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Hydrology and Earth System Sciences
Discussions

Interactive comment on "Development and testing of a large, transportable rainfall simulator for plot-scale runoff and parameter estimation" *by* T. G. Wilson et al.

T. G. Wilson et al.

tiffany.g.wilson@duke.edu

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Thank you very much for your comments. The typos you found will be corrected and your other comments will be addressed here. The format is first your quoted comment or question followed by the response or change to be made in the manuscript.

"Page 4269, lines 12-14: perhaps consider emphasizing the lack of repeated measurements of soil hydraulic properties over time and how your work will help to overcome this issue."

1. On page 4269, replace the text starting with "Therefore" on line 12 through the end of the paragraph with "Specifically, there is currently a lack of studies that estimate soil hydraulic properties at multiple locations in a watershed and at multiple points in time. Indeed, such measurements are needed to improve the runoff response accuracy of watershed hydrologic models. In practice, this requires a large rainfall simulator that is capable of producing high rainfall intensities and can easily be transported between field sites for multiple measurements in space and time."
2. On page 4272, add the following sentence to the end of the paragraph ending on line 15: "Overall, this device will improve the ability of researchers to make more soil hydraulic property measurements over space and time that accurately assess plot-scale runoff response."

"Page 4274: why were the soil moisture probes inserted at an angle? - also why was 0-15 cm depth range selected to measure soil moisture?"

> Replace the sentence starting on line 23 of page 4273 with the following: "Time domain reflectometry probes (Campbell Scientific CS616) were used to measure soil moisture. Due to the presence of large rocks in the soil below 20 cm and the desire to take measurements in a regular grid and over a uniform depth, the probes were inserted at approximately a 30° angle from horizontal to measure the top 15 cm of the soil."

"Would eroding soil in runoff water harm the tipping-bucket mechanism or result in errors in measured amount of water runoff?"

> Add the following to the end of the paragraph ending on line 9 of page 4274: "At the current field site, the amount of sediment was considered

to be negligible compared to the mass of water. Additionally, no sediment appeared to collect in the buckets. In applications with higher erosion rates, a screen could be placed above the flow gate to filter sediment from the runoff."

"Page 4278: line 4: Did the value of K potentially change between 2008-2010?"

Given the premise of this work, it is certainly possible that the hydraulic conductivity at the time of the experiments was different than the 2008 estimate. However, this is the only measurement of K_s at this site other than the estimates made with the rainfall simulator, and neither land use nor overall vegetation cover at the site have changed during this time. We also recognize that the original point estimate is likely to be different from the the plot-scale effective estimate calculated here. That being said, the previous point estimate simply serves as an order-of-magnitude reference. Future work will address the effects of K_s varying in time.

"Page 4280: the meaning of condensed ponding time is unclear. Page 4280, line 15: what is the meaning of the prameters it, Kt, and theta? Page 4281: what is the meaning of T in equation 14? Page 4282: in equation 21 maybe consider using a different letter than Q for cumulative runoff as it is used to represent infiltration on page 4279"

These concerns are addressed with a revision of this section. First, Eq. (3) is revised to be

$$i_t^* = \frac{1}{2} S_t t^{-1/2} + A_t, \tag{3}$$

where i^* [L T^{-1}] is the infiltration rate at time t under ponded conditions...

Then, starting with Eq. (7) on page 4279, the remainder of Section 5 is revised as follows:

$$K_{t,bulk} = K_{s,bulk} \left(\frac{\theta_t}{\theta_s} \right)^{2b+3} \tag{7}$$

where $K_{s,bulk}$ [L T^{-1}] is the saturated hydraulic conductivity of the bulk soil rather than the soil surface.

The calculation of soil moisture comes from a one-dimensional water balance on a soil layer with thickness dz, beginning with $\Delta S = V_{in} - V_{out}$, where S is the water storage in the layer, V_{in} is the water entering the layer, and V_{out} is the water exiting the layer. S can be represented as $\theta \Delta z$, so $\Delta S = \Delta z(\theta_t - \theta_{t-\Delta t})$. V_{in} is the water infiltrating from above, so during a small time step Δt, $V_{in} = i \Delta t$. Neglecting evapotranspiration, V_{out} is the drainage of water through the bottom of the layer. Use of Darcy's Law, $v = -K \frac{\mathrm{d}h}{\mathrm{d}z}$, with a unit gradient yields $V_{out} = K \Delta t$. Therefore, the soil moisture prediction equation is

$$\frac{\theta_t - \theta_{t-\Delta t}}{\Delta t} z = i_t - K_{t,bulk} \tag{8}$$

or

$$\theta_t = \theta_{t-\Delta t} + (i_t - K_{t,bulk}) \frac{\Delta t}{z} \tag{9}$$

where z [L] is the soil depth being considered and i_t [L T^{-1}] is the actual infiltration rate, defined by

$$i_t = min(i_t^*, p). \tag{10}$$

See Table 3 for the parameters used in this analysis.

Infiltration is modeled using the above equations with a time step of $\Delta t = 1$ min. First, A and S are calculated according to Eqs. (6) and (4). Then, i_t^* and i_t are calculated using Eqs. (3) and (10). The current bulk soil hydraulic conductivity is calculated with Eq. (7), and then the bulk soil moisture θ_t is calculated using Eq. (9).

Since Eq. (3) is defined under ponded conditions, a correction must be made to the time used in the infiltration calculations to account for the time before ponding actually begins. Dingman (2004) accomplishes this using a condensed ponding time (t_{cp}), which acts to delay the start of runoff in the Philip model. Without it, modeled runoff begins much before observed runoff. Following Dingman's approach, t_s is defined as the first time in the original calculations when $p > i_t^*$. The total potential volume that can infiltrate before t_s is

$$I_p = \sum_{t=0}^{t_\mathsf{s}} i_t^*, \tag{11}$$

and since $p < i^*$ in this time period, the time it takes for the volume I_p to infiltrate is

$$t_\mathsf{p} = \frac{I_p}{p}. \tag{12}$$

The condensed ponding time is

$$t_{cp} = t_\mathsf{p} - t_\mathsf{s}, \tag{13}$$

which can be thought of as a correction for when runoff will actually begin compared to when it would start under ponded conditions.

Then, the above calculations for i_t, $K_{t,bulk}$, and θ_t are repeated using $\hat{t} = t - t_{cp}$ in place of t, generating the values $i_{\hat{t}}$, $K_{\hat{t},bulk}$, and $\theta_{\hat{t}}$ that now account

for the ponding correction. Finally, the modeled runoff is calculated as

$$q_{\hat{t}} = max(p - i_{\hat{t}}, 0). \tag{14}$$

Equations (3), (4), and (6) show that the infiltration of water through the surface, and accordingly the runoff, depend strongly on $K_{s,surf}$ but not on $K_{s,bulk}$. Likewise, Eqs. (9) and (7) show that $K_{s,bulk}$ affects θ_t but not i_t. Therefore, for a period of total duration T and cumulative runoff Q,

$$e_{Q_\mathsf{T}} = |Q_{T,mod} - Q_{T,obs}| \tag{15}$$

and

$$e_\theta = \left(\frac{\sum_{t=0}^{T} (\theta_{t,mod} - \theta_{t,obs})^2}{T} \right)^{1/2} \tag{16}$$

can be used as measures of error that, when minimized, indicate the optimal values of $K_{s,surf}$ and $K_{s,bulk}$, respectively. e_{Q_T} uses the final Q value to capture the overall behavior of the plot in producing runoff, and e_θ uses the time series of θ to capture the evolution of soil moisture during the experiment.

To optimize $K_{s,surf}$ and $K_{s,bulk}$, the infiltration model was run using all combinations of the two values ranging from 1 to 30 mm h$^{-1} atastepof \Delta K =$ 10^{-7} m s^{-1}$= 0.36$mm h^{-1}. e_{Q_T} and e_θ were calculated for each combination, and the combination with the smallest value of

$$e^* = e_{Q_\mathsf{T}} + e_\theta \tag{17}$$

was selected for the optimal values of $K_{s,surf}$ and $K_{s,bulk}$.

Again, thank you very much for your comments, particularly in regards to Section 5. We hope you find that the responses are adequate and improve the manuscript.

Interactive comment on Hydrol. Earth Syst. Sci. Discuss., 11, 4267, 2014.