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Supplement of

Impact of modellers' decisions on hydrological a priori predictions

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Supplementary material (A)

Here we describe the features of the ten models and document the underlying assumptions and parameterisation used for the three consecutive predictions. The change of prediction quality induced by modifying some assumptions and parameters is rated with the Root Mean Square Error (RMSE) and the Nash-Sutcliffe Efficiency Index (Eq. 1 and 2). Note that we present two of each error estimates for the first year, one based on a reduced record excluding the extreme snow melt event of January 27, 2006 (abbreviated with w/o SME) and one using the entire record. For the two following years the entire record was used and hence only one error estimate is presented,

A-1 Catflow

- *Model user*

  T. Blume (GFZ German Research Centre for Geosciences, Potsdam)

- *Basic model features*

  Physically-based model with detailed process representation, e.g. soil-water dynamic based on Richards equation, evapotranspiration on Penman-Monteith equation and surface runoff on convection-diffusion equation. The model allows simulation of infiltration excess runoff, surface saturation, lateral subsurface flow, reinfiltration of surface runoff, and return flow (Maurer, 1997).

- *Assumptions and parameters (1st prediction)*

  Basic assumption: Best representation of catchment properties yields best prediction.

  Main attempt was to minimize the influence of the modeller's choices. No decision on dominant process(es) using the model primarily as a platform for hypothesis testing. Soil properties were derived from Carsel and Parrish (1988) (K_{sat} = 146 mm/h for sand and K_{sat} = 13 mm/h for sandy clay loam). Soil crusts were considered to be dominant but not included into the model assuming that only the provided data set should be used.

- *Assumptions and parameters (2nd prediction)*

  Introduction of the crust layer (K_{sat} = 0.6 mm/h according to Simunek et al. (1998)) to allow infiltration excess. K_{sat} was reduced to limit subsurface flow. Modifying the lower boundary condition to better represent the influence of the clay dam.

- *Assumptions and parameters (3rd prediction)*

  The spatial resolution of the model grid (upper slope 10 m, middle slope 5 m and lower slope 1 m resolution) was changed to 5 m in order to reduce the numerical problems caused by the implementation of the surface crust. Soil crust (5 cm) was resolved with vertical increments of 1 cm (before: top 20 cm with 4 cm resolution). This resulted in an 18% reduction of the total number of nodes.

Only the soil hydraulic data and the infiltration rates were selected. The virtual costs were the second lowest of all modellers. These data were used to parameterize the soil and the soil crust.

- *Results*

In the 1^{st} and 3^{rd} prediction, Catflow discharge was among the largest of all models (e.g., 262 mm/y and 255 mm/y in 2006/2007) mainly due to the large base flow of 20 to 25 m^3/d. Due to numerical problems Catflow's 2^{nd} prediction is missing.

For the first two years the model performance improved from the 1^{st} to the 3^{rd} prediction (Fig A-1a and A-1b). Neglecting the snowmelt event (SME) discharge was simulated for nearly all years with a similar prediction uncertainty. Q_{90} (77 m^3/d, 3^{rd} prediction stage) was the second largest of all events and Q_5 was >20 m^3/d. Therefore, the base flow was very high compared to surface runoff, which was the lowest relative runoff of all models (<1% in the 1^{st} year to 25% in the 3^{rd} year). The initial conditions used a higher groundwater table than the observed one and reaches complete water saturation of the whole aquifer early in 2008 (Supplementary Material (E)).

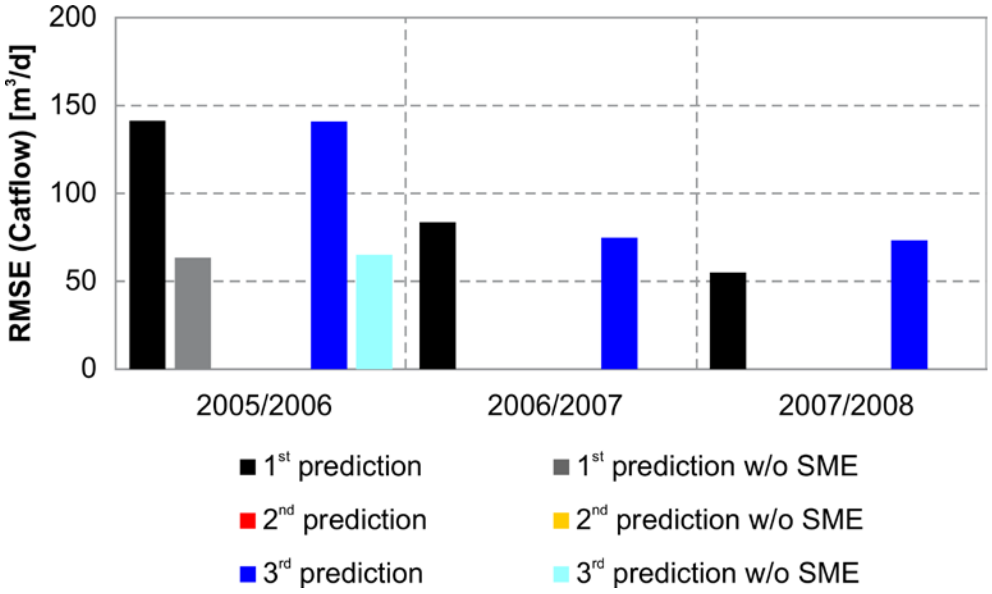


Fig. A-1a: RMSE for all predictions of Catflow

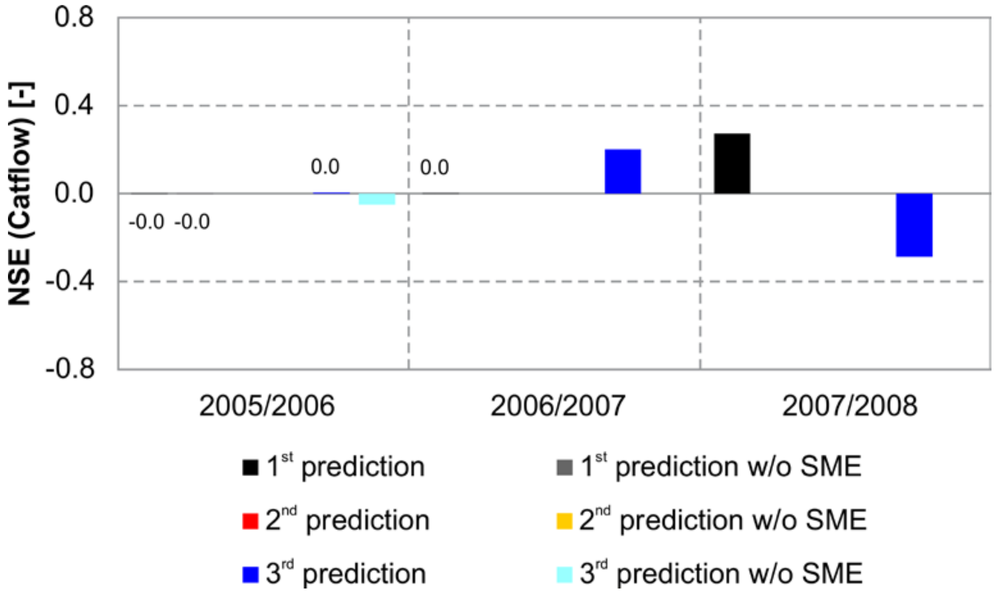


Fig. A-1b: NSE for all predictions of Catflow

A-2 CMF

- *Model user*

P. Kraft (University of Giessen)

- *Basic model features*

Distributed hydrological model that calculates infiltration and unsaturated percolation using Richards equation and the lateral saturated flow using Darcy's law. Infiltration excess is routed to the stream network (Kraft et al., 2008).

- *Assumptions and parameters (1st prediction)*

Opposite to the other models CMF was developed by the user himself using an irregular grid. The modeller intended to evaluate how CMF performs in a region where the model was not used before. His initial parameterization followed a traditional procedure, e.g. using average soil properties derived from texture data (K_{sat} = 416.7 mm/h, AG Boden (1994)) and not considering soil freezing on K_{sat}.

- *Assumptions and parameters (2nd prediction)*

Although the field visit showed the importance of surface runoff due to the deep gullies, the soil crust (to reduce infiltration) could not be implemented due to the model structure. However, the modeller expected that water exfiltrates through preferential flow pathways into the gullies even when the topsoil was still unsaturated. This substantially increased surface runoff through the gullies. In order to more realistically represent the newly constructed catchment, the modeller changed the initial state to quasi-dry conditions (pF

2.5). K_{sat} was reduced to 60 ± 30 mm/h to diminish the large discharge. Finally, the leaf area index (LAI) was set to 1.

- *Assumptions and parameters (3rd prediction)*

After 2nd stage prediction the CMF modeller completed his PhD-program and left the modelling group.

- *Results*

In the 1st prediction stage, the modeller reported one of the largest annual discharge (~220 mm/y), a peak discharge of 461 m^3/d, and a Q_5 of 20 m^3/d. In 2nd prediction peak discharge was only 43 m^3/d, one of the lowest of all models (e.g. 109 mm/y in the 2006/2007). The Q_5 of about 1 m^3/d shows that the predicted slow flow components were low compared to the other models. PET prediction was also lowest (2nd prediction, 443 mm/y in 2005/2006) while most of the other models predicted 600 to 800 mm/y. Since CMF predicted the largest AET/PET ratio of all models (60 to 80%), the AET was average. However, both statistical measures show a decrease in prediction quality from the 1st to the 2nd prediction.

The groundwater module of CMF was not responding to drying periods so that the simulated groundwater table was since spring 2008 in a quasi-steady state at a depth of ~30 cm.

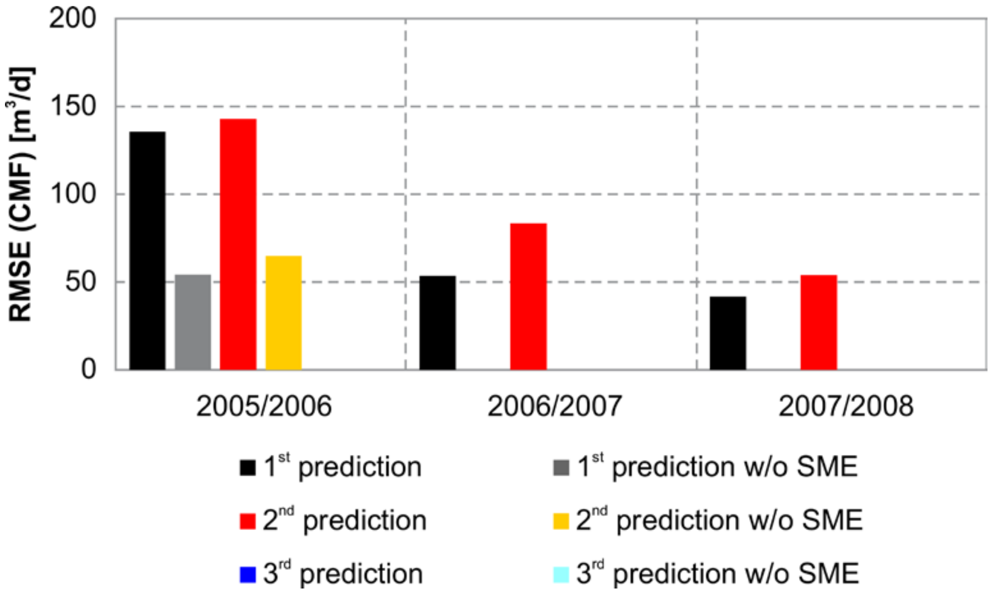


Fig. A-2a: RMSE for all prediction of CMF

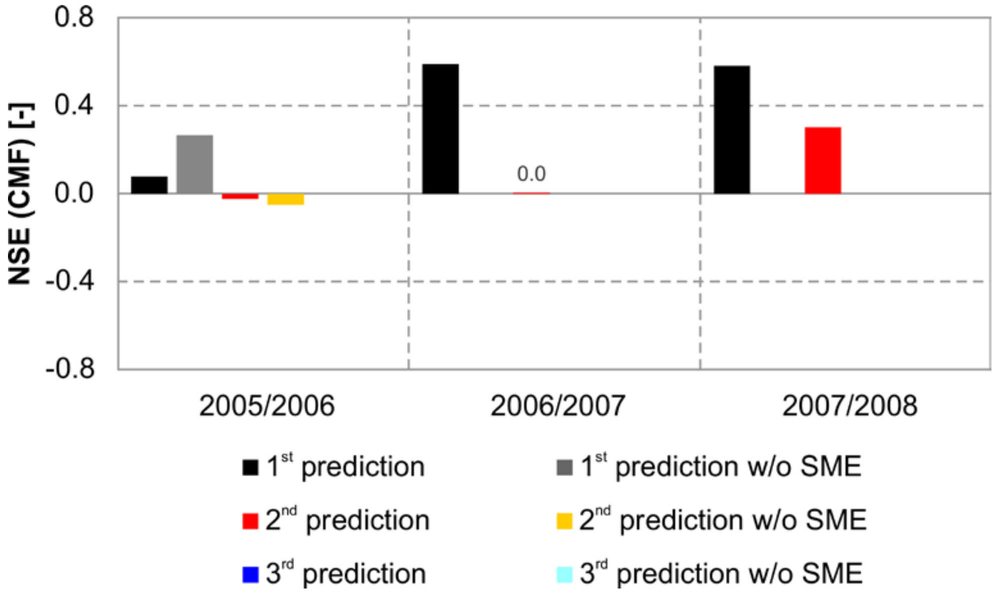


Fig. A-2b: NSE for all prediction of CMF

A-3 CoupModel

- *Model user*

D. Gustafsson (Royal Institute of Technology KTH, Stockholm)

- *Basic model features*

Physically based model which represents the soil-water dynamic based on Richards equation. Lateral fluxes are considered as drainage to the downstream column. Model accounts for soil freezing, including effects on the thermal and hydraulic conductivity (Jansson and Moon, 2001).

- *Assumptions and parameters (1st prediction)*

Average soil properties were derived from texture data (K_{sat} = 84 mm/h, Lundmark and Jansson (2009)) since the sandy soil was assumed to be homogeneous. Soil and snow evaporation are considered to be important.

- *Assumptions and parameters (2nd prediction)*

The different development of the vegetation in the western and eastern half of the catchment resulted in a different parameterizations. The modeller assumed dry initial condition and reduced K_{sat} to slow downstream subsurface flow.

- *Assumptions and parameters (3rd prediction)*

After 2nd stage prediction the CoupModel modeller left the modelling group due to time constraints.

- *Results*

The model predicted the lowest annual discharges in the 1st prediction stage with less than 15 mm/y base flow and 60 mm/y of surface run-off. CoupModel was the only model, which included snow melt. However, the discharge during the SME was strongly under-predicted. Neglecting the SME resulted therefore in a lower RMSE (Fig. A-3a).

Although the discharge was increased to an average of 145 mm/y the RMSE and the NSE do not show a significant change (Fig. A-3a and A-3b). While the peak discharge decreased slightly from 77 m^3/d to 65 m^3/d from the 1st to 2nd prediction, the slower flow events increased (e.g. Q_{25} = 1 m^3/d in the 1st prediction and Q_{25} = 11 m^3/d in the 2nd prediction). Still, the model predicted also 2% of all events with zero discharge. The CoupModel used a too small storage coefficient and predicted too small groundwater table fluctuations (Supplementary Material (D)).

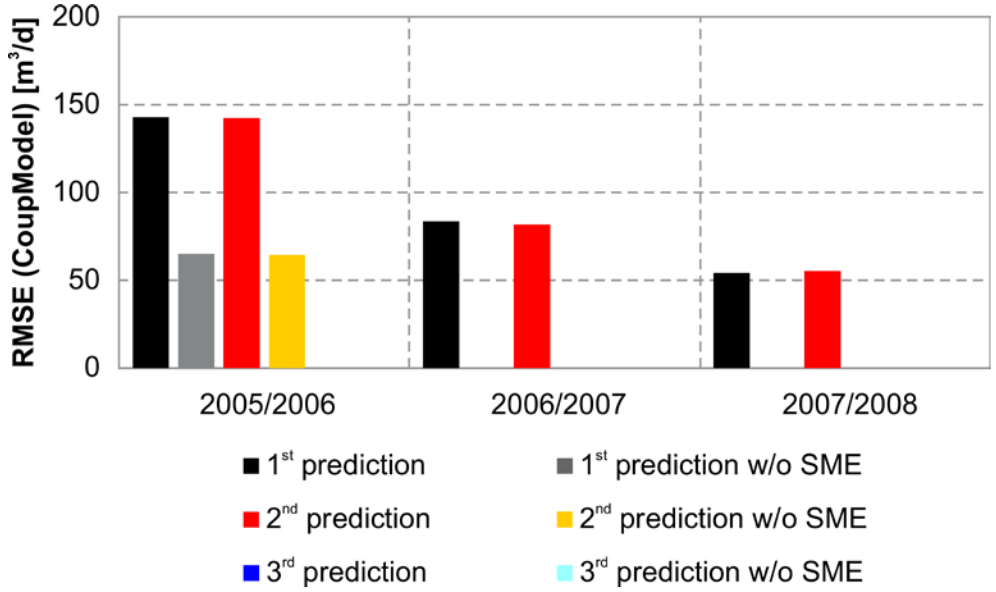


Fig. A-3a: RMSE for all prediction of CoupModel

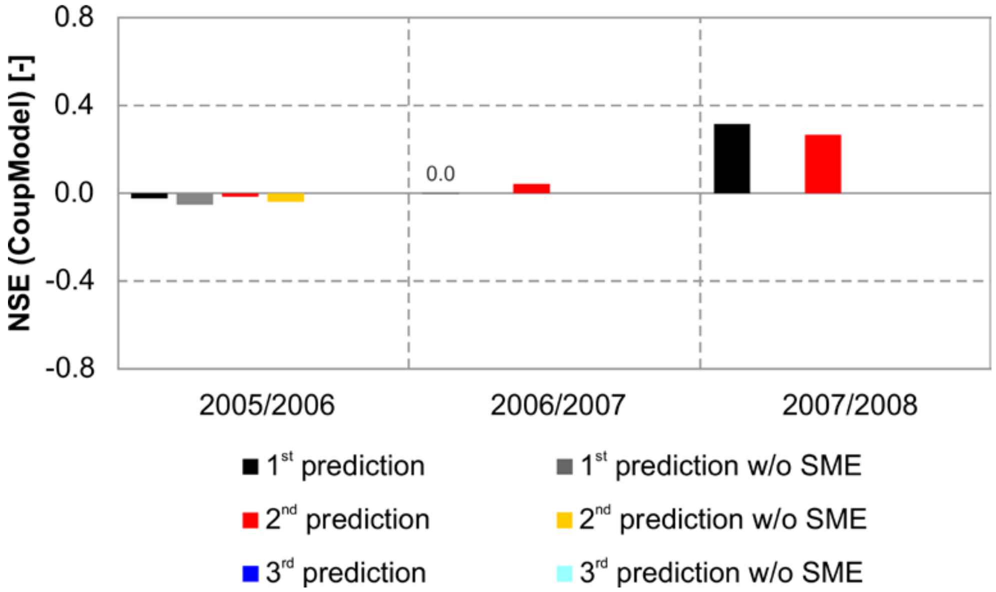


Fig. A-3b: NSE for all prediction of CoupModel

A-4 MIKE SHE / Hill-Vi

- *Model user*

  S. Stoll (University of Freiburg / ETH Zurich)

  Using Hill-Vi for the 1st prediction and MIKE SHE for the 2nd and 3rd prediction

- *Basic model features*

  Hill-Vi: explicit grid cell approach, parameterised based on van Genuchten (1980) for unsaturated and on Dupuit-Forchheimer for saturated storage compartments (Weiler and McDonnell, 2004).

  MIKE SHE: fully coupled, physically-based groundwater – surface water model

- *Assumptions and parameters (1st prediction)*

  Initial model focused on the question how the model performs in a region where it has not been used before.

  Employing pedotransfer functions (PTF) for assessing soil hydraulic properties (mean K_{sat} = 210.6 mm/h, Schaap et al. (2001)). Snow and frost not considered. Initial conditions generated by warm-up runs.

- *Assumptions and parameters (2nd prediction)*

  The field visit made the user aware of deep gullies and different vegetation cover in the western and eastern half of the catchment.

  The original model could neither adequately describe the actual evapotranspiration (AET), soil crusting, nor the clay dam effects on the groundwater dynamics. Therefore, the modeller switched to using MIKE SHE, redefined the initial conditions, and made small changes to reduce AET and PET (potential evapotranspiration). The soil hydraulic properties stayed constant.

- *Assumptions and parameters (3rd prediction)*

Soil crust newly parameterized using information which was later published by Gerwin et al. (2011) and Mazur et al. (2011) and PET adjusted by increasing the vegetation cover.

All soil hydraulic data were selected, but none of the others. This resulted in the lowest virtual costs of all modellers.

- *Results*

The results calculated by Hill-Vi (1st prediction) suffered from overestimating interflow and base flow, which were reduced from about 360 mm/y (1st prediction) to 40 mm/y (2nd prediction) by modifying PET and adding a soil crust. This improved the predictions significantly decreasing RMSE (Fig. A-4a) and increasing NSE accordingly (Fig. A-4b). Excluding the snow melt event (SME) early in 2006 reduced the errors massively because neither Hill-Vi nor MIKE SHE could handle snow melt. This resulted in nearly similar RMSE values compared to the other years. The additional data provided for the 3rd prediction primarily reduced the slow flow components to about 15 mm/y and therefore improved the prediction quality. Slow flow dominated the flow regime in this catchment.

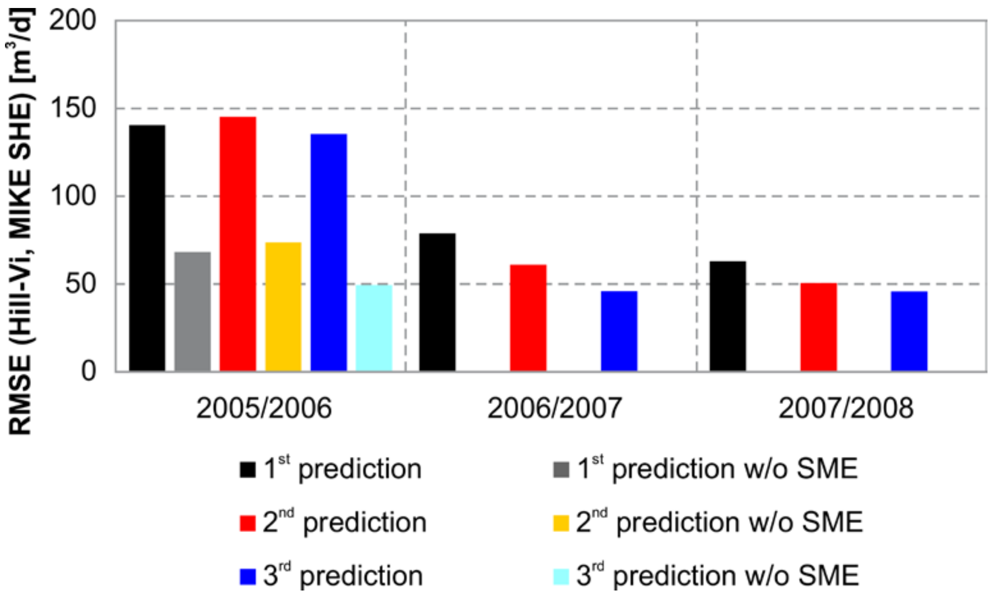


Fig. A-4a: RMSE for all prediction of Hill-Vi/MIKE SHE

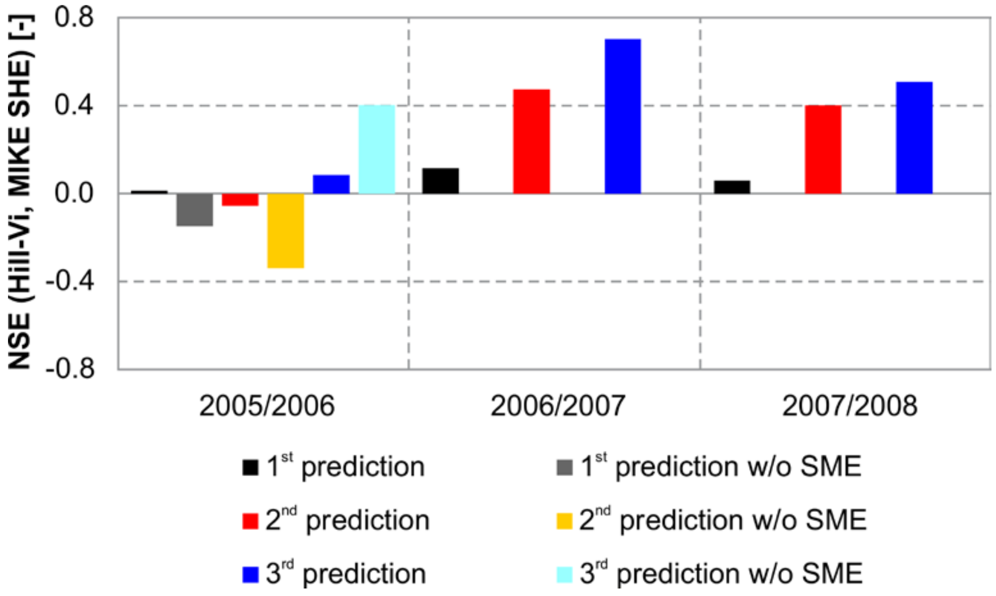


Fig. A-4b: NSE for all prediction of Hill-Vi/MIKE SHE

A-5 NetThales

- *Model user*

G.B. Chirico (University of Naples)

- *Basic model features*

Rainfall infiltrates completely into the soil except when the soil column is entirely saturated. Vertical distribution of soil water within the soil column is not simulated. Lateral and subsurface flows are both calculated one-dimensionally (Chirico et al., 2003).

- *Assumptions and parameters (1st prediction)*

Modeller tried to match the annual water balance with that of other catchments having a similar rainfall regime.

Unsaturated zone was not simulated (model limitations). The soil properties were assumed uniform along the of a soil column. Hydraulic parameters were derived from texture data using PTF (K_{sat} = 50 mm/h, Rawls and Brakensiek (1985)). Initial soil moisture and groundwater levels were assumed to be uniformly distributed throughout the catchment.

- *Assumptions and parameters (2nd prediction)*

The initial state was changed from pre-wetted to quasi-dry. K_{sat} was reduced to slow down discharge and the influence of the clay dam was increased.

- *Assumptions and parameters (3rd prediction)*

Modeller realised that the model is not suitably structured for an efficient description of the groundwater dynamics, particularly in the initial stage of the emerging groundwater table and the clay dam required a spatial structure of the subsurface compartment. Changing the model structure (introducing soil freezing, implementing a soil crust having a hydraulic conductivity of 3 mm/h, and changing K_{sat} to 100 mm/h) caused substantial costs (time) without a significant reduction of the prediction uncertainty due to the uncertainty in the model parameterisation based on the apparently still insufficient data set.

As a result, the modeller tried to obtain the best fit with the best set of the available data thereby using all additional soil data including the actual measurements were selected (average cost compared to other modellers' choices).

- *Results*

During the 1st prediction stage, the slow flow components were too prominent because the model structure allows infiltration until the soil is completely saturated. The high hydraulic conductivity allowed the groundwater to drain rapidly. The changes in parameterization resulted in higher peak flow (287 m^3/d) and little slow flow (e.g. 8% of all days show zero discharge). However, this did not reduce the RMSE (Fig. A-5a) compared to the 1st prediction state. Similarly, the NSE was lowered significantly so that the NSE for all years is even below zero for the 2nd prediction (Fig. A-5b).

Making use of the additional soil data increased discharge more than in all other models (+88 mm/y) and also produced the largest peak discharge (1481 m^3/d) exceeding by far the largest observed value (27th May 2007: 897 m^3/d). Introducing a soil crust reduced the infiltration. This resulted in slower flow events (<75% of all events had a discharge of less than 1 m^3/d). This was the main cause why the RMSE slightly decreased and the NSE increased between the 2nd and 3rd prediction stage (Fig. A-5a). Only the NetThales modeller addressed soil freezing in the 3rd prediction, which improved the predictions for the first hydrological. However, excluding the SME period still results in a better RMSE (Fig. A-5a).

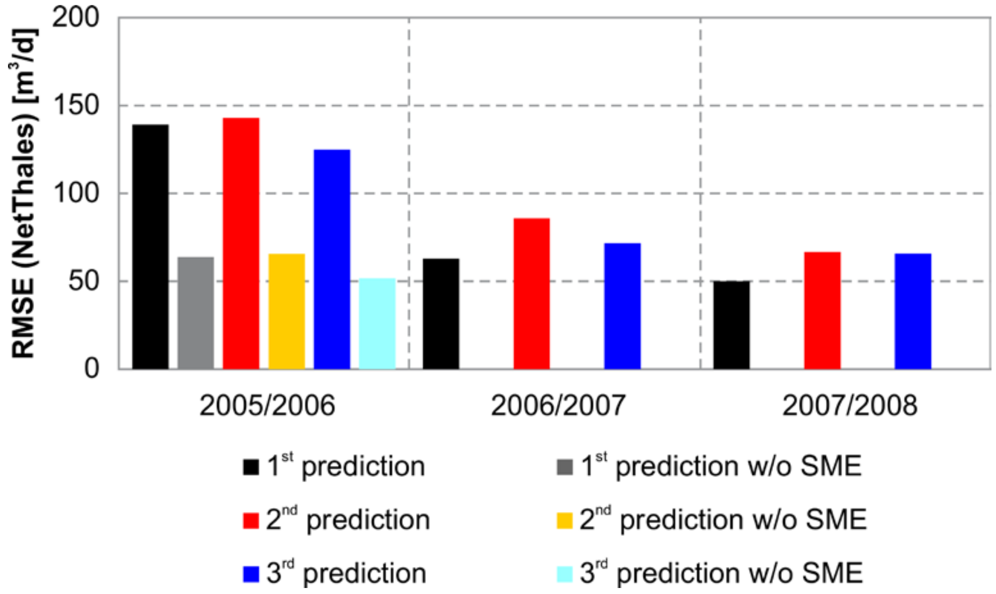


Fig. A-5a: RMSE for all prediction of NetThales

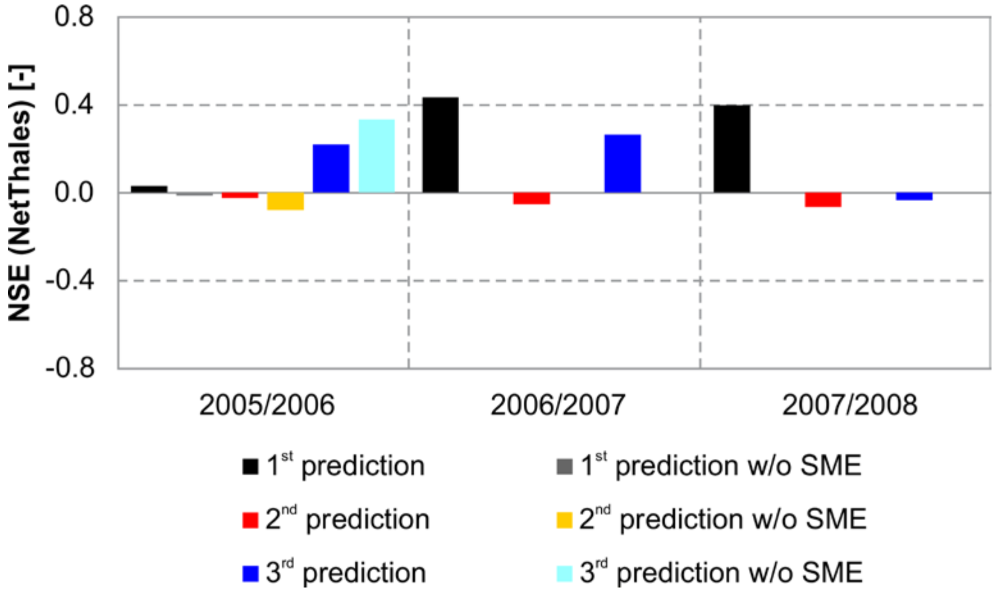


Fig. A-5b: NSE for all prediction of NetThales

A-6 SIMULAT

- *Model user*

H. Bormann (University of Oldenburg, now: University of Siegen)

- *Basic model features*

Physically-based SVAT model (Soil Vegetation Atmosphere Transfer) which solves the Richards equation to estimate infiltration and soil-water fluxes, lateral groundwater flow is addressed by concentration time, and surface runoff is calculated by a semi-analytical solution of the Richards equation (Diekkrüger and Arning, 1995; Bormann, 2008). Evapotranspiration is calculated according to the Penman-Monteith approach.

- *Assumptions and parameters (1st prediction)*

The modeller wanted to minimize the influence of the modeller's choice and did not decide a priori on the dominant process(es) based on his experience from previous studies where the model produced reliable results without prior calibration (Bormann et al., 1999).

The modeller used the pedotransfer function according to Rawls and Brakensiek (1985) to derive soil hydraulic parameters. A national soil data-base (Adhoc AG Boden, 2005) was used to estimate bulk density. These assumptions resulted in a mean K_{sat} of 60.8 mm/h while spatially distributed soil parameters were used for the modelling study (25 m grid). The model started with unsaturated conditions but allowed for partial saturation in case of storage based lower boundary condition. Additionally, the modeller implemented the dynamics of the lake at the catchment outlet.

- *Assumptions and parameters (2nd prediction)*

The modeller assumed a shallow soil layer above the dam. After field visit he considered soil crusts as the major cause for the observed soil erosion. Since the modeller visited the catchment in spring, he noticed the fast development of the vegetation.

He used K_{sat} = 2.1 mm/h taken from Hölzel et al. (2011). To account for catchment heterogeneity he used information on spatial variability of K_{sat} with a standard deviation of σ_{Ksat} = 62.5 mm/h as given by Cosby et al. (1984). The user increased the LAI to > 1 for the year 2008 at selected grid points.

He changed the lower boundary condition of the individual soil columns to a linear storage based boundary condition a solution possible due to the 1-dimensional nature of this model. This accounts for the steadily rising groundwater level and it enhanced the damming effect of the subsurface V-shaped clay dam. Finally, the modeller changed the volume of the already implemented lake to match the volume at the spillway. The detailed description of parameterisation of the 2nd stage prediction of SIMULAT can be found in Bormann (2011).

- *Assumptions and parameters (3rd prediction)*

The modeller noticed that the modelled results still varied significantly among the various models. The simulated water balance was consistently wrong, changes in evapotranspiration parameterisation did not seem to be appropriate, and the subsurface storage needed to be better adapted. As a result, the modeller updated the variability in surface K_{sat} and the lower boundary condition of the soil columns once more in order to better describe the infiltration as well as subsurface storage (Bormann, 2011). Additionally, the initial condition was re-defined as dry soil.

The modeller chose the data based on its usefulness for complementing the model set-up. This resulted in the 2nd highest virtual costs. The additional soil physical data were used to confirm the magnitude of the soil hydraulic parameters in the preceding simulations. The data from the infiltration experiments were used to improve the description of the hydraulic properties of the surface layer. The field data were complemented by literature values to parameterise the spatial variability of K_{sat} (Cosby et al., 1984). Finally, the modeller used soil moisture in two steps. First, he evaluated his model with these data and, in a 2nd step, he used them to calibrate the model by adjusting the lower boundary conditions of the soil columns (Bormann, 2011). This resulted in a hydraulic conductivity of the soil crust of 11.6 mm/h. Although the modeller opted for using the vegetation data, he did not use them after reviewing these data.

- *Results*

The 1st predictions suffered by too much discharge, twice the observed value. More or less all discharge was considered to be base flow.

The base flow was then effectively reduced to about 20% of the total discharge, which was the lowest of all models (157 mm/y) in the 2nd prediction. Since interflow was negligible, about 80% was primarily surface runoff. Although SIMULAT predicted zero discharge for many days, it rose rapidly and produced the largest peak discharge of all models (1433 m^3/d in the 2nd year). SIMULAT predicted primarily surface runoff (~ 80%) and negligible interflow. However, like all other predictions with peak discharge of >400 m^3/d, the discharge between Q_{100} and Q_{95} went down by nearly two orders of magnitude. Due to reduction of the vegetation cover AET was lowered considerably and was the lowest of all models (157, 266 and 260 mm/y for the 1st, 2nd, and 3rd year, respectively).

PET simulated for 2006/2007 did not change from the 2nd to the 3rd prediction. SIMULAT predicted in two of the three years the largest discharge (e.g. 291 mm/y in 2006/2007) and an average increase of discharge by 21 mm/y. This was a consequence of using the soil data. SIMULAT generated little surface runoff (22%) and mainly subsurface runoff and therefore the opposite of what it simulated in the 2nd prediction. This resulted in the lowest peak discharge (106 m^3/d) of all models (Supplementary Material (C)). This is a reduction by >90% compared to the 2nd prediction

The prediction quality for the 1st year did not improve but for the two following years it did (Fig. A-6a). The prediction quality from the 2nd to 3rd prediction shows no significant change. Similar results are also shown by NSE (Fig. A-6b).

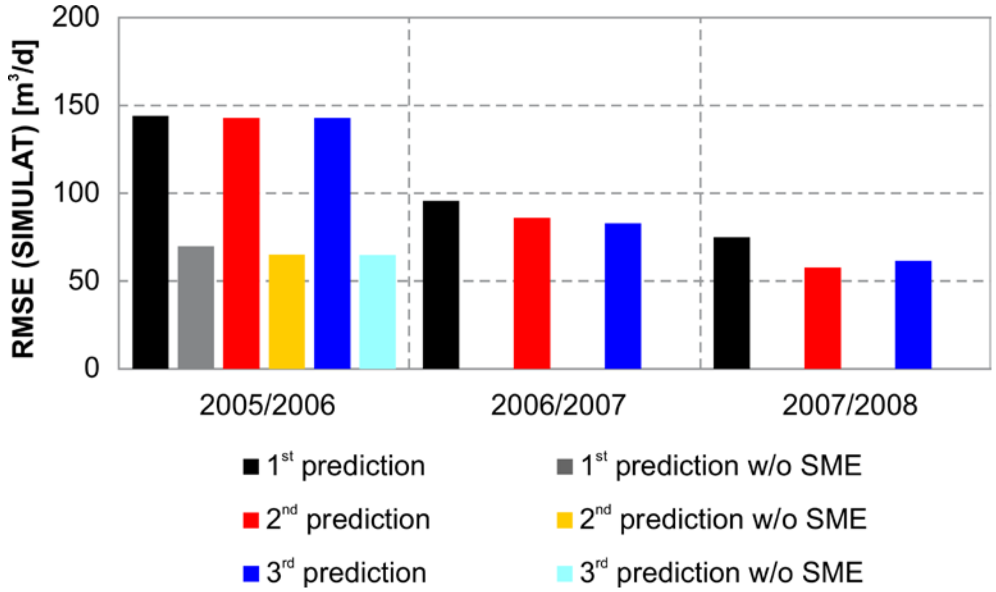


Fig. A-6a: RMSE for all prediction of SIMULAT

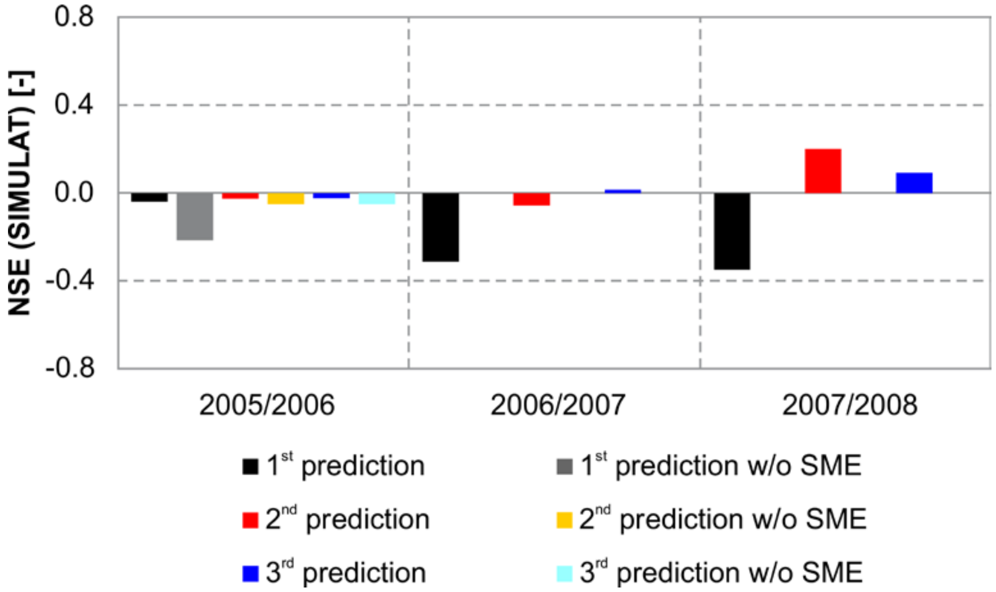


Fig. A-6b: NSE for all prediction of SIMULAT

A-7 SWAT

- *Model user*

J.-F. Exbrayat (University of Giessen, now: University of Edinburgh)

- *Basic model features*

Physically-based semi-distributed model which divides each sub-catchment into Hydrological Response Units. Lateral flow is calculated by the drainage equation, infiltration d by SCS (Soil Conservation Service) curve number method, and the soil-water fluxes are integrated as a bucket model depending on the soil-water content and other soil properties (Arnold et al., 1998). SWAT simulates plant growth and its effects on the water balance based on the EPIC model.

- *Assumptions and parameters (1st prediction)*

Assumptions made in SWAT make it more adapted to simulate mesoscale catchments. Although it cannot be considered a perfect pick for small catchments, applications of SWAT range from hill slope case studies to large basins such as the Mississippi River. The modeller therefore intended to further test its performance for small catchments. He minimized the influence of the modeller's decision and used default values available from the SWAT user manual. The modeller employed PTF (mean K_{sat} = 74.5 mm/h, Rawls and Brakensiek (1985)) for assessing soil hydraulic properties with a cluster analyses to check the soil homogeneity assumption. The dynamics of the lake at the catchment outlet was implemented with a total volume estimated from the DEM.

- *Assumptions and parameters (2nd prediction)*

The user became aware of the deep gullies during the on-site inspection of the catchment. Soil crusting is not included into the model. Ksat stayed constant but he tried to account for a larger surface runoff by allowing reinfiltration from gullies. The modeller removed the warm-up period completely so that the initial state was changed from pre-wetted to quasi-dry conditions. Finally, the modeller changed the volume of the already implemented lake to the actual value provided during the first workshop.

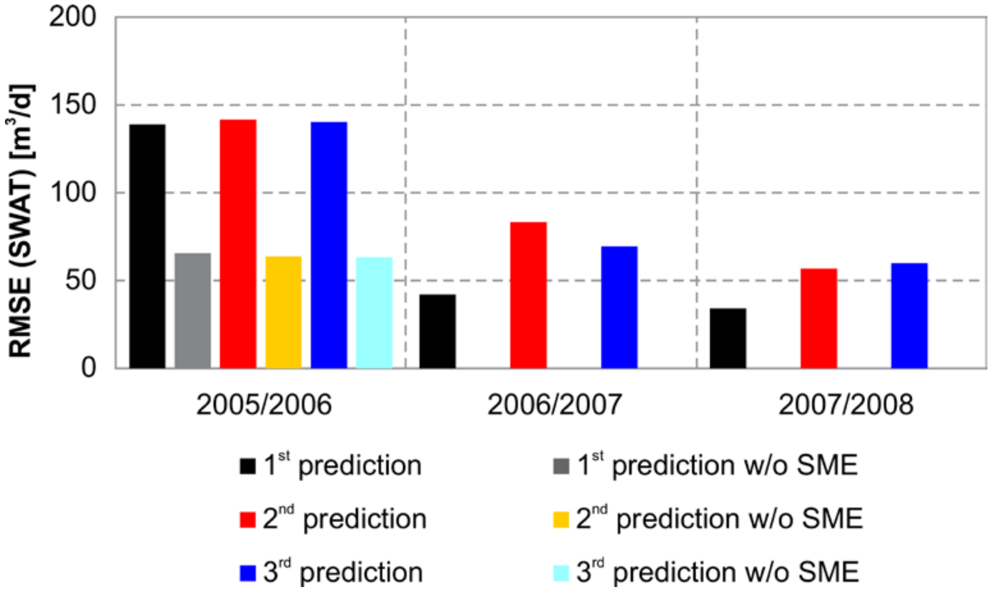
- *Assumptions and parameters (3rd prediction)*

The modeller kept the model setup as used for the 2nd prediction, but corrected some parameter values based on the provided dataset that may affect both physical and plant processes (e.g. the organic carbon content). The modeller selected all soil hydraulic parameters except the water retention curves. By choosing the weather and the vegetation date, the modeller came up with the highest virtual costs (32,540 Euro). The vegetation data were then used to parameterize the prevalent plant species (*Trifolium arvense*) in terms of max. LAI, rooting depth, and stomatal conductance based on literature values from the PlaPaDa database (Breuer et al., 2003).

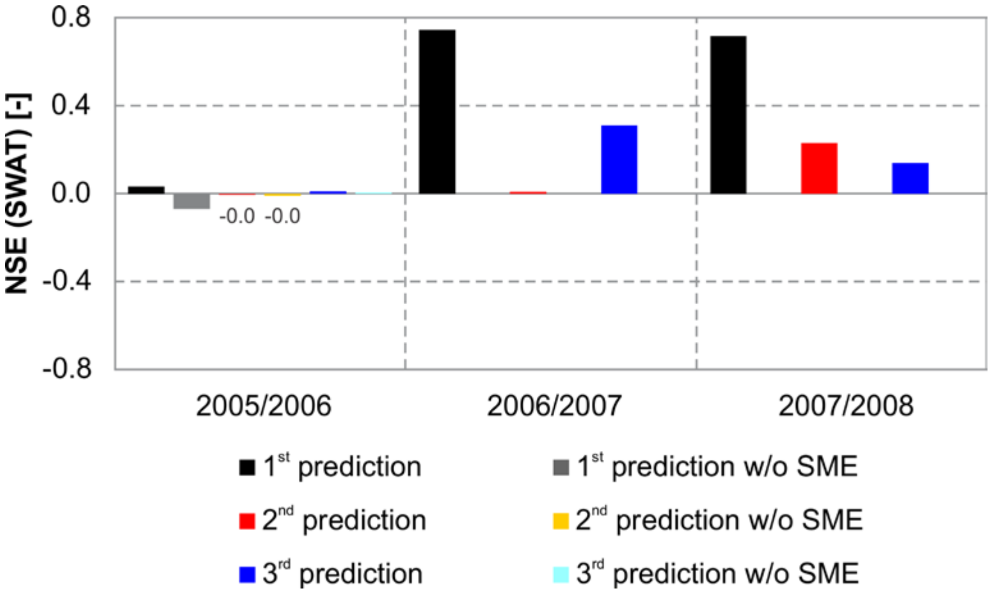
- *Results*

The predictions by SWAT showed too large peak discharge and, as in case of the other models, the snow melt problem. However, especially in the 2nd and 3rd year the results were the best of all models as shown by RMSE and NSE (Fig. A-7a and A-7b) despite the fact that assumptions made in the structure of SWAT can be judged inadequate to represent small catchments.

Although SWAT changed the initial conditions to quasi-dry conditions in the 2nd prediction stage, the storage changes where negative in the 2005/2006 (-24 mm/y). Later they became positive. The peak discharge was strongly reduced (from ~900 m^3/d in the 1st prediction to <100 m^3/d in the 2nd) but the slow flow components strongly increased, e.g. Q_{25} = 9 m^3/d. This resulted in a strong decrease of RMSE and increase of NSE (Fig. A-7a and A-7b). SWAT had similar discharge components comparing the 3rd and 2nd prediction, producing about 50% of surface runoff and base flow. The additional weather data only slightly affected PET (+30 mm/y to 847 mm/y) but increased by +33 mm/y in 2005/2005 and +118 mm/y in 2006/2007. This decreased discharge in the average by -101 mm/y, the second lowest peak discharge, with Q_{25} < 1 m^3/d). This reduced the prediction uncertainties for the first two years slightly but increased them for 2007/2008 (Fig. A-7a and A-7b).



- *Fig. A-7a: RMSE for all prediction of SWAT*



- *Fig. A-7b: NSE for all prediction of SWAT*

A-8 Topmodel

- *Model user*

Wouter Buytaert (University of Bristol, now: Imperial College London)

- *Basic model features*

A semi-distributed hydrological model that assigns a combination of storage compartments such as the root zone, unsaturated and saturated zone. Infiltration is determined by the Green-Ampt equation and a time delay function controls flow within a vertical soil column. The lateral subsurface flow is estimated by an exponential transmissivity function. The model does not consider the influence of soil freezing on K_{sat} nor snow (Beven et al., 1995).

- *Assumptions and parameters (1st prediction)*

The modeller wanted to minimize the influence of the modeller's choice and used published PTFs for parameterization (K_{sat} = 58 mm/h, Saxton et al. (1986)).

- *Assumptions and parameters (2nd prediction)*

The modeller visited the catchment only in a spring period. The rapid appearance of vegetation would be simulated, but the soil crust could not be introduced into the model. This modeller did not include the clay dam for the 1st prediction. He added it in the 2nd stage. The subsurface response was slightly increased by increasing the areal average of the local transmissivities (m^2/h) at saturation from lnTe = -2.5 to -2. This corresponds with Te = 0.082 to 0.135 m^2/h. The clay dam delays the subsurface response and the modeller tried to mimic this by changing lnTe. This is a merely intuitive approach since there was no guidance on how to adapt the parameter. Additionally, a surface runoff of 10% of the precipitation were generated by changing K_{sat} at the surface (5 mm/h) and the capillary drive CD (1 mm) (Morel-Seytoux and Khanji, 1974).

- *Assumptions and parameters (3rd prediction)*

The modeller selected only the information that appeared to be most important since the model is limited by its conceptual nature. This made it difficult to integrate additional data. Therefore, the modeller chose the soil hydraulic parameter without the water retention curves and the soil moisture data set.

The modeller used these data for calibration: all TDR measured at 10 cm depth and the groundwater levels of observation well L4 were averaged and used as proxies for the storage deficit. He expected that these two observations are inversely related. He then performed a Monte Carlo sensitivity test based on the correlation coefficient as performance measure. The modeller deduced from this that only the amount of water (expressed as a depth), which the soil can hold within the root zone (Sr_{max}) is a sensitive parameter. Finally, Sr_{max} was chosen to 0.02 m. Subsequently, the initial root zone storage deficit (Sr_0) and the initial subsurface flow per unit area (q_{s0}) were updated to be compatible with Sr_{max}.

- *Results*

Topmodel showed one of the best predictions during the 1st prediction stage with a RMSE about 50 m^3/d (Fig. A-8a). The main problem were the large discharges, e.g. the 2nd largest peak discharge (777 m^3/d). One reason was the rather low PET of ~570 mm/y.

The changes between the 1st and 2nd prediction stage had nearly no impact in 2005/2006, a positive one in 2006/2007 but a negative one in 2007/2008 expressed as RMSR and NSE (Fig. A-8a and A-8b). Modifying the vegetation values strongly changed PET (e.g. 1014 mm/y in 2005/2006). It became the largest in the 2nd prediction stage. This increased also AET (e.g. 465 mm/y in 2006/2007). Topmodel predicted one of the largest peak discharges (958 m^3/d) with a strong decrease in discharge between Q_{100} and Q_{95} of nearly two orders of magnitude. About an equal amount of discharge was due to surface runoff and due to cumulated interflow and base flow. These relations did not change in the 3rd prediction stage. Also the prediction quality did not change significantly. The quality measures show no changes for the 1st year, slight improvement in the 2nd, and a slight quality decrease in the 3rd year (Fig. A-8a and A-8b). These changes in the prediction quality resulted from an average increase in discharge of 48 mm/y. The major problem was still the too “fast“ slow flow components so that Q_{25} was 8 m^3/d while less than 1 m^3/d was observed.

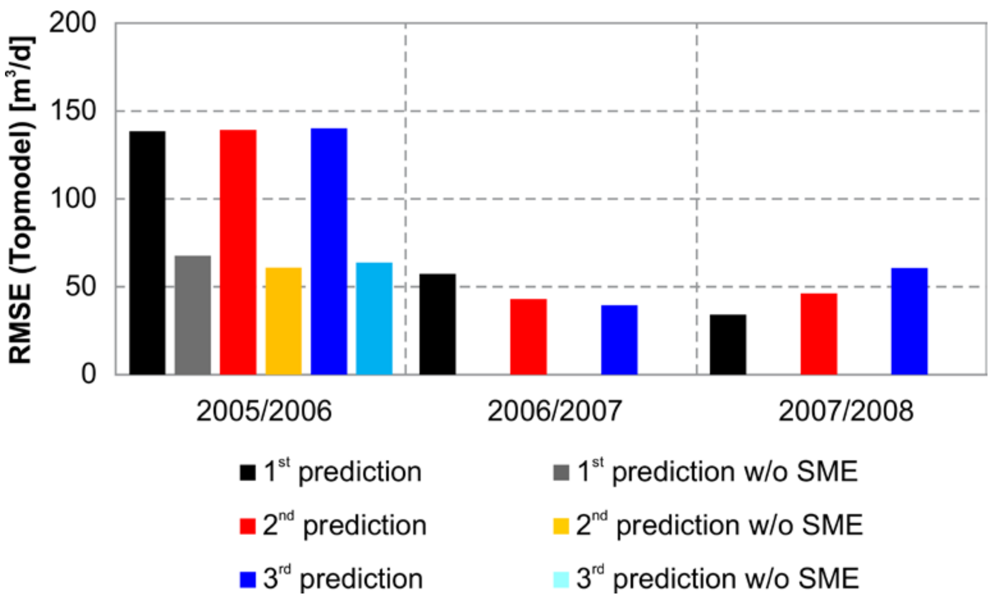


Fig. A-8a: RMSE for all prediction of Topmodel

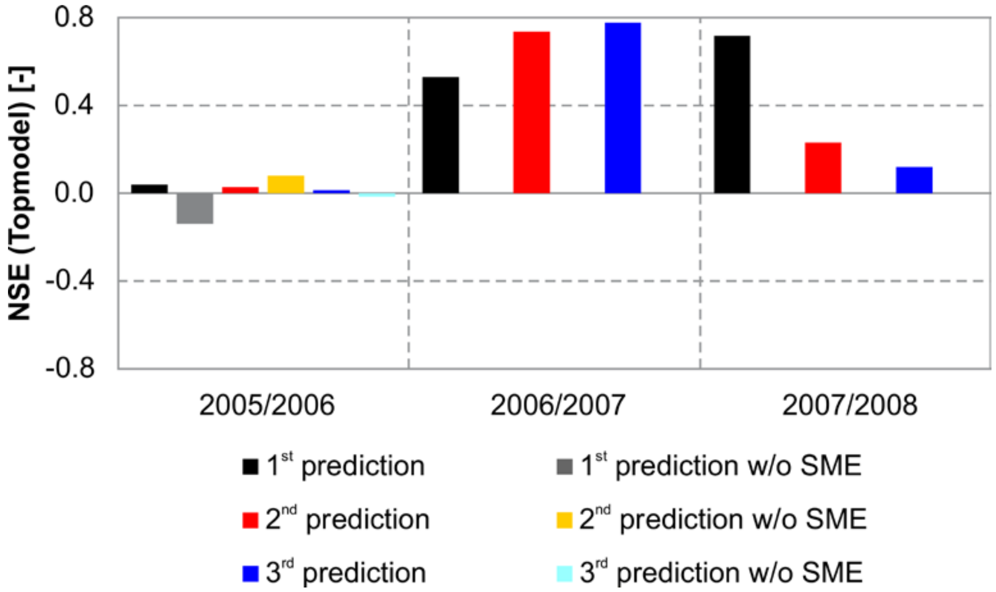


Fig. A-8b: NSE for all prediction of Topmodel

A-9 WaSiM-ETH (Richards)

- *Model user*

H. Hölzel (University of Bonn, now: Vattenfall Europe Mining AG)

- *Basic model features*

Spatially distributed hydrological model. All algorithms except the saturated soil zone routine are physically-based. Infiltration is calculated with the equations by Green-Ampt and the unsaturated zone by that of Richards. The lateral flow is determined by a linear storage approach (Schulla and Jasper, 2007).

- *Assumptions and parameters (1st prediction)*

The modeller relied on the description of the physical processes in his model and thereby minimized the influence of his own decisions. He derived soil hydraulic parameters from the texture data (K_{sat} = 118 mm/h, Adhoc AG Boden (2005)). The model was initialized by several warm-up runs to achieve steady state conditions. The clay dam was not considered.

- *Assumptions and parameters (2nd prediction)*

The on-site inspection of the catchment showed the extent of erosion due to surface runoff and the modeller noticed the different vegetation development in the western and eastern half of the catchment. Therefore, the model was split into a vegetation-free (before 2008) and a vegetation period with a low density grass canopy. To account for the surface runoff, K_{sat} was reduced and a soil crust having with a hydraulic conductivity of 20 mm/h based on NAW (2008) was introduced.

The initial state was changed from pre-wetted to quasi-dry and the lake was included. The formerly constant layer thickness was defined according to the Digital Elevation Model (DEM) in order to account for the clay dam. The detailed description of parameterisation of the 2nd stage prediction of WaSiM-ETH (Richards) can be found in Hölzel et al. (2011).

- *Assumptions and parameters (3rd prediction)*

The modeller emphasized the relevance of the groundwater dynamic by a more realistic representation of the clay dam (Holländer et al., 2009). He replaced the conceptual 1-D by a process-based 2-D groundwater approach (Hölzel et al., 2013).

The modeller still relied on the description of the physical processes and therefore, he requested data which allowed improving the model such as K_{sat} derived from slug tests in the field and K_{sat} determined in the laboratory, water retention, and soil moisture data. He used these data to have control on the soil moisture dynamic. Additionally, the data of weather station II were selected.

- *Results*

In the first prediction WaSiM-ETH (Richards) overestimated discharge discharge mostly predicting >10 m^3/d but peak discharge was rather low (140 m^3/d).

The soil crust with a K_{sat} of 200 mm/h did not effectively reduce the infiltration into the soil. This lowered AET significantly (234, 273, and 285 mm/y) and discharge increased (153, 309, and 306 mm/y), the largest of all models. Therefore, peak discharge increased to 1028 m^3/d, the second largest of all models. Also the base flow was larger (15 m^3/d) than in the 1st prediction. Surface runoff and interflow were obtained each at 20% and 60% base flow. The modeller identified the 1-D groundwater approach used in the 2nd prediction to be a major problem because it prevented the implementation of the clay dam. Including it would have reduced the base flow. The prediction quality did not significantly change from the 1st to 2nd prediction (Fig. A-9a and A-9b).

Using the weather data from the new station for the 3rd prediction reduced PET by about 30 mm/y to 682 mm/y and discharge by -65 mm/y. This affected both, the peak flow (1210 m^3/d) and the base flow (10 m^3/d). However, the predicted discharge was still exceeded the observed values. The reduction in discharge improved the prediction quality for the first two years but got worse in the third year (Fig. A-9a and A-9b) despite the apparent benefit of additional and more specific data.

The contribution of the discharge components to total discharge changed significantly over the period of all three years: in the 1st year surface runoff, interflow, and base flow were similar. Surface runoff dominated in the 2nd year (~ 45%) with base flow the lowest (~ 20%) and interflow dominated in the 3rd year (~ 45%). In the 3rd year the surface runoff component was the lowest (~ 25%).

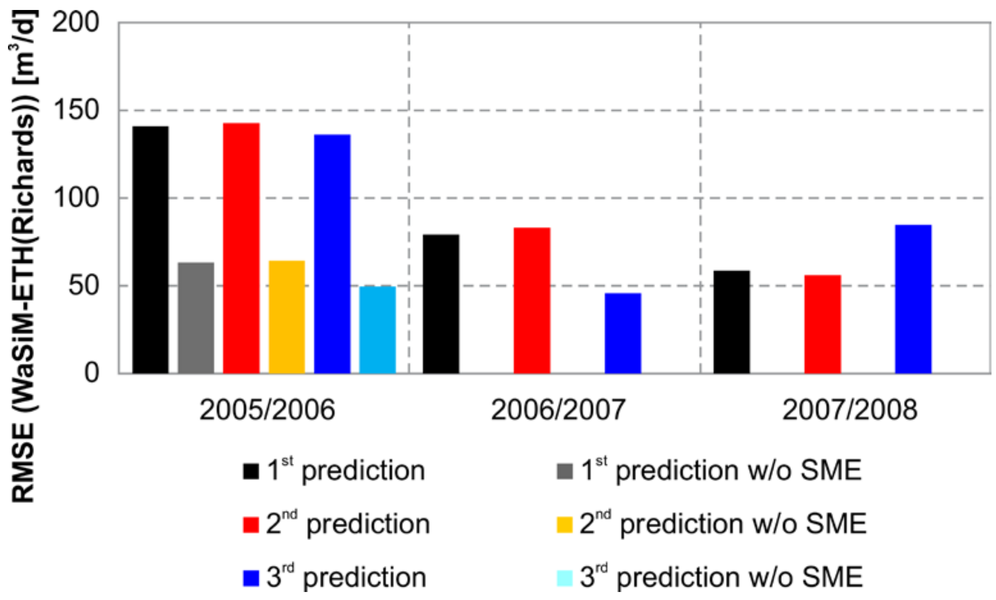


Fig. A-9a: RMSE for all prediction of WaSiM-ETH (Richards)

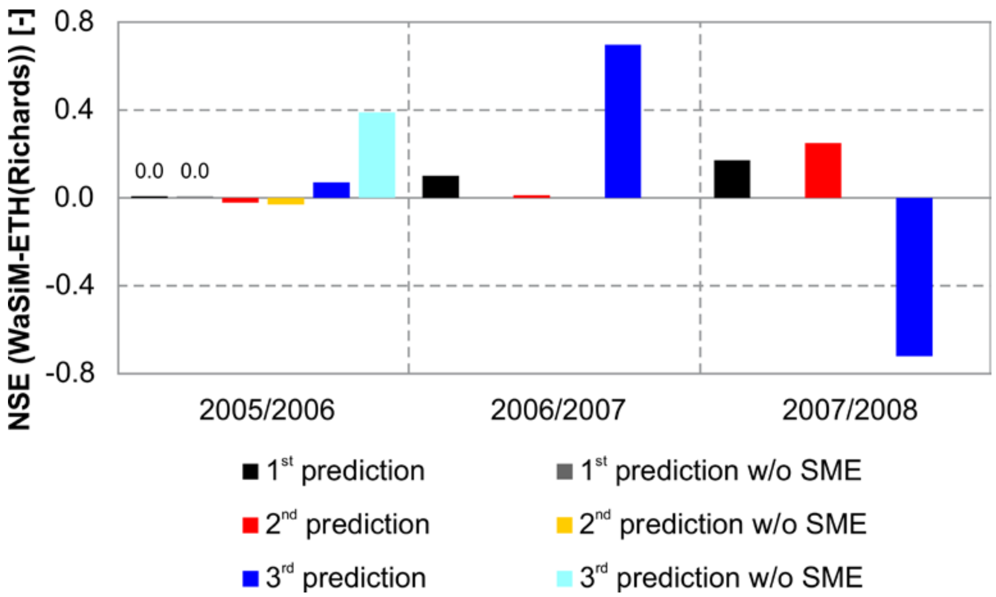


Fig. A-9b: NSE for all prediction of WaSiM-ETH (Richards)

A-10 WaSiM-ETH (Topmodel)

- *Model user*

  Thomas Krauße (University of Technology Dresden)

- *Basic model features*

  A spatially distributed hydrological model which uses the Topmodel attempt (refer to A-8) (Schulla and Jasper, 2007).

- *Assumptions and parameters (1st prediction)*

The WaSiM-ETH (Topmodel) modeller joined the modelling group only in the 2nd prediction stage.

- *Assumptions and parameters (2nd prediction)*

The modeller attended the 1st workshop as an observer and subsequently joined the project. Due to the large variation in the reported water budget and runoff, the modeller concluded from the discussions that a completely physically based model for the unsaturated zone is not needed in this case. During the on-site inspection of the catchment the modeller became aware of the deep gullies, noticed the different vegetation development in the western and eastern half of the catchment, and the rapid changes of the soil surface apparently depending on soil texture.

The modeller used the initial conditions generated by a one-year pre-run using the 1st year data despite the fact that the catchment was initially dry. Soil hydraulic parameters were estimated by PTFs according to Wösten and Nemes (2004) and Saxton et al. (1986) and used a set up based on the DEM data.

- *Assumptions and parameters (3rd prediction)*

After 2nd stage prediction the WaSiM-ETH (Topmodel) modeller left the modelling group due to time constraints.

- *Results*

The non-dry initial conditions resulted in a higher AET in the 1st year (364 mm/y) compared to any other model during the 2nd prediction stage and increased to 459 mm/y in the 2nd year which was nearly 60% of PET. Discharge was relatively constant and varied between 170 and 200 mm/y during the three years. The error in the mass balance was 17% in 2005/2006 and about 5% in the other years.

The largest base flow was predicted by WaSiM-ETH (Richards) at least 15 m^3/d. The peak discharge was 701 m^3/d. Therefore, the modeller obtained at 60% base flow, 21% surface runoff, and 19% interflow.

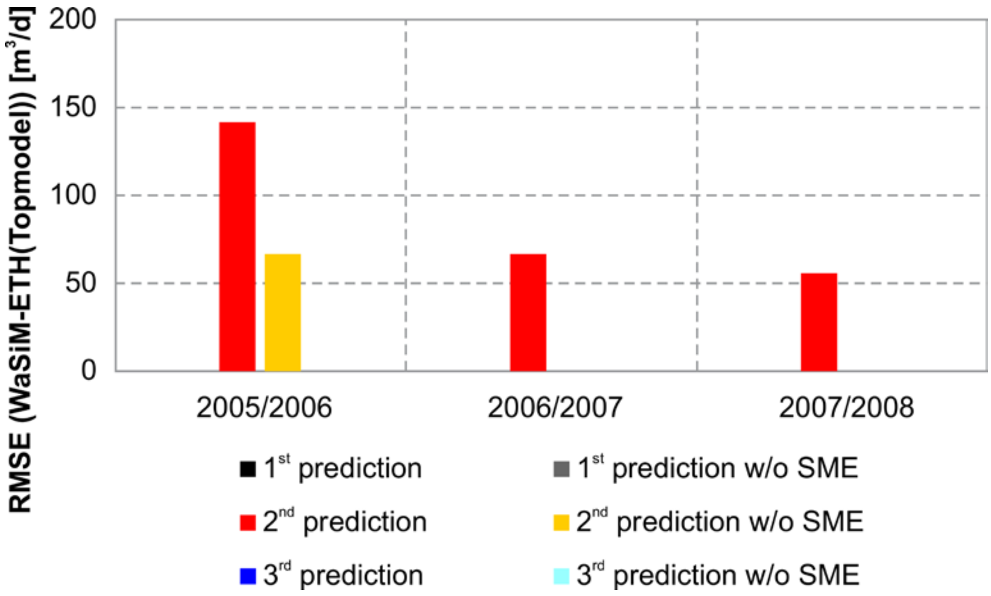


Fig. A-10a: RMSE for all prediction of WaSiM-ETH (Topmodel)

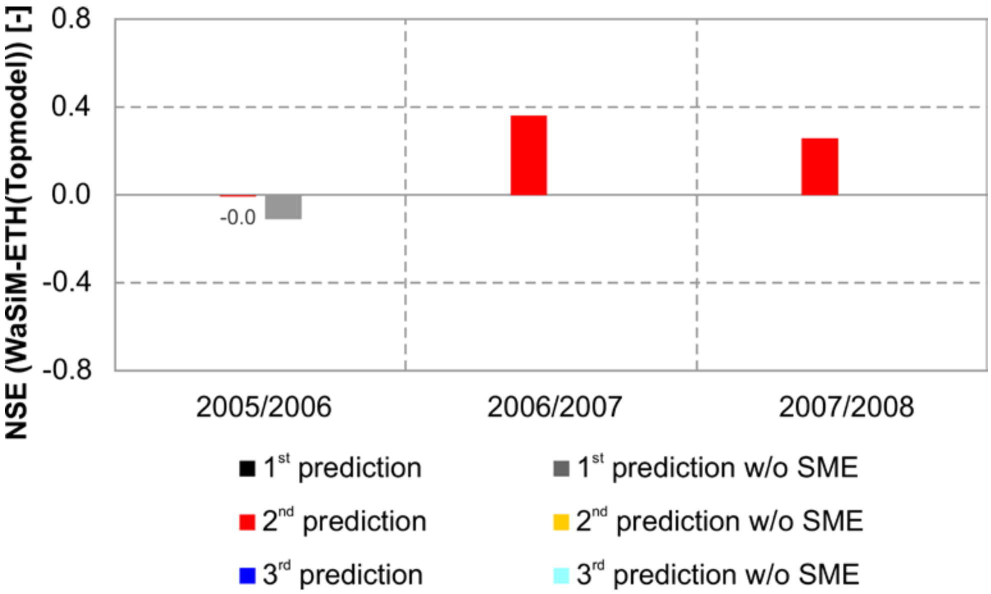
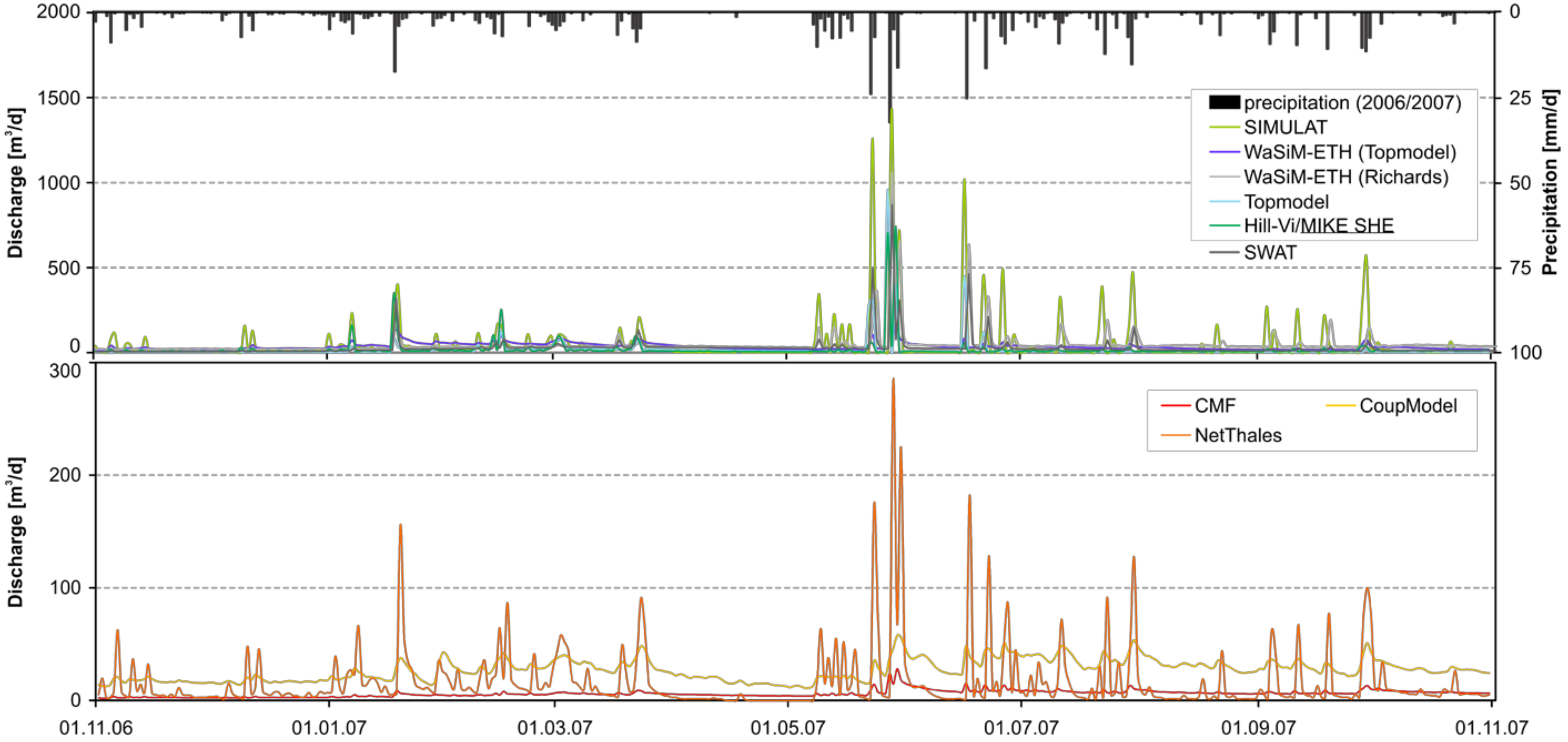
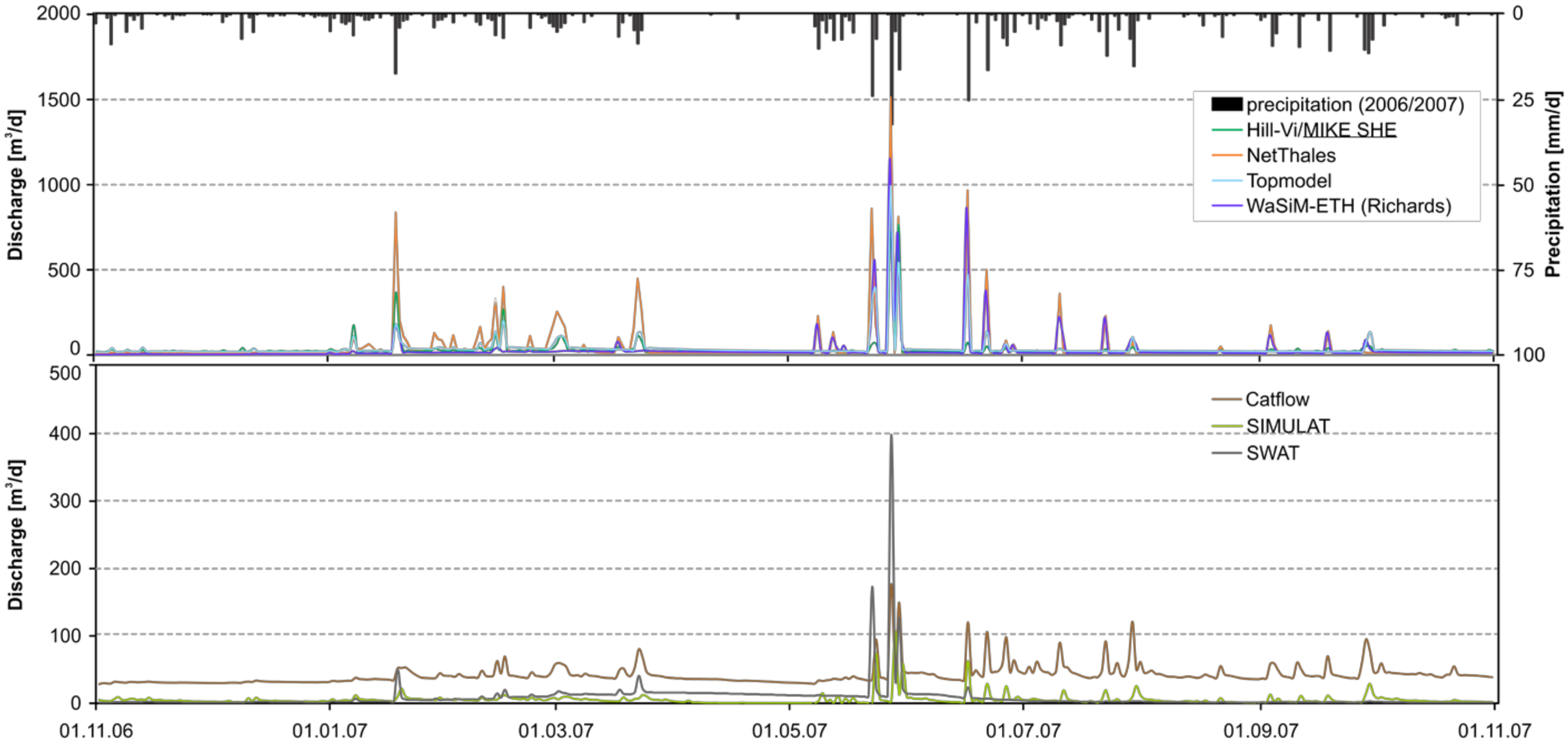


Fig. A-10b: NSE for all prediction of WaSiM-ETH (Topmodel)

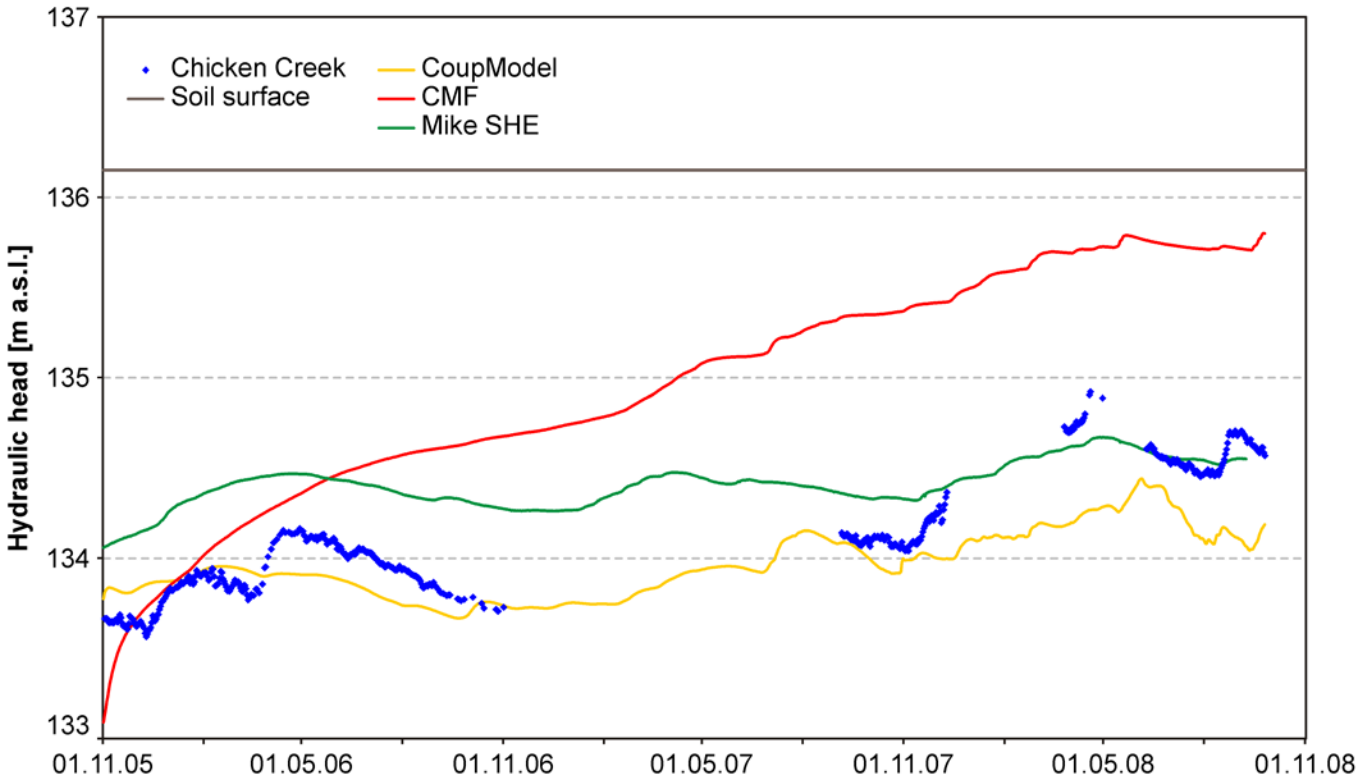
Supplementary material (B). Discharge predicted for the hydrological year 2006/2007 (2nd prediction).



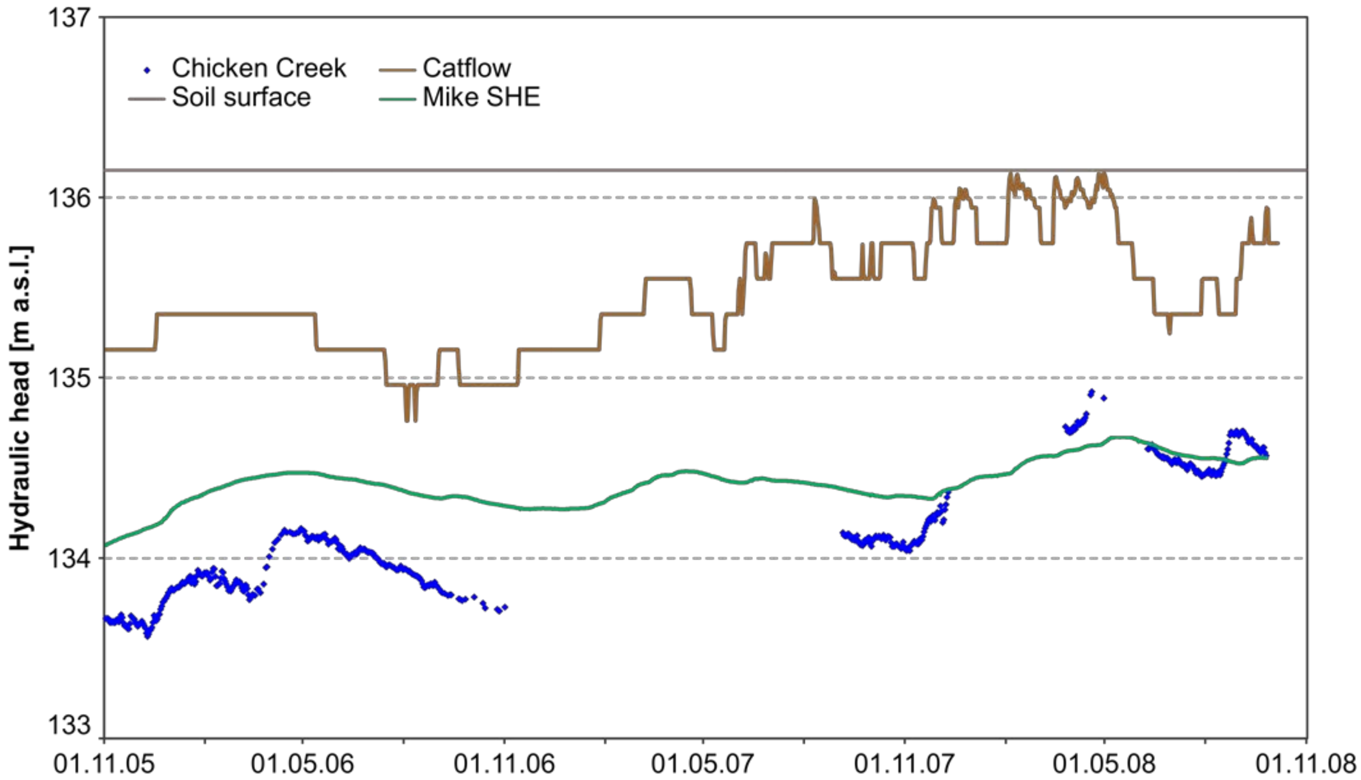
Supplementary material (C). Discharge predicted for the hydrological year 2006/2007 (3rd prediction).



Supplementary material (D). Hydraulic heads (2nd prediction) measured and predicted at the observation wells F4 (Soil surface elevation given as reference).



Supplementary material (E). Hydraulic heads (3rd prediction) measured and predicted at the observation wells F4 (Soil surface elevation given as reference).



References

Adhoc AG Boden: Bodenkundliche Kartieranleitung, 5th ed., Hannover, 2005.

AG Boden: Bodenkundliche Kartieranleitung, 4th ed., Hannover, 1994.

Arnold, J. G., Srinivasan, R., Muttiah, R. S., and Williams, J. R.: Large Area Hydrologic Modeling and Assessment Part I: Model Development, Journal of the American Water Resources Association, 34, 73-89, 10.1111/j.1752-1688.1998.tb05961.x, 1998.

Beven, K. J., Lamb, R., Quinn, P., Romanowicz, R., and Freer, J. E.: Topmodel, in: Computer Models of Watershed Hydrology, Colorado, 1995, 627-668.

Bormann, H., Diekkrüger, B., and Renschler, C.: Regionalisation concept for hydrological modelling on different scales using a physically based model: Results and evaluation, Physics and Chemistry of the Earth, Part B: Hydrology, Oceans and Atmosphere, 24, 799-804, 10.1016/s1464-1909(99)00083-0, 1999.

Bormann, H.: Sensitivity of a soil-vegetation-atmosphere-transfer scheme to input data resolution and data classification, Journal of Hydrology, 351, 154-169, 10.1016/j.jhydrol.2007.12.011, 2008.

Bormann, H.: Treating an artificial catchment as ungauged: Increasing the plausibility of an uncalibrated, process-based SVAT scheme by using additional soft and hard data, Physics and Chemistry of the Earth, Parts A/B/C, 36, 615-629, 10.1016/j.pce.2011.04.006, 2011.

Breuer, L., Eckhardt, K., and Frede, H.-G.: Plant parameter values for models in temperate climates, Ecological Modelling, 169, 237-293, 10.1016/s0304-3800(03)00274-6, 2003.

Carsel, R. F., and Parrish, R. S.: Developing Joint Probability Distributions of Soil Water Retention Characteristics, Water Resources Research, 24, 755-769, 10.1029/WR024i005p00755, 1988.

Chirico, G. B., Grayson, R. B., and Western, A. W.: On the computation of the quasi-dynamic wetness index with multiple-flow-direction algorithms, Water Resources Research, 39, 1115, 10.1029/2002wr001754, 2003.

Cosby, B. J., Hornberger, G. M., Clapp, R. B., and Ginn, T. R.: A statistical exploration of the relationships of soil moisture characteristics to the physical properties of soils, Water Resources Research, 20, 682-690, 10.1029/WR020i006p00682, 1984.

Diekkrüger, B., and Arning, M.: Simulation of water fluxes using different methods for estimating soil parameters, Ecological Modelling, 81, 83-95, 10.1016/0304-3800(94)00162-B, 1995.

Gerwin, W., Schaaf, W., Biemelt, D., Winter, S., Fischer, A., Veste, M., and Hüttl, R. F.: Overview and first results of ecological monitoring at the artificial watershed Chicken Creek (Germany), Physics and Chemistry of the Earth, Parts A/B/C, 36, 61-73, 10.1016/j.pce.2010.11.003, 2011.

Holländer, H. M., Blume, T., Bormann, H., Buytaert, W., Chirico, G. B., Exbrayat, J.-F., Gustafsson, D., Hölzel, H., Kraft, P., Stamm, C., Stoll, S., Blöschl, G., and Flühler, H.: Comparative predictions of discharge from an artificial catchment (Chicken Creek) using sparse data, Hydrology and Earth System Sciences, 13, 2069-2094, 10.5194/hess-13-2069-2009, 2009.

Hölzel, H., Rössler, O., and Diekkrüger, B.: Grope in the Dark - Hydrological modelling of the artificial Chicken Creek catchment without validation possibilities, Physics and Chemistry of the Earth, Parts A/B/C, 36, 113-122, 10.1016/j.pce.2010.04.017, 2011.

Hölzel, H., Diekkrüger, B., Biemelt, D., and Gädeke, A.: Impact of dumped sediment structures on hydrological modelling in the artificial Chicken Creek catchment, Germany, Journal of Hydrology, 477, 189-202, 10.1016/j.jhydrol.2012.11.029, 2013.

Jansson, P.-E., and Moon, D. S.: A coupled model of water, heat and mass transfer using object orientation to improve flexibility and functionality, Environmental Modelling & Software, 16, 37-46, 10.1016/s1364-8152(00)00062-1, 2001.

Kraft, P., Vaché, K. B., Breuer, L., and Frede, H.-G.: A solute and water flux library for catchment models, Proceedings of the iEMSs Fourth Biennial Meeting: International Congress on Environmental Modelling and Software Barcelona, 2008.

Lundmark, A., and Jansson, P.-E.: Generic soil descriptions for modelling water and chloride dynamics in the unsaturated zone based on Swedish soils, Geoderma, 150, 85-95, 10.1016/j.geoderma.2009.01.014, 2009.

Maurer, T.: Physikalisch begründetete, zeitkontinuierliche Modellierung des Wassertransports in kleinen ländlichenen Einzugsgebieten., Inst. für Hydrologie und Wasserwirtschaft (IHW), Universität Karlsruhe, Karlsruhe, 1997.

Mazur, K., Schoenheinz, D., Biemelt, D., Schaaf, W., and Grünewald, U.: Observation of hydrological processes and structures in the artificial Chicken Creek catchment, Physics and Chemistry of the Earth, Parts A/B/C, 36, 74-86, 10.1016/j.pce.2010.10.001, 2011.

Morel-Seytoux, H. J., and Khanji, J.: Derivation of an equation of infiltration, Water Resources Research, 10, 795-800, 10.1029/WR010i004p00795, 1974.

NAW: DIN 4220 Pedologic site assessment - designation, classification and deduction of soil parameters (normative and nominal scaling), Deutsches Institut für Normung (DIN) e.V., Berlin, 50 pp., 2008.

Rawls, W. J., and Brakensiek, D. L.: Prediction of soil water properties for hydrologic modeling, in: Proceedings of Symposium on Watershed Management, ASCE, 293-299, 1985.

Saxton, K. E., Rawls, W. J., Romberger, J. S., and Papendick, R. I.: Estimating generalized soil-water characteristics from texture, Soil Science Society of America Journal, 50, 1031-1036, 10.2136/sssaj1986.03615995005000040039x, 1986.

Schaap, M. G., Leij, F. J., and van Genuchten, M. T.: ROSETTA: A computer program for estimating soil hydraulic parameters with hierarchical pedotransfer functions, Journal of Hydrology, 251, 163-176, 10.1016/S0022-1694(01)00466-8, 2001.

Schulla, J., and Jasper, K.: Model Description WaSiM, ETH Zurich, Zurich, 181, 2007.

Simunek, J., Angulo-Jaramillo, R., Schaap, M. G., Vandervaere, J.-P., and van Genuchten, M. T.: Using an inverse method to estimate the hydraulic properties of crusted soils from tension-disc infiltrometer data, Geoderma, 86, 61-81, 10.1016/S0016-7061(98)00035-4, 1998.

Weiler, M., and McDonnell, J. J.: Virtual experiments: a new approach for improving process conceptualization in hillslope hydrology, Journal of Hydrology, 285, 3-18, 10.1016/s0022-1694(03)00271-3, 2004.

Wösten, J. H. M., and Nemes, A.: Pedotransfer functions for Europe, in: Developments in Soil Science, edited by: Pachepsky, Y., and Rawls, W. J., Elsevier, 431-435, 2004.