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Managing Active Fault Surface Rupture Risk through Land Use Planning: barriers and opportunities

Abstract
This article reflects on the management of active fault surface rupture hazard after the Canterbury and Kaikōura earthquakes. To understand mitigation barriers, interviews were conducted with planners and natural hazard risk specialists in selected districts with active faults, but without land use provisions. The interviews revealed issues with the interpretation and implementation of the Ministry for the Environment's Active Fault Guidelines, *Planning for Development of Land on or Close to Active Faults: a guideline to assist resource management planners in New Zealand*. The purpose and intended use of the New Zealand Active Faults Database (NZAFD) is also explored.

Keywords land use planning, active fault, surface rupture, natural hazard, guidance

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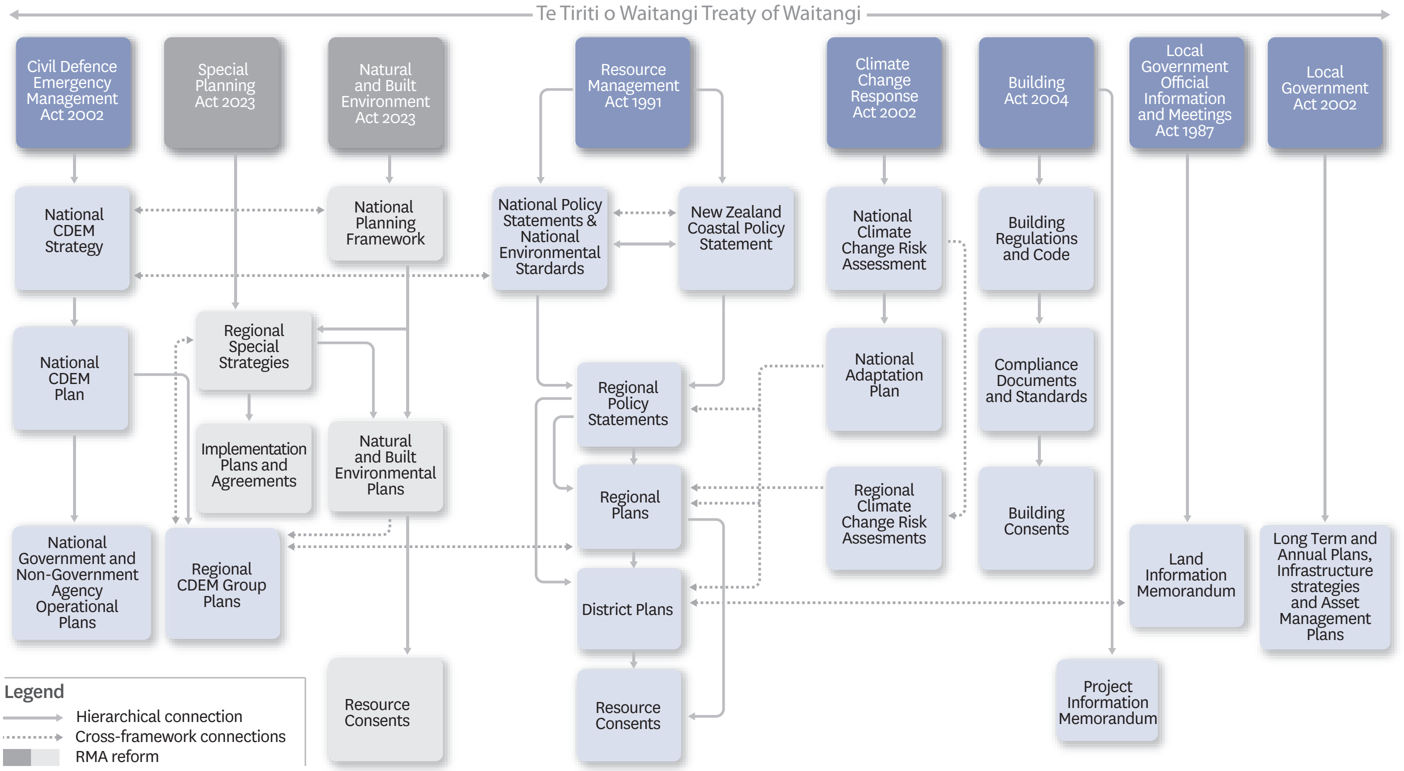
In recent years, Aotearoa New Zealand has been rocked, literally and figuratively, by large earthquakes near Christchurch and Kaikōura. Lives were lost, property and infrastructure were damaged, and the physical environment was substantially altered. Over a decade later, recovery from these events continues. In the aftermath, the Resource Management Act 1991 (RMA) was amended, elevating natural hazards to a 'matter of national importance' requiring 'the management of significant risks from natural hazards' (s6(h)). Resource management has been further refined through the Natural and Built Environment Act 2023, requiring as a 'system outcome' that the 'risks arising from natural hazards and the effects of climate change are reduced' (s6(4)).

This article explores the New Zealand Active Faults Database (NZAFD), a database of active faults compiled and hosted by GNS Science, and barriers to its use in land use planning. The principal issues identified are:

Figure 1: The Natural Hazards Statutory Framework from the draft GNS Science Landslide Guidelines



Notes:
- The Natural Hazards Insurance Act 2023 has not yet been incorporated into this diagram.
- Planning documents recognised by an iwi authority, non-statutory guidance and hazard management strategies are also used by Councils when preparing Resource Management plans.
- The Local Government Official Information and Meeting Act was updated in 2023 to include further direction on LIM details and information sharing.

Source: GNS Science (n.d.)

- the usability of the spatial scale of the publicly available data;
- identification of priority areas; and
- incorporation of non-GNS Science data.

Issues with the Ministry for the Environment's 2003 Active Fault Guidelines (MAFG) were also identified alongside initial interpretation of the NZAFD for plan development. These are:

- the use, appropriateness and alignment of average recurrence intervals and the way in which these are managed for active faults relative to other natural hazards;
- the level of uncertainty for some fault complexity classes and its potential impact on the resource consent activity status: these are both barriers to the effective use of the MAFG for many authorities interviewed;
- that the guidelines are now two decades old and arguably no longer current, as they no longer reflect planning practice; and
- that the Natural and Built Environment Act, the Spatial Planning Act and the draft National Policy Statement for Natural Hazard Decisions further outdate the guidelines.

Legislative context

The legislative context of natural hazards has previously been explored in articles including Glavovic, Saunders and Becker (2010), Saunders et al. (2007, 2015), Saunders and Beban (2012) and Saunders and Kilvington (2016) and is shown in Figure 1. The MAFG do not have statutory weight but are a tool in natural hazard risk management (alongside other hazard management strategies). The authors of the guidelines state:

> We hope that using these guidelines will help to avoid or mitigate the risks associated with building on or close to active faults. Different planning approaches are appropriate in different areas – councils can establish appropriate policies and criteria which are more or less restrictive than those represented here if necessary. (Kerr et al., 2003, p.1)

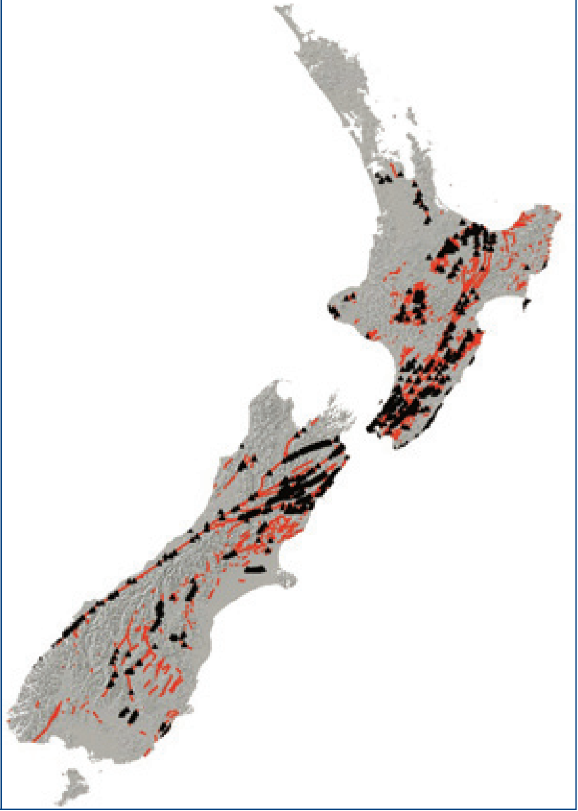
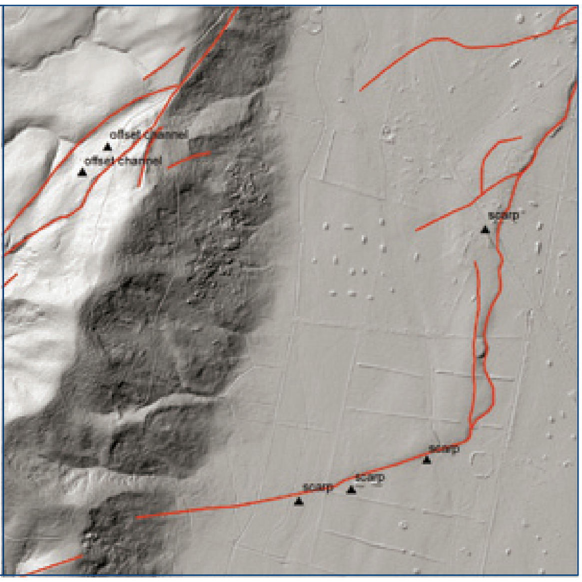
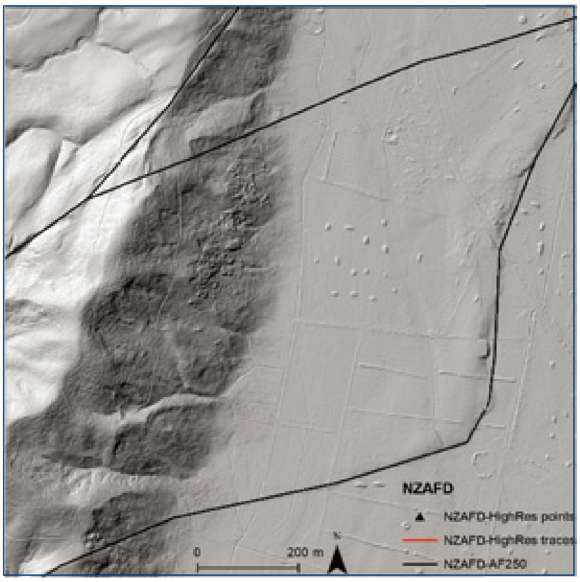
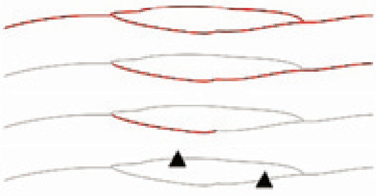
The MAFG set out a risk-based approach to managing risk to life, property and environment, as well as post-event recovery. They do not direct councils to use the NZAFD, but it is used in many regions.

Active faults as natural hazards

Most earthquakes are generated when one side of a geological fault moves relative to the other,[1] in response to a build-up of stress and/or strain. When earthquakes are large enough (generally $M_w>6.5$) and have an epicentre close to the earth's surface (i.e., within 15 km) this can cause a natural hazard known as surface fault rupture. This co-seismic tearing of the ground surface can result in a hazard to life safety through the impact on the natural and built environment.

Understanding of where surface ruptures have occurred in the past has improved with the increased quality and availability of aerial imagery and light detection and ranging (LiDAR) data, as well as physical fault processes. Locations are captured and compiled at a national scale in the NZAFD by GNS Science. This database contains geospatial data (points, lines, polygons) and tables that describe the location and characteristics of known

Figure 2: A comparison between the high-resolution (NZAFD-HighRes) and regional-scale (NZAFD-AF250) versions of the NZAFD highlighting the difference in mapping detail, scale and appropriate use of each

	NZAFD-HighRes	NZAFD-AF250
Spatial extent		
Mapping detail	 	
Feature geometry	Faults (1st order) Sections (2nd order) Traces (3rd order) Points (4th order) 	Faults 
Mapping Scale	Ranges from 1:500 – 1:250,000 (generally ≤1:10,000)	1:250,000
Projection (datum)	NZ Map Grid (NZGD1949)	NZ Transverse Mercator (NZGD2000)
Appropriate use	Research, land use planning at 1:5000-10,000	Regional scale portrayal at 1:250,000
Access	Students via licence, WMS (selected areas), Councils	GNS NZAFD website, WMS, QMAP active faults

Note: WMS is web map service; QMAP is the national, quarter million (1:250,000 scale) digital geological mapping project Source: GNS Science, 2023 terrestrial faults which show evidence of surface rupture and/or deformation in the last 125,000 years.[2] Such spatial active fault data is necessary for generating fault avoidance zones (from the MAFG) and fault awareness areas (Barrell, Jack and Gadsby, 2015). These databases are explored in more detail in Figure 2.

- NZAFD-AF250 is publicly available, designed for regional portrayal and simplified to a consistent scale of 1:250,000 (i.e., 1 cm on the map is equivalent to 250,000 cms on the ground).[3] It is not intended for land use planning purposes.
- NZAFD-HighRes ranges from 1:500 to 1:250,000 scale. Much of it is suitable for land use planning purposes; however, the entire dataset is not publicly available through the GNS Science Web Map Service (WMS).[4]

Despite ongoing efforts to reduce surface fault rupture risks in Aotearoa New Zealand, challenges exist which inhibit the data being useful or used as intended. While exploring the challenges in active fault hazard management, this article also clarifies the purpose and intended use of the data and addresses misconceptions in relation to it, where possible.

Methodology

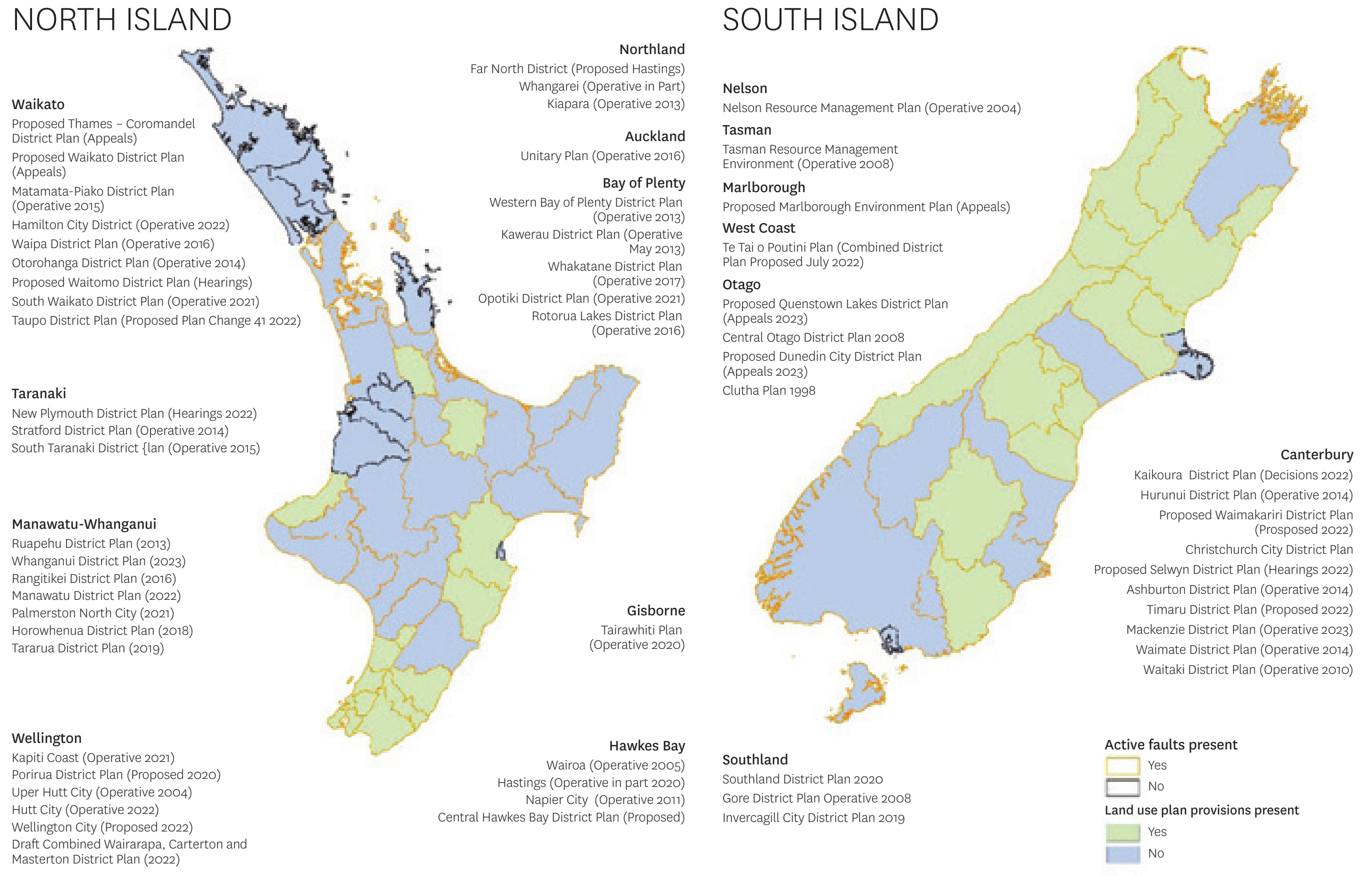
A comparison was made between the NZAFD and proposed/operative district plans[5] to identify which districts have active faults but do not currently have land use provisions (see Figure 3). Councils without land use provisions were then approached to participate in an interview, with human ethics approval granted by GNS Science. Due to ongoing recovery from ex-tropical cyclones Gabrielle and Hale and previous flood events, only one North Island council participated. Five South Island councils participated. Participants included planners and natural hazard risk specialists. To allow council officers to speak freely, the points raised in these interviews have been organised thematically and have not been attributed to a specific individual or territorial authority.

The purpose of the interview was to understand: their knowledge of the NZAFD; how it, fault awareness areas and fault avoidance zones can be used; and the MAFG and any barriers or challenges they face in implementing a management approach for reducing the risk from surface rupture hazards.

Issues with the New Zealand Active Faults Database

All of the officers interviewed were aware of the NZAFD. The 1:250,000 mapping scale of the publicly available NZAFD-AF250 was mentioned by all interviewees as a barrier to use. The MAFG outline that the appropriate scale for land use planning is ≤1:10,000. At a scale greater than that it is not defensible to restrict development. Much of the NZAFD-HighRes is of appropriate scale for planning. However, due to a lack of long-term funding for the NZAFD, there is sometimes a considerable time lag between the completion of a detailed fault mapping study and entering it into the NZAFD-HighRes. As a result, publicly available NZAFD-HighRes data is generally only available upon request, but it comes with disclaimers as the data quality and currency cannot be guaranteed, or it is only available in selected areas where the data has been reviewed and updated, which can be viewed on the GNS Science or council web map portals.

Figure 3: Map of Aotearoa New Zealand showing districts with and without active faults, and with and without land use



The interviewees commented consistently that the ≤1:10,000-scale mapping recommended in the MAFG is not an appropriate scale to be used in rural areas. In the Canterbury region a separate guideline was developed for regional-scale (1:250,000) fault information (Barrell, Jack and Gadsby, 2015), which uses fault awareness areas. This was in recognition that the cost to map at ≤1:10,000 scale (i.e., generating fault avoidance zones) for a large region with many largely unpopulated and mountainous areas was unjustifiable, and, at the time, high-resolution basemaps that would facilitate such detailed mapping (e.g., LiDAR data) were sparse in rural areas and expensive to collect. A multi-year, nationwide project is underway to improve LiDAR coverage across Aotearoa New Zealand. Data is being released following LINZ and regional council quality assurance processes. These high-resolution basemaps will remove this barrier and make district-wide accurate fault mapping much easier.

A participant commented that while there is the opportunity to use LiDAR data to improve fault location accuracy, they felt strongly that LiDAR mapping only is not sufficient. GNS Science and this participant have both stressed that ground truthing and obtaining paleoseismic data are still required when certainty in fault location and characteristics is needed. For example, a geophysical survey or a paleoseismic trench can be very useful to demonstrate and refine the location of a fault and to obtain information about the magnitude, frequency and likelihood of ground-surface rupturing earthquakes. These techniques can also be used to better define the fault deformation zone (zone of likely future surface rupture) and to potentially reduce the fault avoidance zone width. One participant commented that when this ground truthing is needed, it is unclear as to the depth to which surface faults are to be trenched. Typically, as this hazard is specific to the surface rupture, it is not necessary or practical to dig more than a few metres at strategically placed trench sites – this varies between and along faults depending on characteristics such as the type and age of the near-surface sediments, width and complexity of the fault, and local geomorphology.

All respondents commented that they would share data gathered through their own research and consent processes, but that there is currently no pathway to do so for councils that have not commissioned GNS Science to update their data, or for incorporation of new data.

Activity is not always demonstrable: for example, if the near-surface sediments are unsuitable (e.g., too thick or coarse) to clearly see fault offsets, expert judgement is often required based on available data. As a general rule, faults with a clearer surface expression (e.g., a distinct scarp) are generally more active or have ruptured more recently, so will be easier to identify in a trench. Surface expression is also an important criterion for whether active faults are included in the NZAFD or not. For example, if a fault is concealed beneath sediments along much of its length, it will not be included as it cannot be mapped, although short gaps between sections that can be mapped will be included in the NZAFD. Blind or buried active faults – such as the north-eastern end of the Awanui Fault that ruptured in the 1931 Napier earthquake or the Port Hills Fault that ruptured in the 2011 Christchurch earthquake – are faults that do not yet reach the ground surface/have not ruptured the ground surface in the past and therefore have no surface expression. The NZAFD currently does not include these features, and their hazard cannot be defined using traditional trenching techniques or even LiDAR.

For one territorial authority the NZAFD would only be used when there was nothing else available. This authority has gathered its own data through research projects and through resource consent requirements. In urban areas and some specific rural areas their own gathered data is more accurate than what is available through the NZAFD. Other regions have also gathered their own data over years through multiple sources, sometimes including data through GNS Science contracts, but also incorporating data provided through resource consent processes. While the NZAFD is a national database, there is nothing to compel a territorial authority to use it. Moreover, a regional council compiling a database for use by the territorial authorities gives effect in part to section 30(1)(c)(iv)[6] of the RMA. One territorial authority spans a regional boundary, and it uses meshed data, partially NZAFD and partially the regional council database.

There is a willingness to share data gathered by territorial authorities and regional councils with GNS Science and for this to be incorporated into the NZAFD. All respondents commented that they would share data gathered through their own research and consent processes, but that there is currently no pathway to do so for councils that have not commissioned GNS Science to update their data, or for incorporation of new data. A potential future development that would be valued by councils is the ability to incorporate their own data into the NZAFD. This could occur if there was capability and capacity within the council to input this data. If this is not possible, then councils will have to maintain and continue to use their own; however, using two different databases is not an efficient use of resources. Some territorial authorities commented that if this became possible in the future, a condition of doing this would be that they expected to use NZAFD-HighRes without incurring a cost. It also was unclear to participants what the database maintenance frequency is, including being notified of updates. These ideas are aligned with GNS Science's aspirations for the database.

The cartography and connectivity of the NZAFD web map was also discussed, including whether there is the opportunity for the NZAFD to use the same cartography as standard geotechnical cartography, such as dotted and dashed lines where faults are inferred or concealed. This is something that could be explored in the future. The addition of linking reports relating to specific faults through the database would also be very useful. This is already possible for selected faults in NZAFD-HighRes,[7] but not in NZAFD-AF250 because this mapping is simplified and the scale is unsuitable for planning purposes. This allows users to understand the methodology used, limitations and recommendations for use.

The use of 'priority areas' was also discussed, as these are used in some GNS Science reports accompanying updated data. The setting of these priorities was queried, and whether these are areas identified by GNS Science as gaps in the database, or whether they are areas with current/future development pressure, is not clear. The use of priority areas is study specific. For some, the priority areas were defined by the council as areas of planned development. For others, the priority areas were defined by GNS Science in consultation with the council as areas where detailed examination is to be undertaken (e.g., near towns), compared with less time spent on the wider (rural) areas. There have been recent examples where active faults have been newly recognised in or near rural townships, which has only now been made possible with widespread LiDAR acquisition and studies focused specifically on active fault mapping. This is illustrated by one participant who commented that their research focuses on better understanding the location of specific faults close to a large primary industry employer, as its ongoing function is critical to the district's economic wellbeing. The participant identified that further trenching to understand the location and likely fault rupture characteristics is necessary to improve certainty and apply a hazard buffer area. There might not be active fault data currently held in that area, so the process may inadvertently exclude this area if they are not involved in selecting the priority areas. Two authorities commented that it was critical that prioritisation was undertaken robustly to ensure targeted mapping and effective use of the data.

Earthquake science and risk-based management of natural hazards have evolved since the MAFG were first created, and after two decades of their use some aspects no longer align with current practice.

One respondent commented that surface fault rupture is a difficult concept to grasp, unless its effects have been seen on the ground during recent times, such as in the Kaikōura area after the 2016 earthquake. This raises an inherent contradiction: it is easier to accurately locate a fault immediately after its rupture, but, although this is true, the identification of the fault, and application of plan provisions to reduce the risks arising from surface rupture, will be much more effective before the event happens. Some of the faults with long average recurrence intervals[8] are difficult to accurately locate due to their more subtle nature in the landscape (e.g., due to younger erosional/depositional processes or anthropogenic modification) and are therefore more easily dismissed as being irrelevant at human timescales, but they could still present a substantial risk because time since the last surface-rupturing earthquake is not considered in the current MAFG. For example, the average recurrence interval of the Greendale Fault near Darfield has been assessed as being ca 10,000–20,000 years (Van Dissen et al., 2015), and yet it ruptured in 2010. This has been raised in the report *Active Fault Guidelines v2.0: proof of concept* (Gunnell, Jones and Beban, 2022), which tested whether assigning a probability to any surface rupture had the potential to better convey the risk arising from fault rupture hazards.

Issues with the Alpine Fault Guidelines

The respondents commented that recurrence interval classes (Table 1) seemed arbitrary rather than a rigorous estimate of likelihood within the average recurrence window. The linking of recurrence intervals with building importance categories and assigning a resource consent activity status based on that means that there needs to be a reason for them, but why those classes are used is not clear. None of the councils interviewed that are intending to put forward provisions were going to include faults with 20,000–125,000-year recurrence intervals (RI Class VI). The recurrence intervals used in the MAFG also raised a broader query in relation to the variety of recurrence intervals used in management of other natural hazards: for example, guidelines on flooding and sea level rise have far shorter intervals than geohazards (typically 100 years, but these will reduce with climate change). The average recurrence intervals are also not easily relatable to the minimum 50-year building life in the Building Act. The emerging use of the percentage chance that a fault may rupture in a year, rather than using a recurrence interval, may address this implementation gap. For example, the AF8 programme[9] notes a 75% probability of an Alpine Fault rupture occurring within 50 years, and a four out of five chance that it will be greater than a magnitude 8 earthquake. Gunnell, Jones and Beban (2022) explored this concept

Table 1. Current classification of active fault parameters used in the MAFG

Fault recurrence interval (RI) classes	Less than or equal to 2000 years (RI Class I)
	Between 2,000 and 3,500 years (RI Class II)
	Between 3,500 and 5,000 years (RI Class III)
	Between 5,000 and 10,000 years (RI Class IV)
	Between 10,000 and 20,000 years (RI Class V)
	Between 20,000 and 125,000 years (RI Class VI)
Fault complexity classes	Well defined
	Distributed
	Uncertain

There are five building importance categories which the MAFG suggest are then overlaid with the above parameters.

within the Wellington region, with a 100-year conditional probability of rupture determined for the Wellington Fault of 11%, 4.9% for the Ōhariu Fault and 3% for the Wairarapa Fault. There are challenges with this approach, though, as this type of information is only available for a few faults with a large amount of paleoseismic data, and care needs to be taken not to create a perverse outcome whereby once a fault has ruptured, the probability becomes so low that the planning framework may allow or potentially permit building across the fault.

Concern with the level of uncertainty in the parameters used in the MAFG was a repetitive theme from the respondents. One region does not use them due to technical concerns with the underlying data. Specifically, the variety of recurrence intervals and the uncertainty in fault complexity (Table 1) are such that they are not confident of the magnitude and likelihood of the hazard, and how they can convey that to the public in terms of risk. Being able to convey the information to those without technical expertise is needed to change this. Another district does not consider the NZAFD data to be robust enough, and so discretionary resource consent is the most restrictive required by them. They state that the data is simply not strong enough to be able to defend a non-complying or prohibited activity status for resource consent. To reduce uncertainty in this district, subdivision consent triggers the need for geotechnical investigation, which in turn can be used to refine the fault location information. This 'user-pays' model also ensures that the ratepayer does not have to fund the investigation. Another participant said the fault complexity parameter will influence the provisions they put forward in terms of objectives, policies and subdivision rules pertaining to active faults. This includes discretionary rules for critical facilities such as emergency services and utilities, and for infrastructure such as landfills. They say rules to manage residential activities will not be included due to the fault complexity parameter resulting in a high degree of uncertainty for the data in that area. For them, the NZAFD will only be used as an informative tool.

Without site-specific investigations, uncertainty around fault parameters can sometimes be difficult to reduce at the district scale. One territorial authority has chosen to completely remove their fault avoidance provisions in their proposed district plan. The reasons for this are several. The council feels that as there is so much deposited material over the fault traces, there is such a degree of uncertainty about the precise location that using land use provisions is not effective or efficient. Due to the degree of uncertainty, they determined that buffers either side of possible traces are inappropriately restrictive for them, as this is likely to include 'good' ground due to the large spatial uncertainty. The council has instead focused on RMA subdivision provisions requiring geotechnical investigation in all rural areas as well as earthquake strengthening building controls in all areas, which address a lot of the issues that fault avoidance was trying to manage. Through this council's implementation experience, they explained, it is very apparent that network infrastructure providers avoid the riskiest areas, often undertaking their own hazard and risk investigations, as it is not in their interests to invest in such places. Therefore, the council considered it unnecessary to put in place highly restrictive rules for network providers. It is noted that many utility providers are also requiring authorities opening designations as a planning pathway to resource consent.

Earthquake science and risk-based management of natural hazards have evolved since the MAFG were first created, and after two decades of their use some aspects no longer align with current practice. For example, it was commented that the guidelines treat all potential ruptures as likely having the same magnitude. It is perhaps not well understood that only magnitude 6.5 and higher earthquakes are likely to result in a surface rupture, so smaller magnitude ruptures are inherently not included. However, faults within the NZAFD are likely to rupture at a range of magnitude 6.5 and greater, and the rupture damage (displacement) will be larger for higher magnitude earthquakes. Understanding potential displacement and being able to evaluate that against the type of development on a fault would allow for a more refined risk-based approach incorporating consequence (exposure and vulnerability). For example, a region may have significant infrastructure such as an airport or hospital proximate to a fault with a 6.5 forecast rupture magnitude (tens of centimetres of displacement) and a long recurrence interval (e.g., 10,000 years). This region might also be crossed by another fault with a short recurrence interval (e.g., <2,000 years) and a forecast magnitude 7.5+ rupture (many metres of displacement) with little or no development proximate to it aside from individual dwellings in rural areas. The fault with the infrastructure is of much greater concern and carries much greater risk than the one with the forecast higher magnitude rupture.

A territorial authority commented that fault avoidance zones and fault awareness areas are only used in the remote rural areas of their region, where little or no development occurs. It suggests that these provisions are not considered appropriate for urban areas, or for rural areas where activities may occur, including infrastructure provision. One reason for this is that the MAFG do not recognise infrastructure innovation in building materials, including simple things like flexible joins in water pipes. The MAFG may unintentionally be restricting development where it could be accommodated with these kinds of tools.

In another region it was suggested that the fault avoidance zones do not work as tools outside urban areas because (it was believed) they were designed to only manage risk in urban areas. Also, that they are not suitable for critical response facilities, nor for critical infrastructure. While the participant did not expand upon this point, the lead author's own experience in developing district plan provisions is drawn upon to understand this issue. Critical response facilities need to be accessible and functional for all types of natural hazard events for response and recovery. Many parts of Aotearoa New Zealand are subject to more than one type of natural hazard. By avoiding locating these facilities close to active faults to reduce the risk of them not being available or risk to life within them, they may inadvertently not be accessible for other and more frequent types of responses, such as as a flood evacuation centre. Critical infrastructure – for example, electricity generation – may, if following the MAFG, be a non-complying activity. It is assumed that the restriction was included in the MAFG to ensure that electricity provision was possible post-event. However, the level of restriction may make it very challenging for a community to function pre-event. For example, a run-of-the-river hydrological electricity generation plant on a river may be sited on one side of a fault, with the community using it on the other side of the fault. The facilities then cross the potential fault zone and would likely be displaced and fail in a future rupture. However, there may be contingency in place for that community to run on generators, or to switch to another part of the grid. This highlights the need to consider the potential for multi-hazard risk analysis or guidance, rather than considering each hazard and its effects on risk in isolation.

The [Active Fault] guidelines are only attempting to address surface rupture hazards, not ground shaking or cascading hazards such as liquefaction, subsidence, uplift, earthquake-triggered landslides, seiche or tsunami.

One region expressed concern that the MAFG do not address cascading hazards from earthquake fault rupture. The guidelines are only attempting to address surface rupture hazards, not ground shaking or cascading hazards such as liquefaction, subsidence, uplift, earthquake-triggered landslides, seiche or tsunami. There are separate guidelines for the management of liquefaction and tsunami. As noted earlier, there is no active trace of the blind Port Hills Fault in Ōtautahi Christchurch in the NZAFD, where the loss of life is still in recent memory and the damage is still being repaired. Blind fault ruptures are not included in the NZAFD nor MAFG, and users must look elsewhere for information, such as the National Seismic Hazard Model (https://nshm.gns.cri.nz/; Gerstenberger et al., 2022). An alternative approach was put forward by one participant, that focusing provisions on the maximum credible event and the effects, severity, and outcome being sought may be a more effective way of avoiding the risk from rupture. Other provisions outside the MAFG are needed that address and reduce these wider hazards. For example, an offshore fault rupture could potentially create significant onshore effects that are not covered by the MAFG. One authority is seeking funding to undertake mapping of the offshore extension of their onshore faults as they attempt to address this risk.

A point raised by many of the participants is the need for acceptance of RMA plan rules. A critical component of any plan is its implementation. If plan users do not accept the need for restrictions, then developing and implementing plan provisions will be extremely challenging.

The difficulties with applying the MAFG when there are breaks in the observable surface fault trace were also raised. Where the trace cannot be located due to, for example, sediment deposition since the last event, such as an alluvial fan, there are two options – either not applying provisions, or applying a wider buffer to account for the uncertainty. Neither of these are considered appropriate by this participant. Concern was also raised by the participant that the MAFG currently do not account for the style of faulting. In recent years fault avoidance zones generated by GNS Science recognise observations from historical earthquakes that the zone of deformation on the hanging wall (uplifted) side of reverse faults is wider. A wider buffer is therefore applied on the hanging wall side than on the footwall side of such faults.

Lastly, it was raised that, as more faults are discovered, could or should more fault avoidance zones and fault awareness areas be applied. This could lead to large parts of territories being covered with restrictive provisions. The participant suggested that this may not be the most efficient or effective way of managing fault rupture risk and that instead relying on the earthquake strengthening Building Act regulations may be a more appropriate method in places. Future revisions of the MAFG should consider all the tools to manage risks from surface fault rupture efficiently and appropriately.

As we learn more from natural hazard events, the need to plan more effectively to maximise our resilience is ever more critical. The current resource management reforms refocus this again and require Crown research institutes to 'support Regional Planning Committees' (Spatial Planning Act 2023, s67(1)(b)). This may provide an opportunity to improve the way we manage and communicate the risk from active fault surface rupture.

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[1] Faults can have either horizontal (strike-slip) or vertical (dip-slip) displacement across them, or a combination of the two (oblique).

[2] The exceptions to this definition are: (1) the inclusion of offshore faults that ruptured during the 2016 Kaikōura earthquake; and (2) the definition of activity is restricted to only include the last 25,000 years for the rapidly evolving Taupō Rift in the central North Island (Langridge et al., 2016).

[3] NZAFD-AF250 is designed to integrate with QMAP's 1:250,000 scale active fault layer (GNS Science, 2023) and is well-known around the country. It was published by Langridge et al. (2016) and is available to be queried, viewed and downloaded in a variety of formats from the GNS Science NZAFD web map at https://data.gns.cri.nz/af/. Metadata can be found on the GNS Science dataset catalogue at https://doi.org/10.21420/R1QN-BM52.

[4] Currently, selected high-resolution traces are available to be viewed via a GIS-based WMS, on the GNS Science ArcGIS server, which is republished as new data is entered. The REST service for the database is available here: https://gis.gns.cri.nz/server/rest/services/NZAFD/ActiveFaultsDatabase/MapServer. Councils also hold a copy of the NZAFD-HighRes data for their region if they have commissioned an active fault mapping study.

[5] If a territorial authority has a proposed and an operative district plan, only the proposed plan was reviewed and included in Figure 3.

[6] The regional council function to control the use of land for the purpose of the avoidance or mitigation of natural hazards.

[7] Some councils are already tapping into the GNS Science WMS and directly displaying publicly available NZAFD-HighRes data – including links to the GNS Science reports which are downloadable – on their hazard web map portals (e.g., https://gis.hbrc.govt.nz/hazards/). For the WMS, the GIS is only available to be viewed at this stage; however, a copy of both the report and GIS can be downloaded or requested from councils, where public and available.

[8] The average time between ground surface-rupturing earthquakes. These are used in the MAFG, as shown in Table 1.

[9] The AF8 (Alpine Fault magnitude 8) programme combines scientific modelling, community engagement and response planning to build resilience to a large future Alpine Fault earthquake.

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