AUCKLAND COUNCIL HEALTHY WATERS AND FLOOD RESILIENCE

Framework for Assessing Flood Risk at the Property-level

6 June 2025, Version 3.0

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Contents

Appendices (available on request)

Document Control

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Revision History

Version	Date	Revisions	Status
3.0	6 June 2025	Updates to author titles; formatting changes before publishing on Recovery Office library	Current
2.5	15 November 2024	Further amendments to address feedback on Building Stability assessment. Building Stability Danger Rating Matrix amended to include a “Not Determined” option.	Superseded
2.4	23 October 2024	Revision and restructure of Sections 3 and 4 to incorporate the Building Stability assessment. New Building Stability Danger Rating Matrix added (Figure 5). Updated process and decision matrix for determining the property Flood Danger Rating now included as Figure 7. Various other consequential revisions, including revisions to Figures 1, 2, 3, and 6.	Superseded
2.3	25 June 2024	Amended Purpose and Scope section to clarify interpretation of recovery scheme eligibility criteria with respect to surface water vs non-surface water flooding. Amended Figure 1 to reverse steps 2 and 3 (i.e., Hazard Inside assessment should be step 2). Clarification to s.4.4.1 and Figure 2 regarding application of the building stability threshold. Clarification to s.4.4.3 and Figure 3 regarding application of the person stability threshold for low depth / high velocity scenarios. Amended paragraph 93 to include a note about treatment of contingent events and environmental factors. Updated section 5.3 to reflect approach reviewed by Expert Panel 7 June 2024.	Superseded
2.2	12 April 2024	Updated discussion on definition of 1% AEP and added discussion on dealing with uncertainty in the assessments. Revisions to Section 4.5 to improve clarity. Various other minor edits and corrections.	Superseded
2.1	13 February 2024	Updated following Expert Panel discussion 7 February. Added discussion on definition of the 1% AEP event.	Superseded
2.0	29 January 2024	Incorporated definitions content into Section 4 to reduce repetition. Improved framework overview and revised Danger Rating matrices. Added explanation of events to be assessed. Clarified definition of vulnerable people. Removed references to risk modelling. Provided explanation of what the Danger Rating means.	Superseded
1.3 1.2 1.1	5 December 2023 4 December 2023 29 November 2023	Further adjustment to the DR grades. Revised “split” DR schema. Incorporating feedback from Expert Panel.	Superseded
1.0	24 November 2023	Further revision incorporating consensus Flood Danger Rating Schema of 23 November.	Superseded
0.2	16 November 2023	Substantial restructure and revision incorporating outcomes of various issue discussions and ongoing development.	Superseded
0.1	8 September 2023	Initial WIP version	Superseded

Related Documents

- Categorisation Approach, v1.0, 30 October 2023
- Property-level Flood Hazard Assessment Guidance Note
- Property-level Flood Hazard Assessment workbooks and proformas
- Structural Assessment workbook and associated guidance
- Appendix 3a Lit Review Flood Fatality Estimation.pdf
- Appendix 3b Floods and survivability.pdf
- Appendix 3c R Smedley Paper – Flood Risks to People
- Appendix 6 Consensus Flood Danger Rating Schema (23 November 2023).pdf
- Appendix 7 Flood Evacuation Behaviour.pdf

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1 Background

1. Auckland Council has agreed with the Government to implement a voluntary buy-out scheme (Voluntary Buy-out Support Scheme) for Auckland homes severely affected by the extreme weather events over Auckland Anniversary Weekend and during Cyclone Gabrielle 2023.

2. The aim of the buy-out scheme is the removal of risk to severely affected residential properties through voluntary buy-out.

3. Auckland Council has agreed to implement the government's categorisation framework for homes severely affected by the weather events of early 2023. The categorisation framework enables the identification of:

   a. Category 3 properties eligible for a buy-out, being properties where there is an intolerable risk to life from flooding and/or landslides for occupants of residential buildings on the property,

   b. Category 2 properties, for which there is a feasible mitigation at either a community of property level,

   c. Category 1 properties, for which the risk does not meet the threshold of "intolerable risk to life".

4. Auckland Council's approach to categorising flood and landslide-affected properties (Categorisation Approach, v1.0) was authorised on 30 October 2023. That document establishes the following policies in respect of assessing the risk to life from flooding at the property level:

> 22. For flooding, the risk assessment framework anticipates that a building will be "Category 3" where there is a high risk to life to vulnerable people in an existing 1% AEP flood event, and there is no feasible mitigation (at a property or community level) to reduce the risk to a tolerable or acceptable level.
>
> 24. Auckland Council will assess whether there is "intolerable risk to life" by assigning a Flood Danger Rating to a property in accordance with council's Flood Danger Rating Schema. The Flood Danger Rating represents the threat to life to people inside or outside dwellings on residential property that are exposed to flood hazard.
>
> 25. In addition to Flood Danger, the risk assessment framework takes into account the likelihood of an event occurring. Event Likelihood is described by the annual exceedance probability (AEP) of the flood event, which is the probability of the event being equalled or exceeded within a year. As rainfall is the primary driver of flooding in the Auckland region, flood event likelihood can be considered synonymous with rainfall event likelihood.

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2 Purpose and scope

5. This document explains the Property-level Risk Assessment Framework ("the framework") developed by Auckland Council Healthy Waters.

6. The framework provides a methodology for assessing risk to life to individuals at the property level, where risk to life means the potential for individuals to suffer serious injury or death arising from their exposure to flood hazard. The framework does not currently consider damage to buildings (except to the extent that building instability may be a threat to safety) or the wider economic, social, or environmental impacts of flooding.

7. This framework has been specifically designed to enable risk from pluvial 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 policies, processes and criteria for property categorisation are explained elsewhere).

8. The focus on pluvial flooding is driven by the predominantly localised and pluvial nature of flooding in Auckland catchments (see Appendix 2). The framework is not intended to be applied to large-scale fluvial or coastal flood events or flooding arising from dam or stop bank breaches or tsunamis.

9. The focus on the property level reflects the specific need to identify properties where there is a high risk to life from flooding as an input to the property categorisation process. The framework is not intended to be used to assess flood risk on an area-wide basis. The broader spatial distribution of flood hazard and risk at local and catchment levels is considered by other processes (e.g., catchment planning, land use planning, flood emergency response planning).

10. With reference to the published recovery scheme eligibility criteria[1], properties may be considered eligible for the property risk assessment only where the dwelling was impacted by the severe weather events of January and February 2023. For the purposes of applying this framework, the dwelling may be considered to have been impacted where surface water flooding touched or entered the dwelling footprint in those events. Water damage that occurred due to groundwater seepage or leakage arising from lack of building water tightness does not count as surface water flooding.

11. Applying this 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 at a given Annual Exceedance Probability (AEP). Those carrying out risk assessments must be able to recognise and deal with various sources of uncertainty in order to achieve confidence in the risk assessment results (see section 5). In the Recovery context where outcomes for homeowners were required to be delivered at pace, completing sufficient work to confidently determine the existence of intolerable risk to life allows flood risk assessments to be completed in some instances without fully resolving the exact risk at a 1% AEP.

12. The vulnerability of buildings and people to flood hazard is considered in general through the design of the framework. In this regard, the assessment is specific to the property, not the unique circumstances of the individuals who might live at that property.

13. Detailed supporting material referenced from the main body of this framework document can be found in the appendices.

[1] Refer section 5 of the 2P Homeowner Handbook published on the Council website.

3 The framework

14. For a flood event of a given Annual Exceedance Probability (AEP) the Property-level Risk Assessment Framework provides a methodology for assessing four things:
    a. The hazard to the stability of the dwelling.
    b. The hazard to the people who may be sheltering inside the dwelling.
    c. The hazard to people outside the dwelling who may be trying to evacuate.
    d. An overall Flood Danger Rating for the property.
15. The Flood Danger Rating is a qualitative expression of the perceived hazardousness of the peak flood situation on the property for the assessed event. That is:
    a. **Low Danger:** generally, not dangerous for all including vulnerable people.
    b. **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.
    c. **High or Extreme Danger:** Dangerous for vulnerable people, and may be dangerous for all, irrespective of what people decide to do.
16. Figure 1, following page, illustrates some typical flooding scenarios and their Flood Danger Ratings.
17. The relationship between the Flood Danger Rating and risk to life is implied rather than definitive. Danger Ratings of High or Extreme represent situations that are clearly dangerous in terms of their potential for harm, but the Danger Rating does not quantify that potential in terms of mortality. (Refer to section 4.8 for a more detailed explanation of what the Flood Danger Rating means).
18. For the purposes of property categorisation, Danger Ratings of Extreme or High are considered to be intolerable at an Annual Exceedance Probability of 1% or greater. This is consistent with the standards for urban development in Auckland. Situations classified as High or Extreme Danger are dangerous, particularly for vulnerable people. 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.
19. The inputs to the Danger assessment are determined from detailed desktop and site investigations. These include flood event parameters, which describe key features of the flood hazard for an event of a given Annual Exceedance Probability (AEP), and dwelling parameters, which describe key features of the dwelling and property that influence the flood hazard and risk. The separate Hazard Assessment Guidance Note provides detailed instruction and guidance for determining the detailed inputs and completing the Danger Assessment.
20. The Property-level Risk Assessment Framework is presented the figures on the following pages:
    a. Figure 2 provides an overview of the assessment process.
    b. Figure 3 and Figure 4 present the charts that are used for assessing flood hazard.
    c. Figure 5 presents the matrix used to determine the Building Stability Danger Rating.
    d. Figure 6 presents the matrix used to determine the Person Stability Danger Rating.
    e. Figure 7 presents guidance for determining the Property Flood Danger Rating and Risk Category.

<table>
<tr><td rowspan="1">LOW DANGER</td><td></td><td colspan="2">

- 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.

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<tr><td rowspan="2">MODERATE DANGER</td><td></td><td colspan="2">

- 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.

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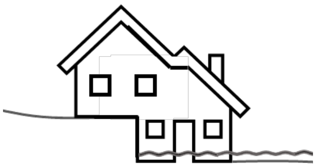
<tr><td></td><td colspan="2">

- Building stability is not at risk.
- Properties in this zone have a lower habitable floor subject to minor flooding <0.5 m 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.

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<tr><td rowspan="2">HIGH DANGER</td><td></td><td>

- There is a lower habitable floor subject to flooding >0.5 m in depth that poses high danger for mobility impaired people.
- At higher levels of flooding (>1.2m) this scenario is dangerous for others in the house who may try to assist those trapped downstairs.

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- The building may also be unstable. While imminent collapse may be unlikely, there remains a heightened risk due to damage or movement of the building's structural elements. The stability of the building under dynamic loads (e.g., wind, flooding) cannot be reliably predicted and the building should be considered unsafe.

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- The dwelling is surrounded by floodwaters that are high hazard for children and the elderly and may also be high hazard for adults.
- 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 event though there is no safe or low-hazard evacuation route available.
- This scenario is dangerous for all.

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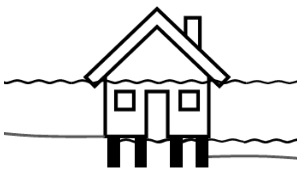
<tr><td>EXTREME DANGER</td><td></td><td colspan="2">

- 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 may experience severe structural damage with a high risk of imminent collapse due to loss of structural support of load bearing elements.
- 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.

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Figure 1. Illustrative flooding scenarios and assumptions underpinning the Danger Ratings

Steps to complete the Danger assessment

Gather Data

Property Assessments

Detailed desktop and site investigations to determine the input parameters for the risk assessment.

Flood event parameters describe key features of the flood hazard for an event of a given Annual Exceedance Probability.

Dwelling parameters describe key features of the dwelling and property that influence the flood hazard and risk.

Assess Flood Hazard

Step 1
Assess threat to BUILDING STABILITY from depth and velocity adjacent to building footprint
→ Plot the DxV adjacent to the building footprint on **DV Chart 1** (Flood Hazard Thresholds for Building Stability) (refer Figure 3)
→ Determine the Building Stability Category.
(If the DV adjacent to the building is above the threshold shown on DV Chart 1 or structural damage has been observed or suspected at DVs below the threshold then carry out a structural Building Stability Assessment).

Step 2
Assess threat to PEOPLE INSIDE from depth over habitable floor
→ Plot the depth over habitable floor on the **Depth Inside Chart** (Flood Hazard Thresholds for Person Stability Inside) (refer Figure 4)
→ Determine the Hazard Inside Rating

Step 3
Assess threat to PEOPLE OUTSIDE from DxV along evacuation route
→ Plot the result on **DV Chart 2** (Flood Hazard Thresholds for Person Stability Outside)
→ Determine the Hazard Outside Rating

Determine Danger Rating

Plot the result on the **Building Stability Danger Rating Matrix** (refer Figure 5)

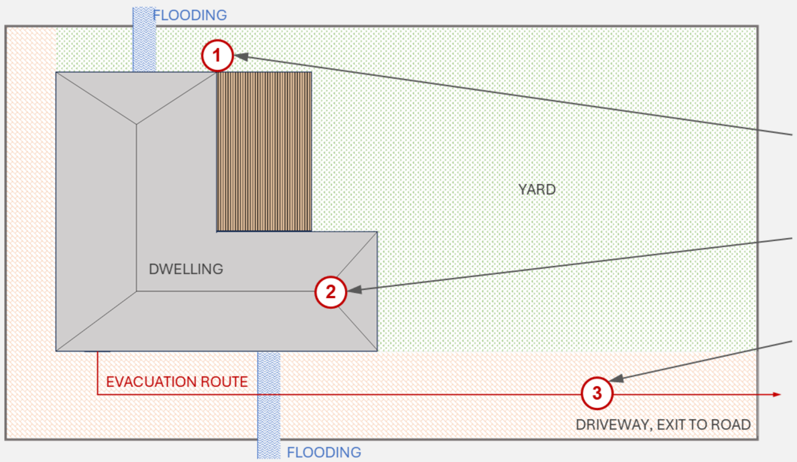
Plot the result on the **Person Stability Danger Rating Matrix** (refer Figure 6)

Step 4
Determine the Property Flood Danger Rating (refer Figure 7)

Steps 1 – 3 must be completed before Step 4. The Flood Danger Rating is determined from the process and decision matrix in Figure 7.

Refer to the Hazard Assessment Guidance Note for detailed instructions and guidance.

Definition of Evacuation Route:
An evacuation route means a route away from the building that is accessible from a doorway and leads to a place that is above the maximum flood level for the nominated event from which people would reasonably be able to access shelter, transport, or assistance. The route must be free of obstacles and able to be traversed – in the absence of floodwaters – by a person walking normally without resorting to extraordinary physical exertion (e.g., scrambling, climbing, jumping).



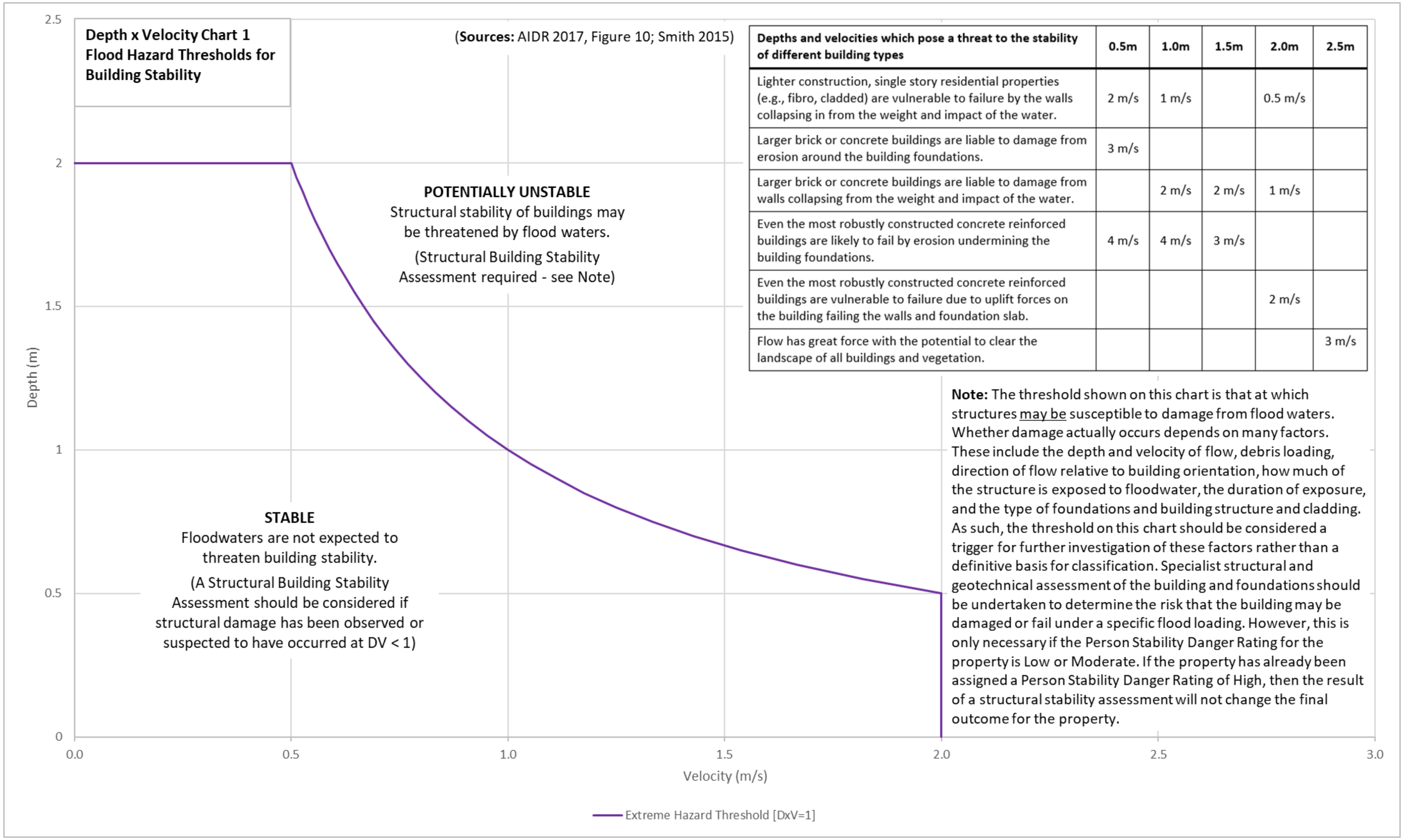
Conceptual illustration of locations for assessing flood hazard on a property

Building Stability Hazard: potential threat to the building from flooding. Assessed at location of max depth and velocity immediately adjacent to the building footprint.

Hazard to People Inside: potential threat to people from flooding inside the building. Assessed as the max flood depth over the lowest habitable floor (or the affected habitable floor in the case of flooding from overland flow).

Hazard to People Outside: Potential threat to people if they try to evacuate. Assessed at the location of max depth and velocity along the most likely evacuation route.

Figure 2. Overview of assessment process



Depths and velocities which pose a threat to the stability of different building types	0.5m	1.0m	1.5m	2.0m	2.5m
Lighter construction, single story residential properties (e.g., fibro, cladded) are vulnerable to failure by the walls collapsing in from the weight and impact of the water.	2 m/s	1 m/s		0.5 m/s	
Larger brick or concrete buildings are liable to damage from erosion around the building foundations.	3 m/s				
Larger brick or concrete buildings are liable to damage from walls collapsing from the weight and impact of the water.		2 m/s	2 m/s	1 m/s	
Even the most robustly constructed concrete reinforced buildings are likely to fail by erosion undermining the building foundations.	4 m/s	4 m/s	3 m/s		
Even the most robustly constructed concrete reinforced buildings are vulnerable to failure due to uplift forces on the building failing the walls and foundation slab.				2 m/s	
Flow has great force with the potential to clear the landscape of all buildings and vegetation.					3 m/s

Note: The threshold shown on this chart is that at which structures may be susceptible to damage from flood waters. Whether damage actually occurs depends on many factors. These include the depth and velocity of flow, debris loading, direction of flow relative to building orientation, how much of the structure is exposed to floodwater, the duration of exposure, and the type of foundations and building structure and cladding. As such, the threshold on this chart should be considered a trigger for further investigation of these factors rather than a definitive basis for classification. Specialist structural and geotechnical assessment of the building and foundations should be undertaken to determine the risk that the building may be damaged or fail under a specific flood loading. However, this is only necessary if the Person Stability Danger Rating for the property is Low or Moderate. If the property has already been assigned a Person Stability Danger Rating of High, then the result of a structural stability assessment will not change the final outcome for the property.

Figure 3. DV Chart 1 – Flood Hazard Thresholds for Building Stability

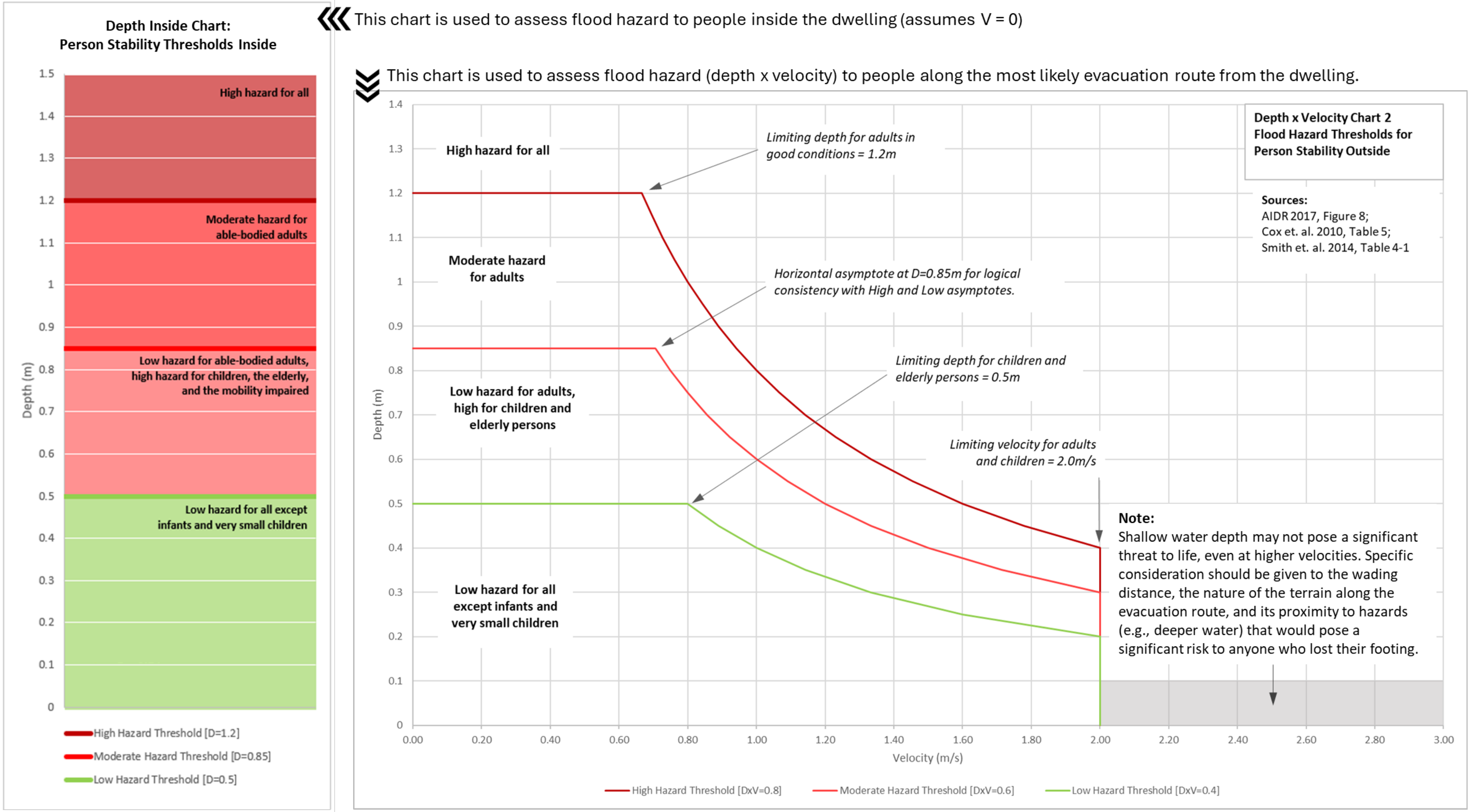


Figure 4. Depth Inside Chart (Thresholds for Person Stability Inside) and DV Chart 2 (Thresholds for Person Stability Outside)

Building Stability Danger Rating Matrix

Hazard to Building Stability		
Assess the flood hazard adjacent to building footprint using **DxV Chart 1** (Flood Hazard Thresholds for Building Stability). If above the threshold, carry out a structural building stability assessment. Show the result here.		
Building Stability Category and Definition		**Danger Rating**
Severe Structural Damage	Under assessed flood conditions, the building has experienced or is expected to experience structural damage and/or instability with a high risk of partial/total collapse that could cause injury or high danger to people. This includes loss of structural support of load bearing elements likely to be associated with greater than 50mm of lateral inter-storey or building element movement. In this state, the behaviour of the building under gravity loads is unpredictable and collapse could be imminent.	EXTREME DANGER
Structural Instability	Under assessed flood conditions, the building has experienced or is expected to experience damage and/or instability that causes movement in the floor, walls, and/or ceiling/roof. The building does or will exhibit signs of distress that are obvious to a structural engineer but which may not be evident to building occupants. For a flexible structure such as a timber framed building this may be less than 50mm of lateral inter-storey or building element movement in some circumstances. For more rigid structures such as concrete and masonry construction, which have a lesser movement threshold, this would typically be any movement and/or cracking of the structure (though this will be dependent on the building design and requires assessment by a structural engineer). While imminent total or partial collapse of the building may be unlikely, there remains a heightened risk due to damage or movement of the building's structural elements.	HIGH DANGER
Stable (Some Damage)	The building has resisted or is expected to resist loads from the assessed flood conditions acting in combination with gravity loads. The building has experienced or may experience non-structural damage (e.g., foundation scour) which would need to be repaired to reduce the risk of structural instability occuring in a future event.	MODERATE DANGER
Stable (No Damage)	The building has resisted or is expected to resist loads from the assessed flood conditions acting in combination with gravity loads. Superficial, non-structural damage has occured or may occur (e.g., cladding damage) which has no impact on building stability. This rating applies for buildings assessed to be below the threshold shown in DV Chart 1.	LOW DANGER
Not Determined	The building may be susceptible to structural damage from flooding. However, a specialist structural assessment has not been carried out.	NOT DETERMINED

Intolerable Risk Threshold @ 1% AEP (between Structural Instability and Stable (Some Damage))

DANGER RATING KEY
- EXTREME DANGER
- HIGH DANGER
- MODERATE DANGER
- LOW DANGER
- NOT DETERMINED

Figure 5. Building Stability Danger Rating Matrix

Person Stability Danger Rating Matrix

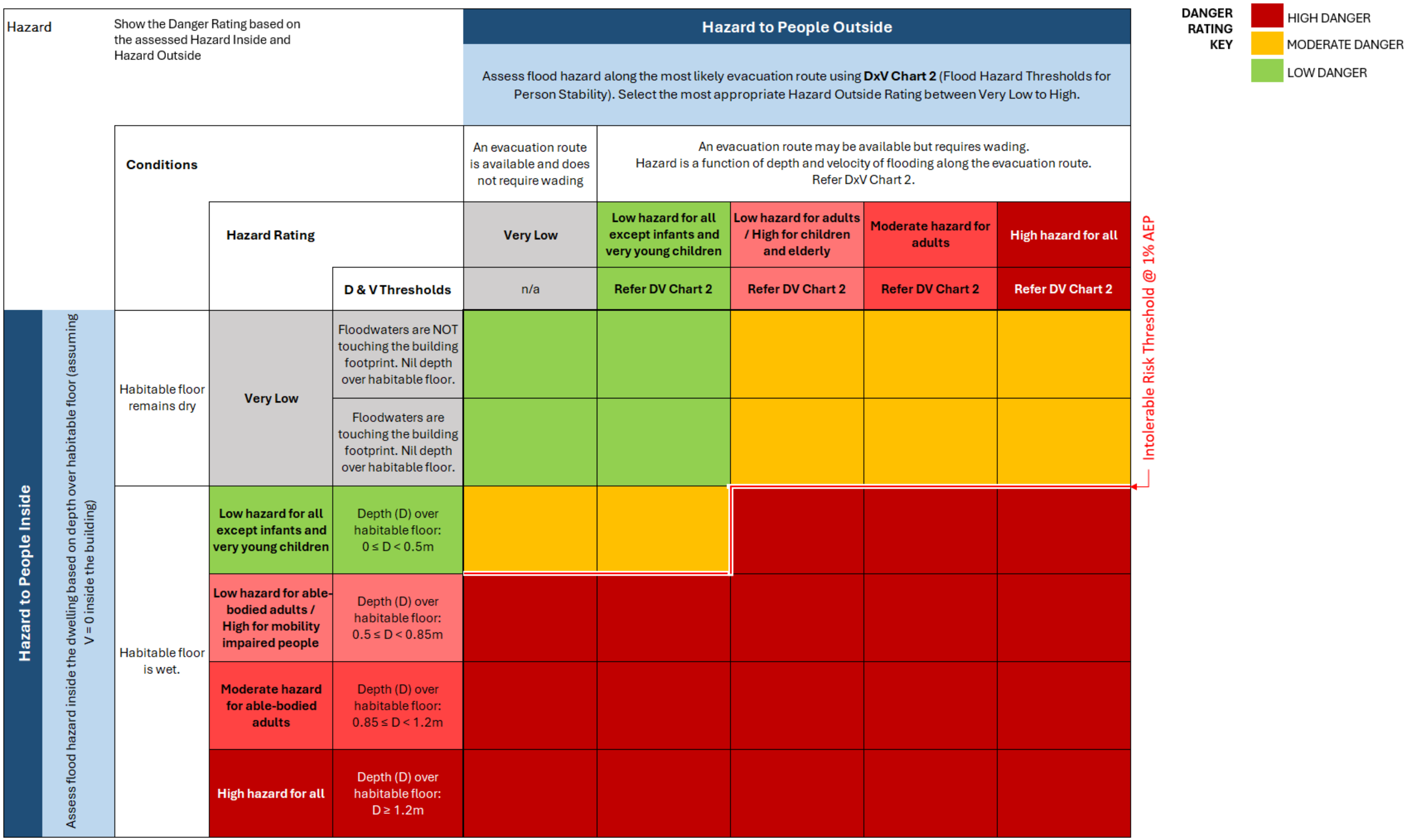
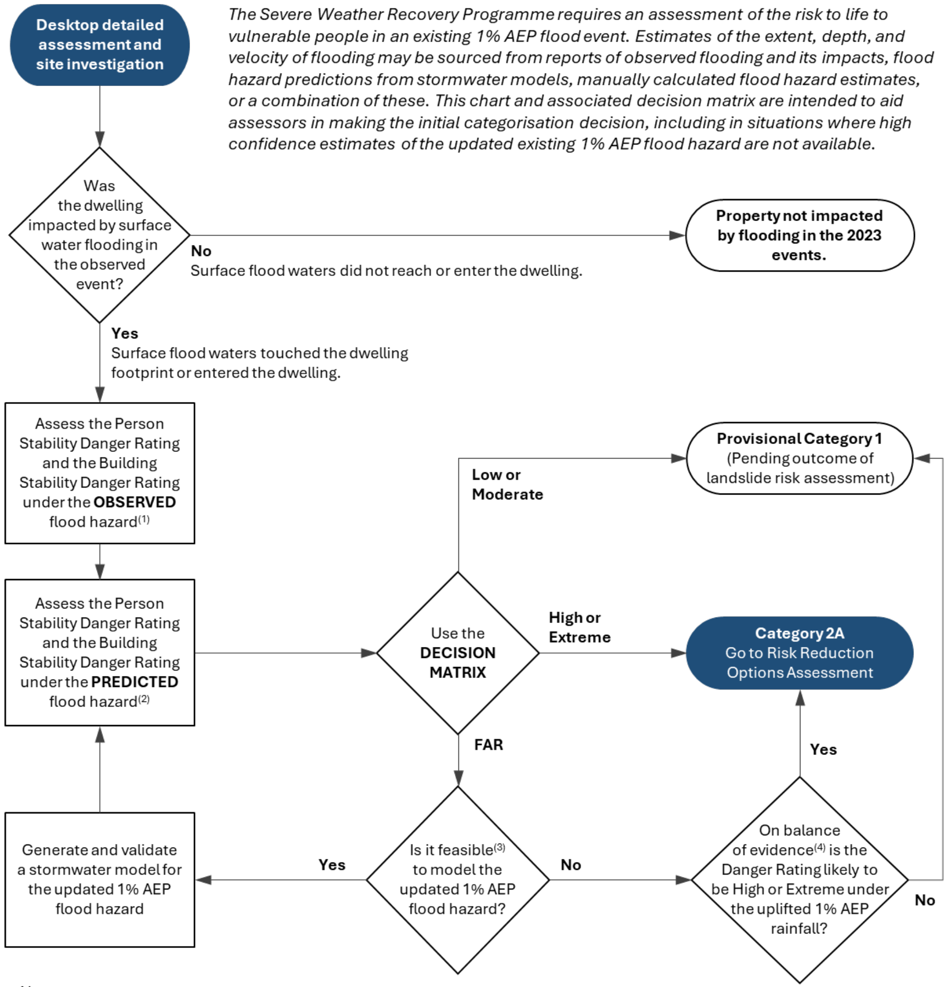


Figure 6. Person Stability Danger Rating Matrix

The Severe Weather Recovery Programme requires an assessment of the risk to life to vulnerable people in an existing 1% AEP flood event. Estimates of the extent, depth, and velocity of flooding may be sourced from reports of observed flooding and its impacts, flood hazard predictions from stormwater models, manually calculated flood hazard estimates, or a combination of these. This chart and associated decision matrix are intended to aid assessors in making the initial categorisation decision, including in situations where high confidence estimates of the updated existing 1% AEP flood hazard are not available.



Notes:

1. *In practice, if the observed event was smaller than or equal to a 1% AEP event (based on either TP108 or updated DDF curve) AND the property receives a Flood Danger rating of High or Extreme for that event, then an initial determination of Category 2A can be accepted on the basis of the observed event alone.*
2. *Predicted flood hazard may be derived from stormwater modelling and/or other estimates (e.g., manual calculation).*
3. *i.e., feasible within the time and budget constraints of the Severe Weather Recovery Programme.*
4. *Consider what is known from observed flooding and any available models, including assessments of nearby properties. Carry out manual calculations, where appropriate and feasible, to estimate the flood hazard for the updated 1% AEP rainfall. Apply logic and judgement and the principles for dealing with uncertainty.*
5. *Discrepancy between results for Observed and Predicted events should be explained.*

DECISION MATRIX (for determining the Property Flood Danger Rating)

Step 1: Apply the assessed Building Stability Danger Ratings for the Observed and Predicted to determine the final Building Stability Danger Rating for the property. **Step 2:** Repeat for the Person Stability Danger Rating . **Step 3:** Take the higher of either the Building Stability Danger Rating or the Person Stability Danger Rating as the final Flood Danger Rating for the property.

Assessment Basis				PREDICTED Flood Hazard				
	Assessed Event Magnitude			Not Available	1% AEP			
		Basis for Assessed Event Magnitude		n/a	TP108		Updated DDF Curve	
			Danger Rating	n/a	Low or Moderate	High or Extreme	Low or Moderate	High or Extreme
OBSERVED Flood Hazard	Smaller than 1% AEP	TP108	Low or Moderate	FAR	FAR	High or Extreme	Low or Moderate	High or Extreme
			High or Extreme	High or Extreme	High or Extreme[5]	High or Extreme	High or Extreme[5]	High or Extreme
		Updated DDF Curve	Low or Moderate	FAR	FAR	High or Extreme	Low or Moderate	High or Extreme
			High or Extreme	High or Extreme	High or Extreme[5]	High or Extreme	High or Extreme[5]	High or Extreme
	1% AEP	TP108	Low or Moderate	FAR	FAR	FAR	Low or Moderate	High or Extreme
			High or Extreme	High or Extreme	High or Extreme[5]	High or Extreme	High or Extreme[5]	High or Extreme
		Updated DDF Curve	Low or Moderate	Low or Moderate	Low or Moderate	Use Judgement	Low or Moderate	Use Judgement
			High or Extreme	High or Extreme	High or Extreme	High or Extreme	Use Judgement	High or Extreme
	Bigger than 1% AEP	Updated DDF Curve	Low or Moderate	Low or Moderate	Low or Moderate	Use Judgement	Low or Moderate	Use Judgement
			High or Extreme	FAR	FAR	High or Extreme	Low or Moderate	High or Extreme

FAR	**Further Analysis Required.** Neither the Observed or Predicted events are representative of the updated 1% AEP event. Additional analysis (e.g., manual estimation or updated modelling) is needed to determine the Danger Rating for the updated 1% AEP event.
(green)	Danger Rating can be determined with high confidence based on assessment of Observed and/or Predicted flood hazard, where one or both of these are representative of the updated 1% AEP event.
(blue)	Danger Rating can be determined with reasonable confidence based on the worst assessed event as the flood hazard in the updated 1% AEP event is not expected to be less severe than this.
Use Judgement	Results from the assessment of Observed and Predicted events are conflicting. Check model validation and explain discrepancies. Use judgement to decide whether, on balance of evidence[4], the Danger Rating likely be High or Extreme under the uplifted 1% AEP rainfall.

Figure 7. Pathways for determining property Flood Danger Rating and initial property category for the existing 1% AEP event

4 Considerations in the design of the framework

21. Flood risk is a combination of the event likelihood, the resulting hazard, exposure, and vulnerability. Each of these components is variable and dependant on a wide range of other factors[2].

22. Sections 4.1 - 4.8 explain the various considerations that influenced the design of the flood risk assessment framework. These include:

    a. Which events should be considered

    b. The factors affecting loss of life from flooding

    c. The definition of “vulnerable people”

    d. How and where to assess flood hazard

    e. How to determine the Flood Danger Rating

    f. What the Flood Danger Rating means

23. Section 5 outlines additional considerations for the application of the framework.

4.1 Which flood events should be assessed

24. In order for risk assessments carried out in different locations to be comparable they must have a common denominator. That denominator is the likelihood of the assessed flood event, which is the probability of an event of a given magnitude being equalled or exceeded within a year (referred to as Annual Exceedance Probability or AEP[3]). While the trigger for the property buy-out scheme was the extreme weather events of early 2023 (the Auckland Anniversary Weekend floods and Cyclone Gabrielle), the property categorisation is based on assessments of the risk to life in the existing and future 1% AEP events.

4.1.1 1% AEP as the baseline event

25. The selection of 1% AEP event as the decision-making baseline is consistent with established urban planning practices and design standards.

26. Auckland Council’s functions under sections 30 and 31 of the Resource Management Act require it to control the use of land for the avoidance or mitigation of the effects of natural hazards. It is neither feasible nor socially or economically justifiable to protect urban development from all natural hazards risk. Rather, Council seeks to manage the effects of flooding within the 1% AEP flood plain, taking into account anticipated development, which results in more people living in the flood plain and increasing imperviousness, and the effects on the flood plain as a whole. This is achieved through the objectives, policies, and rules of the Auckland Unitary Plan (AUP) and the Stormwater Code of Practice:

    a. Section 36 of the Auckland Unitary Plan specifies land use control rules in relation to flood plains in urban areas. Essentially, the rules require that habitable floors should not be subject to flooding in less than a 1-in-100 year (1% AEP) event.

[2] See, for instance, the NSW Flood Risk Management Guideline FB01 - Understanding and Managing Flood Risk (NSW Department of Planning and Environment, 2023) and Flood Risk Management Guideline FB03 – Flood Hazard (NSW Department of Planning and Environment, 2022).

[3] The AEP of an event is approximately the inverse of the Average Recurrence Interval (ARI) (Ball et. al. 2019; Chapter 2.2.5).

b. The Auckland Stormwater Code of Practice specifies design standards for stormwater infrastructure. Essentially, the primary stormwater conveyance network must be able to convey flows in a 1-in-10 year (10% AEP) event, with secondary systems designed to accommodate a 1-in-100 year (1% AEP) event (Stormwater COP s.4.3.5.2).

27. The 1% AEP flood event reflects the level of risk that Council considers to be an appropriate basis for planning decisions in Auckland, especially in light of the increasing demand to use flood hazard areas for development, and the potential effects of climate change (Auckland Council, 2015). The 1% AEP event is widely used in NZ as both a planning control and a design standard for secondary stormwater systems (McComb, 2016), and was the standard used for residential building protection in all the legacy district plans in the Auckland Region prior to the formation of Auckland Council (Auckland Council 2015). It is also recognised as the appropriate standard for residential areas in Australia (AIDR, 2017a). Flood hazard planning based on a 1% AEP flood event is regarded as prudent and appropriate.

28. The Building Act requires that the risk of flooding to a specific building be no more than a 2% probability in any given year (i.e., 2% AEP). However, this requirement is focussed on the structural performance of individual buildings and does not take into account the wider effects of development on the flood plain as a whole (Auckland Council, 2015).

29. The 1% AEP event has therefore been adopted as the frequency threshold for defining intolerable risk to life. That is, high hazard to life in flood events up to 1% AEP should be considered intolerable. A residual risk remains from flood events larger than 1 % AEP.

4.1.2 Existing vs future risk

30. The terms “existing” and “future” refer to different planning and design scenarios (see Appendix 1).

31. The existing (or baseline) scenario represents the existing flood hazard in a catchment based on unadjusted rainfall profiles and the existing impervious area (Existing Development)[4]. At the property-level, the existing scenario is defined by the state of the property and dwelling at the time of assessment. The initial classification of a candidate property as High or Extreme Danger is based on existing risk as it is existing risk that justifies the investment (i.e., if the risk does not yet exist, there is no justification to reduce it)[5].

32. Climate change projections for the Auckland Region indicate that the depth and intensity of rainfall, at any given AEP, will increase over time due to climatic warming (Auckland Council SWCOP; s.4.2.10). Future scenarios therefore represent the future flood hazard in a catchment based on climate change adjusted rainfall profiles, the future impervious area (Maximum Permitted Development), and the future state of catchment infrastructure and the property assuming any proposed community or private risk reduction works have been completed. The final categorisation of a property, as Category 2P/C, or Category 3, involves consideration of the potential risk reduction options. Future risk must be considered in this evaluation to determine whether the proposed property-level or community-level risk reduction interventions are feasible, i.e., the proposed interventions must be designed to mitigate future flood risk. In accordance with the forthcoming Auckland Council Stormwater Code of Practice Version 4, proposed solutions need to be assessed for

4 Strictly speaking “baseline” is the more accurate term. The baseline modelling scenario represents “existing” climate by using unadjusted rainfall profiles, “existing” development being the impervious area in a catchment based on the most up to date impervious area layer at the time a model is developed, and “existing” sea level being the relevant sea level standard at the time the model is development. Appendix 1 provides further explanation.

5 This is a question of the timeliness of the investment relative to the effects of that investment. Investment which delivers risk reduction before it is needed or desired is inefficient and should be postponed until such time as it is justified.

the future design scenario defined by 1% AEP Maximum Permitted Development and a 3.8°C temperature increase[6].

4.2 Factors affecting loss of life from flooding

33. In the international literature, a wide range of factors affecting loss of life from flooding have been identified. For instance, Brazdova and Riha (2014) identified 28 hazard-, exposure-, and vulnerability-related factors influencing loss of life from flooding, while Yari et. Al. (2020) identified 114 risk factors of death from flooding across 48 studies. (See the literature review in Appendix 3 for further details.)

34. However, while there may be a very large number of factors that could potentially affect a person's outcome in a flood situation, only a few are significant. Following Jonkman et. Al. (2008) and Smith and Rahman (2016), the most important factors that influence mortality from flooding are:

    a. Water depth and velocity

    b. Warning and evacuation (this encompasses speed of onset, whether there is warning, how much time there is to evacuate, and whether the population can evacuate).

    c. Rate of water rise (especially rapid rise in combination with deep flood waters)

    d. The availability of shelter

    e. Collapse of buildings

    f. Children and the elderly are especially vulnerable

35. The above factors are considered in this framework as follows:

    a. **Water depth and velocity:** the core of the framework is the assessment of flood hazard in terms of the depth and velocity of flow relative to defined thresholds for person and building stability. This is explained in section 4.4.

    b. **Warning:** Warning is not specifically considered in the assessment of the Flood Danger Rating as the assumed context for the assessment is a person situated on the property at the peak flood condition (noting also that most flooding in Auckland occurs with little warning, see rate of water rise below)[7].

    c. **Evacuation:** Whether the occupant of a dwelling chooses to evacuate is a key determinant of their exposure to flood hazard and subsequent risk to life. However, from a risk assessment perspective this is a fundamental uncertainty. Section 4.7 explains how evacuation is considered within determination of the Flood Danger Rating Schema.

    d. **Rate of water rise:** Rate of water rise has been considered but is not part of the framework for two reasons. First, the unique topography of the Auckland region means that the time of concentration in Auckland's catchments is typically short (less than two hours) such that flooding occurs rapidly with little warning (i.e., flash flooding; see also Appendix 2). Ignoring the rate of water rise is conservative in this context, i.e., the framework effectively assumes

[6] Temperature increases in Auckland due to climate change are quoted relative to 1995, this being the mid-point of the 1986-2005 climate baseline used in Auckland. Temperature increases quoted in the international climate change literature (e.g., that from the IPCC) are typically quoted relative to pre-industrial levels. New Zealand warmed by approximately 0.7°C on average from 1850 to 1995 (Dean 2022).

[7] For the same reason, duration of exposure is not considered in the framework. In principle, it may be expected that the longer someone is exposed to a certain hazard, the more likely they are to suffer an adverse outcome. However, flooding in Auckland is generally of a short duration (a few hours). Also, accounting for duration of exposure would add a significant level of complexity to the assessment without necessarily adding further resolution to the categorisation decision.

the rate of water rise is rapid. Second, accounting for rate of water rise would require additional work to accommodate the rate of change of the flooding situation at a property over time, rather than just the ultimate (worst case) flood hazard. It was considered that this would not likely make a material difference to the assessment outcome in most cases.

e. **The availability of shelter:** The availability of shelter is a basic assumption, i.e., that a person who is still situated on an Auckland property at the time of peak flood hazard will initially be inside the dwelling (see section 4.7).

f. **The collapse of buildings:** the potential for floodwaters to pose a threat to the stability of buildings is explicitly assessed (see section 4.4).

g. **Children and elderly:** Council has determined that "intolerable risk to life" means a high risk to life to vulnerable people in a 1% AEP event. This includes "children and elderly" (see section 4.3).

4.3 The definition of "vulnerable people"

36. Auckland Council's Categorisation Approach states 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. However, the Categorisation Approach does not define the category of "vulnerable people".

37. 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). In its broadest sense, vulnerability is a multifaceted characteristic of exposed people or groups and their situation that influences their capacity to anticipate, cope with, resist, and recover from the adverse effects of physical events.

38. Since all persons exposed to flood hazard are more or less vulnerable to suffering adverse effects, it is assumed that "vulnerable people" means 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.

39. This framework is narrowly concerned with the risk that floodwaters pose to the lives of individuals exposed to those floodwaters. Vulnerability is considered in two contexts:

a. Inside the dwelling, where the most vulnerable people are those who are mobility impaired.

b. Outside the dwelling, where the most vulnerable people are children and the elderly.

40. No distinction is made between the vulnerability of different groups of people in the scenario where building stability is threatened by floodwaters. This scenario is considered the highest threat to all. In this regard, the term "vulnerable people" in this framework does not mean the same thing as the term "most vulnerable user" used in the landslide risk assessment framework. In the context of landslide risk assessment, vulnerability means the likelihood that a person impacted by a landslide will suffer injury or death. The most vulnerable user is the person exposed to the most severe consequences, which depends on where they are and the nature of the impact of the landslide on the building or vehicle that they may be in (refer AGS 2007, s6.4 and Appendix F).

4.3.1 Inside the dwelling

41. Those who are inside the dwelling at the time of flooding must decide whether to shelter in place or evacuate. By definition, disabled people – those with mobility impairment or other forms of physical

and/or intellectual impairment (Statistics New Zealand, 2013) – are more vulnerable in this context because they may not be able to correctly perceive or understand what is happening, make the appropriate choices, or have the physical ability to evacuate unassisted. These people would require support from able-bodied adults to safely evacuate in a flood situation.

42. 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).

4.3.2 Outside the dwelling

43. 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 (e.g., wading distance, slope and unevenness of the ground, and proximity to deep/dangerous floodwaters).

44. Flood stability thresholds for people (see section 4.6 and Figure 4) are defined in relation to a height-mass (H.M) index, being the height of a person, in metres, multiplied by their weight, in kilograms, where the higher the H.M index of a person the greater the depth and velocity of flow that person can withstand before becoming unstable (Cox et. Al. 2010; Smith et. Al. 2014).

    a. People with an H.M index of less than 50 are more vulnerable to losing stability in floodwaters. This corresponds to most children under the age of 14 (ANZSPED, 2023).

    b. Cox et. Al. (2010) and Smith et. Al. (2014) also note that older/elderly and frail persons are unlikely to be safe in any flow conditions. For this reason, the AIDR Guideline on Flood Hazard (AIDR 2017b), on which this framework is based, groups the elderly together with children for the purposes of hazard vulnerability classification. However, since even a short elderly adult, say 1.5m tall, would likely weigh more than the 33 Kg needed to achieve an H.M of 50, this is presumably meant to include older people who lack strength and competence of stability and may therefore become unstable at flow depths and velocities similar to those of children, rather than all older people per se[8].

    c. Infants and very young children are those with an H.M less than 25. Most children achieve an H.M of 25 between ages 5 and 7 (ANZSPED, 2023). In this framework, infants and very young children are not explicitly included within the definition of "vulnerable people" on the basis that anywhere infants and very young children are present there will also be adults present and adults will most likely prioritise attention to infants and very young children and carry them in an evacuation scenario.

[8] The Australian guidance does not define "older person" or "elderly". While a common age-based threshold is anyone over the age of 65, the characteristic which relevant for determining vulnerability in floodwaters is that of frailty.

4.4 Assessing flood hazard

45. Hazard describes the relative degree of threat or danger that physical flood conditions present for people, vehicles, and buildings. Key factors which determine flood hazard are:

    a. The duration and intensity of rainfall: i.e., how much rain falls and how fast.

    b. Land and land use characteristics: Physical characteristics of the land that govern how the ground responds to rainfall (i.e., how much rainfall will become runoff and how fast) and that govern the hydraulic behaviour of runoff over the land (i.e., where stormwater will flow and how fast, and the extent and depth of resulting inundation). These characteristics include, for instance, topography, land use activity and impervious area, soil types and moisture content, and ground roughness.

    c. The stormwater network: the features, characteristics, and capacity of the stormwater network. The stormwater network consists of all channels, conduits, flow paths, and watercourses that convey stormwater runoff, whether over- or underground. This includes engineered stormwater infrastructure such as pipes, drains, and culverts, as well as surface features of the landscape such as overland flow paths, streams, rivers, and floodplains.

46. Flood hazard is a function of the extent of inundation and the depth and velocity of flood flows, and varies across the landscape and in time during a flood event as the combination of peak flow velocity and flood depth change.

47. Exposure is defined as being present in a place or setting that could be adversely affected by a hazard. For a person who lives at a residential property[9] in Auckland, their exposure to flood hazard at that property will depend on:

    a. Whether the property is exposed to flood hazard: The location of the property relative to the flood hazard area (i.e., whether it is located in a floodplain, overland flow path, or flood prone area), the location of the dwelling[10] on the property, and the elevation of the habitable floor(s)[11] relative to the flood level, and whether the evacuation route is exposed to flood hazard.

    b. Occupancy: Whether the person is at home at the time the flooding occurs. This will depend on time of day and the personal circumstances of the individual.

    c. Whether and when they decide to evacuate: the decision to stay or evacuate is highly uncertain and influenced by a range of factors (see section 4.7).

48. Overseas approaches to flood risk assessment tend to assume widespread fluvial or coastal flooding which results in a uniform level of flood hazard across a wide area. In contrast, the pluvial nature of flooding in Auckland and the steep topography of Auckland's catchments mean that the resulting flood hazard has high spatial variability at the property level (see Appendix 2). It is common for flooding to affect one property but not neighbouring properties, or even just part of a property. It is possible to have dangerous flood hazard on one side of a house and no flooding on the other side.

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[9] Residential properties are defined as properties with a residential land zoning under the Auckland Unitary Plan or which are being used for consented residential purposes, e.g. Rural – Countryside Living.

[10] Dwelling: means living accommodation used or designed to be used for a residential purpose as a single household residence contained within one or more buildings, and served by a food preparation facility/kitchen (refer Auckland Unitary Plan J1 Definitions).

[11] Habitable floors are defined in the Auckland Council Survey Specification (ACS1530.5.4.1) as floors used for residential activity including dwellings, home occupations, visitor accommodation, camping grounds, boarding houses, student accommodation, integrated residential development, retirement village, supported residential care and sleepouts. In this document, the term "habitable floor" refers to a floor within a dwelling on residential property.

49. This makes the assessment of risk to life at the property level challenging as it requires considering both the variability in flood hazard across the property as well as the behaviour of people who may be on the property:

   a. The zone of highest flood hazard on the property may not be relevant if it is not where the people are likely to be.

   b. Anyone still on the property at the time of peak flood hazard is likely to be inside the dwelling, but they may also choose to go outside.

   c. Flood hazard outside the dwelling (i.e., adjacent to the building footprint) may pose a threat to those inside the dwelling if it is severe enough to threaten building stability.

50. The assessment framework considers the danger posed by flood hazard at three locations on the property (see Figure 2):

   a. The maximum depth and velocity of flow adjacent to the building footprint, which could pose a threat to the structural stability of the building.

   b. The maximum flood depth over the lowest habitable floor inside the dwelling[12], which is compared with person stability flood hazard thresholds (see Figure 4) to determine the significance of the danger to people who may be inside.

   c. The maximum flood depth and velocity along the most likely evacuation route from the dwelling, which is compared with person stability flood hazard thresholds (see Figure 4) to determine the significance of the danger to people who may try to evacuate.

51. Flood hazard elsewhere on the property is not considered. While it is recognised that some people might choose to enter floodwaters for reasons not to do with evacuation, it is assumed that for the majority of people the key decision will be to stay inside or evacuate.

52. Flood hazard is assessed for the ultimate or peak hazard state for any AEP event. It was considered that accounting for the rate of change of the flooding situation at a property over time would not likely make a material difference to the assessment outcome in most cases (see section 4.2).

4.5 Assessment of building stability under flood conditions

53. Sections 4.5.1 to 4.5.3 explain the approach to assessing building stability under flood conditions.

4.5.1 Trigger threshold for a structural stability assessment

54. Australian guidance offers two thresholds relevant to building stability under flood conditions:

   a. D ≥ 2.0 m, or V ≥ 2.0 m/s, or DxV ≥ 1.0 m^2/s (H5 threshold AIDR 2017b, Figure 6)

   b. D ≥ 4.0 m, or V ≥ 4.0 m/s, or DxV ≥ 4.0 m^2/s (H6 threshold in AIDR 2017b, Figure 6)

55. The lower threshold was adopted for the building stability threshold in Figure 3 (DV Chart 1):

   a. Following review (see Appendix 5) of expert evidence on the stability of people, vehicles and buildings in flood waters provided in Smith (2015), and

   b. Considering that flooding at the upper threshold level is extremely rare in Auckland, and

   c. Considering that a large proportion of Auckland housing stock consists of light, timber framed structures, often on piles. (There were reports of dwellings being damaged by flows at the

[12] Or the affected habitable floor in the case of flooding from overland flow on sloping properties.

lower threshold in the Jan/Feb 2023 events in Auckland, and even more robust structures can be damaged or fail in flood flows less than the upper threshold).

56. The building stability threshold shown in Figure 3 is the lower threshold at which structures may be susceptible to damage from flood waters. Whether damage actually occurs depends on many factors. These include the depth and velocity of flow, debris loading, direction of flow relative to building orientation, how much of the structure is exposed to floodwater, the duration of exposure, and the type of foundations and building structure and cladding.

57. Where a building is subject to flood depths and velocities above the building instability threshold shown in Figure 3 (DV Chart 1), the building should be specifically assessed by a structural engineer to determine its potential susceptibility to structural instability under flood loading. Assessment by a structural engineer should also be considered if structural damage has been observed or suspected to have occurred in an observed flood event at depths and velocities below the threshold shown in Figure 3 (DV Chart 1). However, to avoid unnecessary effort, specialist structural assessment need only be undertaken if the Person Stability Danger Rating (see section 4.6) for the property is Low or Moderate. If the property has already been assigned a Person Stability Danger Rating of High, then the result of a structural stability assessment will not change the final outcome for the property.

4.5.2 Detailed structural stability assessment

58. Assessing how a particular residential building will behave under flood conditions and whether it may become unstable is challenging for several reasons:

    a. Residential buildings in New Zealand are generally not specifically designed for flood loads.

    b. Buildings may be subject to a wide range of forces under flood conditions. These include hydrostatic and hydrodynamic forces from water around the structure, buoyant forces, impact forces from the water or debris, wave action, and erosion and scour (Smith et al. 2014).

    c. There are numerous building types in Auckland that date back over a century, including older villas and Californian bungalows with flimsy foundations, solid plaster brick clad homes on concrete slab foundations, and modern architecturally designed homes with large rooms and glazed facades which have minimal redundancy for additional lateral loads. These building types will perform differently when loaded by floodwater. For example, timber framed residential buildings of the period 1900-1978 typically have poor subfloor bracing resistance to lateral loads. Lightweight timber framed structures can easily become buoyant if floodwaters quickly rise above the floor level and does not enter the building, particularly if air is trapped within the floor construction (NZ design codes, such as NZS3604 don't require fixings to resist these potentially massive buoyancy forces). This could cause the building to become unstable. Conversely, buildings which consist of a concrete slab on grade with perimeter subfloor masonry walls have high resistance to lateral flood loads, are unlikely to become buoyant, and would generally be expected to remain undamaged as well as completely stable if flooding is to the subfloor only.

    d. Failure modes leading to building instability will be different depending on the type of building construction. Flexible structures, such as timber or steel framed buildings, can accommodate large deformations before structural elements rupture and become unstable. Some building types, such as single level weatherboard clad timber framed houses with lightweight roofs, can sustain significant amounts of inter-storey displacement and loss of vertical support due to the stiffening effects of wall linings and claddings and the ability of these materials to withstand plastic deformations in their connections. Conversely, masonry and concrete buildings are rigid and relatively brittle structures which cannot easily deform without becoming unstable. Some modern buildings are hybrid structures with a combination of flexible and rigid elements, such as a mix of masonry and concrete with steel and timber beams and framing. It is also possible that individual elements of a building can rupture – for instance, a pile may fracture, or a subfloor brace may fail at its connections – without the building as a whole becoming unstable and then potentially collapsing.

59. The structural assessment should consider a range of inputs and factors:

a. The type of building and materials and nature of its construction, including inspection of consented building plans (where these are available).

b. A visual inspection of the building integrity and any damage which may have been sustained from flooding. This includes inspection of load bearing elements, such as vertical and lateral loaded elements, including walls, posts/ columns, beams, bracing elements, roof rafters/trusses, floor joists, bearers, piles and foundations and connections (may require access to subfloor spaces and roof cavities) and inspection of structural weaknesses, deformations, deflections or failures that compromise the building's stability, as well as damage to non-load bearing elements, such as ceilings, windows/doors, claddings, that could pose a risk to life.

c. Any identified non-compliances with current code requirements and any observed discrepancies between the consented building plans and the as-built structure that will affect the performance of the building in a flood event.

d. The flooding mechanism and severity of flood hazard to which the building was or may be exposed, including potential debris loading. (However, it may not be possible to formally evaluate the effects of debris loads on residential building structures due to the uncertainties involved, i.e., how large/massive the debris may be, the direction from which the debris may impact the building, or how the impact will occur[13]).

e. NZ structural design and materials codes. These include: the NZ Building Code B1 Structures, NZS3604 Timber-framed buildings, NZS 4229 Concrete Masonry Buildings not requiring specific engineering design, AS/NZS 1170 Structural Design Actions, NZS3101 Concrete Structures Standard, NZS3404 Steel Structures Standard, and NZS4230 Design of Reinforced Masonry Structures.

f. Load checks and calculations as may be appropriate.

g. Application of professional knowledge and judgement, including experience from assessing buildings damaged in other events (e.g., earthquake damage, tornado damage, fire damage).

60. In this framework, the following Building Stability Categories are used to classify building stability under flood conditions (see the Building Stability Danger Rating Matrix in Figure 5):

a. **Severe structural damage:** Under assessed flood conditions, the building has experienced or is expected to experience structural damage and/or instability with a high risk of partial/total collapse that could cause injury or high danger to people. This includes loss of structural support of load bearing elements likely to be associated with greater than 50mm of lateral inter-storey or building element movement. In this state, the behaviour of the building under gravity loads is unpredictable and collapse could be imminent.

b. **Structural instability:** Under assessed flood conditions, the building has experienced or is expected to experience damage and/or instability that causes movement in the floor, walls, and/or ceiling/roof. The building does or will exhibit signs of distress that are obvious to a structural engineer but which may not be evident to building occupants. For a flexible structure

[13] For instance, will the debris impact the building as a single large mass (hydrodynamic/momentum exchange) or will finer material such as branches/ vegetation wash up against the structure and create a dam (hydrostatic pressure differential)?

such as a timber framed building this may be less than 50mm of lateral inter-storey or building element movement in some circumstances. For more rigid structures such as concrete and masonry construction, which have a lesser movement threshold, this would typically be any movement and/or cracking of the structure (though this will be dependent on the building design and requires assessment by a structural engineer). While imminent total or partial collapse of the building may be unlikely, there remains a heightened risk due to damage or movement of the building's structural elements.

c. **Stable (some damage):** The building has resisted or is expected to resist loads from the assessed flood conditions acting in combination with gravity loads. The building has experienced or may experience non-structural damage (e.g., foundation scour) which would need to be repaired to reduce the risk of structural instability occuring in a future event.

d. **Stable (no damage):** The building has resisted or is expected to resist loads from the assessed flood conditions acting in combination with gravity loads. Superficial, non-structural damage has occured or may occur (e.g., cladding damage) which has no impact on building stability. This rating applies for buildings assessed to be below the threshold in DV Chart 1 (Figure 3).

4.5.3 Determining the Building Stability Danger Rating

61. The Building Stability Categories defined in section 4.5.2 have been aligned with the Building Stability Danger Ratings as follows (see the Building Stability Danger Rating Matrix in Figure 5):

    a. Severe structural damage = Extreme Danger

    b. Structural instability = High Danger

    c. Stable (some damage) = Moderate Danger

    d. Stable (no damage) = Low Danger

62. The categories of “severe structural damage” and “structural instability” are both characterised by instability and unpredictability of the building’s behaviour. Buildings in either category should be considered unsafe to be in or around. The difference between the two is a matter of degrees and uncertainty in the perceived risk of “imminent collapse”. A building that has experienced severe structural damage is considered to be fundamentally unstable and could collapse at any moment, thus posing an imminent risk to life to anyone inside the building. Imminent total or partial collapse of a building that is experiencing structural instability may be unlikely, but there remains a heightened risk due to damage or movement of the building's structural elements. Buildings in this category should still be considered unsafe. It also needs to be considered that there is a difference between evaluating the structural state of a building in a post-event context, where the outcome is known, and predicting a building’s performance under the anticipated 1% AEP flood conditions, which may be more or less severe than flooding previously experienced. The rating of High Danger for the category of “building instability” reflects that the outcome in the latter context is subject to greater uncertainty, arising, for instance, from:

    a. Uncertainty about the maximum flood depth and velocity in the 1% AEP event (see section 5).

    b. The effect of time, i.e., how long the building will be exposed to peak flood hazard conditions.

    c. The effects of debris loading the magnitude and behaviour of which may be highly unpredictable, and which cannot be explicitly accounted for in the structural assessment.

    d. The cumulative effects of multiple dynamic load actions in combination – hydrostatic, hydrodynamic, buoyancy, scour, debris, wind, etc.

e. The quality of the building materials and construction, and any defects or non-compliances that may affect building performance under flood conditions.

63. The rating of "stable" indicates that the structural stability and safety of the building has not been or is not expected to be materially changed by the effects of flood exposure. The rating of Moderate Danger is used to indicate that there are observed conditions which may make the building more susceptible to structural instability in future flood events, and which should be repaired.

64. It is possible that the Building Stability Danger Rating may not be determined if a specialist structural assessment is warranted (i.e., DV > 1 on Figure 3) but not carried out. This may occur if the property has already been given a Danger Rating of HIGH for person stability (see section 4.6). In this case, the Building Stability Danger Rating cannot be determined from the results of the DV assessment alone and the NOT DETERMINED rating applies.

4.6 Assessment of person stability under flood conditions

65. Sections 4.6.1 to 4.6.3 explain the approach to assessing person stability under flood conditions.

4.6.1 Flood hazard thresholds for person stability

66. There are various methods for quantifying flood hazard thresholds for person stability (see for instance Cox, Shand, and Blacka, 2010; Smith, Davey, and Cox, 2014). Different methods use different underpinning hazard functions which result in different threshold settings. Two methods considered in the development of this framework were:

a. The Australian depth-velocity (DV) curves published by the Australian Institute for Disaster Resilience (AIDR Guideline 7-3 Flood Hazard, 2017, Figure 8).

b. The UK HR Wallingford DV equation and thresholds (HR Wallingford Ltd, 2006, s.3.5 and Table 3.2).

67. The DV curves generated by these two methods look similar and have similar hazard severity categories, but the thresholds between the categories are quantitatively different because the source equations are different. The Australian thresholds are more conservative than the UK thresholds and employ asymptotes defining limiting values of depth and velocity for person stability. The UK method does not recognise such limiting values.

68. Based on a side-by-side review of both methods (see Appendix 4) and following Cox et. Al. (2010) the Australian flood hazard threshold definitions were adopted for this framework as they are a better fit to empirical evidence of person stability in flood flows and recognise that there are practical upper limits of both depth and velocity. The following changes were made to the thresholds shown in Figure 4:

a. A horizontal asymptote was added to the DV = 0.6 m^2/s curve at D = 0.85 m. This is to simplify the application of the hazard thresholds within the Flood Danger rating matrix.

b. The upper velocity limit was reduced from 3 m/s to 2 m/s, recognising that the value of 3 m/s given in Australian guidance is a maximum upper limit for adults in good conditions. The experimental studies on person stability include results where people have lost their footing under laboratory conditions at velocities ranging from less than 1 m/s up to 3 m/s. As conditions in real life flood evacuation scenarios are unlikely to be ideal, it was considered that a lower upper velocity limit for wading should be adopted. (The revised limit of 2 m/s is consistent with the upper velocity limit for building stability shown in Figure 3.)

69. The person stability thresholds used in this framework are shown in Figure 4.

4.6.2 Assessing flood hazard along evacuation routes

70. The assessment of hazard outside a dwelling requires identifying and evaluating likely evacuation routes (every property will have at least one potential evacuation route).

71. An evacuation route means a route away from the building that:

    a. Is accessible from a doorway, and

    b. Leads to a place that is above the maximum flood level for the nominated event from which people would reasonably be able to access shelter, transport, or assistance, and

    c. Is free of obstacles, and

    d. Can be traversed – in the absence of floodwaters – by a person walking normally without resorting to extraordinary physical exertion (e.g., scrambling, climbing, jumping).

72. The property assessors are required to identify the route that they believe is the route occupants will be most likely to use. This will depend on the topography, layout, and features of the site and surroundings and the location and severity of flood hazard on the property. Where there is more than one potential evacuation route, the most likely route is assumed to be that which meets the above criteria and which is exposed to the lowest flood hazard.

73. An evacuation route may be considered safe (very low hazard) if it is clear of flood waters along the entire route. Practically, this means that, while the ground will be wet and there may be puddles, there are no significant flows or ponding > 50 mm in depth at any point along the route. If there are flows or ponding more than 50 mm in depth at any point along the route then the route should be considered to be exposed to flood hazard and assessed using the chart in Figure 4.

74. However, the assessed flood hazard (depth x velocity) along the evacuation route does not necessarily give a full picture of how dangerous the evacuation route might be. The person stability thresholds which define the flood hazard categories in Figure 4 are derived from laboratory testing of test subjects on level ground. Other factors will influence the difficulty and hazardousness of an evacuation route, including:

    a. The terrain underfoot: the slope and type of ground surface (e.g., uneven, slippery).

    b. Wading distance: the longer the wading distance the greater the likelihood of a person accidentally losing stability or becoming exhausted (depending on their physical characteristics, abilities, and fitness, and the temperature of the water, which can sap strength).

    c. Proximity to hazards: floodwaters can be murky and/or evacuation might take place at night, making it difficult to see potential hazards like debris, holes, or drop-offs.

75. There is no simple, formulaic way to integrate the above factors into the assessment framework. Assessors should consider the above factors together with the estimated water depth and velocity along the evacuation route. A higher OR lower hazard rating than that given by the combination of depth and velocity, alone, may be appropriate. Where this is the case, clear justification must be given, and the decision must be reviewed through the QA process.

4.6.3 Determining the Person Stability Danger Rating

76. The Person Stability Danger Rating Matrix combines the Hazard to People Inside and the Hazard to People Outside to generate a Person Stability Flood Danger rating which represents the overall hazardousness of the situation for an individual who is situated at a property during peak flood conditions.

77. 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 the Person Stability Danger Rating Matrix in Figure 5.

78. A key challenge for the development of the framework was how to combine the assessed hazard to people inside and outside into a single Danger Rating. Simple, arithmetic methods (e.g., averaging, summing, or multiplying) of combining the input ratings were not suitable because they don't correlate with the real or perceived hazardousness of the situation described by the flood hazard inside and outside the dwelling, except for trivial circumstances (e.g., where the hazard inside and outside are the same). Such methods either under- or over-represent the perceived risk or result in equivalences between different situations that do not make sense.

79. The Danger Ratings within the Person Stability Flood Danger Rating Matrix were ultimately determined on a consensus basis by a group of subject matter experts, including Healthy Waters specialists and external consultants, and with challenge from the Expert Panel[14]. This was not straightforward because it required consideration of human behaviour, which is fundamentally uncertain. The Danger Rating necessarily embeds assumptions about what most people will do when confronted by flood hazard, i.e., will they stay, or will they evacuate? It was, therefore, necessary to surface and make explicit those assumptions so that they could be understood and agreed through the consensus rating process.

80. The core assumptions which underpin the Danger Ratings in the Person Stability Matrix are documented in Figure 1. Illustrative flooding scenarios and assumptions underpinning the Danger Ratings. Those assumptions essentially divide the space defined by the Person Stability Matrix into four zones (see Figure 8):

    a. 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.

    b. 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.

    c. 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). While these scenarios offer a way to escape from a hazardous to less hazardous environment, they remain potentially dangerous for those who can't evacuate unassisted. This zone was considered High Danger where the flooding downstairs was more than 0.5m deep because this would be dangerous for mobility impaired people who may not be able to evacuate even if they wanted to. Flooding more than 1.2m deep would also be dangerous for able bodied adults who may attempt to rescue those trapped downstairs.

[14] Appendix 6 contains the supporting materials to the SME discussions.

d. A zone on the top right-hand side of the matrix which describes “safe refuge” scenarios (see Figure 9). 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.

81. 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:

a. 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).

b. 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.

c. Their motivations. The international literature suggests that the expressed and exhibited preference of most people is to evacuate (Thomas 2023a, see Appendix 7). 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.

d. 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.

82. 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[15]. Still other people may opt to enter flood waters for reasons other than evacuating.

83. 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.

[15] While ~60% of people on flood-affected properties chose to evacuate during the 2023 severe weather events in Auckland, this is not necessarily helpful without knowing when they evacuated. Many would have left prior to peak hazard occurring.

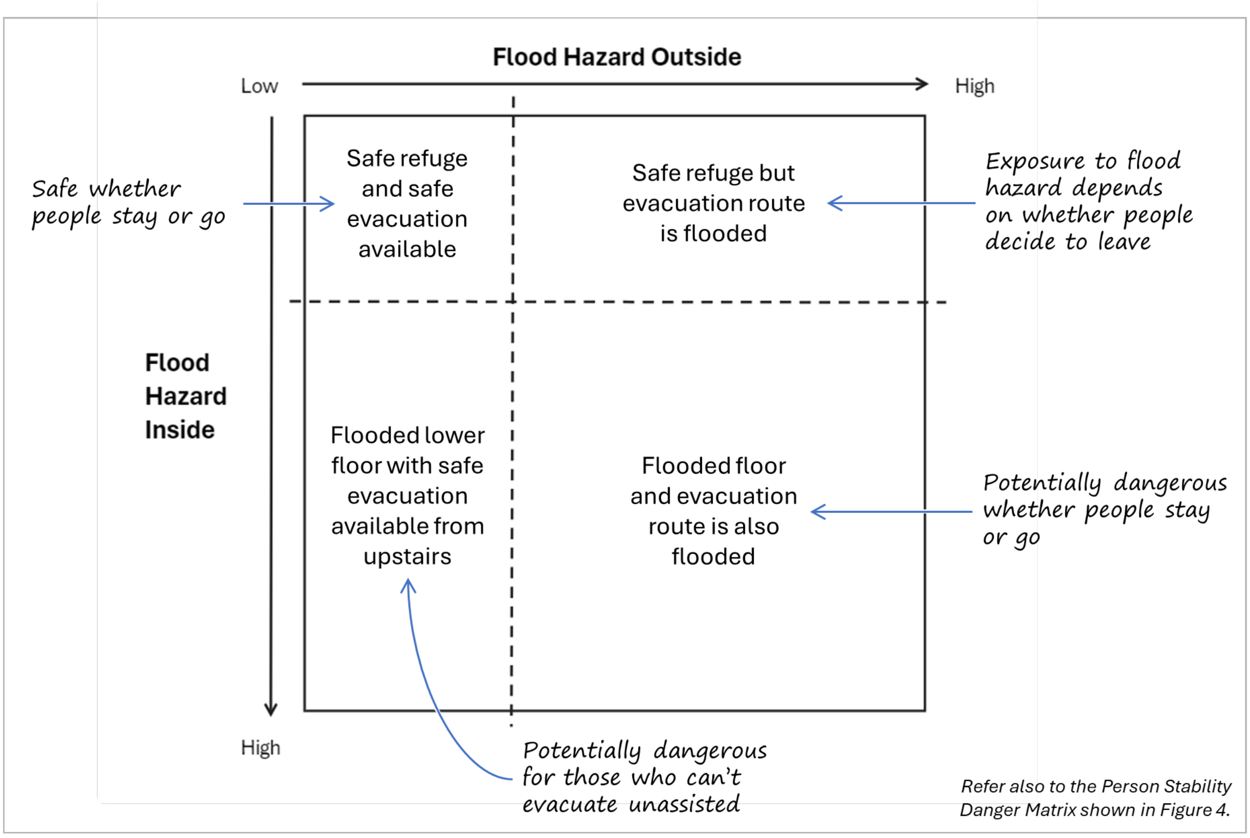


Figure 8. Four zones of danger

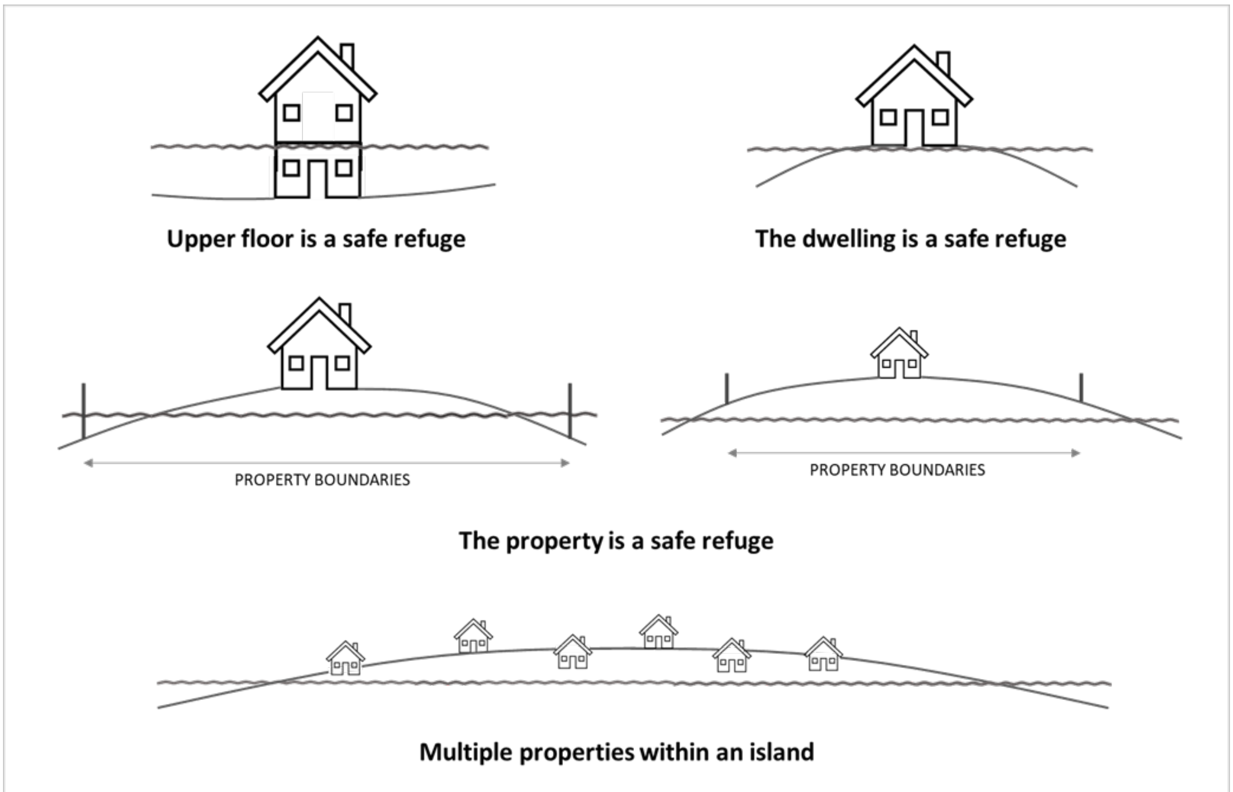


Figure 9. Safe refuge ("island") scenarios

84. In principle, the fact that the habitable floor does not flood means that the building occupants should be safe. If the occupants cannot safely evacuate, and as long as the stability and integrity of the building itself is not threatened by the floodwaters, staying on the island (or in the safe refuge) is objectively safer than being exposed to floodwaters. However, it was also recognised that flooding is a push factor viewed from the perspective of someone inside the dwelling who is unsure about how far the waters might rise. This means that some people will try to evacuate, including through potentially dangerous flood waters even if the habitable floor of the dwelling remains dry[16]. The closer the flood waters are to the dwelling (and the faster they are rising) the more people are likely to try to evacuate. By extension, flooding over habitable floor, even at low levels, is considered to be a strong push factor for evacuation. The deeper the flooding over habitable floor, the more likely it is that most people will try to evacuate, even if that means exposing themselves to a higher level of hazard outside.

85. By this logic, the danger posed by island scenarios depends on the proximity of the floodwaters to the dwelling as a driver of occupant's decision making about whether to evacuate. 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 (see Figure 10). Thus, how close do the floodwaters need to be to the house before most people would be likely to try to evacuate?

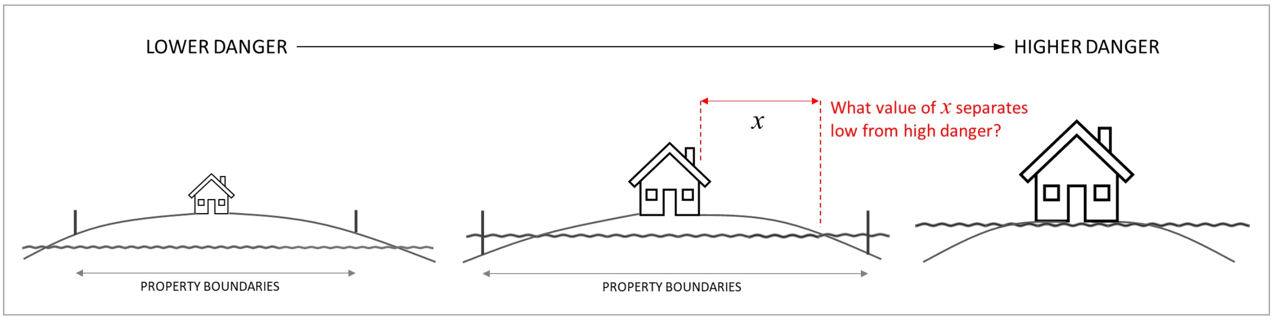


Figure 10. How close do floodwaters have to be to the dwelling to trigger evacuation by most people?

86. The threshold could be set at different levels:

   a. Flooding outside the property boundary

   b. Flooding inside the property

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

   d. Flooding over habitable floor level

   e. Flooding more than 0.5m over habitable floor level

87. 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

[16] There was also anecdotal evidence from early assessments that people did evacuate during the Jan/Feb 2023 events even though they had a safe refuge available to them (though it was acknowledged this was not necessarily informative without knowing when they evacuated).

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.

88. It is worth noting that this treatment of island scenarios is driven by overarching risk reduction objective and policy settings of the severe weather-affected property assessments (see section 1). It does not imply that safe refuge scenarios are always permissible or desirable in a planning context. Policy 14 under s.E36.3 of the AUP requires that redevelopment of sites where existing more vulnerable activities are located within the 1% AEP floodplain must address the location of habitable rooms above flood levels[17] as well as providing safe evacuation routes or refuges. While there are past examples where development in the floodplain has been consented in the absence of a safe evacuation route, the provision of safe evacuation routes should be preferred over the provision of safe refuge alone when behavioural considerations are taken into account.

4.7 Determining the Flood Danger Rating for the property

89. For any given flood event the outputs of the flood hazard assessment are the Building Stability Danger Rating (determined from Figure 5) and the Person Stability Danger Rating (determined from Figure 6). The Danger Rating for the property ***for that event*** should be taken as the higher of either the Building Stability Danger Rating or the Person Stability Danger Rating.

90. The categorisation of properties under Auckland Council's Voluntary Buy-out Support requires an assessment of the existing 1% AEP flood event. However, as is explained in section 5.3, the rainfall events of January and February 2023 have materially changed the statistical estimate of the 1% AEP rainfall depth in Auckland, which is now expected to be much larger than previously thought.

91. The consequence of this is that the inputs to the property categorisation flood risk assessment – being (a) the observed flooding during the 2023 events, and (b) predicted 1% AEP flood hazard, typically from a stormwater model – may or may not be representative of the flooding that would be expected under the revised 1% AEP rainfall. The observed rainfall may have been less than, approximately equal to, or larger than the new estimate of the 1% AEP event, while the predicted flood hazard may be based on a modelled rainfall profile that is less than or approximately equal to the new estimate of the 1% AEP event.

92. Figure 7 provides a process and a decision matrix for determining the Flood Danger Rating (and initial risk category) for the property from the assessed Building and Person Stability Danger Ratings for the observed and predicted events. The Flood Danger Rating can be determined for most combinations of inputs. However, there are some combinations where the rating cannot be determined because neither the Observed nor Predicted events are representative of the updated 1% AEP event. In these cases, additional analysis (e.g., manual estimation or updated modelling) will be needed to estimate the 1% AEP flood hazard.

4.8 What the Flood Danger Rating means

93. Auckland Council's Categorisation Approach states 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.

[17] The Stormwater Code of Practice requires that houses located in a floodplain have at least 500mm freeboard to the lowest habitable floor (refer SWCOP s.4.3.5.7).

94. The term "risk to life" is usually understood to mean the likelihood of death (and sometimes also serious injury), either for a specific individual (i.e., the likelihood of death for that specific individual) or in general (i.e., the likelihood of one or more people suffering a fatal outcome), and is usually discussed in terms of annualised individual fatality risk (i.e., the annual probability of death).

95. 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.

96. Thresholds for what is considered intolerable risk to life vary around the world and in different contexts. Table 1 presents some threshold values for annual individual fatality risk that have been broadly recognised in NZ and internationally, at least as indicators of the relative significance of risk to life. The thresholds are neither crisp nor rigid nor constant across all jurisdictions and are not overly endowed with either scientific provenance or moral justification. They are the product of varying approaches to determining the tolerability of risk, typically with heavy reliance on past experience and professional judgement of the trade-offs between the risks and benefits particular to a given situation. However, they do provide an indication of what has previously been considered the limit of tolerable risk in different times and places. (To put the values in Table 1 into perspective, Figure 11 compares different risks in the NZ context.)

Table 1. Some tolerability criteria for annual individual fatality risk

Annual Individual Fatality Risk	Tolerability
1-in-1,000 (10^{-3})	upper tolerable limit for workers (unacceptable for members of the public)
1-in-10,000 (10^{-4})	upper tolerable limit: › adopted by the UK Health and Safety Executive for members of the public › adopted by the Australian National Committee on Large Dams and the Australian Geomechanics Society for existing dams/ properties › adopted for protecting people near airport runways in the UK › adopted by Auckland Council for categorising properties subject to landslide risk
1-in-100,000 (10^{-5})	tolerable if as low as reasonably practicable (upper limit for new facilities)
1-in-1,000,000 (10^{-6})	lower tolerable limit (broadly acceptable)
1-in-10,000,000 (10^{-7})	negligible (broadly acceptable)

Sources: AICE (2009), EMSA (2015), HSE (2001), Taig et. Al. (2012), Auckland Council Categorisation Approach (30 October 2023).

97. Ideally – and for consistency with the approach being taken to the landslide risk assessments – the assessment of flood risk to life would produce a quantitative result that could be compared against quantitative thresholds such as those shown in Table 1. Figure 12, presents a conceptual model of risk to life for the property-level flooding scenarios relevant to this framework. Some variables in this model can be quantified relatively easily. For instance, the event likelihood or the likelihood of someone being at home at the time of flooding. But other variables are much more difficult to quantify in a pluvial context. Section 4.7 has already discussed the difficulties with anticipating what people will do when confronted with flooding on their property and therefore estimating evacuation rates. Estimating mortality rates from flooding in a pluvial context is also complicated[18]:

[18] See the review of international literature on factors affecting loss of life from flooding and approaches to estimating flood mortality in Appendix 3 for further detail.

a. Extensive international research into flood mortality rates has shown that the proportion of fatalities compared to the at-risk population is typically very small (Smith and Rahman 2016). Even for the most extreme events, including tsunamis and storm surges, mortality rates amongst those directly exposed are in the ranges of 20 – 40% (e.g., Bern 1993, and Central Disaster Management Council 2003 cited in Smith and Rahman 2016). Mortality rates for events where the flood depth is less than two metres tend to be very low, on the order of 0.001 (0.1% or $1x10^{-3}$) to 0.01 (1% or $1x10^{-2}$) as a proportion of the population directly exposed to the hazard (see Smith and Rahman 2016 for a comprehensive review).

b. Flood mortality rates established in the international literature are for flooding contexts very different to the urban pluvial flash flooding experienced in Auckland. They tend to be for large scale fluvial or coastal flooding events, or catastrophic flooding from tsunamis or dam breaches, involving flood depths over two metres. Mortality rates for shallow pluvial flooding in urban areas would be expected to be less than for these large-scale events.

c. There is little precedent for differentiating mortality values by flood depth. Mortality rates for those directly exposed (not evacuated, not in designated shelters) to flooding in New Orleans during Hurricane Katrina were estimated to be between 1 – 3% for flood depths up to five metres (Boyd, 2010), which is consistent with the "1% mortality" order-of-magnitude rule-of-thumb for coastal flood events proposed by Jonkman (2007). Flood hazard-differentiated values of mortality were originally proposed for the NIWA-developed RiskScape model (Reese and Ramsay 2010), however it is not clear how those values were derived. The human susceptibility and loss functions currently used in RiskScape utilise a Dutch-derived loss function combined with assumptions about rates of critical, serious, and moderate injuries (Crowley and Paulik 2017). The equations suggest combined mortality and serious injury rates of 2-3% for flood depths up to three metres in a fluvial / flood defence breach context.

d. There is no precedent for differentiating mortality by person vulnerability. The only relevant data on this found in the literature review was from Priest et. Al. (2007) who found that there was no statistically significant relationship between the percentage of the population with long term illness and fatalities from flooding, and that there was a negative relationship between the number of fatalities from flooding and the percentage of the population over 75 years of age. They postulated that the latter finding, which is somewhat counter-intuitive, may be due to the effect of evacuation protocols in the European context where areas with higher percentages of people over 75 years of age in the population would receive greater assistance for evacuation, thereby removing these people from the exposed population. (It should be noted that for severe, large-scale flooding, people vulnerability is not a determining factor for mortality rate; Priest et. Al., 2007).

e. 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).

98. 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. Therefore, in this framework, "risk to life" is represented by combination of the Flood event AEP (the annual probability of the event) 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.

99. The Flood Danger Rating is a qualitative expression of the perceived hazardousness of the peak flood situation on the property for the assessed event. That is:

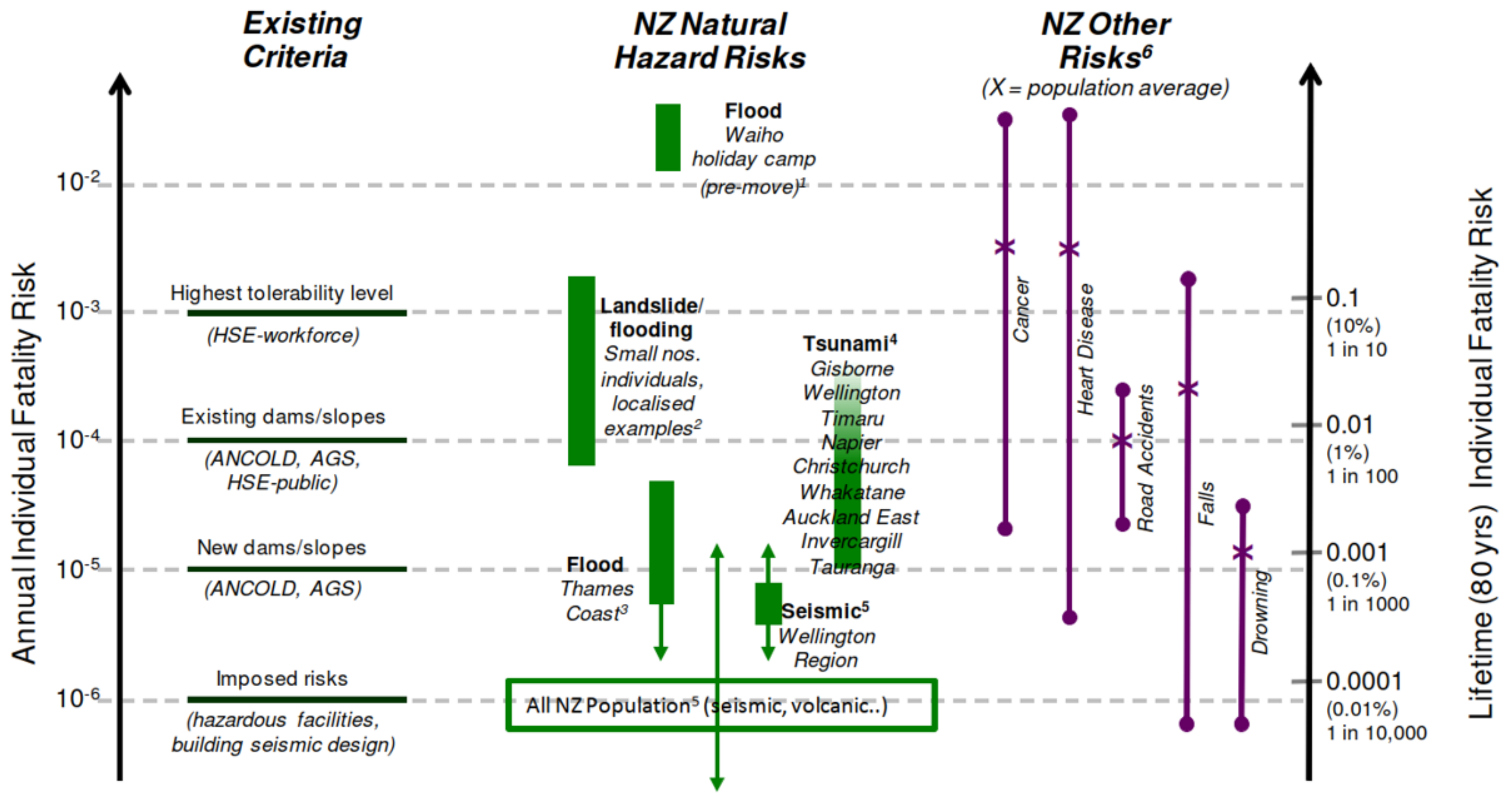
a. **Low Danger:** generally, not dangerous for all including vulnerable people.

b. **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.

c. **High or Extreme Danger:** Dangerous for vulnerable people, and may be dangerous for all, irrespective of what people decide to do.

100. However, the relationship between the Flood Danger Rating and risk to life is implied rather than definitive. The flood hazard thresholds (Figure 4) which underpin the Person Stability Danger Rating define empirically grounded zones of stability and instability for people adapted from Australian guidance. High flood hazard represents the depth and velocity of flow where people are likely to lose stability and be swept away. These situations are clearly dangerous in terms of their potential for harm, but the Danger Rating does not quantify that potential in terms of mortality. Similarly, the building stability categories of "severe structural damage" (Extreme Danger) and "structural instability" (High Danger) describe buildings that are unsafe to be in or around due to loss of structural stability and the consequent unpredictability of building behaviour under static and dynamic loads. The difference between the two is a matter of degrees and uncertainty in the perceived risk of "imminent collapse", but the potential for mortality is not quantifiable.

101. For the purposes of property categorisation, Danger Ratings of Extreme or High are considered to be intolerable at an Annual Exceedance Probability of 1% or greater. This is consistent with the standards for urban development in Auckland. Situations classified as High or Extreme Danger are dangerous, particularly for vulnerable people. 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.



Notes:

1. Derived by the authors from results of MCDEM risk assessment (Optimx, 2002)
2. Estimated by the authors based on reasonable event return periods and likely consequences - see Report Section 4.1.2
3. Upper estimate for High Risk zones; arrow denots wide range of risks downward (URS, 2003)
4. AIFR at 2-4m above sea level, no effectiveness assumed for warning (Webb, 2005)
5. Averages over large populations; arrows denote likelihood of substantial groups of people at higher/lower risk
6. Bars show range of values across age bands for men and women (Ministry of Health, 2008)

Source: *Figure 7 in Taig, T., Massey, C., Webb, T. 2012. Canterbury Earthquakes Port Hills Slope Stability: Principles and Criteria for the Assessment of Risk from Slope Instability in the Port Hills, Christchurch, GNS Science Consultancy Report 2011/319.*

Figure 11. Comparison of risks in the NZ context

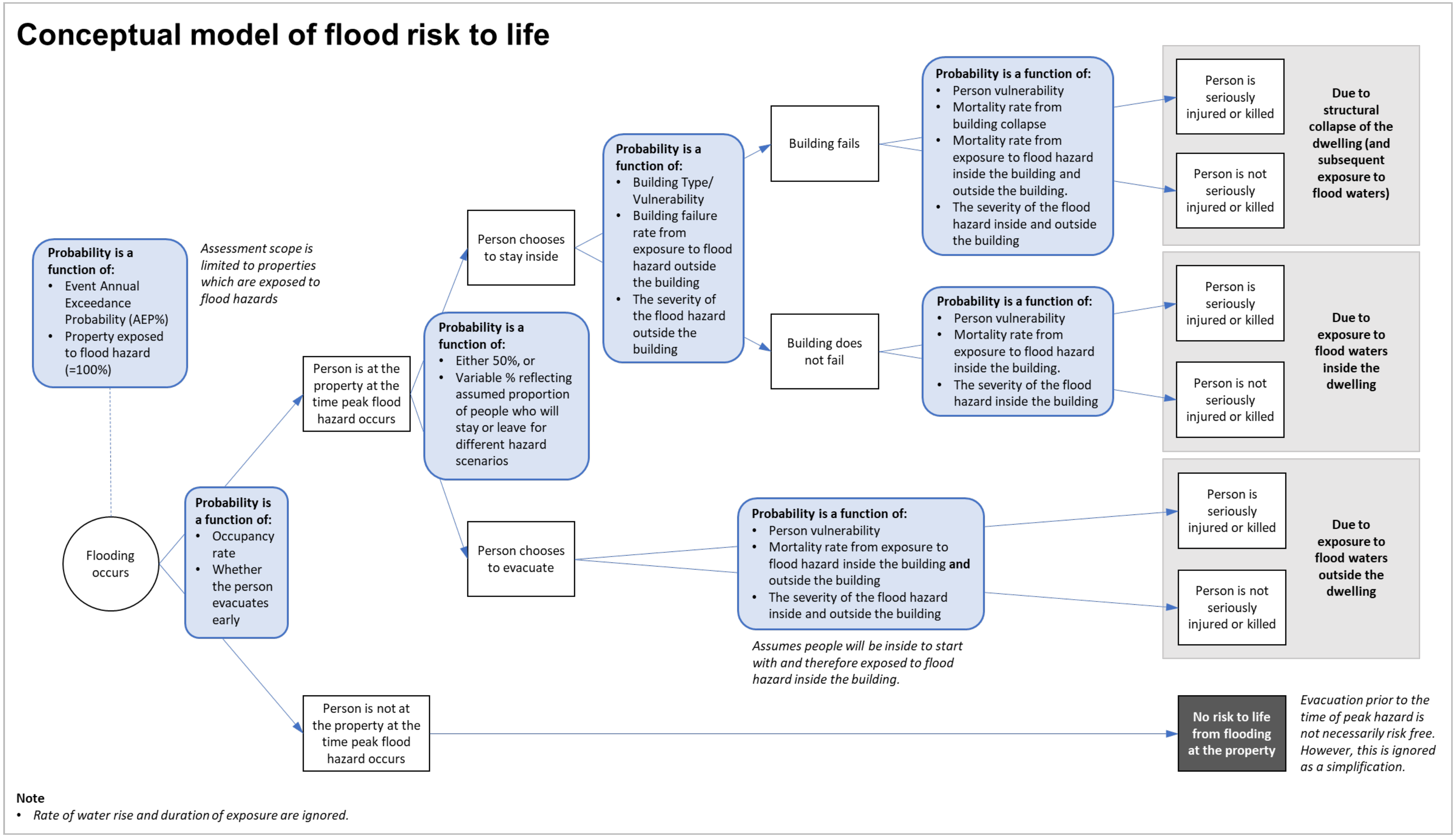


Figure 12. Conceptual model of flood risk to life

5 Considerations for application of the framework

102. 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. Section 5.1 highlights some inevitable sources of uncertainty that assessors need to contend with when carrying out risk assessments. Section 5.2 offers some principles, developed from experience, that may be applied to recognise and overcome uncertainty and achieve confidence in the assessment results.

103. 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. Section 5.3 addresses the practical implications of this for conducting flood risk assessments.

5.1 Sources of uncertainty in the flood risk assessments

104. Some inevitable sources of uncertainty must be considered when conducting the flood risk assessments, including incomplete, inaccurate, or uncertain input data, the limitations of the framework for classifying real-world situations, and results where the margin of error may be material to the outcome of the categorisation.

105. **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 sources of uncertainty. The following is a non-exhaustive list of possibilities:

   a. Reported flood levels and impacts may be influenced by extraneous factors, such as blockage of stormwater networks or overland flow paths, or unconsented development.

   b. Reliable modelled data for the Existing Development scenario may not be available[19].

   c. Rapid flood hazard assessment models may overestimate flood hazard due to simplifying assumptions (e.g., ignoring the piped stormwater network and pre-fill depression areas).

   d. Older stormwater models may underestimate flood hazard because they use outdated impervious area assumptions, sea level boundary conditions, or climate change or sea level adjustment factors.

   e. Estimates of flow velocity may not be available as an output from all stormwater models or may not be reliable.

   f. Ground and floor level measurements may have different levels of accuracy (e.g., LIDAR vs topographic survey), and internal floors, especially of older buildings, may not be completely level.

   g. Model predictions may be sensitive to input assumptions, e.g., soakage rates or how buildings, assets, and features are treated in the model.

[19] Where they exist, results from modelled future scenarios should be used with care if scaled or otherwise adjusted to approximate the existing scenario because the relationship between topography, rainfall, impervious area, and the resulting depth and velocity of flood hazard is highly idiosyncratic.

h. Model predictions may not be reliable in specific locations, even if the model is generally reliable. For instance, stormwater models may not adequately represent flood flows at the transition from 1-D channel flow to 2-D overland flow.

106. **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. However, not all real-world situations can be neatly and unambiguously classified in these terms. For instance, it has already been noted that application of the depth-velocity thresholds needs to be cognisant of real-world factors that will influence the threat that floodwaters pose to building stability (see section 4.5 and Figure 3) and people who may be trying to evacuate (see section 4.6.2 and Figure 4). Assessors will need think critically about unique circumstances on the ground that might not be adequately represented within the constraints of the assessment framework and therefore warrant special consideration.

107. **Contingent events:** In some cases, the specific situation that arose on a property during the events of January and February 2023 may have involved contingent events or environmental factors, such as diversion of overland flows, blockage of downstream infrastructure, or an evacuation route being blocked by a fallen tree or landslip. In general, the risk assessment should only consider the situation on the ground that would reasonably be expected under the defined flood conditions. Contingent events or environmental factors should not be taken into account unless it is expected that those events or factors would be likely to recur under the same or similar circumstances. Additional investigation and expert advice may need to be sought to determine this.

108. **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. Since the margin of error on the flood hazard estimates is not strictly quantifiable, these situations render the outcome of the risk assessment uncertain because the assessment team can't be confident about the final rating.

5.2 Principles for dealing with uncertainty

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

110. 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.

111. The hazard classification charts (Figure 3 and Figure 4) and the Danger Rating matrices (Figure 5) should be viewed as guides to aid decision making rather than rules to follow. Assessors will 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 as appropriate.

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

113. Where uncertainty is material to the outcome, such that the assessment cannot be determined on way or the other, further work is needed. The following questions are useful for identifying these situations and resolving the uncertainty:

a. Can we be 100% confident that the result is High/Extreme or Low / Moderate?

b. Are we inadvertently introducing bias or engaging in goal-seeking behaviour? If we are uncomfortable with the result, then why is that? Is it because we are uncertain about the result or because we don't like the result?

c. What are the sources of uncertainty on the inputs and analysis, and how material are they? How much could they impact the estimate and in which direction?

d. Have we done enough to be confident in the result? If the result were to be disputed, and we did further work, would the answer change?

e. What further data gathering, investigation, analysis, calculation, or cross-validation could be done to reduce uncertainty?

f. Is it possible to apply logic to infer where confidence should be placed even in the absence of calculation?

g. How confident are we that the value in question could not be greater than / less than X?

h. Is a value greater than / less than X still consistent / credible given everything else?

i. Is the result consistent / sensible when viewed in context of neighbouring properties or properties in other locations with similar characteristics?

5.3 Approach where the magnitude of the existing 1% AEP flood hazard is uncertain

114. Since 1999, rainfall profiles used for stormwater modelling and infrastructure design have been defined using the TP108 method, which was developed as a standardised approach for the calculation of stormwater flows in the Auckland Region (Auckland Regional Council 1999). The method produces a standardised 24-hour rainfall profile (the "design storm") for a given AEP based on two key inputs: the expected 24-hour rainfall depth for a given AEP and location in the Auckland Region and a standardised temporal rainfall pattern that distributes the total rainfall depth over 24-hours with peak intensity rainfall occurring at the mid-duration[20].

115. The expected 24-hour rainfall depth for a given location and AEP may be obtained from rainfall contour maps published in TP108[21] or from depth-duration-frequency (DDF) curves generated from statistical analysis of the historic rainfall record at any of Auckland's rain gauges. Conversely, the frequency (recurrence interval or AEP) of observed rainfall at a certain location may be determined by comparing the observed rainfall depth for the critical duration (time of concentration) relevant to

[20] The resulting design storm profile is referred to as "nested" because shorter duration rainfall bursts with a range of durations from 10 minutes to 24 hours are nested within the 24-hour temporal pattern, with the maximum intensity of rainfall for each duration having the same AEP. This means that, for any catchment, the TP108 24-hour design storm embeds the critical duration rainfall for a given AEP. The critical 1% AEP event is the rainfall depth accumulated over the time of concentration for a catchment that has a 1% probability of being exceeded in a year. The time of concentration is the critical duration of rainfall needed to generate maximum discharge at the catchment outlet, since all points in the catchment will be contributing to the flow at the outlet.

[21] Appendix A to TP108 contains contour maps of rainfall depth for average recurrence intervals (ARI) of 2, 5, 10, 20, 50 and 100 years based on an analysis of rainfall gauge data across the region (BCHF, 1999).

the catchment in question with the predicted rainfall depths for that location and critical duration, derived from either the TP108 method or at-site statistical analysis, over a range of AEPs.

116. 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, compared to TP108 (see Figure 13). In many places the magnitude of the exceedance was substantial, especially for longer durations. At Albert Park in Auckland Central, the observed rainfall depth was almost double that of the TP108 1% AEP rainfall at 120 min and 52% greater at 24 hours (see Figure 14). Cyclone Gabrielle, which occurred two weeks after the 2023 Auckland Anniversary Weekend event, was also well in exceedance of the TP108 1% AEP event for parts of the west coast of Auckland.

117. The rainfall events of January and February 2023 have materially changed the statistical estimate of the 1% AEP rainfall depth in Auckland (this is also shown in Figure 14). While updated DDF curves have been generated for 43 of Auckland's rain gauges that received exceedance rainfall during the 2023 events, the change in the statistical estimate of the 1% AEP event applies regionally. That is, the Auckland Region is now expected to receive a greater amount of rain in a 1% AEP event than previously thought. In the longer term, the 1% AEP rainfall contour maps will need to be revised for the whole of the Auckland region to reflect this.

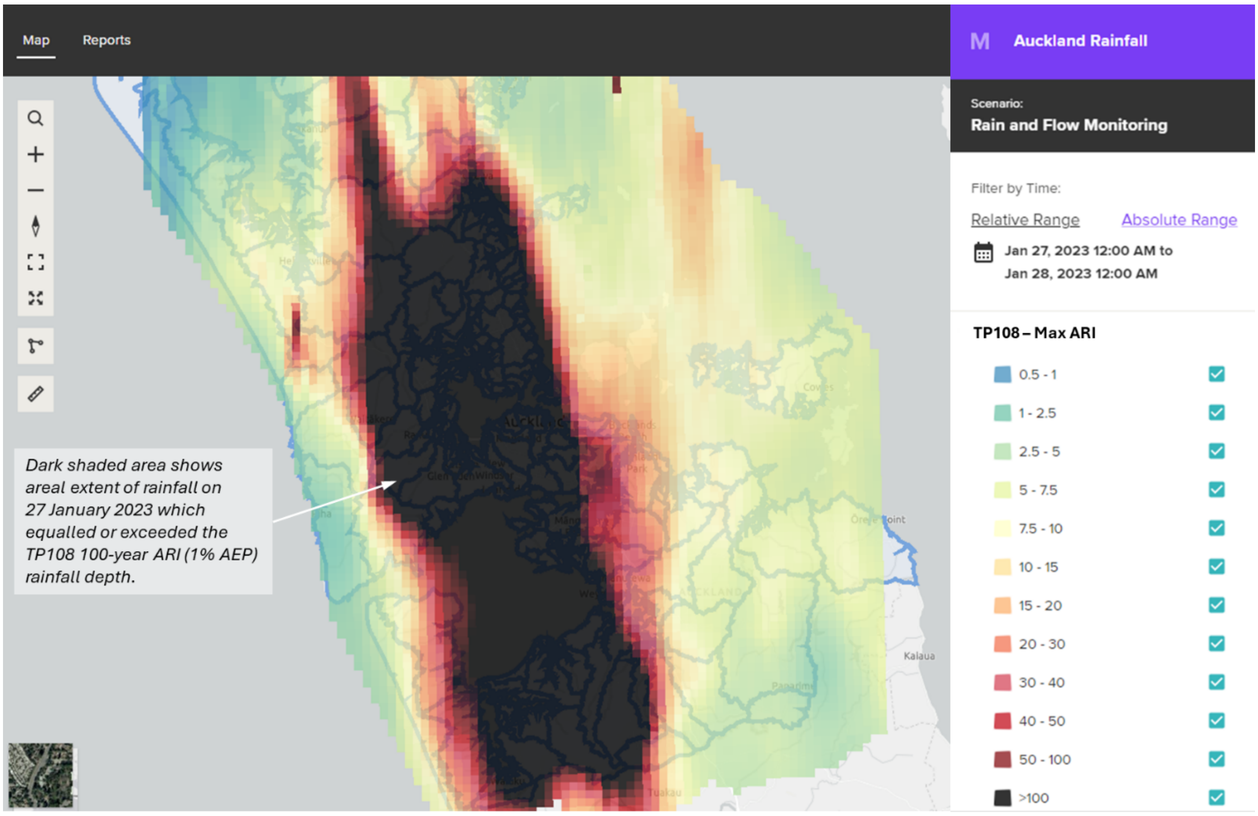


Figure 13. TP108 Max ARI across all durations, 27 January 2023

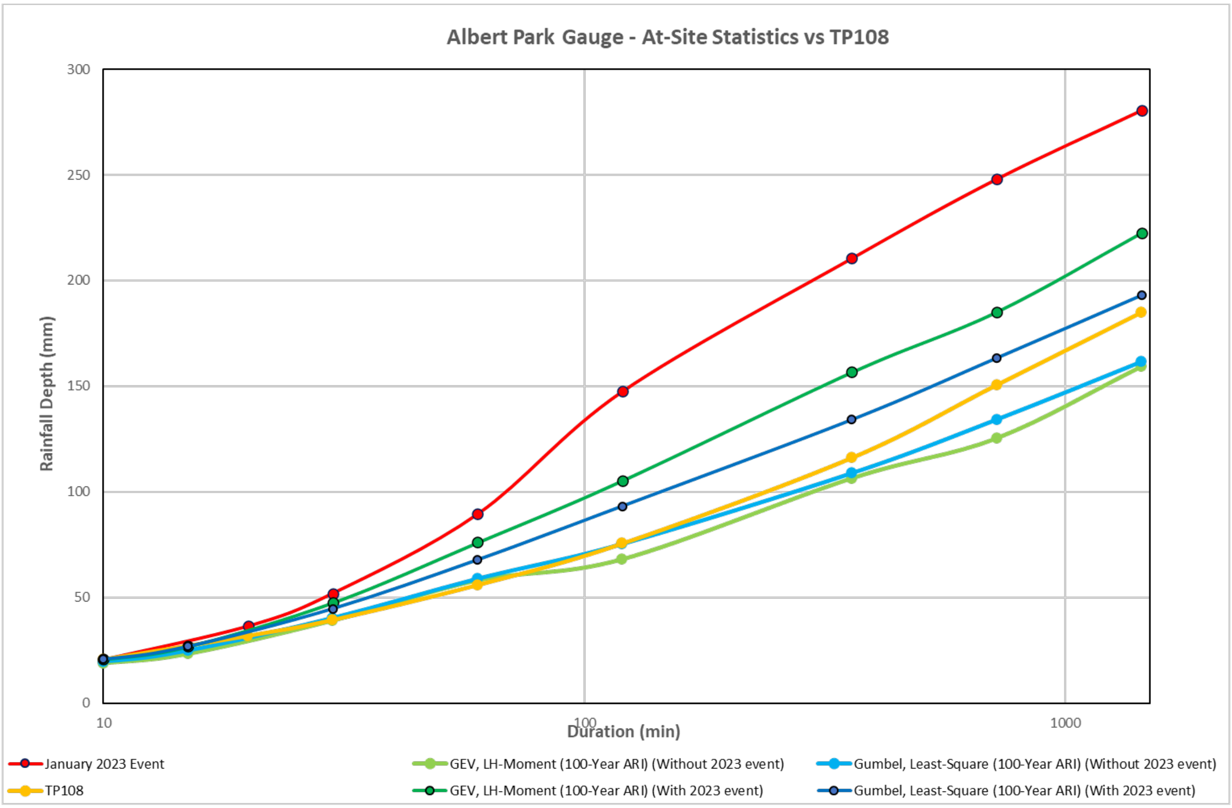


Figure 14. Depth-duration curves for Albert Park, Auckland Central, showing rainfall on 27 January 2023 vs TP108 1% AEP rainfall vs updated extreme value estimates of the 1% AEP rainfall

118. The categorisation of properties under the recovery scheme requires an assessment of the risk to life to vulnerable people in an existing 1% AEP flood event. For each eligible property, the estimate of the AEP of the rainfall received by the relevant catchment during the 2023 events is a key input to the property risk assessment. The AEP of the observed rainfall may be estimated, for the catchment critical duration, by comparison against the extant TP108 rainfall profiles and/or the updated rain gauge DDF curves, meaning there are two potentially different estimates of the event magnitude:

   a. Less than, approximately equal to, or greater than 1% AEP based on TP108, and/or

   b. Less than, approximately equal to, or greater than 1% AEP based on updated DDF curves.

119. Frequently, the AEP of the observed rainfall for the relevant catchment is much greater or less than 1%. This means that, while the observed flooding can be assessed for comparison, it can't always be used as the basis for the property risk assessment because it doesn't represent the existing 1% AEP event.

120. It was initially assumed that Auckland Council's stormwater models would be used to inform the property risk assessments in these cases. However, while the existing 1% AEP event has been modelled for most Auckland catchments, existing stormwater models are based on 1999 TP108 rainfall profiles and so do not represent the flooding that would be expected under the revised 1% AEP rainfall. In other words, the existing stormwater models no longer represent the existing 1% AEP flood (and this affects all Auckland stormwater models, not just those for the areas that experienced exceedance rainfall during the 2023 events)[22]. While Auckland's stormwater models will be updated and revalidated for the uplifted 1% AEP rainfall, the time and resources required mean that this can't

[22] The knowledge that the 1% AEP rainfall depth has changed renders existing models out of date even if the actual magnitude of that change is not yet known for all locations in the Auckland region.

be achieved within the timeframes of the severe weather recovery programme. This means that, for properties where the observed rainfall was significantly less than or greater than 1% AEP, Council does not have a reliable (i.e., high confidence) basis on which to estimate the 1% AEP flood hazard because neither the observed flooding nor existing stormwater models represent the flooding expected under the revised 1% AEP rainfall.

121. For eligible properties where Council does not have a high confidence estimate of the updated existing 1% AEP flood hazard, then Council will need to apply the principles for dealing with uncertainty articulated in section 5.2. In some cases this may mean that further work may be required, such as undertaking additional analysis to manually estimate the 1% AEP flood hazard.

122. The flow chart in Figure 7 maps out the practical steps for making the initial categorisation decision – i.e., whether the property is Category 1 (Tolerable Risk) or Category 2A (Intolerable Risk) – including in situations where high confidence estimates of the updated existing 1% AEP flood hazard are not available. The process includes a Decision Matrix which provides guidance for determining the property category based on the combination of the Danger Ratings for the observed and predicted flood events.

123. Some landowners may wish to dispute the categorisation of their properties. In these cases, the onus should be on the landowner (rather than Council) to provide additional evidence supporting a recategorization. However, Council should be able to demonstrate that it has done what it is reasonably able to do within constraints to identify and consider the best available sources of information and reach an informed professional judgement as to whether the flood hazard that the property would likely be exposed to in a 1% AEP event results in an intolerable risk to life.

References

AGS. (2007). Practice Note Guidelines for Landslide Risk Management. Australian Geomechanics Society Landslide Taskforce, Landslide Practice Note Working Group.

AICE. (2009). Guidelines for Developing Quantitative Safety Risk Criteria, Appendix B Survey of Worldwide Risk Criteria Applications. American Institute of Chemical Engineers.

AIDR (2017a). Australian Disaster Resilience Handbook 7 Managing the Floodplain: A Guide to Best Practice in Flood Risk Management in Australia. Australian Institute for Disaster Resilience.

AIDR (2017b). Australian Disaster Resilience Guideline 7-3 Flood Hazard. Australian Institute for Disaster Resilience.

ANZSPED. (2023). Australian and New Zealand Growth Charts (for boys and girls in Australia and New Zealand). Australia and New Zealand Society for Paediatric Endocrinology and Diabetes. https://anzsped.org/clinical-resources-links/growth-growth-charts/

Auckland Council (2015). Topic 022 Natural Hazards and Flooding and Topic 026 General – Closing Remarks on Behalf of Auckland Council Relating to Flooding, 21 April 2015. https://hearings.aupihp.govt.nz/online-services/new/files/6XYMrW4yUdwxXNIw7nmFsD86RtEdjLpRZTeDIicsA6XY

Auckland Council Healthy Waters Position Paper – Justifying Council-led reduction of existing flood risk (September 2022)

Auckland Council Stormwater Code of Practice. The Auckland Code of Practice for Land Development and Subdivision, Chapter 4: Stormwater, Version 3.0, January 2022.

Auckland Council Stormwater Modelling Specification (2011)

Auckland Council Survey Specification (ACS1530.5.4.1)

Auckland Regional Council (1999). Guidelines for Stormwater Modelling in the Auckland Region. Technical Publication No. 108, April 1999

Auckland Unitary Plan, s.E36 Natural Hazards and Flooding

Auckland Unitary Plan, Chapter J Definitions

Australian Geomechanics Society (2007). Practice Note Guidelines for Landslide Risk Management. https://landsliderisk.org/wp-content/uploads/2017/04/ags_2007c2.pdf

Ball J, Babister M, Nathan R, Weeks W, Weinmann E, Retallick M, Testoni I, (Eds). 2019. Australian Rainfall and Runoff: A Guide to Flood Estimation, Book 1 – Scope and Philosophy, Commonwealth of Australia (Geoscience Australia).

BCHF. (1999). Methods of Analysis for Stormwater Management Design: Guidelines Preparation Stage, prepared for Auckland Regional Council by Beca Carter Hollings & Ferner Ltd., April 1999.

Becker, J. S., et. al. (2015). A Review of People's Behaviour in and around Floodwater. Weather, Climate and Society, 7(4), 321–332. https://doi.org/10.1175/WCAS-D-14-00030.1

Bern, C., Sniezek, J., Mathbor, G.M., Siddiqi, M.S., Ronsmans, C., Chowdhury, A.M.R., Choudhury, A.E., Islam, K., Bennish, M., Noji, E., and Glass, R.I. (1993). Risk factors for mortality in the Bangladesh cyclone of 1991. Bulletin of the World Health Organization, 71 (1): 73-78 (1993).

Boyd, E. C. (2010). Estimating and mapping the direct flood fatality rate for flooding in greater New Orleans due to Hurricane Katrina. Risk, Hazards & Crisis in Public Policy, 1(3), 91-114.

Brazdova, M., and Riha, J. (2014). A simple model for the estimation of the number of fatalities due to floods in central Europe. Nat. Hazards Earth Syst. Sci., 14, 1663–1676, 2014.

Cardona, O.D., M.K. van Aalst, J. Birkmann, M. Fordham, G. McGregor, R. Perez, R.S. Pulwarty, E.L.F. Schipper, and B.T. Sinh, 2012: Determinants of risk: exposure and vulnerability. In: Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation [Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (eds.)]. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press, pp. 65-108.

Central Disaster Management Council. (2003). Risk assessment results of Tokai-Tonankai-Nankai earthquake disaster, Cabinet Office, Government of Japan, Tokyo.

Cox, R. J., Shand, T. D., and Blacka, M. J. (2010). Australian Rainfall and Runoff Revision Project 10: Appropriate Safety Criteria for People, Stage 1 Report. ARR Report P10/S1/006. Engineers Australia.

Crowley, K., and Paulik, R. (2017). Methods for Estimating Human Loss and Susceptibility to Flood Hazards in RiskScape. NIWA Client Report WN-2017-110 CARW1603

de Bruijn, K. M., Klijn, F., van de Pas, B., and Slager, C. T. J. (2015). Flood fatality hazard and flood damage hazard: combining multiple hazard characteristics into meaningful maps for spatial planning. Natural Hazards Earth Systems Science Discussions, 3, 123-159. www.nat-hazards-earth-syst-sci-discuss.net/3/123/2015/

Dean, S. (2022). Temperature Projection Guidance for Auckland Council Healthy Waters. Report prepared for Auckland Council, October 2022. NIWA.

EMSA. (2015). Risk Acceptance Criteria and Risk Based Damage Stability. Final Report, part 1: Risk Acceptance Criteria, European Maritime Safety Agency, EMSA/OP/10/2013, Report No.: 2015-0165.

H R Wallingford Ltd (2006). Flood Risks to People Phase 2 FD2321/TR1, The Flood Risks to People Methodology. Department for Environment, Food and Rural Affairs, UK.

HSE. 2001. Reducing risk, protecting people (R2P2). UK Health and Safety Executive.

Jonkman, S. (2007). “Loss of Life Estimation in Flood Risk Assessment: Theory and Applications.” Ph.D. dissertation, Delft University.

Jonkman, S. N., Vrijling, Æ J. K., and Vrouwenvelder. Æ A. C. W. M. (2008). Methods for the estimation of loss of life due to floods: a literature review and a proposal for a new method. Natural Hazards (2008) 46:353–389

McComb, I. R. (2016). Urban Flow Design Level of Service - Setting the Standard. Water New Zealand Stormwater Conference 2016.

Ministry for the Environment (2022). Aotearoa New Zealand’s first national adaptation plan. Wellington. Ministry for the Environment.

NSW Department of Planning and Environment (2023). Flood Risk Management Guide FB01. Understanding and managing flood risk.

NSW Department of Planning and Environment (2022). Flood Risk Management Guide FB03. Flood Hazard.

Olesen, L., Löwe, R., & Arnbjerg-Nielsen, K. (2017). Flood damage assessment – Literature review and recommended procedure. Cooperative Research Centre for Water Sensitive Cities.

https://watersensitivecities.org.au/wp-content/uploads/2017/03/IN_PC956_B4-1_Flood_Damage_web.pdf

Priest, S., Wilson, T., Tapsell, S., Penning-Rowsell, E., Viavattene, C. and A. Fernandez-Bilbao (2007). Building a model to estimate Risk to Life for European flood events. Floodsite Final Report, T10-07-10. Sixth Framework Programme for European Research and Technological Development (2002-2006).

Reese, S. and Ramsay, D. (2010). RiskScape: Flood fragility methodology. Report prepared for New Zealand Climate Change Research Institute, Victoria University of Wellington. NIWA Technical Report: WLG2010-45. National Institute of Water & Atmospheric Research.

Report and Decisions of the Hearing Commissioners IN THE MATTER of the Resource Management Act 1991 AND IN THE MATTER of Proposed Plan Change 1 to the Whakatāne District Plan and Proposed Plan Change 17 to the Bay of Plenty Regional Natural Resources Plan. https://atlas.boprc.govt.nz/api/v1/edms/document/A3510192/content

Smedley, R. (2022). Flood risk to people by depth – velocity (DxV). Auckland Council Healthy Waters, May 2022, Draft paper.

Smith, G. P. (2015). Expert Opinion: Stability of People, Vehicles and Buildings in Flood Water. University of New South Wales Water Research Laboratory, WRL Technical Report 2015/11.

Smith, G. P., Davey, E. K., and Cox, R. J. (2014). Flood Hazard. University of New South Wales Water Research Laboratory, WRL Technical Report 2014/07, pp 28, 34-36.

Smith, G. P. and Rahman, P. F. (2016). Approaches for Estimating Flood Fatalities Relevant to Floodplain Management. University of New South Wales Water Research Laboratory, WRL Technical Report 2015/09. September 2016.

Storey, B., Owen, S., Noy, I. & Zammit, C. 2020. Insurance Retreat: Sea level rise and the withdrawal of residential insurance in Aotearoa New Zealand. Report for the Deep South National Science Challenge, December 2020

Statistics New Zealand. (2013). Disability Survey: 2013.

Taig, T., Massey, C., Webb, T. 2012. Canterbury Earthquakes Port Hills Slope Stability: Principles and Criteria for the Assessment of Risk from Slope Instability in the Port Hills, Christchurch, GNS Science Consultancy Report 2011/319.

Thomas, J. (2023a). Flood evacuation behaviour – Do people intentionally evacuate upstairs? Memo from WSP Research and Innovation Centre, File Ref 3-awd30.92, 15 September 2023.

Thomas, J. (2023b). Floods and individual survivability based on flood characteristics. Memo from WSP Research and Innovation Centre, File Ref 3-awd30.92, 19 October 2023.

Tonkin and Taylor Ltd. (2015). Supplementary Risk Assessment Debris Flow Hazard Matata, Bay of Plenty. Report prepared for Whakatane District Council. (T&T Ref: 29115.2000).

Yari, A., Ostadtaghizadeh, A., Ardalan, A., Zarezadeh, Y., Rahimiforoushani, A., and Bidarpoor, F. (2020). Risk factors of death from flood: Findings of a systematic review. Journal of Environmental Health Science and Engineering (2020) 18:1643–1653.