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Designing and Implementing a Fault Avoidance Zone strategy for the Alpine Fault in the West Coast region

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ABSTRACT: GNS Science has been working closely with West Coast Regional Council to develop a Fault Avoidance Zone (FAZ) for the Alpine Fault in its region. The Alpine Fault is a Class I fault (according to the MfE Guidelines) with a recurrence interval of 300-500 yr. Expected single-event displacements range from 6-9 m horizontal and 1-2 m vertical. In terms of likelihood, the Alpine Fault is the most likely fault in New Zealand to cause surface rupture within the design lifetime of built structures, therefore, it is imperative to develop a strategy to mitigate against the next surface rupture on the fault. An initial FAZ of width 100-340 m has been presented to WCRC and has been disseminated down to District Council level where planning and building consent decisions are made. With respect to engineering outcomes, at least 5 priority areas were recognised where communities may be affected by their proximity to the zone of deformation along the fault. These include: Maruia River; Haupiri River; Inchbonnie; Toaroha River; and Franz Josef. The impacts to the town of Franz Josef particularly, have been recognised as the most serious in terms of life safety, hazard mitigation and post-event recovery. The FAZ there is currently defined to a width of 190 m and encompasses structures in the town that include hotels, houses, petrol and police stations. Franz Josef has been earmarked for further detailed mapping using LiDAR imagery, which will lead to a revised FAZ and a strategy for future town planning.

INTRODUCTION

1.1 *Project Philosophy*

The Alpine Fault is recognised as one of the major active geological faults of New Zealand. From southwest to northeast, the fault runs from offshore of Fiordland, through the West Coast region (Fig. 1), through Marlborough toward Cook Strait, where it is known as the Wairau Fault. Surface rupture of the Alpine Fault during the next large to great earthquake on the fault was recognised by the West Coast Regional Council (WCRC) as a significant hazard to the people and property of its region. Therefore, WCRC and GNS Science collaborated on a FRST Envirolink project to develop a Fault Avoidance Zone strategy for the Alpine Fault throughout the length of the West Coast's three Districts: Buller, Grey, and Westland (Langridge & Ries, 2009). This strategy follows the Ministry for the Environment guidelines for active faulting (Kerr et al., 2003) which promote the development of planning around the hazard of future surface rupture of active faults in New Zealand.

1.2 *The Alpine Fault*

The dextral-reverse Alpine Fault is the major active tectonic feature related to the Australia-Pacific plate boundary through South Island (Berryman et al., 1992;) (Fig. 1). In the central part of the island, the Alpine Fault strikes NE-SW through the West Coast region, and has a dextral slip rate of c. 25 mm/yr and a reverse slip rate of up to 12 mm/yr (Norris & Cooper 2001; Sutherland et al., 2003). The Alpine Fault is capable of generating an earthquake of c. Mw 7.8- 8 every 300-500 years (Sutherland et al., 2007; Rhoades & Van Dissen 2003). Rupture of the fault during the next large earthquake event will cause surface deformation along and around the fault trace over a distance of hundreds of kilometres. Estimates of the single-event displacement during the next earthquake are c. 6-9 m horizontal and 1-2 m vertical (;).

The most recent rupture of the Alpine Fault is pre-historic and probably occurred during the early part of the 18th century. This event is typically assigned an age of AD 1717 ± 5 yr (Yetton). In terms of recurrence interval and based on the Ministry for the Environment's guidelines for building on or adjacent to faults (MfE guidelines; Kerr et al. 2003), the Alpine Fault is a Class I active fault, i.e. its recurrence interval is ≤ 2000 yr. In addition, the fault is considered to be near the end of its current earthquake cycle. Some estimates place the likelihood of the next large to great earthquake rupture as being between 25-33% probability in the next 50 yr (Rhoades & Van Dissen 2003). As this event has a considerable probability of occurrence it is important to consider the hazard from surface rupture to the people and infrastructure of the West Coast.

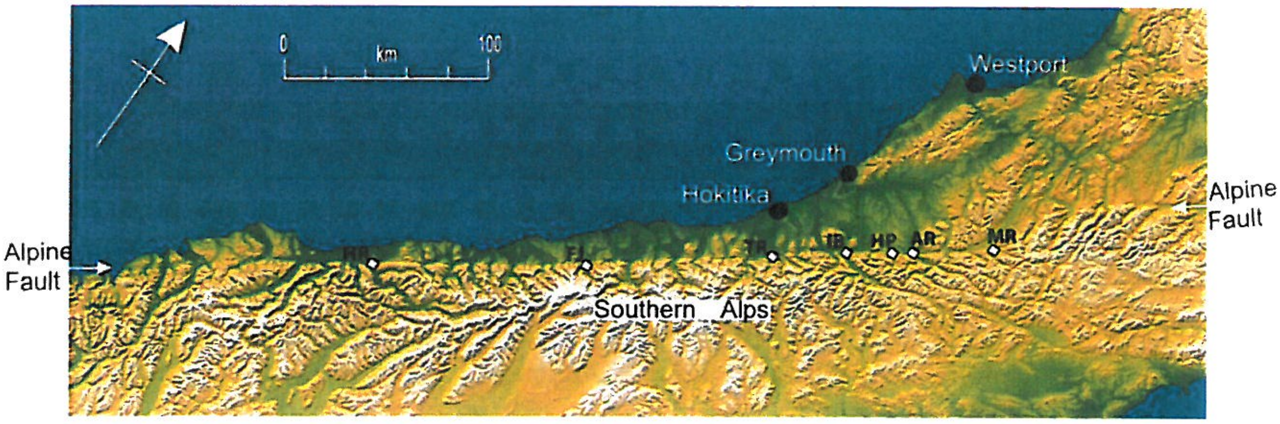

Figure 1 Colour digital model of the Alpine Fault in the West Coast region, shown between Milford Sound and Nelson Lakes (white arrows). The main centres of the region are shown along with a number of moderate to high impact 'priority' areas along the fault (white circles). The priority areas are: HR, Haast River; FJ, Franz Josef; TR, Toaroha River; IB, Inchbonnie; HP, Haupiri River; AR, Ahaura River; and MR, Maruia River.

2 METHODOLOGY

The initial strategy for mapping the Alpine Fault and creating a Fault Avoidance Zone (FAZ) focused around the recognition of priority areas where the Alpine Fault crossed through populated communities. These areas are predominantly in valleys where large rivers emanate from the Southern Alps and cross the Alpine Fault, e.g. Inchbonnie, Maruia River, and correspond with land clearance in these valleys. The most populated centre that is founded across the fault is the tourist town of Franz Josef in Westland District. After designing a Fault Avoidance Zone strategy based on a wide variety of mapping sources, it was decided that a FAZ could be developed for the entire length of the Alpine Fault through West Coast region, covering the estate of the largest landowner on the West Coast; the Department of Conservation.

2.1 *Sources of mapping data*

In this project a number of pre-existing mapping sources of varying scale were used to locate the rupture traces of the Alpine Fault. These include: GNS Science QMap geological maps (e.g. Cox & Barrell 2007; Nathan et al., 2000); publicly-available Otago University mapping, late Quaternary mapping (e.g. Yetton 2000; Berryman 1975), and other published maps (e.g. Berryman et al., 1992; Langridge & McSaveney 2007). In addition, unpublished data from current GNS Science projects where GPS was used to create topographic maps were included. A limited amount of field work and field checking was undertaken to reduce the uncertainty from the smaller-scale mapping sources (Langridge & Ries 2009).

The quality of fault trace location data is subjectively assessed as a function of scale and for this project it was necessary to create a hierarchy of data quality. For example, QMap geological maps are produced at a scale of 1:250,000. The line data is generalised from a scale of 1:50,000 but would lose its integrity if it were used at a large-scale. University of Otago mapping data which is publicly-available on the Internet (see reference list) has a nominal scale of 1:50,000. Late Quaternary maps are typically produced at a scale of 1:10,000 and fault traces are shown as individual elements that can step laterally across young depositional surfaces (Yetton 2000; Berryman 1975; Langridge et al., 2010a). Mapping from RTK-GPS surveying can be considered as being at a scale of better than 1:10,000 when the map is georeferenced to the NZ benchmark system (Fig. 2). Many areas have more than one source of mapping data at differing scales. All data was uploaded into a GIS where maps could be georeferenced and assessed.

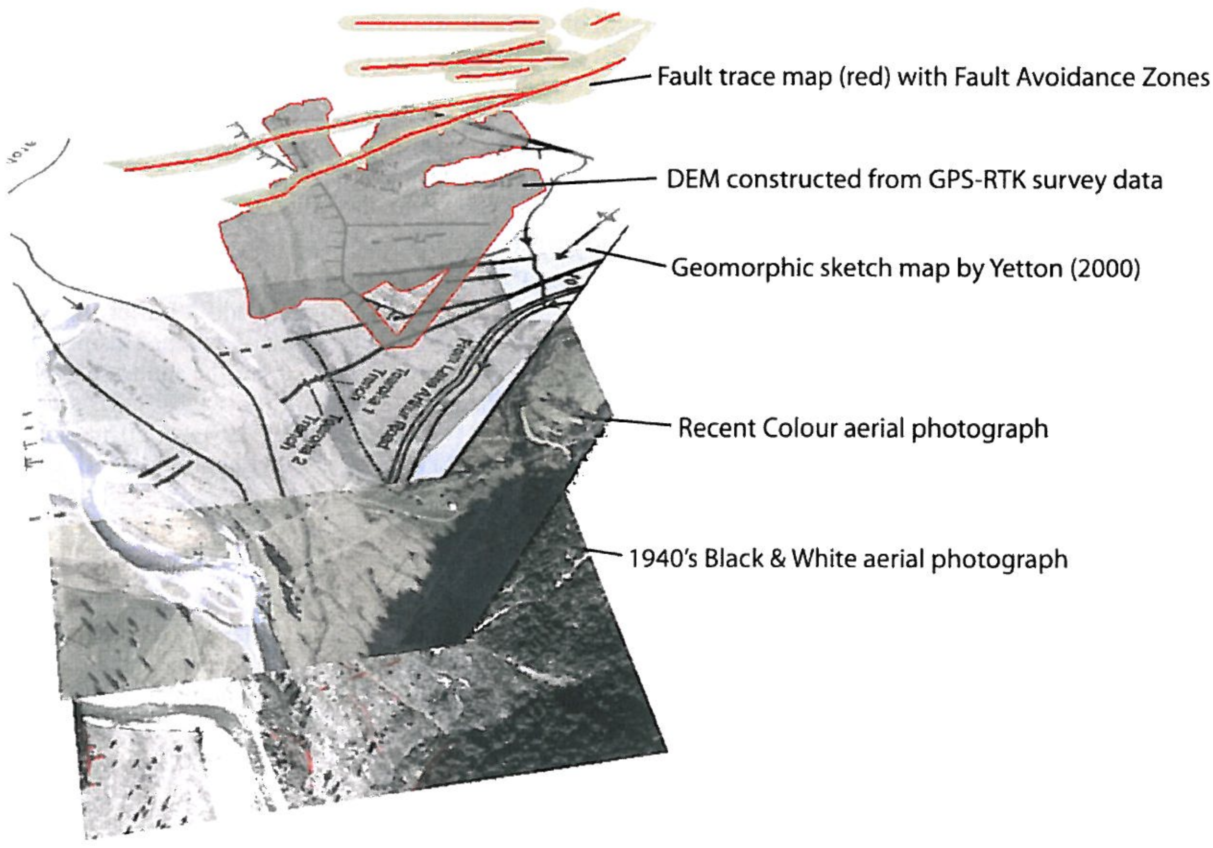

Figure 2 Data layers within the project GIS at the Toaroha River - one of the more open, data-rich areas along the Alpine Fault. Data sources there include aerial photographs, late Quaternary trace maps, RTK-GPS topographic data. The output of mapping includes a fault trace map (red lines) with Fault Avoidance zones (green) about them. The main fault traces here have been confirmed through mapping and from the logging of paleoseismic trenches (Yetton 2000; Langridge et al. 2009).

Most recently, funding was attained to fly a LiDAR mission along the Alpine Fault between south of Franz Josef and north of the Whataroa River. A 2-m digital elevation model (DEM) was created from the LiDAR survey data (Langridge et al. (2010b). This data will be used to update the initial FAZ presented in Langridge & Ries (2009) for use by Westland District Council.

2.2 *Applying the mapping data*

For any given part of the fault, the best possible data was used to create the FAZ about the Alpine Fault. Each part was attributed with a level of fault location accuracy defined by its scale, e.g. for QMap linework the accuracy of the data is deemed to be ± 100 m. In terms of the MfE guidelines, this is equivalent to a fault location that is "Uncertain – Poorly Constrained" (Van Dissen & Heroin 2004; Kerr et al., 2003). This is a reasonable level of uncertainty given the scale of the mapping, which is often through rugged bush-covered country along the rangefront of the Alpine Fault. The fault linework is the best representation of the possible rupture trace of the fault. The lowest trace location uncertainty (± 20 m) is applied to accurate data such as from RTK-GPS maps at trench sites. This is equivalent to the term "Well Constrained" in Van Dissen & Heron (2004).

Global examples of surface faulting along reverse faults, such as the 1999 Chi-Chi (Taiwan) earthquake (Brundson et al., 2000; Kelson et al., 2000), show that deformation is asymmetric with a concentrated zone of surface damage on the upthrown or hangingwall side of the fault[1]. Therefore, with respect to the Alpine Fault, it was deemed practical to assume that the upthrown side of the fault will comprise a broader zone of deformation than on the footwall (downthrown) side. Such a strategy was previously applied to reverse faults in the Hawke's Bay region (Langridge & Villamor 2007; Langridge et al, 2006). Along most of the length of the fault, the upthrown side is to the southeast with Pacific plate rocks overthrusting the West Coast coastal plain ( ). However, in South Westland, south of Haast, the sense of vertical motion changes to neutral (i.e. pure strike-slip) and even west-side-up where the fault occurs in Fiordland (Berryman et al., 1992). This has been taken into account when designing the asymmetric side of the FAZ. In addition, it has also been recognised that individual traces can occur as back thrusts that dip to the northwest, as are seen at small stepovers on the fault at Inchbonnie (Langridge et al. 2010a). Such traces have been asymmetrically buffered to the northwest.

In practice, the fault location uncertainty has been doubled on the hangingwall side of fault traces. Therefore, the fault location uncertainty applied to QMap linework is ± 100 m + 100 m (= 300 m) (Fig. 3). Finally, it is outlined as standard practice in the MfE guidelines to add a buffer of ± 20 m around fault scarps or fault trace location. Therefore, in practice, the FAZ developed using QMap linework has a total width of 340 m, which is asymmetrically weighted about the fault trace (which represents the best estimate of where the rupture trace occurs). These are the widest FAZ's created about the Alpine Fault. The narrowest FAZ's are 100 m wide (± 20 m + 20 m ± 20 m) and are asymmetrically weighted around fault traces mapped onto RTK-GPS maps (Langridge & Ries 2009) (Fig. 3).

3 RESULTS

The results of this strategy are the production of a sausage-shaped Fault Avoidance Zone (FAZ) along the length of the Alpine Fault in West Coast region. Figure 3 shows the generic case of the change in width of the FAZ with varying scale/ line quality from 100-340 m width, while the inset shows a cross-sectional view of the fault zone. Figure 4 shows an example of the FAZ as applied to the Maruia River area in Buller District.

3.1 *Priority mapping areas*

Several priority mapping areas were originally defined for the project. These include: Maruia River (Fig. 4); Ahaura and Haupiri Rivers; Inchbonnie and Lake Poerua; Styx to Toaroha Rivers; Franz Josef; and Haast River. One of the largest communities living near the Alpine Fault is the Gloriavale

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[1] The dominant sense of movement on the Alpine Fault is dextral, while reverse movement is secondary.

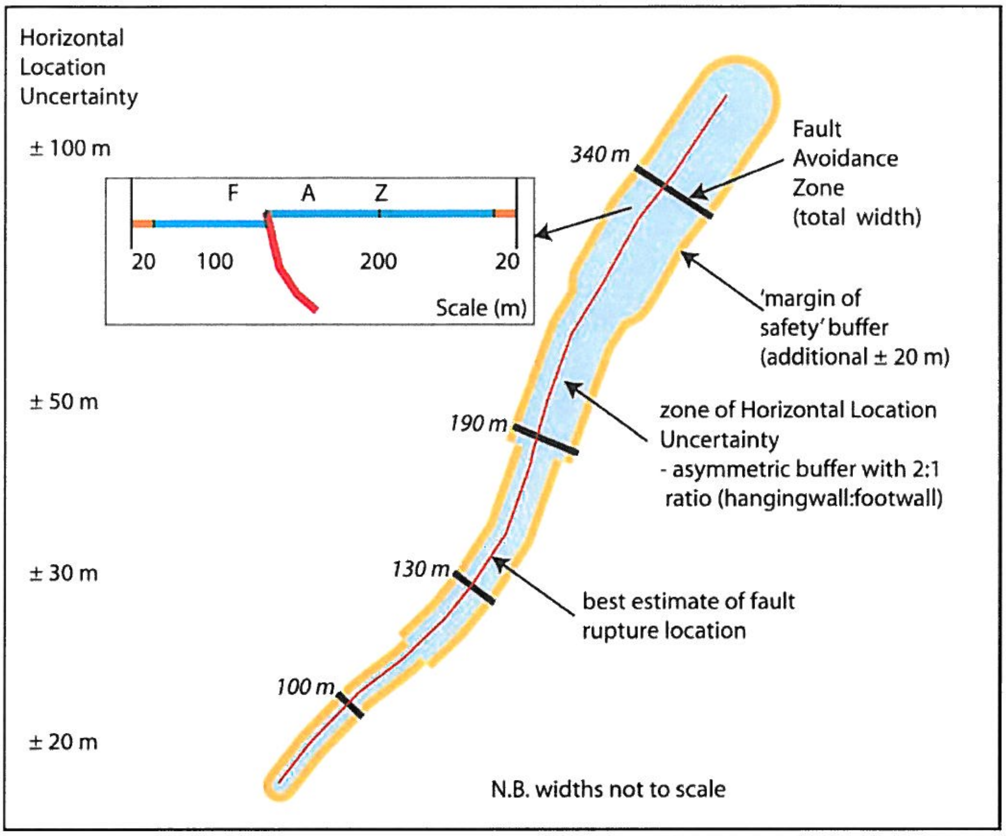

Figure 3 Fault Avoidance Zones (FAZ) for the Alpine Fault. Each FAZ consists of the fault trace (red line), plus a base (Horizontal Location) uncertainty. This uncertainty is doubled on the hangingwall side of the fault, creating the 'Asymmetric buffer' (blue). Added to this buffer is the 'margin of safety' buffer of ± 20 m (orange). Note: this example is applicable to a SE-dipping Alpine Fault. Inset: A cross section of the elements that make up the FAZ for the case of ± 100 m Horizontal Location uncertainty.

Christian Community near the Haupiri River. This group of buildings appears to be several hundred metres to the northwest of the active trace of the fault, so is therefore not likely to be affected by surface faulting related to the Alpine Fault. At Inchbonnie, the Alpine Fault crosses alluvial terraces of the Taramakau River (Berryman 1975; Berryman et al., 1992; Langridge et al., 2010a). The fault strikes NE-SW and also forms the southeastern edge of Lake Poerua (Langridge & McSaveney, 2007). A subdivision application with Grey District for this area is currently under appeal.

The Styx to Toaroha rivers area is a parcel of open farmland to the southeast of Hokitika. The fault trace has been well-mapped in this area, e.g. Yetton (2000). Yetton produced sketch maps at two scales and also excavated paleoseismic trenches near the Toaroha and Kokatahi rivers. Further mapping, including the construction of a RTK-GPS map and additional trenching was undertaken by GNS Science in 2009 (Langridge et al., 2009). At Haast River, the Alpine Fault crosses alluvial terraces southeast of the township. There is currently no development near the fault in this area.

Arguably the most critical community along the entire length of the Alpine Fault is the town of Franz Josef, a rapidly developing tourist centre in Westland District. It has long been known that the trace of the Alpine Fault runs obliquely through the town, as a fault scarp. From southwest to northeast, the fault scarp runs from below the DoC National Park headquarters, across State Highway 6 and Condon, Cron and Cowan streets. At present through this area the scarp has a FAZ of width 190 m shown in Langridge & Ries (2009). This FAZ encompasses a several important buildings and businesses including a new Police Station, Mobil petrol station, motels and also houses.

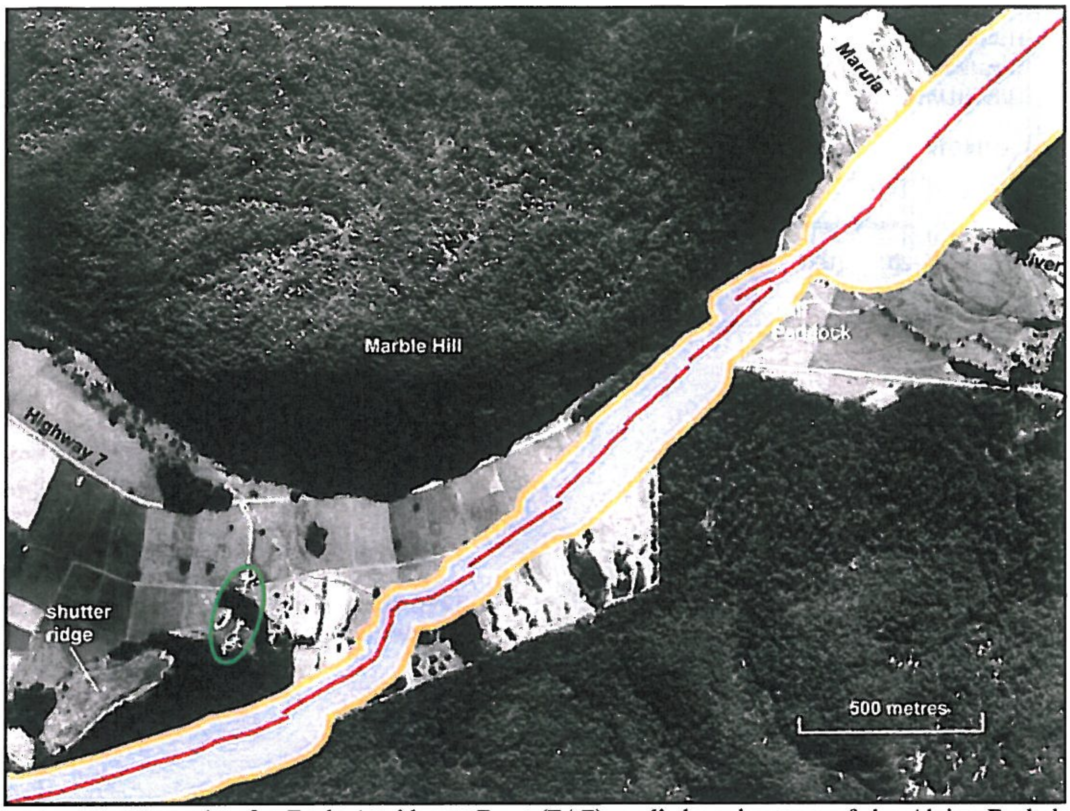

Figure 4 An example of a Fault Avoidance Zone (FAZ) applied to the trace of the Alpine Fault in the Springs Junction-Maruia River area (scale c. 1:10,000). The blue strip represents the Horizontal Location Uncertainty and the Asymmetric Deformation buffer, i.e. twice the width on the hangingwall side of the fault. The entire FAZ for this area includes the orange 'margin of safety' (± 20 m) about the blue strip. The Lewis Pass Motels occur directly to the northeast of the shutter ridge within the green oval.

4 CONSEQUENCES OF FAULT AVOIDANCE ZONE MAPPING

The Alpine Fault is a RI Class I active fault, with surface faulting earthquake events expected at least once every 2000 years (Kerr et al. 2003; Van Dissen et al., 2003). Tables within the MfE guidelines outline the types of buildings (structures) that can be consented within a FAZ about a Class I fault like the Alpine Fault. In both the cases of a 'previously developed or subdivided' zone or 'Greenfield' zone the only consentable building type is a Building Importance Class (BIC) I structure, i.e. a Temporary structure. This is in accordance with the tenets of the MfE guidelines which are designed to consider life safety and post-disaster resilience. Along most of the length of the Alpine Fault there are few locations where buildings are located within the FAZ designed by Langridge & Ries (2009). The main exception, as stated above is the town of Franz Josef.

GNS Science is working closely with WCRC, Westland District Council and local development groups to consider a path forward for Franz Josef township. At present the 190 m-wide FAZ through the town implies that the fault location is only moderately well constrained. Current and future studies will endeavour to better constrain the location of the fault trace and scarp. The scarp is a rather broad feature that rises across the southeast part of the town. In May 2010 a RTK-GPS map was constructed by GNS Science. Following this a c. 33 km long Alpine Fault LiDAR mapping project was funded. LiDAR data from the Franz Josef area will be used to map and profile the fault there, to create a more appropriate FAZ for the town. At present, there are several buildings of BIC 3 (Normal) and even 4 (Critical) and several more homes (BIC 2) within the FAZ at Franz Josef.

The FAZ's defined by Langridge & Ries (2009) act as a guide to the possible zone of surface deformation across and adjacent to the Alpine Fault. It is clearly defined in the MfE guidelines that further geological and/or surveying work can be undertaken to better characterise and even reduce the width of the zone of fault deformation (Kerr et al., 2003).

5 CONCLUSIONS

- Mapping linework has been collated for the Alpine Fault along the length of West Coast region for the purposes of developing a Fault Avoidance Zone (FAZ) that considers the hazard of surface faulting. GNS Science is working closely with the West Coast Regional Council to promote the use of FAZ's for planning future development along the fault. The strategy involves developing FAZ's that are based on the MfE guidelines for
- In terms of recurrence interval, the Alpine Fault is a Class I active fault (i.e., RI < 2000 yr). A large to great earthquake and surface rupture of the Alpine Fault has a high probability of occurrence in the next 50 yr. Surface displacements are expected to be 6-9 m (horizontal) and 1-2 m (vertical).
- Fault linework has come from a variety of sources at varying scales The accuracy of fault location, which is a measure of where the expected rupture trace of the fault lies, varies from ± 20 to ± 100 m. Due to the component of reverse movement on the Alpine Fault, the width of this zone has been doubled on the hangingwall side of the fault.
- The total width of the FAZ along the fault varies between 100-340 m. The narrowest, best defined FAZ's occur where there is high quality late Quaternary fault mapping and RTK-GPS maps. The widest FAZ's occur where the linework comes from compilation or reconnaissance level mapping (QMap/ Otago University mapping).
- Several priority areas have detailed map coverage of FAZ's. These typically occur where roads and rivers cross the fault trace, and where land has been cleared for farming and development, e.g. Toaroha and Haupiri river areas. These areas, therefore, have some of the highest quality map data and narrowest FAZ's.
- The town of Franz Josef in Westland District straddles the scarp of the Alpine Fault. The current width of the FAZ through the town is 190 m. Current and future efforts will attempt to better define the FAZ for Franz Josef, using mapping tools such as LiDAR, and to offer planning solutions for its future.
- The MfE guidelines show that for a Class I active fault the only consentable structures are of Building Importance Class (BIC) I in both the cases of previously developed or subdivided, and Greenfield land status.
- Fault Avoidance Zones provide a basis for defining the hazard of surface rupture. Further geological and/or surveying work can lead to a better definition and reduction of the width of the FAZ's.
- Results from this work have been passed on to WCRC and have been disseminated to the District Councils (Buller, Grey, and Westland) for consideration and uptake into their District plans.

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