## Author Response to Referees

# The potential of green infrastructure in urban pluvial flood mitigation - a scenario-based modelling study in Berlin

Sophia Dobkowitz et al.
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**RC:** ***Referee Comment***, AR: *Author Response*, ☐ Manuscript text

Dear referees,

thank you very much for the positive responses, and for the time and effort spent to examine the manuscript.

With this letter, we provide the responses to both referee reports in one document. They basically correspond to our previous responses in the interactive discussion.

We hope that the revised version of the manuscript meets the standards of HESS.

Kind regards,

Sophia Dobkowitz (on behalf of the author team)

## 1. Responses to referee #1

**General comments:**

- **Different levels of detail in the modelling of individual processes**

**RC:** ***The manuscript uses a detailed, multi-layered, process-based representation of green infrastructure in the SWMM hydrological model, while surface runoff is introduced into the 2D hydrodynamic model via spatially aggregated inflow points rather than distributed precipitation and infiltration. The authors are invited to briefly discuss this trade-off between process complexity and spatial abstraction and to explain why the chosen level of detail of the green infrastructure is appropriate in general, but also in particular given the simplified representation of surface runoff in the 2D model.***

AR: SWMM employs a detailed, multi-layered representation of green infrastructure (GI) through its LID modules, including surface, soil, storage, and drainage layers using the Green-Ampt method. This level of detail is the default in the SWMM LID Module. The primary focus of the study is to assess differences in runoff generation between various GI types at the subcatchment scale.

The resulting runoff is subsequently transferred to TELEMAC-2D via aggregated inflow points. This approach is adopted for two main reasons: (1) SWMM already provides a robust representation of rainfall–runoff processes, and (2) the highly sealed urban environment, characterized by buildings, roads, and inner courtyards, exhibits complex flow pathways (e.g., narrow passages and underground garages) that are not adequately resolved by the available DEM. A fully distributed 2D rainfall–infiltration model would therefore require extensive and uncertain parametrization to represent these features realistically.

The chosen hybrid approach is appropriate because the effects of GI are most critical at the source, particularly in terms of runoff reduction, while the 2D model focuses on the spatial propagation of flooding. This framework ensures a balance between computational efficiency and process relevance and is consistent with established practices in coupled SWMM–2D modelling studies.

- **Justification of different infiltration approaches**

**RC:** ***Green infrastructure elements are modelled using, among other approaches, the Green–Ampt infiltration model, whereas infiltration from permeable surfaces is represented using the Curve Number method. The authors are encouraged to briefly explain the rationale for applying different levels of process representation within the same hydrological model and to comment on the implications of this choice.***

AR: GI is implemented exclusively with the Green-Ampt approach in SWMM. Furthermore, as flood mitigation impact of GI is the focus of our study, it seams appropriate to model GI more detailed than the other urban surfaces. Here, SCS-CN method was chosen due to its widespread application for urban environments and due to the lack of soil hydraulic parameters for urban soils. For further details, see answer to question RC1-11.

- **Spatial aggregation and presentation of spatial results**

**RC:** ***An illustrative figure showing the delineation of subcatchments and the locations of their outflows (corresponding to inflow locations in the 2D hydrodynamic model) would help to better understand the spatial representation within the modelling chain. In addition, an example illustrating the variability of runoff hydrographs among different subcatchments would be informative.***

AR: We added two new figures, showing the subcatchments with their outflow locations (see answer to question RC1-8) and exemplary runoff hydrographs to illustrate the different temporal runoff distribution among subcatchment types (see answer to question RC1-17).

**RC:** ***The final results are derived from spatially explicit information (e.g. water depths, affected buildings, and the area exceeding certain water depth thresholds). However, no spatial results such as inundation extent or water depth maps are presented. Including at least one representative map is recommended to support the interpretation and plausibility of the spatial results and to facilitate understanding of the aggregated indicators (see also the specific comment on Figure 3).***

AR: We added a map showing the inundation extent and water depths for the rain event with a return period of 100 years and described it as follows:

> Figure 5 shows the spatial distribution of the maximum water depth for two exemplary scenarios. It illustrates that $BR_{max}$ reduces flood extent and maximum water depth compared to the base scenario.

**Specific comments:**

**RC:** ***1. p. 4, l. 94-96: Where are the locations of the inflow hydrographs in the 2D model?***

AR: We clarified that the hydrographs are located at the centroids of the subcatchments used in SWMM

**RC:** ***2. p. 5, l. 113: Please briefly specify what is meant with "simplified hydraulic methodology"***

AR: We added the following paragraph to the manuscript to clarify what was meant with "simplified hydraulic methodology":

> Recently, the German Federal Agency for Cartography and Geodesy has released maps of simulated inundation (depth, extent, flow velocity) as a response to two heavy rainfall scenarios (one with a return period of 100 years and one extreme scenario of 100 mm/h), applying a simplified hydraulic methodology (BKG, 2025). However, it is important to be aware that those simulations ignore any storm runoff reduction or retention, e.g. due to inflow into the urban drainage system (gully inflow) or due to infiltration into surfaces, such as parks, green areas, green infrastructure or pervious sealing. That means, these maps show effects of urban surface hydraulics only, but not for hydrological processes, such as infiltration or urban water retention.

**RC:** ***3. p. 7, l. 126: Please indicate which duration for the 5-year precipitation event was chosen.***

AR: We added the information that a duration of 15 minutes was chosen, according to the recommendations of DIN EN 752-2

**RC:** ***4. p. 7, l. 127: Does this mean, a capacity of 16 mm every 15 minutes (i.e. 1.07 mm/min) or only during the first 15 minutes?***

AR: We clarified that the capacity of 16 mm (corresponding to a precipitation event with a return period of 5 years and a duration of 15 minutes) was applied only once at the beginning of the event.

**RC:** ***5. p. 7, l. 142: BR on 10 % of the area subtracted by the area covered by buildings: Has this been distributed over all residential subcatchments only or also road subcatchments?***

AR: Yes, BR was place in the overall catchment, including residential and road subcatchments, we have added this information.

**RC:** ***6. p. 7, l. 151: "we deduced the soil hydraulic parameters from this soil type": Please give the source from which the parameter values have been taken.***

AR: Most of the parameter values were defined based on the information in the EPA SWMM 5.2 User Guide (EPA 2023). We have specified in Table 3 from which source each parameter was deduced.

- EPA SWMM 5.2 User Guide (EPA 2023): *Vegetation volume fraction, Surface roughness, Field capacity, permanent wilting point, Conductivity slope: equation to calculate conductivity slope from soil type (80 % sand, 5 % clay, 15 % silt), Suction head, Storage layer void ratio, Drainage mat void fraction and roughness*
- Dobkowitz et al (2025): *Berm height, Layer thickness, Pavement void ratio and permeability*
- Rossman and Bernagros (2018): *Soil porosity*

- Schaap et al (2001): *Conductivity*

Additionally, we modified the paragraph about the GI parameters as follows:

> The GI types BR, GR and PP are implemented in SWMM as "LID Controls", i.e., "Bio-Retention Cell", "Green Roof" and "Permeable Pavement". For the required input parameters, we extracted typical design parameters and soil hydraulic parameters from Dobkowitz et al. (2025); EPA (2023); Rossman and Bernagros (2018); Schaap et al. (2001). As loamy sand is common in Berlin, we used the soil hydraulic parameters from this soil type. Table 3 shows the resulting set of parameters.

**RC:** ***7. p. 8, Table 2: Are all GI scenarios without gullies?***

AR: Exactly. For clarification, we added this information to table 2.

**RC:** ***8. p. 8, l. 162: A map that shows the subcatchments (and outlet points, i.e. inflow locations for 2D model) would be helpful.***

AR: We added a map showing the subcatchments with the attributed SCS-Curve Numbers and the outlet points used in SWMM and as input for the hydrodynamic model.

**RC:** ***9. p. 8, l. 164: Did topography also play a role in subcatchment delineation?***

AR: Topography did not play a primary role in subcatchment delineation. Subcatchments were defined based on building blocks (including courtyards/Innenhöfe, see Figure 1), which are functionally coherent hydrologic units where flow pathways to streets are difficult to represent — water typically exits only through narrow entrances or garages, which are not resolved in the DEM. Each building block was therefore aggregated into a single residential subcatchment to ensure realistic runoff estimates. Roads were delineated separately, as they are highly impervious subcatchments. While average slope was derived from the DEM, the flat topography (32–45 m a.s.l.) shows minimal elevation variability, making land-use/functional boundaries more relevant than contour-based delineation. This approach aligns with standard SWMM urban practice (Rossman et al., 2010) and supports accurate GI implementation at the block scale.

**RC:** ***10. p. 8, l. 167: "residential subcatchments as pervious except area covered by buildings": Is this rather an overestimation of perviousness?***

AR: You are right, it sounds like that. We deleted the sentence "The roads are defined as impervious, residential subcatchments as pervious, except the area covered by buildings.", as it was misleading. The Curve Numbers were assigned by combining land use and soil types, as explained in line 169.

**RC:** ***11. p. 8, l. 168: Is the SCS-CN method suitable here? Detailed multi-layer GI representation incl. Green-Ampt vs. simplified runoff generation using SCS-CN method for other areas; why was this combination chosen? Why not using Green-Ampt also for infiltration from pervious surfaces? (see also general comment 2).***

AR: The SCS-CN method was selected for non-GI surfaces due to its widespread application in urban catchments, its empirical calibration for land use and soil combinations, and its computational efficiency for event-based simulations (Yao et al., 2018).

The Green-Ampt approach is implemented exclusively within the SWMM LID modules (i.e., without user-selectable alternatives) and provides a more physically based representation of multi-layer soil hydraulics, which is critical for modelling GI processes (Stovin and Peng, 2017).

Figure 1: Example building block within the study area.

This hybrid modelling approach—combining SCS-CN for conventional surfaces and Green-Ampt for GI elements—is well-established in the literature (Baiamonte 2019).

Green-Ampt was not applied to pervious non-GI surfaces because reliable calibration data are lacking for heterogeneous urban areas (e.g., courtyards and parks), where soil properties can vary. For further details on the selection of the GI parameters, see answer to question RC1-7.

**RC:** ***12. p. 9, Table 3: Please briefly explain the surface slope for BR and GR was set to 1. The values for conductivity slope and conductivity are the same, please briefly explain what that physically means.***

AR:

- Surface slope: Regarding BR, surface slope is set to 0 % automatically within the model, so we will correct the value to 0 in table 3 for BR (as recommended by EPA, 2023). For GR we used a slope of 1 % as the majority of the roofs in our study area are flat roofs with inclinations of 0-1.14° (Belz 2010).
- Conductivity slope and conductivity: This is a coincidence. Conductivity = 43 mm/h is the value for loamy sand from Schaap et al. (2001), while conductivity slope was calculated from the soil type loamy sand using the equation specified by EPA (2023):

  conductivity slope = 0.48 * sand [%] + 0.85 * clay [%] = 0.48 * 80 + 0.85 * 5 = 43

**RC:** ***13. p. 10, l. 184-185: Do the output hydrographs strongly differ between the subcatchments? As suggested already before, it would be good to show the inflow locations in the 2D hydrodynamic model. (Furthermore,***

***"point source" sounds more like a pollution source; possibly "inflow hydrograph" or "inflow boundary condition" would be more suitable?)***

AR:

- We added a new figure showing the inflow locations, see answer to question RC1-8.
- We replaced the term point source in the manuscript by "single nodal inflow"
- We added a figure to illustrate how the subcatchment hydrographs differ between the two categories "Road" and "Residential". Looking at the summarized runoff hydrographs per subcatchment type helps to understand the behaviour of the different scenarios throughout the model chain (see answer to question RC1-17).

**RC:** ***14. p. 10, l. 207: "calibration performed well": Please clarify if the calibration has been carried out particularly for this study area or if a more general calibration has been carried out in advance and for another study area. Please explain briefly what "relative building damage" (corresponding to the given RMSE values) mean.***

AR: Calibration was done with the survey data from past urban pluvial events between 2010 and 2016 in Germany (l. 199), using cross validation from the same dataset.

We have added the following information to the paragraph:

- The survey data were split for training and testing
- The survey has no datapoints from within this manuscripts study area
- "Relative building damage" is the ratio between repair or replacement costs and the building value, 0.06 means a 6 % relative damage.

**RC:** ***15. p. 11, l. 209, 210: "In the application the model needs the maximum water depth and velocity from the hydraulic model (from which flood intensity is derived": Maximum water depth and maximum flow velocity do not necessarily occur at the same time, how is the flood intensity defined?***

AR: Flood Intensity is based on a practical information for the stability of people in the flood waters. Based on DEFRA (2006), the „Hazard Rating" = Depth * (Velocity + 0.5), shows a robust relationship to hazard levels for people. The survey data used for calibration depends on people observations, which impedes the acquisition of actual velocity values (in m/s), but instead records a qualitative „intensity". Therefore, we adapt the two different data sources (survey data from model training and hydraulic model for the application) by transforming them into hazard levels, or „flood intensity" using the given equation and defined thresholds. Flood intensity is fed to the model not as m²/s but as classes.

We have modified this paragraph as follows:

> In the application the model needs the maximum water depth and velocity from the hydraulic model (from which flood intensity is derived) and building information from cadastral data (either authoritative or OpenStreetMap data). Maximum water depth and velocity do not necessarily occur at the same time, and this is a potential bias in our approach, in which we potentially overestimate the hazard. We do so for a compatibility of approaches with other data sources, namely (official) flood hazard maps, which often provide solely the max depth and max velocity of a scenario. The same occurs in the survey data used for training, where only maximum depth and maximum „intensity“ are reported.

**RC:** ***16. p. 11, l. 232 ff.: Flow velocities were not used for the damage calculation in this study, but are indicated in the flow chart in Figure 1 - this is a bit misleading; do the authors assume no effect of the flow velocity at all for this study area? What are critical thresholds of flow velocities having an impact and which (maximum) flow velocities occur in the scenarios?***

AR: This sentence was misleading. As explained in the comment above, flood velocity is used in the damage modelling, not explicitly but as component of the „flood intensity“. It is, therefore, relevant for damage estimation.

We only decided not to discuss and plot flow velocity separately in the flood mitigation analysis, as the occurring flow velocities are very small due to the flat topography. Hence, the flow velocities only become relevant when combined with water depth to estimate the damage.

To clarify this, we modified the indicated paragraph as follows:

> Flow velocity in combination with water depth is crucial for damage modelling. However, due to the flat topography of the study area, flow velocities are rather low. Hence, flow velocity was not discussed separately in the flood mitigation analysis.

**RC:** ***17. p. 13, Figure 3: The results indicate that, in medium scenarios, PP reduces total runoff less than BR but leads to greater reductions in flooded area and damaged buildings. Since only runoff from the hydrological model is used as input to the hydrodynamic model, this discrepancy may be due to the spatial variability of inflow hydrographs from different subcatchments. An illustrative figure showing this spatial variability would help to clarify and interpret these effects.***

AR: We appreciate your very detailed observation. In order to illustrate how the hydrographs differ between the different GI scenarios and subcatchment types, we added a figure with hydrographs of some example rain events.

Within the results section, we amended the respective paragraph as follows:

> Among the single GI scenarios, BR produces the lowest runoff with medium and maximum extent. Regarding the flooded area and damaged buildings, BR is also the strongest among the single GI scenarios with maximum extent, however, at the medium scenarios, PP outperforms BR in most events. This can be explained by a look at the temporal distribution of runoff. Figure xx (new figure) shows the runoff hydrographs for the base and single GI scenarios for two exemplary events. In the first column, all subcatchments are included, in the second column only runoff from residential subcatchments and in the third column only runoff from road subcatchments is summarized. It shows clearly how much higher the peak runoff and shorter the runoff duration is for road subcatchments without GI measures compared to the residential subcatchments. In both represented scenarios, the overall peak runoff for $\mathrm{BR_{med}}$ is more than twice as the overall peak runoff for $\mathrm{PP_{med}}$. This results in a larger flooded area and more damaged buildings for $\mathrm{BR_{med}}$, although the runoff volume is lower compared to $\mathrm{PP_{med}}$.

**RC:** ***18. p. 16, l. 294-295: I assume a realization on streets is more challenging, and since Knoche et al. indicated only 4.5 % on streets, the PP max scenario might be very ambitious.***

AR: We agree that in the case of retrofitting GI, as in our study area, unsealing the already built street is a very ambitious plan. Hence, we adapted the corresponding sentences as follows:

> This means that $\mathrm{GR_{med}}$ is realistic within the next 30 years. The scenarios $\mathrm{PP_{med}}$ and $\mathrm{PP_{max}}$, however, require with 25 and 50 % a much higher unsealing of streets. Besides, the 3 scenarios with the largest conversion to GI ($\mathrm{GR_{max}}$, $\mathrm{GR_{max}}$+$\mathrm{PP_{med}}$ and $\mathrm{BR_{max}}$+$\mathrm{GR_{max}}$) require reductions of the total impervious area beyond those elaborated by Knoche et al. (2024) for a timeframe of 30 years. Hence, their realisation within the next decades seems unrealistic.

**RC:** ***19. p. 19, l . 374 ff.: The discrepancy between reductions in total flood volume (from other studies) and in the percentage of area exceeding a water depth of 10 cm could be attributed to strong reductions at localized hotspots with very high water depths, which have a disproportionate influence on total flood volume compared to area-based indicators using a fixed depth threshold.***

AR: This is also a valuable explanation. We added the following paragraph at the end of the indicated section:

> Furthermore, the discrepancy in the flood mitigation impact between the compared studies can be explained by the use of different measures of flood volume itself. Strong reductions at localized hotspots with very high maximum water depth could result in a disproportionate decrease of total flood volume compared to the area-based indicator used in this study.

**RC:** ***20. p. 19, l. 381: The run time of 1D drainage models is usually relatively small compared to that of 2D models, so the overall runtime is not necessarily much higher. However, the effort required for model setup can be considerably higher, particularly if no drainage model exists in advance that can be coupled to the 2D model.***

AR: Ok, we have omitted the run-time argument.

**RC:** ***21. p. 21, Appendix A: Please clarify how the building damage categories ("low" to "very high") are defined and how they correspond to hydraulic variables such as maximum water depth.***

AR: Thank you for pointing out that we had not defined the damage categories in the manuscript. The damage categories are a split of the relative damage (see answer to question RC1-14).

A direct relationship between damage and each predictor variable is hard to plot or define, as the model is by nature non-linear. All predictors interplay in estimating the relative damage and thus the damage categories.

We added the following explanation of damage classes to the table heading:

> Building damage classes, based on the relative building damage: Low: 0–5 %. Medium: 5–10 %. High: 10–15 %. Very High: 15–100 %.

## 2. Responses to referee #2

**General comments:**

**RC:** ***1. The methodological approach of working with different open source models (model chain) leads to inaccuracies in the model interfaces. How sensitive to results are these model interfaces, even if they represent a global boundary condition of the relative comparison?***

AR: We agree that the coupling of the different models leads to certain inaccuracies but this is rather due to the methodological framework of the model chain and not because the models are open source. Looking at each step of the model chain we can say the following:

1. Rain input to SWMM: Here we do not expect uncertainties, as there is no physical feedback between hydrology and meteorology for short heavy rain events in the urban environment.
2. SWMM to TELEMAC: Here we expect an uncertainty, as there is interaction between hydrologic runoff formation and the hydrodynamic runoff concentration. This is especially relevant for the sewer network. Some research groups are recently working on the development of a bidirectional coupling of TELEMAC and SWMM.
3. TELEMAC to FlooDEsT: Theoretically it is possible, that at extreme flood conditions a building gets so heavily damaged that it is simply swept away. However, this is highly unlikely in a flat area with low water velocities. Furthermore, models capable of simulating such scenarios on a large scale are still the subject of active research

We took into account this methodological limitation, which mainly concerns the interface of SWMM and TELEMAC. In the introduction, before specifying the research questions, we added:

> Our aim is not to present a fully calibrated flood model chain, but rather a framework for assessing green infrastructure (GI) effectivity.

**RC:** ***2. Simply taking into account the drainage contribution of the sewer system by reducing the effective precipitation is quite inaccurate. This also fails to take into account overflow effects from the sewer system to the surface. Since this cannot be quantified, it would be helpful at least to be discussed in greater detail.***

AR: In order to consider your concern about the simplified representation of the sewer system, we added the following paragraph to the methods section 2.3.2 Conventional stormwater management:

> This simplification does not allow to represent processes such as sewer overflow to the surface. We opted for this approach nevertheless, as the drainage system of our study area is not publicly available and the sewer system is not the focus of this study.

**Specific comments**

**RC:** ***1. p. 1, l. 3 (abstract): Flood risks cannot be reduced by the influence of evapotranspiration from BGI, as correctly stated on p8, L163 (contradiction)***

AR: Evapotranspiration is important to empty the storage after the rain event but does no reduce flood risk during the event. Consequently, we have removed it here.

**RC:** ***2. p. 3, l. 59: Neumann et al. 2024 do not describe the overflow frequencies of the CSO.***

AR: Maybe this formulation was not clear enough; we are not talking about combined sewer overflow (CSO) frequencies but volumes. In table 8, Neumann shows the sewer overflow volume for the different scenarios, which results in a sewer overflow reduction of 95 % for the described event. As the study area has a combined sewer system, this is CSO volume reduction. We added "volume" to the sentence to make it more understandable:

> CSO volume even decreased by 95 % for the same event.

**RC:** ***3. p. 7, l. 125: Citation of EN 752-2 by Sieker & Neidhart is not necessary (secondary reference)***

AR: We agree and therefore removed the reference.

**RC:** ***4. p. 7, l. 137: GR Soil layer > 1m is the exeption/very rare, not common.***

AR: That's true, such soil layers are not common. Consequently, we have removed it and just state that intensive GR have a soil layer of at least 12 cm.

**RC:** ***5. p. 8, l. 173: Depression storage of roads as a contribution to the sewer network ("gully absorption") is very inaccurate (see above). How high are the contributions in each case (please supplement Appendix A if necessary)?***

AR: As our simplified gully approach was applied only in the gully scenario, the contribution of this "gully absorption" can be seen very easily in Figure 3 and Table A1 by comparing gully to base scenarios and in Figure 4. In order to avoid any confusion if the "gully absorption" might also be used in the GI scenarios, we clarified this in table 2 (see answer to question RC1-7).

**RC:** ***6. p. 9, table 3: the berm height (surface layer) defines how quickly the BGI overflows and thus has a decisive effect on flood mitigation. Were any other values for berm height examined? It would be good to describe the sensitivity of this important parameter.***

AR: It is right that berm height is a very important GI parameter. For instance, we used for BR a berm height of 150 mm. In case of the 100-year event (50 mm), a decrease in berm height to 50 mm increases runoff by 42 %, while an increase in berm height to 200 or even 300 mm decreases runoff by 20 or 55 %, respectively.

For the extreme event (100 mm), the differences in berm height matter less, with runoff increasing by 13 % with a berm height of 50 mm and decreasing by 6 or 18 % when increasing berm height to 200 or 300 mm, respectively. We decided for a berm height of 150 mm based on values from the literature gathered in Dobkowitz et al. (2025), (for further details on the GI parameters, see answer to question RC1-6).

Describing in detail the sensitivity of berm height would require to discuss also more parameter values and go beyond the scope of this study. However, we included this topic by adding the following paragraph in the end of discussion section 4.1:

> Besides the spatial extents of the GI scenarios, flood mitigation is sensitive to design parameters such as berm height and layer thickness, and their hydraulic parameters. These parameters were selected based on the literature as described in section 2.3.3 and we did not include more variations of each GI type, as the focus of this study is the comparison between different rain events and the propagation of the flood mitigation through the model chain. However, testing more parameter sets would allow to investigate if the comparison of different GI types is robust or too sensitive to the parameters.

**RC:** ***7. p. 10, l. 203 ff.: The building damage model is only briefly described with reference to Thieken et al. 2005. However, due to the complex boundary conditions, it can be assumed that it is subject to considerable uncertainty despite extensive modeling. This should be emphasized more clearly, even if the focus is on the relative comparison of the results. Important individual aspects that are not adequately considered are e.g. the lack of cadastral information on basements.***

AR: The model itself is referenced to Samprogna Mohor et al., 2015 (l. 197), whilst Thieken et al., 2005 (Line 206) gives further details about the input variables. We overcome the missing cadastral information by random sampling and use the average damage class as final result (as already stated in l. 210-212). Across the random sampling, despite some variation in the estimated damage degree, in 97 % of runs the estimations fell under the same damage class (low, medium, high, or very high), which indicates a robust result. For the damage model is by nature non-linear, a direct sensitivity analysis per predictor (e.g. basement) is not straightforward.

We added the following sentence to the manuscript:

> After the random sampling process, despite some variation in the estimated damage degree, in 97 % of the runs the estimations fell under the same damage class (not shown), which indicates great stability of results.

**RC:** ***8. p. 11, l. 209, l. 232: In addition to water depth and flow velocity, the duration of exposure also has a major impact. The models and hazard maps only show the maximum amplitude of the flood. This is inaccurate for damage assessments.***

AR: Although duration is, strictly speaking, an influencing factor and could be relevant for a “universal” damage model for all flood types, duration was deemed not statistically significant while training the model specific for urban pluvial floods, which present overall events of shorter duration. The damage model FlooDEsT was developed specific for urban pluvial floods, which is also the application in this manuscript. We can reinforce that this is not a flaw of the Recursive Partitioning approach. Parallel damage model developments based partially on the same survey dataset but using different modelling families (Bayesian Regression - Mohor et al. 2021; Bayesian Network - Vogel et al 2018) similarly show low significance of Duration as a predictor for urban pluvial floods (therein labelled „surface water floods“).

**RC:** ***9. p. 17, table 4: The comparison with other studies is good and valuable. The other studies are cited and described only with a brief comment. However, where possible, it should be explained in more detail how the model boundary conditions differed in the other case studies in order to evaluate the deviations in the results more clearly.***

AR: We added further information to the short presentation of the studies used to compare runoff retention:

- Ercolani et al. (2018) used the model smart-green (MOBIDIC-U and a QGIS plugin) to investigate GR in a 1.9 km2 study area in Milan, Italy (MAP 800 mm). The GR is composed of a 200 mm soil layer and a 150 mm drainage mat.
- Fu et al. (2020) coupled SWMM and Hydrus-1D to model PP in a 3.3 km2 study area in Xiamen, China (MAP 1413 mm). Below the permeable brick layer with a thickness of 60 mm, there are 4 different permeable layers with in total 940 mm.
- Hua et al. (2020) also studied PP, using the model MIKE URBAN for a 7.4 km2 study area in Chaohu, China (MAP 1307 mm). In this study, the pavement layer is 120–180 mm, underlain by 300 mm of permeable material.
- Peng et al. (2019) investigated GR with SWMM in a 0.044 km2 study area in Fuzhou, China (MAP 1500 mm). The GR has a berm height of 15 mm, a soil layer thickness of 150 mm and a drainage mat of 30 mm.
- Schlea et al. (2014) investigated BR with an experimental study, using a rain gauge, graduaded containers for runoff and drainage measurements and piezometers for water table changes. This setup was used in a 869 m2 study area located in Westerville, USA (MAP 1105 mm). The layer thicknesses were not reported in the study.
- Zhang et al. (2020) modeled BR with SWMM in a 6.07 km2 study are in Kyoto, Japan (MAP 1677 mm). The BR has a berm height of 150 mm, soil layer thickness of 700 mm and a storage layer of 300 mm.

**RC:** ***10. p. 21-23, Appendix A, table A1: How are the building damage categories ("low" - "very high") quantified and categorized? Are they corresponding to the max. water level?***

AR: Thank you for pointing out that we had not defined the damage categories in the manuscript. The damage categories are a split of the relative damage (see answer to question RC1-14).

A direct relationship between damage and each predictor variable is hard to plot or define, as the model is by nature non-linear. All predictors interplay in estimating the relative damage and thus the damage categories.

We added the following explanation of damage classes to the methods section about the building damage model:

Building damage classes, based on the relative building damage: Low: 0–5 %. Medium: 5–10 %. High: 10–15 %. Very High: 15–100 %.

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