Response to the comments of Referee #2 (James Ball) on the manuscript „Fluxes from Soil Moisture Measurements (FluSM v1.0). A Data-driven Water Balance Framework for Permeable Pavements"

We thank James Ball for his general remarks, his comments on urban hydrology and the points concerning the structure of FluSM. In the revision, we will consider those points which will help us improving the quality of the manuscript. We are deeply grateful for that.

R2C1: The response time for most urban surface water systems is significantly shorter than 10 min. Using a 10-minute computation step results in a lack of information and data in the surface flow hydrograph

A key characteristic of urban areas is the fast concentration, collection and conveyance of surface runoff (Shuster et al., 2005). This causes a high flashiness in surface flow hydrographs and modelling calls for a high temporal resolution of rainfall data. Besides the temporal resolution, also the spatial resolution of rainfall is decisive, since urban hydrological processes are characterized by a high variability not only in time, but also in space (Cristiano et al., 2017). Since high resolution rainfall data is rarely available, precipitation is often seen as a main source of uncertainty in urban hydrology (Cristiano et al., 2017; Niemczynowicz, 1999). This might also be the case for our study, for which we used rainfall data with a 10-min temporal resolution originating from one single urban climate station. Due to the location of our study sites within the public urban space, it was not possible to set-up site-specific rainfall gauges. We are aware that both factors (the spatial location of precipitation measurements and the temporal resolution) lead to an uncertainty of the precipitation input used for our study. However, we accounted for this uncertainty within our uncertainty analysis.

Within the uncertainty analysis, we accounted for the spatial heterogeneity of rainfall by using time series of different climate stations as ensembles. In order to account for small-scale rainfall variability, we additionally multiplied the time series by a factor ranging between 0.8 and 1.2. By doing so, we considered a large uncertainty range for precipitation (550-1150 mm/year), which we think should also account for the uncertainty caused by the 10-min temporal resolution. The results of the uncertainty analysis reveal that the effect on surface runoff is small for most plots. Only the results for 3 plots (GP15, CP14 and CP13), show large uncertainties in surface runoff, which we attribute to the low infiltration rate of those plots. However, the uncertainty of the results obtained for those plots, is also caused by the input uncertainty of precipitation. We will clarify this in the manuscript. Furthermore, we will point out that the effect of uncertain precipitation input depends on the plot-specific infiltration rate.

R2C2: Errors in the surface flow hydrographs will be balanced by equal but opposite errors in the infiltration component of the water balance (extension of R2C1)

Indeed, errors in the calculated infiltration lead to opposite errors which are equal in absolute value in surface runoff. Uncertainties in precipitation and in the infiltration rate may cause such an error in infiltration and surface runoff. Its possible magnitude is reflected in the uncertainty ranges obtained for surface runoff (Fig. 11). The results show that this error is negligible for plots with an infiltration rate above 70 mm/h while it is high for plots with an infiltration rate below 3 mm/h (CP15, CP14 and CP13). We will clarify this point in the revised manuscript.

R2C3: The distribution between surface runoff and infiltration needs to be provided if the 10-minute computation step is to be validated

Currently, FluSM returns time series for all water fluxes with a temporal resolution of 1 h. We will adapt the code of FluSM in the way that the surface water balance will be returned with a temporal resolution of 10 min.

R2C4: Surface runoff measurements are not provided for validation

We agree that such measurements would be desirable for validation. Most valuable would be measurements at the plot scale, since runoff measurements integrating large areas (e.g. measurements in sewer drains) would be difficult to interpret for the plot scale. Unfortunately, our plots are located in the public urban space (e.g. on residential roads, bicycle tracks, parking lots and pedestrian roads) and we are not aware of any practicable and affordable measurement set-up, suited for continuously measuring plot-scale surface runoff within the public urban space. Due to this, such measurements do not exist. However, there is data for plot-specific infiltration experiments provided in Schaffitel et al. (2019).

R2C5: C_{surf} is defined as the surface storage capacity, which is normally defined as the volume of water in temporary transit to the catchment outlet. It is therefore suggested that C_{surf} refers to the initial loss storage (sometimes also referred to as depression storage)

In FluSM, the surface storage is the water storage exiting at the atmosphere-soil/pavement boundary. Following Mansell & Rollet (2009) the surface storage consists of a depression storage (storage due to the micro relief of the surface) and the wetting capacity of the surface (amount of water required for wetting the surface).

To our knowledge, in urban hydrology, the initial loss is often determined by a linear regression of runoff against rainfall (intersect with the x-axis; e.g. Rodriguez et al., 2000).

For sake of clarity, we decided to use the term surface storage instead of initial loss. Furthermore, we decided to clearly distinguish between the state of this storage (S_{surf}) and its capacity (C_{surf}).

R2C6: A comparison of the obtained C_{surf} values with initial loss obtained by previous studies would be interesting

Indeed, we think that such a comparison would be valuable for the manuscript and we will include this in our discussion.

R2C7: The parameter I_{cap} may vary with time and not be a constant as assumed by the authors. Temporal distribution of storm and inter-storm periods determines the variability of I_{cap} and therefore additional information about precipitation events and mechanisms should be provided. In case of consistent precipitation mechanisms and self-compensating errors, the results could be reliable. Consideration of the rainfall mechanisms and attempting to include a variety of mechanisms would increase confidence in the authors' approach to parameter estimation.

This is a very interesting point. As pointed out in R1C3 and R2C2, we will further discus the parameter I_{cap} in the manuscript. However, we think that an additional analysis of precipitation events and mechanisms will not lead to further insights, which we will explain in the following.

We agree that the infiltration rate may vary with time, which is caused by a change of soil moisture during the infiltration course (which in turn controls the matrix potential and the hydraulic conductivity). However, describing infiltration only by matrix flux might be insufficient for PPs, since infiltration might be controlled also by other processes (e.g. preferential flow and hydrophobicity). For our plots, the variability of the infiltration rate over time is documented by plot-specific infiltration experiments under ponded conditions (see Schaffitel et al., 2019). Those experiments were used to derive a plot-specific infiltration rate for the beginning and for the end of the infiltration course (I_{start} & I_{end}). Thereby, I_{start} represents the infiltration rate when soils are dry, while I_{end} represents infiltration under steady-state conditions (constant soil moisture, matrix potential and hydraulic conductivity). Hence, the documented I_{start} and I_{end} should capture the possible variability of the infiltration rate caused by the temporal distribution of storm and inter-storm periods. We considered this variability in our uncertainty analysis and discussed its effect on the water balance. Thereby, the results show that the uncertainty of the parameter I_{cap} (and hence also the effect of the temporal storm and inter-storm distribution on this parameter) is relevant only for 3 plots with a very low I_{cap}, while it is negligible for the majority of the plots. Due to this, the results of FluSM for plots with a low I_{cap} should be regarded with care, while results are reliable for plots with an I_{cap} of at least 9 mm/h. In the revised manuscript, we will put a stronger emphasize on the requirement of high I_{cap}-values for the reliability of FluSM.

Literature

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