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Date: September 29, 2026  
Journal: Natural Hazards and Earth System Sciences  
  
Subject: Response letter to peer review of referee #1 on manuscript titled: "Split incentives in property-level flood adaptation across households, insurers and government in the Netherlands"

Dear anonymous referee,

We thank the reviewer for the constructive and helpful comments, which we will use to strengthen the manuscript in the revised version. We address the major comments jointly first, followed by point-by-point responses to the minor comments.

### **Major comments:**

#### Referee comment

I found some parts of the methodology not sufficiently described. In particular, I found that the three different hazard models used in the study (primary defence breaches, regional defence breaches, precipitation) are not described with a sufficient level of details for the reader to properly understand the implications of the different modelling choices, and to understand how the different modelling components interact with each other. For instance, there is no mention of the spatial structure of the models' outputs; are these maps, or aggregate, at which resolution? Knowing the spatial resolution of the different hazard models would help the readers to link the hazard models to the exposures model, for which spatial resolution is explicitly mentioned. Furthermore, other details pertaining modelling choices of the hazard are only mentioned allusively (e.g. *Climate change effects on coastal and fluvial flooding are incorporated through scenarios with elevated external water levels.*), whereas the provided reference in Dutch does not allow non-Dutch speakers to look up clarifications for these modelling details (for instance what are the specific scenarios, and elevated water levels). The manuscript would clearly benefit a more detailed description of the different hazard models, where appropriate and where the provided references are not accessible to all.

#### Authors' reply

We agree that the hazard description in the submitted version leaned too heavily on Dutch-language reports, which makes the modelling choices hard to follow for non-Dutch readers. In the revised manuscript, we will expand Section 2.2 so that a reader without access to the Dutch sources can follow i) what each hazard component produces, and ii) at which spatial resolution, and iii) how the components are combined into a single per-property estimate, and (iv) how climate change enters each component. The specifics of the climate representation (line 130) and the one-fifth regional-defence convention (line 133–134) are given in full in the point-by-point replies below; here we summaries the methodological additions to the hazard description.

*Spatial structure and resolution.* All breach and precipitation components are raster-based inundation models whose output is a map of maximum water depth per scenario per grid cell. Resolution varies with the source study from which each scenario was assembled, and it differs between hazard types. This is because the scenarios are commissioned by different water authorities at various moments in time. In the table below you find an overview of the different resolutions. In revising the report, we will decide how exactly we want to include this (with an extra table or in running text).

| <b>Flood source</b>     | <b>Count</b>    | <b>Grid resolution (n scenarios)</b>         | <b>Depth encoding</b> | <b>Failure/exceedance prob. 2025</b>       | <b>2050</b>                              | <b>Climate representation</b>                                      |
|-------------------------|-----------------|----------------------------------------------|-----------------------|--------------------------------------------|------------------------------------------|--------------------------------------------------------------------|
| Primary defence breach  | 1,928           | 100 m (738), 25 m (619), 50 m (568), 5 m (3) | continuous            | VNK, corrected for completed reinforcement | statutory standard ( <i>ondergrens</i> ) | 2050 scenario with external water level plus one decimation height |
| Regional defence breach | 2,894           | 25 m (1,686), 50 m (712), 5 m (470)          | continuous            | 1/5 × statutory standard                   | constant                                 | none                                                               |
| Regional water system   | 108             | predominantly 5 m                            | continuous            | scenario exceedance frequency              | —                                        | none                                                               |
| Precipitation           | 3 design events | ≈2 m                                         | 5 depth classes       | STOWA (2019) frequencies                   | frequencies × 1.21                       | frequency scaling                                                  |

*Combination into per-property risk.* The flood sources are not modelled jointly. For each sampled property, the MyWaterRiskProfile API (HKV, 2025) samples every scenario map at the property coordinate and combines the per-scenario depths with corresponding exceedance probabilities into a single water depth–exceedance probability curve for that location. We will make this explicit in Sect. 2.2.

*Relation to the exposure resolution.* The precipitation input is resolved at ≈2 m, finer than an individual dwelling, whereas breach depth at most locations derives from cells one to two orders of magnitude larger than the building footprint (50–100 m for 68 % of primary-breach scenarios). We now state this explicitly, and we note that the producer of the national maps documents the same limitation: some scenarios are computed at 100 m, "a cell size many times larger than a house, that can even fall across dike-ring boundaries" (our translation of Rikkert et al., 2025, §2.3.2).

## Minor comments:

Referee comment: Line 99-100: *we drew 12,992 dwellings, a ratio of one 100 sampled dwelling per 662 in the Dutch housing stock (Table 1).* Why did you choose these numbers specifically? Please clarify.

Authors' reply: The sample size was set pragmatically and not with a very hard statistical target. We drew the largest sample for which the per-location hazard queries remained computationally practical (the current set resulted in 3 weeks of computing time). At 12,992 locations the narrowest risk band reported in Sect. 3 contains approximately 130 properties, sufficient for stable band means. We will add a brief clarification to the manuscript.

Referee comment: Line 130: *Climate change effects on coastal and fluvial flooding are incorporated through scenarios with elevated external water levels (Rikkert et al., 2025).* Please add descriptions of the modelling of climate change effects as the provided reference is not available in English.

Authors' reply: We will add the following description to Sect. 2.2.1. For coastal and fluvial flooding, climate change is represented for 2050 by scenario substitution: at each breach location the present-day scenario is replaced by the LIWO scenario for an external water level one decimation height higher (the level whose present-day exceedance frequency is a factor of ten rarer. So the modelled inundation depths increase, representing sea-level rise and higher river discharge leading to elevated external water levels during breaches. Independently, 2050 breach failure probabilities are set to the statutory safety standard, reflecting completion of the Flood Protection Programme; the net effect is a lower breach probability but greater depth when a breach occurs.

Referee comment: Line 133-134: *Failure probabilities for regional defences were set at one-fifth of the applicable statutory safety standard, following STOWA (2020).* Why do you choose a ratio of 1/5? Please clarify as the provided reference is not in English.

Authors' reply: For regional flood defences there is no database of failure probabilities or levee assessments similarly to primary flood defences. Hence, the 1/5 assumption is the common practice in the Netherlands and adopted in various water management studies. The idea behind the 1/5 assumption of the statutory standard is that levees don't immediately fail when the design water level is reached. The allowable failure probability is distributed across failure mechanisms, and the water-level-driven mechanism carries only part of that budget, so it is estimated that the resulting flooding probability is about one-fifth of the exceedance-frequency norm. We note that the factor is a standardised convention whose calibration is itself under reconsideration (STOWA, 2021), which is consistent with the methodological-uncertainty theme of this study. We now provided more background in the manuscript so readers can value this assumption better, with also denoting that we currently likely overestimate regional flood risk, because failure probabilities in practice are often lower/safer than 1/5 of the statutory standard.

Referee comment: Line 145-146: You increase the frequencies of the flood events but do not increase their intensities. Is that a reasonable assumption given that future precipitation events are expected to become more intense with climate change? Please explain.

Authors' reply: Intensification shifts the depth–frequency curve, which can be represented equivalently as deeper events at fixed frequency or more frequent events at fixed depth. Because the national pluvial maps exist only for three fixed design events (35, 70, 140 mm in 2 h), we apply the shift on the frequency axis via the STOWA (2019) climate factor of 1.21, which embeds the projected intensification of short-duration extreme rainfall. Important addition is that this holds within the mapped range only: rainfall beyond the 140 mm / 1000-year event is not represented and the highest depth class in the precipitation map is unbounded ('larger than 0.3 m'), so extreme-tail pluvial risk is likely a bit underestimated, which was not explicitly noted in the original manuscript.

Referee comment: Line 168: It is unclear what the Van Ederen curves refer to; please name the different curves that you will describe when introducing the paragraph, in line 165: *We used two sets of depth-damage curves that are in active use among Dutch practitioners; the SSM curves and the Van Ederen curves.*

Authors' reply: For clarification purposes we added that the Van Ederen curves are indeed part of the two sets of curves we started the section with.

Referee comment: Line 173-174: [...] *the Van Ederen vulnerability scenario in this study differed from SSM only in the structure-damage component.* How do the two curves differ? Please clarify.

Authors' reply: The two sets differ only in the structure-damage component; the contents curves showed no material difference (Van Ederen et al., 2025), so the SSM contents curve was used in both vulnerability scenarios. The SSM structure curve remains relatively low up to about 2 m depth and steepens only beyond it, whereas the Van Ederen structure curve, calibrated on the insurance-claim data from the 2021 Limburg flood, is substantially higher across the 0–2 m range in which most modelled events fall. Relative to SSM, the Van Ederen structure damage is roughly a factor of 6 higher at 1 m depth and a factor of 3 higher at 2 m, the gap narrowing as depth increases. Added the clarification.

Referee comment: Line 265: It is not clear to me what *shallow events* means here. Do you mean pluvial flooding? Please clarify.

Authors' reply: Clarified that indeed mean pluvial flooding of several decimeters.

Referee comment: Line 277: what are Lorenz curves? Please describe or provide a reference.

Authors' reply: We will clarify what Lorenz curves show in this context.

Referee comment: *Insurers received the largest share of avoided damages in the P50 - P90 and P99 - P100 bands; in the P90 - P99 bands government received the largest share, because primary defence breach still drove baseline EAD there.* I do not see these specific bands on any of the plots or table, can you please clarify which figure or table you are referring to when describing the results?

Authors' reply: As we changed the tables and corresponding text over time, the descriptions and the tables/figures are not fully in sync anymore. We adjusted the manuscript so that we have a match again. Thank you for this observation.

Referee comment: Line 324: *The corners bracket the plausible range*. This sentence is unclear to me. To which corners are you referring to? If you are referring a figure, please mention it explicitly at the beginning of the sentence or paragraph.

Authors' reply: "Corners" refers to the two extreme combinations of the 3 × 3 hazard × vulnerability grid, shown in the bottom row of Fig. 3. We have made this explicit: "The two extreme grid combinations bracket the plausible range (Fig. 3, bottom row): BREACH × SSM gives the lowest failure probabilities and damages, and standard × Van Ederen the highest."

Referee comment: Figure 3: I find this figure hard to read. If possible, consider other visualizations (e.g. bar plots).

Authors' reply: We will adjust Figure 3 to make it easier to read.

Referee comment: Figure 4: *four range-bars compare households (HH), insurers (INS), government (GOV) and the location total*. Please check consistency between the figure's labels and the legend. What is location total? Please also check for colour-blind friendliness

Authors' reply: The figures are colour-blind friendly, as we use colorschemes from Fabio Crameri (<https://www.fabiocrameri.ch/>). Location total will be reformulated, this is indeed a bit ambiguous. It is about the full coalition budget.

Referee comment: Line 333-334: *per-property EAD followed insurers > government > households in eight of nine method combinations*. Can this be inferred from the figure? If not, clearly state that this is not inferable from the figure or consider alternative visualization.

Authors' reply: The ranking insurers > government > households for each of the nine combinations not readable from Fig. 3. We will note that.

Referee comment: Line 347: *Below P95, the three-way coalition budget spreads remained small relative to plausible adaptation costs*. I think it might be helpful here to remind what are "plausible adaptation costs".

Authors' reply: Agree.

Referee comment: Line 386: *a ten-year record captures mostly frequent events even with Limburg included*. Do we now the estimated return period of an event such as Limburg? If yes, including this information could be helpful for contextualization.

Authors' reply: There debate is not yet settled on the return period as there are many figures floating around but we will give an indication (including references).

Referee comment: Line 391-393: *The three-stakeholder coalition budget remained seven to nine times the household-only budget in every band where adaptation is financially relevant*. Do you mean here that the household-only budget equals the three-stakeholder budget most of the time? If not, please clarify or rephrase.

Authors' reply: The coalition budget is seven to nine times larger than the household-only budget, not equal to it. The current phrasing was apparently ambiguous. We will rephrase to: "In every band where adaptation is financially relevant, the three-stakeholder coalition budget exceeded the household-only budget by a factor of seven to nine."