, which affects runoff. Lutz (1984) gives a lookup table for week value. Week values are low in summer (high crop growth), which refers to a low tendency for surface runoff generation. WZs are high in winter because of low crop growth and/or bare soils after harvest, which results in a greater tendency for surface runoff generation. The factor C2 may be used for optimization (calibration factor) to fit measured and predicted surface runoff (QD). Lutz (1984) recommends fixing C2 depending on land use. The higher the values of C2, the lower the factor of proportionality (a), and the lower the surface runoff.

Baseflow (Q13) is used to characterize the initial soil moisture condition before a rainfall-runoff event takes place. Baseflow information may be derived from the interpretation of hydrographs. Lutz (1984) found that high baseflow values showed a hiah correlation to surface runoff, which is expressed in equation 3. C3 is a calibration factor weighting the influence of baseflow on surface runoff. The higher the value of C3, the lower the factor of proportionality (a), and the lower the surface runoff. The C3 factors in the study of Lutz (1984) ranged between 1.0 and 6.0.

Table 1. Runoff parameters for different land use, soil, and hydrologic conditions calculated by CN and Lutz methods

Land Use	Treatment and Hydrologic Condition	Hydrologic Soil Group	CN Method: CN (-)	CN Method: S (mm)	CN Method: Ia (turn)	Lutz Method: C-value (-)	Lutz Method: S (mm)	Lutz Method: Ia (mm)
Pasture or range	Contoured, poor	B	67	125.1	25.0	0.60	169.3	5.1
Forest	Fair	C	73	93.9	18.8	0.62	155.7	4.7
Row crops	Straight row, good	B	78	71.6	14.3	0.75	84.7	2.5
Smallgrain	Straightrow, good	C	83	52.0	10.4	0.80	63.5	1.9
Fallow	-	D	94	16.2	3.2	0.93	19.1	0.6

The duration of precipitation characterizes the type of rainfall event, i.e., short-duration high-intensity thunderstorms or long-lasting frontal rainfall events. The shorter a precipitation event, the higher the factor of proportionality (a), and the higher the surface runoff. The C4 weights the importance of storm duration. The higher the value of C4, the lower the factor of proportionality (a), and the lower the surface runoff. Lutz points out that the C4 factor may often be neglected (fixed to 0.0) because of its low sensitivity for surface runoff calculations. The Cl calibration factor is most sensitive for surface runoff. In the study of Lutz (1984), the range for CI varied between 0.02 and 0.08.

There are contrasts between the CN and Lutz methods despite both being empirical in character. The CN method was designed for application in unmonitored watersheds without calibration. The parameterization for the Lutz method is more demanding, and calibration is recommended (Lutz, 1984). Antecedent moisture conditions (AMC) are considered in both methods; the CN approach uses hydrologic condition classification (1, 11, and 111), and the Lutz approach uses baseflow. ne initial abstraction value is calculated differently, with the Lutz method usina lower Ia compared to the CN method. For instance, on a homooeneous -rid with forest, fair hydrologic condition, and hydrologic soil group C, the calculated Ia would be 18.8 mm (CN method) compared to 4.7 turn (Lutz method) (table 1). A homogeneous -rid with small grain, straight row, good hydrologic condition, hydrologic soil group C, would result in an Ia of 10.4 min (CN method) compared to 1.9 min (Lutz method). Those calculated initial abstraction values affect surface runoff calculation because no surface runoff occurs until precipitation exceeds Ia.

USLE LS FACTOR

The sediment discharge calculation was modified by replacing the L and S factors of the USLE (Wischmeier and Smith, 1978) with algorithms based on stream power theory (Moore and Burch, 1986). The L and S factors based on stream power theory are calculated using the following equations:

$$f = \frac{A_{pwa}}{b \times l_{pwl}} \quad (5)$$

$$L_{sp} = \left(\frac{f \times l_{pwl}}{22.14}\right)^{0.4} \quad (6)$$

$$S_{sp} = \left(\frac{\sin s_x}{0.0896}\right)^{1.3} \quad (7)$$

where

- f = form parameter (-)
- b = width of contour element (m)
- A_{pwa} = partial watershed area (m^2) (the upslope area draining into each pixel)
- l_{pwl} = partial watershed length (m) (the flow length draining into each pixel)
- L_{sp} = L factor (stream power theory)
- S_{sp} = S factor (stream power theory)
- s_x = slope (°)

These equations are more amenable to landscapes with complex topographies than the original empirical equation of Wischmeier because they explicitly account for flow convergence and divergence through the term A_{pwa} in equation 5.

CHANNEL EROSION

Generally, discharge and flow velocity are greater for large rainfall-runoff events compared to small events, and there is increased channel scouring during large events. Factors influencing, the sediment movement are the particle size distribution, the form and weioht of the particles, the cohesion between particles, the arrangement of particles within the channel, the geometry *of* the channel, the turbulence *of* flow, the discharge volume as well as plant and root growth (Anderson, 1988).

In AGNPS, the user has to set a flag for each grid cell, for each particle size class, and for each rainfall-runoff event for channel scouring. A Boolean decision has to be made with flag = I indicating scouring, of the particle class or flag = 0, no scouring of the particle class. The model considers 5 different particle size classes ranging from primary clay to primary sand (table 2).

A major drawback to running the sediment routine in AGNPS is that channel scouring for each particle class is fixed subjectively by the user. To increase objectivity within the decision process for setting flags, AGNPS was modified such that the setting of the flags (0 or 1) for channel erosion was linked to flow velocity. In table 3,

Table 2. Particle size classes (nurn) considered in AGNPS (Foster et al., 1980)

	Primary Clay (clay)	Primary Silt (silt)	Small Aggre-gates (sA)	Large Aggre-gates (1A)	Primary Sand (sand)
Soils high in silt	0.002	0.01	0.02	0.5	2.0
Soils high in clay	0.002	0.01	0.075	1.0	2.0
Soils high in sand	0.002	0.01	0.03	0.2	2.0

Table 3. Critical flow velocities ($m\ s^{-1}$) **for scouring of particle size classes**

Flow Velocity ($m\ s^{-1}$)	Particle Size Class
0.3	Primary clay
0.6	Primary silt
0.9	Small aggregates
1.2	Large aggregates
1.5	Primary sand

critical flow velocities are listed for each particle size class based on literature values (Maue, 1988; DVWK, 1988). For example, if the calculated flow velocity in a grid-cell exceeds 0.3 m/s but does not exceed 0.6 m/s, then only primary clay would be scoured.

The other factors that have an impact on channel scouring were not considered, because all components of the AGNPS model should be treated with a level of detail congruent with the other components of comparable importance to the simulation outcome. For example, the new approach was selected to be *of* generally comparable precision with the other routines used in AGNPS.

STUDY AREAS

This study was conducted at Glonn watersheds (Roehrers Creek, GI, and Oberdorfer Creek, G2) 50 kin northwest of Munich (Bavaria) within the Tertiary Moraine Landscape of Germany. Watershed GI is 1.2 and G2 is 1.6 km2 in size. The elevation varies between 512 to 550 in sea level in GI and 515 to 560 in in G2, and the average slope is 7% in GI and 6% in G2. Figure I shows the location and elevations for both watersheds. In watershed GI, soil texture is 44.6% loamy sand, 7.4% clay-loam, 43.3% loam, and 4.7% sandy loam. In contrast, soil texture in watershed G2 is 51.7% loamy sand, 2.8% clay-loam, and 45,5% loam. In the valley bottom, soils are more or less saturated throughout most of the year (Aqualfs). Land use distributions in GI were 20.2% forest, 24.7% corn, 17.9% pasture/meadows, 26.1% grain, 5.8% potatoes, 4.1% forage fodder and 1.1% waste land. Watershed G2 was dominated by forest (58.8%) followed by 24.9% grain, 8.9% corn, 6.8% potatoes, and 0.6% pasture/meadow. The longest pathway from the most distant point in the watershed to the drainage outlet was 1900 in (GI) and 1800 in (G2), respectively. The average yearly precipitation amounts for two rain stations nearby were 830 mm (Mering) and 873 mm (Puch). The rainfall events used for this study varied between 17 mm and 89 mm. Measured surface runoff ranged from I turn to 58 mm (GI) and 0.5 to 23 mm (G2). Sediment yield ranged from 0.03 t to 24.5 t (GO and 0.008 t to 167.5 t (G2). For the validation of simulation results, there were 52 pre cipitati on-ru noff events available, covering a three-year period (Bavarian Water Authority, 1984).

METHODS

In watershed G1, 28 rainfall-runoff events were simulated, where 10 events were used for model calibration and 18 for validation. The total rainfall-runoff events simulated in watershed G2 were 24, where 12 events were used for calibration and 12 for validation. While calibrating the model, the total data set (total number of rainfall-runoff

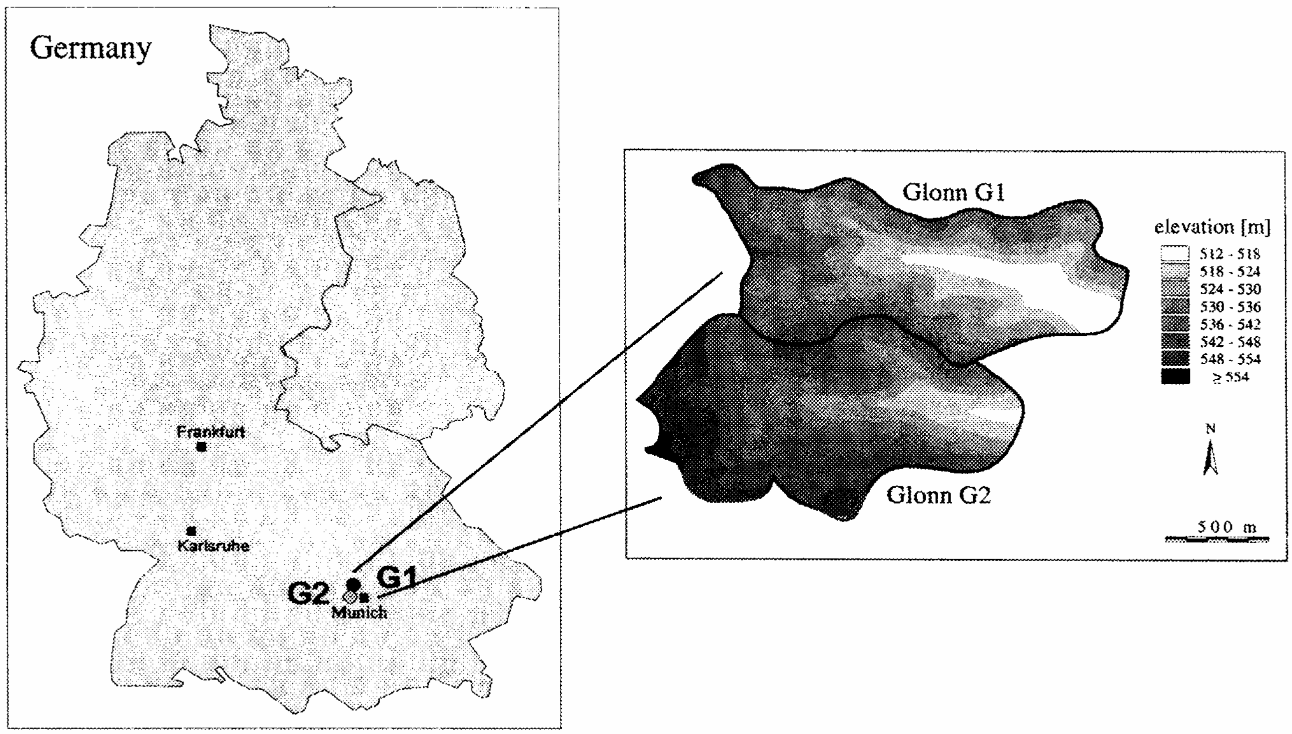

Figure 1–Location and elevations of G1 and G2 watersheds.

events) was divided into one subset for calibration and one for validation. A range of representative rainfall-runoff events in terms of discharge amount and seasonal occurrence were taken for calibration. A grid-size of 25 m was used.

Standard statistics and the coefficient of efficiency were calculated for measured and predicted data. The coefficient of Nash & Sutcliffe (1970) was used as a measure of fit of actual versus predicted data. It is given by:

$$E = \frac{\sum_{i=1}^{n}\left(m_i - \overline{m}\right)^2 - \sum_{i=1}^{n}\left(p_i - m_i\right)^2}{\sum_{i=1}^{n}\left(m_i - \overline{m}\right)^2} \quad (8)$$

where

m_i = measured variable

p_i = predicted variable

$\overline{m}$ = arithmetic mean of m_i for all events i = 1 to n

E is essentially the sum of the deviations of the observations from a linear regression line with a slope of 1. If the measured variable is predicted with high precision for all observations, E is 1. Low values of E represent high deviations between measured and predicted values. If E is negative, predictions are very poor, and an average value for output is a better estimate than the model prediction.

The modeling framework was comprised of the geographic information system (GIS) SPANS, an input interface, the AGNPS model, and an output interface. The modifications of algorithms were integrated in the source code of AGNPS. Further details about the automated modeling framework and the input data are given in Grunwald (1997).

To compare different surface runoff calculations, three different variants were considered.

Uncalibrated CN Method (QI). Surface runoff was calculated using the existing AGNPS model; i.e., using the CN method without calibration for runoff volume.

Calibrated CN Method (Q2). The objective of the calibration procedure was to optimize x in the equation la = x x S in such a manner that the calculated E for all calibration events would be highest. During the calibration procedure, all input parameters were kept constant except x, which was varied between 0.01 and 0.4. Afterwards, the optimized equation was used for validation. In watershed GI, the highest E was found when x was 0.03 (E = 0.87), and in watershed G2, the highest E was found when x had a value of 0.05 (E = 0.86).

Calibrated Lutz Method (Q3). The C2 factor was determined depending on land use as proposed by Lutz (forest 2.0, permanent pasture 2.0, grain 3.0, corn 4.6, potatoes (other row crops) 4.6, wasteland 4.0). The objective of the calibration procedure was to optimize the parameters Cl and C3 in such a manner that E would be highest for the calibration events considered. During the calibration procedure, all input parameters were kept constant except Cl and C3. According to the calibration procedure, a Cl value of 0.06 and C3 of 4.0 provided the best fit for watershed G1. In watershed G2 the same calibration method was used, and a C1 value of 0.04 and 0 of 4.0 demonstrated the best fit.

Three different sediment yield calculations were considered:

Modified USLE (S1). Flags for the scouring of particlesizes for each grid cell had to be set for the sediment yield calculations. A calibration was carried out to optimize the decision for channel scouring. The objective was to identify a combination of flags for particle-size classes that optimize E. The highest E (0.42) was calculated for the combination specifying 'no scouring of particles'.

LS Algorithm by Moore and Burch (1986) (S2). The same calibration procedure was carried out for S2, where soil loss was calculated based on the algorithm of Moore and Burch (1986). The highest E (0.65) was calculated for the combination specifying 'no scouring of particles'.

LS Algorithm by Moore and Burch (1986) plus Linkage of Channel Erosion by Individual Particle-size Categories to Flow Velocity (S3). No calibration was necessary for S3, because setting of flags for channel scouring was linked to flow velocity.

For all sediment yield calculations, surface runoff was calculated based on the Lutz method, because this method gave the best outputs in both watersheds. Therefore, the different outputs of the variants SI, S2, and S3 can be analyzed without bias from the hydrology component. The same errors due to hydrology predictions in AGNPS act on variants S1, S2, and S3 for sediment transport calculations.

RESULTS AND DISCUSSION

SURFACE RUNOFF

Uncalibrated CN Method (Ql). All rainfall-runoff events were underestimated by the uncalibrated CN method compared to measured surface runoffs. Deviations between measured and predicted surface runoff were areater for smaller events (<10 min Q_D) than for larger events (>10 min Q_D)). Statistics comparing measured and predicted surface runoff for the validation rainfall-runoff events are shown in table 4. Coefficients of efficiency of 0.25 (G1) and 0.24 (G2) were calculated and shown to be very low compared to an ideal E of 1. In watershed G1, the median for 28 measured events was 4.5 mm, which was higher than the median for the predicted events (2.0). In watershed Glorm G2, the median for 24 measured events was 3.0 mm, which differs from the predicted median for surface runoff of 0.6 mm.

Calibrated CN Method (Q2). The median for 18 measured validation rainfall-runoff events was 3.8 min compared to a median of 5.2 min for predicted surface runoff in GI (table 4). The measured median for 12 validation rainfall-runoff events of 2.0 mm was lower compared to the predicted median of 2.9 mm in G2. The coefficient of efficiency for all validation events was 0.93 for GI and 0.76 in G2.

Lutz Method (Q3). Deviations between measured and predicted medians were 0.5 min (G1) and 0.7 min (G2) (table 4), which were lower compared to the results from the CN method (QI and Q2) The E for the validation rainfall-runoff events was 0.96 (G1) and 0.83 (G2), which outperformed the predictions by both the uncalibrated and the calibrated CN method.

The measured median for surface runoff was underpredicted by 55.5% using Q1, overpredicted by 36.8% using Q2, and overpredicted by 13.1% using Q3 in G1. In G2, measured median for surface runoff was underpredicted by 80.0% using Q1, overpredicted by 45.0% using Q2, and overpredicted by 35.0% using Q3 in G2. Validation results indicate that a calibration of CN and Lutz methods for surface runoff calculation improves model predictions.

Generally, large surface runoff predictions were calculated for silt-rich soils in the valley bottoms, large CN values (CN method) or large C values (Lutz method), and/or locations with large upslope drainage area. In short, land use pattern, topography, and soils influence the infiltration and surface runoff behavior. Watershed GI and G2 differ in their land use, whereas the area covered by forest (small CN values; small C values) was greater in G2 compared to G1. In both watersheds, there was a predominance of loamy sands and loam-textured soils with a greater area of clay-loam soils (high CN values; high C values) in watershed GI compared to G2. This explains why measured and predicted surface runoff values at the drainage outlet were smaller for watershed G2 in contrast to larger values for G1.

Table 4. Results for Q1, Q2, and Q3 surface runoff calculations in GI and G2

	Watershed Glonn G I					Watershed Glonn G2				
	M* QD	Pt Q1	M QD	P Q2	Q3	M QD	P Ql	M QD	P Q2	Q3
n	28			18		24			12	
Mean (mm)	9.0	4.9	9.0	8.6	8.7	4.4	1.8	3.2	4.1	43
S.E. (mm)	2.3	1.5	3.2	2.5	2.7	1.0	0.6	1.1	0.8	0.8
Median (min)	4.5	2.0	3.8	5.2	4.3	3.0	0.6	2.0	2.9	2.7
Min (min)	0.7	0.04	0.7	1.1	1.0	0.3	0	0.5	2.0	1.4
Max (mm)	58.1	36.4	58.1	46.2	50.0	22.5	12.0	10.9	10.4	9.7
S.D. (nun)	12.3	8.1	13.4	10.7	11.6	4.9	2.9	3.6	2.9	3.1
E (-)	-	0.25	-	0.93	0.96	-	0.24	-	0.76	0.83

* Measured.
t Predicted.

SEDIMENT YIELD AND CHANNEL EROSION

Modified USLE (SI). From the total of 18 validation events, four events overpredicted and 14 events underpredicted measured sediment yield in GI. In G2, from the total of 12 validation events, five events overpredicted and seven underpredicted measured sediment yield. The median for 18 measured validation events was 2.1 t compared to the median for predicted events of 0.9 t in GI. In watershed G2, the median for measured validation events was 2.6 t compared to the median for predicted events of 1.2 t. The coefficient of efficiency was 0.26 in G1 and 0.57 in G2, which is poor compared with the ideal E of 1. In variant S1, sediment yield predictions matched best measured values using the assumption 'no scouring' for channel erosion in both watersheds. This contradicts with observations in the field, where channel erosion was observed for large rainfall-runoff events.

Sediment yield predictions using USLE for sediment loss calculation showed poor results. This might be explained by the fact that the LS-factor in the USLE is a purely empirical relationship that was derived from an extensive database consisting of over 10,000 plot-yr of data. Generally, the USLE plots were rectangular, uniform in slope, had a slope length of 22 m, and were not subjected to Tilling processes. Effects from upslope drainage areas on these plots were not considered.

LS Algorithm by Moore and Burch (1986) (S2). In GI, sediment yield predictions improved when compared to S1, while the improvement in sediment yield predictions in G2 was limited. Deviations between measured and predicted medians were 1.0 t (G1 and G2) which was lower compared to variant S I (table 5). The E was 0.57 (G 1) and 0.60 (G2), which was an improvement in the sediment yield calculations compared to SI, but still low when compared to an ideal E of 1.

The improved sediment yield predictions from S2 to S1 can be traced back to the consideration of the upslope drainage area (A_{pwa}) and their characteristics (slope and shape) in the soil loss calculation. On longer slopes, rilling concentrates overland flow, thereby increasing flow depth and flow velocity, which increases the unit stream power (Moore and Burch, 1986). Moore and Burch used the stream power concept to derive the L_{sp} and S_{sp} factors (eqs. 6 and 7), which accounts for the effects of both flow convergence and rilling. The L_{sp} and $S_{sp.}$ factors use hydrology of the upslope contributing area in its derivation, thus describing soil transport in overland flow, which includes both sheet flow and flow in rills. The improvements in sediment yield predictions from variant S I to S2 were larger in watershed G 1 compared to G2. This miaht be attributed to the large percentage of forest in watershed G2, which covered most of the summit landscape positions and the western part of the watershed. Moore & Burch (1986) did not consider different land use characteristics (e.g., forest) of the upslope drainage area in the derivation of L_{sp} and L_{sp} factors

LS Algorithm by Moore and Burch (1986) plus Linkage of Channel Erosion by Individual Particle-size Categories to Flow Velocity (S3). Results for S3 predictions indicated an improvement when compared to S2 and SI predictions (table 5). In G1, the measured median for 18 validation events yielded 2.1 t which is close to the predicted median of 2.0 t. The deviation between measured and predicted median was 0.1 t which outperformed variant S I and S2. In G2, the median for 12 validation events was 3.0 t (measured) and 3.1 t (predicted). The E-values were 0.90 (Glonn GI) and 0.72 (Glonn G2), which were considerably better than variant S1 and S2 because the Es were closer to 1. Variant S3 outperformed variant S1 and S2 in sediment yield predictions. The scouring of each particle class based on flow velocities in each grid-cell individually is of benefit for sediment yield predictions.

Median sediment yield measurements were under predicted by 57.2% using SI, under predicted by

Table 5. Results for S I, **S2, and S3 sediment yield calculations in GI and G2**

	Watershed Glonn GI					Watershed Glonn G2				
		Pt			P	P				P
	M*	S1	S2	M	S3	M	S1	S2	M	S3
N		18		28			12		24	
Mean (t)	3.6	1.2	1.9	3.5	3.0	2.9	2.1	2.2	4,2	4.2
S.E. (t)	1.4	0.4	0.9	0.9	0.8	0.9	0.3	0.4	0.9	0.8
Median (t)	2.1	0.9	1.1	2.1	2.0	2.6	1.2	1.6	3.0	3.1
min (t)	0	0.18	0.25	0	0.05	0,01	0.8	0.8	0.01	0.75
Max (t)	24.5	7.2	15.9	24.5	21.0	12.0	5.0	5.5	18.0	17.0
S.D. (t)	5.7	1.6	2.7	4.9	4.1	3.2	1.2	1.3	4.4	3A
E (-)	-	0.26	0.57	-	0.90	-	0.57	0.60	-	0.72

* Measured.
t Predicted.

47.6% using S2 and under predicted by 4.8% using S3 in GI. Median for sediment yield measurements was under predicted by 53.9% using SI, under predicted by 38.5% using S2, and over predicted by 3.3% using S3 in G2.

Soil erodibility factors were fixed depending on soil texture, where clay-loam soils have larger soil erodibility factors compared to loamy sands and loamy soils. Larger soil erodibility factors result in larger soil loss. There was a larger percentage of clay-loam soils and a smaller percentage of loamy sands in watershed GI compared to watershed G2, which influenced sediment yield predictions. Topography was similar in both watersheds (elevation, slope), however, there was a difference in slope lengths in G1 and G2. Slope lengths in watershed GI were shorter (maximum slope length was 250 m) compared to G2 (30% of the slope lengths were >250 m). Larger slope lengths result in larger slope-length factors and larger soil loss. There was a larger percentage of forest in watershed G2 compared to GI, where little or no erosion was predicted by the AGNPS model (variant SI). The same management techniques (e.g., plowing, harvesting) were used in watershed G1 and G2; therefore, differences in sediment yield predictions in G1 and G2 cannot be explained by different conservation practice and support practice factors.

CONCLUSIONS

A comparison between three different surface runoff methods, QI, Q2, and Q3 showed that calibration improved the agreement between measured and predicted surface runoff values to a high degree. For the uncalibrated CN method (Ql), poor results were predicted compared to measured surface runoff values. A calibration of model predictions is often not possible because of a lack in measured data; however, as shown in this studv there is merit in calibrating a simulation model such as AGNPS. The improvements in predictions of Lutz method (Q3) when compared to calibrated CN Q2) method are merely the result of having additional parameters to fit the data (Cl, C2, C3, and C4 calibration parameters).

The comparison between three different sediment yield prediction methods demonstrated an improvement of model outputs using, the proposed modifications in sediment yield calculation (S2 and S3). Using variant S3, no calibration in sediment yield calculations was necessary, because flags for channel scouring of particles were set automatically. This fact will prove beneficial to AGNPS users. Variant S3 outperformed variant SI and S2 in sediment yield predictions. The key for this result is seen in the description of scouring of particles in channels, where flow velocity is used for decision making about scouring of each particle class in each grid-cell individually. The method for channel scouring in S3 is more objective than the method used in S I and thus more beneficial for AGNPS users.

Validation results of this study illustrate that a calibration of CN and Lutz method for surface runoff calculations and the use of variant S3 for sediment yield calculations with AGNPS model showed the highest merit to match measurements with predictions at the drainage outlet of two small watersheds. AGNPS and modified versions should be tested in other watersheds that differ in landscape characteristics and climate. Since AGNPS and modified versions are based on empirical and quasi-physically based algorithms model transferability is associated with uncertainty. In short, applying AGNPS and modified versions in unmonitored watersheds run the risk of considerable under- and over-prediction of surface runoff and sediment yield. Management decisions in agricultural unmonitored watersheds that are based on model simulations are associated with uncertainty as well.

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APPENDIX

LUTZ METHOD (LUTZ, 1984)

Objective: Development of a method to predict surface runoff based on watershed and event-based characteristics. The method uses easy-to-obtain data.

Data material used to develop Lutz equations: 981 rainfall-runoff events from 75 different watersheds in Germany.

Watershed characteristics: size of watersheds ranging from 3 to 236 km^2 shape, slope, land use, percentage of urban area, maximum length of channel, soils and infiltration characteristics of soils.

Event-based characteristics: (i) measured precipitation derived from weather stations across the country (point precipitation values were interpolated using the Thiessen polygon method), (ii) precipitation duration, (iii) precipitation intensity, and (iv) measured discharge separated in direct runoff and base flow. Direct runoff consists of surface runoff, channel flow and subsurface flow in unknown proportions. Lutz assumed direct runoff corresponds to surface runoff.

A multiple non-linear regression analysis was used to develop equations, where variables with significant power to predict surface runoff were included.

Equations I and 2 describe watershed characteristics (variables Ia, S, C); equation 3 describes event-based characteristics; equation 4 combines watershed and eventbased characteristics to calculate surface runoff.

CN METHOD (SCS-USDA, 1985)

Derived from data collected in small watersheds (< 0.04 km^2). CN method estimates direct runoff.