Active Fault Guidelines v2.0 – Proof of Concept

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ABSTRACT

Since 2003, land-use planning for active faults in Aotearoa New Zealand under the Resource Management Act 1991 (RMA) has generally been guided by the *'Planning for development of land on or close to active faults'* guidelines published by the Ministry for the Environment (hereafter the 'MfE Active Fault Guidelines' or 'the guidelines') (Kerr et al. 2003). In that time, Aotearoa New Zealand has experienced a number of major earthquakes, including those during the 2010/11 Canterbury Earthquake Sequence and the Kaikōura earthquake in 2016. Land-use planning for natural hazards has also evolved, with a risk-based approach now considered to be best practise. However, while land-use planning for natural hazards has progressed significantly over recent decades, it remains challenging to manage the potential impacts of hazards such as fault rupture, which typically have high consequences but long return periods or recurrence intervals. In the absence of legislation that mandates for active faults to be considered in planning documents, it can prove difficult to restrict development rights in response to a hazard that is perceived as only occurring every 1000 or more years. With increasing need for housing in our cities, there is also increasing pressure to allow for the development of land above and adjacent to active faults.

As such, this 'proof of concept' project sought to consider whether the guidelines are still fit for purpose or if there are potential amendments that might achieve improved land-use planning outcomes for active fault rupture. In particular, the authors were interested to test whether the assigning of a probability to surface fault rupture (as is done for many other natural hazards) had the potential to better convey the risk associated with low-likelihood, high-consequence hazards such as fault rupture to decision-makers and the public, resulting in improved visibility and land-use planning decisions.

This was done by:

- Considering the lessons learnt from the Canterbury and Kaikōura earthquakes and any implications of these lessons on the framework provided in the guidelines.
- Undertaking a stocktake of the implementation of the existing guidelines, particularly in the Wellington region, and any limitations or challenges experienced.
- Examining international land-use planning approaches to manage active fault hazards.
- Exploring the use of rupture probabilities as a potential pathway to increase the political and community understanding of the risk associated with these low-likelihood but high-impact events.
- Inserting rupture probabilities into a risk-based framework using a case study of selected active faults in the Wellington region to test for perverse outcomes.

What was found is that there is merit in assigning a probability of rupture to align with planning timeframes employed for other natural hazards and to allow decision-makers a clearer comparison of the risk posed with that of other hazards. However, initial findings suggest that, while this approach shows potential for well-known faults where conditional probability is based on extensive scientific investigation, it may not work as well for lesser-known faults. For the purposes of this study, Recurrence Interval Class (RIC) boundaries were re-cast as 100-year likelihoods and Annual Exceedance Probabilities (AEP) in lieu of conditional probabilities for lesser-known faults. The testing indicated that this approach can result in a less-nuanced planning outcome than provided for under the MfE Active Fault Guidelines. Further testing of the use of rupture probabilities based on RIC is needed for these lesser-known faults.

One option that was considered was a hybrid approach, where the risk is assessed based on both the RIC and probability of rupture and the most onerous outcome from the two assessments applied. In this way, the risk posed by faults with a long recurrence interval but a high 100-year conditional probability of rupture would be better captured in land-use planning decisions. However, care needs to be taken to not create the perverse outcome whereby, once the fault has ruptured, the rupture probability reduces to such a low likelihood that the planning framework allows for structures to be built across active faults. Past planning decisions have demonstrated that, once buildings are permitted to be constructed on hazard-prone land, it is difficult to reverse, so a precautionary approach needs to be applied. It is recognised that significant advances are being made in seismic engineering, such that constructing buildings over faults may become acceptable provided appropriate mitigation measures are employed. However, at this time, defining fault avoidance and awareness zones is still considered to be the best method for ensuring the safety of people and structures.

KEYWORDS

Active faults, Ministry for the Environment, earthquake, surface fault rupture, rupture probability, risk-based planning, fault avoidance zone, fault awareness area

1.0 INTRODUCTION

Aotearoa New Zealand straddles the boundary between the Pacific and Australian tectonic plates and, as a consequence, is one of the most seismically active countries in the world. Earthquakes are generated by the sudden rupture of the Earth's crust, resulting from the release of accumulated stresses (NZGS and MBIE 2016). When earthquakes are large and/or shallow, the fault rupture may intersect with the ground surface and result in several metres of lateral and vertical offset. The extent of ground deformation associated with the rupture varies and is dependent on the type of fault and the depth and nature of surface soils (NZGS and MBIE 2016). If these areas of surface fault rupture and deformation intersect with buildings and infrastructure, the damage can be significant.

Experience both internationally and in Aotearoa New Zealand shows that buildings constructed over active fault traces will be subjected to significantly more damage than adjacent buildings (King et al. 2003). Land-use planning is a non-structural measure for managing the risk posed to buildings from surface fault rupture by controlling development in these areas. To support local authorities in this role, the MfE Active Fault Guidelines were published in 2003 to assist planning for development of land on, or close to, active faults (Kerr et al. 2003).

It has now been almost two decades since the MfE Active Fault Guidelines were published. During this time, Aotearoa New Zealand has experienced and learnt from both the 2010/11 Canterbury Earthquake Sequence and the Kaikōura Earthquake in 2016. There have also been amendments to the Resource Management Act 1991 that have emphasised the need for the management of significant risks from natural hazards (section 6h), which has resulted in further development of risk-based land-use planning approaches such as those advocated by the guidelines.

While land-use planning for natural hazards has generally been strengthening over recent decades, low-likelihood natural hazards with high consequences, such as fault rupture, are still not adequately recognised in planning documents (Sullivan-Taylor et al. 2022). In the absence of legislation that mandates for this, the prevailing view both within local council authorities (particularly politically) and communities is why restrict development based on an event that may not occur in a person's lifetime.

In an attempt to address this view, what is tested here is the assigning of a probability to surface fault rupture to better convey the risk posed and allow it to be compared to the risk faced from other natural hazards, with the aim that it may ultimately result in better land-use planning decisions.

This report is structured as follows:

- Section 1: Introduction
- Section 2: Legislative Context for Managing Active Faults

  Identifies the current legislation under which natural hazards, including fault rupture, are managed in Aotearoa New Zealand.
- Section 3: MfE Active Fault Guidelines

  Summarises the approach presented by the MfE Active Fault Guidelines and amendments to the approach since 2003 that have been made in practise, along with a summary of the lessons learnt from surface-rupture events here in Aotearoa New Zealand. Identified limitations and challenges with implementing the guidelines are then highlighted.

- Section 4: International Practise

  Considers the management of surface fault rupture in other seismically active countries to understand any learnings that could be applied in Aotearoa New Zealand.

- Section 5: Assigning a Probability to Fault Rupture

  The practicality of assigning a probability to fault rupture is explored as a proof of concept as the basis for a wider review of the guidelines.

- Section 6: Incorporating Rupture Probabilities into a Risk-Based Planning Framework

  A summary of risk-based planning approaches is provided. The assigning of rupture probabilities into a risk-based planning framework is then tested for practicality and the potential for perverse outcomes.

- Section 7: Summary.

2.0 LEGISLATIVE CONTEXT FOR MANAGING ACTIVE FAULTS

Natural hazards are managed in Aotearoa New Zealand by a number of statutes, with the five key pieces of legislation being the Resource Management Act 1991 (RMA), Building Act 2004, Civil Defence Emergency Management Act 2002 (CDEMA), Local Government Act 2002 (LGA) and the Local Government Official Information and Meetings Act 1987 (LGOIMA). Those of specific relevance to land-use planning for active faults are the RMA and the Building Act, with the role of each briefly described below.

2.1 Resource Management Act 1991

The RMA is the principal environmental statute in Aotearoa New Zealand, the purpose of which is to promote the sustainable management of natural and physical resources. This includes enabling people and communities to provide for their social, economic and cultural wellbeing and for their health and safety.

The RMA is implemented through a hierarchy of planning instruments, with National Policy Statements (NPS) and National Environmental Standards (NES) sitting at the highest level, followed by regional Policy Statements (RPS), regional plans and, finally, district plans (Saunders et al. 2007). An RPS must state the significant resource management issues for the region, and objectives, policies and methods (excluding rules) to implement the policies. Regional and district plans must give effect to the RPS.

In response to the devastating effects of the 2010/11 Canterbury Earthquake Sequence, the RMA was amended in 2017 to include the management of significant risks from natural hazards as a matter of national importance under section 6(h), and one that decision-makers must recognise and provide for. Amendments were also made to allow consent authorities to decline an application for resource consent for subdivision (note: not land use) if it considers that there is a significant risk from natural hazards or to grant it subject to conditions in this regard. While ‘significant risk’ is not defined in the RMA, section 106(1A) does provide matters to consider when assessing if the risk is significant (specifically in relation to subdivision), these being:

> *(a) the likelihood of natural hazards occurring (whether individually or in combination); and*
>
> *(b) the material damage to land in respect of which the consent is sought, other land, or structures that would result from natural hazards; and*
>
> *(c) any likely subsequent use of the land in respect of which the consent is sought that would accelerate, worsen, or result in material damage of the kind referred to in paragraph (b).*

In this way, through the requirement to consider both the likelihood and consequences of a natural hazard event, a risk-based approach (as discussed more in Section 6) has been implicitly introduced into the RMA.

2.1.1 Resource Management Act Reforms

The Government has proposed to repeal and replace the RMA with three separate Acts, these being the Natural and Built Environment Act (NBA), the Spatial Planning Act (SPA) and the Climate Adaptation Act (CAA).

An exposure draft of the NBA has been released that outlines a fundamental shift away from managing effects (as is the focus of the RMA) to specifying environmental limits and outcomes. In terms of natural hazards, Section 8(p) of the exposure draft identifies the reduction of significant risks and increased resilience to the effects of natural hazards and climate change as key environmental outcomes, with the accompanying requirement to apply a precautionary approach to these matters (Section 16).

A National Planning Framework will be developed under the NBA and will contain nationally set environmental limits and provisions to achieve the prescribed outcomes. The framework will feed into the Regional Spatial Strategy (RSS) prepared under the SPA that will (in part) identify areas that are susceptible to the effects of natural hazards and climate change. The RSS is to be informed by robust information and evidence, including mātauranga Māori. The NBA also includes a new process for plan-making where the RPS and regional and district plans will be replaced by one Natural and Built Environments Plan for each region. The CAA will seek to address the complex issues associated with managed retreat and the funding and financing of adaptation. Therefore, while the content and subsequent impact of the reforms remains unclear, the exposure draft of the NBA clearly indicates that the reduction of significant natural hazard risk, including from fault rupture, will be emphasised at the national level.

2.2 Building Act 2004

In conjunction with the RMA, the Building Act 2004 and the Building Code regulations established under it are instrumental in managing the effects of fault rupture. Where the RMA seeks to manage the effects of land-use activities and subdivision, the Building Act and Building Code are focused on ensuring the safety of any building constructed for its intended lifetime, being not less than 50 years unless otherwise specified.

The Building Code is a performance-based regulation and therefore states how a building must perform in its intended use and lifespan rather than specifying how it must be designed and constructed. This encourages innovation, as, in practise, as long as the requirements of the Building Code are met, a building can be designed and constructed in any number of different ways. However, in general, buildings are designed based on a range of verification methods that are cited within the Code. In relation to seismic hazard, Loading Standard AS/NZS 1170.5:2004 is identified as a verification method for compliance with the Building Code (MBIE 2014). This Standard requires that residential buildings are constructed to withstand an earthquake with a 500-year return period, which equates to a 10% probability of occurrence if a building has a design life of 50 years, while critical facilities that have a vital post-disaster role such as hospitals must be designed to withstand a 2500-year earthquake event (2% chance of occurring in 50 years) (Saunders et al. 2013).

2.2.1 National Seismic Hazard Model

The New Zealand National Seismic Hazard Model (NSHM) calculates the likelihood and strength of earthquake shaking that will occur in different parts of Aotearoa New Zealand in an earthquake event and underpins the seismic performance requirements in the Building Code (Building Performance 2020). The NSHM has recently been revised by GNS Science to reflect advances in scientific knowledge and best practise, particularly as a result of the Canterbury Earthquake Sequence and Kaikōura earthquake. It is noted that the updates to the NSHM may result in future revisions of the Building Code and the Loading Standards.

3.0 MFE ACTIVE FAULT GUIDELINES

3.1 Introduction

The MfE Active Fault Guidelines remain the primary guidance document to assist land-use planners in Aotearoa New Zealand to manage the hazard posed by ground-surface fault rupture and ground deformation. However, they do not address ground shaking, which is covered by the Building Code. In Aotearoa New Zealand, an active fault is defined as a fault that shows evidence of surface rupture or ground deformation within the last 125,000 years and that paleoseismic evidence indicates is likely to rupture again (Kerr et al. 2003; Langridge et al. 2016). The guidelines adopt a risk-based approach to dealing with development on, or close to, active faults based on four principles:

1. Gather accurate active-fault hazard information.
2. Plan to avoid the fault-rupture hazard prior to subdivision (greenfield sites).
3. Take a risk-based approach in areas already subdivided or developed.
4. Communicate risk in built-up areas subject to fault rupture.

Following these principles, the first steps in the MfE Active Fault Guidelines are to identify the location of active faults and establish fault avoidance zones (FAZ) around them where mapping to a scale of ≤1:10,000 has been completed. The MfE Active Fault Guidelines recommend a minimum setback zone of at least 20 m either side of the fault trace or likely deformation zone, which can be reduced if site-specific investigations can further constrain the fault location and width of the deformation zone.

Within a FAZ, a risk-based planning approach should then be applied, where risk is a function of three factors:

1. Fault recurrence interval – how often the fault ruptures the ground surface.
2. Fault location and complexity – the likely rupture and deformation zone, as used to determine the appropriate width of a FAZ.
3. Building Importance Category – the type of building and activity that is proposed within a FAZ.

Each of these factors are summarised briefly below; refer to Kerr et al. (2003) for a comprehensive explanation.

3.1.1 Fault Recurrence Interval

The fault recurrence interval is the average time in years between each successive surface rupture on that fault and is used to represent the likelihood of rupture of a particular fault (King et al. 2003). While there is always a degree of uncertainty in the assessment of fault recurrence intervals, this is constrained where faults are reasonably active and there is sufficient paleoseismic (i.e. trenching) data on the timing and nature of past movements (King et al. 2003). The fault Recurrence Interval Classes (RIC) in the MfE Active Fault Guidelines are defined based on metre-scale fault rupture, as these are the events that are large enough to pose a significant risk to life and property (Litchfield et al. 2010).

3.1.2 Fault Complexity

Fault complexity refers to the pattern of rupture and/or the level of certainty of the location of the fault (King et al. 2003). The guidelines describe fault complexity as well-defined, distributed or uncertain. These descriptions of fault complexity can be extended where there are particular fault-trace complexities to include well-defined extended, uncertain constrained and uncertain poorly constrained (Table 3.1).

Table 3.1 Descriptors of fault complexity (Van Dissen and Heron 2003; Litchfield et al. 2020).

Fault Complexity	Definition
Well-defined	Fault rupture deformation is well defined and of limited geographic width (e.g. metres to tens of metres wide).
Well-defined extended	Fault-rupture deformation has been either buried or eroded over short distances, but its position is tightly constrained by the presence of nearby distinct fault features.
Distributed	Fault-rupture deformation is distributed over a relatively broad, but defined, geographic width (e.g. tens to hundreds of metres wide), typically as multiple fault traces and/or folds.
Uncertain constrained	Areas where the location of fault rupture is uncertain, because evidence has been either buried or eroded, but where the location of fault rupture can be constrained to a reasonable geographic extent (≤300 m).
Uncertain poorly constrained	The location of fault-rupture deformation is uncertain and cannot be constrained to lie within a zone <300 m wide, usually because evidence of deformation has been either buried or eroded away or the features used to define the fault's location are widely spaced and/or very broad in nature.

Understanding the complexity of the fault will directly impact upon the width of the FAZ, as a wide and complex fault-rupture zone will also have a wide FAZ. The width of the FAZ can also vary along the length of a fault trace, reflecting the level of certainty in the understanding of the complexity of the fault.

Advances in technology now mean that the location of active faults can be more accurately mapped using Light Detection and Ranging (LiDAR) surveys of the land surface. However, uncertainty can still be introduced in terms of the capture and digitising of the data and also how accurately the fault feature and its complexity can be identified from a geomorphic study (Langridge and Ries 2014). How this uncertainty can affect the final FAZ width is demonstrated in Figures 3.1 and 3.2. In the example below, for a fault that is accurately located and mapped using LiDAR, a buffer of ±10 m is applied each side of the fault location to account for uncertainty and then, to create the final FAZ, an additional +20 m buffer is added to each side to result in a total FAZ width of 60 m.

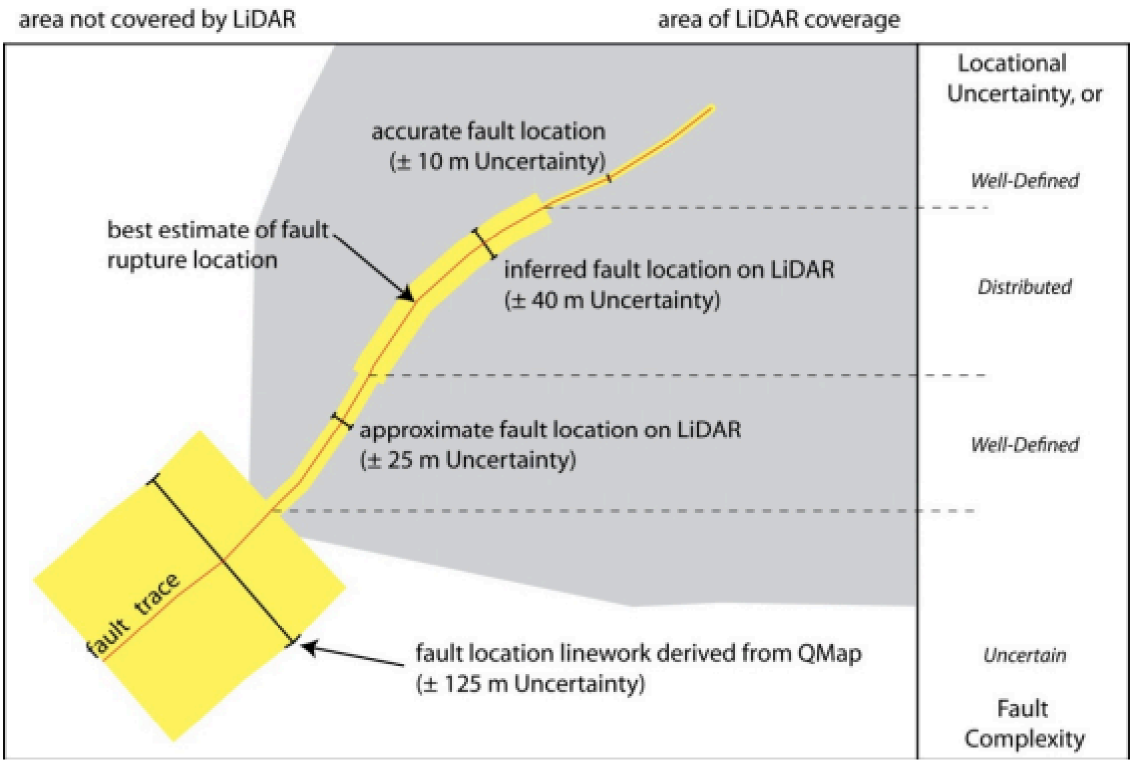

Figure 3.1 Depiction of the fault complexity and uncertainty associated with active-fault mapping. A LiDAR digital elevation model is depicted by the grey area. The red line represents the fault trace, and yellow bands represent the location uncertainty associated with accurate/approximate/inferred linework on LiDAR and the uncertainty for QMap linework (Langridge and Ries 2014).

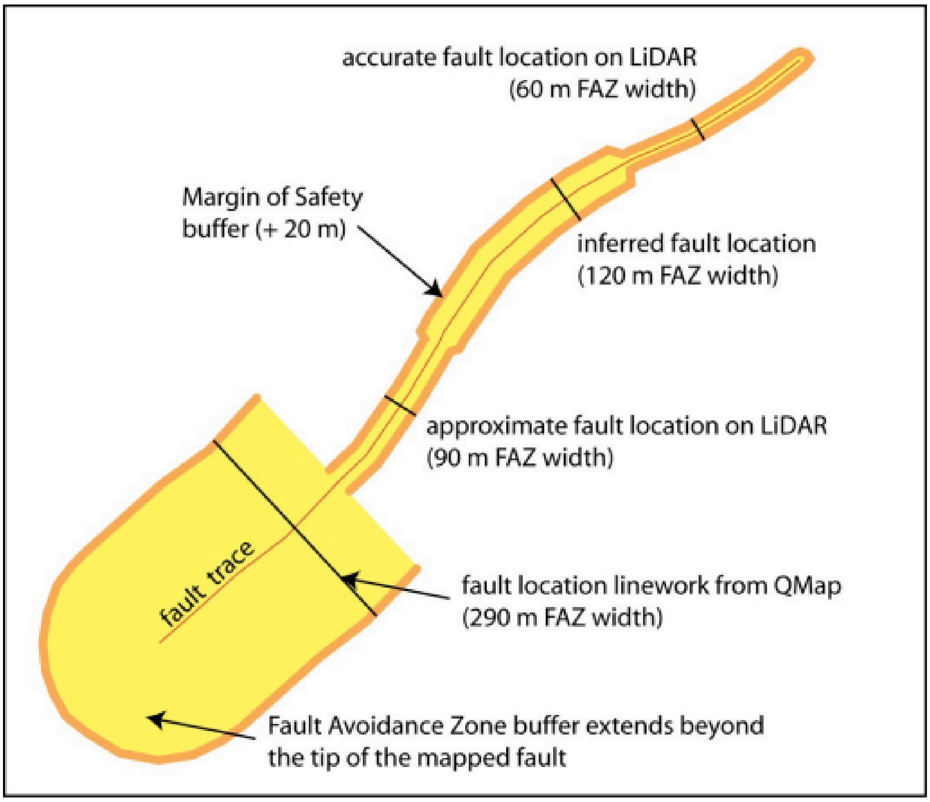

Figure 3.2 Fault Avoidance Zone buffers for a strike-slip or normal fault based on the example provided in Figure 3.1 (Langridge and Ries 2014).

3.1.3 Building Importance Category

The MfE Active Fault Guidelines establish a hierarchical relationship between fault recurrence interval and building importance, whereby the greater the importance of a structure with regard to life safety, the longer the fault recurrence interval needs to be to allow it to be constructed within a FAZ. This is because the risk from fault rupture at a site is not only a function of the location and activity of a fault, but also of the type of structure or building that may be impacted by a rupture of the fault (Van Dissen and Heron 2003). For example, only Category 1 structures are recommended as being acceptable to be constructed over active faults with an average recurrence interval of <2000 years. The MfE Active Fault Guidelines use the Building Importance Categories that were provided by the Building Code regulations at the time they were developed to characterise building type and importance with respect to life safety (Table 3.2).

Table 3.2 Building Importance Categories used by the MfE Active Fault Guidelines (Kerr et al. 2003).

Building Importance Category	Description	Examples
1	**Temporary structures** with low hazard to life and other property	• Structures with a floor area of <30 m^2 • Farm buildings, fences • Towers in rural situations
2a	**Timber-framed** residential construction	• Timber-framed single-storey dwellings
2b	**Normal structures** and structures not in other categories	• Timber-framed houses with area >300 m^2 • Houses outside the scope of NZS 3604 'Timber-Framed Buildings' • Multi-occupancy residential, commercial and industrial buildings accommodating <5000 people and <10,000 m^2 • Public assembly buildings, theatres and cinemas <1000 m^2 • Car parking buildings
3	**Important structures** that may contain people in crowds or contents of high value to the community or pose risks to people in crowds	• Emergency medical and other emergency facilities not designated as critical post-disaster facilities • Airport terminals, principal railway stations, schools • Structures accommodating >5000 people • Public assembly buildings >1000 m^2 • Covered malls >10,000 m^2 • Museums and art galleries >1000 m^2 • Municipal buildings • Grandstands >10,000 people • Service stations • Chemical storage facilities >500 m^2
4	**Critical structures** with special post-disaster functions	• Major infrastructure facilities • Air traffic control installations • Designated civilian emergency centres, medical emergency facilities, emergency vehicle garages, fire and police stations

It is important to note that, in 2012, the Building Importance Categories were amended and are now referred to as Building Importance Levels (BIL). The levels no longer align with the Building Importance Categories used in the MfE Active Fault Guidelines as provided in Table 3.2, with the main changes being that Categories 2a and 2b are now combined into a single level, and Categories 3 and 4 were amended with an additional Level 5 created (Table 3.3).

Table 3.3 Building Importance Levels in the current building regulations.

Building Importance Level	Description	Examples
1	Buildings posing low risk to human life or the environment, or a low economic cost, should the building fail. These are typically small non-habitable buildings, such as sheds, barns and the like, that are not normally occupied, although they may have occupants from time to time.	• Ancillary buildings not for human habitation • Minor storage facilities • Back-country huts
2	Buildings posing normal risk to human life or the environment, or a normal economic cost, should the building fail. These are typical residential, commercial and industrial buildings.	• All buildings and facilities except those listed in Importance Levels 1, 3, 4 and 5
3	Buildings of a higher level of societal benefit or importance or with higher levels of risk-significant factors to building occupants. These buildings have increased performance requirements because they may house large numbers of people, vulnerable populations or occupants with other risk factors, or fulfil a role of increased importance to the local community or to society in general.	• Buildings where more than 300 people congregate in one area • Buildings with primary school, secondary school or daycare facilities with a capacity greater than 250 • Buildings with tertiary or adult education facilities with a capacity greater than 500 • Healthcare facilities with a capacity of 50 or more residents but not having surgery or emergency-treatment facilities • Jails and detention facilities • Any other building with a capacity of 5000 or more people • Buildings for power-generating facilities, water treatment for potable water, wastewater treatment facilities and other public utilities facilities not included in Importance Level 4 • Buildings not included in Importance Level 4 or 5 containing sufficient quantities of highly toxic gas or explosive materials capable of causing acutely hazardous conditions that do not extend beyond property boundaries

Building Importance Level	Description	Examples
4	Buildings that are essential to post-disaster recovery or associated with hazardous facilities.	• Hospitals and other healthcare facilities having surgery or emergency treatment facilities • Fire, rescue and police stations and emergency-vehicle garages • Buildings intended to be used as emergency shelters • Buildings intended by the owner to contribute to emergency preparedness, or be used for communication, and operation centres in an emergency, as well as other facilities required for emergency response • Power-generating stations and other utilities required as emergency back-up facilities for Importance Level 3 structures • Buildings housing highly toxic gas or explosive materials capable of causing acutely hazardous conditions that extend beyond property boundaries • Aviation control towers, air-traffic control centres and emergency aircraft hangars • Buildings having critical national defence functions • Water-treatment facilities required to maintain water pressure for fire suppression • Ancillary buildings (including, but not limited to, communication towers, fuel-storage tanks or other structures housing or supporting water or other fire suppression material or equipment) required for operation of Importance Level 4 structures during an emergency
5	Buildings whose failure poses catastrophic risk to a large area (e.g. 100 km^2) or a large number of people (e.g. 100,000).	• Major dams • Extremely hazardous facilities

3.1.4 Determining Land-Use Activity Status

Fault recurrence interval, fault complexity and Building Importance Category are then combined in a risk-based framework for determining the activity status of different land-use activities, with a further distinction made between greenfield sites and already-developed sites. The rationale for this is that the preferred strategy of avoidance can be more easily achieved through development design for greenfield sites, whereas this is more difficult to achieve in built-up areas where there may be existing development over an active fault trace and a higher expectation of development rights. There are now a number of examples from across Aotearoa New Zealand of how the MfE Active Fault Guidelines are applied in practise, including Langridge and Morgenstern (2019), Litchfield et al. (2019, 2020) and Morgenstern and Van Dissen (2021), that step through the development of FAZs and provide specific advice to councils on how to address active fault hazards in their District Plans.

3.2 Changes in Practise and Lessons Learnt

3.2.1 Engineering Mitigation Measures

King et al. (2003) note that, at the time that the MfE Active Fault Guidelines were developed, there was a lack of data from Aotearoa New Zealand on the effect of buildings on the location and surface expression of fault rupture or the structural damage incurred by buildings directly over surface-fault-rupture zones. Therefore, while recognised as potentially appropriate in some situations, consideration of possible engineering mitigations was not included. Advances in engineering and paleoseismology since the MfE Active Fault Guidelines were published have increased interest in the possibility of incorporating engineering mitigation measures into developments to manage the hazard posed by ground-surface rupture (for example: Rasouli and Fatahi 2019). Bray (2009) further suggests that such measures could include constructing reinforced earth fills; using a slip layer to decouple ground movements from foundations; and designing strong, ductile foundations that can resist rupture pressures.

In addition, since the MfE Active Fault Guidelines were published in 2003, Aotearoa New Zealand has experienced both the 2010 Darfield earthquake and 2016 Kaikōura earthquake, where a number of residential-type structures were directly impacted by ground-surface fault rupture (Van Dissen et al. 2011, 2019; Litchfield et al. 2020). In the Kaikōura earthquake, 12 buildings (mainly single-storey timber-framed houses, barns and woolsheds) were impacted by the surface fault ruptures. While one dwelling was displaced by approximately 10 m, and others were badly damaged, all of the impacted buildings remained structurally intact such that the buildings performed their life-safety function. In the Darfield earthquake, approximately another dozen buildings (mainly single-storey houses and farm sheds) were affected by the Greendale Fault ground-surface rupture, but none collapsed (Van Dissen et al. 2011).

The observations from both earthquakes provided valuable information on the performance of structures when subjected to direct surface fault rupture and suggest the following (Van Dissen et al. 2019):

1. Single-storey, regular-shaped, timber-framed residential buildings with light roofs and a floor area of $\leq$200 m^2 do not appear to pose a collapse hazard when subjected to low/moderate (i.e. in the range of 8–10 m horizontal and 1–3 m vertical) surface-fault-rupture deformation.
2. At those levels of deformation, damage appears to be reduced (and therefore repairability and post-event functionality improved) when the cladding of such residential structures contributes to the robustness of the superstructure (e.g. plywood or timber weatherboard) and is not brittle.
3. This is enhanced if building systems moderate the direct transmission of ground deformation into the superstructure (either by decoupling or by other means) and allow for re-levelling of the structure post-event.
4. Residential structures with the above attributes are able to withstand even higher levels of strain and larger displacements (predominantly horizontal) without collapsing if the superstructure decouples from, and is therefore isolated from, the underlying ground deformation. In this scenario of horizontal displacement, the decoupled superstructure still rests on, and is supported by, the ground. There are no examples in Aotearoa

New Zealand of the performance of residential buildings subjected to similarly large surface-fault-rupture strains and displacements in a predominantly vertical direction. In this situation, there is the possibility that the fault rupture will leave the majority of the decoupled superstructure unsupported, leading to significant tilting and distortions, if not complete collapse, as was seen in the Chi-Chi, Taiwan, earthquake (Kelson et al. 2001).

The observations from the Darfield and Kaikōura events supported the approach of the MfE Active Fault Guidelines, which focuses on Building Importance Category (BIC) and fault complexity, particularly as it was seen that the severity of damage in general increases with both increasing displacement and increasing strain (Van Dissen et al. 2019). However, given the life-safety focus of the MfE Active Fault Guidelines and the non-collapse performance of residential buildings (BIC 2a structures) as described above, consideration could be given to being more permissive for structures with the aforementioned characteristics within the wider deformation zone where avoidance was not possible or desirable. If the focus of land-use planning provisions is damage control or ensuring post-event functionality, such an approach would not be appropriate (Van Dissen et al. 2019). It is further noted that these structures were single-storey in height and located on rural land, with significant separation from other buildings and structures, so observations of similar rupture styles in built-up urban areas could differ drastically. As such, allowing the construction of buildings within the deformation zone of active faults requires careful consideration of potential consequences to ensure that the resultant risk will be low.

3.2.2 Fault Awareness Areas

While not originally included in the MfE Active Fault Guidelines, FAAs are now being implemented in practise. They were developed for the Canterbury region as outlined in the Environment Canterbury report '*Guidelines for using regional-scale earthquake fault information in Canterbury*' (Barrell et al. 2015). FAAs are zones around active faults that have been mapped at a lower resolution (typically 1:50,000–1:250,000 scale), often being those that are outside of LiDAR-surveyed areas. An FAA highlights that an active fault is known or suspected to be present, but existing mapping is not accurate enough to be sure of its exact location, or that there is not enough information to define a RIC. FAAs are developed by buffering the mapped faults according to the level of certainty and their surface form. A buffer of 125 m either side (total 250 m width) or 250 m either side (total 500 m width) of the fault is created, depending on the fault characteristics (Barrell et al. 2015). This approach is useful for lower priority development areas where detailed mapping is not available, but consideration of the location of faults in planning decisions is desired. Barrell et al. (2015) recommend an advisory, non-regulatory approach for proposed timber- or steel-framed single dwellings in FAAs in the Canterbury region. The implementation of FAAs is now being seen throughout new-generation proposed District Plans (e.g. for Kaikōura and Waimakariri).

3.3 Implementation to Date

3.3.1 District Plan Review

The implementation of the MfE Active Fault Guidelines was first studied by Becker et al. (2005), who found that, two years after the release of the guidelines, there were many external factors that could impact on their successful implementation (including timeframes, human resources and cost for data collection and statutory processes). Sullivan-Taylor et al. (2022) repeated the methodology of Becker et al. (2005) to undertake a longitudinal analysis of plan provisions for earthquake hazard in Aotearoa New Zealand, and only minor improvement was seen.

This report has selectively reviewed the implementation of the MfE Active Fault Guidelines in District Plans across the Wellington region, as well as in Kaikōura for comparison, being a district that has experienced a significant earthquake since the guidelines were published. The review considered the consent categorisation and policy approach assigned to subdivision and the construction of new dwellings (excluding multi-unit developments) within existing residential (urban) zones where they are situated within an identified active-fault overlay.

The findings of this review are summarised in Appendix 1 and highlighted that first- and second-generation plans focused largely on avoiding critical infrastructure in areas of natural hazards, with no specific objectives, policies or rules relating to active faults. The latest generation of plans has seen an increase in the implementation of the risk-based approach as set out in the MfE Active Fault Guidelines, with localised modifications applied. The extent of available information about active faults and the consent categorisation for residential development is wide-ranging across councils in the Wellington region, even between those who are affected by the same active faults. While residential dwellings are now generally receiving greater recognition as 'hazard-sensitive activities', the appetite for risk presents differently for each local authority. There is an example where, in a proposed District Plan (so not yet operative), new dwellings in populated urban areas are classified as a Permitted Activity within active fault overlays, with no requirement for any engineering mitigations to be incorporated.

3.3.2 Challenges with Implementation

Therefore, it appears that there remain challenges in the implementation of the guidelines, and approaches to the management of active faults varies. Becker et al. (2005), Sullivan-Taylor et al. (2022) and Van Dissen and Heron (2003) highlight the following:

- There is a lack of mandated national direction on how to manage the risk posed by active faults.
- Councils have tailored the suggested consent categories. While the guidelines encouraged this, it has resulted in diverse planning approaches, which have not always achieved avoidance in fault hazard zones.
- The cost of obtaining information about fault hazards can be relatively high for districts with a low population density (e.g. eastern Tararua and Wairarapa).
- To successfully implement the MfE Active Fault Guidelines, both public and political buy-in is required. Public and political acceptance of the guideline recommendations can be difficult when previous development has already occurred in an area and an earthquake has not occurred in living memory.
- Plan review cycles delay the incorporation of guidelines.
- Staff capacity/turnover/awareness impacts on the implementation of guidelines.
- Decisions that are made (relating to activity status under the RMA) must be justifiable, both in terms of liability and satisfaction of the public. Where there is limited information, it is hard to justify a highly restrictive approach.
- It can be a complex task to determine the appropriate resource-consent categories for different scenarios/combinations of RIC, fault complexity and Building Importance Category.
- It can be difficult to locate active fault traces. There are locations where it may be more expedient to mitigate rupture hazard by appropriate assessment criteria (e.g. the degree to which the proposed building, structure or design work can accommodate/mitigate the effects of fault rupture) rather than by locating the fault.

3.3.3 Limitations with the Approach

The following limitations with the MfE Active Fault Guidelines are those identified by Hale et al. (2017) and Morgenstern and Van Dissen (2021):

- Likelihood of rupture is not just related to the average recurrence interval; it is also a function of variables such as elapsed time since the last rupture of the fault and the size, style and timing of large earthquakes on other nearby faults. These other variables are not used to define rupture hazard in the MfE guidelines.
- The FAZ (≥20 m either side of fault trace) can be established in the absence of detailed paleoseismic studies, and no further investigation is required. In these instances, a 20 m setback distance may not always be adequate.
- FAZs limit the land available for development. Engineering mitigation could be appropriate in some areas (such as deformation zones) and development situations.

In essence, the above points highlight that it would be preferable if FAZs were determined using detailed paleoseismic studies so that they reflected the specific fault characteristics and more reliably captured the area of expected deformation. However, in the absence of government funding and other challenges faced as identified in Section 3.3.2, this simply is not achievable for the majority of local councils in Aotearoa New Zealand. In this context, it is considered that the development of FAZs and FAAs as outlined in Sections 3.1 and 3.2 remains the most practical management option for land-use planning in Aotearoa New Zealand.

4.0 INTERNATIONAL PRACTISE

To understand if there are any examples internationally of approaches to planning for active faults that could be usefully applied here in Aotearoa New Zealand, a review of current practise in other seismically active areas around the world was undertaken.

4.1 California

In California, a state-wide approach to managing the effects of active-fault rupture is mandated by the Alquist-Priolo Earthquake Fault Zoning Act 1972. This state law was passed after the 1971 San Fernando earthquake, with the purpose of prohibiting the construction of buildings used for human occupancy across active fault traces to mitigate surface-fault-rupture hazard (Gath 2015). The Act requires state mapping of earthquake fault zones (EFZ), within which further geologic investigations are required prior to constructing habitable buildings to determine whether the site is underlain by an active fault (defined as a fault that shows evidence of displacement within the Holocene period or, approximately, the last 11,000 years) (Boncio et al. 2018; Hale et al. 2017). Generally, the prescribed EFZ are 150–200 m away from the trace of major active faults or 60–90 m away from well-defined minor faults. Noting that steeply dipping strike-slip faults are predominant in California (He et al. 2022), a minimum setback of 15 m from well-defined fault traces applies, within which habitable structures are not permitted, unless geotechnical investigations can demonstrate that active branches of the fault are not present (Bryant 2010; Gath 2015). In addition, if a property within an EFZ is being sold, the Act also requires that the purchasers are notified of this by the real estate agent.

The Act has generally been successful in its goal of avoiding development across active fault traces, noting that the EFZ can be contested by property owners and their experts, and have been reduced in width in some instances in relation to specific developments.

4.2 Taiwan

In 1999, the Chi-Chi earthquake (M_W 7.6) hit Taiwan and caused the death of 2500 people, with a further 11,000 people injured and $12 billion worth of damage caused (Chen and Chang 2018). Much of the building damage was associated with surface faulting and folding along the Chelungpu thrust fault, where up to 7 m of vertical displacement occurred. Buildings (including single-storey residential buildings) along the path of the rupture zone were extensively damaged or collapsed, whereas similar buildings a short distance from the rupture zone were relatively undamaged (Kelson et al. 2001). In response, the government imposed a temporary 50 m zone along either side of the Chelungpu fault in which building was prohibited until the end of 1999. After more accurate geologic mapping was completed in 2000, this fault avoidance zone was reduced to 15 m either side of the fault until the end of 2001, after which time no zoning regulations applied to the non-urban planning area (Chen and Chang 2018). In urban planning areas, this fault zone continues to be regulated by local planning agencies given the significant damage that resulted from the 1999 earthquake; however, buildings for residential use are permitted within the zone, with building height restricted to 7 m (Chen and Chang 2018). Chen and Chang (2018) note that, currently, of the 41 active faults in Taiwan, the Chelungpu fault is the only fault within the urban planning area that has a fault-zone regulation applied to it.

4.3 China

The Wenchuan earthquake (M_W 7.9) in China in 2008 created a 240-km-long surface-rupture zone along the Beichuan fault and a 72-km-long rupture along the Pengguan fault (Zhou et al. 2010). While the rupture characteristics varied along the length of the thrust with strike-slip faults (He et al. 2022), vertical displacement of around 2 m was generally seen but was ~5–6 m in some regions (Hao et al. 2009; Yunhong et al. 2011; Zhou et al. 2010). Horizontal displacement of up to 2.6 m occurred, and deformation zones were 12–59 m wide (Zhou et al. 2010). Many buildings constructed over the fault-rupture zone were either completely destroyed or severely damaged, including those constructed with reinforced concrete (Zhou et al. 2010). Conversely, as was seen in the Chi-Chi earthquake, buildings a short distance from the rupture zones suffered no or only minor damage. The Wenchuan earthquake highlighted the need for building setbacks from active faults, and, since this time, China's national standards, laws and regulations have incorporated provisions relating to setbacks (He et al. 2022). In 2021, the China Earthquake Administration submitted for review a National Standard for setback distances from active faults that recommended that the setback distance from Holocene and late Pleistocene faults for general buildings (e.g. dwellings) should be determined based on fault characteristics (including type, dip angle, fault scarp height, foundation depth and fault age), with special buildings (such as hospitals) set back further.

4.4 Summary

While research into engineering measures to mitigate the effects of surface fault rupture continues, the focus of international practise remains in determining appropriate setback zones from active fault traces as the most feasible option to avoid the hazard and reduce impacts (He et al. 2022).

While the assigning of conditional probabilities for fault rupture is a common scientific practise (e.g. Lee et al. 2016; Rhoades et al. 2011), no examples were found where these were translated into a land-use planning context. However, one of the criticisms of Gath (2015) about the Alquist-Priolo Earthquake Fault Zoning Act 1972 is that all faults are considered equally hazardous, despite their differing rupture magnitudes, recurrence intervals or timing since last event. Gath (2015) suggests that, to be consistent with the assessment of risk posed by other natural hazards, the Act be amended so that the focus is not on faults that have been active during the Holocene but those that have not had movement within 500 years of their average recurrence interval or are already past it. This equates to a 10% probability of exceedance in 50 years or a 20% probability of exceedance in 100 years. For higher-occupancy structures, Gath (2015) suggests that an average recurrence interval of 1000 years (10% probability of exceedance in 100 years) might be more appropriate, as well as an average recurrence interval of 2500 years (4% probability of exceedance in 100 years) when assessing the risk to critical facilities and infrastructure. Gath (2015) also recommends that any mitigation solution that results in life-safety performance by buildings and resilient underground infrastructure should be permitted, recognising that avoidance may still be the only option.

As such, the attention of this report now turns to consider whether the use of a probability for surface fault rupture might result in improved planning practise for managing the risk posed by this hazard in Aotearoa New Zealand.

5.0 ASSIGNING PROBABILITY TO FAULT RUPTURE

5.1 Possible Benefits for Land-Use Planning

What is evident from the preceding sections is that a revision of the MfE Active Fault Guidelines is overdue. While international practise appears to still focus on the determination of appropriate fault setbacks, there have been a number of advances in practise here in Aotearoa New Zealand, including in the use of risk-based planning approaches. With the limitations and challenges of the current guidelines identified in Sections 3.3.2 and 3.3.3 in mind, this part of the report scopes whether there is merit in utilising the probability of rupture, as opposed to likelihood and recurrence interval, within a risk-based planning approach as part of any update of the guidelines. There are a number of reasons for this, including:

- **Better representation of changing likelihood over time**

  The current guidelines use recurrence interval to categorise active faults, which does not provide for any consideration of timing since the last surface-rupturing earthquake and assumes that the likelihood of a rupture does not change over time. Yet, this is not the case, as, once a fault has ruptured, the stress on the fault reduces (Rhoades et al. 2004) and the likelihood of another rupture occurring decreases. Stress on the fault will then begin to build up again, with an increasing likelihood of another similar rupture over time (Rhoades et al. 2004). The use of probability allows for the changing likelihood over time to be considered within land-use planning decisions, for example, in the instance where a fault may have a long recurrence interval but a high probability of rupture in the next 100 years.

- **Better representation of risk**

  A desired outcome is that the assigning a conditional 100-year probability of rupture will allow for the risk posed to be better understood by decision-makers, political representatives and the public. For example, if a fault has a recurrence interval of 5000 years but has not ruptured in the last 5000 years, it has a high probability of occurring within a person's lifetime. Yet, the public perception is that it has one chance of occurring in 5000 years and as such is of no concern. There is a general shift within natural-hazards planning toward using probability (i.e. AEP) as opposed to likelihood (i.e. 1 in 100 years) in recognition of the poor understanding of the actual hazard risk posed. A review into seismic risk and building regulation in Aotearoa New Zealand (Building Performance 2020) noted that "earthquakes and recovery effects during the past 10 years have revealed weakness in communication and public understanding of seismic risk". It is thought that a change from likelihood to probability would contribute to addressing this.

- **Better alignment of timeframes**

  While it is understood that a revision of the Building Act and Building Code are being contemplated (Building Performance 2020), planning for a 100-year probability (as opposed to a likelihood of 1 in 2500 years for example) will not only better align with planning practise for other natural hazards (e.g. flood hazards, coastal erosion, coastal inundation and rainfall-induced landslides) but also the Building Act and Building Code regulations, which currently require that residential dwellings are constructed to meet an expected lifetime of 50 years and withstand the effects of an earthquake with a return period of 500 years.

In addition to the above, consideration was given to each of the limitations and challenges with implementing the guidance identified above in Section 3.3.2 and 3.3.3 and to whether the assigning of a probability to fault rupture will alleviate these, as summarised in Tables 5.1 and 5.2 below.

Table 5.1 Challenges with the implementation of the MfE Active Fault Guidelines (Sources: Becker et al. [2005]; Van Dissen and Heron [2003]; District Plan review [Appendix 1]).

Issue/Limitation with the Implementation of the MfE Active Fault Guidelines	Can Assigning a Probability within the Risk-Based Approach Address This?	Discussion
Lack of mandated national direction on active faults.	No	However, the process of revising the guidelines could be beneficial to raising the profile of earthquake risk generally and providing impetus for implementing land-use planning provisions.
The guidelines seek to avoid building within FAZs where possible. The application of the guidelines have not always resulted in these outcomes.	Potentially	The application of the guidelines is not mandatory. A probability risk-based approach that utilises rupture probability could simplify the implementation of the current guidelines and align practise with that for other natural hazards and, in doing so, result in better risk-based land-use outcomes.
Councils have tailored the suggested consent categories. While the guidelines encouraged this, it has resulted in diverse planning approaches.	No	The forthcoming National Planning Framework would better assist in achieving consistency for land-use planning in proximity to active faults.
There are high costs to obtain information about natural hazards in a district, particularly in districts with a low population density.	No	However other options are available in the interim, including developing FAAs, and there may be value in assigning a probability that can also be assigned to lesser-known faults, as discussed further in Section 6.2.
To successfully implement the changes recommended in the guidelines, both public and political buy-in is required. Public and political acceptance of the guideline recommendations can be difficult when previous development has already occurred in an area.	Potentially	Assigning probability is expected to ease communication and awareness of the potential risks from each active fault. Where limited information is available about an active fault in populated urban and future growth areas, assigning probabilities may give greater awareness of risk and justification for further research. It will also integrate with risk tolerability thresholds that are set by a region/district.
Plan review cycles delay the incorporation of guidelines.	Potentially	The use of rupture probabilities within a risk-based framework has the potential to allow new information to be more easily incorporated into plans, for example, where the planning framework is based around high, medium or low hazard or risk, as opposed to reference to specific hazards. An example of this is provided by the Porirua City Proposed District Plan.

Issue/Limitation with the Implementation of the MfE Active Fault Guidelines	Can Assigning a Probability within the Risk-Based Approach Address This?	Discussion
Staff capacity/turnover/ awareness impacts on the implementation of guidelines.	Potentially	Offering a rupture probability within the risk-based approach may enhance awareness of the guidelines and the need to plan for active faults within the planning community. Alignment with other hazards via the use of probability is also expected to be helpful when considering multiple hazards.
Decisions that are made (relating to activity status under the RMA) must be justifiable, both in terms of liability and satisfaction of the public. Where there is limited information, it is hard to justify a 'heavy handed' or overly restrictive approach.	Yes	A risk-based approach to surface fault rupture takes into consideration the level of uncertainty in data, as well as community and stakeholder tolerance of risk. This will help to justify land-use planning decisions.
It is a complex task to determine the appropriate Resource Consent Categories for different scenarios/combinations of RIC, fault complexity and Building Importance Category, especially when trying to anticipate the level of risk that a community may or may not be willing to accept.	Yes	Using a probability will generally reduce the complexity of assigning resource consent categories, and, if used within a risk-based planning framework, this should be based on the outcomes of community, mana whenua and stakeholder engagement (e.g. Kilvington and Saunders 2015).
Additional paleoearthquake studies on faults could yield data that would better constrain their respective recurrence intervals.	No	While assigning a probability itself will not help with constraining recurrence interval, conditional probability can be re-calculated as new information becomes available on each active fault.
There are locations where it may be more expedient to mitigate rupture hazard by appropriate assessment criteria (e.g. the degree to which the proposed building, structure or design work can accommodate/mitigate the effects of fault rupture) rather than by locating the fault.	No	While the assigning of a rupture probability will not address this, it is noted that updated guidance would incorporate learnings on buildings that can withstand fault rupture and where it might be appropriate to allow development within the vicinity of an active fault.

Table 5.2 Consideration of whether assigning a probability of fault rupture will address identified limitations and challenges with the approach set out in the MfE Active Fault Guidelines (Source: Hale et al. [2017]; Morgenstern and Van Dissen [2021]).

Limitation/Challenges with the approach in the MfE Active Fault Guidelines	Can Assigning a Probability within the Risk-Based Approach Address This?	Discussion
Likelihood of rupture is not just related to the average recurrence interval, it is also a function of variables such as elapsed time since the last rupture of the fault and the size, style and timing of large earthquakes on other nearby faults. These other variables are not used to define rupture hazard in the MfE Active Fault Guidelines.	Yes	Assigning a probability to the likelihood can take into account all of these variables.
The fault avoidance zone (≥20 m either side of the fault trace) is established in advance and no further investigation is required. A 20 m setback distance may not always be adequate.	Potentially	Defining a probability of rupture may help to highlight with decision-makers and politicians those faults where further investigation into possible deformation zones would be beneficial.
Fault avoidance zones limit the land available for development. Mitigation could be appropriate in some areas.	No	Although, the assigning of a probability to fault rupture could help highlight those faults where mitigation measures may be appropriate, as opposed to complete avoidance.
Defines short fault recurrence intervals that depend on faults having developed characteristic rupture cycles and an ability to date ruptures accurately. It may be easier to class faults as Holocene-active or Late-Pleistocene-active.	Potentially	It is considered that applying a probability to surface rupture has the potential to result in better planning outcomes compared to classifying faults into two recurrence intervals.
Likelihood of rupture is not just related to the average recurrence interval, it is also a function of variables such as elapsed time since the last rupture of the fault and the size, style and timing of large earthquakes on other nearby faults. These other variables are not used to define rupture hazard in the MfE Active Fault Guidelines.	Yes	Assigning a probability to the likelihood can take into account all of these variables.

The assessment above highlights that, while there are a number of potential positive outcomes from assigning a probability to surface fault rupture, the key change will be a better determination of the likelihood of rupture, as a range of key variables can be incorporated, perhaps most importantly the timing of the last rupture.

5.2 Probability of Rupture of Wellington Faults

There are a number of known active faults within the Wellington region, as summarised in Table 5.3 below. As shown, many of these cross jurisdictional boundaries within the region, highlighting the importance of a consistent regional approach to these types of hazards.

Table 5.3 Major named active faults in the Wellington region.

Active Fault	Wellington City	Porirua	Kāpiti	Lower Hutt	Upper Hutt	Wairarapa*
Akatarawa					✓	
Aotea	✓					
Battery Hill						✓
Carterton						✓
Dreyers Rock						✓
Dry River						
Evans Bay	✓					
Gibbs			✓			
Huangarua						✓
Martinborough						✓
Masterton						✓
Mokonui						✓
Moonshine	✓	✓			✓	
Northern Ōhariu			✓			
Ōhariu	✓	✓	✓			
Otaki Forks			✓		✓	
Otaraia						✓
Pukerua		✓				
Shepherds Gully	✓					
Southern Reikorangi			✓			
Te Maire						✓
Terawhiti	✓					
Wairarapa				✓		✓
Wharekauhau						✓
Wellington	✓			✓	✓	
Whitemans Valley				✓	✓	

* This table does not include recently discovered/mapped faults in the Wairarapa (Litchfield et al. 2022).

Of these active faults, enough paleoseismic research has only been undertaken on the Wellington, Wairarapa and Ōhariu faults to enable determination of a 100-year conditional probability of rupture as follows:

- Wellington Fault – c. 11% (Rhoades et al. 2011) or a 0.1% AEP.

The Wellington Fault is the most active in the region. The Wellington – Hutt Valley section of the Wellington Fault extends from 20 km off the south coast, through Wellington City and along the western side of the harbour and Hutt Valley to Te Marua (Robinson et al. 2011). It is expected to be capable of producing earthquakes of approximately magnitude 7.5, has a recurrence interval of 715–1575 years and last ruptured the surface about 300 years ago (Langridge et al. 2011; Rhoades et al. 2011). Surface-rupture earthquakes are expected to generate between 3.5 and 6.5 m of horizontal displacement, with a lesser amount of vertical displacement (Little et al. 2010; Morgenstern and Van Dissen 2021).

- Ōhariu Fault – c. 4.9% (Van Dissen et al. 2013) or a 0.049% AEP.

The Ōhariu Fault is another major earthquake-generating fault in the region (Morgenstern and Van Dissen 2021) and extends from north of Waikanae, through Porirua City to within 5 km of Wellington City (Van Dissen et al. 2013). It has a recurrence interval of 800–7000 years (Litchfield et al. 2006), with the most recent major rupture approximately 1000 years ago. A mean recurrence interval of 2200 years has been calculated for the Ōhariu Fault (Litchfield et al. 2006). It is expected that the Ōhariu Fault would generate a magnitude 7.5 earthquake that could generate 3–5 m of lateral displacement, with a less and variable amount of vertical displacement (Van Dissen and Heron 2003).

- Wairarapa Fault – c. 3% (for the southern portion of the fault southwest of the intersection with the Carterton and Masterton Faults) (Van Dissen et al. 2013) or a 0.03% AEP.

The Wairarapa Fault last ruptured in 1855 with a magnitude 8+ earthquake that resulted in severe shaking across the Wellington region, as well as uplift of the Wellington harbour and massive landslides (Van Dissen et al. 2013). The 1855 earthquake generated an average of 14–17 m of lateral displacement and up to 6 m of vertical displacement (McSaveney et al. 2006; Rodgers and Little 2006). It has a mean recurrence interval of 1230 $\pm$ 190 years (Little et al. 2009).

The basic statistical method used to determine the conditional probability of the Wellington, Wairarapa and Ōhariu faults expresses the probability of rupture of the fault in some future time interval as a single value that accounts for both data and parameter uncertainties. A range of different recurrence-time distributions were considered, being the exponential, lognormal, Weibull and inverse Gaussian (or Brownian passage-time) distributions. An explanation of each of these recurrence-time distributions is provided in Van Dissen et al. (2013).

For those faults in the region that are known, but not enough information exists on to enable the probability of rupture to be sufficiently constrained, it is tested below whether the existing RIC boundaries could be re-cast into 100-year likelihoods and AEPs using the lower boundary of the RIC presented in the MfE Active Fault Guidelines as shown in Table 5.4.

Table 5.4 Possible rupture probabilities for less-constrained faults based on Recurrence Interval Class (RIC).

Corresponding RIC	MfE Active Fault Guidelines RIC Lower Boundaries (Years)	Approximate 100-Year Likelihood (AEP %)	Approximate Chance in Next 100 Years (%)
I	2000	0.0500	5%
II	3500	0.0286	2.9%
III	5000	0.0200	2%
IV	10,000	0.0100	1%
V	20,000	0.0050	0.5%

6.0 INCORPORATING RUPTURE PROBABILITY INTO RISK-BASED PLANNING FRAMEWORKS

6.1 Summary of the Risk-Based Planning Approach

A risk-based approach involves consideration of both the likelihood (or probability) of an event occurring as well as the potential consequences. Past land-use planning practise for natural hazards in Aotearoa New Zealand has focused only on the likelihood of an event occurring, with little thought given to the consequences of an event when design standards for development are exceeded (Saunders et al. 2013). This has meant that low-likelihood natural hazard events that have high consequences, like fault rupture, have been largely ignored in planning decisions.

Consequently, natural hazard risk has overall not been managed well, as demonstrated by the 2010/11 Canterbury Earthquake Sequence, where extensive damage resulted due to building design standards being exceeded (Saunders et al. 2013) and areas known to be susceptible to liquefaction had been developed (St. Clair and McMahon 2011). In response, a risk-based approach is now considered best practise when managing natural hazard risk under the RMA, as discussed in Section 2.1, a move designed to improve the sustainability and resilience of our communities. Yet, with the ever-increasing pressure on councils to provide housing through national legislation (such as the National Policy Statement on Urban Development), there is a high chance that areas subject to low-likelihood high-consequence natural hazards will be made available for development.

As described above, the risk-based approach taken by the MfE Active Fault Guidelines is based on three factors:

- fault recurrence interval
- fault complexity, and
- Building Importance Category.

When determining resource consent activity status, further consideration is given to whether the development is proposed in an already developed area or an undeveloped greenfields site.

Since the MfE Active Fault Guidelines were published in 2003, work has been done by Saunders et al. (2013) to develop a framework and methodology for a multi-hazard risk-based planning approach that is based upon the standards for risk management ISO 31000:2009 and AS/NZS 4360:2004. It consists of five key steps, being:

1. Know your hazard.
2. Determine the severity of consequences.
3. Evaluate the likelihood of an event.
4. Take a risk-based approach.
5. Monitor and evaluate.

Engagement activities are required at each step, with a particular emphasis on the need for decisions on what level of risk is acceptable, tolerable or unacceptable to be made in conjunction with the wider community, with input from experts and regulators (Kilvington and Saunders 2015). A core component of the approach is the consequences table (Figure 6.1) that was developed to support Step 2.

Severity of Impact	Built				Economic	Health &Safety
	Social/Cultural	Buildings	Critical Buildings	Lifelines		
Catastrophic (V)	≥25% of buildings of social/cultural significance within hazard zone have functionality compromised	≥50% of affected buildings within hazard zone have functionality compromised	≥25% of critical facilities within hazard zone have functionality compromised	Out of service for > 1 month (affecting ≥20% of the town/city population) OR suburbs out of service for > 6 months (affecting < 20% of the town/city population)	> 10% of regional GDP	> 101 dead and/or > 1001 inj.
Major (IV)	11-24% of buildings of social/cultural significance within hazard zone have functionality compromised	21-49% of buildings within hazard zone have functionality compromised	11-24% of buildings within hazard zone have functionality compromised	Out of service for 1 week – 1 month (affecting ≥20% of the town/city population) OR suburbs out of service for 6 weeks to 6 months (affecting < 20% of the town/city population people)	1-9.99% of regional GDP	11 – 100 dead and/or 101 – 1000 injured
Moderate (III)	6-10% of buildings of social/cultural significance within hazard zone have functionality compromised	11-20% of buildings within hazard zone have functionality compromised	6-10% of buildings within hazard zone have functionality compromised	Out of service for 1 day to 1 week (affecting ≥20% of the town/city population people) OR suburbs out of service for 1 week to 6 weeks (affecting < 20% of the town/city population)	0.1-0.99% of regional GDP	2 – 10 dead and/or 11 – 100 injured
Minor (II)	1-5% of buildings of social/cultural significance within hazard zone have functionality compromised	2-10% of buildings within hazard zone have functionality compromised	1-5% of buildings within hazard zone have functionality compromised	Out of service for 2 hours to 1 day (affecting ≥20% of the town/city population) OR suburbs out of service for 1 day to 1 week (affecting < 20% of the town/city population)	0.01-0.09 % of regional GDP	<= 1 dead and/or 1 – 10 injured
Insignificant (I)	No buildings of social/cultural significance within hazard zone have functionality compromised	< 1% of affected buildings within hazard zone have functionality compromised	No damage within hazard zone, fully functional	Out of service for up to 2 hours (affecting ≥20% of the town/city population) OR suburbs out of service for up to 1 day (affecting < 20% of the town/city population)	<0.01% of regional GDP	No dead No injured

Figure 6.1 The consequences table developed by Saunders et al. (2013).

The above consequence rows (I–V) are then combined with likelihood (Table 6.1) in a risk matrix (Figure 6.2) that determines the consent status (i.e. how the risk will be treated).

Table 6.1 Likelihood descriptors (adapted from Saunders et al. 2013).

Likelihood	Indicative Frequency
Likely	Up to once every 50 years (2% AEP or more)
Possible	Once every 51–100 years (2–1% AEP)
Unlikely	Once every 101–1000 years (1–0.1% AEP)
Rare	Once every 1001–2500 years (0.1–0.04% AEP)
Very Rare	2501 years plus (<0.04% AEP)

	Consequences				
Likelihood	1	2	3	4	5
5	5	10	15	20	25
4	4	8	12	16	20
3	3	6	9	12	15
2	2	4	6	8	10
1	1	2	3	4	5

Level of risk	Consent
Acceptable	Permitted
Acceptable	Controlled
Tolerable	Restricted Discretionary
Tolerable	Discretionary
Intolerable	Non complying, prohibited

Figure 6.2 Risk and activity status matrix (Saunders et al. 2013).

A full description of each of the steps to be taken when implementing a risk-based approach is provided in Saunders et al. (2013).

The Bay of Plenty Regional Policy Statement (BOP RPS) has taken the approach of Saunders et al. (2013) and adapted it to suit the specific context in which it is implemented. This includes specifying the probabilities of the scenarios that must be modelled for each different hazard to inform the risk assessment. For fault rupture, the specific likelihoods that must be used in the risk analysis are an event with a likelihood of 0.017% AEP for the primary risk assessment analysis and events with likelihoods of 0.2 and 0.005% AEP for the secondary analysis. These AEPs were decided in consultation with specialists and members of a Technical Working Group who assisted with the development of the Plan Change (Bay of Plenty Regional Council 2016). The consequences of each of these scenarios is then combined with the probability to determine the level of risk under the Risk Screening Matrix (Figure 6.3). This was developed in consultation with local communities (Kilvington and Saunders 2015) and so varies slightly from those of Saunders et al. (2013). Under this matrix, only the 0.2% AEP scenario where the consequences are catastrophic has the potential to be classified as High Risk, with the less likely 0.017% and 0.005% AEP scenarios classified as Medium Risk where the consequences are catastrophic, noting that, for all scenarios where the consequences are catastrophic, none are classified as Low Risk.

As the risk-based approach provided by the BOP RPS is based upon the use of probability it is the primary framework used to test the use of rupture probabilities here for the Wellington region, noting that these are inserted into the framework below as opposed to the probabilities specified in the BOP RPS. The results of the assessment are then compared with those using the recurrence interval and likelihood methodology under the MfE Active Fault Guidelines and the approach of Saunders et al. (2013), respectively. Note that only the primary analysis of the BOP RPS is applied in Table 6.2. In practise, if the result of the primary risk assessment is a Medium Risk, a further quantitative step to calculate the Annual Individual Fatality Risk (AIFR), or the probability of a fatality for an individual at a specific site in any given year, is required to ensure that maximum likely risk is captured. If the results of the primary assessment under the BOP RPS are a High Risk level, no further assessment is required.

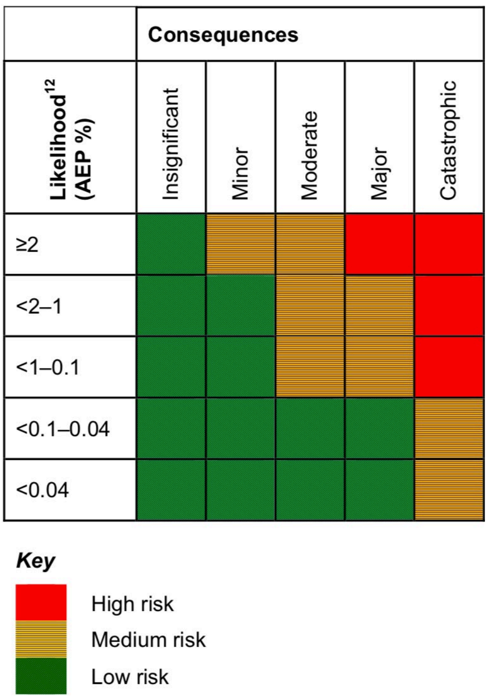

Figure 6.3 The Risk Screening Matrix from the Bay of Plenty Regional Policy Statement.

A fourth risk-based planning approach is considered here, which uses the sensitivity of activities to the effects of natural hazards as a proxy for the consequences table in Figure 6.1. This has been incorporated into the proposed District Plans for Porirua and Wellington City within the Wellington region. In a similar approach to the MfE Active Fault Guidelines, land-use activities are classified as a Hazard-Sensitive Activity (e.g. a residential dwelling), Potentially Hazard-Sensitive Activity (e.g. a commercial building), or a Less Hazard-Sensitive Activity (e.g. sheds).

6.2 Testing the Probability of Fault Rupture in a Risk-Based Planning Framework

The use of recurrence interval and probability were tested within the three different risk-based approaches discussed above (being Saunders et al. [2013], the BOP RPS and the Hazard-Sensitive Activity approaches), as well as that of the MfE Active Fault Guidelines, to allow a comparison between the risk assessment outcomes. A number of assumptions have been made to standardise the results and allow comparison, including:

- Catastrophic consequences are assumed in all instances. However, it is recognised that this may not necessarily be correct, particularly in relation to the lesser-known faults assessed.
- Assessment has been undertaken in relation to single-storey timber-framed residential structures (BIC 2a or BIL 2 / Hazard Sensitive Activity) in already developed areas only, noting that the activity status for high-occupancy or critical buildings in these areas is the same or more onerous in every case.
- Where activity status is related to fault complexity, the activity status for well-defined is used, as this certainty attracts the most onerous status. For example, residential structures within the Distributed, Uncertain Constrained and Uncertain Poorly Constrained areas for the Ōhariu Fault are a Permitted Activity under the Kāpiti Coast District Plan but a Restricted Discretionary Activity where the fault is well defined.
- The likelihood descriptors and indicative frequencies in Table 6.1 are used, noting that they can vary in practise.
- Because Regional Policy Statements only include objectives and policies, not rules, for the purposes of this study, the levels of risk developed by Saunders et al. (2013) and shown in Figure 6.2 above are equated with the risk categories of the BOP RPS such that an Intolerable Risk is a High Risk, Tolerable Risk is Medium Risk, and Acceptable Risk is Low Risk.

Also tested is the re-casting of recurrence intervals into probabilities (Table 5.4) where there is insufficient information to determine a conditional probability of rupture for lesser-known faults in the region, as discussed above. For this exercise, the Shepherds Gully, Pukerua, Moonshine and Terawhiti faults were selected, as they are incorporated into proposed District Plan frameworks in the Wellington region that adopt the Hazard-Sensitive Activity approach and thereby provide an opportunity to compare the outcome in terms of activity status with the other risk-based approaches considered (being that of the MfE Active Fault Guidelines, Saunders et al. [2013] and the BOP RPS).

It is emphasised that the risk assessment table below (Table 6.2) is indicative only and for the purposes of initial comparison, with a number of assumptions made as detailed above. It should not be used in any other context outside of this report.

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Table 6.2 Risk assessment results comparing the use of likelihood and probability in established risk-based planning frameworks.

	Active Fault		Testing under Risk-Based Planning Frameworks: MfE Active Fault Guidelines	Testing under Risk-Based Planning Frameworks: Saunders et al. (2013)	Testing under Risk-Based Planning Frameworks: Bay of Plenty Regional Policy Statement [1]	Comparison with Implementation in Recent District Plan Changes in the Wellington Region: Porirua City Proposed District Plan 2021	Comparison with Implementation in Recent District Plan Changes in the Wellington Region: Kāpiti Coast Operative District Plan 2021 [2]	Comparison with Implementation in Recent District Plan Changes in the Wellington Region: Wellington City Proposed District Plan 2022
Testing of Conditional Probabilities	**Wellington** RI – 715 to 1575 yrs RIC – ≤2000 yrs AEP – 0.11%	**Likelihood/Probability Parameters**	RIC I	Unlikely	0.11% AEP	-	-	Basis not provided
		Hazard/Risk Parameters	Well defined	Tolerable Risk	High Risk	-	-	High Hazard
		Activity Status for BIC 2a Structure/Activity	*Non-complying*	*Discretionary*	*Non-complying* [3]	-	-	*Permitted*
	Ōhariu RI – 800 to 7000 yrs RIC – >2000 to ≤3500 yrs AEP – 0.049%	**Likelihood/Probability Parameters**	RIC II	Rare	0.049% AEP	Very Unlikely	RIC II	Basis not provided
		Hazard/Risk Parameters	Well defined, distributed and uncertain	Tolerable Risk	Medium Risk	High Hazard	Well defined	High Hazard
		Activity Status for BIC 2a Structure/Activity	*Permitted* [4]	*Restricted Discretionary*	*Restricted Discretionary / Discretionary* [3]	*Non-complying*	*Restricted Discretionary*	*Permitted*
	Wairarapa RI –1230 ± 190 yrs RIC – ≤2000 yrs AEP – 0.03%	**Likelihood/Probability Parameters**	RIC I	Rare	0.03% AEP	-	-	-
		Hazard/Risk Parameters	Well defined	Tolerable Risk	Medium Risk	-	-	-
		Activity Status for BIC 2a Structure/Activity	*Non-complying*	*Restricted Discretionary*	*Restricted Discretionary / Discretionary* [3]	-	-	-
Testing of Re-Casted Probabilities [5]	**Shepherds Gully** RI – ~4000 yrs RIC – >3500 to ≤5000 yrs AEP – 0.03%	**Likelihood/Probability Parameters**	RIC III	Very Rare	0.029% AEP	-	-	Basis not provided
		Hazard/Risk Parameters	Well defined, distributed and uncertain	Acceptable	Medium Risk	-	-	Low Hazard
		Activity Status for BIC 2a Structure/Activity	*Permitted*	*Controlled*	*Restricted Discretionary / Discretionary* [3]	-	-	*Permitted*
	Pukerua RIC – >3500 to ≤5000 yrs AEP – 0.03%	**Likelihood/Probability Parameters**	RIC III	Very Rare	0.029% AEP	Extremely Unlikely	-	-
		Hazard/Risk Parameters	Well defined, distributed and uncertain	Acceptable	Medium Risk	Medium Hazard	-	-
		Activity Status for BIC 2a Structure/Activity	*Permitted*	*Controlled*	*Restricted Discretionary / Discretionary* [3]	*Discretionary*	-	-
	Moonshine RIC – >5000 to ≤10,000 yrs AEP – 0.01%	**Likelihood/Probability Parameters**	RIC IV	Very Rare	0.01% AEP	Extremely Unlikely	-	-
		Hazard/Risk Parameters	Well defined, distributed and uncertain	Acceptable	Medium Risk	Low Hazard	-	-
		Activity Status for BIC 2a Structure/Activity	*Permitted*	*Controlled*	*Restricted Discretionary / Discretionary* [3]	*Restricted Discretionary*	-	-
	Terawhiti RIC – >5000 to ≤10,000 yrs AEP – 0.01%	**Likelihood/Probability Parameters**	RIC IV	Very Rare	0.01% AEP	-	-	Basis not provided
		Hazard/Risk Parameters	Well defined, distributed and uncertain	Acceptable	Medium Risk	-	-	Low Hazard
		Activity Status for BIC 2a Structure/Activity	*Permitted*	*Controlled*	*Restricted Discretionary / Discretionary* [3]	-	-	*Permitted*

[1] Based on Primary Risk Analysis only.

[2] Provisions are based on the MfE Active Fault Guidelines.

[3] Based on risk thresholds in Saunders et al. (2013), where High Risk = intolerable, Medium Risk = tolerable and Low Risk = acceptable, as Regional Policy Statements do not include rules.

[4] The MfE Active Fault Guidelines note that this activity status could also be Controlled or Discretionary where the fault is well-defined.

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6.3 Discussion

Overall, the above comparison suggests that the use of fault-rupture probabilities for assessing risk would perform well, with consent activity status results being comparable across the frameworks tested.

Perhaps the best example of the impact of utilising a conditional probability within a risk-based planning framework is provided by the Wairarapa Fault. While it has a recurrence interval of 1230 $\pm$ 190 years, it last ruptured the surface relatively recently, in 1855. This means that, while it has a shorter recurrence interval that the Ōhariu Fault, it has a lower 100-year conditional probability of occurring. The consequence is that, while residential development within the FAZ of the Wairarapa Fault is a Non-Complying Activity in accordance with the MfE Active Fault Guidelines, which does not consider timing since last rupture, the low probability of rupture makes it a Restricted Discretionary Activity under the Saunders et al. (2013) approach and a Restricted Discretionary or Discretionary Activity under the BOP RPS framework. While this less-restrictive activity status might better reflect the current risk posed, care would need to be taken to avoid the perverse outcome where the lower probability of rupture would satisfy matters under section 6(h) of the RMA and result in development being permitted on a fault that actually presents a high hazard and significant risk, such as the Wairarapa Fault. This matter can be addressed through an approach where future guidance could require the more onerous of either:

- the recurrence interval of the fault, or
- the probability of fault rupture in the next 100 years.

This would avoid the perverse outcome identified. Conversely, in situations where faults have a long recurrence interval but a high probability of surface rupture, the use of 100-year conditional probabilities would capture this where the use of recurrence interval would not. In this way, the most appropriate land-use planning response could be determined.

The Ōhariu Fault presents a different case for applying a conditional probability to surface fault rupture. As explained by Morgenstern and Van Dissen (2021), because of the range of uncertainty in the recurrence interval estimates, the Ōhariu Fault spans several RICs. This can create difficulty when determining which RIC to use for the purposes of land-use planning. However, this is where the conditional probability can be used to help provide justification to the RIC category to assign to the fault. In the case of the Ōhariu Fault, the conditional probability of 0.049% equates to a RIC II categorisation under the MfE Active Fault Guidelines, which supports the classification that arises from use of the mean recurrence interval (being 2200 years) for the fault. Such a classification would still ensure most development forms on this fault are managed and would not result in a significant increase in risk.

While the testing of the re-casted fault recurrence intervals for lesser-known faults appeared to generate acceptable results, further testing would be required to confirm that this approach adequately accommodates the uncertainty in recurrence intervals. This testing highlighted the effect that the risk matrix can have on the risk assessment outcome. The BOP RPS risk matrix classifies all scenarios that have catastrophic consequences as at least a Medium Risk event. This means that the most permissive activity status that could apply within a FAZ in the Bay of Plenty region is Restricted Discretionary. Risk tolerances were decided through community engagement and technical and scientific advice, yet it is noted that the BOP RPS approach has not yet been tested in the region for active faults. The above testing has highlighted that the BOP RPS risk framework is not as nuanced for surface fault rupture as the MfE Active Fault Guidelines, or the approach by Saunders et al. (2013), as all faults aside from the

Wellington Fault were classified as Medium Risk. This will also be partly due to the assumption in the above assessment that all consequences from a fault rupture will be catastrophic, which may not necessarily be the case for lesser-known faults such as the Shepherds Gully and Terawhiti faults, particularly as they do not pass through any urban areas, although it is noted that critical infrastructure is over or in close proximity to these faults (Morgenstern and Van Dissen 2021). Therefore, under the BOP RPS framework, the consequences from a rupture of these faults may be reduced from 'catastrophic', where even 'major' consequences would reclassify the risk as Low, with a likely activity status for BIC 2a of Permitted under the Saunders et al. (2013) framework, which aligns better with what is in place in practise in the relevant district plans.

In addition to being cognisant of the effect of the risk matrix categories, the effect of the likelihood intervals must also be understood. For example, while the likelihood ranges presented in Table 6.1 are those proposed by Saunders et al. (2013), as they allow for the evaluation of multiple hazards within one framework, the Porirua proposed District Plan has tailored the likelihood intervals to suit the specific hazards faced by this district. This means that, if applied to a Wellington Fault rupture, for example (which does not impact Porirua City), it would result in this scenario being classified as 'very unlikely' (being a 1:501–1:2500-year event or AEP range of 0.04–0.2%) and a Medium Risk under the BOP RPS.

Overall, it is considered that a hybrid approach where the activity status to be applied is the most onerous from the risk assessment based on using recurrence interval as per the MfE Active Fault Guidelines, or probability within a multi-hazard risk-based planning framework, could be a workable solution. Where the value of the hybrid approach exists is where faults have a long recurrence interval. In these instances, the probability of rupture is likely to be much greater than indicated by the recurrence interval. As such, land-use planning measures may be needed to ensure that the risk for future development is managed. Under the current MfE Active Fault Guidelines, the potential land-use controls for low-recurrence faults can be light. The potential approach to use a probability of rupture would help address this issue and allow for improved planning around active faults, as it would assist with closing a gap in our current approach.

7.0 SUMMARY

Consideration of the lessons learnt from ground-surface-rupturing earthquakes in Aotearoa New Zealand and abroad clearly demonstrates the risk posed to life and property when buildings are constructed in zones of active-fault rupture, while, immediately outside these areas, the risk decreases markedly. Consequently, the use of FAZs continues to be widely accepted and applied in seismically active countries globally as a key method for reducing the risks from surface fault rupture.

Yet, our study notes that there remains a distinct challenge in convincing the public, politicians and decision-makers of the importance of managing the risk posed by surface fault rupture. One reason for this is the long recurrence interval of surface-rupturing earthquakes, which, in practise, means that management of the risk posed by surface fault rupture is superseded by planning issues that are perceived as more urgent.

One option to strengthen land-use planning for active faults in Aotearoa New Zealand is for it to be mandated through legislation, which was found by Lyles et al. (2014) to have a positive influence on plan quality, potentially as part of the forthcoming RMA reforms and proposed National Planning Framework. However, for this to succeed, there would have to be investment to fund the research required to ensure that the paleoseismic information required to successfully implement a risk-based approach was available.

In the absence of central government mandate, this proof of concept report confirms that, while the MfE Active Fault Guidelines remain a key tool in land-use planning for active faults, a revision is clearly overdue. The use of rupture probabilities was explored as an option for any revision, primarily to allow consideration of the risks from fault rupture in a common framework alongside other natural hazards, so that decision-makers, politicians and the public have a better understanding of the risk posed. While only a preliminary testing of the concept was undertaken, the results showed merit in this approach, both for well-known and lesser-known faults, but would benefit from more extensive testing.

Aside from this, matters that need to be addressed in a revision of the MfE guidelines include:

- Updates to reflect changes in legislation and planning approaches.
- Updates to the practical application of the guidance, including the use of FAAs.
- While the recommended mitigation strategy continues to be avoidance, more consideration needs to be given to circumstances in which engineering mitigation strategies appropriate and provide guidance on this. This would incorporate lessons from the Canterbury and Kaikōura earthquakes.
- Further consideration of how the risk-based approach of the MfE Active Fault Guidelines can be integrated into risk-based planning frameworks being used by local authorities around Aotearoa New Zealand (including further testing of the assigning of probabilities to fault rupture).
- Increased emphasis on the need for community engagement about what level of risk is acceptable. This is of particular importance when considering low-likelihood high-consequence hazards due to the inter-generational impact that planning decisions might have on future generations.

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APPENDICES

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APPENDIX 1 DISTRICT PLAN REVIEW

Table A1.1 Review of district plans in the Wellington region and Kaikōura to compare planning provisions for active fault hazards.

District Plan	Implemented MfE Active Fault Guidelines?	Policy Approach	Mapping	Activity Status of Residential Houses within Active Fault Areas	Activity Status of Subdivision
Wellington City Council Proposed District Plan	No	• Residential houses are considered 'Potentially Hazard-Sensitive Activities'. • Policy approach is to manage Potentially Hazard-Sensitive Activities, including additions to existing buildings, within the Wellington Fault and Ohariu Fault overlays by ensuring that the activity incorporates mitigation measures that ensure the risk from fault rupture to people, property and infrastructure is reduced or not increased.	Hazard overlays (e.g. Wellington Fault Overlay) on planning maps.	***Permitted*** Construction of a residential unit or conversion of any non-residential building into a residential unit in the Wellington Fault and Ohariu Fault overlays where: • The development involves the construction of no more than one additional residential unit to a site. • The total number of residential units on a site is no more than two.	***Discretionary*** Subdivision that creates building platforms for Potentially Hazard-Sensitive Activities within the Wellington Fault and Ohariu Fault overlays
Wellington City Council Operative Plan	No	• Policy approach is to ensure that structures within the Hazard (Fault Line) Area are not occupied by or developed for vulnerable uses. • Matters to consider for residential activities in the Hazard (Fault Line) Area include: - The extent to which the building height or construction type can be varied without jeopardising the safety of occupiers and neighbours. - Whether the development is located in the fault-rupture hazard area and the extent to which the siting and layout of the development will reduce the effects of fault rupture on the safety of occupiers and neighbours. - The extent to which a geotechnical report and an engineering design report show that the risk of building failure following a fault rupture can be reduced to minimise the effects of fault rupture on the safety of occupiers and neighbours.	Hazard (Fault Line) area identified in planning maps.	***Permitted*** In any Hazard (Fault Line) Area, provided that residential buildings shall be built with a light roof and light wall cladding and be no greater than 8 m in height.	***Controlled***
Porirua City Proposed District Plan 2020	Yes	• Residential houses are considered 'Hazard-Sensitive Activities'. • Policy approach is to avoid the establishment of Hazard-Sensitive Activities and Potentially Hazard-Sensitive Activities within the High-Hazard areas of the Natural Hazard Overlay unless the following is demonstrated: - critical need to locate there - mitigation measures to avoid risk to life and building damage - evacuation measures, or - risk to the activity or surrounding properties is avoided.	Hazard overlays (high, medium and low) in planning maps.	***Non-complying*** – any Hazard-Sensitive Activity and Potentially Hazard-Sensitive Activity and associated buildings within the High-Hazard areas in a Natural Hazard Overlay	***Non-complying*** – all subdivisions where the building platform would be located within an identified High-Hazard area
Porirua City Operative District Plan 1999	No	Policy approach seeks to minimise structural damage to buildings and utility services that straddle a fault.	'Seismic Hazard Areas' identified in planning maps. The notes to Planning Map 1 explain the nature of the information used to define the Seismic Hazard Areas. The width of this band reflects the accuracy of the known location of the fault.	***Permitted*** *Note: Essential Activities are Restricted Discretionary*	***Permitted***
Upper Hutt Operative District Plan 2004	No	Policy approach is that, in areas of known susceptibility to natural hazards, activities and buildings are to be designed and located to avoid, remedy or mitigate, where practicable, adverse effects of natural hazards on people, property and the environment.	Fault band identified in planning maps.	***Discretionary*** if within the fault band.	***Controlled***

District Plan	Implemented MfE Active Fault Guidelines?	Policy Approach	Mapping	Activity Status of Residential Houses within Active Fault Areas	Activity Status of Subdivision
Upper Hutt Plan Change 47	Yes	• Upper Hutt City Council are proposing to update the District Plan maps to identify the current understanding of the fault position. This would result in a plan change for the Wellington Fault and other natural hazards, with changes to the rules for development in these hazard-prone areas. • Residential buildings to be considered 'hazard-sensitive activities'. • Policy approach is to provide for Hazard-Sensitive and Potentially Hazard-Sensitive Activities within the poorly constrained or the uncertain constrained areas of the Wellington Fault Overlay and avoid those activities in the well-defined or well-defined extension areas of the Wellington Fault Overlay.	TBC.	***Restricted Discretionary*** in uncertain poorly constrained or the uncertain constrained areas of the Wellington Fault Overlay. OR ***Non Complying*** in the well-defined or well-defined extension areas of the Wellington Fault Overlay.	***Restricted Discretionary*** in uncertain poorly constrained or the uncertain constrained areas of the Wellington Fault Overlay OR ***Non Complying*** in the well-defined or well-defined extension areas of the Wellington Fault Overlay
Lower Hutt Operative District Plan 2021	No	-	Wellington Fault Special Study Area identified in planning maps.	***Restricted Discretionary*** if within the Wellington Fault Special Study Area	***Controlled***
Wairarapa Combined District Plan 2021	No	Policy approach is to control the location and design of land use and subdivision in identified areas of significant risk from natural hazards to avoid, remedy or mitigate adverse effects, with the controls appropriate to the level of risks.	Faultline Hazard Areas are identified on the planning maps. There are three types, differentiated by the accuracy of the information known about each fault line.	***Discretionary*** Any new structure containing a habitable room, or additions or alterations to a habitable room of an existing structure, shall not be constructed or located within the Faultline Hazard Area identified on the Planning Maps. *(District Wide Land Use Rule 21.6)*	***Controlled***
Kāpiti Coast Operative District Plan 2021	Yes	Policy approach for development within fault avoidance areas is to consider a range of matters that seek to reduce the risk of building failure (excluding minor buildings) and loss of life from a fault rupture hazard (e.g. geotechnical information, design, construction techniques, etc).	Five active fault traces identified. Fault Avoidance Areas (i.e. a buffer around fault traces) are identified on planning maps.	***Permitted*** (for Type 2a) or ***Restricted Discretionary*** (for Type 2b) in the Distributed, Uncertain Constrained and Uncertain Poorly Constrained areas for the Ōhariu and Northern Ōhariu faults.	***Restricted Discretionary –*** subdivision proposing additional developable lots where any part of the land is in the Fault Avoidance Area ***Discretionary*** – subdivision where any part of the land is within the Fault Avoidance Area for all of the Ōhariu and Northern Ōhariu faults
Kaikōura Natural Hazards Plan Change 3	Yes	A residential house is a Hazard-Sensitive Building. Policy approach relating to land use and development is: 1. Enabled only where there is an acceptable risk to life and property. 2. Avoided for Hazard-Sensitive Buildings in the Fault Avoidance Overlay where these result in an unacceptable risk to life and property; 3. Managed for Hazard-Sensitive Buildings in the Fault Awareness Overlay by locating the building away from the fault or where it can be demonstrated that mitigation measures will result in an acceptable risk to life and property. *Note: While there are many active faults in the district, the fault avoidance zones and fault awareness areas do not directly affect Kaikōura's township. However, they do affect some of the smaller settlements (Oaro and Kēkerengū).*	Fault avoidance zones and fault awareness areas identified on planning maps.	***Restricted Discretionary*** in the fault avoidance zones and fault awareness areas. *Note: Additions to existing dwellings are **Permitted.***	***Restricted Discretionary –*** subdivision locating a platform for a new hazard-sensitive building in fault awareness areas ***Non Complying –*** subdivision locating a platform for a new hazard-sensitive building in fault avoidance zones
Kaikōura Operative District Plan 2008	No	Policy approach to avoid or mitigate loss of life, damage to assets or infrastructure and disruption to the community as a result of natural hazard events. No specific policy context around active faults.	No	***Permitted***	***Controlled***

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