COMMENTS TO EDITOR

I have now heard from two reviewers regarding your revised manuscript. One reviewer (who had seen the original version of your manuscript) is satisfied with the modifications you have made. Another reviewer (who had not reviewed your original manuscript) also finds merit in your work but would like you to address a few points before your manuscript can be ready for publication, particularly one regarding the limits/challenges associated with your methodology. I agree that a more "balanced" discussion of the advantages and disadvantages of your methodology will be helpful to the readers of HESS. I am therefore returning your manuscript for minor revisions.

Response:

This document contains the replies to the comments of the article hess-2020-136 titled "Assessing different imaging velocimetry techniques to measure shallow runoff velocities during rain events using an urban drainage physical model" by Juan Naves et al. In this document, we respond the comments that have arisen in this new review and indicate the relevant changes made in the manuscript. These changes focus mainly on clarifying the advantages and disadvantages of each method. Finally, we would like to thank the editor and the reviewers for their accurate and fair review and for all the time invested in improving our manuscript.

COMMENTS TO REVIEWER 1

The authors have responded to all my comments and I have none further. I thank the authors for considering my comments and responding in a detailed way, with modifications to the paper where appropriate. I think that the facility is an important one for testing these types of techniques and that the paper should be a valuable contribution to the field.

Response:

Thank you again for your time and helpful comments.

COMMENTS TO REVIEWER 3

The review relates to the revised version of the manuscript, and it considers the answers that had been given to the previous review. The well-prepared manuscript compares the performance of different imaging velocimetry techniques for overland flow velocity estimation under the influence of raindrops by means of controlled pilot-scale experiments. It represents a valuable scientific contribution in the field, in particular as the study comes with a comprehensive data set, i.e. findings that are based on solid experimental research. Well-done and very appreciated!

Response:

We would like to thank the reviewer for the interest showed on our work and the positive evaluation. We think that the external point of view of the reviewer has led to fair, concise, and useful comments. We have done our best to address them and improve the discussion of our results, so that it is helpful and clear for future laboratory and real-world applications.

R3C1: Revised manuscript follows a classical structure, provides (considering references to other publications of the group) sufficient insights in the design of the experiments, presents illustrative results, followed by a discussion slightly biased towards the benefits, avoiding the challenges. The "all-too-positive" tenor, that had been criticized by a previous reviewer (which I agree with), was only partially addressed in the first review.

This is a major point, and it needs to be addressed before final publication. To be more precise: the discussion of the ability of the techniques to correctly measure under real-life conditions (line 388 ff) is essential, but still too optimistic. For instance (cf. line 390 ff.), it is obvious that the results achieved for unseeded techniques show severe deficiencies for rain intensities higher than 30 mmh-1. This aspect however is qualified by underlining the advantages of the technique, e.g. not having to rely on artificial particles to be added to the flow, etc. The doubtlessly existing advantages of unseeded techniques cannot hide the fact that overland flow velocities for higher rainfall intensities cannot be estimated accurately. On the other hand, statements like the one in line 394 is rather wishful thinking, relating to other studies which may show the potential under real-life conditions, but for single events and without the interference of raindrops. IMO the study here provides evidence that the evaluated techniques have limitations, and this should be unambiguously stated.

In a similar fashion, in the Conclusions (line 444, ff) it should be made clearer which method can potentially be applied under which conditions (shallow flows, events of low intensity, influence of raindrops for different intensities). In the current version of the manuscript, I am missing clear sentences like "seeded techniques are not able to measure velocities in areas with extreme shallow flows" which are included in the answer to previous reviews. I think making these aspects crystal-clear (e.g. like "method xy is suitable for rain intensities below a threshold of yz mm h-1") does not diminish the value of this excellent work, but it helps to do further research or to apply techniques under real-life conditions.

Response:

Following the comments of the reviewer, we have tried to un-bias the discussion and conclusions of the manuscript to reflect the remaining challenges and the how to deal with some limitations of imaging techniques during rainfall events in urban catchments. Thus, the first paragraph of the discussion (section 3.3) has been rewritten clarifying the limitations of unseeded techniques as follows (Pg 19, Ln 404):

"The assessment of different imaging velocimetry techniques and the analysis of the influence of different factors on the velocity results contribute to understanding how these methodologies could be adequately transferred to real urban catchments. The use of these techniques would favor new velocity data sources to calibrate physically-based urban drainage models, such as traffic, public or surveillance cameras (Leitão et al., 2018; Moy de Vitry et al. 2020) or even unmanned aerial vehicles, which have already been used in river flow measurements (e.g. Lewis and Rhoads, 2018; Pearce et al., 2020). The insights gained in this study show the limitations of unseeded LSPIVu and BIV techniques to estimate runoff velocities under high rain intensity conditions or when complex flows are developed. Raindrop impacts on the water surface produce disturbances in the movement of the bubbles used as tracers that can prevent cross-correlation algorithms from obtaining reliable velocity distributions. In our experiments, this problem was observed when the rain intensity was higher than 30 mm/h, but this threshold may vary depending on the overland flow velocity or the raindrop kinetic energy. However, as there is no need to add artificial particles in the unseeded techniques they benefit from being straightforward to implement. Their ability to estimate velocities in extremely shallow flows,

where particles tend to be deposited, also make these techniques a potential tool for measuring velocities in field applications without the interference of raindrops or under light rain conditions. In contrast, it was observed that using artificial particles as tracers makes the LSPIV and LSPIVb techniques robust against heavy rain conditions and complex flows, such as those developed in Area 3 of the present study (Fig. 8). Therefore, the use of seeded techniques is recommended to estimate overland velocities in real urban catchments under rainy conditions, or when the measured flows are not simple enough. Special attention must be paid to the deposition of particles when the flow is extremely shallow."

In addition, the second and third bullet of conclusions have been modified to include clearer sentences and specify which method can potentially be applied under which conditions (Pg 22, Ln 467):

"- Both the seeded and unseeded techniques provide suitable velocity distributions in cases of unidirectional flows and the lowest rain intensity of 30 mm/h, with an offset of approximately 0.05 m s-1 between them. This offset is a consequence of the different tracers used in the seeded and unseeded experiments, which are affected to different degrees by raindrop impacts and may be transported at different velocities. Lower velocity indexes are thus required in the case of unseeded techniques to convert the results to depth-averaged velocities and these are affected by rain intensity.

- LSPIVu and BIV unseeded techniques are not able to estimate runoff velocities for higher rain intensities due to the disturbances introduced by raindrop impacts, which prevent cross-correlation algorithms from obtaining displacements and thus velocity distributions. The use of artificial particles as tracers by LSPIV and LSPIVb makes these seeded techniques robust against heavy rain conditions and are thus recommended in future field studies during rain events. Seeded techniques are also able to measure complex flows, where bubbles have difficulties in following the overland flow avoiding unseeded techniques to determine velocities. However, unseeded techniques can be suitable in field and laboratory applications in unidirectional flows and without the interference of raindrops or under light rain conditions, since they require a simpler experimental setup and are able to measure velocities in extremely shallow waters where artificial particles tend to be deposited."

R3C2: line 19 - replace "feasibility" with "potential". The study illustrates the feasibility for controlled experiments but not for real-life applications!

Response:

This is completely true, so it was changed (Pg. 1 Ln. 19). Following this comment, "feasibility" has been also substituted by "potential" in introduction (Pg. 3 Ln. 8) and discussion (Pg. 20 Ln. 427).

R3C3: Abstract as well as Conclusion: despite it is mentioned in the Conclusion, that further research in real urban catchments should be done: it must be emphasized that the usefulness, i.e. the robustness of the techniques for real-life applications yet remains to be proven by means of further studies in non-controlled environments. With this respect, tangible recommendations on how to approach a validation under real-life conditions should be made to facilitate future research. What about the influence of

different surfaces/surface roughness in real-life catchments, or the influence of wind, similarly occurring as raindrops, etc.

Response:

We agree with the reviewer in the importance of emphasizing this point. The following sentence has been added to the abstract (Pg. 1 Ln. 21):

"The robustness of the techniques for real-life applications yet remains to be proven by means of further studies in non-controlled environments."

In addition, a comment regarding further research on non-controlled conditions has been added to conclusions (Pg. 23 Ln. 501):

"The potential use of seeded and unseeded techniques in urban catchments has been proven, but future research should be oriented towards studying their robustness in real-world applications under non-controlled environments. The influence of the wind on rainfall distribution, catchment surface roughness or variable illumination conditions should be assessed in order to develop suitable pre-and post-processing procedures and correctly estimate runoff velocity results."

Other minor issues:

- line 120: replace "rugosity" with "roughness". Plus, it would be very helpful to know the roughness value of the concrete slab in the physical model to put results into context, e.g. when considering other surfaces.

Response:

Fixed (Pg 5, Ln 126). The roughness value following Naves et al. (2019a) is 0.016. It has been added to the facility description in Pg 3, Ln 94. It is true that this value can be helpful if the present results are compared with works on other surfaces, thank you for the remark.

"The roughness value of the roadway concrete surface is 0.016 (Naves et al., 2019a)."

- line 288: "To do this and following the previous results". Awkward formulation. Consider rewriting.

Response:

We have rewritten it for a better readability as follows (Pg 12, Ln 289):

"Following the previous results (Sect. 3.1), the reference values of the parameters (Table 1) have been considered for this comparison."

- The English should be checked again prior final publication! Sentences are partially very long, i.e. complex (e.g. line 301 ff). Along with the language check, the authors may want to simplify the text at a few occasions in order to improve readability.

Response:

We have revised the full text trying to improve readability. In addition, the new version of the manuscript has been again checked by a native professional to ensure the quality of the writing. The changes are spread through the entire manuscript.