AUCKLAND FLOODS 2023: ASSESSING RISK TO LIFE FROM FLOODING AT THE PROPERTY LEVEL

F. Macdonald; N. Brown (Auckland Council Healthy Waters)

R. Donnelly (Richard Donnelly Ltd)

ABSTRACT

The extreme weather events of early 2023 caused widespread flooding in the Auckland region. In response, Auckland Council Healthy Waters (ACHW) initiated a rapidly evolving programme of work to quantify and understand the magnitude of the events and their impacts on the community, support and shape the wider recovery effort, and to develop the frameworks and tools that would be needed to enable the assessment of affected properties for potential buyout or risk mitigation works.

For the purposes of Auckland Council's response to the severe weather events of 2023, Council determined that flood-affected properties would be eligible for consideration for buyout or subsidised risk mitigation where there was a high risk to life to vulnerable people in an existing 1% AEP flood event. However, at the time of the 2023 floods, Healthy Waters did not have a defined framework for assessing risk to life from flooding. This paper describes the framework developed by Auckland Council Healthy Waters to assess risk to life at the property level in the Auckland Region.

A literature review revealed that existing approaches to flood risk assessment in New Zealand and overseas tend to assume widespread fluvial or coastal flooding which results in a uniform level of flood hazard across a wide area. In contrast, Auckland's small catchments and steep topography tend to produce pluvial flooding that is highly localised and flashy. This has material implications for the risk assessment methodology. Key challenges encountered in the development of the framework included how to account for the spatial variability of flood hazard at the property level, how to account for the decision making of people who might be on a property at the time of flooding, how to account for those who are most vulnerable, and how to integrate flood hazard assessments at multiple locations on a property into a single rating that represents risk to life in a 1% AEP event.

The paper discusses how these, and other challenges were addressed in the development and application of the Property-level Risk Assessment Framework and illustrates the application of the framework with a worked example.

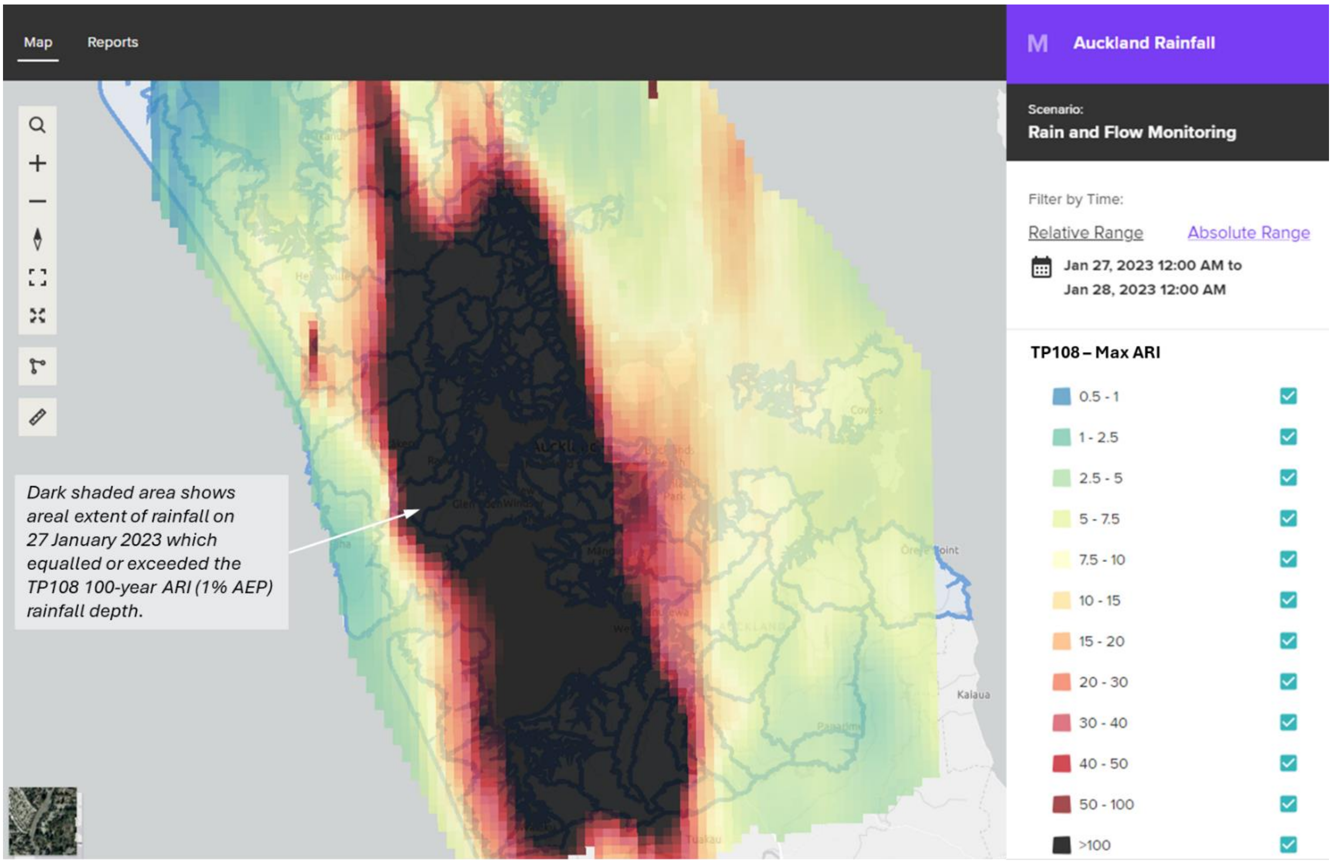
KEYWORDS

AUCKLAND FLOODS, RECOVERY, FLOOD RISK ASSESSMENT, RISK TO LIFE, PROPERTY CATEGORISATION, FLOOD ASSESSMENT FRAMEWORK, PROPERTY PURCHASE, INTOLERABLE RISK

1 INTRODUCTION

In early 2023, the Auckland Region experienced a series of extreme rainfall events. During the Auckland Anniversary event on Friday 27th January, 60% of urban Auckland experienced a rainfall event of 1% AEP or greater in magnitude (see Figure 1). It is estimated that approximately 12,000 habitable floors flooded in this event. This was followed by Cyclone Gabrielle, which was well in exceedance of a 1% AEP event along the west coast of Auckland. Parts of the Auckland Region also experienced extreme events equalling or exceeding a 2% AEP event on 31st January, 23rd February, and 9th May.

Figure 1. TP108 Max ARI, 27 January 2023



In response to these severe weather events, which affected large parts of the North Island including Auckland, the New Zealand government announced its intention to fund residential property buyouts and risk mitigation works for affected properties. On 1st May 2023 the government published a framework for categorising the properties that had been affected by those events. There were three categories:

- Category 3 properties, which would be eligible for a buy-out where it is determined that future risk cannot be mitigated.
- Category 2 properties, which would be eligible for subsidies for risk mitigation works, where these were feasible.
- Category 1 properties, which would not be eligible for risk reduction.

The government's category definitions established the key eligibility criterion as the existence of intolerable risk to life from either flooding or landslide (i.e., risk of death or serious injury to occupants of residential buildings). However, at that time, Auckland Council did not have a framework for assessing risk to life from flooding in the Auckland region. Up to that point, flood risk had been conceptualised and measured in terms of buildings and habitable floors affected by flooding. Implementation of the government's policy setting would require the set of flood-affected properties to be differentiated into those where flooding posed an intolerable risk to life and those where it didn't.

This paper describes the Property-level Flood Risk Assessment Framework that was developed by Auckland Council Healthy Waters to enable the risk to life from flooding on individual residential properties in the Auckland region to be assessed in a consistent, transparent, and objective manner in support of the property categorisation process.

The framework was developed by a core subject matter expert (SME) Working Group, made up of both Healthy Waters staff and consultants and supported by targeted input from other stakeholders and specialist consultants as required. Oversight was provided by an independent Expert Panel that was convened on a regular basis to review the evolving framework and provide critical feedback.

The framework (shown in Figure 2) employs a Flood Danger Rating system, which classifies the flood hazard at a property during peak flood conditions based on water depth, flow velocity, and the combined effect of these factors on the stability of people and buildings. The Flood Danger Rating describes the perceived hazardousness of flooding on a property (see Figure 3):

- **Low Danger:** generally not dangerous for all, including vulnerable people.
- **Moderate Danger:** Whether the situation is dangerous depends primarily on people's decision making. Their choices will determine the level of hazard to which they are exposed.
- **High or Extreme Danger:** Dangerous for vulnerable people, and may be dangerous for all, irrespective of what people decide to do.

For the purposes of property categorisation, Auckland Council determined that Danger Ratings of Extreme or High should be considered intolerable at an Annual Exceedance Probability of 1% or greater (refer Appendix 2 of Auckland Council, 2023).

Sections 2 and 3 of this paper explain some of the key challenges encountered in the development and application of the framework and how these were addressed. Those wanting further detail on any of the points discussed in this paper are referred to the framework document and supporting appendices (see Auckland Council, 2024). A worked example is provided in Section 3.

Figure 2. The Auckland Council Property-level Flood Risk Assessment Framework

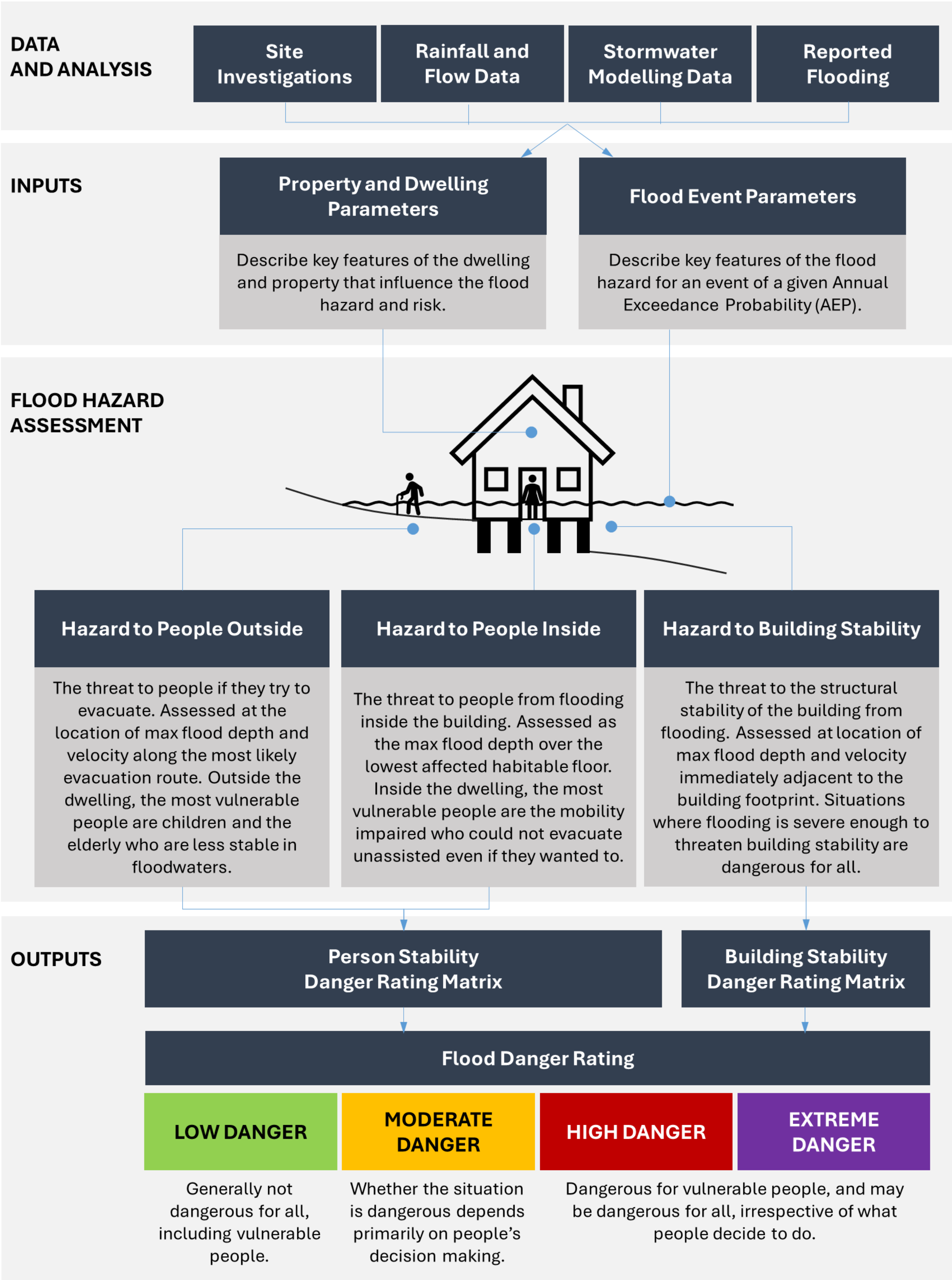
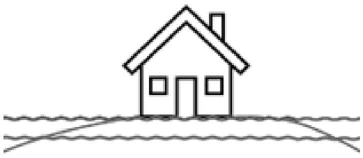


Figure 3. Illustrative Flooding Scenarios and Flood Danger Ratings

LOW DANGER		• Building stability is not at risk. • Flooding may or may not be up to the dwelling footprint. The habitable floor of the dwelling remains dry. • An evacuation route is available which does not require wading or requires low-hazard wading only. • Low danger, including for the mobility impaired.
MODERATE DANGER		• Building stability is not at risk. • The dwelling is surrounded by floodwaters that pose high hazard for children and the elderly and may also be high hazard for adults. The floodwaters could be right up to the dwelling footprint, but the habitable floor remains dry. • There is no safe or low-hazard evacuation route available. • While the safer option would be to shelter in place, some people may choose to evacuate due to uncertainty about the evolving flood situation. This would be dangerous for children and the elderly and may also be dangerous for adults.
		• Building stability is not at risk. • Properties in this zone have a lower habitable floor subject to minor flooding <0.5m in depth. • A safe or low hazard evacuation route is available but must be accessed from the upper levels of the dwelling. • For able-bodied people who are likely to evacuate or take refuge upstairs, this scenario represents low danger. • For mobility impaired people who may be downstairs, the danger is moderate.
HIGH DANGER		• Building stability is not at risk. • The dwelling is surrounded by floodwaters that are high hazard for children and the elderly and may also be high hazard for adults. • There is no safe or low-hazard evacuation route available. • The floodwaters extend right up to the dwelling footprint and there is flooding over habitable floor, which could be deep. • A significant proportion of people may try to evacuate. • This scenario is dangerous for all.
		• Building stability is not at risk. • Properties in this zone have a lower habitable floor subject to flooding >0.5m in depth that poses high danger for mobility impaired people. At higher levels of flooding (>1.2m) this scenario is dangerous for all, including others in the house who may try to assist those trapped downstairs.
EXTREME DANGER		• The floodwaters extend right up to the dwelling. There may be flooding over habitable floor, which could be deep. • There are deep and/or fast flowing floodwaters immediately adjacent to the building footprint. • The building stability may be threatened by erosion of the building foundations or uplift forces causing failure of the walls and foundation slab. • Even if a safe or low-hazard evacuation route is available, occupants may not be able to access it in the event of building failure. • This scenario would be dangerous for all.

2 DEVELOPMENT OF THE FRAMEWORK

Key challenges encountered in the development of the framework included defining what "intolerable risk to life" means, accounting for the spatial variability of flood hazard at the property level, which is a consequence of Auckland's topography and predominantly pluvial flooding, defining who "vulnerable people" are and how their vulnerability should be accounted for, and how to integrate flood hazard assessments at three different locations on a property into a single measure that could represent risk to life, which required accounting for what people will do when confronted with flooding on their property. These challenges are discussed in the following sections.

2.1 WHAT "INTOLERABLE RISK TO LIFE" MEANS

In safety engineering contexts, "risk to life" means the likelihood of death, which is typically quantified. For example, in civil aviation, amongst the 320 airlines that are members of the International Air Transport Association, the five-year average fatality risk for 2018-2022 was 0.05 per million flights (IATA, 2024), which translates into a roughly 1-in-2 million ($5x10^{-7}$) annual chance of being involved in fatal crash for someone who flies on average 20 hours per year, assuming an average flight duration of two hours.

Situations involving intolerable risk to life imply a level of danger or threat to human life that is unacceptable and therefore cannot be tolerated regardless of the potential benefits or rewards. Such situations must be avoided, or, if they cannot be avoided, the risk must first be reduced to tolerable levels.

Thresholds for what is considered intolerable risk to life vary around the world and in different contexts. However, an annual risk to life to individuals of 1-in-10,000 ($1x10^{-4}$) has often been considered an upper tolerable limit. This value was adopted by the UK Health and Safety Executive for members of the public and recommended as a reference threshold in relation to slope instability in the Port Hills following the Canterbury earthquakes (Taig et al., 2012) and was used in determining areas of intolerable risk on the Awatarariki Fanhead in Matatā following the 2005 debris flow (Boffa Miskell Ltd, 2018). It was also adopted by Auckland Council for categorising properties subject to landslide risk following the 2023 severe weather events (Auckland Council, 2023).

Ideally – and for consistency with the approach being taken to the landslide risk assessments – the assessment of flood risk to life would be quantitative. However, risk to life from flooding is the product of numerous conditional probabilities, including whether the property is exposed to flooding, whether people are home at the time of flooding, whether and when they choose to evacuate, and whether they suffer a fatal outcome from being exposed to flood hazard. Only some of these probabilities can be credibly quantified. Aside from the difficulties with estimating evacuation rates, which requires anticipating what people will do when confronted with flooding on their property (discussed later in section 2.4 of this paper), there is no credible basis for estimating mortality rates in a pluvial flooding context.

A review of international literature on factors affecting loss of life from flooding and approaches to estimating flood mortality revealed that the proportion of fatalities compared to the at-risk population is typically very small and there is little precedent for differentiating mortality values by flood depth and no precedent for differentiating mortality by person vulnerability (see section 4.6 and Appendix 3 of the framework document for a fuller discussion). Moreover, published mortality rates and estimation methods tend to be for large scale fluvial or coastal flooding events or catastrophic flooding from tsunamis or dam breaches involving flood depths over 2m, which are not necessarily representative or applicable to Auckland's mostly shallow and highly variable pluvial flooding.

In the Auckland context, there have been seven known fatalities from flooding, including the two deaths in the Wairau valley during the 27 January 2023 event. While there are numerous stories of near misses, past fatalities from flooding in Auckland have all been associated with risk taking behaviour rather than due to people trapped in their homes or trying to evacuate from their homes (Smedley, 2022; see also Appendix 2 of the framework document).

Ultimately, it was concluded that is not possible to quantitatively estimate risk to life in property-level flooding scenarios in the Auckland context as there is insufficient information to reliably estimate all the relevant probabilities. It was, therefore, necessary to represent risk to life another way, as the likelihood of exposure to life threatening flood hazard. In the framework, this is done through the combination of the flood event likelihood (annual exceedance probability, AEP) and the Flood Danger Rating. Since the Danger Rating is specific to a property and a flood event of a given AEP, both the AEP and the corresponding Flood Danger Rating must be stated to convey the risk. For the purposes of the property categorisation, Danger Ratings of Extreme or High are considered to be intolerable at an AEP of 1% or greater.

The 1% AEP flood event is widely used in NZ as both a planning control and a design standard for secondary stormwater systems (McComb, 2016) and recognised as the appropriate flood risk standard for residential areas in Australia (AIDR, 2017a). Auckland Council considers the 1% AEP flood event to be an appropriate basis for planning decisions and infrastructure design in Auckland (Auckland Council, 2015). Section 36 of the Auckland Unitary Plan requires that habitable floors should not be subject to flooding in events with an AEP of 1% or greater and the Auckland Stormwater Code of Practice requires that secondary stormwater systems be designed to accommodate the 1% AEP event.

Situations classified as High or Extreme Danger are dangerous as they represent conditions of instability for people (High Danger) and buildings (Extreme Danger). While the relationship between the Flood Danger Rating and risk to life is implied rather than definitive, these situations are clearly dangerous in terms of their potential for harm, and properties where these situations are expected to occur with an annual probability of 1% or greater should be considered unsafe for long-term residential occupation.

2.2 DEALING WITH THE SPATIAL VARIABILITY OF FLOODING

The topography of the Auckland region is a primary driver of flooding characteristics. Many of Auckland's catchments, and particularly the urban catchments, are small, steep, and drain to the coast, resulting in localised pluvial flooding. The time of concentration in Auckland's catchments is typically less than two hours, which means flooding occurs rapidly with little warning (i.e., flash flooding).

Unlike in large scale coastal or fluvial flooding contexts where flooding is likely to be of relatively uniform depth over a wide area, flooding in Auckland has high spatial variability at the property level. Flooding may affect only one or two properties in an area and may only affect part of the property. It is possible to have dangerous flood hazard on one side of a house and no flooding on the other side.

This makes the assessment of risk to life at the property level challenging because the risk depends on where the people are relative to the hazard. The zone of highest flood hazard on the property may not be relevant if it is not where the people are likely to be. Even if it is assumed that people are likely to be inside the dwelling, they may also choose to go outside, and flood hazard outside the dwelling may pose a threat to those inside if it is severe enough to threaten building stability. For this reason, the framework requires the assessment of flood hazard (depth and velocity) at three locations on the property:

- **The hazard to building stability:** this represents the threat to the structural stability of the building from flooding and is assessed at the location/s of maximum flood depth and velocity immediately adjacent to the building footprint. Very deep and/or fast flowing waters can damage the structural integrity of the building and pose a risk that the building might collapse.
- **The hazard to people inside:** this represents the threat to people from flooding inside the building and is assessed as the maximum flood depth over the lowest affected habitable floor.
- **The hazard to people outside:** This represents the threat to people if they try to evacuate and is assessed at the location/s of maximum flood depth and velocity along the most likely evacuation route. (The framework requires the property assessors to identify the evacuation route that they believe people will be most likely to use to escape the property.)

Flood hazard elsewhere on the property is not considered. While it is recognised that people may choose to enter floodwaters for a variety of reasons, it is assumed that for the majority of people the key decision will be whether to stay inside or evacuate.

The assessment also assumes the ultimate or peak hazard state. It was considered that accounting for the rate of change of the flooding situation at a property over time would add considerable complexity to the assessment but not likely make a material difference to the assessment outcome in most cases given the flashy nature of Auckland's flooding.

The depth-velocity (DV) curves published by the Australian Institute for Disaster Resilience for building stability and person stability were adopted, with slight modifications, as the basis for the flood hazard assessments (Figures 6 and 8, respectively, in AIDR, 2017b). Following Smith (2015), the lower threshold of D ≥ 2.0m, or V ≥ 2.0m/s, or DxV ≥ 1.0m^2/s (the H5 threshold in Figure 6 of AIDR 2017b) was adopted as the building stability threshold for residential properties in Auckland, considering that a large proportion of Auckland housing stock consists of light, timber framed structures, often on piles, and that flooding at the upper H6 threshold level is extremely rare in Auckland. It was also noted that there were reports of dwellings being damaged by flows at the lower threshold in the Jan/Feb 2023 events in Auckland, and that even more robust structures can be damaged or fail in flood flows less than the upper threshold.

2.3 WHO ARE "VULNERABLE PEOPLE"?

The policy settings for Auckland Council's property buyout programme were that flood-affected properties would be eligible for consideration for buyout or risk mitigation where there is a high risk to life to "vulnerable people" in an existing 1% AEP flood event.

In the context of natural hazards, vulnerability is the propensity or predisposition of people, their livelihoods, and assets, to suffer adverse effects when impacted by hazard events (Cardona et al., 2012). Since all persons exposed to flood hazard are more or less vulnerable to suffering adverse effects, the category of "vulnerable people" implies a sub-group of all exposed people for whom exposure to floodwaters poses a greater threat than the general population due to some particular characteristics of that sub-group; in this sense what might more accurately be called "more vulnerable" or "particularly vulnerable" people. Since the property categorisation scheme was specifically targeted to reducing the risk that flooding poses to life, the risk assessment framework considers vulnerability in the narrow sense of the physical attributes of people that may make them more likely to suffer a fatal or serious injury if they are exposed to floodwaters. It is necessary to consider that those who are most vulnerable depends on context.

Nearly a quarter of the NZ population, and 59% of those over 65, have some form of disability (Statistics New Zealand, 2013), though not all forms of disability would preclude unassisted evacuation in a flood situation. The largest disability cohort is those who are mobility impaired, which includes 14% of the adult population in NZ and 46% of those aged over 65 (Statistics New Zealand, 2013). Mobility impairment means that someone has difficulty with or couldn't do one or more of the following: walk about 350 metres without resting, walk up or down a flight of stairs, carry an object as heavy as five kilograms over a distance, move from room to room within the home, stand for period of 20 minutes, bend down without support, get in and out of bed independently (Statistics New Zealand, 2013). By definition, people with mobility impairment are the most vulnerable group inside the dwelling because they may not be able to evacuate unassisted even if they wanted to.

Outside the dwelling, negotiating an evacuation route through flood waters implies mobility. In this context, vulnerability depends on the stability of a person in floodwaters, which is a function of the person's physical characteristics (height and weight) and abilities relative to the depth and velocity of flow and the difficulty of the terrain they are attempting to traverse. The most vulnerable people outside the dwelling are therefore children and the elderly who are less stable in floodwaters (Cox et al., 2010 and Smith et al., 2014).

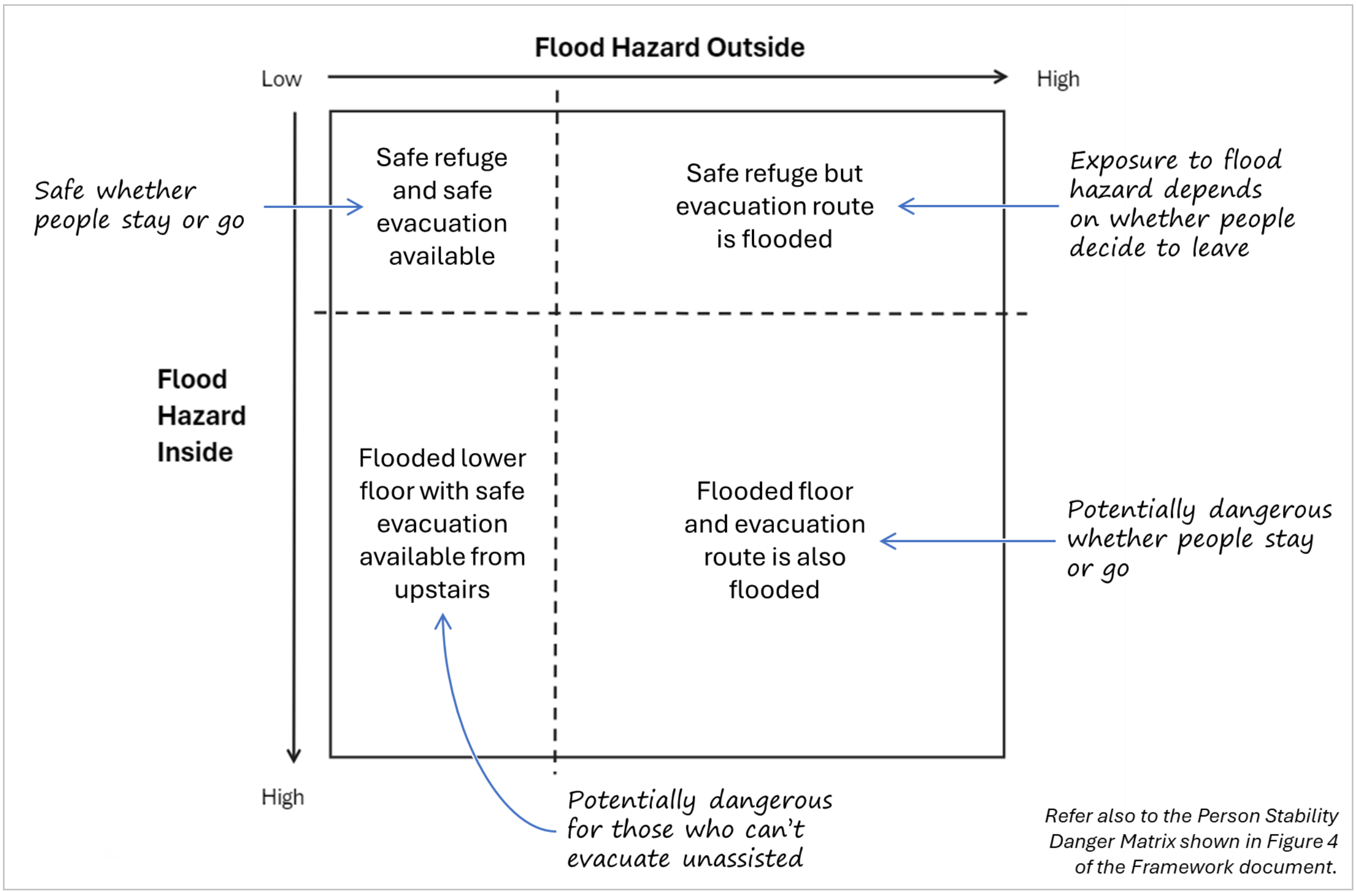
2.4 GETTING TO SINGLE MEASURE OF "FLOOD DANGER"

A principle challenge for the development of the framework was how to combine hazard assessments at three different locations on the property into a single measure of the hazardous of the flooding situation on the property.

Regardless of anything else, situations where the stability of the dwelling are threatened by floodwaters are the most dangerous. In this situation, everyone is considered vulnerable as people inside the building may not have time to evacuate to safety if the building were to collapse. This scenario would be dangerous for all and therefore has the highest Danger Rating of Extreme.

But what about situations where building stability is not threatened? A basic assumption is that a person who is still situated on an Auckland property at the time of peak flood hazard will initially be inside the dwelling. They will, therefore, already be exposed to the hazard inside the dwelling. They may then also be exposed to the hazard outside the dwelling should they choose to evacuate. In simple terms, the risk faced by that person is therefore a function of (assumed) certain exposure to the hazard inside the dwelling and uncertain exposure to the hazard outside the dwelling. Together, the assessed hazard inside and outside the dwelling (along the potential evacuation route) represent the hazard space for that individual; conceptualised as a matrix with the Hazard Inside and Hazard Outside constituting the opposing axes (see Figure 4).

Figure 4. Four zones of danger



Within that space, four zones are apparent:

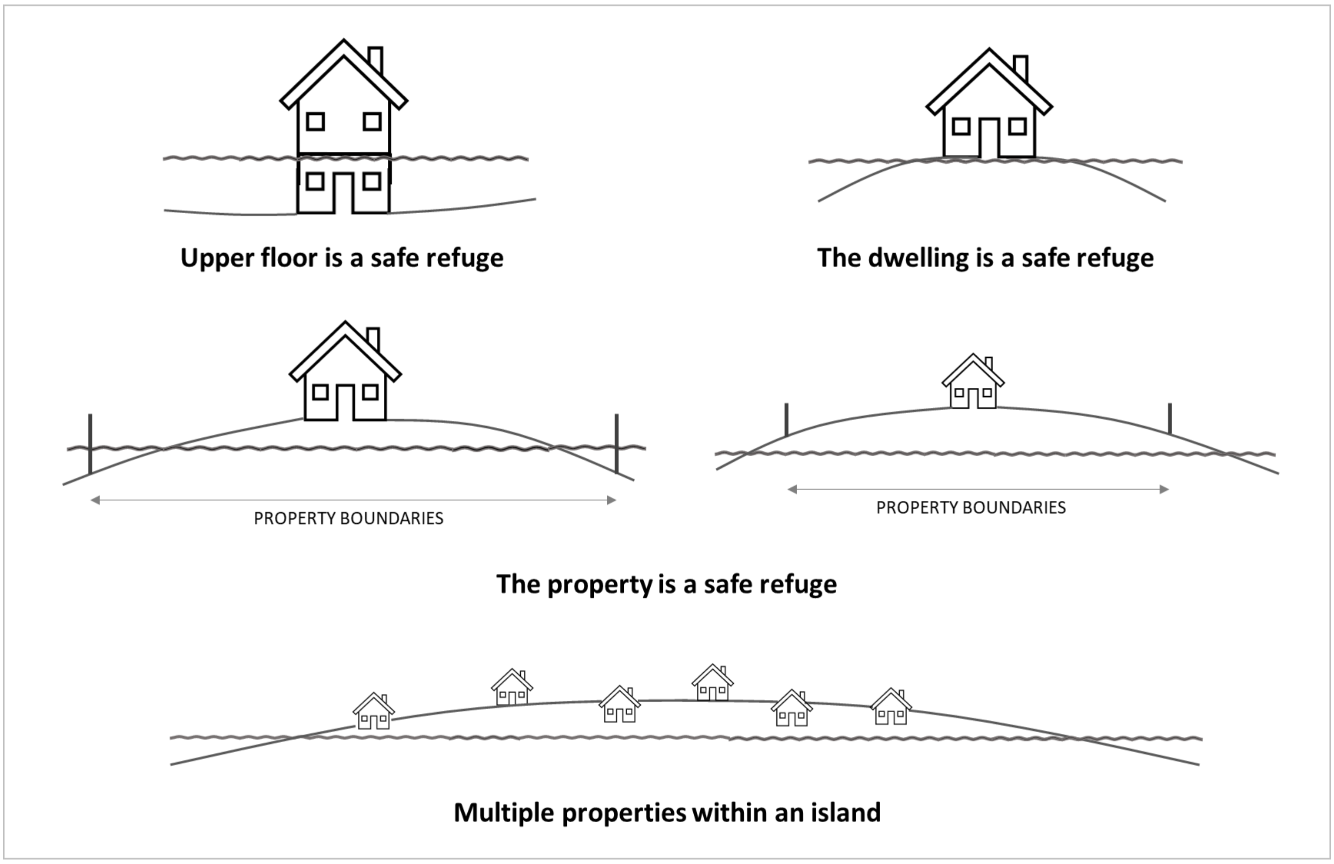
- A Low Danger zone where there is no flood hazard inside the dwelling and a safe (i.e., flood hazard free) evacuation route is available. This zone, located on the top left-hand side of the matrix, is safe for all, irrespective what the occupants of the dwelling decide to do. The majority of properties in Auckland would be expected to fall within this zone.

- A High Danger zone where there is potentially dangerous flood hazard inside the dwelling and outside the dwelling along the evacuation route. This zone, located on the bottom right-hand side of the matrix, is dangerous for all, irrespective of what the occupants of the dwelling decide to do.

- A zone on the bottom left-hand side of the matrix which describes "flooded lower floor" scenarios where a lower habitable floor of the dwelling is subject to potentially dangerous flooding, but a safe evacuation route exists from an upper floor of the dwelling and is accessible from inside the house (e.g., via an internal stairway). Since flooding downstairs of more than 0.5m over floor level would be dangerous for mobility impaired people, because they may not be able to evacuate even if they wanted to, this zone was classified as High Danger. Flooding more than 1.2m deep would also be dangerous for able bodied adults who may attempt to rescue those trapped downstairs.

- A zone on the top right-hand side of the matrix which describes "safe refuge" scenarios (Figure 5). These encompass a range of situations where there is no evacuation route that does not pass through potentially dangerous flood waters but a safe refuge exists above the flood level. There are conceivable variations ranging from where the dwelling itself may be surrounded by flood waters, but a lower or upper habitable floor remains dry, to where the property or perhaps multiple properties are situated on an island surrounded by flood waters.

Figure 5. Safe refuge (island) scenarios



Determining the appropriate Danger Rating for the "safe refuge" zone was more controversial than the other three zones of the matrix because the hazard exposure depends on what people will choose to do. With full knowledge of the potential severity of flooding, it is possible to say that the objectively safer thing to do for most people would be to shelter in place. However, in a real flood people must make critical, time-sensitive judgements in a highly stressful, uncertain, and emergent situation without full knowledge of the ultimate event magnitude. Their decision to stay or evacuate is highly uncertain (in terms of what they will decide) and influenced by a range of factors:

- People's ability to perceive and accurately judge the flood hazard. Research into why people enter flood waters has shown that people's perception of the hazard posed by floodwaters is frequently affected by underestimation of the hazard, overestimation of their own abilities, optimism bias about outcomes, and social influences (Becker et al. 2015).

- How much warning people have and the rate of change in the flooding situation, and their uncertainty and fears about how bad the situation might get and whether they might be trapped. The outcome can go both ways. Some people may evacuate early while others may wait, possibly until it is too late to evacuate. There is evidence of both of these things happening in the 2023 Auckland floods.

- Their motivations. The international literature suggests that the expressed and exhibited preference of most people is to evacuate (Thomas 2023; see also Appendix 7 of the framework document). However, there is also evidence that a varying but significant percentage of people are also likely to choose other courses of action, including sheltering in place, due to other motivations, such as protecting or rescuing pets or other people or protecting or salvaging property. There is evidence of people doing all of these things during the 2023 Auckland floods.

- Instructions that people may have been given by emergency services. Evidence from the 2023 Auckland floods is that emergency services sometimes gave instructions to shelter in place and in other cases gave instructions to evacuate.

The many ways in which those factors come into play in a real-life flood situation create fundamental uncertainty: we simply don't know what people will choose to do and therefore which hazard they will be exposed to. Some people may try to evacuate if they believe they can do so successfully, even if it may not be the safest option available to them, while other people may opt to shelter in place, again even if that is not the safest option available to them. Still other people may opt to enter flood waters for reasons other than evacuating.

Since the danger posed by "safe refuge" scenarios depends on whether people choose to leave the refuge, and therefore expose themselves to the flood hazard outside, deciding where to draw the High Danger threshold across this zone ultimately came down to a distinction between scenarios in which **some** people might choose to leave (less dangerous) versus those in which **most** people are likely to choose to leave (more dangerous). This, in turn, involved judgement about how the proximity of the floodwaters to the dwelling influences occupants' decision making about whether to evacuate. Intuitively, scenarios where potentially dangerous flooding is present on part of a property or even outside the property boundary, but where the dwelling is otherwise unaffected by floodwaters, and, indeed, may be some distance from the floodwaters, clearly do not pose the same level of danger as when dangerous floodwaters are immediately adjacent to and completely surrounding the dwelling, or where there is already flooding over floor level. Thus, how close do the floodwaters need to be to the house before most people would be likely to try to evacuate? The threshold could be set at different levels:

- Flooding outside the property boundary

- Flooding inside the property

- Flooding right up to the building footprint, but below habitable floor level

- Flooding over habitable floor level

- Flooding more than 0.5m over habitable floor level

In the absence of definitive insight from the literature, the question of where to draw the threshold was answered by consensus of the SME working group. The group considered that flooding over habitable floor level is a much stronger push factor for people to evacuate than proximity of flood waters to the dwelling, and therefore decided that scenarios where the lowest habitable floor of a dwelling remains dry should, as a general rule, be treated as less dangerous (i.e., Moderate Danger) compared to flooded floor scenarios (High Danger). It was, however, noted that there could be unique circumstances on the ground (e.g., extremely fast water rise) which might need to be considered on a case-by-case basis.

3 APPLICATION OF THE FRAMEWORK

Section 3.1 highlights some inevitable sources of uncertainty that assessors need to contend with when carrying out risk assessments, and offers some principles, developed from experience, that may be applied to recognise and overcome uncertainty and achieve confidence in the risk assessment results.

Section 3.2 describes how the occurrence of the rainfall events during Auckland Anniversary Weekend 2023 and Cyclone Gabrielle changed expectations of the magnitude of the 1% AEP rainfall event in the Auckland region and how this was dealt with when conducting property risk assessments in the post-event recovery context.

Section 3.3 illustrates the application of the framework with a worked example.

3.1 DEALING WITH UNCERTAINTY IN THE RISK ASSESSMENTS

There are some inevitable sources of uncertainty which must be considered in the flood risk assessments:

- **Incomplete, inaccurate, or uncertain input data:** The primary inputs to the flood risk assessments are information on the extent, depth, and velocity of flooding across the property and measurements of ground and habitable floor levels. This information comes from four main sources – reports of observed flooding and its impacts, measurements, flood hazard predictions from stormwater models, and flood hazard estimates from manual calculation (engineer's estimates) – all of which are subject to various limitations and inaccuracies. For instance, reported flood levels and impacts may be influenced by extraneous factors (e.g., blockage), while model predictions may be sensitive to input assumptions (e.g., soakage rates) or may not be reliable in certain locations (e.g., at the transition from 1-D channel flow to 2-D overland flow).

- **Limitations of the framework for classifying real-world situations:** The risk assessment framework relies on the classification of flood hazard by comparison against defined, quantitative thresholds for the depth and velocity of flow. But not all real-world situations can be neatly and unambiguously classified in these terms. For instance, the assessed flood hazard (depth x velocity) along an evacuation route does not necessarily give a full picture of how dangerous the evacuation route might be under real-world flood conditions. The depth-velocity thresholds which define the flood hazard categories for person stability are derived from laboratory testing of test subjects on level ground (Cox, Shand, and Blacka, 2010 provide a detailed review of international experimental data on test subject stability in flood flows) but other factors will influence the difficulty and hazardousness of an evacuation route, including the nature of the terrain underfoot, the wading distance, and proximity to hazards such as holes or drop-offs.

- **Margins of error:** Where the flood hazard estimates are close to a threshold, the margin of error on the estimates of depth and velocity may be material to the final classification, i.e., a small increase or decrease could be the difference between a Category 1 or Category 3 determination. Given the nature of the assessment and multiple inputs, the margin of error on the flood hazard estimates is not strictly quantifiable. These situations therefore render the outcome of the risk assessment uncertain because the assessment team can't be confident about the final rating.

A robust risk assessment process should, ideally, provide reasonable confidence that the result of the risk assessment appropriately represents the situation on the ground. This requires diligence in investigation, rigour in analysis, and the prudent application of professional judgement. The following general principles were articulated to provide guidance to assessors in conducting the flood risk assessments:

- All available information should be collated, reviewed, considered, and integrated as appropriate to provide the best possible basis for the assessment.

- Assessments should be based on the best available information. This may be from a single source, or multiple sources combined (triangulation). If different sources of information yield different or conflicting results, then these must be investigated and explained. Assessors should provide their professional opinion on whether the differences are explainable and reasonable and explain why they may place greater or lesser reliance on some sources of information over others.

- The hazard classification charts and the Danger Rating matrices should be viewed as guides to aid decision making rather than rules to follow. Assessors need to apply judgement in how they interpret the data and decide hazard classifications and Danger Ratings. Where unique circumstances warrant special treatment, assessors should document their professional judgement and socialise and agree their recommendations with their supervisors and quality assurance teams.

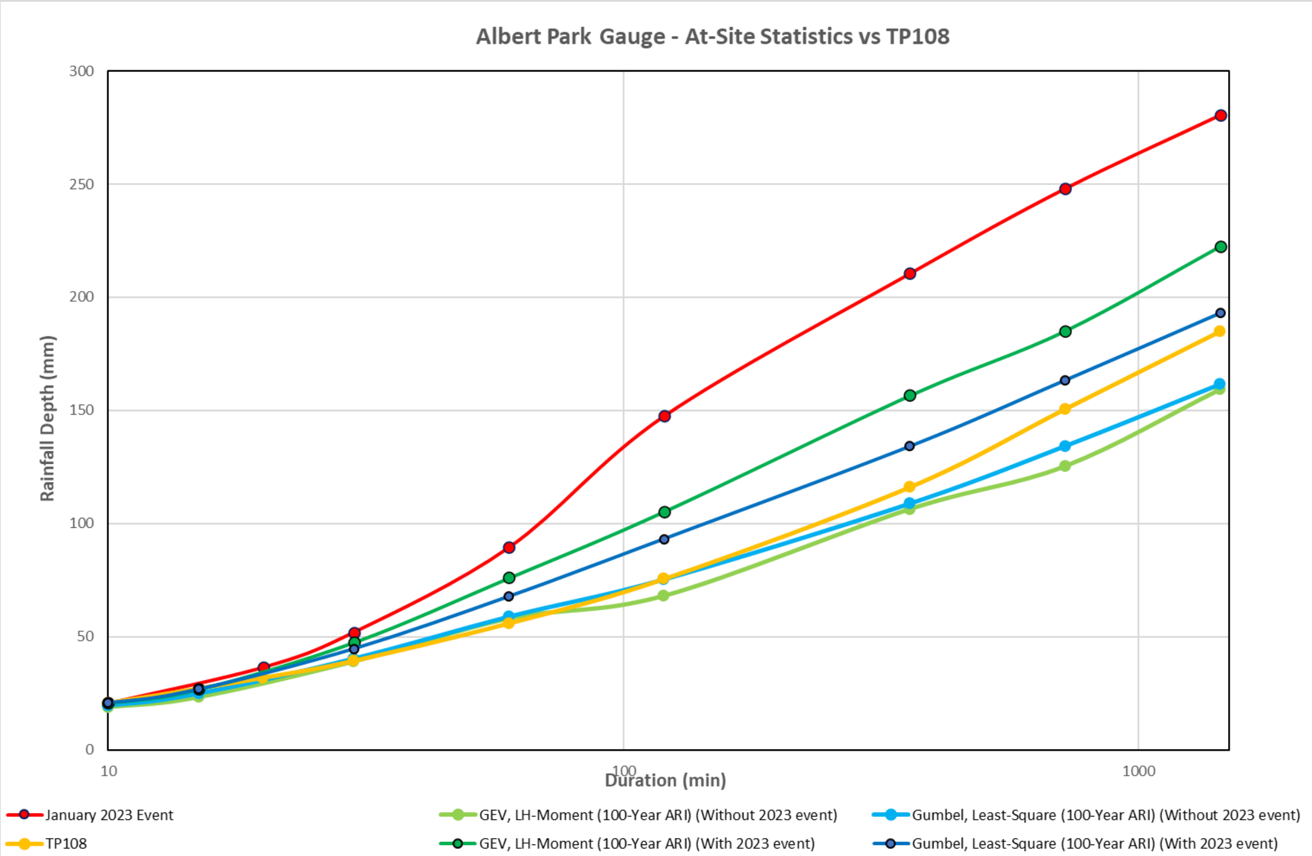
- Challenge and verification of assessments through peer review, QA checks, and consultation on a selection of assessments by the Expert Panel are essential to ensure consistency across assessments, bottom out sources of uncertainty, and resolve special cases.

- Where uncertainty is material to the outcome, further work is needed. (The framework document includes a list of questions that are useful for identifying these situations and finding ways to resolve the uncertainty.)

3.2 ACCOMMODATING CHANGED EXPECTATIONS OF 1% AEP RAINFALL

Analysis of the rainfall that occurred on 27 January 2023 showed that it was an exceedance event (i.e., < 1% AEP) for large parts of the Auckland region when considering the worst-case AEP over the full range of durations (see the dark shaded area in Figure 1). Furthermore, in many places the magnitude of the exceedance was substantial. At Albert Park in Auckland Central, the observed rainfall depth was double that of the TP108 1% AEP rainfall at 120 min and 54% greater at 24 hours (see Figure 6). Incorporating the event of 27 January 2023 into the historic rainfall record had a material impact on statistical predictions of the magnitude of the 1% AEP event. This is also illustrated in Figure 6, which shows the effect of the 2023 Auckland Anniversary Weekend event on statistical estimates of the 1% AEP event for Albert Park in Auckland Central.

Figure 6. Depth-duration curve for Albert Park showing rainfall on 27 January 2023 vs TP108 1% AEP rainfall vs updated extreme value estimates of the 1% AEP rainfall



A significant uplift in statistical expectations of the magnitude of the 1% AEP event can't be ignored. If the statistical methods which underpin those expectations are valid, then there is a new reality to contend with, and that new reality is not just limited to those areas which received the exceedance rainfall, but, rather, must be considered on a regional basis. The geographical extent of the dark shaded area in Figure 10 is essentially arbitrary, as it is defined by where the heaviest rain fell on 27 January 2023. If it is only by chance that the exceedance rainfall fell where it did, then it might fall somewhere else next time. Indeed, Cyclone Gabrielle, which occurred just two weeks after the Auckland Anniversary Weekend event, was also well in exceedance of the 1% AEP event along the west coast of Auckland. Thus, if expectations of the magnitude of the 1% AEP event rainfall were materially altered by the rainfall event of 27 January 2023, then those revised expectations should apply everywhere.

The most obvious impact of changing the statistical definition of the 1% AEP rainfall event is that where existing stormwater models use the previous estimates of 1% AEP rainfall, by definition, those models no longer accurately represent the flooding that would be expected under the new 1% AEP rainfall. A significant uplift in the 1% AEP rainfall depth means than the outputs from existing stormwater models cannot necessarily be relied upon to inform the assessment of flood risk at the property-level. Since the relationships between rainfall, topography, impervious area, and the depth and velocity of flow at specific locations in a catchment can be highly variable (see Appendix 8 of the framework document), manual calculation or re-running and validating stormwater models under the new rainfall conditions is necessary to confirm the impact on predicted flood hazard.

In the context of Auckland Council's severe weather recovery programme, this implied a significant additional workload on the Healthy Waters team at a time when there was considerable pressure for property risk assessments to be completed at pace. Careful consideration therefore had to be given to how stormwater model outputs were used to inform risk assessments, how much reliance was placed on model outputs vs observed flood impacts, and the conditions under which decisions could be taken in the absence of reliable model results. It was determined that there were certain conditions where modelling of the new 1% AEP flood hazard was not required to inform property categorisation decisions, and, conversely, certain conditions where it was (likely to be) necessary. For instance:

- When assessing existing risk, a classification of Category 2A (High or Extreme Danger) or Category 1 (Low or Moderate Danger) could be accepted without needing modelling validation where the observed rainfall for the critical duration was assessed to be approximately 1% AEP against the relevant updated at-site DDF curve and the assessment was based on the observed flood impacts. In these cases, the observed event could be used as the basis for assessing existing risk because it met the policy criterion.

- When assessing existing risk, a classification of Category 2A (High or Extreme Danger) could be accepted where the observed rainfall for the critical duration was assessed to be ≥ 1% AEP against TP108 and the assessment was based on the observed flood impacts and/or existing modelled 1% AEP flood. In these cases, assessing flood hazard for the uplifted 1% AEP rainfall would not be necessary as it would not materially change the categorisation.

- When assessing existing risk, if the observed rainfall for the critical duration was assessed to be ≥ 1% AEP against TP108 and the assessment returned a classification of Category 1 (Low or Moderate Danger) based on the observed flood impacts and/or existing modelled 1% AEP flood, then reassessing the flood hazard for the revised 1% AEP rainfall could potentially change the categorisation. In these cases, the assessment team would need to consider whether the uplifted 1% AEP rainfall would be likely to cause flooding resulting in High or Extreme Danger at the property. If so, further analysis, calculation, and/or development of a (re)validated stormwater model would be required to confirm the existing risk.

- When assessing future risk, a classification of Category 3 could be accepted where potential private and/or community solutions could be ruled out as infeasible or ineffective at mitigating future risk without detailed modelling of the future flood hazard. Where this wasn't possible, the classification of the property as either Category 3 or Category 2P/2C would require further analysis, calculation, and/or development of a (re)validated stormwater model to confirm the effectiveness of proposed solutions.

Table 2 in the risk framework document provides the full set of conditions for making property categorisation decisions with and without updated models. In practice, the uplift in the definition of the 1% AEP event was an issue for only for a small percentage of the property assessments and most properties could be categorised without needing detailed modelling of the uplifted 1% AEP flood hazard.

3.3 WORKED EXAMPLE

Context

A residential property located in a floodplain and flood prone area with maximum ponding depth of 6.5 m and a spill elevation of 74.15 m RL. The main site area located below road level with an RL difference of approx. 3m between the lowest point on the property and the top of the driveway. Single, two-storey, detached dwelling with the lowest habitable floor at 69.06 m RL.

Auckland Anniversary Event

The upstream catchment received 267.5mm of rain over 24-hours during the 2023 Anniversary Weekend event, which was more severe than the existing 1% AEP storm for all durations. Observed flood depth of 70.11 m RL during the 2023 Anniversary Weekend event determined from debris line inside the house, 1.05 m above floor level. The egress and evacuation route was up the driveway to the road, which is above the predicted 1% AEP flood level and the flood level observed in the 2023 Anniversary Weekend event. Total wading distance of approx. 35m with maximum depth along egress route exceeding 1.2m.

Modelled 1% AEP Event

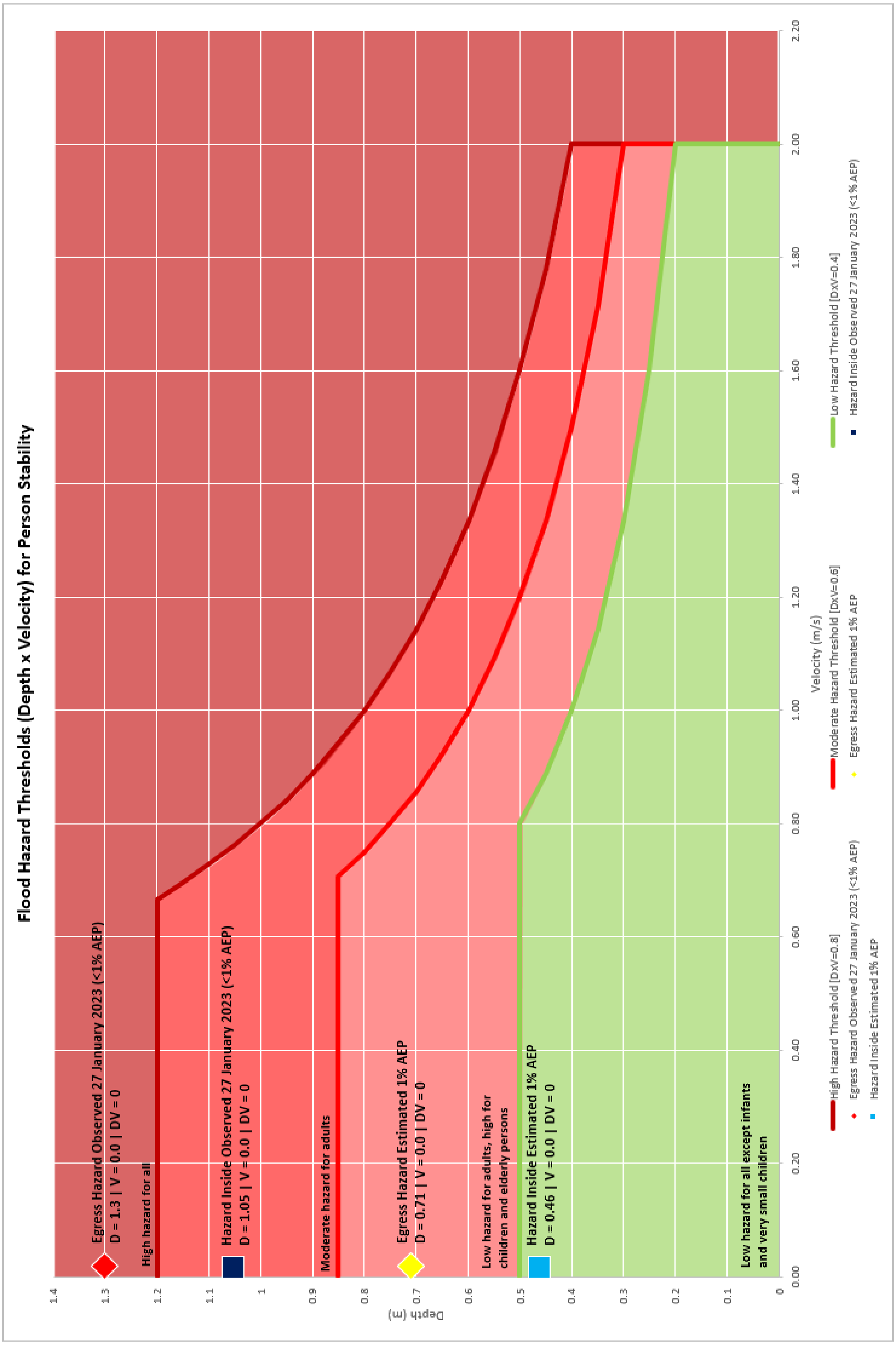
Detailed 1D/2D coupled MIKE Flood model developed in 2016 but results only available for the future scenario and not validated against actual storm events. The model was found to produce unjustified flood levels higher than those observed during the Auckland Anniversary storm event for the same input rainfall. As a new model would not be completed in time to inform the property categorisation, simplified basin modelling for the depression areas was developed to estimate the existing 1% AEP flood levels based on updated at-site statistics (averaging of nearby rain gauges) applied to the TP108 design storm profile. Estimated rainfall depths for the 1% AEP event were lower than observed during the Auckland Anniversary storm event with predicted flood level of 69.52 m RL, which is 0.59 metres lower than the observed flood level of 70.11 m RL.

Flood Hazard Assessment Results

Table A.1. Worked Example – Flood Hazard Assessment Inputs

	Observed during 2023 Anniversary Weekend	**Estimated 1% AEP (updated stats)**
24-hour rainfall depth	267.5 mm	220 mm
Flood level	70.11 m RL	69.52 m RL
Flood depth inside	D = 1.05 m	D = 0.46 m
Flood depth and velocity outside (adjacent to dwelling footprint)	D = 1.93 m V ~ 0 m/s	D = 1.34 m V ~ 0 m/s
Flood depth and velocity outside (along evacuation route)	D = 1.3 m V ~ 0 m/s	D = 0.71 m V ~ 0 m/s

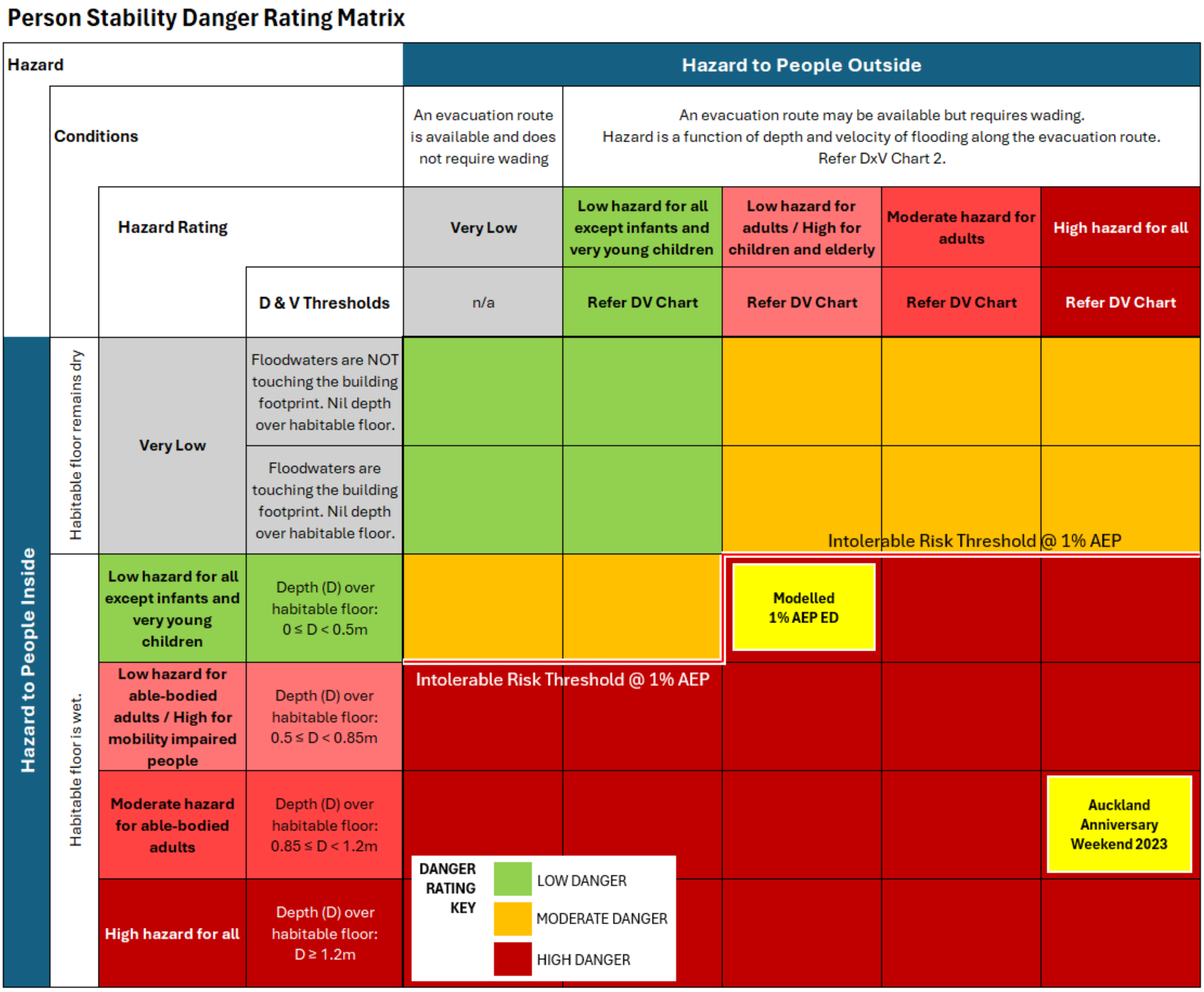
Figure A.1. Worked Example – Flood Hazard Assessment Outputs



Danger Rating

Since the estimated flood hazard was not severe enough to threaten the building stability ($D \geq 2.0m$, or $V \geq 2.0m/s$, or $DxV \geq 1.0m^2/s$), the Danger Rating was assessed based on threat to person stability. For both the observed 2023 Anniversary Weekend event and the existing 1% AEP flood event, the assessed Danger Rating is High (see Figure A.2).

Figure A.2 Worked Example – Flood Danger Rating



4 CONCLUSIONS

The Auckland Council Property-level Flood Risk Assessment Framework was developed specifically to implement the property categorisation criteria for Auckland Council's severe weather recovery scheme. The risk category definitions published by the NZ Govt on 1st May 2023 had already established the intervention threshold as "intolerable risk to life". The risk framework translates this concept into terms that are practical to implement for decision making purposes.

As this paper has highlighted, while flood hazard is relatively well understood, the relationship between hazard and mortality cannot be reliably quantified, especially in pluvial flood contexts where flood hazard can vary significantly within a given property. Observations from the 2023 weather events, as well as the findings of research conducted during the development of the framework, showed that behavioural factors are critical. What people do – as opposed to what they should do – when confronted with the reality of flooding on their property determines the risk they will be exposed to. (In this regard, behaviour should be considered, not only when assessing risk, but also when deciding on risk mitigation measures; for instance, the provision of safe evacuation routes should be preferred over the provision of safe refuge alone.) The concept of the Flood Danger Rating avoids the potential quagmire of quantifying mortality by focussing on the potential for harm that is inherent in different levels and combinations of flood hazard.

Decisions on the tolerability (or intolerability) of risk are about deciding whether the level of risk is so low it can be ignored (accepted), low enough to tolerate when considered alongside other factors, or so high that it overrides all other considerations (intolerable / unacceptable). There is no absolute criterion because tolerability is a judgement that depends on the circumstances and who is judging them. For the purpose of the current scheme, it was the Working Group – with endorsement from the Expert Panel – that determined where to set the threshold for "intolerable risk to life". This was the subject of intense debate and was eventually drawn as a distinction between those situations which the group felt were dangerous for vulnerable people and those which were not, recognising that those who are most vulnerable to the physical effects of flooding are the mobility impaired, children, and elderly people. This reflects the group's collective judgement that such situations should not be tolerated in urban residential areas where they are expected to occur with an annual probability of 1% or greater.

When applying this framework in other contexts, others may choose to judge the tolerability of flood risk on a different basis. It should be remembered that a judgement of "intolerable risk" carries significant consequences. It requires urgent, timely action to avoid or reduce the risk, action which may have large financial ramifications for ratepayers and taxpayers. Those making a determination of intolerable risk will need to be comfortable that the risk is sufficiently high as to warrant urgent and disruptive intervention and be prepared to defend this to landowners and the community (who may have differing views on the risk, its tolerability, and what should be done about it).

Applying the framework to assess flood risk at the property-level requires detailed knowledge of the specific characteristics of the property – including the likely egress route – and the flood hazard across the property. This paper has highlighted some inevitable sources of uncertainty that assessors need to contend with when carrying out risk assessments and offered some principles, developed from experience, that may be applied to recognise and overcome uncertainty and achieve confidence in the risk assessment results. It was originally anticipated that records of observed flooding as well as modelled data would be used in the assessments. In reality, the Danger rating for the majority of properties was driven by the observed event. Uplifts in rainfall expectations resulting from the occurrence of extreme events meant that the outputs from existing stormwater models – which are based on previous rainfall expectations – could not necessarily be relied upon to inform the risk assessments.

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Principal contributors to the development of the Auckland Council Property-level Flood Risk Assessment Framework were:

Subject Matter Expert Working Group

- Nick Brown, Regional Planning Manager, Auckland Council Healthy Waters
- Fiona Macdonald, Principal – Flood Risk, Auckland Council Healthy Waters
- Richard Smedley, Principal – Network Planning, Auckland Council Healthy Waters
- Allan Leahy, Principal – Growth Planning, Auckland Council Healthy Waters
- James Reddish, Technical Director – Stormwater and Catchment Management, WSP
- Richard Donnelly, Executive Director and Principal, Richard Donnelly Ltd

Expert Panel

- Dr Tim Fisher, Technical Director – Water, Tonkin & Taylor
- Peter Christensen, Storm Environmental Stormwater Group Chair – Water NZ
- Dr Graeme Smart, Natural Hazards and Hydrodynamics Specialist
- Wallace Potts, Director City Waters – Tauranga City Council

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