Environmental Science

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Chapter 3

Application of Modified AGNPS in German Watersheds

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3.1
Objectives

The objectives have been the application and verification of the AGNPS model (Agricultural Non-Point Source Pollution Model) by Young et al. (1987,1994) to assess runoff volume, sediment and nutrient yield in medium to large-sized watersheds (>i km') in Germany. The aim was to adapt the model to climate and land use conditions in Germany and to modify some model algorithms to improve description of transport processes (AGNPSm: modified AGNPS).

3.2
Methodology

The event-based water quality model AGNPS Vers. 5.0 was used in this study (Young et al. 1987,1994). In the original version by USDA-ARS (United States Department of Agriculture -Agricultural Research Service) the empirical Curve-Number-Method was used for runoff volume calculations (SCS 1972). Peak flow rate was computed by the Smith and Williams (ig8o) algorithm, and Manning's Equation described flow velocity. Soil loss was calculated by a modified Universal Soil Loss Equation (Wischmeier and Smith 1978), which includes the energy-intensity value and a slope-shape factor. Sediment transport and deposition were calculated by a steady-state continuity equation (Foster et al. ig8o; Lane 1982), whereby routing was done on a per cell and per particle-size basis. Sediment transport capacity was calculated with a modified Bagnold stream power equation (Bagnold 1966) and, based on the Einstein (1950) approach, each particle class was calculated separately. For the calculation of soluble N and P and nutrients in sediment, analytical approaches from the CREAMS model were used (Frere et al. 198o).

The following modifications were integrated in the AGNPS:

Lutz (1984) method for runoff volume calculation:

$$RO = (P - Ia)\,C + \frac{C}{a}\left(e^{-a(P-Ia)} - 1\right) \qquad (3.1)$$

$$Ia = 0.03S \qquad (3.2)$$

$$S = 25.4\left(\frac{10}{C} - 10\right) \qquad (3.3)$$

$$a = C1e^{(-C2/WZ)}e^{(-C3/q_B)}e^{(-C4D)} \tag{3.4}$$

- RO = runoff volume (mm) by Lutz
- P = storm precipitation (mm)
- Ia = initial abstraction (mm)
- C = maximum discharge value (-)
- a = Lutz factor (mm^{-1})
- S = potential maximum retention (mm)
- $C1, C2, C3, C4$ = weighting parameters for optimization (-)
- WZ = week value
- q_B = base flow ($\mathrm{l\,s^{-1}\,km^{-2}}$)
- D = duration of precipitation (h)

- Smith and Williams (1980) algorithm for peak flow calculation:

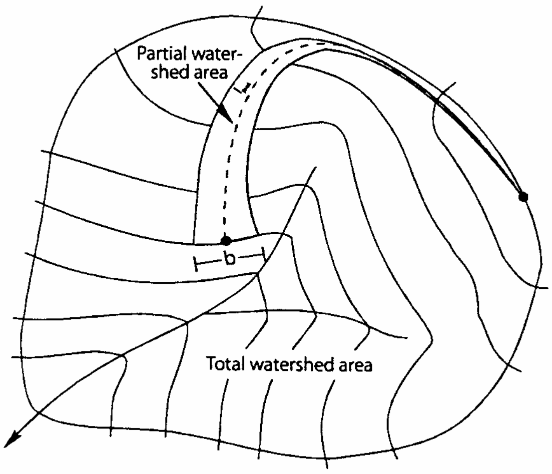
$$Q_{\max} = 3.79{A_{EO}}^{0.7} J^{0.16}\left(\frac{RO}{25.4}\right)^{(0.903{A_{EO}}^{0.017})}\left(\frac{L^2}{A_{EO}}\right)^{-0.19} \tag{3.5}$$

- $Q_{\max}$ = peak flow rate ($\mathrm{m^3\,s^{-1}}$)
- A_{EO} = drainage area ($\mathrm{km^2}$)
- J = channel slope (%)
- L = maximum flow path (km)

- LS-factor algorithm based on 'stream power theory' by Moore and Burch (1986) (compare Fig. 3.1):

$$f = \frac{A_{pwa}}{bl_{pwl}} \tag{3.6}$$

Fig. 3.1. Partial watershed area concept by Moore et al. (1986)



$$Lsp = \left(\frac{f l_{pwl}}{22.14}\right)^{0.4} \tag{3.7}$$

$$Ssp = \left(\frac{\sin s_x}{0.0896}\right)^{1.3} \tag{3.8}$$

- f = shape parameter (–)
- A_{pwa} = partial watershed area (m^2)
- b = width of contour element (m)
- l_{pwl} = partial watershed length (m)
- Lsp = L-factor (stream power theory)
- Ssp = S-factor (stream power theory)
- s_x = slope of partial watershed area (°)

- Scouring of particles in channel linked to water flow velocity.

In Table 3.1, critical flow velocities for different particle classes based on literature are shown.

- Grid-based precipitation input instead of uniform rainfall input for large watersheds.

The modeling concept comprised a Geographic Information System (GIS), an input- interface, the model AGNPSm, and an output-interface (Fig. 3.2). The program Digital Elevation Drainage Network Model (DEDNM) of Garbrecht and Martz (1993) was used to derive the watershed boundary, flow directions, and the drainage network. The GIS (SPANS and IDRISI) was used to store the spatial input data (land use, soil, topography). An interface program written in C linked the spatial data as well as the climate data to AGNPSm. By means of the interface, AGNPSrn input variables were calculated by primary and secondary derivation based on spatial data and if-struclures. For example, input variables that vary seasonally (e.g. Manning's roughness coefficient) were derived by time-dependent if-structures and land use data. in Table 3.2, the data sources and AGNPS input variables are listed.

The watersheds used in this study denoted G1 and G2, are located on Glonn Creek, in Bavaria, Germany. The watershed Gi is 1.2 km' and G2 1.6 kM2 in size. 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 predominantly loamy-sands, loam, and clay-loam soils with some influence of loess. In the valley bottom, gleyed soils are present. The

Table 3.1. Critical flow velocities for different particle classes (Imhoff 1972; Maue 1988; DVWK 1988)

Flow velocity (m s-1)	Particle classes'
0.3	Primary clay
0.6	Primary silt
0.9	Small aggregates
1.2	Large aggregates
1.5	Primary sand

' Particle classification: Foster et al. (1980).

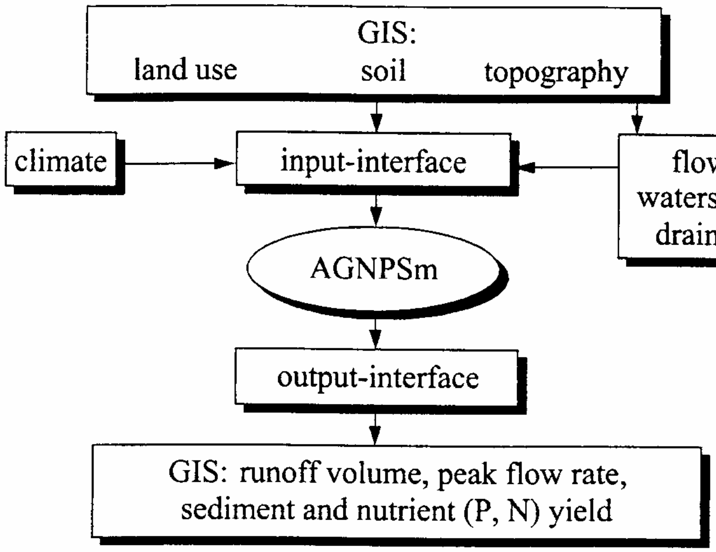


Fig. 3.2. Flow chart of the modeling concept

Table 3.2. Data sources and AGNPS input variables used for the Glonn watershed

Data source	AGNPS input variable
DEM (digitized contours 1 : 5 000) + DEDNM	→ Numerical order of cells → receiving cells (flow directions) → identification of channel cells → slope and slope shape
Topographic map 1 : 5 000	→ Slope length
Mapping of land use + interview of farmers + standard values	→ Manning's n Roughness Coefficient → Surface Condition Constant → Soil Loss Ratio (USLE) → N and P fertilizer amount and availability → organic matter content
Mapping of soil types (1 : 5 000) + soil texture (Reichsbodenschätzung –soil survey)	→ Soil texture → K-factor (USLE)
Analysis of soil N and P	→ Soil P and N
Mapping of land use + soil data information + digitized street and alley system	→ Curve Numbers; maximum discharge values
Mapping of contouring	→ P-factor (USLE)
Data from 2 rain stations + 1 rain recorder	→ Precipitation amount → duration of rainfall event → energy-Intensity-value (USLE)
Rainfall data + measured discharge	→ K-value (% runoff)
Field investigation + DEDNM	→ Channel slope → channel side slope → channel width → channel length

total area in Gi 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 yearly precipitation for two rain stations nearby are 830 mm (Mering) and 873 mm (Puch). The number of rainfall/runoff events used in this study were 29 (Gi) and 24 (G2). These rainfall events varied between 17 and 89 mm, and measured runoffvolume ranged from 1-58 mm (Gi) and 0.5-23 mm (G2), respectively. Measured data at the drainage outlet were collected by the Bavarian Water Authority (1984).

Additionally, simulations were carried out in the Salzboede watershed, in the hilly midlands of Germany. This watershed is 81.7 km' in size. The elevation range is 190-564 M, and the average slope of the arable land is 9.7%. The watershed is predominantely (46.o%) forest, with 21.5% pasture/meadow, and 23.5% arable land dominated by grain. The soils are predominantely loamy sands, loam or clay-loam soils mixed with loess. The average yearly precipitation is 786 mm. For model verification, 16 measured rainfall/runoff events were used (Rode 1995).

3.3
Results

The prediction results for the Gi watershed are presented in detail, while the results for G2 and Salzboede are summarized. In this study, a grid resolution Of 25 m was used, with 1965 cells representing the watershed G1.

Runoff volume by the SCS CN-Method (SCS 1972) under predicted measured runoff volume. The calculated runoff was very low, due to the magnitude of the initial abstraction (M), which was calculated by the equation: Ia = 0.2S (S: potential maximum retention). Especially for small events (<50 mm precipitation amount), the predictions were unreliable with a coefficient of efficiency (Nash and Sutcliffe 1970) of 0.25. Because the results of the SCS CN-Method do not match the conditions of land use, soil, and climate found in watershed G1, a calibration was carried out. For this purpose, the weighting factor for initial abstraction was varied between 0.01 and 0.20. Ten calibration events were used to calculate the coefficient of efficiency *E* for each weighting factor combination. The highest *E* was found for a weighting factor of 0.03. The results for the calibrated SCS CN-Method are shown in Table 3.3 and Fig. 3.3. The calibrated runoff volumes for SCS CN-Method show reliable results compared to measured runoff volumes. The *E* was 0.87 (calibration events) and 0.93 (validation events), respectively. The differences between measured and predicted median of runoff volume for validation events were justifiably low. The results correspond well with literature. For example, Maniak (1992) recommended a reduction of the Ia value to 5% Of the water storage capacity in the sod (Ia = 0.05S) for German watersheds.

Results for runoff volume calculations by the method of Lutz (1984) are shown in Table 3.4 and Fig. 3.4. C2 was set according to Lutz (1984), dependent on land use. In calibrating the Lutz method lo representative rainfall events out of a total Of 29 were used. The calibration parameters C1 and C3 were varied between 0.02-0.08 and 1.0-6.0, respectively. For each parameter combination, the 10 rainfall events were simulated, and predicted and measured runoff volumes were compared using E.

Table 3.3. Statistics for runoff volume (*RO* in mm) calculated by calibrated SCS CN-Method (SCS 1972) – ($Ia = 0.03S$); watershed G1

	Calibration events		Validation events	
	Measured	Predicted	Measured	Predicted
Mean	8.1	9.4	9.0	8.6
Median	5.7	6.3	3.8	5.2
S. dev.	9.9	9.5	13.4	10.6
N	10		19	
E	0.87		0.93	

Table 3.4. Statistics for runoff volume (*RO* in mm) calculated by Lutz Method; watershed G1

	Calibration events		Validation events	
	Measured	Predicted	Measured	Predicted
Mean	8.1	8.1	9.0	8.7
Median	5.7	5.9	3.8	4.3
S. dev.	9.9	9.1	13.4	11.6
N	10		19	
E	0.98		0.96	

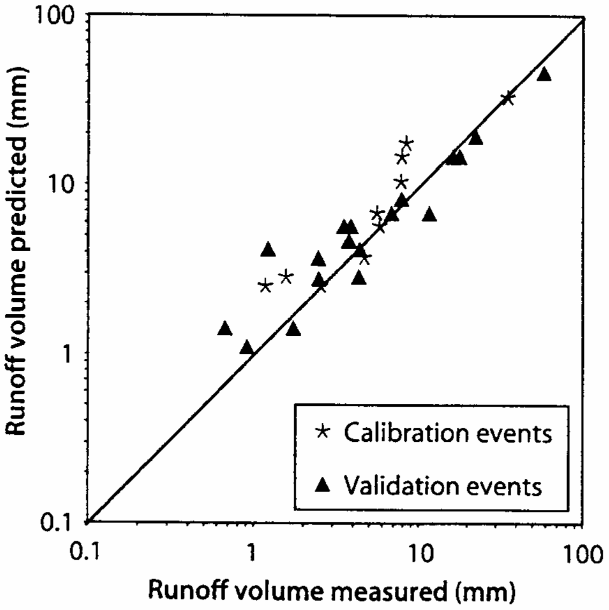
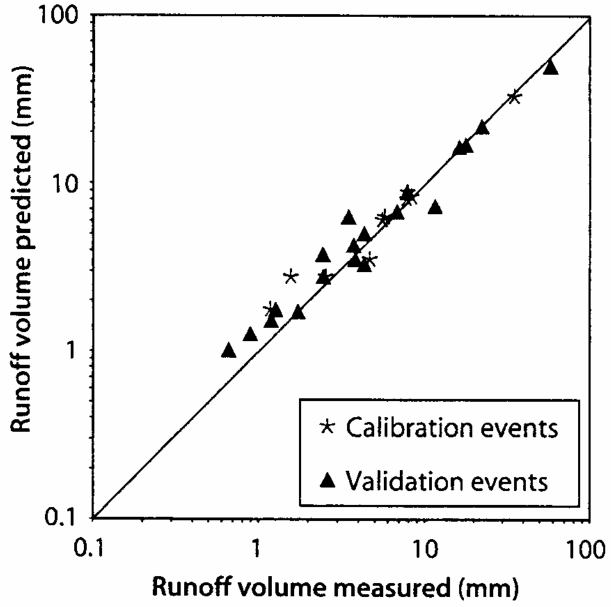


Fig. 3.3. Measured and predicted runoff volume (*RO* in mm) calculated by calibrated SCS CN-Method ($Ia = 0.03S$); watershed G1

Fig. 3.4. Measured and predicted runoff volume (*RO* in mm) calculated by Lutz method; watershed G1



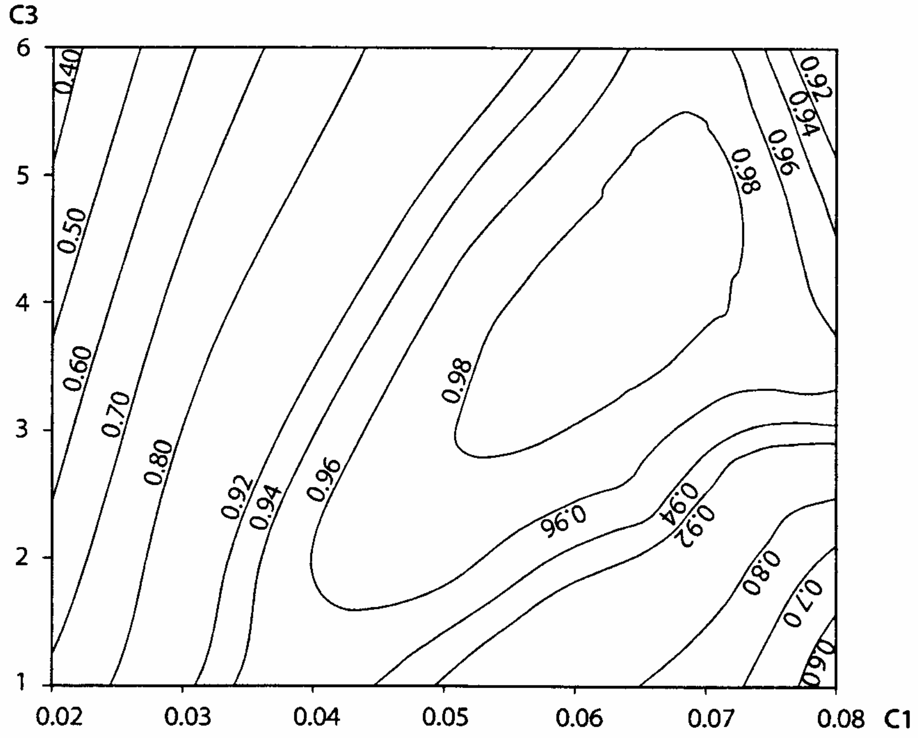


Fig. 3.5. Coefficients of efficiency (Nash and Sutcliffe 1970) for different combinations of Lutz parameters *C1* and *C3*

In Fig. 3.5, the isolines of E are shown for different calibration parameter combinations. According to the calibration procedure, a C1 value of o.o6 and C3 of 4.0 gave one of the best simulation results for watershed G1.

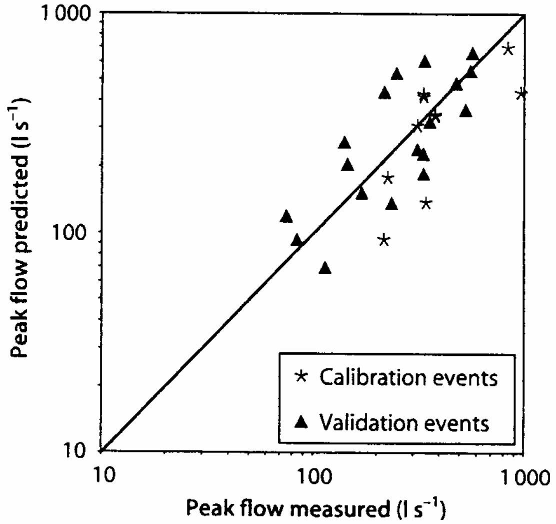
Even for small events, the measured and predicted values are scattered near the 1: 1 line in Fig. 3.4. The difference between measured and predicted medians for the validation events of 0.5 mm (Table 3-4) was very low compared to the CN-Method. For all subsequent calculations, the Lutz method was used, as it provides the highest degree of suitability for simulations in the G1 watershed.

Because peak flow calculations by the algorithm of Smith and Williams (1980) over predicted measured values, a calibration was carried out. Ten calibration events were used, and a calibration factor f calculated as a function of runoff volume, was integrated into the peak flow algorithm ($f = 0.328e^{(-0.812RO)}$) Eq. 3.5. The results for peak flow predictions are shown in Table 3.5 and Fig. 3.6. For 19 validation events, a coefficient of efficiency of 0.84 was calculated, which is reliably high.

Table 3.5. Statistics for peak flow rate (Q_{max} in l s-1); watershed G1

	Calibration events		Validation events	
	Measured	Predicted	Measured	Predicted
Mean	435.3	340.4	306.7	334.2
Median	341.4	345.4	312.9	260.9
S. dev.	255.7	176.8	169.9	201.0
N	10		19	
E	0.85		0.84	

Fig. 3.6. Measured and predicted peak flow rate (Q_{max} in $l\,s^{-1}$); watershed G1



In Table 3.6 and Fig. 3.7, the results for sediment delivery calculated by the Universal Soil Loss Equation (Wischmeier and Smith 1978) are shown. Calibration was carried out to determine which particle class has to be scoured within the channel. Based on calibration for lo events, the highest E (0-42) was calculated for 'no scouring of particles within channel' (see Table 3-7). It should be indicated that the assumption 'no scouring of particles' contradicts observations in watershed G1, because there was channel erosion when large runoff events occurred. The coefficient of efficiency for the validation events was 0.26, which is very low.

In Table 3.8 and Fig. 3.8, the results for sediment delivery calculated by AGNPSm (LS-factor by method of Moore and Burch 1986) are shown. There, too, the calibration procedure gave the highest E (o.65) for the option 'no scouring of particles within channel' (Table 3-9), and this has been assured for validation. The coefficient of efficiency for validation events was 0.57, which is higher compared with the sediment

Table 3.6. Statistics for sediment delivery (Sed in t) calculated by USLE (Wischmeier and Smith 1978); watershed G1

	Calibration events		Validation events	
	Measured	Predicted	Measured	Predicted
Mean	2.93	1.14	3.64	1.23
Median	2.01	0.90	2.10	0.86
S. dev.	2.75	0.91	5.71	1.58
N	10		18	
E	0.42		0.26	

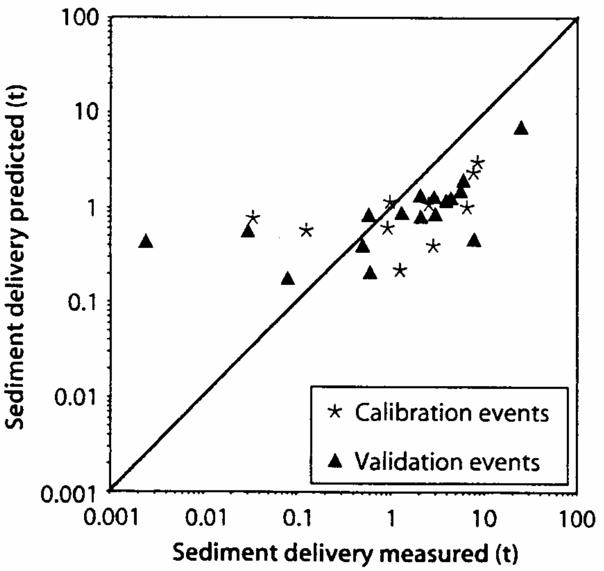


Fig. 3.7. Measured and predicted sediment delivery (*Sed* in t) calculated by USLE (Wischmeier and Smith 1978); watershed G1

Table 3.7. Coefficients of efficiency (Nash and Sutcliffe 1970) for sediment delivery *(Sed in* t) for different combinations of scouring of particles within channel. Sediment delivery was calculated by USLE (Wischmeier and Smith 1978)

	Combinations									
Clay	-	x	x	x	x	x	-	-	-	-
Silt	-	-	x	x	x	x	x	-	-	-
Small aggregates	-	-	-	x	x	x	x	x	-	-
Large aggregates	-	-	-	-	x	x	x	x	x	-
Sand	-	-	-	-	-	x	x	x	x	x
E	**0.42**	**0.30**	**0.05**	**-0.03**	**-0.50**	**-0.63**	**0.15**	**0.21**	**0.22**	**0.27**

- No scouring of particle within channel;
x Scouring of particle within channel.

Table 3.8. Statistics for sediment delivery (Sed in t) calculated by USLE (Wischmeier and Smith 1978), and LS-factor by method of Moore et al. (1986); watershed Gi

	Calibration events		Validation events	
	Measured	Predicted	Measured	Predicted
Mean	2.93	1.76	3.64	1.86
Median	2.01	1.49	2.10	1.10
S. dev.	2.75	1.48	5.71	2.71
N	10		18	
E	0.65		0.57	

Fig. 3.8. Measured and predicted sediment delivery (*Sed* in t) calculated by USLE (Wischmeier and Smith 1978), and LS-factor by method of Moore et al. (1986); watershed G1

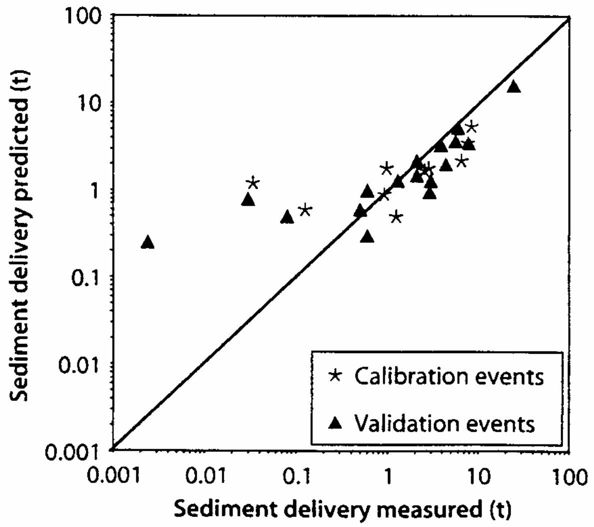


Table 3.9. Coefficients of efficiency (Nash and Sutcliffe 1970) for sediment delivery (Sed in t) for different combinations of scouring of particles within channel. Sediment delivery was calculated by
AGNPSm (LS-factor of Moore et al. 1986)

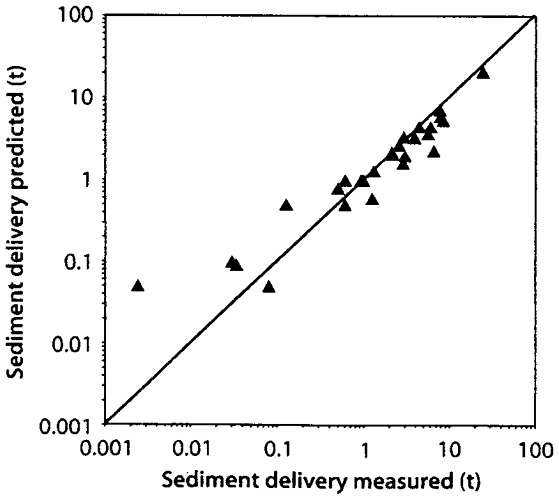
	Combinations									
Clay	-	x	x	x	x	x	-	-	-	-
Silt	-	-	x	x	x	x	x	-	-	-
Small aggregates	-	-	-	x	x	x	x	x	-	-
Large aggregates	-	-	-	-	x	x	x	x	x	-
Sand	-	-	-	-	-	x	x	x	x	x
E	0.65	0.55	0.28	0.07	-0.30	-0.44	0.36	0.52	0.60	0.62

- No scouring of particle within channel;
x Scouring of particle within channel.

Table 3.10. Statistics for sediment delivery (*Sed* in t) calculated by USLE (Wischmeier and Smith 1978), LS-factor by the method of Moore et al. (1986), and scouring of particles linked to flow velocity; watershed G1

	Validation events	
	Measured	Predicted
Mean	3.59	2.92
Median	2.08	2.00
S. dev.	4.95	4.11
N	28	
E	0.90	

Fig. 3.9. Measured and predicted sediment delivery (*Sed* in t) calculated by USLE (Wischmeier and Smith 1978), LS-factor by the method of Moore et al. (1986), and scouring of particles linked to flow velocity; watershed G1



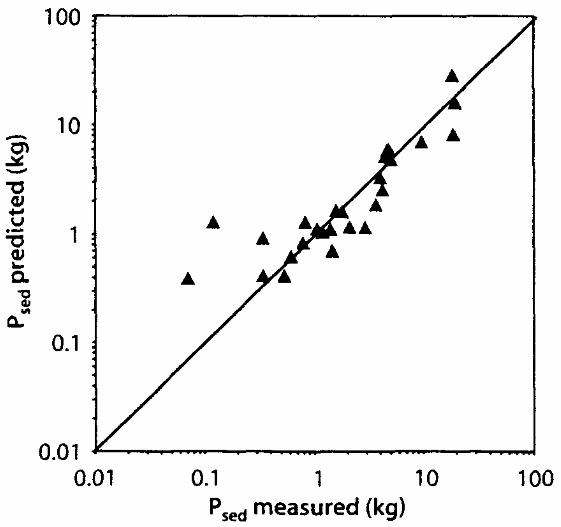
calculation by AGNPS. The deviation between measured and predicted medians was 1 t. This indicates that the modification using the LS-factor of Moore and Burch (1986) improved sediment delivery calculations. With this modification in the AGNPS model, the description of soil erosion on the field is improved but this does not affect channel erosion.

In Table 3.10, the results for sediment delivery calculated by means of AGNPSm (scouring of particles in channel is linked to flow velocity) are shown. It should be emphasized that no calibration of the sediment routine was necessary. The coefficient of efficiency was 0.90 and the deviation between measured and predicted medians was o.o8 t. These very good results for sediment predictions are plotted in Fig. 3.9. This modification improved the description with respect to channel erosion.

Table 3.11. Statistics for phosphorus in sediment (Psed) and soluble phosphorus (Psol in kg); watershed G1

	Validation events Pd		Validation events P	
	Measured	Predicted	Measured	Predicted
Mean	4.24	3.88	3.64	4.24
Median	1.78	1.29	1.57	1.76
S. dev.	5.74	6.00	5.52	6.64
N	28		28	
E	0.71		0.40	

Fig. 3.10. Measured and predicted phosphorus in sediment (P_{sed} in kg); watershed G1



In watershed G1 for nutrient delivery assessment, results for phosphorus in sediment (Psed) as well as for soluble phosphorus (Psol) are shown in Table 3.11 and Fig. 3.10 and 3.11. The reliable results for Psedwere based on the excellent results for sediment delivery from AGNPSm. The predictions for Psol were poorer compared to Psed.

In Tables 3.12 and 3.13, a summary for all predictions (AGNPSm) in watersheds G1 and G2 is shown. The predictions were slightly poorer for watershed G2 Compared to G1. For runoff the results were reliable for both watersheds. Sediment delivery, phosphorus, and nitrogen in sediment calculated with AGNPSm gave satisfactory results. Very poor results were calculated for soluble nutrients.

The Salzboede watershed was divided into grids Of 200 m in width or 2032 grid cells in total. For all events, rainfall rasters were generated by ordinary kriging with the GEOEAS software package (Englund and Sparks 1988), to use for the grid-based precipitation input to AGNPSm. The Lutz C1-factor was fixed at 0.05 and C3-factor at 2.0 (see Rode 1995). Peak flow was calculated based on the algorithm of Rode (1995). The re-

Fig. 3.11. Measured and predicted soluble phosphorus (P_{sol} in kg); watershed G1

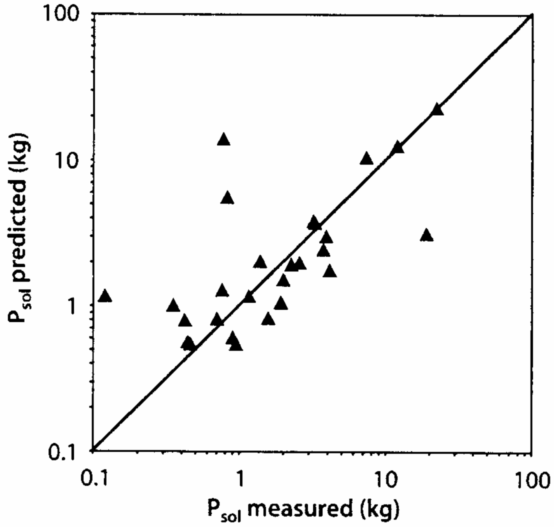


Table 3.12. Summary of predictions calculated in watershed G1

	RO(CN)	RO(Lutz)	Qmax	Sed	Psed	Psol	Nsed	Nsol
E(-)	0.93	0.96	0.84	0.90	0.71	0.40	0.79	0.60
D.m.[a]	1.4mm	0.5mm	52 l s^{-1}	0.08t	0.49kg	0.19kg	0.06kg	5.30kg
N(-)	19[a]	19[b]	19[b]	28	28	28	28	28

[a] Deviation between measured and predicted median

[b] Validation events.

Table 3.13. Summary of predictions calculated in watershed G2

	RO(CN)	RO(Lutz)	Qmax	Sed	Psed	Psol	Nsed	Nsol
E(-)	0.76	0.83	0.82	0.72	0.64	-1.92	0.40	0.13
D.m.[a]	1.5mm	0.8mm	14 | s^{-1}	0.10t	1.66kg	0.48kg	7.85kg	56.8kg
N(-)	12[a]	12[b]	12[b]	24	24	24	24	24

[a] Deviation between measured and predicted median

[b] Validation events.

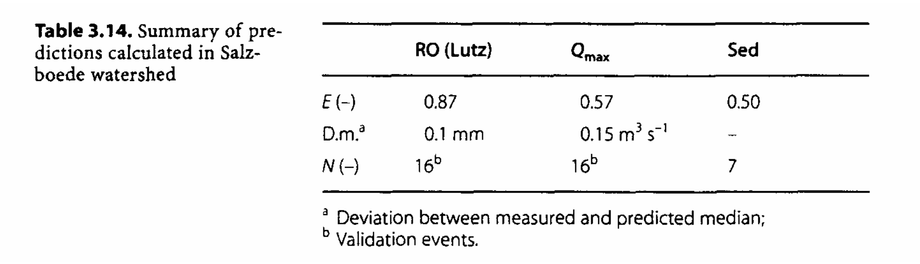


Table 3.14. Summary of predictions calculated in Salzboede watershed

	RO (Lutz)	Q_{max}	Sed
E (–)	0.87	0.57	0.50
D.m.[a]	0.1 mm	0.15 m^3 s^{-1}	–
N (–)	16[b]	16[b]	7

[a] Deviation between measured and predicted median;
[b] Validation events.

suits in hydrology calculated by AGNPSm are shown in Table 3.14. The median between measured and predicted runoff volume differed only slightly. The coefficient of efficiency for runoff volume was o.87, for peak flow rate 0.57, and for sediment delivery 0.49.

3.4
Conclusions

Verification of the modified AGNPS model (AGNPSm) was carried Out in 3 different watersheds in Germany. The results in hydrology were satisfactory in all watersheds. Sediment delivery was calculated satisfactorily after modifications (LS-factor calculation and scouring of particles linked to flow velocity) were integrated into the AGNPS model. Reliable results were calculated for nutrients in sediment but not for soluble nutrients (P,,,j). Reasons for the difficulties in nutrient delivery predictions include lack of data on fertilizer application, detailed time of application, and seasonal change in soil nutrients caused by plant uptake, mineralization, vertical wash out, and so forth.

AGNPSm is not a very complex model but uses many empirical algorithms, hence the number of parameters needed is not very high. The advantage of AGNPSm in combination with a GIS and an interface is the possibility it offers to predict runoff volume, sediment, and nutrient yield in mediumto large-sized watersheds. In this study, it was shown that AGNPSm can calculate results in runoff volume, peak flow, and sediment delivery reliably. This tool promises to be useful as a decision support system in further studies.

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