Dear editor,

We thank you for the opportunity to revise and improve our manuscript according to the comments made by the reviewers. Below we have detailed our point-by-point response to the comments with references to the line number where adjustments have been made in the manuscript.

Thank you for your time and consideration in reviewing the revisions we have made.

Kind regards,

Karen Gabriels, Patrick Willems and Jos Van Orshoven

COMMENT REVIEWER 1

I think this is an interesting paper with a good data-based approach, but it needs more work on explanations, understanding of hydrological processes being modelled, the impact of antecedent soil moisture and some analysis of sensitivity to modelling assumptions such as interpolations of water surface on the outcomes. The reduction in impacts for afforestation is very large.

Thank you for your time and consideration in reviewing our manuscript. We agree that the discussion of our manuscript can further be extended. We further elaborate on how we propose to adjust our manuscript according to your remarks.

The derivation, calibration and validation of hydrological rainfall-runoff model is further detailed in a recently published paper:

Gabriels, K., Willems, P., & Van Orshoven, J. (2021). Performance evaluation of spatially distributed, CN-based rainfall-runoff model configurations for implementation in spatial land use optimization analyses. *Journal of Hydrology*, *602*, 126872. https://doi.org/https://doi.org/10.1016/j.jhydrol.2021.126872

This paper also includes an extensive discussion of the limitations of this model. We propose to provide a reference to this paper in our manuscript and to strengthen the discussion of our manuscript to include the implications of the most relevant modelling processes and assumptions, including the adjustments of the model to antecedent soil moisture conditions. The interpolations of water surfaces will impact the estimate of water depth and therefore also the flood risk assessments. However, this uncertainty relates to both the reference situation, before land use change, and after land use changes have been implemented. The uncertainty related to the water depth does therefore pose less of an issue in the relative assessment of both situations, as proposed in this framework. We will clarify and extend on this in the discussion of our manuscript (L434–441 in revised manuscript).

The reduction in impacts for the land use change scenarios are difficult to validate, as validation data are lacking. To provide some indication on the accuracy of the flood risk assessment, we provided a comparison with the flood risk model LATIS (Beullens et al., 2017):

Beullens, J., Broidioi, S., De Sutter, R., De Maeyer, P., Verwaest, T., & Mostaert, F. (2017). *Ontwikkeling LATIS 4 Deelrapport bis: Actualisatie basiskaarten en schadewaarden. Versie 3.0. WL Rapporten, 13_159_7.* Universiteit Gent, Antea Group, Waterbouwkundig Laboratorium: Antwerpen.

This model has been used in Flanders to provide a benchmark economic flood risk assessment. The discussion on the uncertainty related to the comparative risk assessment will be strengthened by adding additional information regarding the assumptions made in the land use change scenarios (L229–234 in revised manuscript). For instance, the assumption is made that a full-grown forest is implemented, which will lead to the overestimation of the impact of afforestation (L354–359 in revised manuscript). In addition, the combination of a limited number of flood events with a limited number of return periods does also influence the impact assessment of the land use changes, with a larger number of events and return periods leading to a more accurate assessment (L449–454 in revised manuscript).

COMMENT REVIEWER 2

I have three main queries under flood damage estimates: residential damage is likely overestimated, the role of property-level flood risk adaptations (PLFRA), and the critical role of duration.

Thank you for your time and consideration in reviewing our manuscript. Your comments definitely provide an interesting perspective on our manuscript. Below we provide a response to your remarks and indicate how we will adjust and improve our manuscript accordingly.

For the estimates of flood damage to residential buildings – the value of a home includes the land, the services to the land, e.g. sewer, water, electricity, and the property itself. Therefore, the cost of refits/rebuilding after a flood is some fraction of the value of the property. Estimates could be based on insurance pay-outs or other data.

For the analysis there are repeat floods in the same areas, yet the estimates of damage use the same formula – however, we might expect households, farmers, etc to implement PLFRA. Indeed, insurers may require such PLFRA. Some articles on PLFRA are:
https://wires.onlinelibrary.wiley.com/doi/full/10.1002/wat2.1404 and
https://www.witpress.com/elibrary/sse-volumes/5/3/995

Duration is discussed earlier in the paper, but Figure 3 is just extent and Figure 6 is depth and damage estimates. Duration is critical in terms of damage costs to farmland and to residential properties – including to intangible costs. See here for estimates of the role of duration on farmland damage,
https://onlinelibrary.wiley.com/doi/epdf/10.1111/jfr3.12041

The maximum damage values in our manuscript provide an estimation of the values of the properties exposed to the flood. These estimates are based on the average housing prices in the different municipalities. We hereby follow the approach as implemented in the LATIS model, the benchmark model in Flanders for flood risk assessments (Beullens et al., 2017):

Beullens, J., Broidioi, S., De Sutter, R., De Maeyer, P., Verwaest, T., & Mostaert, F. (2017). *Ontwikkeling LATIS 4 Deelrapport bis: Actualisatie basiskaarten en schadewaarden. Versie 3.0. WL Rapporten, 13_159_7.* Universiteit Gent, Antea Group, Waterbouwkundig Laboratorium: Antwerpen.

The damage after flooding is then derived from the expert-based water depth-damage curves, which are also applied in LATIS. These curves detail the fraction of the value of the property representing the flood damage for a given water depth. We implemented this approach, as there is a lack of consistent, complete and spatially distributed data on insured flood damages in Flanders. Indeed, this economic flood risk assessment does not consider the resilience to flood damage, which can be increased through

the implementation of property-level flood risk adaptations. It also does not take into account the duration of flooding, though we acknowledge that this will also influence the total damage resulting from the flood event. The economic assessment in our manuscript is limited to the direct, tangible flood damage. Therefore, the ecosystem insurance value estimates only relate to these direct, tangible damages.

We will make the assumptions related to the damage estimates, and the underlying reasons for these assumptions, more explicit in the introduction of our manuscript (L54–55 and L82–85 in revised manuscript). We will add to the discussion the limitations of this direct, tangible economic flood risk assessment and discuss the implementation of PLFRA and the impact of flood duration with the inclusion of the interesting references you have provided and other relevant publications (e.g. https://www.cogitatiopress.com/urbanplanning/article/view/4246) (L404–424 in revised manuscript).

I understand how you estimated the afforestation and sealing scenarios, but I wondered if there is a threshold in either scenario? There must be threshold effects with increased sealing of the uplands and with undermining the benefits delivered by natural upstream areas, i.e. once they are opened for development the natural area will be under greater pressure for development. Surely these areas contribute a lot to the provision of flood regulation ecosystem services?

Our land use scenarios do not take into account threshold effects. The land use scenarios pertain to the optimization exercise, and provide an indication where afforestation and sealing will resp. maximally reduce or minimally increase flood hazard in the flood-prone areas. Socio-economic land use dynamics are thus not considered in the implemented afforestation and sealing scenarios. However, these dynamics will surely play a role and influence the ecosystem insurance value. Our generic comparative flood risk assessment framework allows any land use change scenario to be evaluated, also more detailed, socio-economic based scenarios. As such, the generic capacity of the framework provides perspectives for research on questions of the type the reviewer mentions.

The takeaway that it is OK to build in the uplands near forest patches and afforestation is primarily around rivers seems somewhat counterintuitive and these unexpected results are not explicitly discussed and need to be. Are there other more realistic scenarios that could be generated, i.e. a scenario that pays attention to development and conservation planning in this catchment? This might include afforestation that also occurs in the upland and development that occurs in already residential areas or near these areas. Yet another scenario could try to estimate the mitigation fraction provided by upland conserved/forested areas by modelling the removal and/or partial removal of these areas.

The message of our manuscript is not that it is OK to build in the uplands and afforestation should only occur in the lowlands, but rather that building in the uplands leads to a lesser increase of peak discharge and flood volumes than building in the lowlands, and that afforestation of the riparian zones leads to a larger reduction of peak discharge and flood volumes than afforestation of the uplands. We can add further context to the results of the optimization analysis, thereby also highlighting the limitations in allocating sealing and afforestation with the single objective to reduce flood hazard. We will further nuance the findings of the optimization exercise and add references to other research reflecting these findings (e.g. https://hess.copernicus.org/articles/14/325/2010/) (L236–243 in revised manuscript).

As the land use change scenarios were selected to reflect the spatial planning context in Flanders, a highly urbanized region, we can also refer to recent policy measures implemented in Flanders, protecting and

restoring wetlands in river valleys with a view to reduce flood hazard. As mentioned, the proposed framework allows ecosystem insurance value to be derived for any land use change scenario. As the focus of this manuscript is more on the proposed risk assessment framework rather than on the land use change scenarios, analysis of additional land use change scenarios, although perfectly possible, would be beyond the scope of this manuscript. The land use change scenarios we addressed are related to Gabriels et al. (2022):

Gabriels, K., Willems, P., & Van Orshoven, J. (2022). An iterative runoff propagation approach to identify priority locations for land cover change minimizing downstream river flood hazard. *Landscape and Urban Planning*, *218, 104262. https://doi.org/10.1016/j.landurbplan.2021.104262*

In future research the implementation of other types of solutions can be considered, for instance the implementation of flood control reservoirs or the establishment of floodplains. The latter would require a more detailed hydrological model, to enable the consideration of small-scale landscape elements. These measures could indeed reduce associated costs. We propose to add a section to the discussion related to the perspectives on future research offered by our generic flood risk assessment framework (L361–382 in revised manuscript).

As you note the costs of afforestation are high, another scenario could assess other NBS, i.e. the best places for floodplain floodwater storage. An advantage of such a scenario is that the storage of floodwaters would be temporary which might reduce associated costs.

The afforestation mitigation outcomes seem very high – are these % reductions similar to those found in other research?

The validation of land use change scenarios is challenging, and little comparable research is available assessing the impact of land use change scenarios on flood risk. A comparison is made with the findings of Koks et al. (2014) (https://link.springer.com/article/10.1007/s10113-013-0514-7). We will also include a reference to our recently published paper, outlining the rainfall-runoff model implemented in the flood risk assessment framework:

Gabriels, K., Willems, P., & Van Orshoven, J. (2021). Performance evaluation of spatially distributed, CN-based rainfall-runoff model configurations for implementation in spatial land use optimization analyses. *Journal of Hydrology*, *602*, 126872. https://doi.org/https://doi.org/10.1016/j.jhydrol.2021.126872

This paper provides additional insights into the uncertainty related to the hydrological modelling. In order to provide some validation for the flood risk assessment itself, a comparison was made between the estimated flood risk with the original land use and the bench-line economic flood risk estimates provided by the model LATIS (Beullens et al., 2017).

It would be useful for Readers who do not know the area to have the main towns located on the figures and to have an overall view of the area, i.e. an indication of where the rural areas, farmland, residential areas are.

We agree and will add a land use map of the study area to our manuscript (p. 8 in revised manuscript).

Many of the references seem older or perhaps it is the absence of more recent references that is an issue.

We have tried to include the most relevant references to our research. We could search for more recent references; however, limited research has been done to assess the impact of land use/ecosystem changes on flood risk. Our manuscript presents a novel perspective on the ecosystem insurance value, which could provide an interesting incentive for future research in this important field of study.

Word choice:

- *Around line 33 – elements – perhaps 'assets'. This word is repeated several times.*
- *Around line 124 – analogue – perhaps 'an analogue to…' or 'analogously' or 'similar to' – again this word is repeated several times.*

We agree and will adjust our manuscript accordingly.