

ANSWER TO EDITOR

Journal: NHESS

Author (s): Contreras-Jara et al.

Manuscript ID: egusphere-2025-4016

Title: “Indirect Costs of Floods: A Case Study of Highways Road Users”

Iteration: Second review (Editor comments)

Executive Editor: Prof. Margreth Keiler (NHESS)

#	Comment	Answer
EC-0	The manuscript addresses a timely and relevant topic and presents a potentially useful framework for estimating the indirect costs of flooding to highway users. In particular, the integration of hydrological and hydraulic modelling, infrastructure vulnerability, traffic assignment, travel-time losses, and fuel consumption is of interest. Both reviewers nevertheless identified substantial issues concerning the structure, methodological transparency, reproducibility, and justification of the main modelling assumptions. I therefore invite you to submit a major revision that addresses all reviewer comments carefully and comprehensively.	We thank the Executive Editor and both reviewers for their constructive assessment. The manuscript has been thoroughly revised: it was restructured to separate the conceptual framework, the methodology, the case study, the discussion and the conclusions (R1-15); the input data sources, the flood-depth selection criterion, the vulnerability models and all model parameters are now reported explicitly to ensure reproducibility (R1-3, R1-8 to R1-10); and the main modelling assumptions are stated and justified. The editorial remarks (a)–(g) are addressed individually below. The submission includes the replies to both reviewers, this reply to the Editor, and the revised manuscript in tracked and clean versions.
EC-1	(a) Please use a clear and consistent definition of flood risk. The definitions given around lines 44 and 87 appear to differ. Please distinguish explicitly between hazard, event probability, exposure, vulnerability, consequences, and risk.	Both definitions have been homologated following Aven (2011). The definition in the Introduction (line 47) has been simplified, and Sect. 2.1 (lines 91-94) now follows it instead of restating it, specifying that the consequences depend on the intensity of the event, the exposure of the elements within the flooded area and their vulnerability, and that they are expressed here as the costs transferred to road users.
EC-2	(b) Please strengthen the discussion of the scientific added value beyond the case study. Clearly identify which elements are novel and which findings or methodological insights are transferable to other road networks and flood contexts. Relevant recent literature should be considered, including Papilloud et al. (2024), Science of the Total Environment, 956, 177140.	The novel elements of the study are now identified at the beginning of Sect. 5 (lines 452-459), and the transferable elements are distinguished from the case-specific ones in the Conclusions (lines 469-471). The suggested reference has been considered, together with related literature on flood-induced road disruption (Coles et al., 2017; Arrighi et al., 2019; Papilloud et al., 2024), and incorporated in Sect. 2.2 (line 123) and Sect. 5.
EC-3	(c) Please provide clear and sufficiently visible source information for all maps, background imagery, and spatial datasets. Where required, attribution should appear both within the figure and in the caption.	Source information has been added to all maps. Figures 3, 4 and 5 now carry the base map credit, Esri World Imagery, both within the figure and in the caption, and the captions state the origin of the flood extent and the coordinate system.
EC-4	(d) Please improve the data and code availability statements. The data, model inputs and outputs, scripts, parameters,	We have revised the Data Availability statement to clarify access to the underlying data and code. The road network baseline

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	and processing workflows should be deposited in appropriate repositories where possible. Any restrictions should be explained.	information and traffic simulation results for the Aconcagua River Basin are openly deposited in Datos de Investigación UC (Contreras-Jara et al., 2026), available at https://doi.org/10.60525/04teye511/FHGMNE . The traffic assignment code used in this study (Kumar, 2019) is open-access and is now cited in Sect. 4.4.2, line 404.
EC-5	(e) Please report the main quantitative findings in the abstract and check the consistency of the return periods and indices used in the expected annual cost calculation. The valuation year and any inflation or currency-conversion assumptions should also be stated.	The abstract has been revised to report the main quantitative findings, and consistency of return periods and indices in the EAC calculation has been checked. The valuation year and currency-conversion assumptions have also been added.
EC-6	(f) Please cross-check all citations and references and ensure that the standard Copernicus end-matter sections are included.	All citations and references have been cross-checked for accuracy and consistency, and the standard Copernicus end-matter sections have been included in the revised manuscript.
EC-7	(g) Please carefully revise the English throughout the manuscript, including spelling, grammar, and sentence structure. English-language editing is not provided by NHESS at any stage. If needed, please consider using a professional language-editing service at your own discretion.	The English throughout the manuscript has been carefully revised for spelling, grammar, and sentence structure.
EC-8	Would you please also provide an author's reply to both reviewers and to the editorial comments above. Please include a track-changes document showing the differences between the original and revised manuscripts.	Point-by-point responses to both reviewers and to the editorial comments are provided below. We also attach a track-changes version and a clean version of the revised manuscript, in which all differences relative to the original submission are clearly identified.

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Iteration: First review

Reviewer #1

#	Comment	Answer
R1-1	The manuscript presents an integrated framework to estimate Expected User Costs (EUC) for highway networks affected by flooding. The approach combines hydrological and hydraulic modelling, bridge and road vulnerability models, and static traffic assignment to quantify indirect impacts on users in terms of increased travel time and fuel consumption. The method is applied to the “Aconcagua Bajo” watershed in Chile, and EUC is computed across return periods from 2 to 100 years. The topic is timely and important, particularly because quantifying indirect economic impacts on road users remains insufficiently addressed in flood-risk literature. The explicit inclusion of fuel consumption in the EUC metric is a notable and useful contribution. The manuscript is scientifically relevant and addresses an important gap by estimating user-based indirect flood losses. However, several aspects of the structure, clarity, and methodological transparency require improvement before publication.	We thank Reviewer 1 for the positive assessment of the manuscript and for the constructive comments that have helped improve its clarity and methodological transparency.
R1-2	clarity and Structure: The narrative often anticipates methodological elements that are described in detail only later. The overall structure (methodology vs. case-study description vs. results vs. discussion) could be reorganised to follow a more conventional and reader-friendly flow.	The manuscript has been reorganized to follow a more conventional flow. The new structure is described in response to comment R1-15
R1-3	replicability: Some essential modelling details are missing or only partially provided (e.g., input data sources, flood-depth selection per road segment, functioning of vulnerability models). Providing these details is crucial for transparency and reproducibility.	The modelling details flagged in this comment have been addressed individually in the responses to comments R1-8, R1-9, and R1-10, where the exact data sources and URLs, the flood depth selection criterion, and the description of the vulnerability models have been clarified and incorporated into the revised manuscript
R1-4	key modelling assumptions: several strong assumptions (e.g., traffic assignment minimising travel-time only, constant capacity for flooded roads, threshold probabilities for interruption) require clearer justification and references.	The modelling assumptions highlighted in this comment have been addressed as follows: the travel time cost and fuel consumption cost components of the traffic assignment are clarified in the response to R1-11; the 15% traffic

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		interruption threshold is justified in the response to R1-14. Regarding the assumption of constant road capacity under flooding, this is valid within the scope of the study, which evaluates a fixed maximum flood depth scenario for each return period. The analysis does not consider temporal variability of flood depth during an event; therefore, capacity and interruption states are treated as static conditions associated with the peak flood scenario. This assumption has been acknowledged in the revised Discussion section (lines 477- 479): “The traffic assignment model assumes constant road capacity and static interruption states for each flood scenario, based on the maximum flood depth for each return period. Temporal variability of flood depth during an event, which could result in variable capacity and transient interruption states, is not considered in the present study.”
R1-5	Overall, I recommend major revision to strengthen structure, clarity, and methodological completeness.	All specific comments have been addressed individually in the responses incorporating clarifications on structure, data sources, modelling assumptions, and methodological transparency into the revised manuscript. The improved structure is explained in response to comment R1-15.
R1-6	Conceptual clarity & definitions Line 89 (Risk-receptor consequences): The definition is unclear. Please clarify what is meant by risk-receptor consequences within this framework, or provide a reference.	We change the paragraph to clarify the term as follows (line 92 - 94): “Consequences comprise three factors (Gouldby and Samuels, 2005): exposure, vulnerability, and the potential affection on people or damage to infrastructures.”
R1-7	State of the art & motivation Line 108: The statement “Engineers face challenges in estimating traffic reassignment...” requires a supporting reference. Several works in the hybrid flood-risk modelling literature could be cited.	Supporting references were introduced. The following change is included between Lines 112-114: “Engineers face challenges in estimating traffic reassignment and road user costs as a proxy for the expected annual damage (EAD) in flooded highway networks (Pregolato et al., 2017b; Hackl et al., 2018; Zhang and Alipour, 2019, 2020; Qiao et al., 2023; Rebally et al., 2026).”
R1-8	Data and replicability Line 143: “The traffic assignment model uses road and traffic data obtained from national road and traffic surveys...”	The road and traffic datasets used are publicly available. We introduce a paragraph with explicit references and data sources in lines 405-410 as follows: “The traffic assignment model uses road and traffic data obtained from national

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	Please specify the exact datasets, source years, and URLs if publicly available, to ensure replicability.	road and traffic surveys conducted yearly by the Chilean Ministry of Public Works (MOP): the National Road Network geodatabase (MOP, 2020a; available at http://www.mapas.mop.cl/), its dimensions and characteristics (MOP, 2020b), and the National Traffic Survey 2019 (MOP, 2020c; available at https://vialidad.mop.gob.cl/plan-nacional-de-censo-vial/). All datasets are freely accessible online.”
R1-9	Road-flood overlay and hydraulic outputs Line 163: When overlaying flood maps with the road network, each segment may experience varying flood depths. Please clarify which water-depth value is used for computing vulnerability and speed reduction (e.g., maximum depth along the segment? average? depth at centroid?).	The flood maps produced by HEC-RAS 2D represent the maximum flood depth at each pixel for each return period. When overlaying these maps with the road network, the flood depth assigned to each segment corresponds to the maximum value recorded along that segment, which represents the most restrictive condition for traffic operability. This criterion was clarified in lines 172-185 as follows: “The flood maps represent the maximum flood depth at each pixel for each return period. For each road segment, the maximum flood depth along the segment was extracted from these maps and used as input to the traffic interruption probability model (Eqs. 5 and 6) and the speed reduction model (Eq. 7), as it represents the most restrictive condition for traffic operability”
R1-10	Vulnerability models Lines 165–167 (Contreras-Jara et al. 2018): Equations (5) and (6) provide the calibrated probability of interruption, but a brief qualitative description of the underlying model is needed for readers unfamiliar with the reference. For example, explain in a sentence whether it is an empirical fit derived from controlled experiments, traffic data, or physical modelling.	A brief description of Eqs. (5) and (6) was included in the revised manuscript in lines 209–212. “The traffic interruption probability model for flooding, given by Eqs. (5) and (6) for light (Pint-light) and heavy (Pint-heavy) vehicles respectively, were used to estimate road vulnerability. Contreras-Jara (2018) calibrated Eq. (5) and Eq. (6) for Chilean conditions using reliability principles. The models estimate the probability of traffic interruption in terms of the flood height (h, m).”
R1-11	Traffic modelling Line 173: The sentence mentions speed, traffic volume, and travel time, but not fuel consumption. Since fuel consumption is essential for EUC, clarify how FCC is computed, linking clearly to Section 7.5.	The term FCC is wrong. The actual term is f_v (line 268). We erase the text “....and fuel consumption costs (FCC)” The value was obtained from the reference MDS (2020). It is included in section 4.4.3, line 430.
R1-12	Hydraulic modelling Section 5.2:	We confirm that the same DEM was used in hydraulic modeling. The

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	The DEM resolution of 12.5 m is used in hydrological modelling; confirm explicitly whether the same resolution is used in HEC-RAS 2D hydraulic simulations.	following change is included in lines 353 to 355: “The same ALOS PALSAR digital elevation model (12.5 × 12.5 m resolution, JAXA 2011) used for hydrological modelling was used as terrain input for the HEC-RAS 2D hydraulic simulations.”
R1-13	Also clarify whether road elevations (crest level, crown elevation) are known or assumed based on DEM.	Road surface elevations were extracted from the ALOS PALSAR DEM (12.5 × 12.5 m) at the centerline of each road segment. Given the DEM vertical resolution, deriving more precise road elevations from this source is not feasible; this limitation has been acknowledged in the revised manuscript at Line 377 – 378: “Road surface elevations were obtained from the ALOS PALSAR DEM (12.5 × 12.5 m, JAXA 2011), extracted at the centerline of each road segment. Given the vertical margin of error of the DEM, more precise road surface elevations cannot be derived from this source”.
R1-14	Traffic interruption thresholds Line 300: “The limit values of Pint-light and Pint-heavy of 15% were defined.” This choice is unclear. Please explain why 15% was selected, whether this threshold is standard in the literature, and how sensitive results are to this assumption.	The 15% threshold is derived from the calibration range of the speed reduction model by Pregnolato et al. (2017a, b), which is valid for light vehicles up to $h = 0.3$ m. A justification was included in lines 222 – 225: “In the flooded links, the limit values of $P_{\text{int-light}}$ and $P_{\text{int-heavy}}$ were set at 15%, consistent with the upper calibration limit of the speed reduction model of Pregnolato et al. (2017a, b) for light vehicles at $h = 0.3$ m. The same threshold was applied to heavy vehicles using Eq. (6), yielding a flood depth limit of $h = 1.0$ m.”
R1-15	Structure and flow The manuscript currently mixes theory, methodological detail, and case-study information across sections. I strongly suggest adopting a clearer structure: (i) Methodology (all models, equations, thresholds), (ii) Case-study description (all input data and site characteristics), (iii) Results (hydraulic outputs, exposure, vulnerability, network costs), (iv) Discussion and limitations. This would significantly improve readability.	We change the paper structure as follows (third level titles are omitted): 1 Introduction 2 Flood risk in highways networks 2.1 The flood risk concept 2.2 Flood risk in highway networks modeling 3 Methodology for estimating the road network flooding risk 3.1 General description of the procedure 3.2 Workflow 3.3 Step 1: Hazard modeling 3.4 Step 2: Road network exposure modeling 3.5 Step 3: Road network risk modeling

#	Comment	Answer
		4 Case study and application: Road Network of Aconcagua Basin 4.1 Study area 4.2 Flood hazard modeling 4.3. Road network exposure to floods 4.4 Road network risk modeling 5 Results discussion 6 Conclusions

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Reviewer #2

#	Comment	Answer
R2-1	This study presents a method/procedure that integrates hydrologic and hydraulic flood modeling with road and bridge vulnerability analysis and traffic modeling to estimate user-related costs. The framework is applied to the Aconcagua Bajo watershed in Chile, analyzing floods of varying exceedance probabilities (2-100 year return periods) and their effects on bridges, roads, and overall traffic efficiency. Overall, this study is comprehensive, and the findings are meaningful for accurately estimating indirect costs due to floods. However, I still have several comments and suggestions for improving the current work.	We thank Reviewer 2 for the constructive comments that have helped improve its clarity and methodological transparency.
R2-2	1) Line 17: “EUC” stands for expected road user cost or expected user cost? Please make sure it is consistent throughout the manuscript, and write the full name for its first appearance and use the acronym afterwards, e.g., “EAD” in Lines 94 and 109, why “HMH” stands for hazard modeling, and so on. Also, it is suggested to add a list of all the acronyms to the appendix part.	We standardize the term through the paper using “Expected User Cost” (EUC). The same criterion has been applied to all other acronyms (e.g., EAD, HMH).
R2-3	2) Line 25: Floods can be also caused by rapid snowmelt.	Snowmelt has been added as a flood-triggering mechanism in the revised manuscript at Line 28 of the new version as follows: “Floods are primarily caused by rainfall, and in mountain watersheds, by rapid snowmelt, which, increases.....”
R2-4	3) Equation (3): The second term on the right-hand side of the equation should be $P(h_{j+1})$ instead of $PD(h_{j+1})$.	We thank the reviewer for catching this typo. The notation has been corrected in Eq. (3) of the revised manuscript.
R2-5	4) Equation (4): Please make it clear that $T_1 > T_2 > T_3$.	We introduce in the right-hand side of Eq. (4) the aclaration “where $T_1 > T_2 > \dots > T_3$.”
R2-6	5) Sections 5.1 and 5.2: What is the spatial resolution of the DEM data used in hydrological and hydraulic modeling?	The hydraulic model was built using the ALOS PALSAR DEM (12.5×12.5 m, JAXA 2011). We introduce the resolution in lines 173, 320, 349 and 377.
	How were the model parameters, such as the Manning’s roughness coefficients, calibrated in this study?	This clarification was introduced in revised version in lines 350 – 351. “Manning’s roughness coefficients were assigned based on land use/land cover classification derived from satellite imagery, following Chow (1988)...”.

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R2-7	6) Section 5.2: It should be noted that the uncertainty in the hydraulic modeling process determines the accuracy of the model outputs. Thus, it is suggested to employ the probabilistic flood inundation maps instead of the deterministic maps for the future analysis if possible. Please refer to the paper below. Reference: “Uncertainty analysis and quantification in flood insurance rate maps using Bayesian model averaging and hierarchical BMA” (https://doi.org/10.1061/JHYEFF.HEENG-5851)	We acknowledge that probabilistic flood inundation mapping would reduce uncertainty in model outputs. However, the deterministic approach adopted in this study is consistent with network-level flood risk analyses, where the primary objective is to evaluate system-wide user cost impacts across multiple return periods rather than to characterize inundation uncertainty at individual locations. The use of probabilistic flood maps is recognized as a valuable direction for future work, and this limitation has been incorporated into the Discussion section of the revised manuscript, citing the reference suggested by the reviewer (Huang & Merwade, 2023).
R2-8	7) Table 5: What do the terms, H_{av} and L, stand for?	The definitions of H_{av} (average water depth in flooded roads, in m) and L (total length of flooded roads, in m) have been added below Table 5 of the revised version.
R2-9	8) Figures 3 and 4: Please add a scale bar to the maps. For some reason, the inundation extents under different flood scenarios in Figure 4 look quite similar.	A scale bar has been added to Figures 3, 4, and 5 in the revised manuscript. Although the flood maps for different return periods look similar because of the map scale, the simulations produced different water depths for each flood scenario.
R2-10	9) Section 7.4: It would be helpful to add a conceptual sketch of the mechanism of the traffic assignment model.	We introduce a diagram (Figure 2) in the revised version, between lines 240 and 242.
R2-11	10) Figure 6: To avoid confusion, it is suggested to change the horizontal axis to the exceedance probability of return periods in years.	A panel was introduced in figure 7 fo the revised manuscript, presenting the results with the horizontal axis expressed in return period (years), complementing the original figure which retains the annual exceedance probability axis.
R2-12	11) Lines 400-406: It is also important to note that the uncertainty in model calibration/evaluation should not be ignored, given the sampling uncertainty over limited space and time. Please refer to the paper below for more information about the limitations of some commonly used evaluation metrics in flood modeling. Reference: “Beyond a fixed number: Investigating uncertainty in popular evaluation metrics of ensemble flood modeling using bootstrapping analysis” (https://doi.org/10.1111/jfr3.12982)	This has been acknowledged in the Discussion section of the revised manuscript, and the suggested reference (Huang & Merwade, 2024) has been incorporated.
R2-13	12) Lines 450-457: This paragraph is similar to the paragraph above and thus redundant. It is suggested to remove it.	We agree. The redundant paragraph at Lines 450–457 was removed.
R2-14	13) Line 497: The terrain data are “digital terrain models” or “digital elevation models”?	To avoid confusion, the sentence at line 497 was removed.