Responses to the second reviewer about: "Quantifying uncertainty in flood predictions due to river bathymetry estimation"

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Dear editorial support team and reviewer,

We thank you so much for the opportunity to reply to the reviewer about "Quantifying uncertainty in flood predictions due to river bathymetry estimation". Please see below, in green, for our responses.

Summary of reviewer's comments: The reviewer was asking for further information and clarification about the flood model used in the paper, adequate assessment for the uncertainty in flood model outputs, summary of previous publication - Nguyen et al. (2024b), context of this uncertainty analysis, and more case studies for robustness.

Summary of authors' responses: We thank you so much for helping us point out where we lack clarification and need improvement. In general, we have added further information about LISFLOOD-FP - the flood model used in the paper. In this answer sheet, we have also indicated how we analysed the flood model outputs in the paper and summarised the previous publication - Nguyen et al. (2024b) which is now published as Nguyen et al. (2025). We have finally explained the robustness of our paper and suggest that another study would be better to investigate a wide range of rivers.

1 Question 1

Question: Generally, the authors need to significantly improve the methods section to convey the methods used in this study. In particular, they did not provide enough explanation regarding the LISFLOOD modeling and the input data utilized. It is important to summarize the processes implemented by the model to understand the relationships presented in the results section. For example, processes such as, backwater effect, sediment processes, human regulations, etc.

Answer: The information about LISFLOOD-FP model was shortly mentioned between lines 105-106: *"These DEM and Manning's n were then applied to the LISFLOOD-FP flood model (Bates et al., 2010; Neal et al., 2018), which was calibrated for this site in Nguyen et al. (2024b), to run the flood simulations."*. However, for clarification, more information have already been added from line 105: *"In this study, LISFLOOD-FP model, a 2D hydrodynamic model, is chosen to simulate the January-2005 flood event because it is well known for its computational efficiency and highly accurate flood model outputs (Nguyen et al., 2025). In this flood model, the formula to compute the water flow, Qcell, between cells at index i over a time step Δt is:*

$$Qcell_{i+1/2}^{t+\Delta t} = \frac{q_{i+1/2}^{t} - gh_{flow}^{t}\Delta t Scell_{i+1/2}^{t}}{[1 + \frac{g\Delta t n^2 |q_{i+1/2}^{t}|}{(h_{flow}^{t})^{7/3}}]}\Delta x \tag{1}$$

where q^t represents the flux at time t, Δx denotes the cell width, $Scell$ and h_{flow} are the water surface slope and flow depth between cells (Bates et al., 2010). The flow formula here is displayed for the x direction, the y direction can be obtained analogously. The cell water depth h is updated based on the discharge through the four boundaries of that cell as below, where i and j denote the cell coordinates (Shustikova et al., 2019):

$$\frac{\Delta h^{i,j}}{\Delta t} = \frac{Qcell_x^{i-1,j} - Qcell_x^{i,j} + Qcell_y^{i,j-1} - Qcell_y^{i,j}}{\Delta x^2}. \tag{2}$$

This flood model was calibrated for the Waikanae River site in Nguyen et al. (2025).".

The main inputs for the LISFLOOD-FP model to simulate the January-2005 flood event are the river flow data, tidal data, DEM, and Manning's n converted from roughness length. The main outputs of the model are the water surface elevation and water depth across the time series and their maximum values. Among them, the study chose the maximum water depths (MWDs) to analyse. The information about these inputs and outputs was mentioned between lines 163-164, but has been rewritten: *"These DEMs and Manning's n maps that include the simulated river bathymetric data, along with January-2005 flow and tidal data, were then used in the LISFLOOD-FP flood model to produce 50 maximum water depths (MWDs) for further statistical analysis."*.

According to Bates et al. (2010), the LISFLOOD-FP flood model does not assume uniform flow and includes the surface slope, $Scell$, which allows the model to simulate the situations like backwater effects - where the water flows uphill or slows down due to downstream resistance like tides. However, the flood model does not include sediment processes. Also, for human regulations, it partially supports by representing the levees/embankments, for example, through the DEM or manually inserted structures. In this study, the LISFLOOD-FP flood model and our research focuses on the pixel-level hydrodynamics and spatial water depth. Hence, the processes including backwater effect, sediment processes, and human regulations are not our main focus.

2 Question 2

We divided it into two sub-questions to answer as below:

Question: I do not believe the authors adequately assess the uncertainty of floods, as they primarily evaluate the uncertainty of DEMs, bathymetry estimations, and roughness coefficients.

Answer: The reviewer is correct, we do not assess all the uncertainties in floods as this would be an incredibly big task. As we clearly stated in the Introduction section, or especially between lines 75-84, we are focussing on this one particular aspect of uncertainty which can then be added to studies of other sources of uncertainty to understand the bigger picture. We now briefly explain how we analyse this uncertainty in flood predictions arising from the estimated river bathymetry.

The variability of simulations of the topographic data like DEM and roughness length/Manning's n gather around the river due to the simulated river bathymetric data. Hence, we only focus on the variability of the simulated river bathymetric data as seen in Figure 5 in the paper. This information has been added between lines 161-164: *"Similar to Durand et al. (2008); Moramarco et al. (2019); Kechnit et al. (2024), and especially Nguyen et al. (2024b), our research also applied a Monte Carlo framework to generate 50 DEMs and 50 Manning's n maps with 50 different bathymetries using the method mentioned in Section 2.1 for each dataset. Since the variability of simulations of these topographic data gathers around the river, we only focus on the variation in the simulated river bathymetric data. The simulated topographic data including DEMs and Manning's n maps were then used for modelling the January-2005 flood event to produce 50 maximum water depths (MWDs) for further statistical analysis."*.

After that, we analysed how the variability in the river bathymetric data can affect the flood model outputs - maximum water depths (MWDs). Specifically, for each of eight datasets of 50 MWDs, we computed their mean (mMWDs), standard deviation (sdMWDs), and coefficient of variation (covMWDs). Here, because the mMWDs and sdMWDs did not provide further insights, they are not considered in the paper. We also calculated proportion of simulations in which a given pixel was flooded (pFs) to distinguish where was always flooded, never flooded, and sometimes flooded throughout these realisations. For the flood extent, its calculation information has been added at line 169: *"The flood extents were then calculated based on these pFs by multiplying the area of one pixel (10 m x 10 m) with number of pixels that were always and sometimes flooded."*. Apart from this, we also validated each flood simulation with the observed flood data using the RMSE metric.

The results of covMWDs, flood extents, and RMSEs were shown in Figures 6-7, Figures 8-9, and Figure 10. This corresponds to the Sections 3.3, 3.4, and 3.5. In particular, we used boxplots (Figures 6, 8, 10) to compare the variations of eight datasets and maps (Figures 7 and 9) to visualise and explain. Here, our explanation linked with what we found in the variations of simulated river bathymetric data.

Generally, based on those Figures, we found that the variations in the MWDs based on covMWDs and flood extents correspond to the variations in the estimated river bathymetries. In particular, with the same amount of uncertainty added to each of eight datasets, the variation in the slope parameter corresponds to the smallest variation in the MWDs, followed by the flow and the width. Between two formulas, the errors in the parameters of the UF formula are associated with greater uncertainty in the MWDs than those of the CMR formula. We provided the explanation as below for each Section:

- For covMWDs, Section 3.3, lines 290-295: *"To explain, between parameter datasets, the small variability in the river bathymetry corresponding with the variation in the river slope does not significantly affect the water spreading into the floodplain, unlike the variations in the river bank-full flow and width. The impacts of all these variations become more apparent in floodplains farther from the river, especially at flood boundaries in midstream, where the water has less direct connection with the river. Between two formulas, because the variations in the UF-formula river bathymetries are higher than the CMR-formula ones as seen in Fig. 5, the variations in the flood depths of the UF-formula datasets are also higher than the CMR-formula datasets."*.

– For flood extents, Section 3.4, lines 307-312: *"Between the two formulas, the blue zoomed-in images highlight a location surrounding the river upstream to 1000 m downstream where the UF-formula river bathymetries are lower than the CMR-formula ones, resulting in greater flood extent here in the UF-formula datasets. This leads to that, in the UF-formula datasets, the flood extent variation appears not only in locations already totally flooded in the CMR-formula but also in new regions that are never flooded in the CMR-formula datasets. Consequently, there are more variations in flood extent in the UF-formula datasets compared to the CMR-formula datasets."*.

– For RMSEs, Section 3.5, lines 312-325: *"To explain, the CMR is developed for coarse-grained rivers like the Waikanae River, leading to lower RMSEs than the UF formula. In contrast, the UF formula was not developed for any specific river types, which may contribute to its slightly higher RMSE. However, these small differences in RMSEs between the two formulas highlight a broad applicability of the UF formula on rivers without categorizing their types."*.

Question: In addition, the authors did not indicate whether their sources of uncertainty are valid by referring to the ranges of DEM values, any reported roughness, etc.

Answer: For each parameter, we selected the errors from a normal distribution with zero mean and standard deviation set to 10% of the best estimates of that parameter. This 10% was chosen because: (i) several observed cross-sectional riverbed elevations fall within the area of simulated riverbed elevations - calculated from the simulated river bathymetric data as seen in Figure 1 in this answer sheet; (ii) with the same amount of errors, we can then compare the influences of those errors, between datasets, on the flood model outputs. This helps us to see, with this small amount of errors, how they propagate through the flood modelling and affect the flood predictions. Higher levels of errors such as 20%, 30%, etc. should also be considered, but due to the time intensity and complexity, another research would be a better fit. This information and the Figure 1 in this answer sheet will be added into the paper.

3 Question 3

Question: In addition, they refer to a previous publication, Nguyen et al. (2024b), to get the key details for the methods used. For a smooth reading experience, the authors should summarize that key information in this manuscript as well.

Answer: The summary of the similar key information in methodology to Nguyen et al. (2025) has been added at line 91 before the section 2.1.: *"Our data and methodology were based on Nguyen et al. (2025) where the uncertainty in flood predictions due to arbitrary conventions in grid alignment was quantified. To explain, their research is also about how the uncertainty in the process of generating the topographic data like DEM and roughness length can propagate through the flood modelling to the outputs. Hence, their data and methodology can be applied in our research.*.

Accordingly, we simulated the same flood event using the LISFLOOD-FP flood model and applied a similar method to generate topographic data. Moreover, a Monte Carlo framework was also designed in our research to observe how the uncertainty in estimated river bathymetries propagates through the flood modelling to the flood model outputs. To assess the

(a)

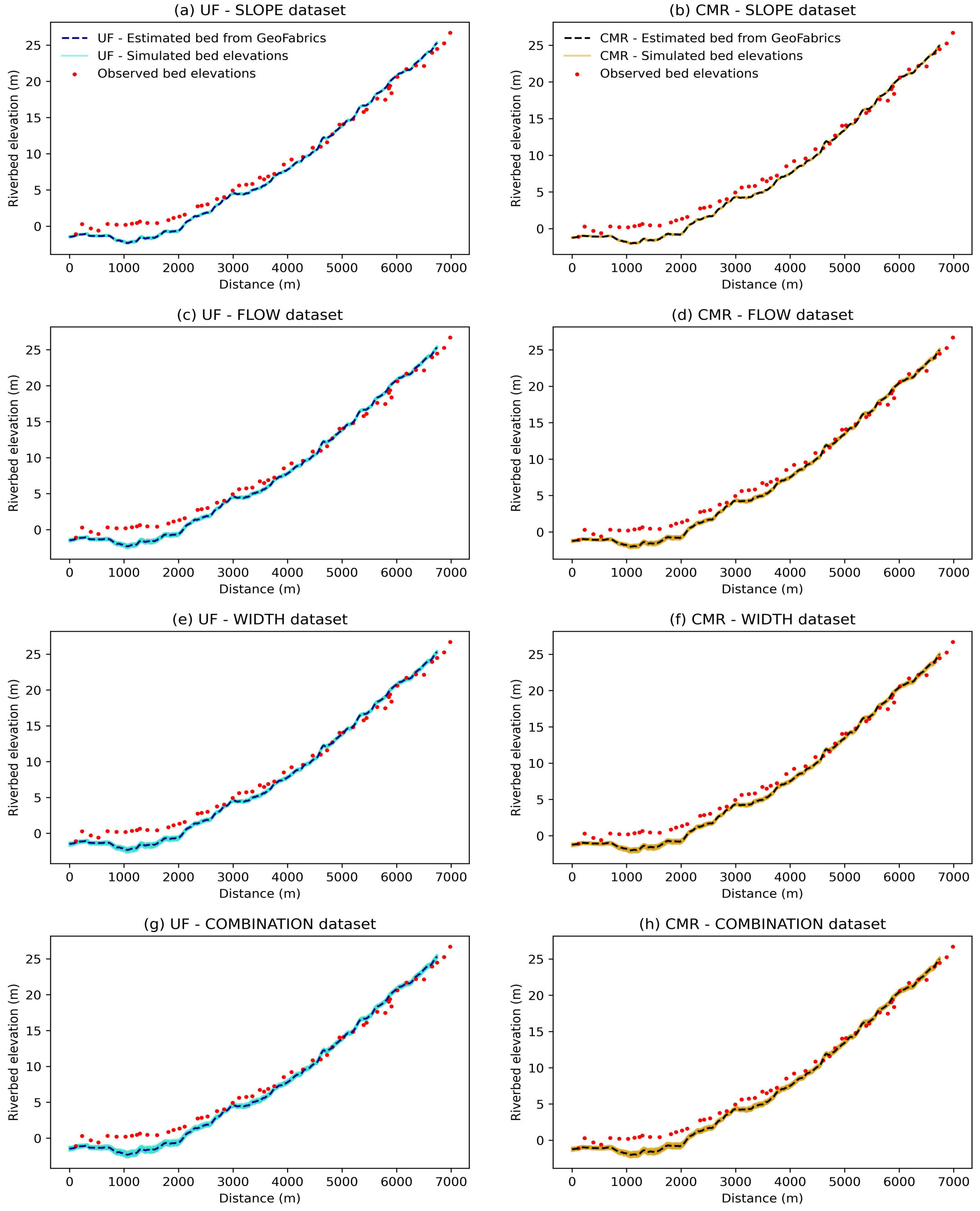

Figure 1. Observed cross-sections, best estimates, and simulations of riverbed elevations at the Waikanae River: the Uniform Flow formula - (a) slope, (c) bank-full flow, (e) width, and (g) combined; the Conceptual Multivariate Regression formula - (b) slope, (d) bank-full flow, (f) width, and (h) combined.

uncertainty, some similar measurements were used, some were not because they did not provide further information, and some were added to understand better the uncertainty. These similarities will be mentioned in details in the sections below.".

4 Section 4

Question: Moreover, the authors did not explain the context of this uncertainty analysis of the flood prediction. Also, they need to include the details about the flood event they used in this study to demonstrate what they want to establish from this study.

Answer: We have explained the context of this uncertainty analysis of the flood in the paper as below:

– Between lines 18-24: *"River bathymetry refers to the river depth measurement (Panigrahi, 20140. It plays a crucial role in flood modelling because it determines when and where water leaves the river channel and starts to flood overland (Cook and Merwade, 2009; Awadallah et al., 2022). Currently, hydrographic surveys and remote sensing methods, especially swath beam sonar and blue-green LiDAR, are prevalently employed to obtain these river bathymetric data (Coasta et al., 2009; Kinzel et al., 2013; Dey et al., 2019). Multi-beam sonar is effective but time-consuming, while blue-green LiDAR is faster but unable to obtain measurements in sediment-laden or deep water, and both of them are expensive (Bailly et al., 2010; Flener et al., 2012; Bures et al., 2019). For these reasons, various approaches have been proposed to estimate these data (Ghorbanidehno et al., 2021; Araujo and Hedley, 2023)."*. We have added "... and both of them are expensive ...".

– Between lines 52-55: *"Regardless of the approach, errors in the measurements or estimations can introduce uncertainties that significantly deviate the simulated river bathymetries from the actual ones. Consequently, using these modelled river bathymetries can affect the flood predictions. Currently, only limited studies concentrate on these errors in bathymetry estimation (Durand et al., 2008; Lee et al., 2018; Moramarco et al.,2019; Kechnit et al., 2024).". This paragraph has been rewritten for clarification: "Regardless of any approaches, due to the inability to capture the randomness of the river systems, errors in the measurements or estimations can introduce uncertainties that significantly deviate the simulated river bathymetries from the actual ones. Consequently, using these modelled river bathymetries to represent the river in flood modelling can affect the flood predictions. Currently, only limited studies concentrate on how these errors in bathymetry estimation can have impacts on the flood model outputs (Durand et al., 2008; Lee et al., 2018; Moramarco et al.,2019; Kechnit et al., 2024)."*.

– Between lines 75-78: *"Generally, these previous studies have addressed certain gaps in quantifying uncertainties in estimated river bathymetry and show that errors can arise from various sources. However, they have not considered the spatial variability of estimated parameters used for river bathymetry generation, or performed a thorough sensitivity analysis to examine the impact of each parameter on the estimated river bathymetry, particularly in flood modelling contexts."*.

– Between lines 79-84: *"In this paper, we quantified the uncertainty in flood predictions due to errors in estimated parameters used in two formulas described in Rupp and Smart (2007) and Neal et al. (2021). Using a Monte Carlo* *framework, we generated multiple realisations of river bathymetry, then used this to perform a sensitivity analysis to evaluate the impacts of each parameter on flood predictions, individually and collectively. In the next section, we describe a method to explore relationships between parameters within these two formulas and show a process to examine how errors in these parameters affect the flood predictions."*. This paragraph has been rewritten for clarification: *"To contribute to this field and fulfill the unresolved gaps, in this paper, we quantified the uncertainty in flood predictions due to errors in estimated parameters used in two formulas described in Rupp and Smart (2007) and Neal et al. (2021). Using a Monte Carlo framework, we generated multiple realisations of river bathymetry. The riverbed elevations calculated from these estimated river bathymetries were then used to represent the river in the topographic data. The flood predictions generated from flood modelling using these data as the input were then utilised to perform a sensitivity analysis to evaluate the impacts of each parameter on flood predictions, individually and collectively. In the next section, we describe a method to explore relationships between parameters within these two formulas and show a process to examine how errors in these parameters affect the flood predictions."*.

We have rewritten the lines 92-93 and added more information about the study site as well as the flood event: *"Similar to Nguyen et al. (2025), the Waikanae River, located at the West Coast of the Wellington Region in New Zealand, was chosen in this paper. It spans about 149 km2 from the foothills of the Tararua Ranges towards the West to the coast. There are recurring flooding issues at this study site that have influenced the regions around the river.*.

In this study, we simulated a flood event with an 80-year return period that occurred at this place from January 5th to 7th, 2005 and reached its peak on 6th. Here, we focused on fluvial flooding in which the water exceeding the riverbank is the main source. This helped us to observe how the uncertainty in the estimated river bathymetric data can impact on the flood model outputs. Figure 1a depicts our site study extending about 7 km from the Waikanae Water Treatment Plant gauge to the coast. Figures 1b and 1c show the flow information recorded at the gauge by the Greater Wellington Regional Council (2005) and the tidal data estimated by the NIWA Tide Forecaster (2005) respectively.".

5 Section 5

Question: The authors need to enhance their experimental methods to strengthen the robustness of their findings, such as applying these analyses to various case studies across a wide range of rivers.

Answer: As we mentioned in the paper and in Question 4, there are many approaches to estimate the river bathymetric data. However, due to the inability to capture the randomness of the river systems, errors in the estimations can introduce uncertainties that significantly deviate the simulated river bathymetries from the actual ones. Consequently, using these estimated river bathymetries to represent the river in the flood modelling can affect the flood predictions. Currently, only limited studies concentrate on how these errors in estimated river bathymetries can have impacts on the flood model outputs.

To contribute to this field, we quantify the uncertainty in flood predictions due to the estimated river bathymetries. We investigated how the errors inherent in the estimated parameters (river slope, flow, and width) used in two formulas (CMR and

UF) can propagate through the flood modelling to the flood predictions. These formulas were validated for the Waikanae River and Buller River by Pearson et al. (2021).

Although our research was conducted at one study site, it helps raise awareness of flood modellers who use estimated river bathymetries to represent the river in the flood modelling. Furthermore, in this study, we provided a thorough Monte Carlo framework to capture the uncertainty in the flood model predictions. We designed this framework with more solutions for unsolved issues in previous studies including Durand et al. (2008), Lee et al. (2018), Moramarco et al. (2019), and Kechnit et al. (2024). Specifically, we used a larger sample of estimated river bathymetries to capture the variations in the flood predictions and included the spatial variability into our method. We also performed a sensitivity analysis collectively and individually. Hence, this framework can be applied to a wide range of formulas used to estimate river bathymetries.

Between lines 327-332, we have rewritten for clarification: *"Our research went a step further than previous studies to quantify the uncertainty in flood predictions due to the errors in the estimated river bathymetry. It helps raise awareness of flood modellers who also use estimated river bathymetries to represent the rivers in the flood modelling. Here, we applied the Monte Carlo method and errors selected from Gaussian distributions like Durand et al. (2018); Lee et al. (2018); Kechnit et al. (2024). However, unlike Lee et al. (2018), we selected a larger sample to capture the typical variability in the flood predictions and included the spatial variability into our method. Moreover, we not only considered associated error distributions in parameters collectively like Moramarco et al. (2019); Kechnit et al. (2024), but we also performed a sensitivity analysis to assess each parameter impact. This analysis framework can then be applied to a wide range of formulas that are used to estimate river bathymetries to represent rivers in the flood modelling."*.

Based on our results, we found out some key points that can develop further research. Specifically, we have suggested the applicability of the UF formula without the need of river categorisation. However, we have only compared it with the CMR formula and still needs further investigations with other equations. Between lines 335-337, we have rewritten the idea for clarification: *"... However, because we have only compared the UF formula with the CMR developed for coarse-grained rivers, other comparisons with other formulas still need further research to confirm the applicability of the UF formula."*.

We also observed that the uncertainty in flood predictions associated with the errors in the river slope parameter is the smallest, followed by the river flow, and width. This information can help the data collection process in which the parameters that have the greatest impact (specifically flow and width) should be focused on measuring if resources are limited. Meanwhile, the parameter associated with the lowest influence (river slope) can be deprioritised. However, due to the time-intensity and complexity, we have not explored the errors in the river friction as well as α and β coefficients. Hence, further research is necessary to perform a more thorough sensitivity analysis between these parameters and perhaps between formulas. This key point has been rewritten between lines 338-341 as: *"The results of our research can help the data collection process in which the parameters that have the greatest impact (specifically river flow and width) should be focused on measuring if resources are limited. Meanwhile, the parameter associated with the lowest influence (river slope) can be deprioritised. Nevertheless, due to the time-intensity and complexity, we have not explored the errors in the river friction as well as* α *and* β *coefficients. Furthermore, the Waikanae River bank-full flow is not strongly correlated with the variability of the bathymetry along the river* *as it nearly stays constant. Hence, future studies should investigate the errors associated with these factors and perform a thorough sensitivity analysis to support the data collection process better."*.

In practice, different rivers will have different characteristics, so we agree that the suggestion for applying our investigation to various case studies across a wide range of rivers is necessary. However, due to the amount of work, we think another research about this would be a better fit. We have added this idea after line 341: *"In practice, different rivers will have different characteristics. Hence, it is necessary to generalise this study by considering a wide range of rivers for comparison and confirmation for the results found here. Accordingly, another research focusing on a number of rivers with diverse features is essential."*.