PERGAMON

Physics and Chemistry of the Earth 27 (2002) 645–654

PHYSICS and CHEMISTRY of the EARTH

www.elsevier.com/locate/pce

Comparison of two different approaches of sensitivity analysis

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Received 10 February 2001; received in revised form 16 January 2002; accepted 16 January 2002

Abstract

Due to spatial variability, budget constraints or access difficulties model input parameters always are uncertain to some extent. Therefore the knowledge of sensitive input parameters is beneficial for model development and application. It can lead to a better understanding and to better estimated values and thus reduced uncertainty.

In the present paper two simple approaches of sensitivity analysis are compared by the use of the physically based, continuous time hydrological model SWAT. In both approaches, one parameter is varied at a time while holding the others fixed, but the way of defining the range of variation is different. Similar results are obtained suggesting that parameter sensitivity may be determined without the results being influenced by the chosen method. Most sensitive parameters for hydrology and water quality are the physical soil properties such as bulk density, available water capacity or hydraulic conductivity. Plant specific parameters like maximum stomatal conductance or maximum leaf area index as well as slope length, slope steepness, and curve number also show a high sensitivity. Both approaches can be considered as equivalent, as they provide the same overall ranking into more and less sensitive parameters. An identification of the sensitive parameters is possible independently from the chosen variation range.

Keywords: Sensitivity analysis; Uncertainty; Model calibration; Water quality; Distributed models

1. Introduction

Physically based models are used to simulate a wide range of complex aspects. The purpose of using a model is to establish baseline characteristics whenever data is not available. Furthermore, there are long-term impacts that are difficult to calculate, especially in ecological modeling. Using long data series, process-based deterministic models can compute the great number of calculations required to describe the complexity of a system (lake, river, watershed, etc.). They can provide reliable information on the behavior of the system.

Due to spatial variability, budget constraints or access difficulties model input parameters always contain uncertainty to some extent. However, a model user has to assign values to each parameter. The model is then calibrated against measured data to adjust the parameter values according to certain criteria. This implies that the modeler has a clear understanding of all the parameters used as input to the model and of the processes represented in the model. Parameters that are not well understood may be left unchanged even though they are sensitive or are adjusted to implausible values. Not knowing the sensitivity of parameters can also result in time being uselessly spent on non-sensitive ones. Focus on sensitive parameters can lead to a better understanding and to better estimated values and thus reduced uncertainty.

Therefore sensitivity analysis as an instrument for the assessment of the input parameters with respect to their impact on model output is useful not only for model development, but also for model validation and reduction of uncertainty (Hamby, 1994).

There are many different methods of sensitivity analysis (Beven, 2001; Hamby, 1994). Yet, do they yield equivalent results? Are the same parameter sensitivities identified, regardless of the chosen method?

2. Materials and methods

2.1. The hydrologic model

In this article, the results of two different, relatively simple approaches are compared using the example of

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1474-7065/02/$ - see front matter
PII: S1474-7065(02)00049-9

the hydrological model SWAT-G (Eckhardt et al., 2002b, in press). SWAT-G is a river basin scale model operating on a daily time step. It is a derivative of soil and water assessment tool (SWAT; Arnold et al., 1998), which was developed to predict the impact of land management practices in meso- to macroscale basins. It is physically based. Major model components describe processes associated with water movement, sediment movement, soils, temperature, weather, plant growth, nutrients, pesticides and land management. The water balance is represented by several storage volumes in each of the spatial subunits. These include: canopy storage, snow, soil profile, shallow aquifer and deep aquifer.

Surface runoff is calculated using a modification of the curve number technique (USDA-SCS, 1972). The soil profile is subdivided into multiple layers. Soil water processes include infiltration, evaporation, plant uptake, lateral flow and percolation to deeper layers. Percolation from the bottom of the soil profile recharges the shallow aquifer. The flow from the aquifer to the stream is lagged by using a recession constant. Other shallow aquifer components include evaporation, pumping withdrawal and seepage to the deep aquifer.

Plant growth is simulated using a simplification of the EPIC crop model (Williams et al., 1984). Growth can only occur if the daily temperature exceeds a plant specific base temperature. Temperature excess is counted in "heat units" and accumulated over the time. Phenological plant development is controlled by comparing the actually accumulated heat units to the predefined heat unit sum for maturity. SWAT uses Montheith's approach to estimate potential biomass (Monteith, 1977) coupled with stress adjustments for water, temperature and nutrients. The leaf area index is simulated as a function of heat units and varies between plant-specific minimum and maximum values.

Potential evapotranspiration is estimated with the Penmann–Monteith method (Monteith, 1965). Canopy evaporation is a function of potential evapotranspiration, maximum interception capacity and the ratio of actual to potential maximum leaf area index. Plant water uptake is a function of potential evapotranspiration, leaf area index and rooting depth and is limited by the soil water content.

SWAT is used worldwide and has been chosen by the Environmental Protection Agency to be one of their better assessment science integrating point and nonpoint sources (BASINS) models (Whittemore, 1998). Thus, regulating environmental agencies will likely be using it increasingly.

2.2. Model sensitivity analysis

Sensitivity is expressed by a dimensionless index I, which is calculated as the ratio between the relative change of model output and the relative change of a parameter. The two investigated approaches differ in the way the ranges of parameter variation are defined.

The conventional variation by a fixed percentage of the initial parameter value is problematic for two reasons. On the one hand, if the model response to parameter variations is nonlinear, then the results will depend on how the initial value was chosen because a small initial value leads to a small variation and a greater initial value to a larger variation. On the other hand, if the initial parameter value is located nearby the upper or lower bound of the valid parameter range, the variation can lead to inadmissible values beyond the bounds of the range. This can easily happen by just accepting the default settings of the parameters derived by the model or the GIS used to compose the initial data.

Therefore, an alternative approach to define the parameter variation is considered in which the parameters are not varied by a fixed percentage of the initial value but by a fixed percentage of the valid parameter range.

2.3. Calculation of the sensitivity index

Mathematically, the dependence of a variable y from a parameter x is expressed by the partial derivative $\partial y/\partial x$. This expression is numerically approximated by a finite difference: be y_0 is the model output calculated with an initial value x_0 of the parameter x (Fig. 1). This initial parameter value is varied by $\pm\Delta x$ yielding $x_1 = x_0 - \Delta x$ and $x_2 = x_0 + \Delta x$ with corresponding values y_1 and y_2. The finite approximation of the partial derivative $\partial y/\partial x$ then is

$$I' = \frac{y_2 - y_1}{2\Delta x} \tag{1}$$

To get a dimensionless index, I' has to be normalized. The expression for the sensitivity index I then assumes the form

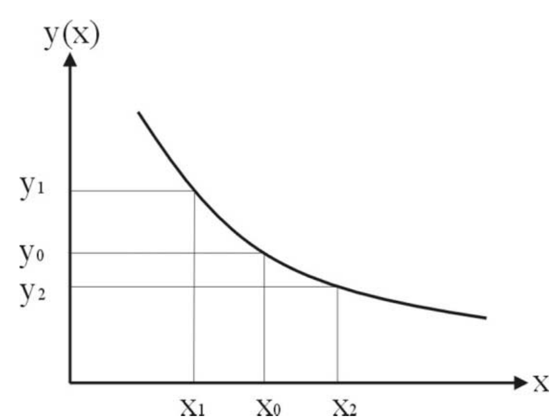

Fig. 1. Schematic of the relation between an output variable y and a parameter x.

$$I = \frac{(y_2 - y_1)/y_0}{2\Delta x/x_0} \quad (2)$$

The sign of the index shows if the model reacts codirectionally to the input parameter change, i.e. if an increase of the parameter leads to an increase of the output variable and a decrease of the parameter to a decrease of the variable, or inversely.

2.4. Model parameterization for sensitivity analysis

Natural basins mostly show a great variability and complexity with respect to soil, land cover, topographic characteristics etc. Saturated hydraulic conductivity, for example, varies in nature over a wide range. If it is changed in only one layer of one soil, then the magnitude relationship to the conductivity values of other layers of the same soil or of other soils may be violated. To avoid this, the parameter has to be changed simultaneously for all layers of all soils.

Therefore, a simple structured artificial catchment is used in this study. In a more complex natural catchment an overlay of effects caused by sub-areas with different characteristics can occur. This is excluded here, as the spatial variability of the parameters is reduced to an absolute minimum. Another advantage is that the handling is easier. Less storage capacity and computing time is required. Eckhardt et al. (1999) showed that the results obtained by using the artificial catchment can be transfered to a natural catchment. They compared the sensitivity of parameters with regard to streamflow using a similar artificial and a natural catchment. The calculations led to almost the same sensitivity indices and ranking in both cases.

The artificial catchment is formed as a V-shaped valley (Fig. 2). Its base area of 2 km^2 can be considered as being typical for the smallest spatial subunits (''hydrotopes'' or ''hydrologic response units'') normally used in models of mesoscale catchments. By its parameterization the artificial catchment is characterized as a low mountain range catchment: the mean elevation amounts to 400 m above sea level, the hillslope is 15% and the soil mainly consists of a shallow cambisol (soil depth: 1.1 m) over a hard rock aquifer. Only alongside the stream, on 10% of the area, deeper gley is found. The assumed landcover is set as deciduous forest for the whole catchment to avoid influences caused by management operations. The weather input data are taken from the station Dillenburg (50°44′N, 8°16′E) of the DWD (Deutscher Wetterdienst/German Weather service) located in a low mountain range area in Central Germany. The average annual air temperature is 6.6 °C, the annual precipitation amounts to about 900 mm.

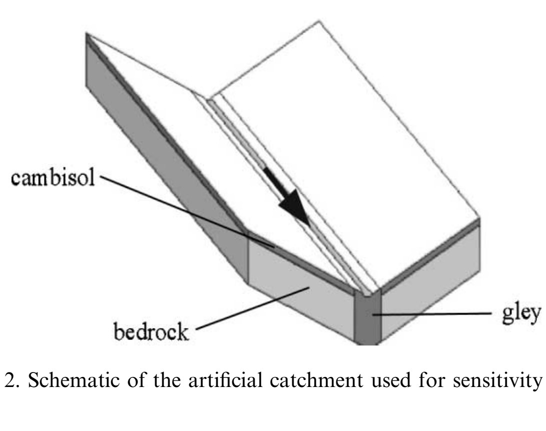

Fig. 2. Schematic of the artificial catchment used for sensitivity analysis.

Altogether 44 separate input parameters (e.g. surface runoff lag time, channel slope, Manning's N value, SCS curve number, average slope length, soil bulk density, max. stomatal conductance, etc.) are considered which are varied twice by an increment Δx (see Section 2.3). Two different approaches are compared.

In the first approach (variant A), Δx is 10% of the initial value x_0 of the respective parameter x regardless of the potential range of this parameter. This is probably the simplest way to carry out a sensitivity analysis, frequently found in literature (Hamby, 1994), yet it does not allow to consider interactions and relationships of parameters.

In the second approach (variant B), the different relative width of the ranges is taken into account by varying x by $\Delta x = 25\%$ of the entire range, with x_0 chosen as the mean. The plausible ranges for plant and soil parameters were defined using information provided by Eckhardt et al. (2002a, in press) and Breuer et al. (2002, submitted for publication).

Every model run covers six hydrologic years. The first year is used as ''warm-up'' period. The remaining five hydrologic years are evaluated with respect to eight different output variables related to water and nutrient budget (runoff, surface runoff, evapotranspiration, sediment yield, nitrate, organic N, phosphorous and organic P) (compare Tables 2 and 3). Mean values of these variables over the winter and summer half-year as well as over the whole period are calculated. To assess the calculated sensitivity indices are ranked into four classes (Table 1).

To support the results for a larger variation range an additional examination is performed. The soil parameters as the most sensitive of all model parameters under investigation are varied 250% with the same initial parameter set as in variant B.

Table 1
Sensitivity classes

Class	Index	Sensitivity
I	$0.00 \leqslant \lvert I \rvert < 0.05$	Small to negligible
II	$0.05 \leqslant \lvert I \rvert < 0.20$	Medium
III	$0.20 \leqslant \lvert I \rvert < 1.00$	High
IV	$\lvert I \rvert \geqslant 1.00$	Very high

Table 2
Sensitivity of SWAT-G output to input parameters (variant A)

	Runoff			Surface runoff			Evapotranspiration			Sediment yield		
	Summer	Winter	Total	Summer	Winter	Total	Summer	Winter	Total	Summer	Winter	Total
∗.BSN—file												
Peak rate factor (tributary channels)												
Linear sediment parameter												
Exponent sediment parameter												
Peak rate factor (main channel)												
Nitrogen uptake distribution factor												
Phosphorus uptake distribution factor												
Nitrogen percolation coefficient												
Phosphorus percolation coefficient												
Residue decompostion factor												
Phosphorus soil partitioning coefficient												
Surface runoff lag time										III		II
∗.RTE—file												
Channel width	III									III	II	
Channel depth										III	II	III
Channel slope										II	III	III
Channel length	II									II		
Manning's *N* value for main channel										IV	II	III
Channel erodibility factor												
Channel cover factor												
∗.GW—file												
Groundwater delay										II	II	II
Groundwater revap coefficient	II											
Deep aquifer percolation fraction	II									II		II
∗.SUB—file												
SCS curve number				IV	III	III				IV		III
Tributary channel slope										II	II	II
Tributary channel width												
Manning's *N* value for tributary channel										III		II
Manning' *N* factor for overland flow										II		II
USLE support practice factor *P*										III	III	III
Average slope length	II			III	II	II				III	III	III
Average slope steepness	II			II	II	II				III	IV	IV
∗.SOL—file												
Depth of bottom layer				IV	IV	IV	II	III		IV	IV	IV
Bulk density	III			IV	IV	IV		II		IV	IV	IV
Available water capacity	III	II	II	IV	IV	IV	II	II	II	IV	IV	IV
Hydraulic conductivity	III			III	III	III		II		II	III	III
Albedo	III	II	II	III				II	II	III	II	I
USLE soils factor *K*										III	III	III

Table 2 (*continued*)

	Runoff			Surface runoff			Evapotranspiration			Sediment yield		
	Summer	Winter	Total	Summer	Winter	Total	Summer	Winter	Total	Summer	Winter	Total
CROP.DAT												
Max. stomatal conductance	IV	III	III	IV		II	III	III	III	IV	III	II
Maximum plant height	II									II	II	II
Maximum rooting depth	II			III						II	IV	IV
Maximum leaf area index	III	III	III	IV		II	III		III	III	III	II
Optimal temperature	I	III		III			II	II		III	III	II
Base temperature	III	II	II	IV		II	II	II	III	III	III	III

	Nitrate			Organic N			Phosphorous			Organic P		
	Summer	Winter	Total	Summer	Winter	Total	Summer	Winter	Total	Summer	Winter	Total
∗.BSN—file												
Peak rate factor (tributary channels)												
Linear sediment parameter												
Exponent sediment parameter												
Peak rate factor (main channel)												
Nitrogen uptake distribution factor												
Phosphorus uptake distribution factor												
Nitrogen percolation coefficient	II	II										
Phosphorus percolation coefficient												
Residue decompostion factor	II	II	II									
Phosphorus soil partitioning coefficient												
Surface runoff lag time					III	III		III	III		III	III
∗.RTE—file												
Channel width												
Channel depth												
Channel slope												
Channel length												
Manning's *N* value for main channel												
Channel erodibility factor												
Channel cover factor												
∗.GW—file												
Groundwater delay												
Groundwater revap coefficient												
Deep aquifer percolation fraction												
∗.SUB—file												
SCS curve number	II	II		IV	II	III	IV	III	III	IV	III	III
Tributary channel slope				III	II	II	III	II	II	III	II	II
Tributary channel width								I			I	
Manning's *N* value for tributary channel				III	II	II	III	II	II	III	II	II
Manning' *N* factor for overland flow				II			II			II		
USLE support practice factor *P*				III	III	III	IV	III	III	IV	III	III

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Table 2 (*continued*)

	Nitrate			Organic N			Phosphorous			Organic P		
	Summer	Winter	Total	Summer	Winter	Total	Summer	Winter	Total	Summer	Winter	Total
Average slope length	III	III	III	IV	III	III	III	III	III	III	III	III
Average slope steepness	III	III	III	IV	IV	IV	III	IV	IV	III	IV	IV
∗.SOL—file												
Depth of bottom layer	IV	IV	IV	IV	IV	IV	IV	IV	IV	IV	IV	IV
Bulk density	IV	IV	IV	IV	IV	IV	IV	IV	IV	IV	IV	IV
Available water capacity	IV	IV	IV	IV	IV	IV	IV	IV	IV	IV	IV	IV
Hydraulic conductivity	III	III	III	II	III	III		III	III		III	III
Albedo	II			III			III			III		
USLE soils factor *K*				III	III	III	III	III	III	III	III	III
CROP.DAT												
Max. stomatal conductance	III	III	II	IV	II		IV	II		IV	II	
Maximum plant height	II			II								
Maximum rooting depth				III								
Maximum leaf area index	III	II	II	IV	II		IV	II		IV	II	
Optimal temperature	IV	III	III	III	III	III		III	III		III	III
Base temperature	IV	III	III	IV	II		IV	II	II	IV	II	II

Reaction of the model: (light grey) positive, (dark grey) negative; II—medium, III—high, IV—very high.

3. Results

Tables 2 and 3 show the results of both approaches for sensitivity analysis. In general the obtained sensitivities are consistent with results determined in other studies (e.g. Baffaut, 2001, submitted for publication).

Regarding the general watershed attributes, such as surface runoff lag time, residue decomposition factor or peak rate factor for tributary channels, (listed in the SWAT input file ∗.BSN) some of these parameters which according to variant A are sensitive show no or lower sensitivity in variant B. Mainly the sensitivity of the surface runoff lag time differs. In variant A it is classified as high, in variant B as small to negligible, probably because different initial parameter values were chosen for the two variants.

The sensitivity of the main channel characteristics (files ∗.RTE) is inevitably underestimated because the artificial catchment is small and therefore flow times are very short. Nevertheless, channel characteristics prove to be substantial for the sediment concentration. There is a significant difference in the assessment of the channel slope sensitivity in both approaches, probably also caused by the different initial parameterization. Yet, in both cases the same parameters prove to be sensitive.

The tested groundwater parameters are of minor importance for the considered mean values of model output.

The sensitivity of slope length, slope steepness and curve number is medium to very high for most output variables, independent of the chosen method. The parameters directly influence surface runoff and thus sediment and nutrient yield. The sensitivity of surface roughness and tributary channel characteristics is smaller. Again, this result is favoured by the use of the artificial catchment with its short flow times.

In both sensitivity analysis approaches, the overall greatest importance is attributed to soil parameters. They are predominantly of high to very high sensitivity.

Concerning plants, maximum stomatal conductance, maximum leaf area index, and optimal and base temperature are the most relevant parameters. The two approaches hardly differ in this aspect.

Altogether, both approaches of sensitivity analysis yield similar results. The classification of some parameters may not be the same, but this is mostly caused by minor differences of the sensitivity index around the class boundaries.

As can be seen in Table 4 there is no great difference caused by choosing a larger variation range. Even with a variation up to 250% only some parameters like bulk density and hydraulic conductivity with respect to streamflow and the USLE soils factor *K* with respect to sediment yield are stressed more than in variant B.

4. Discussion

Both sensitivity analysis approaches provide approximately similar results and hence can be considered as equivalent. Though in individual cases differing results are possible, the overall ranking into more and less sensitive parameters is the same. Thus an identification of the sensitive parameters is possible, independently from the chosen variation range.

Because of methodical limitations the results of the present study can only provide an orientation. Nevertheless the obtained results can be of great use for the practical work not only with SWAT-G. As it uses common methods like the curve number method or Penmann–Monteith and incorporates features of several

Table 3
Sensitivity of SWAT-G output to input parameters (variant B)

	Runoff			Surface runoff			Evapotranspiration			Sediment yield		
	Summer	Winter	Total	Summer	Winter	Total	Summer	Winter	Total	Summer	Winter	Total
∗.BSN—file												
Peak rate factor (tributary channels)												
Linear sediment parameter												
Exponent sediment parameter												
Peak rate factor (main channel)												
Nitrogen uptake distribution factor												
Phosphorus uptake distribution factor												
Nitrogen percolation coefficient												
Phosphorus percolation coefficient												
Residue decompostion factor												
Phosphorus soil partitioning coefficient												
Surface runoff lag time												
∗.RTE—file												
Channel width	II									III		III
Channel depth										III		III
Channel slope												
Channel length	II									III		III
Manning's N value for main channel										II	II	II
Channel erodibility factor												
Channel cover factor												
∗.GW—file												
Groundwater delay											III	
Groundwater revap coefficient												
Deep aquifer percolation fraction		II	II									
∗.SUB—file												
SCS curve number	III			IV	III	III					III	II
Tributary channel slope												
Tributary channel width												
Manning's N value for tributary channel											II	
Manning' N factor for overland flow											II	
USLE support practice factor P											III	
Average slope length	II	II	II	III	III	III				IV	IV	IV
Average slope steepness	II	II	II	II	III	III				II	III	II
∗.SOL—file												
Depth of bottom layer	II			IV	IV	IV	II	II		IV	IV	IV
Bulk density	II	II		IV	IV	IV		II	II	IV	IV	IV
Available water capacity	III	II	II	IV	IV	IV		II		IV	IV	IV
Hydraulic conductivity				III	III	III				II	III	II
Albedo	III	II	II	II				II		II	II	II
USLE soils factor K											III	

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Table 3 (*continued*)

	Runoff			Surface runoff			Evapotranspiration			Sediment yield		
	Summer	Winter	Total	Summer	Winter	Total	Summer	Winter	Total	Summer	Winter	Total
CROP.DAT												
Max. stomatal conductance	IV	III	III	III	III	III	III	III	III	II	II	II
Maximum plant height	II											
Maximum rooting depth				II							IV	II
Maximum leaf area index	IV	III	III	III	III	III	III		III	III		III
Optimal temperature	IV	II	III	IV	II	II	II		II	III	II	III
Base temperature	IV	II	III	IV	II	II	III	II	III	III		III

	Nitrate			Organic N			Phosphorous			Organic P		
	Summer	Winter	Total	Summer	Winter	Total	Summer	Winter	Total	Summer	Winter	Total
**.BSN—file*												
Peak rate factor (tributary channels)												
Linear sediment parameter												
Exponent sediment parameter												
Peak rate factor (main channel)												
Nitrogen uptake distribution factor												
Phosphorus uptake distribution factor												
Nitrogen percolation coefficient		II	II									
Phosphorus percolation coefficient												
Residue decompostion factor												
Phosphorus soil partitioning coefficient												
Surface runoff lag time												
**.RTE—file*												
Channel width												
Channel depth												
Channel slope												
Channel length												
Manning's *N* value for main channel												
Channel erodibility factor												
Channel cover factor												
**.GW—file*												
Groundwater delay												
Groundwater revap coefficient												
Deep aquifer percolation fraction												
**.SUB—file*												
SCS curve number	II	II	II	IV	III	III	IV	III	III	IV	III	III
Tributary channel slope				II	II	II		II	II		II	II
Tributary channel width												
Manning's *N* value for tributary channel				II	II	II		II	II		II	II
Manning' *N* factor for overland flow				II	III	III		III	III		III	III
USLE support practice factor *P*				III	III	III	III	III	III	III	III	III
Average slope length	III	III	III	III	III	III	III	III	III	III	III	III
Average slope steepness	II	III	III	IV	IV	IV	III	IV	IV	III	IV	IV

Table 3 (*continued*)

	Nitrate			Organic N			Phosphorous			Organic P		
	Summer	Winter	Total	Summer	Winter	Total	Summer	Winter	Total	Summer	Winter	Total
∗.SOL—file												
Depth of bottom layer	IV	IV	IV	IV	IV	IV	IV	IV	IV	IV	IV	IV
Bulk density	IV	IV	IV	IV	IV	IV	IV	IV	IV	IV	IV	IV
Available water capacity	IV	IV	IV	IV	IV	IV	IV	IV	IV	IV	IV	IV
Hydraulic conductivity	III	III	III	II	II	II		II	II		II	II
Albedo	III		II								I	I
USLE soils factor *K*				III	III	III	III	III	III	III	III	III
CROP.DAT												
Max. stomatal conductance	III	III	III	III	III	III	III	III	III	III	III	III
Maximum plant height	II			II								
Maximum rooting depth				II								
Maximum leaf area index	III	III	III	III	II	II	III	II	II	III	II	II
Optimal temperature	IV	IV	IV	IV			III	II	II	III	II	II
Base temperature	IV	IV	IV	IV	II	II	III		II	III		II

Reaction of the model: positive, negative; II—medium, III—high, IV—very high.

Table 4
Comparison of sensitivity calculated with different variation ranges

	Variant B (25%)						Variation 250%					
	Runoff			Surface runoff			Runoff			Surface runoff		
	Summer	Winter	Year	Summer	Winter	Year	Summer	Winter	Year	Summer	Winter	Year
∗.SOL—file												
Depth of bottom layer	II			IV	IV	IV	II		II	IV	IV	IV
Bulk density	II	II		IV	IV	IV	IV	IV	IV	IV	IV	IV
Available water capacity	III	II	II	IV	IV	IV	III	II	II	IV	IV	IV
Hydraulic conductivity				III	III	III	III	II	II	IV	IV	IV
Soil albedo	III	II	II	II			III	II	II	III		
USLE soils factor												
	Sediment yield			Nitrate			Sediment yield			Nitrate		
Depth of bottom layer	IV	IV	IV	IV	IV	IV	III	IV	IV	IV	IV	IV
Bulk density	IV	IV	IV	IV	IV	IV	IV	IV	IV	IV	III	IV
Available water capacity	IV	IV	IV	IV	IV	IV	IV	III	IV	IV	IV	IV
Hydraulic conductivity	II	III	II	III	III	III	IV	IV	IV	III	III	III
Soil albedo	II	II	II	III		II	III	II	III	III		
USLE soils factor *K*		III					III	IV	III			

other models, like simulator for water resources in rural basins (SWRBB; Williams et al., 1985), chemicals, runoff and erosion from agricultural management systems (CREAMS; Knisel, 1980), groundwater loading effects on agricultural management systems (GLEAMS; Loenard et al., 1987) and erosion-productivity impact calculator (EPIC; Williams et al., 1984) they can give an orientation for the work with other models using the same concepts.

As only one parameter was varied at a time respectively, interactions between parameters are not considered. This problem could be solved by performing a multiparameter or global sensitivity analysis, such as the Hornberger–Spear–Young method (Hornberger and Spear, 1981; Young, 1983). However this method is based on Monte-Carlo simulations, which use many different model runs with randomly chosen parameters sets. Parameter values are chosen from uniformly distributions spanning the feasible parameter range. The idea is to obtain a sample of model simulations from throughout the valid parameter space. Sensitivity is obtained by comparing the cumulative distributions of one parameter in each set. Sensitive parameters show strong differences between the distributions. A disadvantage of this is the computational effort, as the number of calculations to describe the parameter space is a power-function (Beven, 2001). However, we intended to support model users carrying out a calibration. As in most practical cases, this will also be done by varying only one parameter at a time as well, we decided to use this method.

The whole catchment is parameterised with only two soils and one land cover. Modifications of these parameters therefore affect the whole catchment. In a natural catchment, changes of single soils or land covers will affect only a small part of the catchment area. Therefore, the influence of soil and plant parameters may be overestimated. Inversely, the sensitivity of channel parameters and surface roughness is probably underestimated because of the small size of the catchment. In a larger and more heterogeneous natural catchment a compensation of effects through other effects can occur. This is avoided by the use of the artificial catchment, but it has to be kept in mind, that sensitivities can differ for a natural catchment.

Similar results and similar ranking into sensitive and less sensitive parameters are obtained with both methods. Furthermore, as the results are also affected by the employed catchment, the use of simple approaches seems to have advantages, as they are easier to perform.

Acknowledgements

This study has been supported by the Deutsche Forschungsgemeinschaft within the scope of the Collaborative Research Centre (SFB) 299.

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