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Interactive comment on "Improved calibration of Green-Ampt infiltration in the EROSION-2D/3D model using a rainfall-runoff experiment database" *by* Hana Beitlerová et al.

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Dear reviewer,

thank you for your worthwhile comments on our manuscript. We will reflect your recommendation on providing more background information on the infiltration module to the readers by adding relevant equations used in the EROSION-2D/3D model. The key parameters of the Green and Ampt infiltration module in EROSION-2D/3D, saturated hydraulic conductivity, unsaturated pore space and matric potential, are calculated internally based on pedotransfer equations (Ks Campbell, 1985, matric potential Van Genuchten, 1980, Vereecken et al., 1989, see references in the manuscript). The

model user is entering input parameters of the functions, which are clay, silt and sand content, bulk density, organic carbon content, initial soil moisture and the correction parameter of Ks, skinfactor. The model user cannot influence the Ks and matric potential calculation, as EROSION-2D/3D is closed source software. That is why we let interested readers get the background information from existing relevant literature and put focus directly to the skinfactor, its estimation and impact on the model results. However, we agree, that in the first submitted structure the paper is more interesting for EROSION-2D/3D users and important information is missing for readers facing gaps in mathematical description of infiltration process in general. Your suspicion that the water potential of dry soil is used as a proxy for the water potential at the wetting front is right - please see the full answer to this issue on your detailed comment (P15). We provide answers to your further detailed comments in this response and will restructure the paper based on your recommendations, including the background information and equations.

Answers to detailed comments:

R: Title: You cannot 'calibrate' infiltration. You calibrate a model or parameters of a model. I think you should make clear that you estimated a scaling factor of the saturated hydraulic conductivity, which was estimated with the Campbell equations.

A: Here we politely dare to disagree with your opinion. Green-Ampt is one of the broadly used infiltration models. We assume it is understandable from the title, that we calibrate a model, not the infiltration itself, however, we suggest to add the world module in the title to make it clear. We find that the title "Improved calibration of Green-Ampt infiltration module in the EROSION-2D/3D model using a rainfall-runoff experiment database" sufficiently expresses the content of this paper and more detailed information can be specified in the background section.

R: P3 ln 9: I do not understand the role of the matrix potential in this context and how the matrix potential can be estimated since it is not a static soil property. It is tempting to interpret the soil matrix potential in the dry soil as the matric potential at the wetting front. But this is an incorrect interpretation of the matrix potential at the wetting front. The matric potential at the wetting front is in fact independent of the antecedent soil moisture.

A: At this point we must again disagree. To quote Dingman Physical Hydrology (3rd edition, 2015, p. 371): "In general, the wetting-front suction ψ_f is a function of time, ponding depth, initial water content, and soil type." There might be situations in which an estimate of the matrix potential independent of initial (or antecedent) soil moisture is sufficient, but the independence is not a fact. So indeed EROSION-3D uses the initial soil moisture as input parameter in EROSION-2D/3D to estimate matric potential at the wetting front with the Van-Genuchten/Vereecken equations. We will provide the equations in the manuscript.

R: P3 ln 16: These are very strange units of the saturated conductivity. Normally saturated conductivity is expressed in m s-1.

A: The units are used by Campbell (1985), which is source of the calculations of Ks in EROSION-2D/3D model. According to Campbell (1985) an hydraulic conductivity of 1 kg * s /m^3 equals 9.8 * 10ˆ(-3) m/s (divided by water density and multiplied by the gravitational constant).

R: P3 ln 24: I am wondering how the skinfactor is derived from the infiltration rate at the end of the experiment. If the infiltration experiment lasts long enough, then the infiltration rate converges to the saturated hydraulic conductivity and the skinfactor can be derived directly from the infiltration. In fact, no Green Ampt infiltration model is needed then to derive the parameter. The authors should be more explicit on how they derived the skin factor from the infiltration rate at the end of the experiment. Did they use the Green Ampt infiltration model or not? How did they decide that the infiltration rate did not change over time anymore? Another question is how were the initial and saturated soil moisture content defined and what was the pressure at the wetting front?

A: The infiltration curve of each experiment was simulated by EROSION-3D. Skinfactor was iteratively adapted, until the simulated and measured end infiltration of the experiment matched. The two established methods of skinfactor derivation are shown in Fig. 1 - upper dashed line is simulated infiltration to match the end infiltration of the experiment, lower dashed line to match the cumulative runoff. We only assume that the infiltration rate did not change over time any more. The experiments of TUBAF last until a steady runoff rate is reached, which is decided by the knowledge of the experts in field. The dry experiments of RISWC last 30 minutes, in most cases measured curves look like the blue one in the picture, where steady state seams to be reached. Wet experiments last 15 minutes, steady state seems to be reached after first few minutes. Initial soil moisture was measured in field for each experiment. Saturated soil moisture is calculated by Vereecken, 1989 and pressure head at wetting front (matric potential) by Van Genuchten, 1980. We will provide the equations and references in the corrected manuscript.

R: P5, table 2: You used time of consolidation as a predictor variable. But, also relevant for consolidation is the cumulative precipitation after the last topsoil disturbance.

A: We are aware about this, however, information on cumulative rainfall is not available for the experiments. An experimental site is usually prepared in spring and experiments are performed during whole vegetation season. No rainfall gauge to collect rainfall is installed in case of used experiments. As given on P6 ln 2 time of consolidation was removed from the statistics, because of autocorrelation with vegetation cover, which is easier to obtain for the model users and is an input parameter of EROSION-3D model, so the model user must have the information about it anyway.

R: P6 ln 6: 'Dry soil leads to lower skinfactors than saturated soils' This comes a bit unexpected since no results have been shown yet.

A: We will work on the paper structure and move this to results or discussion.

R: P6 ln 8: 'While dry experiments represent the natural conditions of the soil cover, wet experiments represent the soil cover after rainfall and impacts from the destruction of soil aggregates and soil crust, loss of trapped air, or water repellence.' How is this related to the difference between the skin factors for dry and wet experiments?

A: Initial soil moisture and the version of experiment - dry and wet can be seen as the same variable by the readers, just once given as numerical and once as two-level categorical variable. Therefore we found important to explain, that the dry/wet express rather difference in state of the soil, than the difference in the wettnes itself. If the mentioned features - soil crust, trapped air, water repellency, are developed in the soil, the infiltration can be decreased significantly. However, none of the feature is considered in the infiltration module. It can play a role in the result of our analysis, that infiltration in dry soils is overestimated by the model and why skinfactors of dry soils are smaller than for wet runs.

R: P6 ln 10: 'The crop type and soil texture group also have an impact on the skinfactor, but only on the inter-level stage.' What is inter-level stage?

A: It means, that overall the predictor has no significant impact on skinfactor, but significant difference can be found between some of the variable levels (categories). We will reformulate the part to be more clear.

R: P6 ln 25: You must explain which variables are used in the 'Parameter Catalogue'. This catalogue is probably not known to many readers.

A: Table 4 contains the list of variables, we give a reference to the table here or will add the missing information directly in the text.

R: P6 ln 33: Explain what you mean with 'environmental sensitivity'.

A: This is what the "manually controlled“ backward elimination means. There are automatic model selection methods, however, the algorithms behind these methods do not know the studied processes. The variable selection can be correct mathematically and statistically, but it can be nonsense from the environmental point of view. Therefore we were deciding manually which variables are removed from the model, not only based on the significance and AIC, but also based on our knowledge of the infiltration process. The expression "environmental sensitivity“ is confusing and we reformulate it.

R: P6 ln 34: You must give more information about how STEP1 was simplified and what the difference is between STEP2 and STEP3.

A: In this section we describe methodology. Our intention is to give the best model STEP1 and then more simple models to be easier to use for the model users, but at this point we do not know how they look like. The final selected models are given in table 4 in results. We will formulate the methods section more clearly and give more space to the model description in the results.

R: P6 ln 14: Is there actually a difference between RSR and the square root of the coefficient of determination?

A: R2 describes the proportion of the variance in measured data explained by the model. RSR is calculated as the ratio of the RMSE and standard deviation of measured data. Root square of R2 is not equal to RSR.

R: P7 ln 16: Give information about the location of the site.

A: We will add the location in the revised paper.

R: P12 Figure 3 and 4: It is not clear to me whether the runoff volumes and sediment 'volumes' were measured or were predicted using the experimentally derived skin factors. I think the latter is the case. What are 'sediment volumes' and why are they expressed in tons? That is not a volume unit.

A: They were simulated with the experimentally derived skinfactors as written in the title of the figures. You are right regarding the units. We correct it to sediment mass.

R: P12: 'skinfactor corrected by -MAPE to increase the infiltration rate, produced no runoff'. I did not understand this. If you add a negative number, then the skinfactor decreases and shouldn't the infiltration rate then decrease and more runoff be produced?

A: MAPE was calculated for ln(skinfactor), which has negative numbers for skinfactor<1. Therefore -MAPE correction leads to less negative numbers of ln(skinfactor), which result in higher skinfactor and thus lower surface runoff.

R: P13 ln 10: How did you decide that the dataset provided sufficient data?

A: We did not test any hard criterion to decide, but followed the basic statistical principles. There is many times higher amount of experiments than independent variables, skinfactor (log) has near normal distribution, same as most of numerical variables follow near normal or other expected distribution, categorical data were recategorized to avoid under-represented categories. Rainfall experiments data in general are of limited amount and presented calibration process requires input parameters, which are usually not all measured. Bigger open datasets exist, but all we examined did not have complete set of measured parameters for our purposes. This dataset contains more than twice more experiments, than the original dataset used in previous studies.

R: P15: 'An alternative explanation is the misfit of the empirical estimation functions for the saturated hydraulic conductivity and matrix potential. The experimental basis behind Campbell's model is unknown (Campbell, 1985). The equations for the matrix potential estimation are based on the measurements of 40 important Belgian soil series.' I suppose that the matrix potential was calculated from the initial soil moisture content using the water retention curve and that the parameters of the water retention curve were derived from other soil information using pedotransfer functions. But it is not clear to me how this matrix potential was afterwards used in the Green-Ampt infiltration model.

A: Indeed the algorithms of EROSION-3D follow the tempting approach to use soil matric potential. For a better understanding of the infiltration algorithms implemented in the model the equations will be added to the revised paper.

R: It is incorrect to assume that this is the water potential at the wetting front, hf. hf is related to the sorptivity of the soil, Ks, and the difference between the saturated and initial water content. The sorptivity of the soil depends on the water potential of the dry soil but only very weak. The sorptivity is the integral of the weighted unsaturated conductivity between the water potential of the dry soil and the pressure head at the soil surface (which is 0 in case of saturation). Since the unsaturated hydraulic conductivity decreases so strongly with more negative matrix heads, this integral is not very sensitive to the lower boundary of this integral (the matrix potential in the dry soil). As a consequence, the sorptivity and hf are not very sensitive to the matrix potential of the dry soil. Furthermore, hf varies from a few cm to about -30 cm in clayey soils. This is of course much less negative then the matrix potentials in dry soils. As a consequence, using the matrix potential of the dry soil as hf will lead to a strong underestimation of the pressure head at the wetting front and a strong overestimation of the infiltration that is driven by capillarity. In order to compensate for this overestimation of infiltration, the saturated conductivity must be reduced to match the measured infiltration rates. This may be the reason why the skin factors are reduced when the initial soil moisture content is lower.

A: We totally agree that the reduced skinfactor values may be caused by improper use of the hydraulic conductivity and the matric potential. While the matric potential in EROSION-3D is dependent on soil moisture of dry soil, the hydraulic conductivity equals the saturated hydraulic conductivity without reduction with decreasing soil moisture. The skinfactor therefore compensates for this feature of the infiltration module of EROSION-3D. Unfortunately we are not able to address this issue by changing implemented algorithms, as EROSION-3D is a closed source tool maintained by a third party, but we will make a request with the developers to improve the implementation at this point. By a quick check of two other modelling tools for soil erosion, it seems that there are many different ways to implement the Green-Ampt infiltration approach. OpenLisem follows a comparable approach to EROSION-3D using saturated hydraulic conductivity, but allows wetting front suction as direct input parameter (https://blog.utwente.nl/lisem/basic-theory/infiltration/). SWAT uses a CN-factor and saturated conductivity to estimate effective hydraulic conductivity and wetting front matric potential is a function of porosity, percent sand and percent clay (https://swat.tamu.edu/media/99192/swat2009-theory.pdf, p.108). From this we think that the outcomes of each infiltration model should be checked carefully and wherever possible should be validated. For the revised paper we will add a paragraph to the discussion section addressing this issue.

R: P15 ln 37: ‘This method reduces the number of experiments’ Do you mean: the number of parameters?

A: In the previous studies, the whole dataset with experiments was split into smaller subsets based on manual decision. Regression equations to predict skinfactors were calculated based on low number of experiments in each subset.

R: P 15 ln 38: ‘Previous studies determined different dependencies for the prediction parameters (e.g., the intercept of soil moisture) on each single subset, whereas this study assumed an equal dependency on each parameter for the entire dataset.’ But in the STEP1 model, you considered interactions between the categorical and continuous predictors.

A: You are right, we will correct it. The difference is, that in previous studies only categorical predictors were included in the analysis. Experiments were grouped into various subsets based on categories of different predictors and relationships between skinfactor and the predictors were searched within the subset. The interactions (subsets) were predefined by the authors without checking for its statistical reliability. In our approach, continuous and categorical predictors were put together, one initial complex model was applied on the whole dataset, including interactions between continuous and categorical predictors and the best model was then selected by a selection procedure. Only significant predictors and their interactions are included in the STEP1 model.

R: P 16 ln 17: ‘Other significant predictors of soil texture’ You do not predict soil texture but you use soil texture as a predictor. ‘Other significant predictors such as soil texture’

A: Yes, thank you.

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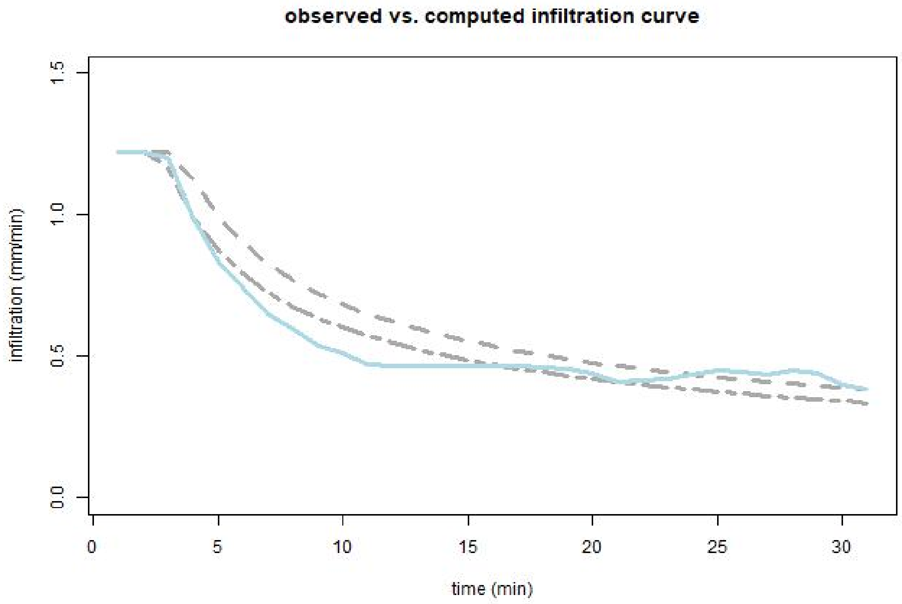

Fig. 1. An example of measured (blue) and modeled infiltration curves to match the end infiltration (upper dashed) and cumulative runoff (lower dashed)