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Managing rising residual flood risk: A national survey of Aotearoa-New Zealand

Xinyu Fu[1] | **Rob Bell**[1,2] | **Juliana Reu Junqueira**[3] | **Iain White**[1] | **Silvia Serrao-Neumann**[1]

[1]The University of Waikato School of Social Sciences, Hamilton, Waikato, New Zealand

[2]Bell Adapt Ltd, Hamilton, New Zealand

[3]Hamilton City Council, Hamilton, New Zealand

Correspondence
Xinyu Fu, The University of Waikato School of Social Sciences, Hamilton, Waikato, New Zealand.
Email: xinyuf@waikato.ac.nz

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Abstract

Flooding is one of the most frequent and costliest natural hazards around the world. Traditionally, flood risk management has relied on building protective structures such as levees and dams to protect assets based on historical data (e.g., 1% AEP flood), which encourages development on floodplains, provides a potentially false sense of security to communities, particularly in the context of climate change, and increases residual flood risk (the risk remaining after implementing risk reduction measures). This article aims to contribute to the management of residual risk by drawing on empirical findings from a survey carried out with flood risk practitioners from the public and private sector in Aotearoa New Zealand. Findings indicate fundamental concerns relating to how to best manage residual flood risk, despite its long profile and integration in current policy and practice. Other issues revolve around the use of outdated information to guide decisions and the lack of regulatory power to restrict developments in flood-prone areas protected by hard defense structures. Identified barriers to improving current practice include the lack of national guidance and support, financial resources, public awareness, and some technical constraints such as uncertainties in flood modeling, staff expertise, and data availability.

KEYWORDS

climate change, flood mitigation, residual risk, urban planning

1 | INTRODUCTION

Floods are one of the costliest natural hazards worldwide (ICNZ, 2022; Swiss Re, 2022a). While managing flood risk has long been conducted to reduce its impacts, there has still been an increased number of occurrences causing significant socio-economic disruption and devastating losses (WMO, 2022). Recently, in Aotearoa-New Zealand (hereafter referred to A-NZ), Cyclone *Gabrielle* caused widespread devastation and 11 casualties in February 2023; the highest death toll from a flood event since 1938 (Harrington et al., 2023; Kerr et al., 2023). For Auckland City, the largest urban area in A-NZ, *Gabrielle* followed soon after a major flood in late January 2023, which also caused extensive damage and four fatalities (NZ Herald, 2023). Many of the ~55,000 houses in

floodplains in Auckland were inundated during the January event, including those recently built (Newton, 2023). These recent events have been a vivid manifestation of the increasing flood risk in A-NZ (including residual risk), particularly *Gabrielle* that resulted in breaches or overtopping of around 30 levees/stopbanks (Bidwell, 2023).

In part, this increase in flood impacts is due to more frequent and intense precipitation events arising from climate change (Arnell & Gosling, 2016; Frame et al., 2020; Harrington et al., 2023; Hirabayashi et al., 2013). However, one of the primary reasons for this upward trend in impacts can be attributed to the increased development and urbanization of flood-prone areas (Iglesias et al., 2021; Swiss Re, 2022b). This is especially the case in A-NZ because a lack of coordination between flood risk management and spatial planning enables private developers to pressure local decision makers about development in low-lying floodplain and coastal areas that are often high in economic value (van Buuren et al., 2018). This has led to continuous development in the floodplains and significantly increased flood risk profile nationwide in A-NZ over time (Ministry for the Environment, 2008) and manifested in the recent floods experienced in Auckland. These pressures present challenges to how we manage and plan for present and future flood risks (Scott et al., 2013; Tullos, 2018), especially for the often unseen and lower profile residual flood risk—that is, the risk that remains after the implementation of risk treatment actions (Serra-Llobet et al., 2022).

No matter how effectively a flood hazard risk is managed, residual risk can still be realized. In the flood risk management context, typical strategies include structural protective measures such as levees (stopbanks) and dams which are designed to withstand up to a certain risk level (e.g., a 1% or higher annual exceedance probability). This is problematic because protective structures tend to offer a false sense of security, further encouraging floodplain development (White et al., 2001). Structural protection measures have adaptation limits (i.e., no absolute protection; Berkhout & Dow, 2023; Serra-Llobet et al., 2022), which means they can fail through overtopping or breaches during extreme flood events. More investment is needed to upgrading the existing levees with outdated design standards, building new protective structures (giving more room for rivers and streams), or undertake managed retreat to keep up with increasingly more frequent and intense floods due to urban development and climate change (Collins, 2021; Lawrence et al., 2013). Consequently, understanding the management of residual risk is important in avoiding catastrophic loss or lengthy disruption, yet research suggests it can be overlooked and under-managed and thus not perceived by either floodplain communities or infrastructure providers (Ludy & Kondolf, 2012). In reality, current flood risk management practice generally relies on insurance to help manage residual risk, but only a fraction of the losses—5% in emerging economies and 34% in advanced economies globally—are actually insured (Swiss Re, 2022a). This means that there is a high potential for residual risk transfer onto the public through current insurance mechanisms, which means if a major disaster takes place most households would need to bear the significant economic losses themselves.

Residual risk is not a new concept in risk management. With regard to flood risk however, it has taken on increasing importance as flood risk management moved away from the conventional river engineering view of hazard control to a more holistic understanding of the concept of risk (Bubeck et al., 2017; Serra-Llobet et al., 2022). This includes, inter alia, the consideration of residual risk behind the protective measures (Serra-Llobet et al., 2022), resilient spatial planning approaches (White et al., 2010), or the implementation of concepts, such as creating more room for rivers (Dottori et al., 2020; Rijke et al., 2012). Yet, literature specifically on residual risk as a component of effective flood risk management remains scarce (Wagner et al., 2021). In a recent comparative study between the United States, France, and Quebec (Canada), Serra-Llobet et al. (2022) found significant variability in how residual flood risk is managed. For example, in the US residual flood risk is depicted in the national regulatory Flood Insurance Rate Maps (FIRMs) under the National Flood Insurance Program (NFIP). The minimum NFIP land use standards and the purchase of flood insurance are only required in flood-prone areas (the 1-in-100-year flood) which are not protected by accredited levees. Hence, developments are allowed behind accredited levees and residual flood risk is generally managed by a national flood insurance scheme. In contrast, France has adopted a more top-down approach to managing residual flood risk which mandates land use restrictions and building codes in areas behind levees, designated as part of their regulatory flood-prone area. Similarly, Quebec's approach also regulates the development of areas behind levees through mandatory development restrictions with few exceptions.

Aotearoa-New Zealand comprises a suitable case study to investigate how residual flood risk is evaluated and managed because of its high flood risk profile (Craig et al., 2021). The country has little national-level hazard policy statement, or guidance, dedicated to managing flood risk, and it is currently unclear how residual flood risk is being managed (Rouse, 2011). It is therefore imperative to understand how and to what extent the country's flood risk management practices considers,

analyses, and treats residual flood risk and how this is understood, communicated, and utilized in land-use planning decisions. Importantly, if the country's present flood risk governance does not understand and act on residual flood risk, insurance penetration may reduce, posing difficult decisions for risk managers, land-use planners, and ultimately the community in managing pre-existing or new development (Serra-Llobet et al., 2022). To fill this gap in research, this article aims to draw on practitioners' knowledge from A-NZ through a national survey to understand how present and future residual flood risk is evaluated and managed across the country. Our objectives are to investigate: (1) to what extent residual flood risk is considered, (2) how residual flood risk is managed, and (3) what barriers there are for managing residual risk locally.

This article is organized in the following order: we first start by outlining current flood risk management practice and implications for managing residual flood risk. We then discussed our survey methodology followed by the presentation of results. We lastly conclude by discussing implications for future research and practice with applicability in A-NZ and elsewhere. While the discussion focuses on A-NZ we anticipate that this research will be of interest to other jurisdictions internationally similarly grappling with the growing issue of residual risk.

2 | FLOOD RISK MANAGEMENT AND RESIDUAL FLOOD RISK

A core activity of flood risk management typically involves the implementation of government-funded structural measures aiming at risk reduction (Jha et al., 2012). These include the application of physically constructed engineering techniques to minimize hazard or improve resilience of structures or systems (Batica & Gourbesville, 2014). Examples of structural measures include flood storage reservoirs, flood walls, levees, embankments, and tidal barriers (Birkland et al., 2003). Extreme rainfall events are, however, testing the protection capacity of flood defense structures with climate change impacts set to escalate this further (Hutton et al., 2019; Kreibich et al., 2022).

In parallel, recent flood risk management approaches also incorporate non-structural measures, including the involvement of the public, communication of flood risks, and dialog about mitigation options (Hammond et al., 2015; Jha et al., 2012). Non-structural measures also include the strengthening of legislation for urban flood management; urban planning; institutional coordination and cooperation; improvement in investment for monitoring; capacity building; and, decentralization of resources from national to local levels (Batica & Gourbesville, 2014). Residual flood risk is primarily managed through non-structural measures, especially related to development control legislation and regulations, albeit information about residual flood risk is also used to guide the design of structural measures (Serra-Llobet et al., 2022).

Importantly, as there has been a shift in responsibility for flood risk management from water managers to community members (Puzyreva et al., 2022; Thaler & Hartmann, 2016), quantification and understanding of residual flood risk is, therefore, paramount. Whether directly or indirectly, many actors are involved in the development of flood risk management initiatives (Jha et al., 2012), hence how people perceive and understand residual flood risk has implications for the assets and communities being the subject of such initiatives. For example, if not properly accounted for in land-use planning regulatory maps, development may intensify in flood-prone areas protected by physical structures, thereby increasing overall flood risk profile for the community (Serra-Llobet et al., 2022). It is also important to note that people's perception and understanding of the risk they face influences their decision to adopt protective measures themselves (e.g., insurance, property improvements, or relocation; Ludy & Kondolf, 2012; Starominski-Uehara, 2021). This is especially important when structural measures are being used to mitigate floods, therefore, reducing people's direct flood experience and potentially undermining their flood preparedness (Gissing et al., 2017). With population growth and housing demand placing pressure on urban development and intensification to continue along floodplains, it is critical to both (i) understand how residual flood risks are understood and managed so as to avoid putting more people at greater risk (Hutton et al., 2019), and (ii) clearly communicate and disclose this to communities involved in collaborative flood risk management initiatives so that personal or community disaster management plans are up-to-date (Goodwin, 2009).

In A-NZ, the two main pieces of legislation relevant to flood risk management and effects of climate change are the Resource Management Act (1991) (RMA) and the Civil Defense Emergency Management Act (CDEMA) 2002 (Ministry for the Environment, 2010), both of which devolved responsibilities for flood management and recovery from events to the local/regional government (after decades of a more centralized model, including substantial funding of flood schemes). A third older, but revised, statute (Soil Conservation and Rivers Control Act 1941), includes objectives of prevention of damage by floods, prevention and mitigation of soil erosion, and the utilization of land in a manner that attains these

objectives. Under this legislation, regional councils can make bylaws for flood protection works and allow acquisition of land (with fair compensation) for such purposes. In summary, regional councils are responsible for river/stream and catchment management (including flood and drainage schemes) and territorial authorities for managing stormwater in urban or peri-urban catchments, with unitary councils combining both sets of functions. This has resulted in fragmented governance and resourcing (staff and funding), with each local authority developing their own approaches and measures with no collaboration, funding, or coordination between and across government levels (van Buuren et al., 2018). Risk reduction is supposed to be achieved through proactive planning as required by the RMA and the CDEMA, along with other relevant legislation such as the Building Act 2004, the Local Government Act (2002; Ministry for the Environment, 2010), which is mainly undertaken at the district or city level (rather than regional level). This complex array of responsibilities for flood management presents challenges in understanding the spatiality of residual risk, such as where it could be well or poorly managed (including maintenance and re-investment), how this could affect future climate-influenced risks, and how and what adaptation pathways can be developed and implemented (Lawrence et al., 2020; Lawrence & Haasnoot, 2017). It also makes it difficult to address and communicate residual risk in a nationally consistent way to different actors (e.g., governmental agencies, private consultancies, and communities) as well as its integration into land-use planning, operational management, and broader risk reduction strategies.

Regional or unitary councils have the primary responsibility for operational management of flood risk under the RMA for rural or large catchments; therefore, their flood managers are the core survey respondents for understanding residual flood risk management in this research. However, regional councils can delegate or transfer responsibilities to a territorial authority, and territorial authorities also have the responsibility to manage flood and stormwater risks through their district plans, but how such powers have been separated varies from region to region (McSweeney, 2006). In practice, most territorial authorities are small councils (i.e., median total population of territorial authorities is 50,562 according to the latest NZ Census[1]) and, therefore, lack the resources and expertise to manage flood risk by themselves so they usually rely on the relevant regional council or consultants for addressing flood risks, with the exceptions of the larger, resourceful territorial authorities. However, jurisdictional responsibilities for flood and stormwater risk management at the territorial level across the nation are unclear. To this end, the national survey in this study targeted regional or unitary councils primarily, given their principal role in flood risk management, but also sent out survey requests to some territorial authorities with flood-risk expertise and also distributed it through the key river and stormwater professional networks, since private consultancies often worked closely with councils, to obtain additional insights. The following methodology section further describes the procedure for survey distribution.

3 | METHODOLOGY

Data were collected through a nationwide survey aimed to collect information on the level of awareness and availability of residual flood risk information, how the risk was managed, and the barriers to manage residual risk. The survey was developed into a self-administered, web-based questionnaire using Google Form. The target participants were primarily practitioners, including planners and river managers, from regional and unitary councils. We also extended the surveys to territory authorities and private consultancies to get a more well-rounded picture of the residual flood risk management practices in A-NZ. We asked in total 20 questions regarding awareness of residual flood risk, causes of residual risk, available risk information, how such risk is managed, and a few other relevant questions about the outlook of future risk management. The majority of the survey questions are qualitative and open-ended, allowing respondents to provide their individual viewpoints. There is also one qualitative Likert scale question on barriers, in which we asked survey respondents to identify key barriers by rating a list of choices on a linear scale of 0 to 4 based on their importance, where 0 denotes not important (i.e., not a major barrier) and 4 denotes very important (i.e., a major barrier). The full survey protocol can be found in Appendix A.

We followed the procedures of the Total Design Method (TDM) proven to be effective in improving response rates for online surveys (Dillman, 2000). We first compiled a list of potential participants from 11 regional councils, 6 unitary councils, and 61 territorial district councils. The survey was initially sent out to key contact persons in local governments (March 2022), followed by two remainders a month apart from each other; one in April and one in May. The survey was also distributed through two key professional networks of flood risk management: The Engineering New Zealand/Water NZ Rivers Group, and the water-sector professional group Water New Zealand, through their social media and

[1]New Zealand 2018 Census: https://nzdotstat.stats.govt.nz/

newsletter to further extend the survey exposure to potential participants in the public and private sectors, with also two remainders.

After collating the survey responses, we first prepared them into an Excel spreadsheet and then analyzed the qualitative content using deductive coding to group responses and label quotes to answer specific research questions and to identify emergent themes. For the quantitative Likert scale question on barriers, we visualized each of the responses over the different barriers in a heatmap chart and provided a mean for each barrier to highlight the dominant ones.

4 | RESULTS

We received 17 responses, 10 of which were from the regional council (5 out of 11 regional councils) and unitary councils (5/6), with a combined response rate of 59% at the regional level. Of the rest 7, 4 responses were from the territorial authorities (out of 61) and 3 were from private consultancies who work closely with councils. As discussed previously, regional and unitary councils have the primary responsibility for flood risk management and, therefore, it is not surprising that we have a low response rate from the territorial authorities. From early responses to our survey request, a dozen of them pointed to the staff at the regional council for any information regarding flood risk. The low response rate from territorial authorities can also be explained by their small size as they usually have very few staff members, and where stormwater/flood management is intertwined with a wider responsibility for delivery of three waters infrastructure and other utility services and felt disinclined to participate in the survey. Nevertheless, respondents in the survey are largely from regional and unitary councils, and, combined with the territorial authorities, cover major urban areas with over 80% of the national population and nearly half of the larger catchment flood schemes (Walsh et al., 2019). Hence, our survey provides a reasonable national representation of flood risk management practice. Our survey respondents are also very knowledgeable about flood risk management as over 88% (15/17) have worked in flood risk management for over 5 years and 76% (13/17) for over 10 years.

4.1 | Awareness and availability of residual flood risk information

All survey respondents were aware of and concerned with residual flood risk affecting their communities. The two predominant types of residual risk mentioned were related to extreme weather events and potential failure of protective structures (see Figure 1). While a few responses combined them as one risk type, that is, flooding that occurs exceeding the design standard, the majority recognized them as two separate risks, yet highly interconnected. This is because protective structures can still fail in the absence of an extreme flooding event such as "stormwater network blockage," "floodgate debris blockage leading to backflow," and "stormwater pumping station outrage" (quotes from a regional council official). According to one of the respondents from the private sector who has ample experiences working with councils across the nation: "Council vary in their awareness of the residual risk; while residual risks such as dam failure and stopbank (levee) overtopping are commonly recognized, most councils fail to quantify and carry these risks into broader flood asset management." Several respondents identified the misunderstanding and misperception of flood risk among stakeholders (including some council departments, developers, and the public) as another type of residual flood risk. Many also recognized that residual flood risk stems from the mismatch between dynamic external environments and the conventional "static" risk analyses that only offers a snapshot of a risk at the time of the assessment and corresponding design of the flood-management asset, as well as the uncertainties inherent to the actual hazard and risk modeling.

Respondents unanimously agreed that residual flood risk was increasing. Although many causes were reported, one respondent from a regional council noted that "whether residual risk is increasing is a complex consideration" due to the complex relationship between risk and risk management measures in urban systems. Among the reported causes, climate change and urban intensification of floodplains were the two primary answers (see Figure 2). Additionally, the majority of respondents expressed serious concerns about continuing development of floodplains and the political or regulatory ability to prevent that. One respondent from the regional council reported that "development in some cases is still occurring in floodplains, reliant on infrastructure or building design solution"; and, one respondent from a territorial authority added that "there is pressure from land developers to want to develop areas within existing low areas and potential floodplains, because land prices are high (in these areas) and many landowners want to take advantage of the potential financial gain." Other reported causes included the lack of flood mitigation actions, lack of robust (residual) flood risk information, weak public risk literacy, and changing geographic topography. Most respondents also expressed serious concerns

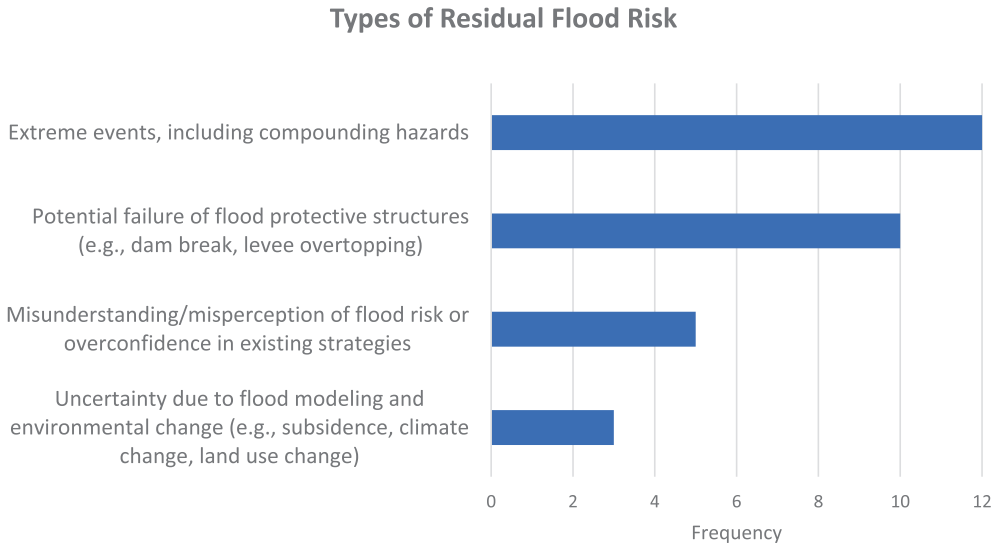

FIGURE 1 Frequency table of types of residual flood risk reported.

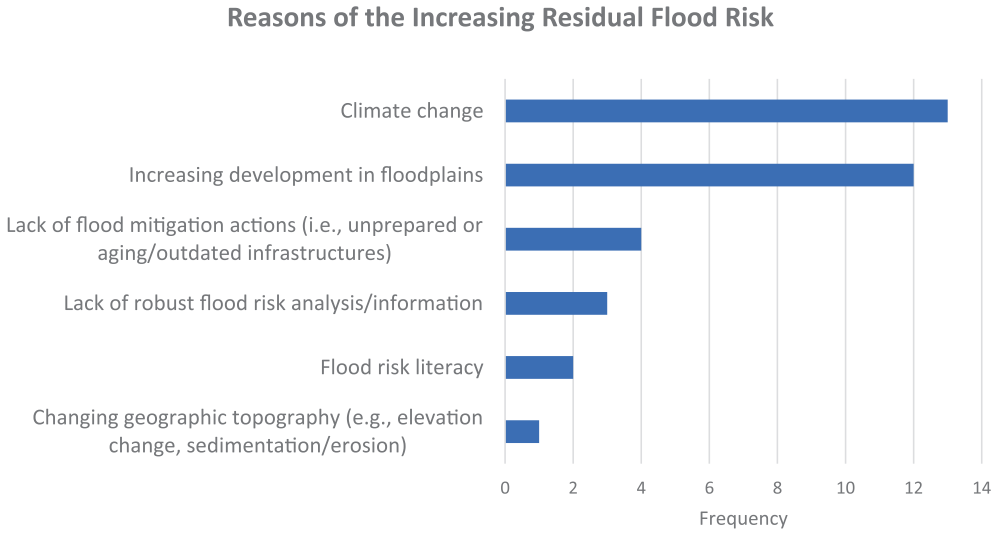

FIGURE 2 Frequency table of reported reasons of the increasing residual flood risk.

regarding the lack of financial resources to upgrade or maintain existing protective infrastructures to keep pace with the rising residual flood risk. Although lack of financial resources is quite a common issue internationally, local governments in A-NZ are additionally burdened by technical issues, including having to undertake their own flood risk assessments without any consistent directive, national guidance or standards (van Buuren et al., 2018; Woods et al., 2010) and, in many cases, without high-precision spatial data for robust hydrological modeling. Significantly, 18% of the respondents reported that there was no reliable flood risk information available at the local level (e.g., outdated flood maps). While the rest (82%) reported having reliable risk information, only half of them (40%) claimed to have made it publicly available, which inhibits the ability for residual risk management by a wider range of stakeholders.

4.2 | Residual flood risk management

The majority of the respondents reported that residual flood risk has been considered (29%), or at least partially considered (65%), in the available flood risk information. The most common approach is the inclusion of protective structures in flood modeling, and generating flood maps for failing schemes (e.g., flood defense failure, drainage system blockage, or dam breach) using the 1% annual exceedance probabilities (AEP) or 100-year flood design event. Many respondents were unsatisfied with their existing flood risk information. Several explicitly acknowledged that the 1% AEP design event was not adequate to represent the actual flood risk mainly due to ongoing climate change risks. Some reported that the existing flood risk information was outdated and did not consider the changed land use patterns and

intensification. Others discussed the technical insufficiencies in the existing modeling approach, including the fact as reported by the respondents from the private sector that "limited and inconsistent breach mapping creates more risks such as mapping a breach at one location rather than along length of a defense" and the adoption of "bathtub inundation projections rather than fully hydrodynamic modeling of overland flow." However, respondents also identified the use of more advanced approaches to manage residual risk, including taking climate change rainfall projections and/or sea-level rise into account, and undertaking joint probability analysis for compound flooding, such as combined fluvial, pluvial, and coastal flood levels.

When asked whether residual flood risk is an integral element of local flood risk management, the majority reported positive, with half of the respondents (53%) reported "Yes," four "Partially" (24%), three "No" (18%), and one "Unknown" (5%). Depending on the quality of the information, residual flood risk was reported to be incorporated into local long-term land use planning, building codes, risk assessments for new developments and capital improvement programs, as well as emergency management endeavors. Additionally, when asked about the future outlook in this rapidly evolving space, particularly with respect to the potential for insurance retreat, participants agree that risk-based insurance scheme would become the norm and over time private insurance would eventually become unaffordable. The majority expressed that local councils remain unsure how they might respond but they expect better flood risk information including about residual risk and anticipate stronger support and guidance from the state.

While A-NZ has high insurance penetration that includes flood insurance, underinsurance remains a substantial issue nationally (Stepanova, 2021) and internationally (Lamond & Penning-Rowsell, 2014). When asked their opinion on the recent adoption of risk-based pricing by insurance providers and how councils may respond to the potential for private insurance retreat which would raise residual risk, some were generally in support of the risk-based approach, and most respondents were uncertain and unsure what their council will do at this stage, yet they all acknowledged that councils will need to respond to this eventually. One respondent from a unitary council commented: "I suspect that private insurance retreat would drive a reduction in risk appetite amongst the affected community, leading to calls on the council to increase protection." Another anticipated that the risk-based approach and insurance retreat will lead to the more rapid transformative move from disaster response to disaster risk reduction, and will thus vacate high-risk properties out of the floodplains over time and changed land-use patterns to activities with lower consequences from flooding. A common theme from the responses was the large regulatory uncertainty regarding the (new) role councils should play in flood risk management. Many were looking for more guidance from the central government with the upcoming planning reform (i.e., the RMA reform) and potential update of the regulatory framework guiding local governments for better land use and natural hazards management.

4.3 | Barriers to managing residual flood risk

Participants reported the existence of significant barriers to managing residual flood risk at the local levels, albeit we note the barriers we listed to choose from (see Figure 3) may not be necessarily limited to managing residual flood risk but to flood risk management in general. Although some specific barriers seem to be more prevalent, large variation exists in terms of the major barriers that hinder local residual flood risk management. All 13 barrier choices were rated at least as slightly important (mean ≥ 1), and nine were rated as greater than important (mean ≥ 2). Unsurprisingly, the lack of national guidance/support (mean $= 2.9$) was the most significant barrier, which was already repeatedly mentioned across the prior survey responses, followed by financial resources (2.8), and public awareness (2.6). Barriers related to evaluating and modeling local residual flood risk were also among the most significant barriers. These included data availability (2.6), uncertainties due to modeling and future climate change (2.6), data quality (2.6), and staff experience and expertise (2.2). Other important barriers included guidance on recording flood risk in land information memorandums (LIMs) of properties (2.2), local political will (2.1), economic disincentives from private insurers (1.8), and institutional inertia (1.8).

5 | DISCUSSION

Two key messages can be distilled from the results to better manage residual flood risk in A-NZ. First, a clearer national directive of how flood risk and residual risk should be managed is urgently needed, particularly for guidance on the regulatory provisions to restrict inappropriate development in flood-prone areas, including those behind protective structures. Second, more dedicated resources and support are necessary to allow local

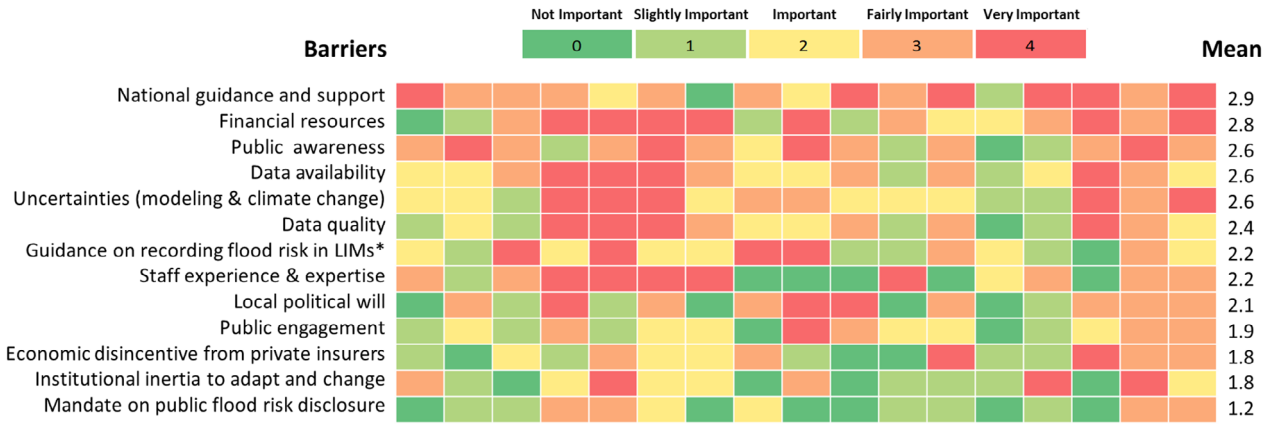

FIGURE 3 Heatmap for survey respondents' perception of barriers (* LIMs, Land Information Memorandums).

councils to compile more rigorous and consistent (residual) flood risk information and to actively engage with the public for better flood risk awareness and outreach.

A lack of a clear national directive on managing flood risk and residual risk is a repeated theme raised by participants in the survey. Local practitioners in A-NZ agree that residual flood risk is increasing, mainly due to climate change and continuing development in the flood-prone areas. As climate change is constantly changing the risk profiles of flood-prone communities, the current practice of flood risk management that relies on lengthy historical observations to predict and design for future extreme events is seen by some as no longer adequate. Although a more adaptive approach is deemed necessary, participants note that such a change is difficult due to the existing institutional context, such as the long-standing defense-oriented risk management paradigm. This supports other research which has similarly identified the strong influence of administrative traditions, disciplinary practices, or outdated standards or codes of practice in continuing more "static" practices (Gersonius et al., 2016; Hanna et al., 2022, Lawrence et al., 2013; van Buuren et al., 2018; Vojinovic, 2015; White & Lawrence, 2020).

The clear direction is vital as preventing new developments in flood-prone areas remains a key challenge facing flood managers and land use planners. It is especially the case in the low-lying coastal regions, such as New York City and Miami in the United States, which are accessible to a range of amenities and often have very high land values (Fu & Nijman, 2021; Qiang et al., 2017). Flood managers and land use planners in these areas often have very limited capacity to restrict developments in floodplains (even with the rising climate risks), within a neoliberal market-driven regulatory framework that can hardly restrict or deny development proposals in either fluvial or coastal floodplains, such as in New Zealand, Australia and the United States (Cradduck et al., 2020; Elrick-Barr & Smith, 2021; Glavovic et al., 2010; Hutton et al., 2019; Local Government NZ, 2014).

In addition to the lack of a national directive, a lack of financial support and poor (residual) flood risk modeling and information are among the most important barriers as ranked by the survey participants. Our findings are aligned with a previous study that surveyed researchers and risk professions about flood risk management research in A-NZ (Rouse, 2011), implying that there has been little improvement within the last decade. These are also consistent with the barriers identified in the literature on flooding mitigation (Brody et al., 2010) and other planning efforts, such as climate change adaptation planning (Eisenack et al., 2014; Fu, 2020; Hamin et al., 2014) and extreme heat (Meerow & Keith, 2022). Several respondents reported "other" barriers, including "public perception and expectation relating to legal liability and risk transfer" and "Iwi interests" (i.e., Māori tribe). Clearly, practitioners were quite concerned with the political and public buy-ins for proactive flood risk reduction actions that are transformative and can be deemed radical, such as pre-emptive managed retreat (Anderson, 2022; Lawrence et al., 2020; Tubridy et al., 2021).

Although residual flood risk has recently emerged in the flood risk literature, it is more positive to note that local practitioners in A-NZ are generally well aware of the issue in managing local flood risk. Given the lack of national directives or standards to work within the context of devolved local responsibility for flood risk management, and large variation in local capacity and resources, it is not surprising to find that how residual risk is considered varies significantly across the nation between regions and districts. Many councils, especially the smaller ones, do not have the resources or expertise to develop rigorous flood risk information to share with

developers and the public. Such risk information is not only important for local government to inform risk management and land use planning, but also critical for effective risk communication with local communities to increase the public understanding of the potential flood risk including residual risk, foreknowledge of emergency management arrangements and to improve public buy-in for risk mitigation measures (Feldman et al., 2016; Henstra et al., 2019; White et al., 2010). Even when councils have good (residual) flood risk information, the "levee effect," a false sense of security caused by protective measures like levees, is likely in play across communities, which hinders the ability of proactive councils to regulate development of hazard-prone areas or better inform individuals from buying properties in areas behind protective measures.

This unveils two common gaps in the existing flood risk management not exclusive to the A-NZ context, within which local governments and communities often fail to mainstream residual flood risk into managing flood risk, and a lack of consideration for (residual) flood risk from a wider systemic view. It is worth noting that the systems perspective entails a deeper understanding of interconnectedness of various flood-relevant sectors such as land-use planning, insurance, financial institution, infrastructure, society, and emergency management, as well as how their connections influence flood risk behaviors within individual communities (Mai et al., 2020; Sayers et al., 2013). It also resonates with the ongoing aspirations for urban resilience internationally which advocates systems thinking and transformative adaptions (Fu & Li, 2022).

Most communities in A-NZ, as well as in many other western countries, rely heavily on flood insurance to cover residual flood risks, but most existing insurance schemes are not sustainable because they generally do not fully account for the growing risk due to climate change, and the insurance pay-outs are often used to rebuild in the same location where flood risk remains high (known as the "build-disaster-rebuilt" cycle). More fundamentally, there is the risk of insurance retreat, whereby a private sector actor could greatly increase residual flood risk due to a private commercial decision. In A-NZ, the state-operated Earthquake Commission (EQC) insurance cover for rare, high-impact hazards, does not include climate change induced flooding apart from damage to land or land-supporting structures (Paster et al., 2018). Therefore, as climate change continues exacerbating the risk of flooding in most areas, insurance premiums, and/or policy excesses will increase and ultimately retail insurance will become unprofitable or unviable in many places leading to the retreat by private and/or public insurers (Lamond & Penning-Rowsell, 2014; Raschky & Weck-Hannemann, 2007; Siders, 2019; Storey et al., 2020). This is a particularly imperative issue in A-NZ, because unlike many other countries that provide publicly subsided flood insurance (e.g., the United States, the United Kingdom, France), flood insurance on assets is only offered through the private sector, that is, changing practices on a company level. An example is the recent adoption of a spatial risk-based approach for pricing flood insurance by Tower, a private insurer in A-NZ, who are the first to do so. This move signals a long-term issue facing local communities and state governments with respect to how to support the insurance sector, both public and private, so that residual risk can be effectively managed.

While awareness is high professionally, it is clear that residual risk remains an emerging topic for flood risk management more generally, particularly with regards to effective governance, appetite for more control over private sector development rights, and public awareness of the unseen potential harm. Even though this study provides a useful first step into understanding residual flood risk management in A-NZ, research on this topic, even globally, is still limited particularly in the face of rising climate change influence of flooding and parallel agendas, such as relating to the housing crisis, demanding easier planning or the widening of development rights. Hence, we argue more future research is needed to better address residual risk in two specific contexts: (1) flooding in urban areas that are subject to significant growth pressures, particularly those facing more intense precipitation events or compounding flood hazards including pluvial, fluvial, groundwater rise, coastal storm surge, and sea level rise; (2) flooding in peri-urban and rural areas predicted to experience more intense compounding pluvial and/or fluvial flooding hazards. Additionally, based on this survey, there is still a need for more quality information on the extent to which residual flood risk is actually leading to different planning decisions or influencing wider risk management decision-making processes in practice. Future research can also focus on how residual flood risk is managed in other countries in comparison to A-NZ with a view to deriving transferrable best practices, or to undertake in-depth case studies of residual flood risk management in specific communities to better understand local barriers and how they can be overcome. Data such as these would also be useful in tracking the extent to which the state of practice has changed or how the forthcoming new resource-management legislation and hazard planning framework proposed for A-NZ influences effective residual flood risk management. With the rising attention paid to residual flood risk and better understanding of how to manage it (including adaptive approaches), it enables more

informed land use planning, policy changes, and risk decision-making to improve the resilience of our cities and rural floodplains in the face of climate change and significant development pressures.

6 | CONCLUSION

Flooding is one of the most frequent, harmful, and costliest natural hazards around the world. For many years, structural measures, such as levees and seawalls, have been the principal mitigation actions for flood risk management, focusing primarily on reducing flood exposure to a certain level (e.g., 1% AEP). While it will always play a role, this conventional engineering-oriented approach to manage flood risk can have more hidden side-effects because development usually increases behind protective structures due to a false sense of security known as the "levee effect," thereby increasing residual flood risk (e.g., Hutton et al., 2019). Adding climate change to the formula, flooding is exacerbating the threat to communities, as evidenced by the increasing frequency and severity of flooding around the world. In this context, it is imperative that we need a more holistic understanding of risk and manage flood risk more effectively by addressing residual flood risk and how it changes over time (Lawrence et al., 2020; Lawrence & Haasnoot, 2017). We conducted a national survey of practitioners from local councils (i.e., regional and territorial) and consultants who work closely with councils on managing flood risk in A-NZ, which provides a valuable baseline study to understand how residual flood risk is being managed and to identify the barriers that hinder such endeavors.

We find that flood risk professionals are well aware of and concerned with residual flood risk in their communities. All acknowledged that residual risk is increasing in their communities for multiple reasons, including climate change, increasing developments in the floodplains ("levee effect"), inadequate flood mitigation measures, lack of robust (residual) flood risk information, low public (residual) flood risk literacy, and changing topography. The majority reported that residual flood risk had been considered when managing local flood risk, but to varying levels. The most common approach incorporates protective structures into flood hazard/risk assessments and generates specific levee or dam failure scenarios from flood modeling to inform risk decision-making. However, many expressed concerns regarding their existing approach such as using 1% AEP design event that could underestimate flood risk, relying on outdated risk information that fails to consider the changed land use patterns, and adopting unsophisticated (i.e., non-hydrodynamic "bath-tub") flood modeling.

Finally, we find that significant barriers exist in managing (residual) flood risk at the local levels in A-NZ. The highest-rated barriers are the (lack of) national guidance/support, (lack of) financial resources, (lack of) public awareness, and a number of technical barriers related to flood data, modeling, and staff expertise. Consequently, we argue that to better manage residual flood risk in A-NZ requires a clearer national directive of how flood risk and residual risk should be managed, particularly on enabling the local governments with the regulatory provisions to restrict developments from flood-prone areas behind protective structures. Moreover, more dedicated resources and support are needed to allow local governments to acquire more rigorous and consistent (residual) flood risk information, and actively engage with the public for better (residual) flood risk awareness and outreach. Without these improvements, residual flood risk will likely continue rising in flood-prone communities, which will cause all stakeholders to underestimate their flood risk as well as the necessary insurance coverage. Without a change in approach regarding residual risk, we anticipate we will witness an increased national flood risk exposure into the future and reduced insurance affordability and penetration.

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DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

ORCID

Xinyu Fu https://orcid.org/0000-0002-3591-4158

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APPENDIX

Survey on understanding residual flood risk management in Aotearoa-New Zealand

The survey was developed based on a review of the latest literature on residual flood risk management, and then pilot-tested with academics and practitioners in this field to seek external feedback. The survey was later finalized after revising the survey by incorporating the collated comments and feedback. Then ethical approval was later obtained from the Human Research Ethics Committee at the University of Waikato before survey distribution.

This survey aims to explore how and to what extent flood risk management in NZ considers, analyzes, and treats residual risk. Your response will help us better understand and potentially improve flood risk management nationally.

This survey has five sections with 20 questions in total, which will take ~10–15 min to complete. It is up to you if you wish to take part. If you start and change your mind, you can stop at any time. Your responses are confidential.

- *Respondent Information (1/5)*

The following questions about the survey participant are to ensure the responses are robust and representative for New Zealand. All the information will remain confidential and be later aggregated to reduce the risk of spontaneous recognition.

1. Please identify the authority or consultancy you work for.
2. Please identify the council department that you work in (or work with as consultancy).
3. What is your position title?
4. How many years have you worked in this position?
5. How many years have you worked in flood risk management?

- *Knowledge about Residual Flood Risk (2/5)*

Questions in this section are to understand your knowledge about residual flood risk and how such risk is managed in your jurisdiction. Residual flood risk is defined as the potential risk of flooding that remains after the implementation of risk treatment actions.

6. What are the types of flood risk in your jurisdiction?

- fluvial flooding
- pluvial flooding (including stormwater and drainage)
- coastal flooding
- compound flooding (compound flooding refers to a phenomenon in which two or more flooding sources occur simultaneously or subsequently within a short period of time)

7. What types of residual flood risk is the council aware of? (Please add 1 idea per line)
8. Is the residual flood risk increasing in your community, and, if yes, what do you think are the underpinning causes for the increasing residual flood risk? (Please add 1 idea per line)
9. Is high quality flood risk information available for your jurisdiction yet?

- Yes, it is available to all the practitioners.
- Yes, it is available to both the practitioners and the general public.
- No, we do not have reliable flood risk information.

10. Does the flood risk information consider residual flood risk?

- Yes
- No
- Partially

11. (Optional) If yes (or partially), how does the flood risk information consider residual flood risk?

- *Council Behavior Questions (3/5)*

The following questions ask about your practical understanding of how council may alter its current practice in response to the external changes such as climate change and private insurance retreat. Please use your best knowledge to address these questions, but note that they are optional so you can skip if you are unsure.

12. (Optional) What is the council's current insurance scheme on flood-protection assets? For example, is the council covered by insurance of their flood-protection assets up to an agreed flood protection threshold or self-insured? Do you expect changes in the council's insurance scheme in the near future and, if so, why?
13. (Optional) How will the council respond to private insurance retreat from the flood-prone areas (e.g., Tower recently adopted risk-based pricing)?
14. (Optional) Under the Climate Change Response (Zero Carbon) Amendment Act 2019, how would regular requests for information on how the council manages climate risks (Section 5ZW), alter you council's approach to residual flood risks?

- *(Residual) Flood Risk Management and Land Use Planning (4/5)*

The following questions ask whether (residual) flood risk is being integrated into land use planning in your jurisdiction and how.

15. To your best knowledge, how is flood risk information utilized in land use planning and decision-making in your jurisdiction?
16. Is residual risk considered as an integral element of flood risk decision-making and management in your jurisdiction?

- Yes
- No
- Partially
- Do not know

17. (Optional) What mechanisms or planning instruments are being utilized to manage residual flood risk in your jurisdiction?

- *Barriers and Obstacles for Managing Residual Flood Risk (5/5)*

This section aims to gain insights into existing barriers and obstacles that hinder the effective management of residual flood risk in your community and collectively in New Zealand.

18. What are the barriers that hinder your council from managing the residual flood risk? (rate the following with respect to their importance being an existing barrier one a scale of not at all important, slightly important, important, fairly important, very important, or no opinion).

- Lack of local political will due to other priorities
- Lack of national guidance and support
- Lack of public/stakeholder engagement
- Lack of public community awareness
- Lack of systematic mechanisms to revisit and improve flood risk management (i.e., institutional inertia to adapt and change)
- Lack of a mandate on public disclosure of flood risk to properties
- Lack of financial resources
- Lack of staff and expertise
- Insufficient data
- Poor data quality
- Uncertainties due to flood modeling, and future climate change
- Lack of a mandate on flood risk disclosure on properties to the public
- Lack of disincentive/price signals from the private insurers
- No clear guidance entering residual risk on LIMs (LIM: Land Information Memorandum)

19. (Optional) Are there any other barriers other than those listed?
20. (Optional) If you would like to explain the reasons for your choice, please leave your comments below.

Ka nui te mihi

Thank you very much for your participation and your contribution will help us better understand how we can manage flood risk more wisely at our local communities and collectively as a nation. If you would like to receive future updates of this research, please leave your email information below.