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Quantifying Flood Risks in New Zealand: A National Scale Assessment

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ABSTRACT

Flooding from fluvial and pluvial sources poses a significant and growing threat to buildings across New Zealand, yet national-scale estimates of direct economic losses have remained scarce. This study fills that gap by implementing the country's first end-to-end, nationwide flood risk workflow that integrates state-of-the-art hydraulic modelling with a flexible risk analysis framework. The approach enables consistent, building-level calculation of expected annual damage (EAD) and scalable reporting across multiple administrative boundaries. We estimate New Zealand's national building EAD to be NZD $190 million per year, with two regions (Canterbury, Waikato) accounting for 35% of total losses. Residential and appurtenant buildings account for 71% of national EAD, demonstrating the high vulnerability of the residential building portfolio, particularly to more frequent flood events. These findings provide the first comprehensive, evidence-based baseline of direct building-related flood risk for the country.

This work establishes a reproducible foundation for strategic, location-based flood mitigation and climate adaptation planning. By advancing the availability of our high-resolution, nationally consistent flood risk models and outputs, it supports more effective investment decisions to reduce flood impacts under both present and future conditions.

KEYWORDS: Flooding, Buildings, Risk, Expected Annual Damage, New Zealand

1 INTRODUCTION

Flooding is among the most frequent and damaging natural hazards globally, with fluvial and pluvial sources causing significant economic and social disruption (Merz et al. 2021). In New Zealand, despite several significant events in the past five years resulting in billions of dollars (NZD) in direct building economic losses (Insurance Council of New Zealand 2025), national-scale building risk assessments have received limited research attention beyond first-order exposure studies (Paulik et al. 2019). Understanding the magnitude and spatial distribution of building economic losses from fluvial and pluvial sources is critical for informing optimal location-based investment in flood mitigation interventions and climate adaptation strategies.

This study addresses a key research gap for New Zealand by presenting the first nationwide evaluation of expected annual damage (EAD) to buildings from fluvial and pluvial flooding under present-day climate conditions. The work applies an end-to-end workflow that integrates state-of-the-art hydraulic modelling with a modular flood risk analysis framework, enabling consistent EAD calculation at the building scale and enumeration at different jurisdictional levels. This paper outlines the model workflow, including the principal hydraulic and risk model components. We then report building EAD at national, regional council, territorial authority and urban-rural area scales, demonstrating the present-day spatial distribution of fluvial and pluvial flood risk. Finally, we identify current limitations of the model workflow and future enhancements.

2 METHODS AND MATERIALS

The model workflow for simulating nationwide fluvial and pluvial flooding hazards and risks is presented in Figure 1. The framework consists of several core components. First, the *Cylc* engine workflow scheduler (Oliver et al. 2018) orchestrates the sequencing of tasks within three modules for simulating and mapping fluvial and pluvial flooding hazards, including digital elevation, design storm, and flood hazard models. Secondly, the *RiskScape* engine (Paulik et al. 2023) combines output flood inundation maps with building exposure and vulnerability models to calculate and report risk at different spatial scales. The following sections describe these model components.

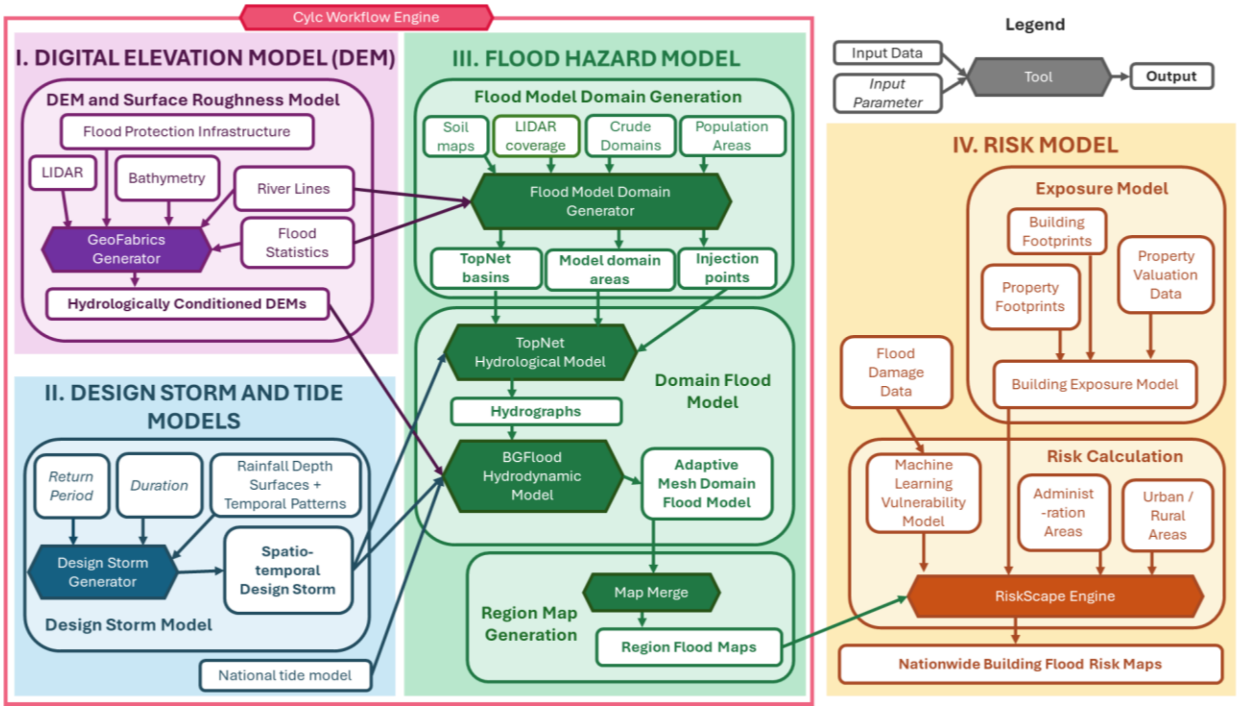


Figure 1: Conceptual diagram of components forming the national fluvial and pluvial flood risk model workflow.

2.1 Flood hazard model

The three modules contributing to fluvial and pluvial flooding hazard map generation several key steps (Figure 1): (I) hydraulically-conditioned digital elevation model (DEM) and surface roughness map generation from LIDAR (Pearson et al. 2023), (II) design storm generation for 10, 20, 50, 100, 200, 500 and 1000-year ARI rainfall events using the high intensity design rainfall system (*HIRDSv4.2*) (Carey-Smith et al. 2018), (IIIa) simulation domain, basin and rain-on-grid mask generation, (IIIb) *TopNet* (McMillan et al. 2016) hydrograph generation at river flow injection points, and (IIIc) inundation modelling incorporating output data from previous steps using the hydrodynamics model *BGFlood* (Bosserelle et al. 2020). Flood hazard intensity maps representing both fluvial and pluvial flood events from ARI rainfall were generated for maximum water depth (m), maximum flow velocity (m/s), and water depth duration (hr) at an 8 m grid resolution.

2.2 Exposure and vulnerability

Building replacement values (B_R) for direct economic loss evaluation were calculated using the general formula:

$$B_R = \sum_{i=1}^{n} C_{RVi} \cdot B_{Ai} \tag{1}$$

where for building i, B_{Ai} is the area (m^2), C_{RVi} is the m^2 unit cost rate (NZD) for structural, external finishes, internal finishes and service components, n is the number of components for B_R calculation. Local unit cost rates were adopted from the first quarter of 2024 (Quotable Value 2024). Buildings mapped from roof outlines represented 3,288,916 structures (Land Information New Zealand 2024). The replacement value calculation utilized physical and non-physical characteristics derived from several nationwide datasets (Paulik et al. 2023a; Scheele et al. 2023). These characteristics include area (m^2), floor level, primary use, number of stories, structural frame, and wall cladding.

Building vulnerability to direct economic loss (L) was calculated using a unit loss approach:

$$L = \sum_{i\,=\,1}^{n} R_i \, f_i\big(d_{ij}, b_i\big) \tag{2}$$

where for building i, R_i is the replacement value, and f_i the damage function that computes a damage ratio (ranging from 0 to 1). f_i is a function of the maximum water depth (d) sampled at inundation points intersecting building location j and the building's physical and non-physical characteristics (b_i).

In large-scale flood risk models, f_i is typically implemented using univariable 'depth-damage' curves. This study employs an extreme gradient boosting regression algorithm, trained on an empirical dataset comprising 2,320 buildings damaged in seven New Zealand flood events (Paulik et al. 2023b; Paulik et al. 2024; Paulik and Horspool 2024). Model hyperparameter selection involved a grid search to optimize performance over a range of decision trees (100 to 10,000 trees) and learning rates (0.01 to 0.2). Model evaluation employed a leave-one-out cross-validation procedure, with mean absolute error (MAE) and root mean squared error (RMSE) as performance metrics. The optimal model configuration, with 1000 trees and a learning rate of 0.2, achieved an MAE of 0.09 and an RMSE of 0.12 when applied to explanatory variables, including maximum water depth, maximum water depth above floor level, area (m^2), primary use, number of stories, structural frame, and wall cladding.

2.3 Risk analysis

Direct economic loss was enumerated as the expected annual damage (EAD). First, the exceedance probability loss (EPL) for each flood event of probability P was calculated using the formula:

$$EPL(P) = \sum_{i\,=\,1}^{N} L(P) \tag{3}$$

where $L(P)$ is the economic loss due to the flood event of probability P, and N represents the total number of buildings impacted by the event. A hypothetical loss curve is formed between EPL and P, representing a positive monotonic trend where EPL increases response to decreasing P. EAD is then calculated using trapezoidal integration to compute the 'area under the curve':

$$EAD = \int_{p_{min}}^{p_{max}} EPL(p) \tag{4}$$

where p_{min} and p_{max} respectively denote the highest and lowest annual probability of occurrence, and $EPL(P)$ is the economic loss for the flood event, given the probability of occurrence P. The integral computes the area under a hypothetical damage-probability curve, representing the monetary loss expected in a single year from flood events simulated within the probability range p_{min} to p_{max}. The EAD computed for each individual building was enumerated at the national level, regional council and territorial authority administration areas, and several urban (major (pop. ≥100,000); large (pop. 30,000–99,999); medium (pop. 10,000–29,999); small (pop. 1,000–9,999) and rural (pop. <1000) land areas on mainland New Zealand.

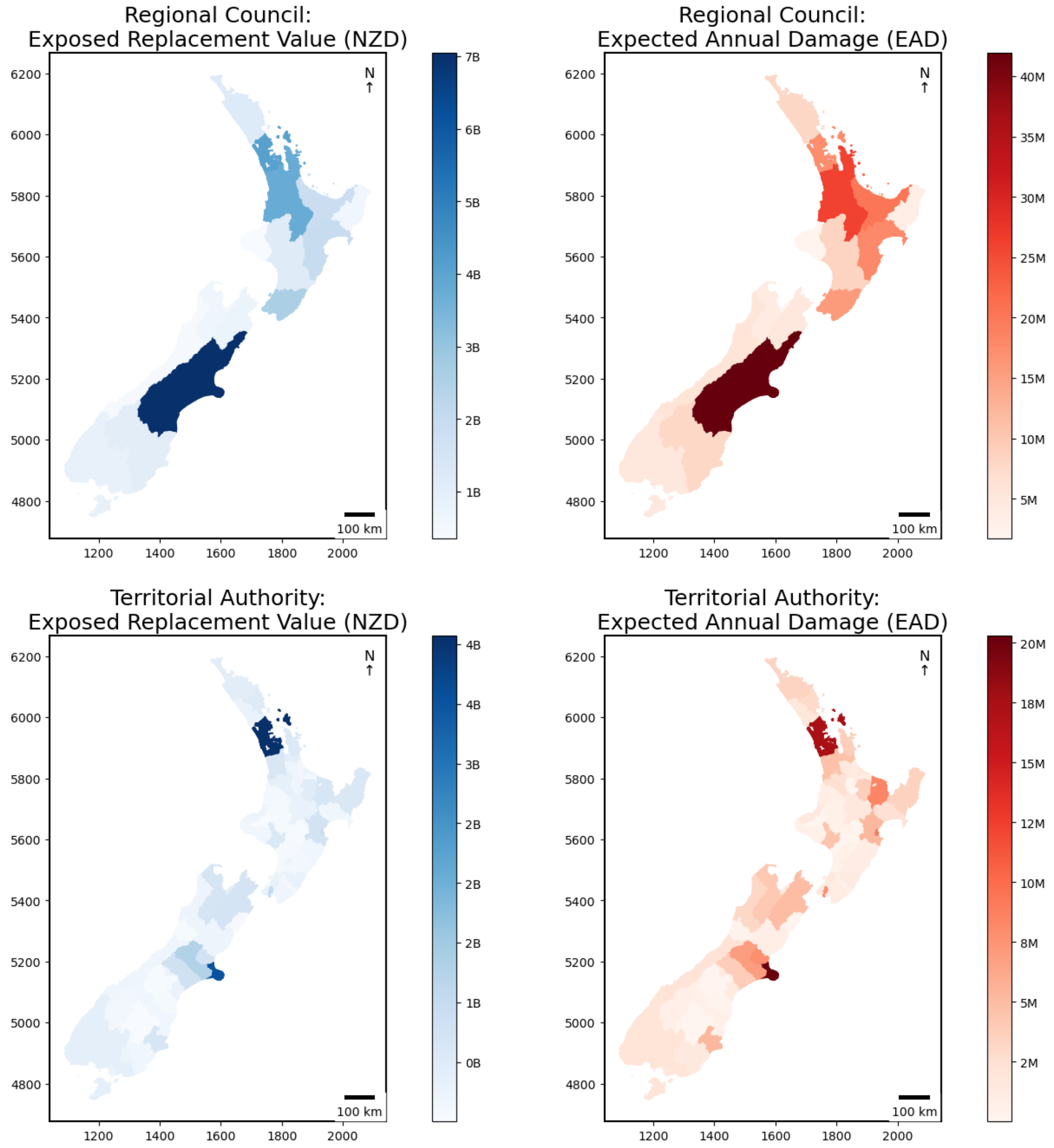
3 RESULTS AND DISCUSSION

We estimated the EAD for New Zealand buildings to be NZD 190 million. EAD demonstrates significant regional variations (Figure 2), with Canterbury contributing the highest regional EAD at NZD 41.9 million (22% of the national total), mostly occurring in Christchurch City (Figure 3). Waikato and Bay of Plenty follow, contributing NZD 26.2 million (~13%) and NZD 20.3 million (~10%), respectively. Auckland, New Zealand's most populous region, accounts for NZD 17.6 million (~9%). Less populous regions such as Taranaki, Nelson, and Marlborough each contribute less than 3% of the national EAD. EAD as a percentage of the expected annual building replacement value exposure (EAE) exceeds 20% in several territories, including Central Otago District, Clutha District, Opotiki District, Wairoa District and Rotorua District. Despite these territorial authorities making a small contribution to regional EADs, buildings are more likely to sustain economic losses when exposed to flood waters.

The residential building EAD exceeds NZD 78 million, accounting for 41% of the total national EAD. Combined with appurtenant buildings (NZD 57 million), buildings on residential properties account for 71% of the national EAD. The relatively significant contribution of appurtenant buildings signals their vulnerability to damage from relatively frequent flood inundation (i.e., < 50-year ARIs), meaning they contribute more significantly to national EAD than buildings with higher economic value but lower flood exposure. Agriculture has the highest EAD (NZD 23.8 million) for non-residential buildings. Over 50% of national EAD occurs in the Waikato, Bay of Plenty and Canterbury regions, due to the prevalence of high-producing dairy farmland in floodplains (Craig et al. 2021). Commercial and industrial buildings combined account for NZD 15.4 million (8%) of EAD.

EAD reaches NZD 128.6 million (67%) in urban areas (populations >1000), and NZD 62.2 million (33%) in rural areas. While agricultural buildings represent the highest proportion of EAD (37%) for rural land and settlements (pop. <1000), the combined EAD for residential and appurtenant buildings reach NZD 29.9 million (48%). The equivalent EAD for major urban areas (pop. >100,000) exceeds NZD 40 million, accounting for 81% of the total EAD for these areas. Total EAD in rural areas exceeds that in major urban areas by NZD 13 million (23%), and is considerably greater than in small (62%), medium (98%), and large (83%) urban areas. Despite New Zealand's extensive flood protection schemes in rural areas (Walsh et al., 2019), these findings highlight the significant residual risk for buildings in rural communities.

This study employed a state-of-the-art model workflow and datasets, featuring notable advancements in digital elevation model generation, two-dimensional hydraulic flood inundation modelling and mapping, and building risk analysis. Despite these advancements, several limitations and future focus areas for model and data improvement have been noted. Modelled economic losses could not be validated for historic events, as an official economic flood damage database is not currently available for New Zealand. Evaluating model predictive performance then requires flood hazard intensity simulations for historic events, coupled with building exposure inventories and physical damage data, to compare modelled and government-reported economic losses. Flood inundation modelling and mapping also considered ~73% (197,415 km^2) of New Zealand's mainland area, where topographical data from LiDAR was available. This area covers 95% of mapped building structures; however, extending modelling and mapping toward continuous national land coverage requires further LIDAR acquisition from government agencies or the inclusion of lower-resolution, satellite-derived topographical data. Flooding hazards and building risk under present-day climate and socio-economic conditions were evaluated. Escalating flood risk under climate-projected flood regime changes towards the end of this century is well-documented internationally. Incorporating such scenarios in the New Zealand context is required in future modelling and data iterations to inform risk-based flood management. This should be considered in conjunction with anticipated changes in flood mitigation (e.g., levee construction, detention areas), building location, design, and construction materials, as well as the subsequent responses to flood damage vulnerability. The modular model framework is configurable to simulate both spatial and temporal changes in flood risk and associated uncertainty, resulting from model parameters, without requiring significant structural changes.


Regional Council: Exposed Replacement Value (NZD)

Regional Council: Expected Annual Damage (EAD)

Territorial Authority: Exposed Replacement Value (NZD)

Territorial Authority: Expected Annual Damage (EAD)

Figure 2: Spatial distribution of exposed building replacement value (NZD) and expected annual damage (EAD) enumerated by regional council and territorial authority area.

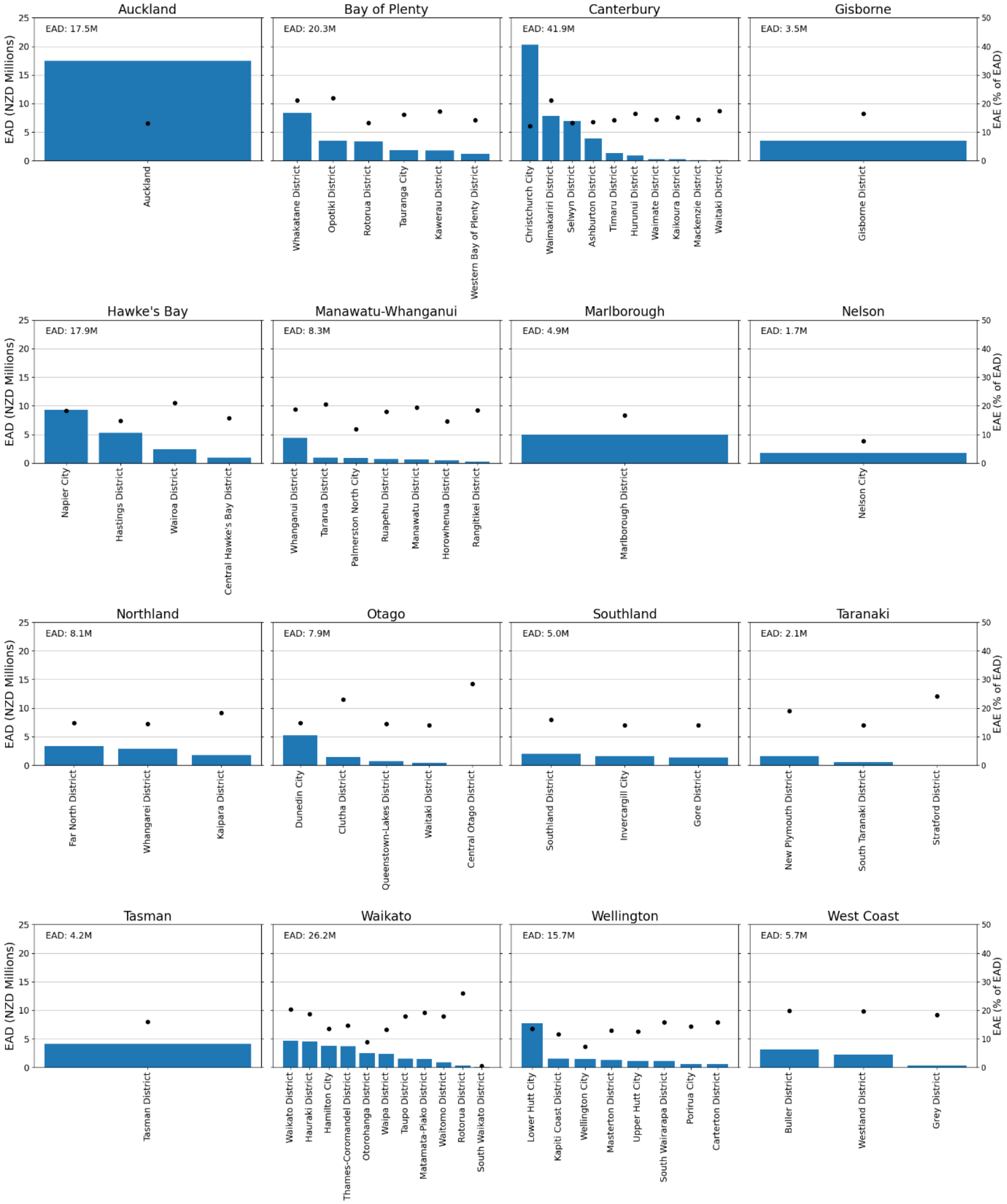


Figure 3: Expected annual damage (EAD) (blue bar) reported as monetary loss (NZD) and as the percentage of the expected annual building replacement value exposure (EAE) (black dot) enumerated by regional council and territorial authority area.

4 CONCLUSION

This study delivers the first nationwide, building-level assessment of expected annual damage (EAD) from fluvial and pluvial flooding in New Zealand, addressing a longstanding gap in the country's flood risk evidence base. By integrating state-of-the-art hydraulic modelling with a modular, end-to-end risk analysis workflow, we compute building-scale losses and consistently aggregate them across national, regional, and local administrative units. The results indicate annualised direct building losses of approximately NZD 190 million, with the greatest concentrations of risk occurring in urban areas and among residential and appurtenant structures, which together account for 71% of national EAD.

While the workflow advances national flood risk modelling capability, several limitations remain. Current inundation modelling covers 73% of mainland New Zealand due to gaps in high-resolution topographic data, highlighting the need for continued LIDAR acquisition or the incorporation of coarser satellite-derived elevation products to achieve full national coverage. Moreover, the present analysis reflects only current climate and socio-economic conditions. Future iterations should integrate climate-change-conditioned flood regimes, evolving patterns of settlement and construction, and the potential influence of mitigation interventions such as new flood defences or changes in building design. Incorporating these dynamics will be essential for characterising future flood risk trajectories and for supporting long-term, risk-informed adaptation planning.

Overall, this work establishes a robust, reproducible framework for national-scale flood risk assessment in New Zealand. By providing the first spatially explicit, evidence-based baseline of direct building flood losses, it supports more targeted and strategic investment in mitigation and adaptation across multiple levels of decision-making.

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