EFFECT OF UNSATURATED FLOW MODEL CONCEPTUALIZATION ON THE DYNAMIC RESPONSE OF AN INTEGRATED DISTRIBUTED HYDROLOGICAL MODEL

LU, X. H.[1,2*] – JENSEN, K. H.[3] – JIN, M. G.[4] – WANG, P. F.[2]

[1]*Key laboratory of Agricultural Water Resources & Hebei Key Laboratory of Agricultural Water-Saving, Center for Agricultural Resources Research, Institute of Genetics and Developmental Biology, Shijiazhuang 050021,China*

[2]*School of Earth Science and Engineering, Ministry of Education Key Laboratory of Integrated Regulation and Resource Development on Shallow Lakes, Hohai University, Nanjing 210098, China*

[3]*Department of Geosciences and Natural Resource Management, University of Copenhagen, Copenhagen, Denmark*

[4]*School of Environmental Studies, China University of Geosciences, Wuhan 430074, China*

**Corresponding author*
e-mail: luxiaohui945@hhu.edu.cn
(phone: +86-25-83787234; fax: +86-25-83787234)

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Abstract. Water dynamics in the unsaturated zone is one of the most important processes as it controls model precision. One of the limitations in using a catchment model based on a Richards' equation is the huge amount of parameters required to run the model. In this study, we investigate the effect of unsaturated flow conceptualization models on the dynamic response of an integrated distributed hydrological model, which are (1) Richards equation (simple parameterization RI2) (2) Two layer water balance model (TLM). The physically based distributed modelling system, MIKESHE is applied to the Skjern catchment with the objective to test and analyze the effect of using different models for unsaturated flow on the dynamic response of an integrated distributed hydrological model. Results from this study show that regarding peak discharge at the catchment outlet follows the TLM, RI2 sequence. Similar results were found for the discharge characteristics of the sub basin. The close agreement between the simulated results of the two models also indicates that the simple TLM model is more suitable than the complex Richard equation model at least for the condition of the Skjern catchment, while its weaknesses is not describing the groundwater dynamics well.
Keywords: *unsaturated flow model; lag effect; groundwater and surface water coupling; hydrodynamic response; MIKESHE*

Introduction

The Water Framework Directive adopted by the European Union prescribes that water resources management strategies must be developed at catchment scale-the natural geographical and hydrological unit - instead of according to administrative or political bounds and the ecological state of both surface- and groundwater must be considered. The catchment or basin scale is also used as the management scale in the concept of Integrated Water Resources Management (IWRM) that is widely adopted as the management principle in developing countries. Integrated hydrological catchment models are useful tools for developing such water resources management strategies. Integrated catchment models are also required for addressing hydrological

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consequences of anthropogenic and natural interferences such as land use and climate change. A number of modeling tools have been developed over the past decades with quite diversity in complexity and in how the individual hydrological processes are represented. Water dynamics in the unsaturated zone is one of the most important processes of surface water and groundwater exchange as it controls evapotranspiration rates and water stress of vegetation and crops on one side, and recharge to the aquifer system on the other.

Integrated hydrological models may be categorized in either lumped conceptual models that provide a process description integrated for the whole catchment or distributed models that allow for spatial resolution of the catchment response (Ajami et al., 2015). The spatial distribution in the horizontal plane may be considered in different ways ranging from the concept of hydrological response units mainly associated with the topographical variation to a more regular discretization in the form of a numerical mesh. Physically based distributed models operate on a numerical mesh and are traditionally based on Richards' equation for unsaturated flow. In recent developments this equation forms the basis for solving subsurface flow in three dimensions (Brauer et al., 2014) while earlier developments assume one-dimensional flow in the unsaturated zone and independent flow solutions are thus used for transmitting precipitation falling at the ground surface to the groundwater table (Barron et al., 2013).

One of the limitations in using a catchment model based on a Richards' equation formulation is the huge amount of parameters required to run the model. Constitutive relationships in the form of retention and hydraulic conductivity functions need to be specified in each element of the model and these requirements can not easily be honored from field measurements. The parameters of physically based models are intended to be measurable in the field or derivable from field measurements (Curtu et al., 2014), which raise several concerns both from theoretical and scaling arguments. Richards' equation for unsaturated flow is originally developed for small-scale homogeneous systems and even though it has been widely used at larger scale to represent flow in natural heterogeneous systems. There has been a long-standing debate in the literature whether the model indeed is applicable and valid at larger scale (Henriksen et al., 2003). There is abundant field evidence that soil properties may exhibit large spatial variation even within short distances and a pertinent question is therefore how to define hydraulic parameters that incorporates the effect of sub-grid spatial variability. Several approaches have been proposed ranging from complex stochastic formulations to simpler parameterization schemes determined by calibration (Liu et al., 2007; Mogens et al., 2007). An interesting approach that has some operational advantages is indirect parameter estimation techniques based on regression. These techniques are referred to as pedo-transfer-functions (PTFs) and they relate soil hydraulic functions to readily available soil properties (Rossatto et al., 2012). The relationships are developed from comprehensive soil data bases and in some manner they also incorporate the effect of variability and scale.

Using Richards' equation as the modeling platform for unsaturated flow simulations at catchment scale increases the computational demand as small spatial and temporal discretizations are required in the numerical approximation of the equation. Given these complications a relevant question therefore arises whether simpler and less demanding modeling approaches will provide same results or perhaps even better at catchment scale.

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The objective of this study is to test and analyze the effect of using different models for unsaturated flow on the dynamic response of an integrated distributed hydrological model. For this purpose we use the MIKE SHE system as the modeling platform which implicitly implies that the unsaturated flow model conceptualization is constrained to independent soil columns subject to vertical flow. In order to find more suitable and more effective model for unsaturated flow in the MIKE SHE catchment modeling, we analyze the following model approaches: Richards' equation (simple parameterization) and Simple two layer water balance model for the root zone and instantaneous routing of the excess water to water table.

The test area is a sub-catchment of the Skjern catchment in western Denmark which the MIKE SHE model already has been calibrated (Shokri and Bardsley, 2016; Srivastava et al., 2014; Sacchi et al., 2013).

Experiment

MIKE SHE is a distributed physically based modeling system capable of describing the entire land phase of the hydrological cycle over the model area.

Model based on Richards' equation

Richards' equation for vertical unsaturated flow may be written as

$$C(h)\frac{\partial h}{\partial t}=\frac{\partial}{\partial z}\left[K\left(h\right)\frac{\partial h}{\partial z}\right]-\frac{\partial K\left(h\right)}{\partial z}-S \qquad \text{(Eq.1)}$$

where z is the vertical coordinate [L], t is time, h is pressure head [T], C is water capacity[L T−1], K is hydraulic conductivity [LT−1]; and S is a sink term to account for root water uptake [T−1].

The constitutive relationships in the form of the retention function θ (h) and the hydraulic conductivity function K (h) may be represented in various ways; in this analysis we will assume that the parametric function proposed by Van Genuchten (Simunek et al., 1999) apply

$$\theta\left(h\right)=\begin{cases}\theta_r+\dfrac{\theta-\theta_s}{\left[1+\left|\alpha h\right|^n\right]^m} & h<0 \quad (m=1-1/n)\\ \theta_s & h\geq 0\end{cases} \qquad \text{(Eq.2)}$$

and

$$K\left(h\right)=\begin{cases}K_sS_e^{1/2}\left[1-\left(1-S_e^{1/m}\right)^m\right]^2 & h<0\\ K_s & h\geq 0\end{cases} \qquad \text{(Eq.3)}$$

where θ is the volumetric water content [—], h is the pressure head [L] θr is residual moisture content [—], θs is saturated moisture content [—], Se is effective saturation

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(=θ(h)- θr)/(θs- θr)) [—], Ks is saturated hydraulic conductivity [LT−1], and α and n are parameters.

Two-layer water balance model

The two-layer water balance model implemented as an option in MIKE SHE represents a major simplification to the unsaturated flow processes and is based on the principles described by Yan and Smith (1994). The model does not consider the constitutive relationships between water content, pressure head and hydraulic conductivity. In this modeling concept the unsaturated zone is divided in to two layers where the upper one represents the zone from which water can be extracted for evapotranspiration while the second layer extends from the bottom of the upper layer to the water table. Evapotranspiration is calculated as the sum of evaporation from canopy interception, evaporation from water ponded on the ground surface, and transpiration from the unsaturated zone, and transpiration from the saturated zone (Troldborg et al., 2007). The computations are based on prescribed values for potential evapotranspiration and the controlling factor for actual evapotranspiration is the root zone capacity, defined as the difference between water content at field capacity and wilting point, multiplied by the depth of the root zone. For water contents higher than corresponding to field capacity evapotranspiration occurs at potential rate while for water contents less that wilting point evapotranspiration is zero. In between a linear reduction function is assumed. Water in excess of field capacity leaves the upper layer and is instantaneously routed to the water table without any lag time. This model is simple in concept and in computational demand but may fail in representing a proper timing of recharge as any delay in routing is neglected.

Results and discussion

Catchment characteristics

The study catchment, the Ahlergaarde catchment in the Skjern watershed, is located in the western part of Denmark. It has an area of approximately 1055 km^2. The topography slopes gently from east to west with land surface elevations from 130 meters above sea level in the eastern part to near 0 meter in the western part (seen in *Fig. 1*). Most of the land is agriculture while forest, heather and urban areas represent about 15% of the land surface. The climate is dominated by westerly winds that give rise to mild winters and relatively cold summers with highly variable weather conditions characterized by frequent rain. The mean annual precipitation is about 1050 mm/year and the mean annual reference evapotranspiration is 563 mm/year (1985-1999).

The soils are generally highly permeable and most of the precipitation infiltrates. Geologically the study catchment is dominated by glacial outwash sand and gravel of Quaternary age, with isolated islands of Salian sandy till. The thickness of the Quaternary deposits is generally less than 50 m in the central and northeastern part of the area. The thickness of the Quaternary deposits increases in the southern and western part and in some places reaches depths of approximately 250 m. Alternating layers of marine, lacustrine, and fluvial deposits of Miocene age underlie the Quaternary deposits. The sequence is formed by layers of mica clay, silt, and sand, together with quartz sand and gravel. Thick clay layers from Paleogene underlie the Miocene

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deposits. The Quaternary and Miocene sand formations often form large interconnected aquifers. At depth, however, confined Miocene sand units are found on top of the Paleogene clay that acts as an impermeable flow boundary (Van Genuchten, 1985).

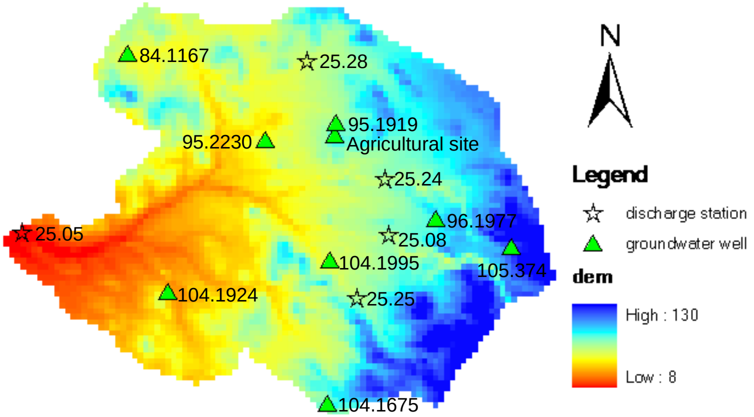

Figure 1. *Location of gauge and observed groundwater level stations*

The main river in the catchment is the Skjern River. The river water flows from north and east to west determined by the land surface elevation. Average discharge at Ahlergaarde discharge station at the outlet of the catchment is 16 m3/s corresponding to 480 mm/year (1990-1995).

Hydrological data

Daily values for precipitation were retrieved from the Danish Meteorological Institute for the period 1985-1999 on a 40 km grid basis (Troldborg et al., 2007). To compensate for biases due to turbulence effects at the orifice of the precipitation gauges the grid data were corrected using correction factors of shelter class B (Van Genuchten, 1985). Two 40 km grids cover the Ahlergaarde catchment. 40 km grid values for potential evapotranspiration were collected for the same period.

Daily values for streamflow were collected from five stations representing the total catchment (25.05) and four sub-catchments (25.08, 25.24, 25.25 and 25.28), see *Fig. 1*.

Daily groundwater level data for the area of interest were accessed from a database at the Geological Survey of Denmark and Greenland (GEUS). 12 wells were selected for the analysis. Among these we selected five wells with long time series and representing different distances to water table as candidates for a closer comparison to simulations (wells 84.1167, 104.1924, 105.374, 104.1675, and agricultural site shown in *Fig. 1*).

Land use data, topographic data and soil data

Land use data

Land use is classified from available vegetation maps and satellite data. Five classes are defined: grain/maize, grass, forest, heather, and urban areas. For each of these classes standard values for the seasonal variation in leaf area index and root zone depth were used (Van Roosmalen et al., 2007).

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Topographic data

Digital elevation data at 500 m resolution were used for defining the surface topography of the study area.

Soil data

Two sets of soil classifications were used in the analysis. The first one is a simple classification that was used in National Water Resources Model (Sakaguchi et al., 2005) and later by Van Roosmalen et al. (2009). For the study area the soil was classified into two dominant soil types represented by fine and coarse sands respectively.

Model set-up, calibration and validation

Model set-up

The model setup is based on the National Water Resources Model (Sakaguchi et al., 2005) with the modifications introduced (Van Roosmalen et al., 2007). The model covers a total area of 1055 km2 and is simulated on a 500 m × 500 m computational grid. Ground surface elevation for grid cells are derived from digital elevation maps on the scale of 1:25,000. In the unsaturated zone when using a formulation based on Richards' equation a variable discretization is used ranging from 5 cm near the soil surface and increasing to 50 cm deeper in the profile. The geological model of the catchment is defined from 8 geological units and characterized by their spatial extent in space and imported into a groundwater model with 16 computational layers of non-uniform thickness. Each geological unit is characterized by a horizontal and vertical hydraulic conductivity. The boundary of the model is placed along to the topographical boundary of the catchment which does not at all places coincide with the groundwater divide. Thus the boundary conditions specified for the groundwater model is a mix of no-flow and specified gradient, see *Fig. 1*.

The stream system was digitized and bank elevations assigned to specific points along the river course. Cross sections were assessed based on measurements at specific locations in the stream system. A Manning number (river bed resistance) of 0.08 $m^{1/3}$ s^{-1} was used throughout the area. As the hydrograph is dominated by slowly varying base flow, the river routing itself has no significance for the shape of the hydrograph. A thin low-permeable layer is assumed to exist between river and aquifer characterized by a leakage coefficient. Drains represent both artificial tile drains and ditches. Additionally, the drainage description captures flow through creeks and small streams not explicitly described by the river setup. The information on the drainage system in the area is limited and therefore the model setup was simplified using drains in the entire model area parameterized with a constant drain level of 0.5 m below soil surface (Sakaguchi et al., 2005).

The parameter values for the evapotranspiration and interception models were adopted from previous studies in Denmark (Van Roosmalen et al., 2007).

Model calibration and validation

The MIKE SHE model was first applied and calibrated for the total Ahlergaarde catchment. 15 years of data were available of which 5 years were used to build a conceptual period (1/1/85–1/1/90) and the following ten years (1/1/90-12/31/99) were

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used to calibrate and validate the model. 5 years of warm-up period was required to eliminate the impact of initial conditions.

Van Roosmalen et al.(2009) (Simunek et al., 1999) calibrated and applied the model for a much larger area where Ahlergaarde catchment was a sub-catchment. We have therefore used the parameters values obtained in this study and from the National Water Resources Model (Sakaguchi et al., 2005) as a point of departure for a dedicated calibration to the Ahlergaarde catchment.

Daily river discharge data and observations of groundwater levels from selected wells were used as calibration targets and for evaluating calibration and validation we used three performance criteria:

(1) Root Mean Square Error (RMSE) for hydraulic heads

$$RMSE = \frac{\sqrt{\sum_{n} \left(h_{obs} - h_{sim}\right)^2}}{n} \quad \text{(Eq.4)}$$

where h_{obs} and h_{sim} represent observed and simulated hydraulic heads and n is total number of measurements. RMS values for the groundwater heads should be compared to uncertainty of the observed head data. Henriksen and Sonnenborg (2003) (Van Roosmalen et al., 2009) estimated the aggregated uncertainty of the observed head data relative to model simulations at a 1 km scale to have a value of 3.1 m, corresponding to RMS values of 6.2 m at the 95% confidence levels.

(2) Correlation Coefficient (R) for streamflow

$$r = \sqrt{\frac{\sum_{t=1}^{T} \left(Q_{sim}^{t} - \overline{Q}_{obs}\right)^2}{\sum_{t=1}^{T} \left(Q_{obs}^{t} - \overline{Q}_{obs}\right)^2}} \quad \text{(Eq.5)}$$

where ${Q_{obs}}^t$ and ${Q_{sim}}^t$ are the observed and simulated river discharges at time t, respectively, and $\overline{Q}_{obs}$ is the average observed discharge.

(3) Nash Sutcliffe Correlation Coefficient (E) for streamflow

$$E = 1 - \frac{\sum_{t=1}^{T} \left(Q_{obs}^{t} - Q_{sim}^{t}\right)^2}{\sum_{t=1}^{T} \left(Q_{obs}^{t} - \overline{Q}_{obs}\right)^2} \quad \text{(Eq.6)}$$

where ${Q_{obs}}^t$ and ${Q_{sim}}^t$ are the observed and simulated river discharges at time t, respectively, and $\overline{Q}_{obs}$ is the average observed discharge.

The parameters subject to calibration are (1) hydraulic parameters for each geological unit (i.e. horizontal hydraulic conductivity, vertical hydraulic conductivity, specific yield and storage coefficient), (2) leakage coefficient for stream system, (3) drainage parameters, (4) and hydraulic parameters for the unsaturated zone. When

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Richards' equation is used as the modeling framework for simulating unsaturated flow the specific yield of the aquifer is, in reality, a passive parameter. Owing to the coupled unsaturated-saturated zone description in MIKE SHE, water storage or release is determined by the soil moisture retention curve of the corresponding layer of the unsaturated zone. When the two-layer water balance model is used for simulating ET and recharge specific yield parameter is requested.

Two-layer model (TLM)

The main calibration effort was carried out for the case where the two-layer water balance model is used to represent evapotranspiration and recharge. This type of model was also used by (Simunek et al., 1999) who calibrated the model to an area that encompassed the catchment considered in this study. The simple soil classification formed the basis for this model analysis. Two soil types were considered, fine and coarse sands, respectively. Initial estimates of the aquifer parameters and their expected ranges were assessed from previous modeling results are given in *Table 1*. For the two-layer model the controlling soil parameters are water contents at field capacity and wilting point and we adapted the parameter values that were found by (Simunek et al., 1999) and given in *Table 1*. First, a simple sensitivity analysis was carried out. This showed that the most sensitive parameters were horizontal conductivity and aquifer-river bottom leakage coefficient. The calibration was based on a manual trial-and error procedure by comparing non-steady simulations of discharge at the catchment outlet and groundwater levels against measurements. The calibrated values for the aquifer parameters are listed in *Table 1*.

Through parameter sensitivity analysis of Skjern model, the leakage coefficient and vertical hydraulic conductivity are the most sensitive parameters. After calibration, the average RMSE value for differences between observed and simulated groundwater levels was 4.5 m and thus within the uncertainty range of the measurements.

Table 1. *Initial hydraulic parameter values and expected ranges (Shokri and Bardsley, 2016) and Calibrated hydrulic parameters (seen in the brackets)*

Items	Geological Layers	Horizontal hydraulic parameters(m/s)	Vertical hydraulic parameters(m/s)	Specific yield(m/m)	Specific storage coefficient (m^{-1})
Governing parameters for groundwater flow	Layer 1 (fractured till)	$1*10^{-5}$ (2.19*10-4)	$1*10^{-7}$ (2.19*10-5)	$2.5*10^{-1}$	$1*10^{-4}$ (5*10-5)
	Layer 2, 4, 6, 8 and 10 (till and clay)	$1*10^{-7}$ (6.21*10-8)	$1*10^{-9}$ (6.21*10-9)	$2.5*10^{-1}$	$1*10^{-4}$ (6*10-5)
	Layer 3, 5, 7 and 9 (meltwater sand and gravel)	$1*10^{-4}$($2.78*10^{-4}$)	$1*10^{-5}$($2.78*10^{-5}$)	$2.5*10^{-1}$	$1*10^{-4}$($5*10^{-5}$)
Governing parameters for surface water flow	Leakage coefficients(s^{-1})	$1*10^{-7}$($1.72*10^{-5}$)			
	Drainage time constant (s^{-1})	$8*10^{-7}$($7*10^{-7}$)			
	Surface Manning roughness($m^{1/3}$/s)	2(4)			

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Observed and simulated discharges are shown in *Fig. 2*. As shown in the figure the two hydrographs compare well as also reflected by the water balance and model efficiency. Low flow situations are captured less accurately by the model.

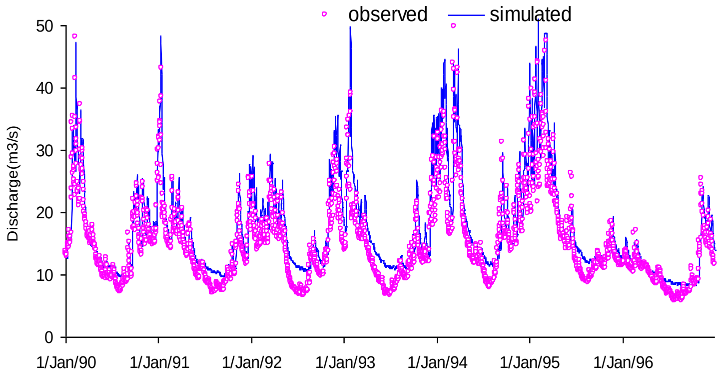

Figure 2. *Simulated and observed discharge for the entire catchment for the calibration period together with figures for average observed and simulated flows, OBSave and SIMave, and model efficiency on a daily basis, R2)*

A split-sample validation test was conducted against data from the same discharge station and ground-water observation wells as used for calibration. The period 1996-1999 was used for validation. The validation results showed that both hydrograph shapes, water balance and model efficiency (E criteria) are of the same level of accuracy as the calibration results.

Model based on Richards' equation and simple soil classification (RI2)

In this model approach unsaturated flow is described by Richards' equation in combination with the simple soil classification as for the previous approach. The hydraulic functions for the two soil types involved were adopted from a modeling study in the neighboring Karup catchment that has the same geological and hydrogeological characteristics as Ahlergaarde catchment. The retention characteristics were represented by corresponding values of suction and water content and cubic spline interpolation techniques were used to develop continuous and differentiable functions for the whole moisture regime. This and the following model approaches were subject to simple trial-and error calibrations by modifying a few sensitive parameters such that the same water balance was obtained as for the two-layer model. Goodness of fit criteria for the calibration and validation periods are listed in *Table 2*.

Table 2. *Calibration and validation results for Skjern catchment (1997–1999). Root mean squared error (RMSE), Nash-Sutcliffe model efficiency coefficient (E), and Correlation coefficient(R) are shown*

	Calibration results (1990-1996)		**Validation results (1997-1999)**	
	TLM	RI2	TLM	RI2
RMSE(m)	3.42	3.35	3.16	3.23
R	0.96	0.94	0.97	0.95
E	0.81	0.72	0.83	0.73
Water balance(mm)	-8	-13	0	-15

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Results and discussion

Simulations by the two different unsaturated zone models are compared in terms of stream discharges and the contributing components at catchment and sub-catchment scales, recharge, and groundwater levels. We have analyzed the simulated dynamics for a wet year (1990) and a dry year (1996), respectively.

Comparison of hydrological response in discharge dynamics according to the five different conceptual models

Simulated discharges by the various models at the catchment outlet (station 25.05) are shown in *Fig. 3* for 1990. For the wet year, the TLM model provides the best overall comparison to observed discharges in terms of dynamics and levels. Particularly, it is noticeable that the rapid responses to rainfall for periods outside the summer season are captured well by the model.

In contrast the simulations based on the traditional and physically-based Richards' equation (RI2) fails to capture the dynamics properly. The model does not have the proper timing of increases in discharge and the high-flows are severely underestimated. Also the lag time during recession periods after rainfall has ceased is too high and in consequence the simulated discharge during these periods is too high. A possible explanation for the shortcomings of this model is that the spatial variability across the catchment is not incorporated in sufficient details. In this manner it could be expected that more dynamics would be added to the model. For the dry year 1996 the difference between the different model approaches are less distinct; yet, TLM approach is also for this hydrological situation superior to the other.

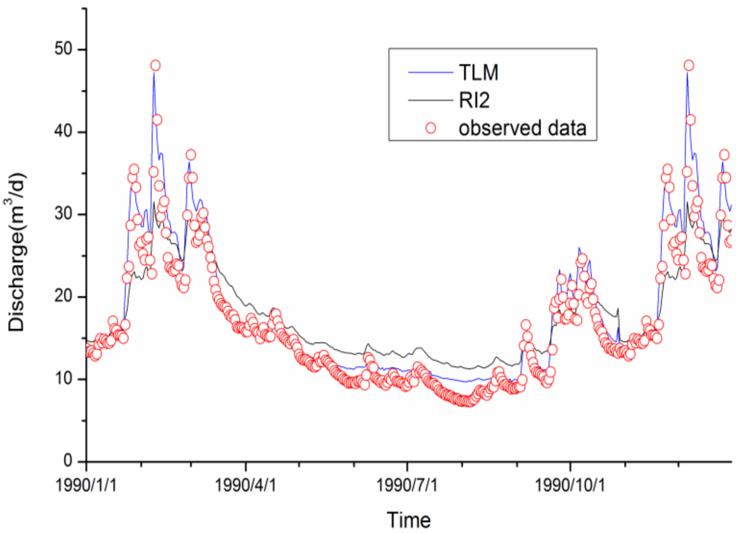

Figure 3. *Comparing discharge of 2 unsaturated flow model with observed data in wet year (1990)*

In terms of stream flow the TLM approach provides a much more accurate simulation in comparison to the approaches based on the traditional Richards' equation. Similar results were found for the discharge characteristics of the sub basin (discharge station 25. 28, 25.24, 25.08, 25.25).

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Comparison of Hydrological response in groundwater dynamics according to the five different conceptual models

Deep groundwater type

Station No.105.374 (groundwater level station seen in *Fig. 1*) is chosen as a deep groundwater type, which groundwater depth is 21 m. When a rainfall event occurs, the infiltrated water takes a long time to reach groundwater table. It also shows that the peak recharge did not occur in the month with the largest rainfall (seen in *Fig. 4*).

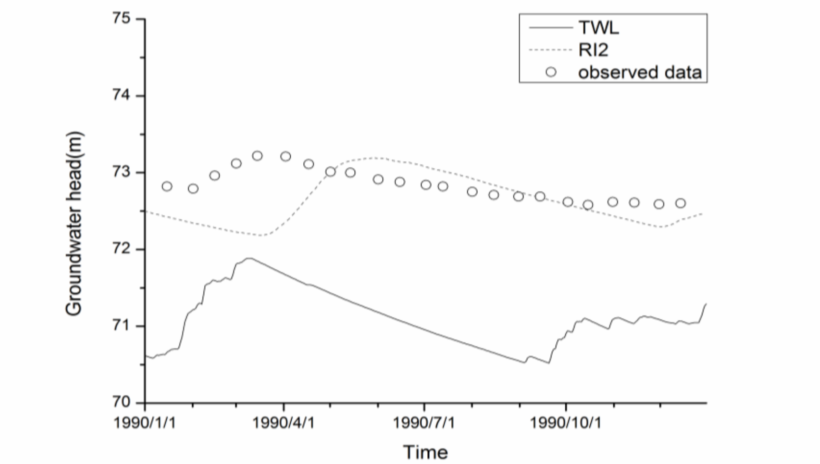

Figure 4. *Groundwater dynamics of site 105.374 in 1990*

In contrast the simulations based on the traditional and physically-based Richards' equation (RI2) fails to capture the surface water and groundwater dynamics properly and after the peak, RI2 decreased very smoothly. TLM always have a response to rainfall even the small one.

Shallow groundwater type

Station Agricultural site (groundwater level station seen in *Fig. 1)* is chosen to represent shallow groundwater type, which is very near the boundary and groundwater depth is about 5 m. Infiltration reaches groundwater relatively quickly, so that most of the individual rainfalls correspond to isolated infiltration recharge events with very small time-lags (generally only about one or two days). Comparing to the deep groundwater types, the groundwater recharge of these three models have more peaks, which shows that some small rainfall events also produced groundwater recharge in shallow groundwater type.

In shallow groundwater type, the two models have a time lag between rainfall and groundwater recharge peak occurs. Groundwater recharge of TLM is higher than RI. Comparing to the wet year (1990), the groundwater reduced significantly and groundwater head declined more clearly than the wet year due to the rainfall reduced.

Strengths and weaknesses of 2 different conceptual models

In the present study the same top and bottom boundary conditions were assigned to both models to be able to compare the results more clearly. Their difference is restricted only to the subsoil part in which Richards' equation model simulates the soil water flow

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in the root zone based on Richards' equation while the simple TLM employs a simple water balance equation. Both approaches are capable of simulating the slow groundwater level fluctuation of the Skjern catchment. Regarding the goodness of fit with recorded groundwater levels, it can be stated that both models perform equally good. Full Richards equation is the most computationally intensive and need a set of soil hydraulic parameters which is hard to obtain due to time consuming and costly nature of laboratory measurements.

Conclusions

The MIKE SHE set-up is a suitable method to assess the effect of different unsaturated flow model conceptualization on the dynamic response through output variables. In this study, two different unsaturated flow model conceptualizations were compared: simple parameterization of Richards' equation (RI2) and two layer water balance model (TLM). The methods were compared in terms of their functional impacts on the MIKE SHE outputs. Significant effort was made to compare 2 different unsaturated flow models in terms of stream discharges and the contributing components at catchment and sub-catchment scales, recharge and groundwater levels.

Results from this study show that the simple TLM was the less complex one in 2 unsaturated flow models and needs less computation time. The close agreement between the simulated results and observed ones show that it is the most appropriate approach for Skjern catchment, while its weaknesses is not describing the groundwater dynamics well.

This study concentrated on unsaturated conceptualization model and the soil hydraulic parameters as input. The parameter distributions resulting from the different methods were presumed to be effective at grid scale, hereby disregarding any scaling issues. The match of true effective parameters versus the different methods will be assessed in follow-up work.

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