Planning for a safer Franz Josef-Waiau community, Westland District: considering rupture of the Alpine Fault

R.M. Langridge J.G. Beban

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CONTENTS

FIGURES

TABLES

APPENDICES

EXECUTIVE SUMMARY

GNS Science has undertaken mapping and analysis of the Alpine fault in the Franz Josef-Waiau area in order to develop Fault Avoidance Zones, through the town of Franz Josef and to the areas northeast of the town between Tartare Stream and Stony Creek.

The Alpine Fault is a Recurrence Interval (RI) Class I fault with a recurrence interval of <2000 yr (average recurrence interval is c. 333 yr). The last fault rupture event is believed to have occurred around AD 1717. The single-event displacement in the next earthquake is expected to be c. 8-9 m horizontal and 1-2 m vertical. The probability of rupture of the Alpine Fault in the next 30 yr is estimated to be c. 20%. Therefore, there is a measureable risk to both life and property as a consequence of the next Alpine Fault rupture through the town of Franz Josef.

A RTK-GPS map was made in the town of Franz Josef which helped define the topographic scarp of the Alpine Fault, which runs SW-NE through the southern part of the commercial portion of the town. LiDAR imagery was used to accurately define active fault traces (reverse and strike-slip), fold traces, and lineaments created by deformation related to the Alpine Fault Zone in a GIS.

Based on the mapped fault structures, individual and merged Fault Avoidance Zones were developed for the town. Individual reverse fault traces have a Fault Avoidance Zone width of 130 m that comprises a ±30 m Fault Location Uncertainty, which is doubled on the hangingwall side of the fault, due to the asymmetric nature of deformation. A ±20 m Margin of Safety buffer is added to this 90 m wide zone. Individual strike-slip faults have a Fault Avoidance Zone width of 100 m, as it is asserted that the deformation is relatively symmetric across these faults. Where there are multiple fault traces across the width of deformation a merged Fault Avoidance Zone is developed. Along the rangefront of the Alpine Fault where there are often multiple fault traces, these merged zones can be hundreds of metres in width.

In the developed part of Franz Josef township a number of buildings ranging from Building Importance Class (BIC) 1 to BIC 4 exist within or close to the 130 m wide Fault Avoidance Zone. These include hotel/motel accommodations, the police station, a petrol station, a supermarket, shops and the Dept. of Conservation National Park headquarters. In the area between Tartare Stream and Stony Creek there is currently very little development, i.e. the area is mostly in a 'greenfield' situation. Only a small portion of the current road plan enters the Fault Avoidance Zone near Stony Creek.

The Resource Management Act 1991 tasks Councils with developing rules, objectives and policies to mitigate the effects from natural hazards within their jurisdiction. Currently, the West Coast Regional Policy Statement (2000) identifies the need to mitigate the effects associated with the Alpine Fault rupturing. However, there are no rules within the Westland Council District Plan which controls development within close proximity to the Alpine Fault.

Several potential planning responses have been identified within this report which could be used to control development within close proximity to the Alpine Fault. These mitigation measures include the creation of Fault Avoidance Zones, adopting a risk based planning approach, preparing a pre-event recovery plan and relocation of essential services away from the Fault Avoidance Zone. While no single approach has been recommended in isolation, it is likely that a variety of the above measures will best address the effects

associated with the Alpine Fault rupturing. The combination and the degree to which each approach are implemented by the council will need to be determined through consultation with the local community.

The methodology for implementing a risk-based planning approach has been provided within this report. A risk based approach could be incorporated in the Westland Council District Plan when the objectives, policies and rules are developed to control development within the identified Fault Avoidance Zone. A risk-based planning approach would enable more robust planning decisions to be made, as it allows for the full consideration of the consequences resulting from Alpine Fault rupture on future developments.

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1.0 INTRODUCTION

1.1 Project Outline and Brief

GNS Science and the West Coast Regional Council (WCRC) have received funding through the FRST Envirolink Program to provide further advice regarding active fault avoidance and planning measures for the Alpine Fault. In particular, the township of Franz Josef/Waiau and surrounding areas in the Westland district have been recognised as the most significant communities at risk from surface rupture along the Alpine Fault.

The dual aims of this project are:

(i) To better characterise a fault surface rupture planning zone (“Fault Avoidance Zone”) where the Franz Josef-Waiau community has potential to be adversely affected, and

(ii) To assist the West Coast Regional Council (WCRC) and Westland District Council (WDC) in making informed decisions with regards to the social, economic and political implications of this process, while developing plans for community resilience.

The project brief stated that:

The earthquake science aspect of this project would deliver, in paper and GIS shape files:

- A detailed Fault Avoidance Zone (FAZ) for the greater Franz Josef-Waiau area developed from LiDAR digital elevation models (DEMs)
- “Ground truthing” of that FAZ using GPS/geo-referencing to establish areas where development will/will not be subject to fault rupture; and

The social science aspect of this project would deliver, in paper/e-format:

- Discussion about risk reduction (ways and means); and
- Possible planning responses to the adverse effects faced by the community.

The current work builds on a region-wide report written for WCRC and Envirolink by GNS Science (Langridge and Ries, 2010). That report collated map information for the Alpine Fault along its entire length in the West Coast region. The Langridge and Ries (2010) report concluded that for developed areas along the fault such as at Franz Josef township, the level of mapping accuracy provided by QMap (1:250,000 scale) and University of Otago mapping (1:50,000 scale) was insufficient to create useful FAZs for these areas.

The first chapter of this report introduces the Alpine Fault, Ministry for the Environment’s (MfE) Guidelines and outcomes from the Langridge and Ries (2010) report in regards to Franz Josef. Chapters 2 and 3 outline the new mapping and fault avoidance methodologies and presents maps of the Franz Josef-Waiau area. Chapter 4 discusses the geological implications of surface faulting and the FAZs that have been developed. Chapter 5 provides a review of current legislation regarding natural hazards and planning. Chapter 6 identifies several planning approaches to managing further development on the Alpine Fault and Chapter 7 provides a risk-based approach to land use planning for these towns. The report concludes with recommendations regarding the future planning of these communities for Westland District Council to consider.

1.2 Neotectonics of the Alpine Fault

New Zealand lies within the plate boundary zone between the Australian and Pacific plates (Fig. 1). The area administered by West Coast Regional Council (WCRC) lies within one of the most active parts of this deformation zone. The Alpine Fault forms the main plate boundary structure through the central South Island and forms the link between the Hikurangi and Fiordland subduction zones (Berryman et al. 1992). Other active faults within West Coast region include those parts of the Marlborough Fault System that are west of the Main Divide (e.g. the Kelly Fault), and faults west of the Alpine Fault, such as those of the Paparoa Tectonic Zone (e.g. Maimai, Lower Buller and Inangahua faults etc.) (Ghisetti and Sibson 2006).

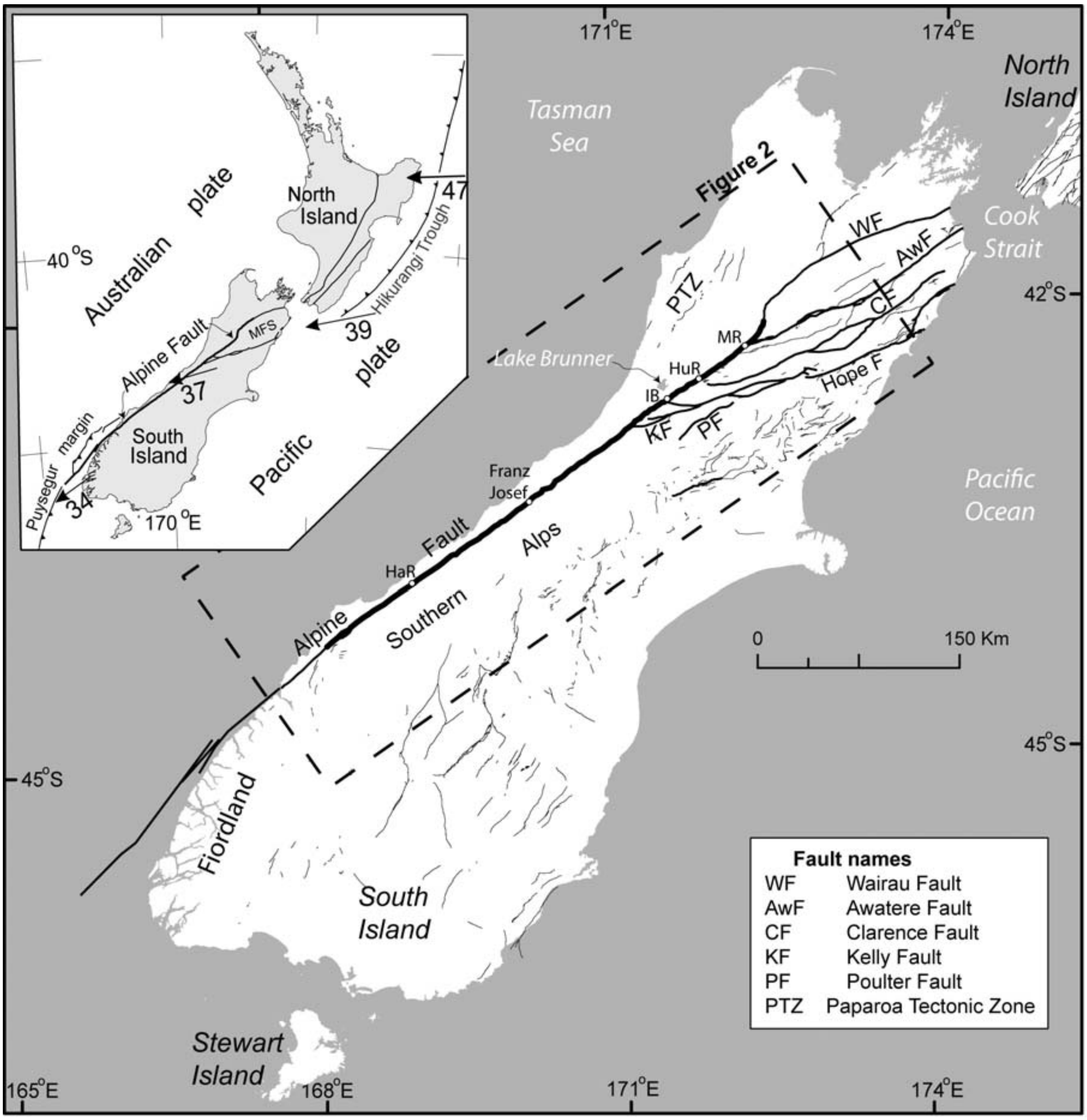

Figure 1 Active fault map (black & grey lines) of South Island highlighting the Alpine Fault (bold within West Coast region). Faults are derived from the GNS Science Active Faults database (http://data.gns.cri.nz/af/). Inset: Plate tectonic setting of New Zealand, including the locations of subduction margins and the Marlborough Fault System (MFS). Relative motion between the Pacific and Australian plates is shown in mm/yr from De Mets et al. (1994).

The Alpine Fault is one of the most studied faults in New Zealand and the general location of the fault has been known for a long time (Wellman, 1953; Walcott and Cresswell 1979 and papers therein; Berryman et al. 1992). Geologic maps show the Alpine Fault as one of the major tectonic features of South Island (e.g. Bowen 1964; Nathan et al, 2002; Cox and Barrell, 2007). The Alpine Fault is recognised onland from Milford Sound to the Nelson Lakes area; a distance of c. 500 km (Fig. 2). East of the Nelson Lakes, the Alpine Fault is referred to as the Wairau Fault. Long-term, strike-slip displacements of bedrock terranes have occurred across the combined Alpine-Wairau Fault (Fig. 1). The Alpine Fault also continues offshore to the southwest of Milford Sound as an active strike-slip[1] fault across the continental shelf of Fiordland (e.g. Barnes 2009). Despite the prominence of the Alpine Fault, it has been difficult to map onland due to the thick forest cover and is often poorly characterised at a scale that is useful for planning purposes.

The Alpine Fault has not ruptured during the modern period of New Zealand history, i.e. since the beginning of European colonisation in AD 1840, and for some time the low level of seismicity along the fault was taken by some as an indication that the fault was inactive. However, paleoseismic studies of the Alpine Fault have revealed that large to great earthquakes (M 7.8-8) have occurred on the fault several times during the last millennium (Adams 1979; Berryman et al. 1992; Sutherland et al., 2007). Consensus at present points towards a large earthquake rupture at c. AD 1717, with other large rupture events having occurred at c. AD 1615 (±5 yr), c. AD 1430 (±15 yr) and AD 1230 (±50 yr) (Yetton 2000; Rhoades and Van Dissen, 2003; Wells and Goff, 2007; Wells et al. 1999, 2001). The average recurrence interval for rupture events along the Central segment of the fault, i.e. between Milford Sound and Hokitika, using average values for displacement of c. 9 m and a slip rate of 27 mm/yr is c. 333 years.

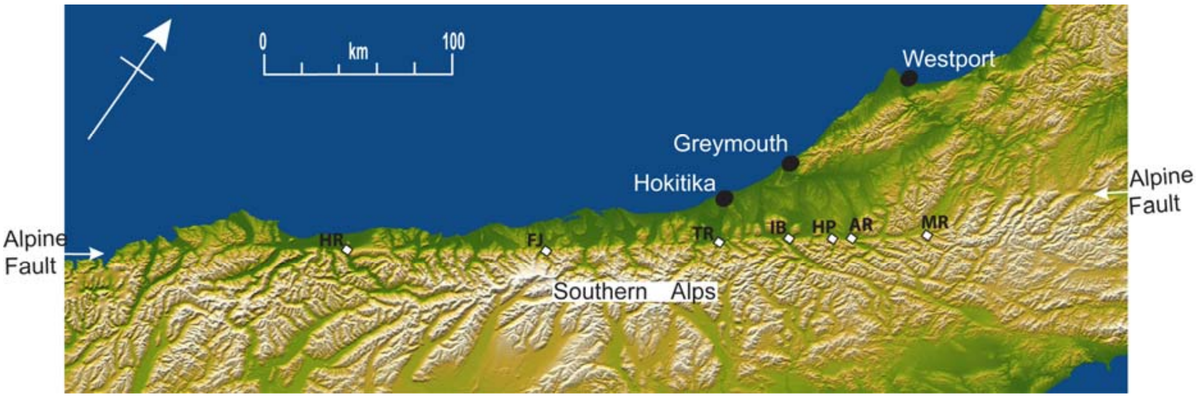

Figure 2 Colour DEM of the West Coast region which clearly shows the trace of the Alpine Fault between Milford Sound and Nelson Lake (tips of white arrows). The main urban centres of West Coast are shown, along with a number of moderate to high impact ‘priority’ areas along the fault that were mapped for the Langridge & Ries (2010) report. These are from southwest to northeast: HR, Haast River; FJ, Franz Josef; TR, Toaroha River; IB, Inchbonnie; HP, Haupiri River; AR, Ahaura River; and MR, Maruia River.

The Alpine Fault is characterised by right–lateral (horizontal) slip, with a component of vertical movement which brings about uplift of the Southern Alps on the southeast of the fault trace (Cooper and Bishop 1979) (Fig. 2). By measuring the displacement of landforms that were offset by previous fault ruptures, the typical horizontal displacement in a single,

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[1] A glossary of terms is presented at the end of this report.

surface-rupturing earthquake is considered to be large (c. 9 ± 1 m), while vertical displacements may be on the order of 1-2 m per event (Berryman et al. 1992; Langridge et al., 2010a). The long term result of this movement is c. 470 km dextral displacement of bedrock terranes along the fault (Wellman 1953; Sutherland 1994) and the uplift of the Southern Alps (Adams 1979; Wellman 1979). From the Hokitika area to Milford Sound (Central segment), the Alpine Fault has a Holocene slip rate of c. 27 ± 5 mm/yr. (Norris & Cooper 2001), while to the northeast there appears to be a stepwise decrease in its slip rate, as plate boundary strain is partitioned onto individual faults of the Marlborough Fault System, such as the Hope Fault (Langridge and Berryman 2005; Berryman et al. 1992; Langridge et al., 2010a).

Fault rupture is a distinct hazard, compared to the local to regional ground shaking that will result from a large to great earthquake (i.e. M 7-8) on the Alpine Fault. Property damage should be expected and loss of life may occur where buildings, and other structures, have been constructed across and close to the fault trace. The zone or width of deformation can be variable along the strike of the fault, due to changes in the ratio between vertical and horizontal movement and related to stepover zones along the fault. Considering both the short calculated average recurrence interval of the Alpine Fault and the elapsed time since the last event, the next surface-rupturing earthquake may occur in the ensuing decades. Estimates of the probability of this event are c. 20% in the next 30 years (Rhoades & Van Dissen 2003; Berryman et al., in prep.).

1.3 The Alpine Fault and MfE Active Fault Guidelines

During 1999, four damaging, shallow crustal earthquakes ruptured faults to the ground surface in Turkey, Taiwan and the USA (e.g. Barka et al. 2002; Brunsdon et al. 2000; Langridge et al. 2002). These events have highlighted the potential for similar surface rupture of faults in New Zealand and the likelihood that loss of life and damage to infrastructure could occur (see King et al. 2003; Kerr et al., 2003 and next section). The hazard of surface rupture along New Zealand faults was highlighted by the occurrence of the M 7.1, 4 September, 2010 Darfield earthquake, which ruptured a previously unmapped fault on the Canterbury Plains west of Christchurch (Gledhill et al., 2010; Quigley et al., 2010; Van Dissen et al., 2011). Up to 5 m of right lateral slip occurred at the ground surface along the Greendale Fault (average slip c. 2.5 m) as a consequence of the Darfield earthquake. Surface rupture along the Alpine Fault will result in a zone of intense ground deformation as opposite sides of the fault move past (and over) each other during the next earthquake, with c. 8-10 m horizontal and c. 1-2 m vertical displacement. While it may be possible to engineer buildings to withstand certain levels of ground shaking, it is less feasible to engineer a building or infrastructure to withstand metres of ground displacement. Hence it is best to avoid building across active fault traces.

The Ministry for the Environment (MfE) has published Guidelines on “Planning for Development of Land on or Close to Active Faults[2] (Kerr at al. 2003, see also King et al. 2003; Van Dissen et al. 2003). The aim of the MfE Guidelines is to assist resource management planners tasked with developing land use policy and making decisions about development of land on, or near, active faults. The MfE Active Fault Guidelines provide information about active faults, specifically fault rupture hazard, and promotes a risk-based

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[2] The Ministry for the Environment’s Guidelines "Planning for Development of Land on or Close to Active Faults: A guideline to assist resource management planners in New Zealand" is now available on both their main website and their Quality Planning website.

approach when dealing with development in areas subject to fault rupture hazard. In the MfE Guidelines, the surface rupture hazard of an active fault at a specific site is characterised by two parameters: a) the average recurrence interval of surface rupture of the fault, and b) the complexity of fault deformation expressed on the Earth’s surface.

The Alpine Fault is the most active onland fault in New Zealand and has a high slip rate and short recurrence interval. The Alpine Fault is a Recurrence Interval Class I active fault (average RI <2000 yr) along its entire length. Therefore, it is expected that the Alpine Fault will rupture along its trace at least once during any 2000 yr interval (Berryman et al. 1992; Van Dissen et al., 2003).

The MfE Active Fault Guidelines advance a hierarchical relationship between fault-avoidance recurrence interval (RI) and building importance (BIC) (see Table 3, and Appendix 1 for more detail). For example, only low hazard structures, such as farm sheds (e.g. Building Importance Category 1 structures), are permissible structures on or adjacent to RI Class I active faults, such as the Alpine Fault. In a “Greenfield” (i.e. undeveloped) setting, more significant structures such as school halls, airport terminals, and large hotels (BIC 3 structures) should not be sited across faults with average recurrence intervals shorter than 10,000 years (i.e. all RI Classes I-IV). Taking this approach, the recommendations of this report will be that a Fault Avoidance Zone around the Alpine Fault should be avoided, as the probability of a surface rupturing earthquake in the foreseeable future is moderately high.

1.4 Franz Josef and nearby townships

This study is focused on the wider community of Franz Josef/Waiau, which is c. 100 km southwest of Hokitika (Fig. 2). These townships have been identified as being at risk of fatalities and damage from the next Alpine Fault rupture. In particular, Franz Josef is the largest and most economically valuable planned community developed across the Alpine Fault Zone. Given the likelihood of fault rupture event during the next 30 years it is imperative that good geological and planning information is provided to councils and their communities. The District Council will need to consider a broader range of guidelines (other than solely the MfE Guidelines) that include other statutes that deal with Natural Hazards, e.g. the Resource Management Act 1991, Building Act 2004, CDEM Act 2002, Local Government Act 2002, Local Government Official Information and Meetings Act 1987.

The input mapping data that was used to create a preliminary Fault Avoidance Zone (FAZ) through the town of Franz Josef by Langridge and Ries (2010) was considered to be of low reliability (high uncertainty), due to the scale of mapping undertaken by QMap (1:250,000 scale) and the University of Otago.

There are a considerable number of buildings that occur within the preliminary Alpine Fault FAZ within Franz Josef/Waiau. These range from BIC 1 through to 4 and include houses, hotels, tourist hostels, a petrol station, a police station, the Dept. of Conservation (DoC) National Park Headquarters, a DoC supply/staging yard, and tourism and retail stores. The short to medium term viability of these homes and businesses (BIC 2-3), and the post-disaster Civil Defence functionality of essential services (BIC 4) should be of considerable concern and focus for current and future town planning in Franz Josef.

2.0 METHODOLOGY

To develop better Fault Avoidance Zones for Franz Josef-Waiau, the following tools were employed to provide new mapping data: (i) collection of RTK-GPS point data throughout the town; and (ii) collection of airborne LiDAR point cloud data that could be used to create an accurate DEM. These are discussed below.

2.1 RTK-GPS map of Franz Josef

In May 2010 and prior to the collection of airborne LiDAR data, RTK-GPS survey points were collected within the town of Franz Josef during a field visit. This exercise was undertaken because at the time there was no detailed survey data available for the town, and it allowed the topography related to the scarp of the Alpine Fault through the town to be accurately located. Point data could only effectively be collected in areas where there was no vegetation or buildings, as these obscure the ground from visibility to the satellite network. Points were collected using the RTK-GPS attached to a vehicle or on foot. The ensuing set of point data (c. 5000 points) is dominated by points collected on the streets within Franz Josef and in open alleys and house yards (Fig. 3). The data was tied to the NZ Geodetic Network via a benchmark on State Highway 6 south of the Waiho River.

The point data is focused around the central part of Franz Josef town and is shown with the DEM in Figure 3. Contouring programs cannot adequately interpolate the topography across wider areas where there is no point data due to vegetation and/or a lack of access. The DEM is colour contoured and also line contoured at 0.5 m intervals. The map has both good and poor aspects in terms of locating the fault through the town. These can be summarised as follows:

1. The broad topographic change through the town can be observed from the higher elevations in the southeast (white to brown colours) to lower elevations in the northwest (green colours).

2. There is generally good point coverage through the town which defines the NE-SW striking fault scarp through the higher part of the township. Secondary topographic breaks occur where the data quality is bad due to a lack of coverage.

3. Conversely, several poorly-controlled topographic breaks have been defined by the contouring program due to a lack of points in key areas, e.g. between the Franz Josef airfield, the town, and the DoC carpark.

4. In addition, the point distribution and processing has led to an irregular contouring scheme, even where the point coverage is good along the fault. This may in part be due to real modification of the ground surface due to development and building practices.

The scarp of the Alpine Fault can be clearly traced through the town from below the DoC parking lot through the area of Condon Street and projecting to the eastern end of Cowan Street (Fig. 3). This is consistent with the fault location as observed in field visits to the town. In general, the northwestern edge of the scarp is fairly sharp and distinct. To the southeast, the scarp climbs broadly to the south of Condon Street. Through the town the width of the scarp is c. 100 m with its location and width becoming less certain to the west between the DoC carpark and the airfield. The estimated location of the fault as a line, i.e. the point where the fault trace intersects the ground surface is highlighted by arrows in Figure 3. This is where we interpret the greatest amount of fault displacement will occur during the next earthquake. In addition to this, there is likely to be further faulting and folding within the scarp.

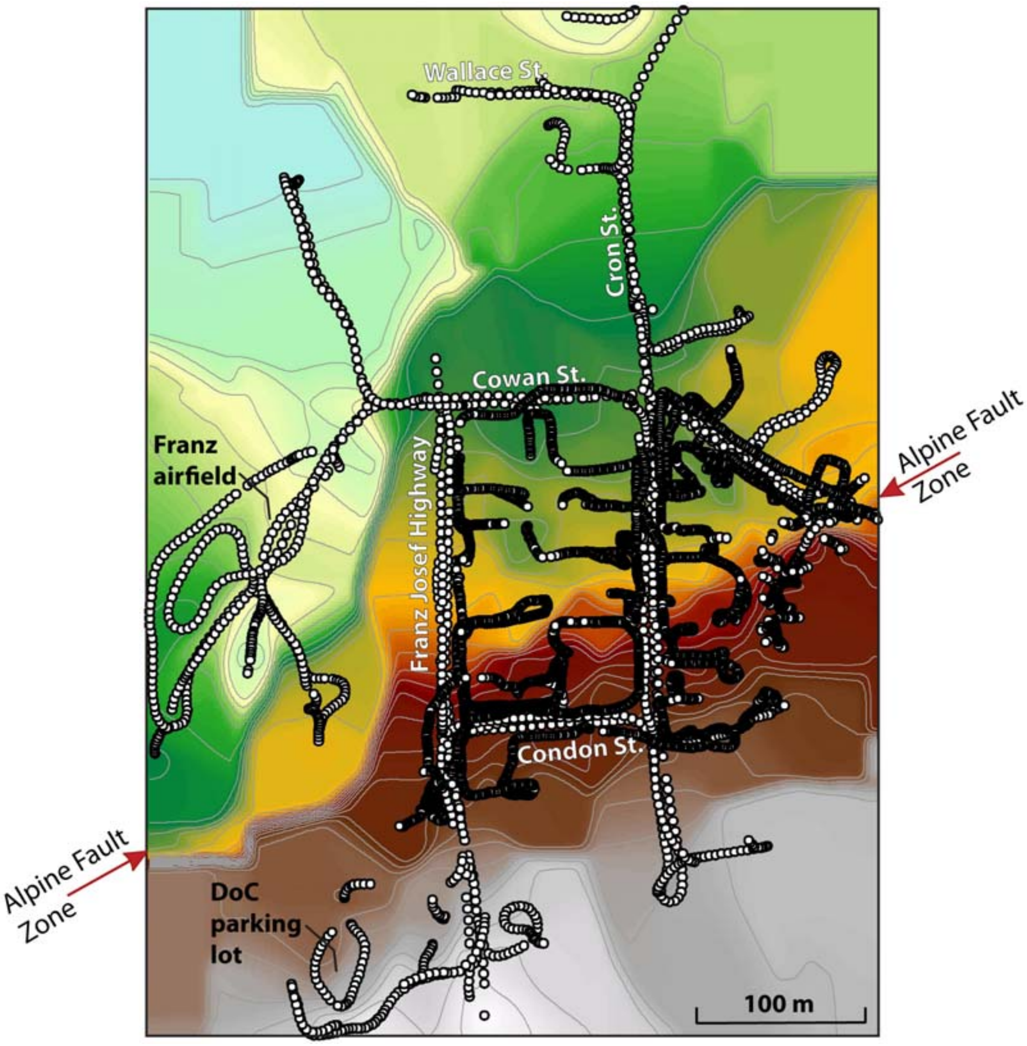

Figure 3 Topographic map of Franz Josef overlain by the collected RTK-GPS points. These points allow individual streets to be identified in the map. The scarp of the Alpine Fault occurs as a northeast-southwest striking feature through the map, and its zone of deformation has a considerable width. Arrows mark a point near the base of the scarp. Contour line interval is 0.5 m. White/grey colours are higher elevations; blue/green colours are lower elevations.

The RTK-GPS map provides a significant improvement on the data used in the Langridge and Ries (2010) report. It would be possible to use this map to define a Fault Avoidance Zone for Franz Josef. Such a zone would run NE-SW through the town and include the width of the scarp (c. 100 m) with an additional factor of safety buffer of ± 20 m, i.e. a total width of 140 m. This is somewhat narrower than the 190 m FAZ width assigned by Langridge and Ries (2010), due in large part to a higher quality of map data with which to construct the FAZ.

As will be illustrated in the next section, this survey data is superseded by higher quality LiDAR point data, which becomes the primary data source for defining faults, deformation and the new Fault Avoidance Zones for the Franz Josef area.

2.2 Airborne LiDAR data

Airborne LiDAR was flown along a 33 km long and 1.5 km wide swath along the rangefront of the Alpine Fault between southwest of Franz Josef (Docherty Creek) and northeast of Whataroa (Vine Creek) in August 2010 (Fig. 4; Langridge et al., 2010b). This effort was funded by the Natural Hazards Platform Contestable Fund and was designed to test the viability of airborne LiDAR along the most active and densely vegetated faults in the country, in particular the Alpine Fault. A series of flight path runs were designed for NZ Aerial Mapping Ltd (NZAM) who acquired and processed the data. Colour aerial orthophotographs were taken simultaneously with the LiDAR to provide ground cover control. Processing of the LiDAR point data includes filtering to acquire the lowest returns, which are assumed to be ground returns. All other data is typically removed, e.g. trees, buildings etc. that provide non-ground returns. From the ground return points DEMs can be constructed.

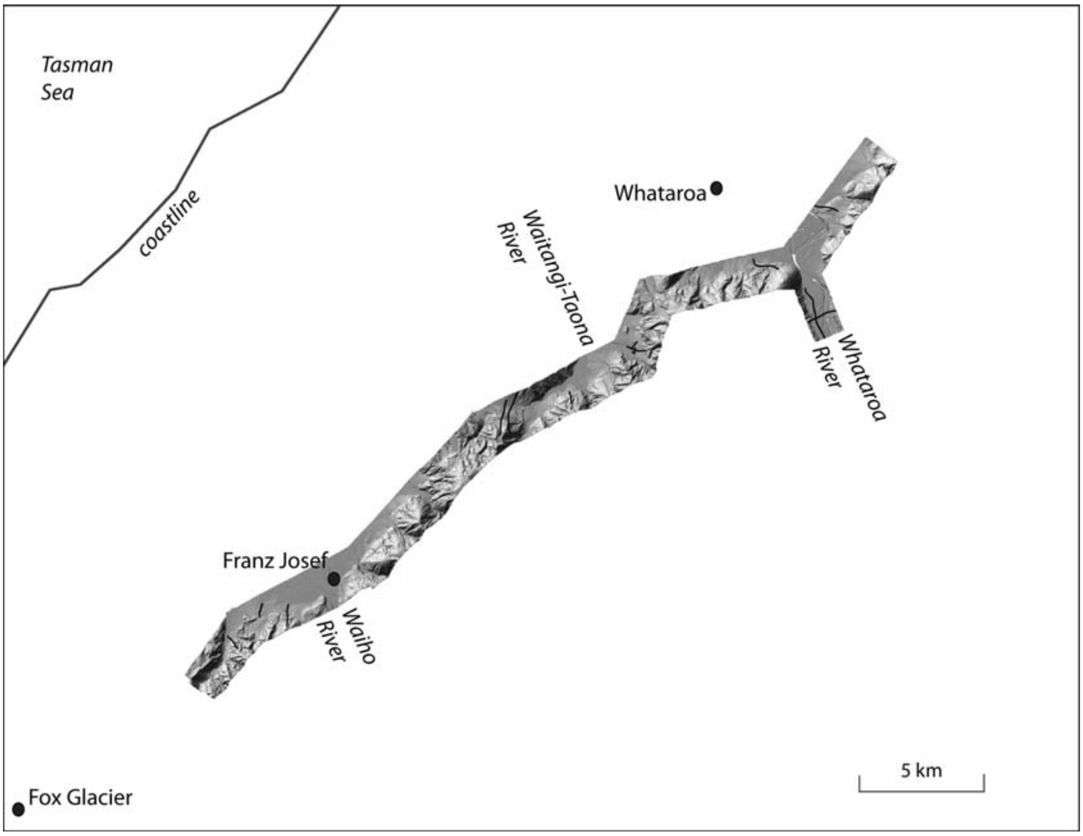

Figure 4 Extent of the LiDAR DEM flown along the Alpine Fault. The zigzagging active trace of fault is encompassed within a c. 1.5. km swath between SW of Franz Josef and east of Whataroa.

A 2-m DEM was developed from the point cloud supplied by NZAM. The LiDAR technique has proved to be successful at attaining points beneath the dense podocarp covered range-front of the Southern Alps along the West Coast. The new topographic model exceeds expectations in delineating geomorphic features beneath the bush, including previously un-seen views of the tectonic geomorphology of the Alpine Fault.

Figure 5 shows the un-interpreted 2-m DEM through the town of Franz Josef covering the same area as shown by Figure 3. The LiDAR also has the capability of defining fluvial bedforms, stopbanks, drains, berms, roads and walking tracks (see Fig. 5).

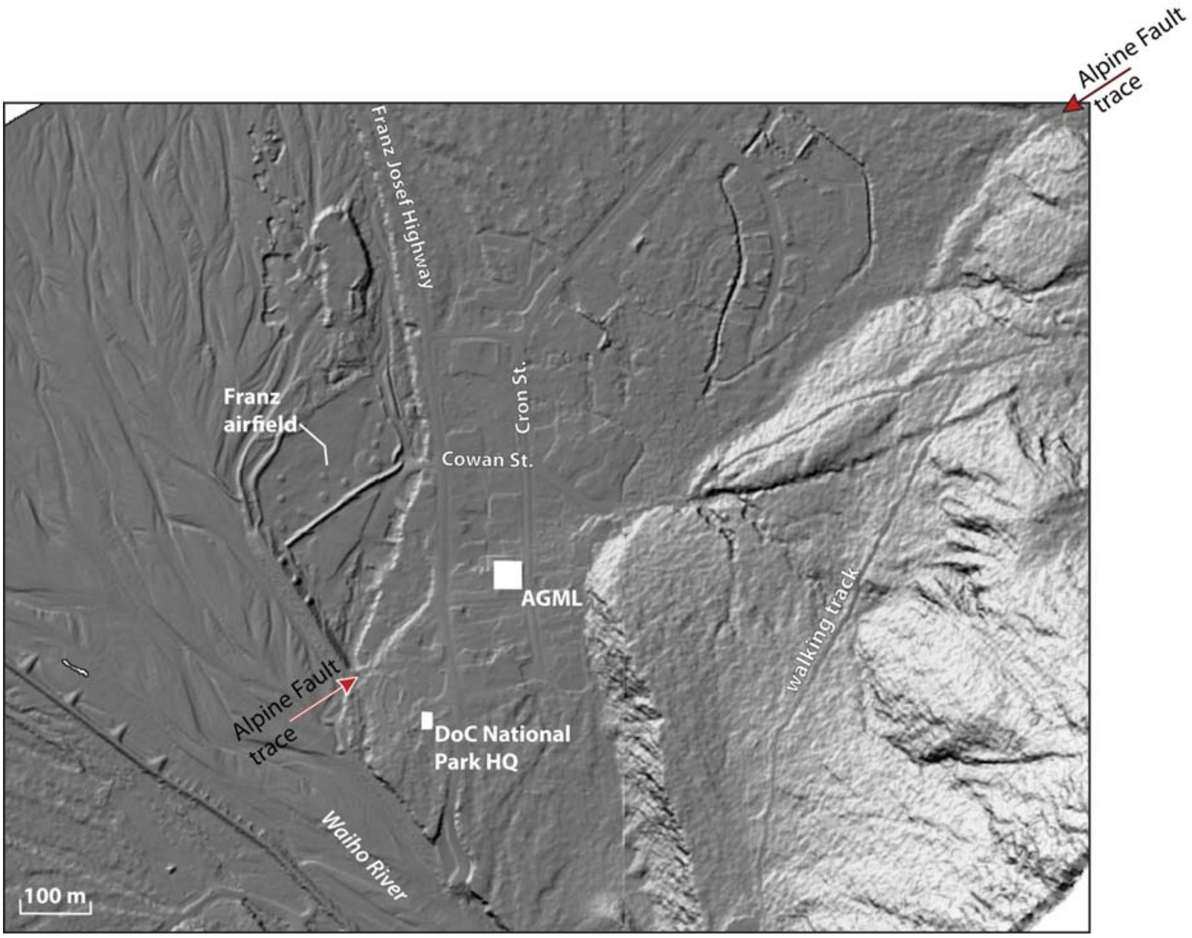

Figure 5 2-m LiDAR DEM of Franz Josef township (extracted at 1:6000 scale). AGML refers to the Alpine Glacier Motor Lodge. This can be compared with the map shown in Figure 3.

An advantage of using LiDAR-based DEMs is the ability to quickly create cross-sectional profiles. Figure 6 shows a profile constructed along Cron Street in Franz Josef. The profile, which is sited oblique to the fault scarp, shows the form of the scarp of the Alpine Fault along the street. This shows the height difference across the scarp (>8 m) and the width across which the scarp occurs, which is c. 200 m.

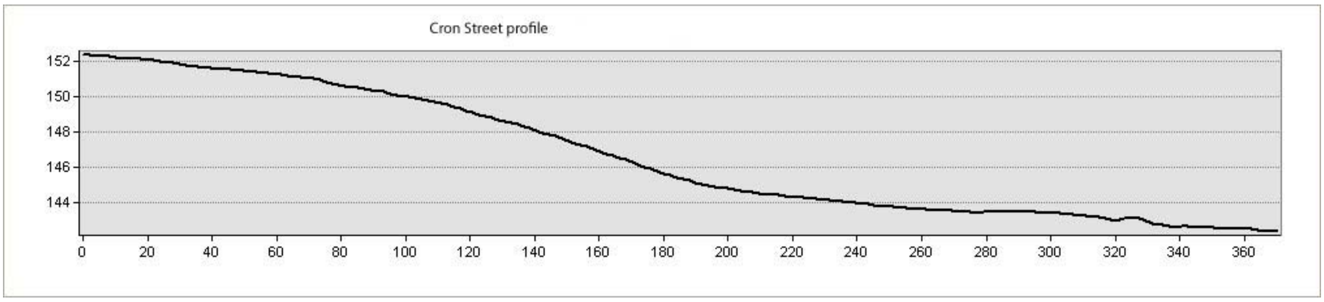

Figure 6 Profile of the scarp of the Alpine Fault across surface FJ-0 (Town Terrace) measured along Cron Street in Franz Josef.

2.3 GIS mapping using LiDAR coverage

To build a Fault Avoidance Zone it is essential to first map all of the recent tectonic features (faults, folds etc.). This can be achieved within a Geographic Information System (GIS).

Several ArcMap Shapefiles have been created in a GIS to categorise the types of features that have been mapped onto the LiDAR from Franz Josef/Waiau and to the northeast of the town between Tartare Stream and Stony Creek (see Fig. 7). These features have been classified into[3]:

1. Reverse fault – an active reverse-slip or thrust fault trace that can be recognised cutting across an alluvial or hillslope surface creating a scarp, or a trace that shows clear vertical displacements;
2. Strike-slip fault – an active strike-slip fault trace that can be recognised cutting across an alluvial or hillslope surface creating a scarp, or a trace that shows clear horizontal displacements;
3. Lineaments – this is a broad category referring to geomorphic indications of linear features in the landscape. The term lineaments includes possible fault traces, secondary fault traces, or features of unknown origin (that may sometimes turn out to be man-made). The term 'lineaments' is also used for geomorphic features such as ridge rents within the bedrock; and
4. Folds – these linear features include active folds such as anticlinal warps that form on the upthrown side of active reverse fault traces.

Figure 7 shows the interpreted map of tectonic features for Franz Josef township and Figure 9 shows the Tartare Stream to Stony Creek (Donovan Drive) area. The type of fault slip (reverse or strike-slip) is transitional along this part of the fault. That is, at any given point there is probably a combination of both reverse and strike-slip movement on mapped fault traces. Where the style is not well known, the model of Norris and Cooper (1995) is followed, which shows that NNE- to NE-striking faults are likely to be reverse-slip faults and ENE- to NE-striking faults are likely to be strike-slip faults. The importance of understanding the type of faulting relates to the width and symmetry of deformation across the fault zone (see Section 3.1.1).

2.3.1 Mapping of faults and structures through Franz Josef

Through the centre of Franz Josef/Waiau township a single fault trace has been mapped, while to the northeast along the rangefront behind Cowan Street and Kamahi Crescent many more features, including fold axes and strike-slip faults have been mapped (Fig. 7). This is because there is partitioning into reverse and strike-slip faulting that occurs in the frontal edge of the rangefront (Norris and Cooper 1995) and also because the rangefront slope between the Waiho River and Tartare Stream is an older landscape feature than the surface through the town. Therefore the rangefront has been through a longer period of earthquake deformation and it is more structurally complex. The fault scarp through Franz Josef occurs across an abandoned alluvial terrace of the Waiho River (here called FJ-0 or the Town Terrace). The age of this surface is not known at this time, however, it can be said that since the river abandoned this surface at least 8 m of vertical slip has accumulated. It is evident that at least the SW half of the rangefront behind Franz Josef, i.e. behind Cowan Street is a deformed high alluvial terrace that likely corresponds to the Waiho River outwash surface (here called the High Terrace or FJ-1) that post-dates the Last Glacial Maximum (Barrell et al., 2011). Apart from the features mapped as lineaments, we expect that all fault traces are Class I faults, i.e. they will rupture repeatedly during any 2000 yr period.

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[3] A glossary of terms is presented at the end of this report.

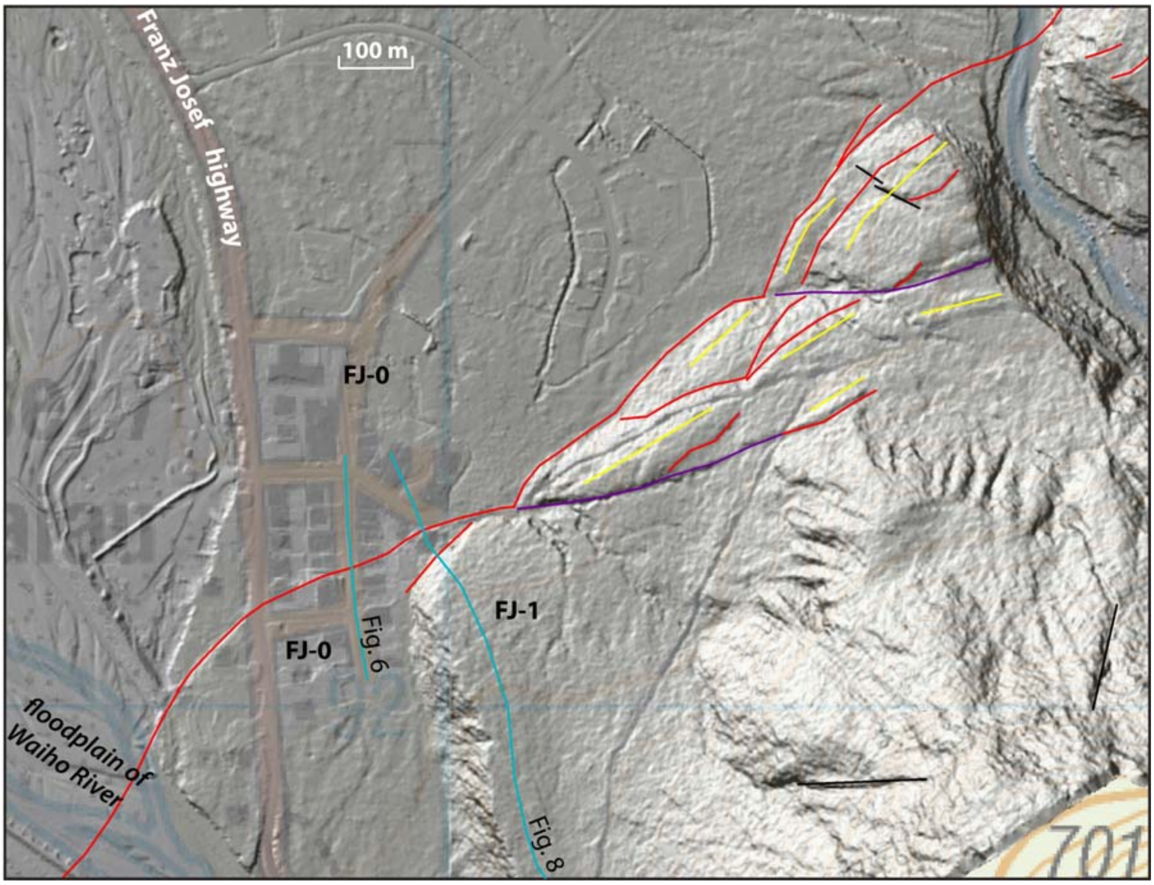


Figure 7 GIS fault interpretation map of Franz Josef township. Linear mapped features are: reverse faults (red), strike-slip faults (purple), fold axes (yellow), and lineaments (black). The post-glacial terrace (identified as FJ-1; High Terrace) and FJ-0 (Town terrace) show differing amounts of accumulated deformation. The blue lines identify two profiles drawn across the FJ-0 (see Figure 6) and FJ-1 terraces as they cross the fault zone.

Figure 8 shows a topographic profile generated from the LiDAR data, the profile runs parallel to the Waiho River along the top of surface FJ-1 (High Terrace) across the Alpine Fault zone and across the FJ-0 terrace within Franz Josef. One purpose of this profile is to demonstrate

that when deformation is measured across older, geomorphic surfaces, such as FJ-1, it is evident that the zone of deformation is broad. At least 45 m of vertical deformation can be measured across the fault zone. This comprises a sharper zone of c. 25 m vertical that occurs in a c. 100 m wide zone, and a broad zone that includes a further c. 20 m of bending that occurs over a width of several hundred metres on the hangingwall (upthrown) side of the fault.

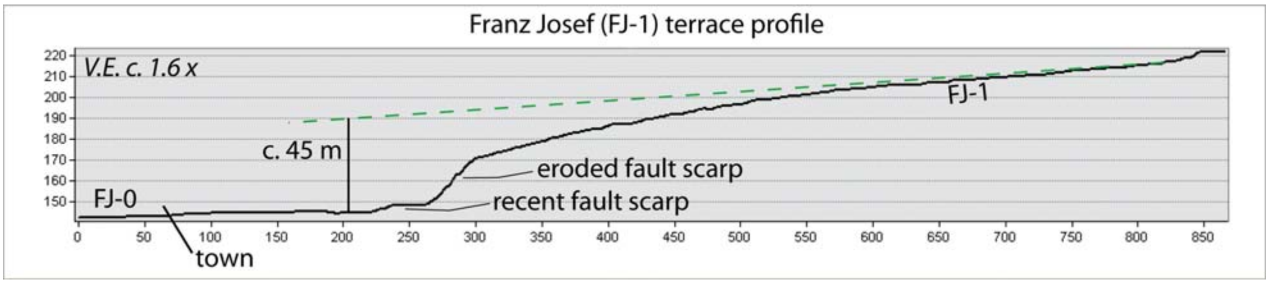


Figure 8 Topographic profile constructed from the LiDAR DEM, measured along the FJ-1 (or High) terrace of the Waiho River and into the town of Franz Josef on the late Holocene? FJ-0 surface.

2.3.2 Mapping of faults and structures from Tartare to Stony Creek

As the town of Franz Josef has grown as a tourist attraction, the need for new areas to be subdivided for tourist operators and their staff has increased. This has led to the subdivision of land adjacent to Tartare Stream and Stony Creek, northeast of the main township. These areas encroach upon the active traces of the Alpine Fault at the foot of the Southern Alps, particularly those developments extending off Donovan Drive in the Stony Creek area. We have extended our LiDAR mapping to cover these areas (Fig. 9).

For these areas we have used the same mapping philosophy outlined for the town, i.e. we map reverse and strike-slip faults, lineaments and folds. As we observed to the southwest, in strips along the rangefront in between the major streams we can map at least one reverse fault trace along the range-front. However, where primary and secondary streams exit from the rangefront, fault traces become difficult to map as the fault zone is buried by young fan debris. This is particularly true within ± 1 km of Stony Creek, near the southern extension of Donovan Drive. In this area, we have modified the mapping to include two concealed reverse fault traces that link up three mapped traces in this area, because we believe that there are likely to be fault traces beneath these young fans that most certainly post-date the most recent faulting event. These concealed traces are later buffered to reflect the higher uncertainty, and this extends the Fault Avoidance Zone for this area to the southernmost end of the Donovan Drive development.

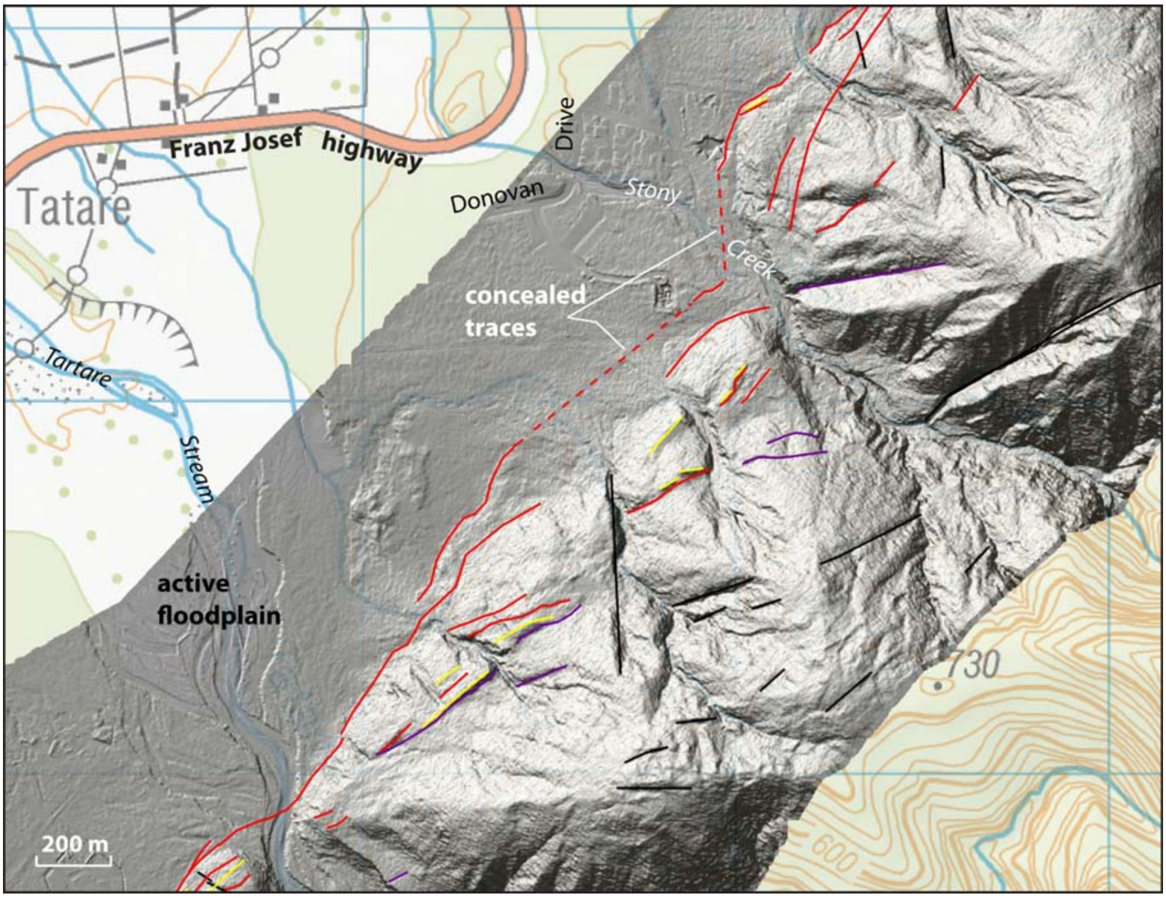


Figure 9 GIS fault interpretation map of the area between Tartare Stream and Stony Creek. Linear mapped features are: reverse faults (red), strike-slip faults (purple), fold axes (yellow), and lineaments (black). Two possible fault traces in front of the range-front are shown as concealed (dashed) traces.

3.0 DEVELOPING IMPROVED FAULT AVOIDANCE ZONES

Fault and fold deformation features related to the Alpine Fault have been mapped in the Franz Josef area, extending as far north as Stony Creek. To do this, our primary mapping data source has been the new LiDAR DEMs. In this chapter we take the fault trace data and develop improved Fault Avoidance Zones (FAZs) for the areas shown in Figures 7 and 9. In each of the following sections we consider what kinds of uncertainties go into the construction of the FAZs.

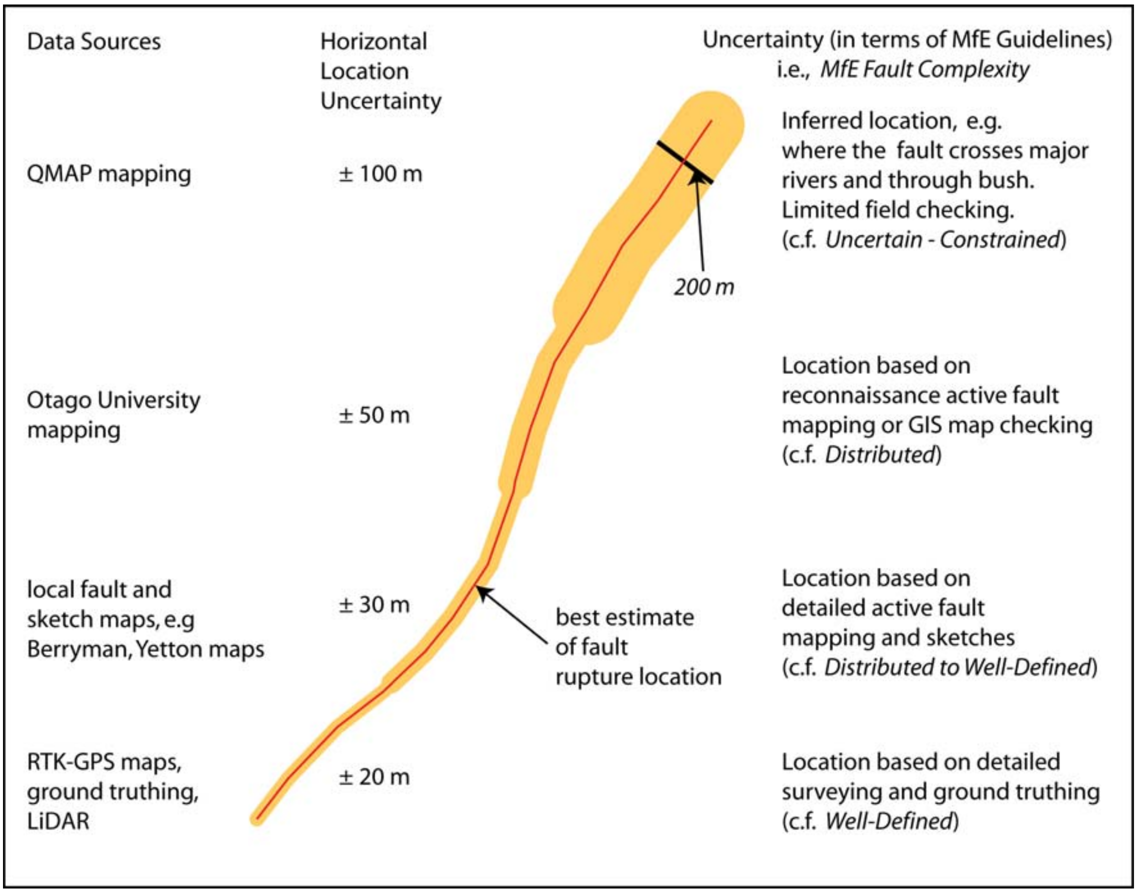
3.1 Accuracy of mapping data source

In working toward the final FAZ products, considerable thought has been put into the accuracy of the data and our ability to estimate how wide the “critical” zone of fault deformation may be around the Alpine Fault, i.e. in terms of life safety and damage to buildings from multi-metre fault displacements.

In the Langridge and Ries (2010) report, which covered the entire length of the Alpine Fault within the West Coast region, a level of mapping accuracy was assigned to each of the data sources. The level of mapping accuracy ranged from ±20 m to ±100 m about a fault trace (see Figure 10). These values were defined by the level of confidence that the data can be used to define the fault location.

The MfE Guidelines (Kerr et al., 2003) discuss fault complexity, which refers to “the width and distribution of the deformed land around the fault trace in terms of either: *Well-defined, Distributed, or Uncertain*. In this study, because we have used LiDAR DEMs, the fault mapping data is generally *Well Defined*. Even without the LiDAR data, the RTK-GPS map of the town of Franz Josef (Fig. 3) is accurate enough to consider the fault location as *Well Defined*. Similar fault mapping studies in central Hawke’s Bay that used LiDAR to define FAZs for reverse faults there typically used a fault location uncertainty of ±20 m where LiDAR DEMs were available (Langridge and Villamor 2007; Langridge et al. 2006).

However, this high level of certainty is related to the ability to define a fault trace based on the geomorphology shown by the LiDAR. In reality, both Figures 6 and 8 show that the zone of deformation is broader than a simple ±20 m measure about a fault line. We also need to consider what each line represents, i.e., is this line the exact place where multi-metre single event displacements occur on the Alpine Fault, or, is this a rough indication of where the faulting is centred? These uncertainties are discussed below.



Data Sources	Horizontal Location Uncertainty	Uncertainty (in terms of MfE Guidelines) i.e., *MfE Fault Complexity*
QMAP mapping	± 100 m	Inferred location, e.g. where the fault crosses major rivers and through bush. Limited field checking. (c.f. *Uncertain - Constrained*)
Otago University mapping	± 50 m	Location based on reconnaissance active fault mapping or GIS map checking (c.f. *Distributed*)
local fault and sketch maps, e.g Berryman, Yetton maps	± 30 m	Location based on detailed active fault mapping and sketches (c.f. *Distributed to Well-Defined*)
RTK-GPS maps, ground truthing, LiDAR	± 20 m	Location based on detailed surveying and ground truthing (c.f. *Well-Defined*)

Figure 10 Fault Location in terms of uncertainty for the Alpine Fault. The uncertainty is an estimate of how well-mapped or located the fault is at any given point, based on the type of data that has been used in this study (from Langridge and Ries, 2010).

3.1.1 Uncertainty on the location of the fault line/ rupture plane

An uncertainty is derived from the actual position of the future fault rupture within a fault scarp or fault zone. Paleoseismic trenching is one means of understanding where faults rupture at the Earth's surface. Trenches are excavated across fault scarps as these are the locations of single to repeated movements on faults (Fig. 11). On vertical strike-slip faults, the zone of deformation is typically symmetric about the rupture trace, e.g. the North Anatolian Fault (Rockwell et al. 2002). However, due to the transpressive nature of the New Zealand setting, many strike-slip faults in New Zealand, including the Alpine Fault, have a sub-vertical dip and develop a linear fault scarp. Individual ruptures within these scarps vary in their position from high in the scarp to low in the scarp. Therefore, there is usually a minor uncertainty associated with the location of the main rupture trace or plane. For dipping reverse faults, the zone of deformation is typically an asymmetric zone which exhibits increased damage/deformation in the hangingwall side of the fault (Figs. 11, 12). This phenomenon is described in more detail below.

More often than not, reverse and thrust faults have rupture traces near the middle of, or toward the base of the scarp, respectively. In reality, if the scarp is well located or *Well-Defined*, then this uncertainty is rather small compared to the overall uncertainty of fault location.

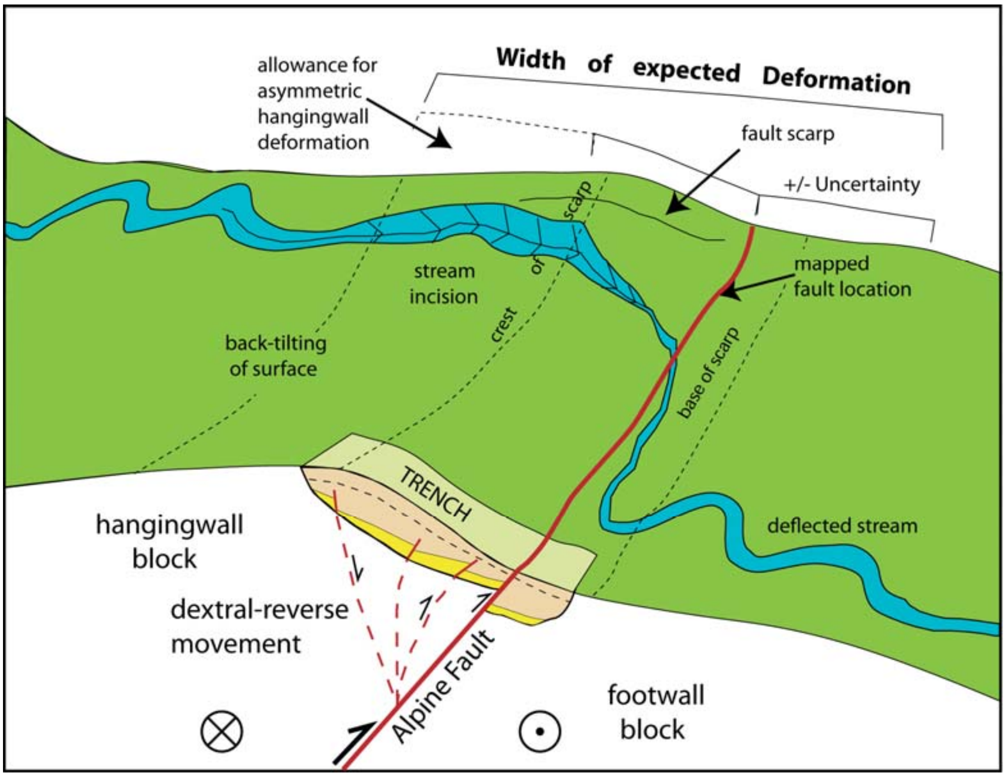


Figure 11 Schematic diagram of the dextral-reverse Alpine Fault and its scarp. In this case the mapped fault trace (rupture surface; bold red line) is located near the base of the scarp. The dominant movement on the fault is horizontal as shown by circle symbols at the base of the figure (arrow away/towards). A zone of uncertainty is shown in association with the mapping of the main rupture trace. The zone of uncertainty is doubled on the hangingwall side of the fault to account for the increased fault deformation due to bending and warping of the upper plate. This makes up the expected width of fault deformation, to which a Margin of Safety Buffer of ± 20 m is added.

Where fault features are preserved, the accuracy with which the fault can be located on the ground depends on the type and geometry of the feature. A fault scarp is one of the best features that can be used to define the location of a fault. For example, in places, the scarp of the Alpine Fault is sharp and distinct (c. ≤ 5 m wide), and here it is possible to define the location of the fault quite accurately (to within several metres, e.g. *Well-Defined* fault complexity (see Figs. 5, 7). However, in other places, scarps are broad topographic rises over a distance of 20 metres or more. Without trenching or other subsurface investigations at these sites, the ability to capture/define the position of a future rupture plane cannot be significantly more accurate than the distinctness/sharpness of the topographic expression of the fault feature. However, if a fault scarp is preserved it is almost certain that the majority of fault deformation occurs within the scarp itself.

In some areas, the location of the fault trace is inferred. This occurs when the trace is currently not visible (or mapped), but would be there if it were preserved. An obvious case of an inferred trace occurs where a fault projects across a major river, e.g. the Waiho River. In these cases, the scarp is either eroded by river activity, or buried beneath the youngest alluvium. Along the West Coast, many rivers have a low unfaulted (i.e. without a fault trace) terrace adjacent to the modern floodplain. The fault trace may be inferred across such terraces. Another example of an inferred trace of the Alpine Fault occurs across much of the native bush-covered areas where no field checking has been undertaken. Since LiDAR has proved to be a very successful tool at seeing through the vegetation, it has changed our ability to map faults, thus the location of inferred traces is now mainly restricted to areas that have had active erosion or deposition since the last surface rupture, i.e. related to active streams and fans.

3.1.2 Asymmetry of fault deformation due to reverse faulting

An additional important source of uncertainty related to the Alpine Fault and its future surface rupture comes from its oblique style of faulting, which combines both right-lateral strike-slip movement and reverse fault movement (Fig. 11). For reverse faults, the hangingwall block (upthrown block) is pushed up and over the footwall block. Secondary reverse faults can splay upward through the hangingwall to the surface above the main fault plane, and in some instances, flexure (bending) of the hangingwall block can generate normal faulting (see examples in Kelson et al., 2001 from the Chi-Chi earthquake). Figures 11 and 12 graphically document this kind of asymmetric deformation. The Alpine Fault is characterised by a relatively moderate dip of 45-60° (compared to near-vertical dip for other well-known strike-slip faults like the San Andreas Fault). While in the case of the Alpine Fault, the dip-slip (reverse) component of motion is secondary, because of the moderate dip, the fault will also have an asymmetric distribution of surface deformation about the surface rupture.

Due to the effect of greater deformation focused in the hangingwall block of reverse faults, we believe that the Fault Avoidance Zone should be asymmetric about the best estimate location of the fault rupture. As the amount of uncertainty varies from trace to trace, we consider it likely that the zone of deformation in the hangingwall could be twice as wide as that in footwall block. Therefore, we have doubled the width of the Fault Location uncertainty on the hangingwall (typically southeast) side of the Alpine Fault (Figs. 5, 11).

Figure 12 Photograph taken of a surface rupture related to the 1999 Chi-Chi earthquake, Taiwan. The view is looking toward the fault, which has ruptured through a school's 400 m athletic track, which was obviously flat before the rupture. Note how the scarp has grown by thrusting out and over the former ground surface, and how deformation is focused in the hangingwall (uplifted) block.

3.2 Constructing a Fault Avoidance Zone

The mapped fault traces were used to construct Fault Avoidance Zones (FAZ's). An FAZ is a zone within which the future surface rupture of a fault is likely to occur and within which there is a likelihood of ground deformation. As discussed, these zones are developed around the position of a linear fault line, and the width of the zones reflects the accuracy of linework capture. In some places, the zone is based on complex features or inferred where no features are preserved. In these areas the width of the zone is large and reflects both the complexity and uncertainty of the fault location on the ground, and the accuracy of capture. In specific cases, detailed fault studies (trenching or ground surveying) could, in the future, be used to reduce the uncertainty of fault location and thereby reduce the width of the recommended FAZ (see Fig. 13).

Generally, a fault is a zone of deformation rather than a single linear feature. The zone of future deformation may range in width from metres to tens of metres. Structures sited directly across an active fault, or close to a fault, are in a potentially hazardous area, and are very likely to be damaged in the event of fault rupture. As is suggested in the MfE Guidelines (Kerr et al. 2003, see also King et al. 2003), the FAZ also includes an additional ± 20 m setback or 'margin of safety' around the likely fault rupture zone (Fig. 13).

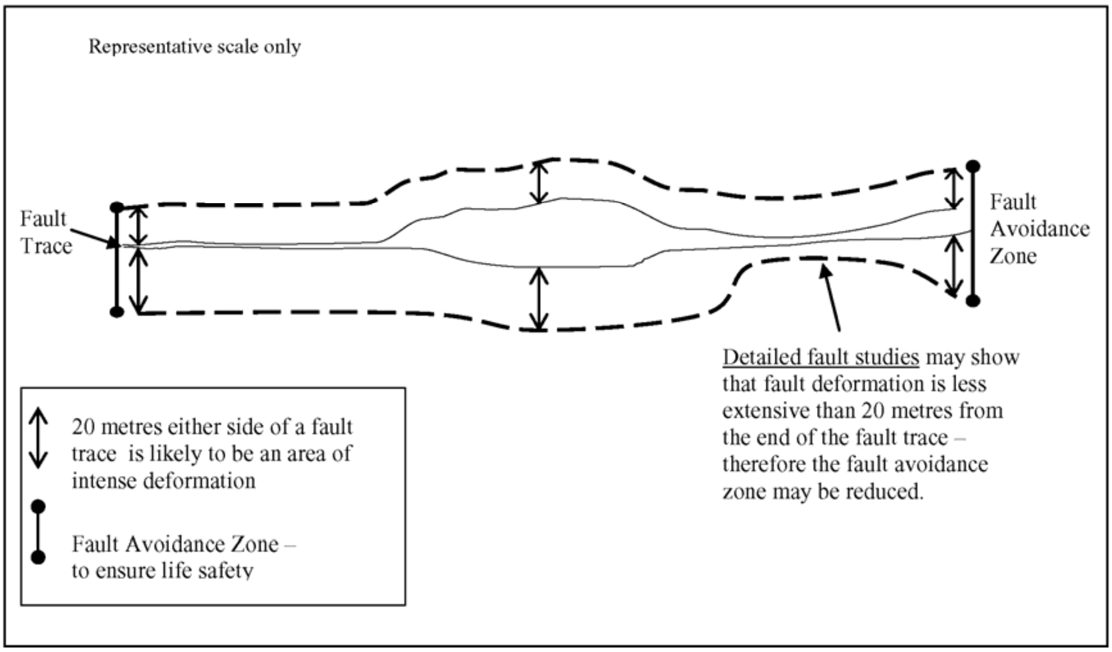


Figure 13 Original caption from Kerr et al (2003) – 'A fault avoidance zone on a district planning map'. After trenching and mapping work it could be possible to narrow the Fault Avoidance Zone by better understanding the width of the deformation and fault location.

In this study we have constructed a local scale (1:6000-12,000) Fault Avoidance Zone (FAZ) for the Alpine Fault in the Franz Josef and Stony Creek areas. Figures 7 and 9 show the new line data for the Alpine Fault within Franz Josef and from Tartare to Stony Creek, respectively. Only definite reverse faults and strike-faults have been mapped and buffered (i.e. turned into a FAZ). Typically NNE- to NE-striking reverse faults have been "doubly-buffered" on the hangingwall side of the fault. This approach has not been used for the typically NE- to ENE-striking strike-slip faults in the area. In the latter case, a symmetrical ± 30 m buffer has been applied to each fault trace.

Figure 14 shows how the FAZ was constructed for the reverse fault traces. The simplest (thinnest) element within the FAZ is the fault trace, shown by the red line, which represents the best estimate of future fault rupture position. This line has essentially no width, but carries with it a number of uncertainties that are incorporated into the Horizontal Location Uncertainty. The total width of these FAZs for a single reverse fault trace is 130 m (3 x 30 m + 2 x 20 m). For individual strike-slip fault traces mapped here the total FAZ width is 100 m (2 x 30 m + 2 x 20 m).

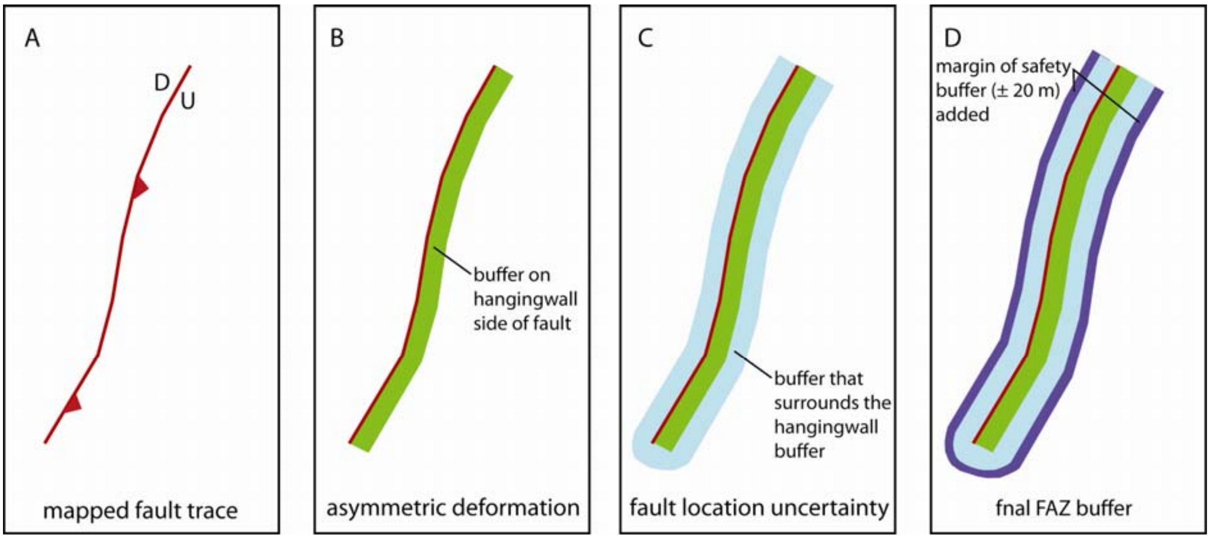


Figure 14 Construction of a Fault Avoidance Zone (FAZ) for reverse fault traces in the Franz Josef area. A. Reverse fault traces (red) are mapped and attributed; B. The ‘Asymmetric buffer’ (green) with width of 30 m is first applied to the hangingwall side of the fault C. This is then buffered on all sides by a ± 30 m (blue) buffer to define the Fault Rupture Location Uncertainty; D. A ‘margin of safety’ buffer of ± 20 m (purple) is added to this. The total area inside this buffer represents the full width of the FAZ. Note: this example is applicable to an ESE-dipping Alpine Fault.

All of the individual FAZs have been merged to form the entire FAZ shown in the GIS (e.g. Fig. 15). The FAZ should be considered as a zone where the Alpine Fault will most likely rupture with multi-metre displacements, and where most secondary deformation (other fault traces, warping, folding, overthrusting) will be located. This is not meant to represent a zone of complete ground devastation, but rather a zone where building plans and planning consents should take into account the potential for ground deformation due to fault rupture[4].

3.3 Fault Avoidance Zone for Franz Josef

Figure 15 presents a Fault Avoidance Zone (FAZ) spanning the township of Franz Josef. Through the core business part of town, i.e. the north-south corridor bounded by the Franz Josef Highway and Cron Street, the FAZ has a designated width of 130 m. The greater part of the town is built on the FJ-0 Town terrace. The Alpine Fault has faulted the FJ-0 terrace many times during the late Holocene and has built the fault scarp that is evident through the town. To the northeast of this part of town (toward Tartare Stream) the zone of faulting has been mapped as considerably wider and more complex and includes both reverse- and strike-slip fault traces. As a consequence the FAZ reaches widths of 280-350 m across this rangefront area.

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[4] This does not include other types of ground deformation that may occur within the FAZ, such as landsliding, slumping, liquefaction , or alluvial aggradation.

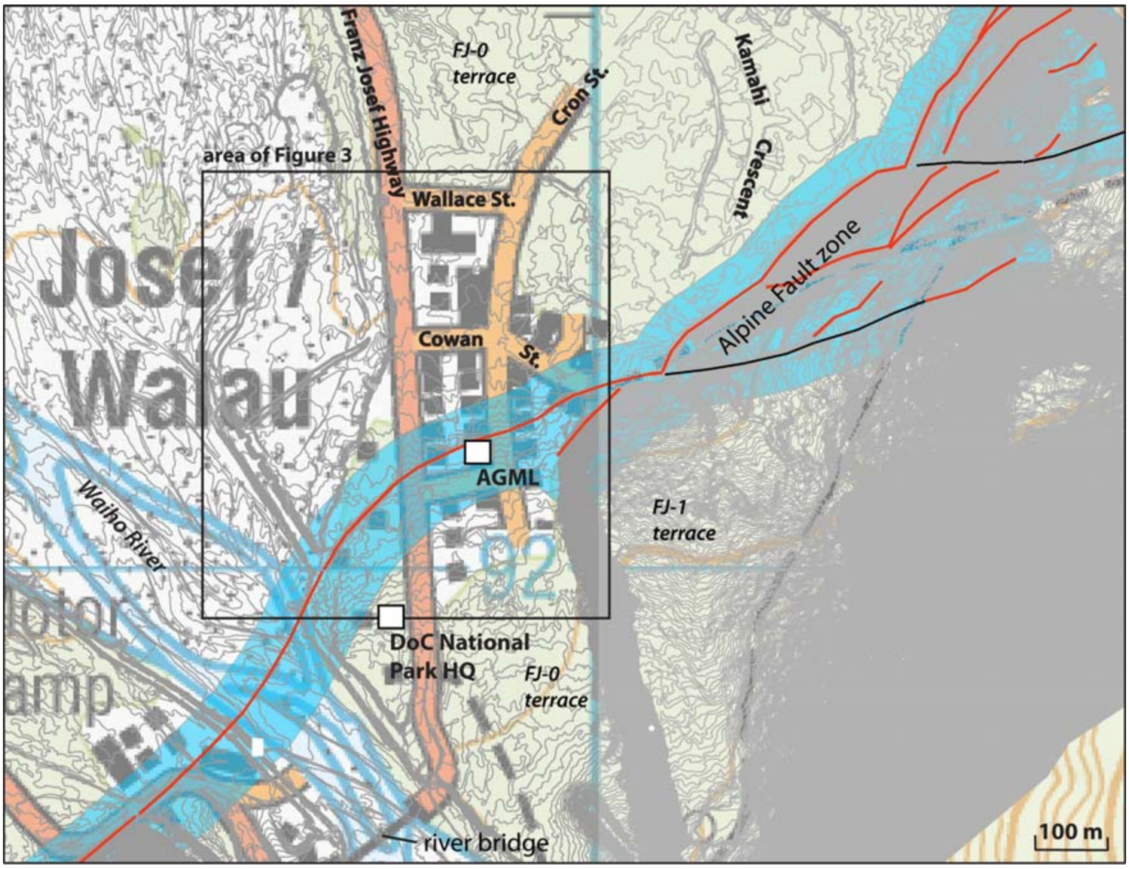


Figure 15 Fault Avoidance Zone (FAZ) for the town of Franz Josef; overlain on NZMS 260 map. Reverse fault (red) and strike-slip fault traces (black) form the basis for the FAZ (extracted at 1:6000 scale). 0.5 m contours (grey) are shown from the LiDAR data. Two building complexes are shown to highlight future concerns regarding fault rupture deformation. AGML refers to the Alpine Glacier Motor Lodge.

The increase in fault complexity is due to a real change in the style and width of faulting, and perhaps also due to the older age of the rangefront edge compared to the FJ-0 terrace. That is, when a surface or slope is geologically older, it will have suffered more accumulated deformation, and the growth of individual secondary faults may be more pronounced. It may be the case, therefore, that through the town itself, there has not been enough time for secondary strike-slip and reverse faults to have developed scarps, as they have along the rangefront. In addition, some subtle topography on the upthrown side of the fault within the town may have been smoothed away during the sub-division process. As such, a 130 m wide FAZ through the town of Franz Josef is warranted and may even be too conservative. The implications of the FAZ and the buildings within it shown in Figure 15 are discussed in Chapter 4.

3.4 Fault Avoidance Zone for Tartare to Stony Creek area

Figure 16 presents a Fault Avoidance Zone (FAZ) covering the rangefront of the Alpine Fault between Tartare Stream and Stony Creek, northeast of the town of Franz Josef. This is a developing part of the greater Franz Josef-Waiau community where recent roading infrastructure (Donovan Drive) has already been established for future housing developments. Reverse and strike-slip traces of the Alpine Fault have been mapped through this area using the same criteria as for the town. The FAZ has a variable width, of between 130 and 500 m, depending on the number and complexity of traces that have been mapped along the rangefront. The northwestern edge of the Alpine Fault zone is marked by three or more frontal traces that have been linked by two inferred traces. These are important because buffering of these inferred traces takes the FAZ to the edge of roading that has already been developed, i.e. the farthest continuation of the Donovan Drive cul-de-sacs near Stony Creek (Fig. 12).

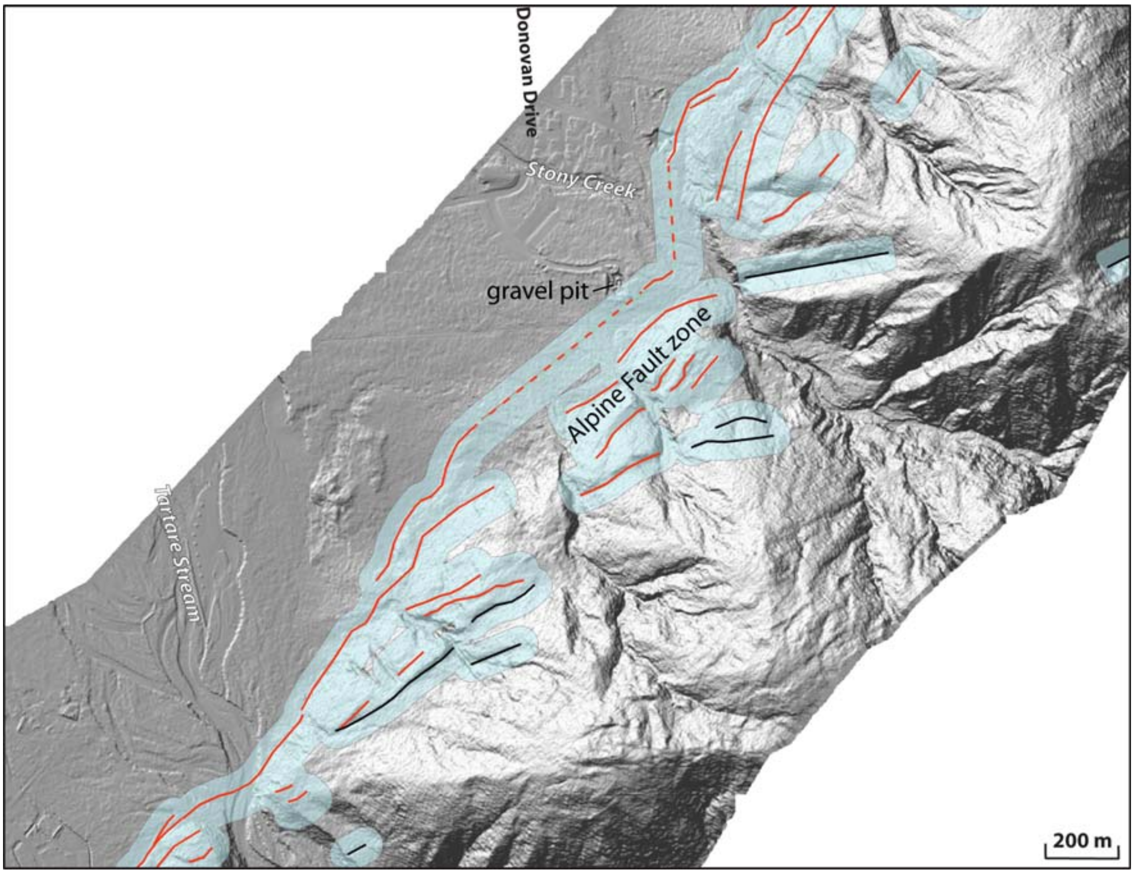


Figure 16 Fault Avoidance Zone (FAZ) for the Tartare to Stony Creek area. Reverse fault (red) and strike-slip fault traces (black) form the basis for the FAZ (extracted at 1:12,000 scale). Two dashed and buffered traces at the rangefront are inferred fault traces. The FAZ impinges on the end of developed cul-de-sac roads at the southern extension of Donovan Drive across a gravel pit.

The very broad, complex zone of deformation where the FAZ is 400-500 m wide occurs along the rangefront of the fault. As with the FAZ shown in Figure 15, more extensive deformation (traces) are mappable where the landscape feature is older. In the case of the rangefront slopes, these are remnant slopes from the Last Glacial Maximum that have been degrading during the Holocene. Thus, the Alpine Fault zone can be mapped as broader because deformation on secondary traces can be observed as it has accumulated greater offset over 10,000 years or more.

4.0 OUTCOMES OF FAULT AVOIDANCE ZONE MAPPING

This section summarises the results and implications of the mapping of fault traces and Fault Avoidance Zones for Franz Josef-Waiau and surrounding areas with respect to the Ministry for the Environment's Guidelines (Kerr et al., 2003).

4.1 Fault Avoidance Zones for the Franz Josef-Waiau area

A FAZ was developed for Franz Josef township that is 130 m wide in the southwest of the town, and increases to c. 350 m in width in areas southeast of the recently developed subdivisions in Kamahi Crescent area. The following discussion focuses on the older part of Franz Josef-Waiau, as none of the houses in the Kamahi Crescent area encroach on the FAZ (Fig. 15). In addition, much of the FAZ created along the rangefront behind Cowan Street and Kamahi Crescent is currently held in Department of Conservation stewardship and is unlikely to be developed in the short to medium term.

In the older part of the town, the FAZ includes a significant number of established buildings that range in importance, relative to the New Zealand Building Code, of BIC 1 to BIC 4, which are shown in Table 1. BIC 1 buildings (non-occupied structures) are permitted within the FAZ. There are several houses of BIC 2a status within the FAZ between Cron and Cowan Streets.

BIC 2b or “Normal structures” is a distinction that is made in the MfE Guidelines for residential homes that are large (>300 m^2), multi-storeyed, or non-timber-framed. BIC 2b also includes many building types including shops, offices, small businesses and car parking buildings. It is likely that some of the houses in the FAZ are of BIC 2b status, and some houses at the eastern end of Cowan Street may even be split-level houses that straddle the fault scarp. In addition, there are several shops including the supermarket, hotel/motel facilities and restaurants that are within or very close to the 130 m wide FAZ. While most shops in the area are tourism related, they may have a relevance that could be considered >BIC 2b due to the hazard posed during an earthquake rupture, e.g. hotels/motels, or the necessity of their post-disaster functionality, e.g. the supermarket. Of some concern are the accommodation businesses such as the Alpine Glacier Motor Lodge (Fig. 15; and other hotels/motels), that have been constructed within the FAZ, and indeed either straddle the fault scarp, or have modified the tectonic geomorphology of the fault to improve their footprints.

BIC 3 or “Important” structures are buildings with high occupancies or functions. Service (petrol) stations are included within BIC 3. Some of the structures listed in the preceding paragraph may be considered as BIC 3, such as the DoC National Park headquarters which currently lies on the edge of, or just outside the 130 m wide FAZ.

BIC 4 or “Critical” structures are those buildings and utilities that have a distinct emergency or post-disaster function, including police, medical, fire and civil defence functions. In Franz

Table 1 Building Importance Categories and representative examples. For more detail see Kerr et al. (2003), and King 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 <30m^2 • Farm buildings, fences • Towers in rural situations
2a	**Timber-framed** residential construction	• Timber framed single-story 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 >500m^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

Josef this includes the Police Station (which is inside the FAZ on the fault scarp) and possibly the National Park headquarters.

It needs to be stated that buildings outside of the 130 m wide FAZ may still suffer damage by fault rupture deformation, in the form of folding, titling, or secondary faulting. In particular, it is likely that further tilting to the north will occur on the SE side of the fault outside of the

FAZ. In such a case, buildings such as the National Park Headquarters may suffer a permanent tilt, that in itself may not represent a life safety risk, but could lead to a situation of non-functionality to the building. In addition, intense ground shaking could cause greater damage to poorly constructed buildings immediately adjacent to the FAZ than the effects of secondary deformation to some buildings within the FAZ.

In summary, a considerable amount of infrastructure of BIC Class 2-4 exists within the FAZ in the older developed part of Franz Josef-Waiau. The implications of this will be discussed in sections 4.3 and 4.4.

In contrast to the Franz Josef-Waiau township, the FAZ strip between Tartare Stream and Stony Creek does not currently contain any known BIC 2-4 structures. This undeveloped area within the FAZ would be considered 'Greenfield' in nature. Future growth of the area may bring some pressure on council to open up development of these areas. However, we advise against any new development within the FAZ shown in Figure 16 along the rangefront between Tartare Stream and Stony Creek. The implications of this will be discussed in the following sections.

4.2 The MfE Guidelines and Fault Avoidance for Franz Josef

The MfE Guidelines concerning building on or adjacent to active faults have outlined a risk-based approach to the hazard of surface faulting in which life safety is the most important criteria (Kerr et al., 2003). These guidelines deal with the activity of any given fault in terms of its Recurrence Interval (RI Class), Fault Complexity and the Built Environment in terms of the Building Importance (BIC) and the Land Zonation. Land Zonation can be considered in terms of either: (i) developed or already subdivided sites; or (ii) 'greenfield' sites, where no previous development or planning has taken place. Tables have been constructed that relate RI Class, Complexity, BIC and land zonation together in order to develop clear guidelines for councils, planners and developers (Table A1; Appendix 1). With regards to the Franz-Josef-Waiau area, these tables show that:

(i) For already developed or subdivided land, only BIC 1 structures are Permitted structures within a Fault Avoidance Zone around a RI Class I fault, i.e., the Alpine Fault. All structures of BIC 2b and higher are considered Non-Complying structures, regardless of the Fault Complexity. The Activity Status of BIC 2a are either Non-Complying or Discretionary for *Distributed* Fault Complexity.

(ii) For greenfield sites, the guidelines offer the same Activity Status, except that BIC 4 structures are Prohibited where the Fault Complexity is *Well Defined*. The latter would be the case for the current Police Station, or a medical centre that was planned for the area of the FAZ in Franz Josef-Waiau, as the fault has been well-defined in this area.

The main part of Franz Josef-Waiau township is clearly already subdivided or developed, while other parts of the rangefront of the Alpine Fault between the town and Stony Creek are in greenfield situations. As stated above, where the land is currently not subdivided or developed, we recommend that no structures >BIC 1 be constructed within the FAZ. Where the land has already been subdivided or developed the issues are more complex.

The MfE Guidelines were constructed so as not to interfere with or disadvantage those who were already built on or adjacent to active faults in a Non-Complying to Prohibited situation. This holds true for all Classes of faults in all areas of New Zealand. However, there is a high probability of failure of the Alpine Fault in the next few decades (i.e. c. 20% in 30 years; Rhoades and Van Dissen 2003). In light of the 2010 Darfield and 2011 Christchurch earthquakes and lessons learned from these events, greater consideration should be given to post-event functionality of townships.

Some of the major goals of this study are to make councils, planners and developers aware of the hazards that exist to the township of Franz Josef-Waiau and to consider more thoughtful approaches to dealing with the hazard of surface faulting through the town before it happens. The second half of this report is devoted to considering different options including doing nothing (*status quo*), managed retreat from Fault Avoidance Zones; and relocation of Franz Josef-Waiau. The action that is taken, based on this report, should be related to the perceived risk in light of not only the MfE Guidelines relating to active faulting, but also in considering responsibilities under the Resource Management Act 1991, the Building Act 2004, the CDEM Act 2002, the Local Government Act 2002 and the Local Government Official Information and Meetings Act 1987.

Table 2 Relationships between Recurrence Interval Class, Average Recurrence Interval of Surface Rupture, and Building Importance Category for Previously Subdivided and Greenfield Sites. For more detail see Kerr et al. (2003), and King et al. (2003). Note: In relation to the Alpine Fault, RI Class I has been highlighted.

Recurrence Interval Class	**Average Recurrence Interval of Surface Rupture**	**Building Importance (BI) Category Limitations** (allowable buildings)	
		Previously subdivided or developed sites	**“Greenfield” sites**
I	≤2000 years	**BI Category 1** temporary buildings only	**BI Category 1** temporary buildings only
II	>2000 years to ≤3500 years	**BI Category 1 & 2a** temporary & residential timber-framed buildings only	
III	>3500 years to ≤5000 years	**BI Category 1, 2a, & 2b** temporary, residential timber-framed & normal structures	**BI Category 1& 2a** temporary & residential timber-framed buildings only
IV	>5000 years to ≤10,000 years	**BI Category 1, 2a, 2b & 3** temporary, residential timber-framed, normal & important structures (but not critical post-disaster facilities)	**BI Category 1, 2a, & 2b** temporary, residential timber-framed & normal structures
V	>10,000 years to ≤20,000 years		**BI Category 1, 2a, 2b & 3** temporary, residential timber-framed, normal & important structures (but not critical post-disaster facilities)
VI	>20,000 years to ≤125,000 years	**BI Category 1, 2a, 2b, 3 & 4** critical post-disaster facilities cannot be built across an active fault with a recurrence interval ≤20,000 years	
Note: Faults with average recurrence intervals >125,000 years are not considered active			

4.3 Other natural hazards that confront Franz Josef-Waiau

This report focuses on the hazard of rupture along the Alpine Fault through the community of Franz Josef-Waiau. The location of this town on the West Coast of the South Island, at the foot of the Southern Alps means that there are a number of weather/climate and geological related hazards that could affect the township and surrounding area. Any future plan that deals with the hazard of surface faulting must also take into account the effects of moving houses or businesses from near the fault, may put those structures in danger or peril of another natural hazard.

In this regard, there are basically two main forms of natural hazard in the area:

(i) Weather and climate related events. These include: heavy rainfall events, flooding of local rivers and streams, thunderstorm, landsliding, snow events etc. The most obvious of these is flooding of the Waiho River, Tartare Stream or Stony Creek. The Waiho River has the power to erode significant high ground near its banks, flood land, or change from its current course. The river is under intense management in terms of building large stopbanks and flood protection systems.

(ii) Geological effects. These include: fault rupture (already discussed), earthquake ground shaking, rangefront collapse (landsliding), alluvial fan growth, and river blockage and breakout. Earthquake ground motions along the Alpine Fault will be intense (Modified Mercalli Scale 10-11) along the fault and within c. 8 km of the fault trace, including within the zone of surface rupture and deformation. Secondary effects of the shaking are: rangefront collapse (landsliding), alluvial fan growth, river blockage and breakout (Davies and McSaveney 2008). Liquefaction is not expected to be a significant problem in this environment due to the predominance of gravelly sediments as opposed to sandy sediments. Along the fault, it is evident that where the fault trace cannot be clearly mapped, that alluvial fans have expanded out across the fault since the last rupture event, which occurred at c. AD 1717. This means that the landscape is young and though presently benign, resets itself after large earthquakes on the Alpine Fault. Landsliding is likely along the rangefront. Some slides may temporarily block rivers or streams and cause breakout floods days to years after the earthquake. National guidelines have also been established to deal with the hazards of building on or near landslides and alluvial fans (Saunders and Glassey 2007) and Davies and McSaveney (2008) have considered the sustainability of building on or near active alluvial fan environments.

5.0 LEGISLATION REVIEW

This section of the report reviews the legislation which is relevant to addressing the risk associated with natural hazards. This chapter will focus on the relevance of the legislation and planning responsibilities to the Franz Josef region and will focus on national legislation, national guidance, the West Coast Regional Policy Statement and the Westland Council District Plan.

5.1 National Legislation and Planning Responsibilities

Landuse planning is one of several tools available to local and regional governments to mitigate and avoid the effects associated with a natural hazard. While these tools are often used in isolation, a holistic approach which incorporates a combination of land use planning, design and construction, and emergency management options is recommended to allow for the effective mitigation and avoidance of the effects from a natural hazard (Saunders *et al, 2011*).

Five key pieces of legislation contribute to natural hazard management in New Zealand: the Resource Management Act 1991 (RMA), Building Act 2004, Civil Defence Emergency Management Act 2002 (CDEM Act), Local Government Act 2002 (LGA), and the Local Government Official Information and Meetings Act 1987 (Saunders *et al, 2011*).

Figure 17 presents the five main statutes that govern natural hazards planning at different levels of government, namely central (orange), regional (green) and district/city (blue) levels. The hierarchy of plans established under each law provide various statutory and non-statutory tools for natural hazards planning. The solid arrows show established relationships in the hierarchy of provisions. The hashed arrows highlight relationships between existing provisions that can be improved. These relationships may be one- or two-way. These legislative provisions and the array of tools they provide constitute a robust ‘toolkit’ for natural hazards planning. However, many of these tools are not well known or used to their full potential to reduce hazard risk and build community resilience (Glavovic *et al*. 2010).

The legislation shown in Figure 17 has been designed to be integrated, as reflected in commonalities in their purposes (sustainable management or development). They also share the common well-beings of social, economic, environmental, cultural, and health and safety (Saunders *et al. 2011*).

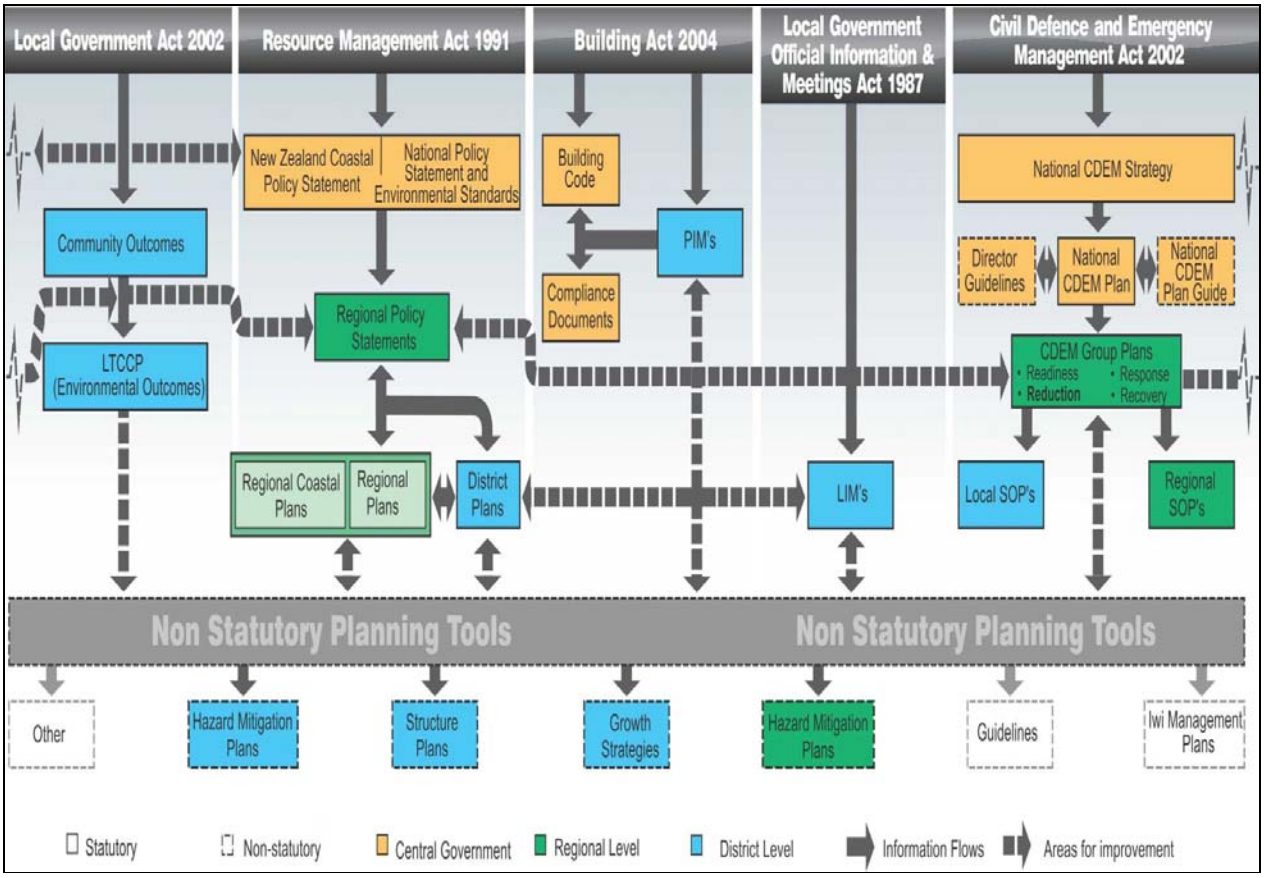


Figure 17 Legislative contexts for hazard management in New Zealand (Glavovic *et al*. 2010, Saunders et al, 2011).

Table 3 provides a summary of how these statutes manage the earthquake risk in New Zealand. The reduction of risk primarily lies with the RMA, whereas emergency management (readiness, response, recovery) lies with the CDEM Act (Saunders et al *2011*).

Table 3 Summary of how statutes contribute to the management of earthquake risk (Adaptation of the table within Saunders *et al* 2011).

Statute	Implication for natural hazard management
Resource Management Act 1991	• Health and safety issue must be addressed. • Local authorities are required to avoid or mitigate the effects of natural hazards, not their occurrence (*Canterbury RC v Banks Peninsula DC, 1995).* • S106 allows for Councils to consider the potential erosion, falling debris and flooding effects which could affect a subdivision (not landuse development). It should be noted that S106 does not allow for the consideration of all natural hazards as defined under the RMA (in particular fault rupture and tsunami which can be associated with an earthquake). • The ability to develop National Policy Statements of National Environmental Standards to address natural hazards (none currently exist).

Statute	Implication for natural hazard management
Building Act 2004	• Requires all buildings are 'safe from all reasonably foreseeable actions during the life of the building' • Reference is made to the joint Australian/New Zealand loading standard AS/NZS1170. Within Table 3.1 of Part 0 the acceptable annual probability of exceedance for wind and earthquake loads are identified. These relate to the return period for an event (being 1/500, 1/1000 and 1/2500) and the building importance categories of II (ordinary) III (Important) and IV (Critical). The more important the building, the longer the return period of an event is the structure required to be designed for. • These annual probabilities of exceedance correspond to a 10%, 5% and 2% probability within the nominal 50 year life of the building. • The ability to resist actions from other hazards is specified in the Building Code (a regulation that accompanies the Building Act) but no acceptable intensity of action or recurrence interval is prescribed either in the Code or in the Loading Standard (except for snow which has a nominal annual probability of exceedence of 1/150 years). • Sections 72 – 74 of the Building Act identify the process that Councils must follow when considering a building consent on a site subject to 1 or more natural hazards. The Building Act allows for Council to decline a building consent if, by granting the consent, the development would worsen or accelerate the effects from a natural hazard. Alternatively, building consent can be granted if: i) adequate provision has been or will be made to protect the land, building work, or other property from the natural hazard or hazards; or ii) restore any damage to that land or other property as a result of the building work. • The definition of natural hazards under the Building Act is limited and does not include tsunami or fault rupture
CDEM Act 2002	• 4R (readiness, reduction, response and recovery) philosophy – risk reduction is assumed to be managed under the RMA (refer Saunders et al 2007). • Encourage and enable communities to achieve acceptable levels of risk. • Readiness and response driven.
Local Government Act 2002	• Financial planning for risk reduction activities. • Take into account the foreseeable needs of future generations.
Local Government Official Information & Meetings Act 1987	• Provides for natural hazard information to be included in LIMs. • If the natural hazard is identified within the District Plan, this information is not required to be provided within a LIM (S44A(2)(a)(ii).

5.2 National Guidance

In 2001, the Parliamentary Commissioner for the Environment (PCE) directed that guidance was needed on how to address the hazards associated with fault rupture (Parliamentary Commissioner for the Environment, 2001). In 2003, the Ministry for the Environment commissioned planning guidelines, to assist with addressing the hazard associated with fault rupture. These guidelines were entitled *Planning for the Development of Land on or Close to Active Faults* (Kerr et al., 2003).

The active fault guidelines provide a risk-based approach for dealing with the fault rupture hazard. Within these guidelines, it is recommended that information on the nature of the fault rupture hazard (e.g. location, recurrence interval) and development type (e.g. use and construction type) is obtained before decisions are made about if and how, the risk associated with fault rupture will be treated. The key principles of the guidelines are:

- gather accurate active fault hazard information
- determine how to avoid fault rupture areas before development and subdivisions
- consider, and as appropriate, account for fault rupture hazard in areas already developed or subdivided
- communicate risk in built-up areas subject to fault rupture.

These guidelines contain suggested examples of consent categories to assist practitioners with addressing differing types of faultlines. Generally speaking, these guidelines recommend a more restricted consent activity status as the risk associated with a development increases.

It has been eight years since the Active Fault Guidelines were released. Recently, a revised risk-based approach to landuse planning has been proposed (Saunders *et al* 2011). While the risk-based approach of Saunders et al 2011 addresses landuse planning in context of a tsunami, the general principles are directly transferable to active faults. This revised risk-based approach will be described in more detail later in this report.

5.3 West Coast Regional Policy Statement

A natural hazard is defined within Section 2 of the Resource Management Act as:
"...any atmospheric, or earth, or water related occurrence (including, earthquake, tsunami, erosion, volcanic and geothermal activity, landslip, subsidence, sedimentation, wind, drought, fire or flooding), the action of which adversely affects or may affect human life, property or aspects of the environment."

Section 30 (c)(iv) of the Resource Management Act provides for Regional Councils to have control over the use of land for the purpose of avoiding or mitigating natural hazards.

Sections 62(1)(i) and (j) of the Resource Management Act 1991 state:

- the local authority responsible in the whole or any part of the region for specifying the objectives, policies, and methods for the control of the use of land—

  (i) to avoid or mitigate natural hazards or any group of hazards; and

  (j) the procedures used to monitor the efficiency and effectiveness of the policies or methods contained in the statement;

The Resource Management Act 1991 therefore requires a regional policy statement to provide for the avoidance and mitigation of the effects from a natural hazard.

Issue 11 of the West Coast Regional Policy Statement (2000) recognises the threat of an earthquake from the Alpine Fault to the communities on the West Coast. This includes the hazards associated with a large earthquake including landslides, damming of rivers, liquefaction and tsunami. However, neither ground shaking or fault rupture from the Alpine Fault is specifically mentioned within this section of the West Coast Regional Policy Statement.

Table 4 identifies the most relevant policies and implementation methods within the West Coast Regional Policy Statement for avoiding and mitigating the risk from an earthquake.

Table 4 The relevant policies and implementation methods of the West Coast Regional Policy Statement which address natural hazards.

Policy		Implementation Methods	
Policy 11.2	*Recognise the risks to proposed and existing development from natural hazards and promote measures to reduce this risk to an acceptable level. Where necessary further development in hazard-prone areas will be restricted (refer Policy1.3).*	11.1	*Identification of areas at risk from natural hazards by the Regional Council through exchange of information between other agencies and consultation with the public. The Regional Council will liaise with and provide information to territorial authorities and promote the inclusion of natural hazard information in district plans, through the resource consent process and land information memoranda.*
Policy 11.3	*Consult with people and communities directly affected when making decisions on levels of risk from natural hazards. When making decisions on levels of risk matters to be considered will include:* *a) The probability of occurrence, magnitude and location of events;* *b) The potential consequence of an event including potential loss of life, injury, social and economic disruption, civil defence implications and cost to the community;* *c) The measures proposed to avoid or mitigate the effects of the event, the degree of mitigation they will provide and effects on the environment from adopting such measures;* *d) The benefits and costs of alternative mitigation measures; and* *e) The possibility of locating activities away from areas at risk.*	11.2	*Encourage improved public awareness of hazards within the region.*
		11.3	*When requested, the Regional Council will provide regional civil defence and disaster recovery assistance to the region's territorial authorities. This will include seeking assistance from the Crown.*
		11.5	*Place controls on development in areas subject to risk from natural hazards, through rules in relevant regional and district plans.*

The policies within Table 4 recognise that differing natural hazards and magnitude of events have varying return periods. These policies require the potential consequence from natural hazards to be recognised and considered when developments are undertaken. The use of the word “consequence” is important as this allows for the consideration of events that have a low recurrence but high economic, social, environment or cultural effects within the relevant planning frameworks. This in turn encourages a risk-based planning assessment of developments to be undertaken (which is described in further detail in Chapter 7).

5.4 Westland Council District Plan

Chapter 3.13 of the Westland Council District Plan concentrates on the range of natural hazards that affect the local region. Within this chapter, earthquakes (and associated natural hazards such as landslides and tsunami) are recognised as potentially the most destructive natural hazard that could affect the region.

Objective 3.13.1 of the District Plan identifies that rules for the avoidance and mitigation of natural hazards have been incorporated into the District Plan. This objective is supported by a series of policies that seek to avoid developments within areas of known natural hazard risk, unless the risk of damage to property and infrastructure, community disruption, injury and potential loss of life can be adequately mitigated. The identified methods to achieve these policy outcomes include preventing or restricting developments in areas of known natural hazard risk, increasing community awareness, and working with other territorial authorities, agencies, stakeholders and communities to develop a comprehensive “package” of measures, statutory and non-statutory, to avoid, remedy or mitigate the adverse effects of natural hazards within the District. (Westland District Council District Plan 2002).

The objective and policies of the Westland Council District Plan are clear in their intention to ensure that the risks from natural hazards for the region are identified, and that appropriate mitigation measures are adopted into developments to avoid or mitigate any resulting effects. Within the Westland Council District Plan the only natural hazard which has specific rules which seek to mitigate the risk from an event occurring is flooding. Currently, there are no rules within the Westland Council District Plan that seek to avoid or mitigate the effects from the rupture of the Alpine Fault, even though there is a large risk of this faultline rupturing.

6.0 PLANNING APPROACHES TO MANAGING FURTHER DEVELOPMENT ON THE ALPINE FAULT

This section of the report explores six planning options available to address the risk associated with the Alpine Fault rupturing. While this section does not recommend any one particular outcome over another (as this is something that the Council and local community will need to decide through consultation), the advantages and disadvantages of each option have been identified. It should be noted that it is likely that a combination of the planning options below will be required to manage future development on the Alpine Fault.

6.1 Do nothing

Within the current Westland Council District Plan, there are no rules pertaining to developments on or near the Alpine Fault. If a resource consent is required for a development as a discretionary or non-complying activity, the risk from the Alpine Fault could be considered as one of the assessment criteria, through the virtue of S104 (1) (a) – (b) of the Resource Management Act 1991. As previously identified, there are objectives and policies within the Westland District Plan directly relating to the mitigation and avoidance of the effects from a natural hazard, which would assist with the assessment of these applications.

There are however several problems if no rules were created and incorporated into the District Plan to manage development on the Alpine Fault. Firstly, the Resource Management Act 1991 is clear in its requirement for local authorities to avoid or mitigate the effects from natural hazards (sections 30 (c)(iv) and 62(1)(i) and (j)) Furthermore, Part 2, section 5 of the Resource Management Act 1991, states:

"*Sustainable management means managing the use, development, and protection of natural and physical resources in a way, or at a rate, which enables peoples and communities to provide for their social, economic and cultural wellbeing* ***<u>and for their health and safety</u>*** *while –"*

Given these legislative requirements, if the risk from the Alpine Fault is not identified within the relevant statutory documents, the local territorial authorities are not fulfilling their statutory requirements under the Resource Management Act 1991.

Secondly, The Civil Defence Emergency Management Act (CDEM) relies on the RMA for risk reduction (Figure 17). If rules are not developed to reduce the potential risk from future development on or along the fault, there are effectively no risk reduction procedures in place. This may result in a greater level of damage to local infrastructure and buildings after the fault ruptures than if there had been rules in place to limit development. This greater level of damage would make it more difficult for the Civil Defence to respond immediately after the event and also mean that it would take longer for the community to recover.

Thirdly, the Regional Policy Statement requires that natural hazard information (including active faults) is identified within the local territorial authority's District Plans and relevant planning frameworks are developed. If the Council do not develop rules when controlling development on or close to the Alpine Fault, the District Plan could be seen to be ignoring a directive from the Regional Policy Statement. This in turn could create potential legal issues for the Council, if the fault ruptured and inappropriate developments had been approved to be undertaken on or close to the Alpine Fault.

Finally, if there are no rules specific to the development of buildings or structures or the change of use of these, where they are located close to the fault, there is the potential for inappropriate development to occur, which could have significant consequences when the fault ruptures. This is particularly relevant for permitted, controlled or restricted discretionary activities where the fault hazard has not been identified as a matter for consideration when assessing a development. The lack of appropriate controls relating to developments in close proximity to the Alpine Fault could lead to Council having to consider and approve inappropriate developments, without any ability to consider the associated risks and consequences. This could have significant consequences when the Alpine Fault ruptures in terms of risk to people's lives and damage to properties.

6.2 Fault Avoidance Zones

A common approach adopted by many councils is to identify the position of the fault within the District Plan. The fault often has a buffer around it, which can vary in width depending on the level of certainty associated with its position (Kerr et al., 2003). These buffers are known as Fault Avoidance Zones (FAZs) and any development within these are controlled by rules with supporting objectives and policies. Many of these FAZs have rules limiting new developments within their confines (particularly habitual buildings).

However, these rules often have a downfall, in that they only cover new construction works that either establish a building on a site or increase the footprint of an existing structure. These rules often do not address the effects associated with the change in use of an existing building within an identified fault avoidance zone. It is therefore important, when using FAZs, that the new rules address both the effects associated with the construction of a new building, as well as the change in use of existing structures. One approach that can be used is a risk-based planning assessment, as described in more detail in Section 7 of this report.

Any rules created for FAZs must have clear supporting objectives and policies which define what outcomes the rules are intending to achieve. These objectives and policies should use terms such as “risk” and “consequence”. These terms would support a risk-based planning approach being undertaken to developments in close proximity to active faults. These objectives and policies should also define the acceptable, tolerable and intolerable threshold levels for the consequences resulting from a fault rupture. This approach would then give planners a more defined set of criteria to assess a proposal against, which would also allow for any mitigation measures proposed as part of an application to be considered (as these measures would reduce the consequence for an event). This approach is also supported by the West Coast Regional Policy Statement which requires the risks from natural hazards to be reduced to acceptable levels and consequences of an event on life safety, social and economic disruption, civil defence implications and cost to the community to be considered (West Coast Regional Policy Statement 2000).

Franz Josef is a relatively small township and the fault avoidance zone identified within this report encompasses a significant part of the commercial centre. Given the purpose of this avoidance zone is to limit future development and mitigate the risk from the Alpine Fault rupturing, it is important that areas are identified where the town can expand into in the future. When determining where potential expansion could occur, the new development area should not be at the same or greater risk from a natural hazard as the current town centre.

Based on a desktop study of the local area, it may be possible to expand Franz Josef to the immediate north of the existing township. This area is reasonably well separated from the Alpine Fault and therefore any development would not be within the identified FAZ. This area also locates new development some distance from the immediate path of other natural hazards such as landslides, debris flows and alluvial fans that could occur immediately after a large earthquake event. This area is also not within the General Flood Hazard Area as identified within the District Plan (Figure 18).

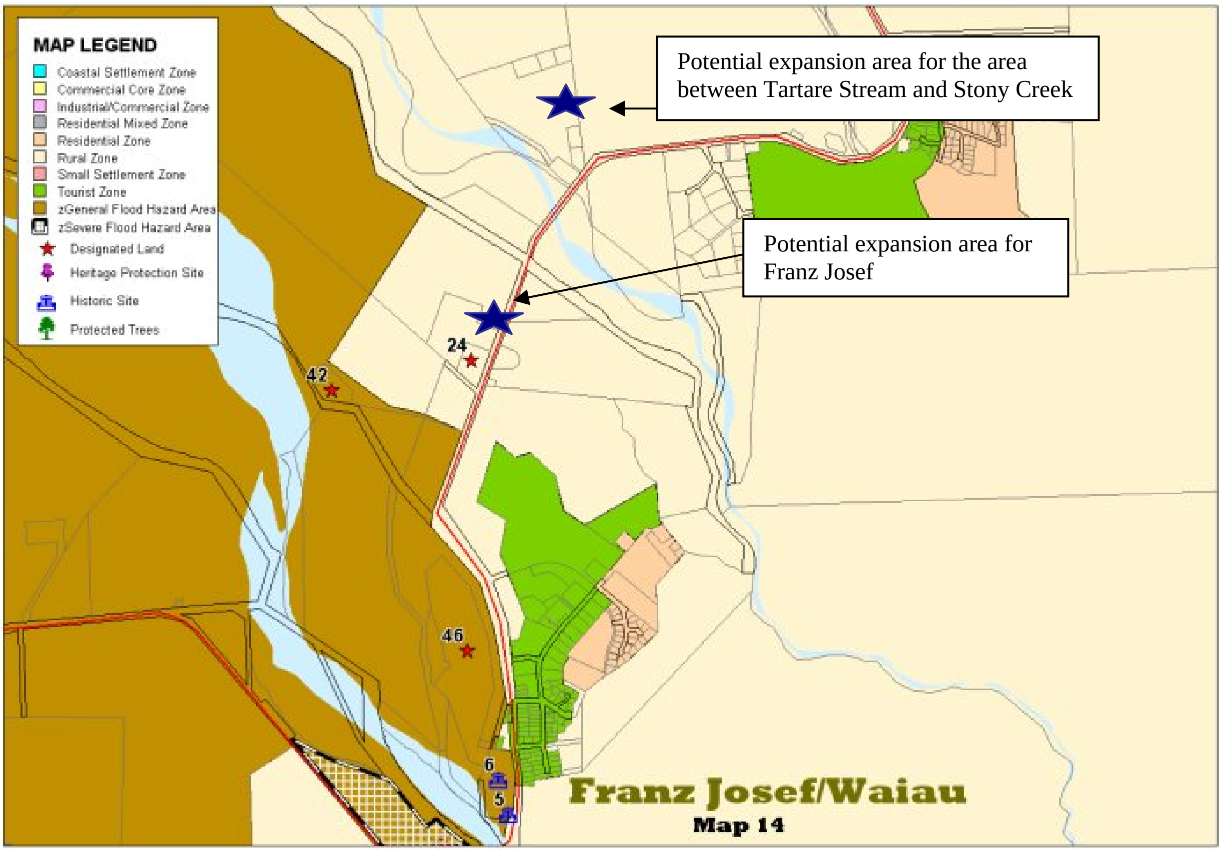


Figure 18 Identifying the potential expasion area for Franz Josef (Source: Westland District Council District Plan 2002).

The area between Tartare Stream and Stony Creek has similar issues as Franz Josef, with the Alpine Fault passing through the edge of the settlement. However, compared with Franz Josef, when the suggested Fault Avoidance Zone is overlaid onto this community, only a small portion is situated within this area. A similar desktop analysis has been undertaken to investigate a potential expansion area available for the community between Tartare Stream and Stony Creek. The area that appears to be appropriate for the expansion is to the west of State Highway 6 (Figure 18). This area is reasonably well separated from the Alpine Fault and therefore future development would not be within the identified FAZ. Alternatively, the community could be relocated overtime to the area to the immediate north of Franz Josef as identified within the above figure.

It is recognised that these two potential expansion areas are within the tourism and rural zones of the District Plan. A plan change would therefore be required to facilitate the expansion of the Franz Josef township into these areas. As part of this plan change, an analysis would need to be undertaken to ensure that these suggested areas are not at a high risk from another natural hazard which could affect future development e.g debris flows, flooding.

6.3 Risk-Based Planning Approach

As identified within Chapter 5.2 of this report, national guidelines have been developed which form a framework for taking a risk-based approach to dealing with the fault rupture hazard.

The risk-based approach has been adopted into the Kapiti Coast District Plan as a way to control development within their identified FAZs. The Kapiti Coast District Plan determines the status of a resource consent within their identified FAZs through a combination of the Building Importance Category, Fault Complexity and Recurrence Interval.

This approach is more robust than just identifying that all new habitual buildings require resource consent, as the activity status of the development is directly related to the building importance category. This approach helps ensure that buildings that would either contain large number of people or are critical facilities are not located on the faultline.

However, like the FAZs, careful attention should be given to ensure that change in use of existing buildings is captured. This is particularly important as the acceptability of a development within a FAZ could be linked to the importance category of the building. If there was a change in the use of the building, then its associated importance may increase and subsequently the risks associated with the new use within the FAZ may become unacceptable.

The risk based approach within the Active Fault Guidelines have been refined and adapted in a manner which allows for Councils to use them for a wider variety of development scenarios since they were originally released. The current risk-based approach is detailed within Saunders et al (2011) and is explored in more detail within section 7 of this report.

6.4 Pre-event Recovery Planning

Pre-event recovery planning is the consideration of landuse recovery issues, and implementation of solutions, before a disaster occurs. By working through issues and solutions before an event occurs, the process of recovery can be greatly improved, resulting in better coordination, efficiency and appropriately targeted reinstatement of affected areas (Becker et al., 2008).

In 2008, Becker et al. published a methodology on pre-event planning for land use, which outlines key things that regional and district councils can put into their policies and plans, to address the impacts of disasters and aid an effective recovery. Based on this methodology, a workshop was run within the Wellington Region exploring the methodology relating to pre-event recovery and what opportunities existed to incorporate this methodology into future planning. Table 5 is one such example and describes some suggestions of pre-event recovery planning for earthquakes (Becker et al, in prep).

Regardless of which of the planning tools are adopted to address the risk from the Alpine Fault rupturing, pre-event recovery planning should be included to increase the resilience of the Franz Josef community. However, if a specific pre-event recovery plan is not desired, it is possible to consider incorporating many of these recovery aspects into other documents such as district or regional plans, civil defence emergency management plans, financial plans or other non-statutory plans (Beban et al 2011 in prep).

Table 5 Pre-event land use recovery measures that could be investigated to improve the long-term recovery following an earthquake (Becker et al, in prep).

Opportunity	**Pre-Event Recovery Action**
Examine the lessons learnt from previous events	• Following previous events, a number of lessons were learnt. Use these to identify appropriate land use recovery measures for future events. • Form a working group comprised of lifeline organisations, civil defence and emergency management officers, and planners to disseminate the information.
Develop rules and guidelines	• Undertake research to define and map the active fault. • Include rules in the district plan for development on and near the active fault. This will serve to avoid development in the areas most susceptible to damage and where these areas cannot be avoided, require measures to reduce the damage to any buildings and infrastructure. • Develop guidelines for people wanting to locate development within the active fault zone or looking at rebuilding following an earthquake event.
Review building standards	• Ensure that any buildings rebuilt after the event are designed to increased standards recognising the active fault risk within the city and change to national standards.
Identify areas for temporary housing	• Identify areas of land within the city which could act as temporary housing (0-6 months) and ensure that the relevant bylaws are in place to allow temporary facilities to be established in these areas. • Identify areas of land within the city that could be developed for the relocation of dwellings following an earthquake.
Identify areas for temporary/and or permanent relocation of vital community assets and infrastructure	• Consider zoning changes which allow key community assets such as schools, council service centres, business district etc to be located in new (greenfield) sites away from the fault avoidance zone.
Plan for secondary hazards	• Other natural hazards such as landslides may be triggered by an earthquake. Landslides could block roads, prolonging recovery activities. Council could establish a memorandum of understanding with the road controlling authorities so that debris blocking identified roads can be removed to recognised locations without the need for additional approvals.
Demolition material	• Identifying sites for the temporary and permanent storage of demolition material. Using the earthquake scenarios to assist in identifying the volume of material that may need to be disposed of. Obtain resource consents for the disposal of material at several sites in and around the city. See Johnston et al. (2009) for further information about debris disposal following an earthquake.
Emergency consents	• Initiate a procedure for the processing of emergency consents and consents for the rebuilding of structures following an event.

Opportunity	Pre-Event Recovery Action
	• Undertake staff training to ensure that Council staff are aware of the systems and processes. This could speed up the approval process if an event occurs.
Building Safety Inspection	• Increase capacity and expertise of staff (or arrange MoU's with other Councils) so that efficient and skilled assessment of building damage can occur as soon after an event as is practical • Develop guidelines and registers for combining building damage data to facilitate recovery planning
Educate planners about earthquake hazard consequences	• Include planning staff in CDEM planning and training, particularly exercises, so they can gain experience in dealing with possible consequences of earthquake hazards that can be reduced by land-use planning.

6.5 Relocation of Essential Services / Managed Retreat

The relocation of essential services and the managed retreat from the identified fault avoidance zone is another approach for reducing the potential consequences from the Alpine Fault rupturing. This approach includes using planning rules, providing financial or other incentives for the relocation of essential services (for example the police station and the service station).

This approach is limited to existing services and businesses located within the fault avoidance zone. In New Zealand, managed retreat has happened in a number of instances and by a variety of mechanisms. In some cases the local council has purchased properties from landowners and turned them into reserve, in other situations the central government has done so, and other acquisitions have resulted from partnership agreements between individuals and authorities (*Beban et al. in prep*).

For a small community like Franz Josef, there are potential budget constraints, especially if properties were purchased or financial incentives were provided for the relocation of businesses. If this approach is undertaken, planning rules should be developed to limit potential developments in the FAZ. Otherwise, there is the potential for Council to provide incentives for one business to leave a site, only to have it replaced with another use which may be inappropriate within the fault avoidance zone.

6.6 Relocation of Franz Josef

The final option for addressing the risk for Franz Josef from the Alpine Fault would be to relocate the township. This option should only be explored after extensive consultation had been undertaken with the local community and relevant stakeholders. There are many planning issues that would need to be considered if this approach was to be undertaken, including:

- determining where the new position of the township would be located;
- the potential social and economic consequences associated with relocating the township, especially if the township was to be no longer located on State Highway 6;

- ensuring that the new township location was not at the same or greater risk from a natural hazard (e.g flooding, landslide etc.);
- the potential cultural and social impacts of relocating the township; and
- the potential environmental impacts of the proposed township location.

6.7 Summary

There are a variety of planning mechanisms available to address the potential effects associated with the Alpine Fault rupturing. While no single approach has been recommended, it is likely that a variety of the above measures will best address the effects associated with the Alpine Fault rupturing. The mix and the degree to which each approach are implemented by the council will need to be determined through consultation with the local community. The following section will provide an option for taking a risk-based approach to planning.

7.0 TAKING A RISK-BASED APPROACH TO LAND USE PLANNING

Traditionally the planning approach for addressing natural hazards has been based on the likelihood of an event occurring. There has been little consideration of the consequences associated with a natural hazard event where it exceeds the design occurrence interval. For example the recent events in Christchurch demonstrated the potential damage that can occur to buildings and communities when an earthquake occurs which exceeds the ground accelerations designed for in the Building Act 2004.

A risk-based planning assessment can be used when addressing the effects from a particular natural hazard – in this case an earthquake on the Alpine Fault. A risk-based assessment ensures that the economic, environmental, social and cultural consequences of specific developments are explored and quantified as part of future planning decisions.

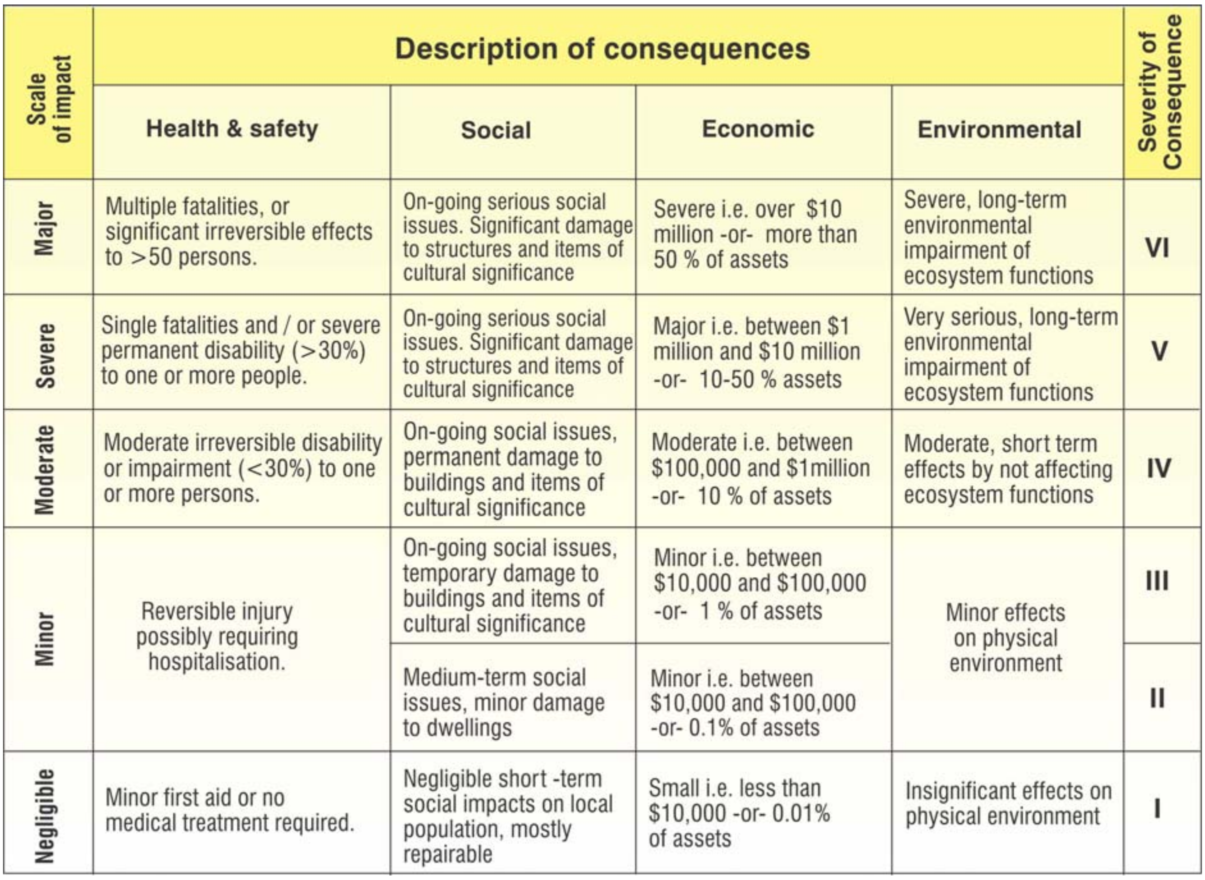
The advantage of a risk-based assessment is that once it has been incorporated into a district plan, it allows for the consideration of the effects associated with both the construction of buildings and a change in use to an existing building within a Fault Avoidance Zone. This in turn allows for more robust planning decisions to be made when determining what activities Council's wish to occur within their FAZs.

The methodology for a risk-based planning approach is as follows and is a summary of the approach detailed within Saunders et al (2011) and Saunders (2011). It should be noted that the levels of risk and risk descriptors provided within this summary are examples of potential threshold levels which can be used. Depending on the outcome of the public consultation undertaken by the Westland District Council, these threshold levels could change. This in turn would result in the potential risk based calculations being different than those detailed within this chapter. However, further examples of how this approach can be used for various natural hazards are currently the focus of an Enviro Tools project funded by the Ministry of Science and Innovation. This project is due for completion in 2013.

Step 1: Determine severity of consequences

The first step of the process is to determine what the land use (zone) of a property or property's is. This can be assisted by consulting the relevant district/city plan These zones identify the types of land use permitted in a particular area, which assists in determining what form of development is predominantly at risk from the natural hazard. This approach also ensures consistency with the terms used within the District Plan context. Inspections on the ground should then confirm the actual land uses as it is not uncommon for activities to be located out of zone.

Once the land use has been confirmed, the consequences of an event on that land use need to be determined. Figure 19 provides a matrix consisting of three key parts: scale of impact, description of consequences, and severity of consequence.



Scale of impact	Description of consequences				Severity of Consequence
	Health & safety	Social	Economic	Environmental	
Major	Multiple fatalities, or significant irreversible effects to >50 persons.	On-going serious social issues. Significant damage to structures and items of cultural significance	Severe i.e. over $10 million -or- more than 50 % of assets	Severe, long-term environmental impairment of ecosystem functions	VI
Severe	Single fatalities and / or severe permanent disability (>30%) to one or more people.	On-going serious social issues. Significant damage to structures and items of cultural significance	Major i.e. between $1 million and $10 million -or- 10-50 % assets	Very serious, long-term environmental impairment of ecosystem functions	V
Moderate	Moderate irreversible disability or impairment (<30%) to one or more persons.	On-going social issues, permanent damage to buildings and items of cultural significance	Moderate i.e. between $100,000 and $1million -or- 10 % of assets	Moderate, short term effects by not affecting ecosystem functions	IV
Minor	Reversible injury possibly requiring hospitalisation.	On-going social issues, temporary damage to buildings and items of cultural significance	Minor i.e. between $10,000 and $100,000 -or- 1 % of assets	Minor effects on physical environment	III
		Medium-term social issues, minor damage to dwellings	Minor i.e. between $10,000 and $100,000 -or- 0.1% of assets		II
Negligible	Minor first aid or no medical treatment required.	Negligible short -term social impacts on local population, mostly repairable	Small i.e. less than $10,000 -or- 0.01% of assets	Insignificant effects on physical environment	I

Figure 19 Scale of impact and consequences (Source: Saunders 2011).

Thresholds relating to the risk of death or injuries to individual or multiple people can also be used in the 'health and safety' consequence column, however this attribute does not contain the likelihood of an event occurring (rather than being the next step). If risk thresholds pertaining to death or injuries were included, it could be as follows for an individual:

Intolerable	above ~ 10^{-2} / year
Generally tolerable with consent	~ 10^{-3} to 10^{-4} / year
Tolerable	~ 10^{-5} to 10^{-6} / year
Acceptable	~ 10^{-6} to 10^{-7} / year

The description of consequences should be completed by the Council with participation from the community, to reflect the local 'hazardscape' and social, economic and environmental contexts. The consequences in Figure 19 are presented as an example of what can be considered (based on legislative provisions); other categories and subcategories could be added (e.g. built environment).

Saunders (2011) suggests two options for ranking of consequences. The first option is where the most severe consequence is taken as representing the severity of an event. The second approach is that the Ministry for Civil Defence and Emergency Management (MCDEM) has created a “SMG: model for determining hazard priorities” (MCDEM 2009). Under the SMG model; S = seriousness, M = manageability and G = Growth. Under the seriousness ranking, MCDEM (2009 p17) recommends that the social consequences (which includes health and safety, built, economic and natural environments) are weighed as follows:

- Social – 50% of the total value, due to the high priority of protecting human life and safety, and community readiness, response and recovery in Civil Defence Emergency Management Act;
- Built – 25% of the total value, due to the importance of protecting lifelines and other critical infrastructure in relation to social concerns;
- Economic – 15% of the total value, reflecting a secondary priority, and that the built environment will normally account for most of the economic damage; and
- Natural – 10% of the total values, reflecting the relatively low level of concern within the CDEM sector.

Step 2: Evaluate the likelihood of an event

Once the land use and consequences have been determined, only then should the likelihood be evaluated. By focusing on consequences first, the current approach of putting people and property in harm’s way based on small timeframes, should be overcome. Table 6 provides a likelihood scale which can be used as a guide.

Table 6 Likelihood scale (adapted from Standards New Zealand, 2004)

Level	Descriptor	Description	Indicative Frequency (expected to occur)	AEP*
7	Almost certain	The event will occur on an annual basis	Once a year or more frequently	1
6	Likely	The event has occurred several times or more in your career	Once every three years	0.3
5	Possible	The event might occur once in your career	Once every ten years	0.1
4	Unlikely	The event does occur somewhere from time to time	Once every thirty years	0.03
3	Rare	Heard of something like this occurring elsewhere	Once every 100 years	0.01
2	Very rare	Have never heard of this happening	One in 1000 years	0.001
1	Almost incredible	Theoretically possible but not expected to occur	One in 10,000 years	0.0001

- AEP – annual exceedance probability (Source: Saunders 2011)

Table 6 is only a guide to the potential likelihoods which could be associated with the relevant risk level for a natural hazard. As these likelihoods differ for different natural hazards, it is difficult to have a consistent all-hazard probability when planning for natural hazards (e.g. a flood would have a different scale shown in Table 6 to a fault rupture). While some hazards have similar return periods, their likelihood, consequences, forecasting and warning capabilities may be different (for example high rainfall events can be forecast, flood warnings can be given, and evacuation of communities are possible – unlike the situation for earthquakes which may also have greater consequences than a flood) (Saunders 2010). Therefore, to ensure that the likelihood of a natural hazard occurring is accurate reflected, the relationship between the frequency of an event and the likelihood level assigned has to be specific to the natural hazard. Figure 20 demonstrates how the relationship between the frequency of an event and the assigned likelihood level may differ between an earthquake and a flood.

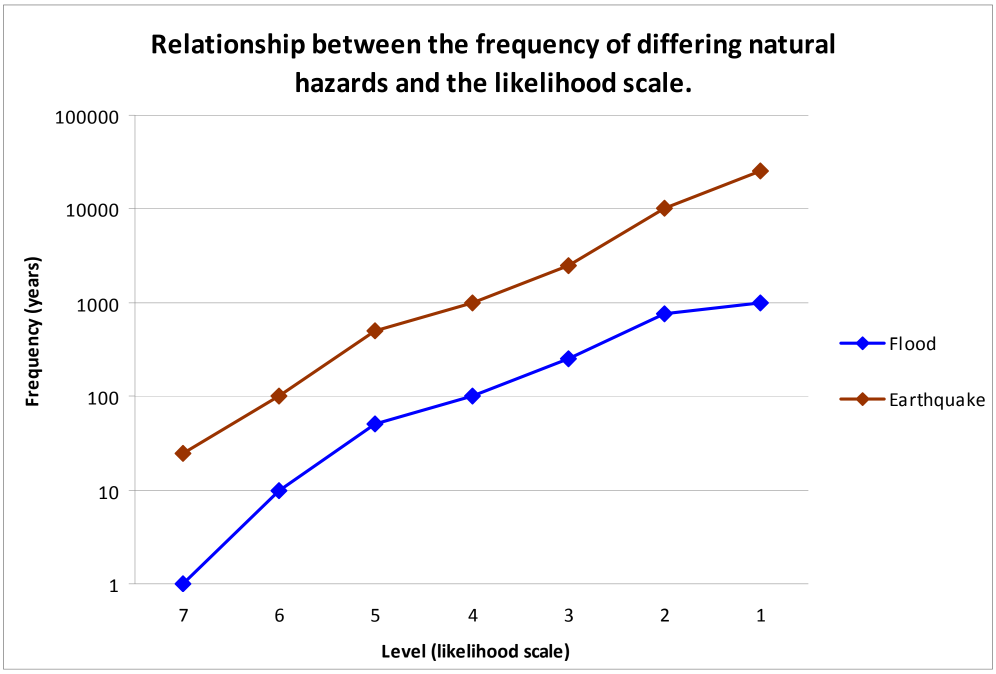


Figure 20 Relationship between the frequency of differing natural hazards and the likelihood scale (adapted from Saunders 2010).

Once the land use, consequences and likelihood (steps 1 and 2) have been determined, then the options for land use planning can be assessed. The methodology of this final stage of the process is outlined in the following section.

Step 3: Take a risk-based approach

In order to take a risk-based approach, the consequences and likelihood need to be quantified to provide a level of risk. To achieve this, a matrix can be used incorporating the relevant risk level, expressed as a function of consequences multiplied by likelihood (Figure 20). Consequences are relabelled from roman numerals into Arabic numerals to allow for the calculation. The risk then ranges from 1 (extremely low) to 42 (extremely high).

	Consequences					
Likelihood	**1**	**2**	**3**	**4**	**5**	**6**
7	7	14	21	28	35	42
6	6	12	18	24	30	36
5	5	10	15	20	25	30
4	4	8	12	16	20	24
3	3	6	9	12	15	18
2	2	4	6	8	10	12
1	1	2	3	4	5	6

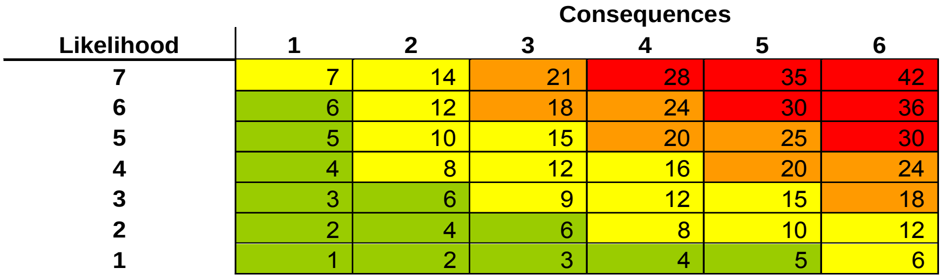
Figure 21 Quantifying consequences and likelihood (Source: Saunders 2011).

The risk levels then need to be determined. Figure 22 shows how the risk levels were determined from Figure 21. In practice, participation and associated debate would be required within Council and with the community to determine the thresholds for the levels of risk.

Risk	Level of risk
1-6	Acceptable
7-14	Tolerable
15-24	Tolerable with consent
25-42	Intolerable

Figure 22 Qualifying levels of risk from Figure 21 (Source: Saunders 2011).

Once levels of risk have been determined, the matrix is then colour coded (Figure 23), based on the levels of risk shown in Figure 22. The use of colours allows a faster assessment of the levels of risk involved. The colours of green (acceptable), yellow (tolerable), orange (tolerable with consent) and red (intolerable) are considered standard colours for this approach (Standards New Zealand, 2004).



	Consequences					
Likelihood	**1**	**2**	**3**	**4**	**5**	**6**
7	7	14	21	28	35	42
6	6	12	18	24	30	36
5	5	10	15	20	25	30
4	4	8	12	16	20	24
3	3	6	9	12	15	18
2	2	4	6	8	10	12
1	1	2	3	4	5	6

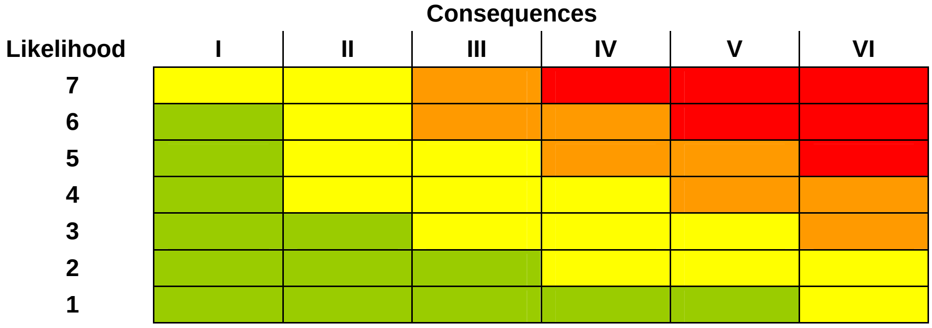
Figure 23 Colour coding the matrix based on level of risk (Source: Saunders 2011).

Consequence values 1 – 6 are relabelled into roman numerals to ensure no confusion between the likelihood scale and consequence scale. The final stage of the process uses the colours, based on the levels of risk, to determine the consent status (i.e. treatment) of the activity (Figure 24).

Level of risk	Consent status
Acceptable	Permitted
Tolerable	Controlled
Tolerable with consent	Discretionary
Intolerable	Non complying, prohibited

Figure 24 Level of risk and associated consent status (Source: Saunders 2011).

Figure 25 provides the final framework where risk equates to consent status applied.



	Consequences					
Likelihood	**I**	**II**	**III**	**IV**	**V**	**VI**
7	🟨	🟨	🟧	🟥	🟥	🟥
6	🟩	🟨	🟧	🟧	🟥	🟥
5	🟩	🟨	🟨	🟧	🟧	🟥
4	🟩	🟨	🟨	🟨	🟧	🟧
3	🟩	🟩	🟨	🟨	🟨	🟧
2	🟩	🟩	🟩	🟨	🟨	🟨
1	🟩	🟩	🟩	🟩	🟩	🟨

Likelihood	
7	Almost certain
6	Likely
5	Possible
4	Unlikely
3	Rare
2	Vary rare
1	Almost incredible

Consent Status	
🟩	Permitted
🟨	Controlled
🟧	Discretionary, Restricted Discretionary
🟥	Non Complying, Prohibited

Figure 25 The risk-based planning framework (Source: Saunders 2011).

Non-complying and prohibited are merged together, but it is acknowledged that the former allows for development, while the later avoids development. For the purposes of this example, the two are merged to allow for high consequence activities to take place in high risk areas, which may not be able to be avoided e.g. a port.

Figure 25 is only a guide to what can be achieved – community engagement and participation are required to determine the levels of risk and consequences. The evaluation of levels of risk in Figure 22 and assigning consent categories (Figure 24) may change depending on the context and community tolerability to risk. Other options may also be available to reduce losses, to a level which are acceptable or tolerable for communities. For example, sharing the risk of potential losses via insurance, or accepting/tolerating the risks involved.

8.0 SUMMARY

- GNS Science has undertaken mapping and analysis of the Franz Josef-Waiau area in order to construct Fault Avoidance Zones for the Alpine Fault, through the town of Franz Josef and to the areas northeast of the town between Tartare Stream and Stony Creek.

- The Alpine Fault is a RI Class I fault with a recurrence interval of <2000 yr. It has an average recurrence interval of c. 333 yr. The last rupture event is believed to have occurred around AD 1717. The single-event displacement in the next earthquake is expected to be c. 8-9 m horizontal and 1-2 m vertical. The probability of rupture of the Alpine Fault in the next 30 yr is 20%.

- A RTK-GPS map was made in the town of Franz Josef which helped define the topographic break related to the scarp of the Alpine Fault, which runs SW-NE through the southern part of the commercial portion of the town.

- LiDAR imagery was used to accurately define active fault traces (reverse and strike-slip), fold traces, and lineaments created by deformation related to the Alpine Fault Zone in a GIS.

- Individual and merged Fault Avoidance Zones were developed for the town. Individual reverse fault traces have a Fault Avoidance Zone width of 130 m that comprises a ±30 m Fault Location Uncertainty, which is doubled on the hangingwall side of the fault, due to the likely asymmetric nature of deformation. A ± 20 m Margin of Safety buffer is added to this 90 m wide zone.

- Individual strike-slip faults have a Fault Avoidance Zone width of 100 m, because the deformation is typically symmetric across these faults. Where there are multiple fault traces across the width of deformation, the GIS allows us to compose them together into a merged Fault Avoidance Zone. Along the rangefront of the Alpine Fault these merged zones can be hundreds of metres in width.

- In the developed part of Franz Josef township a number of buildings ranging from Building Importance Class (BIC) 1 to BIC 4 exist within or close to the 130 m wide Fault Avoidance Zone. These include hotel/motel accommodations, police station, petrol station, supermarket, shops and the DoC National Park headquarters.

- In the area between Tartare Stream and Stony Creek there is currently very little development, i.e. the area is mostly in a ‘greenfield’ situation. Only a small portion of the current road plan enters the Fault Avoidance Zone near Stony Creek.

- We consider that there is a measureable risk to both life and property as a consequence of the next Alpine Fault rupture.

- There are a variety of potential planning tools available to control development in close proximity to the Alpine Fault. Mitigation measures include the creation of Fault Avoidance Zones, adopting a risk-based planning approach, preparing a pre-event recovery plan and relocation of essential services away from the Fault Avoidance Zone. No single approach has been recommended, but it is likely that a variety of the above measures will best address the effects associated with the Alpine Fault rupturing. The mix and the degree to which each approach are implemented by the council will need to be determined through consultation with the local community.

- Franz Josef is a relatively small township and the fault avoidance zone identified within this report encompasses a significant part of the commercial centre. Given the purpose of this avoidance zone is to limit future development and mitigate the risk from the Alpine Fault rupturing, it is important that areas are identified where the town can expand into in the future. When determining where potential expansion could occur, the new development area should not be at the same or greater risk from a natural hazard as the current town centre.
- When future rules are developed for addressing the risk from the Alpine Fault, a risk based planning approach would allow for more robust planning decisions to be made. A risk based approach would result in a greater consideration of the consequences resulting from the Alpine Fault rupturing on future developments.

9.0 RECOMMENDATIONS

- West Coast Regional Council and Westland District Council should adopt the new Fault Avoidance Zones constructed for the Franz Josef-Waiau area, as they are developed from state-of-the-art mapping and surveying techniques.
- Once adopted, councils need to consider what the best forward approach will be toward mitigating the hazard of surface rupture from the Alpine Fault, and indeed from other natural hazards that could affect the township and surrounding area.
- In this regard, we have not defined a recommended path forward but have suggested a range of options ranging from maintaining the status quo through to relocation of the town.
- The planning tool(s) which are implemented to control development around the Alpine Fault should be determined by undertaking consultation with the local community. It is likely that a variety of the tools described within this report will need to be implemented to mitigate the risks from the Alpine Fault rupturing.
- Any potential planning rules created to control development within the Fault Avoidance Zone should consider using a risk based planning approach as this will allow for a full consideration of the consequences associated with a fault rupture and result in more robust planning decisions.

10.0 ACKNOWLEDGEMENTS

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11.0 GLOSSARY

Anticlinal warp – An anticline is a fold where the buckling forms an upward bulge (syncline = downward buckling). An anticlinal warp is a geomorphic feature which is suggestive of compression and uplift

Bedrock terranes – Bedrock refers to older, harder rocks that make up the middle to upper crust of the Earth. Old rocks are often arranged into terranes which belong to past active tectonic regimes

DEM – digital elevation model. A modelled contour map using xyz point data

Dextral-slip (fault) – “right-handed” horizontal movement (or fault), i.e. when observed from one side of a strike-slip fault, the displacement or movement of the other side is off to the right

Dip-slip - refers to a fault movement which takes place in the dip direction of the fault plane and creates a vertical change between two rock masses. Dip-slip can be divided into normal, reverse, and thrust fault movement

Displacement – a measurable movement on a fault, typically caused by an earthquake.

Fault – a plane in the Earth across which displacement of rock masses takes place.

FAZ - Fault Avoidance Zone: a hazard zone in which fault deformation is expected, in the form of faulting or folding. Construction is generally not recommended within a FAZ.

Fold axis – A fold is a buckle in rocks or soil material that is caused by compression between two rock masses or across a reverse/ thrust fault. A fold axis is the line which defines a mappable fold structure based on geomorphology or strike-and-dip attitudes.

Reverse-slip (fault) – a dip-slip movement (or fault) in which the hangingwall block rides over the footwall block, relative to the fault. Reverse fault dips are typically 45-70°.

Ridge rents – secondary linear structures or features that display extension or opening. Ridge rents are common features in the high country of New Zealand, and often occur in the rock mass near active faults. These can open or move sympathetically with faults movements.

Strike-slip – refers to a movement which is horizontal, i.e. the movement takes place in the strike of the fault plane

Thrust fault – a variety of reverse-slip, where the dip angle is low (c. 30°) and may taper toward 0° dip at the surface

Transpressive – motion that includes both strike-slip (translational) and compressive (reverse) movement

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APPENDICES

APPENDIX 1 RESOURCE CONSENT PLANNING TABLES

Table A1 The relationship between Resource Consent Category, Building Importance Category, Fault Recurrence Interval Class, and Fault Complexity for developed and/or already subdivided sites for the Alpine Fault, based on the MfE Active Fault Guidelines (for detail see Kerr et al 2003).

Developed and/or Already Subdivided Sites					
	Fault Recurrence Interval Class I [#]				
Building Importance Category	**1**	**2a**	**2b**	**3**	**4**
Fault Complexity	**Resource Consent Category**				
Well Defined	Permitted	*Non-Complying*	*Non-Complying*	*Non-Complying*	Non-Complying
Distributed, & *Uncertain - constrained	Permitted	*Discretionary*	*Non-Complying*	*Non-Complying*	Non-Complying
*Uncertain - poorly constrained	Permitted	*Discretionary*	*Non-Complying*	*Non-Complying*	Non-Complying
Greenfield Sites					
Building Importance Category	**1**	**2a**	**2b**	**3**	**4**
Fault Complexity	**Resource Consent Category**				
Well Defined	Permitted	*Non-Complying*	*Non-Complying*	*Non-Complying*	Prohibited
Distributed, & *Uncertain - constrained	Permitted	*Discretionary*	*Non-Complying*	*Non-Complying*	Non-Complying
*Uncertain - poorly constrained	Permitted	*Discretionary*	*Non-Complying*	*Non-Complying*	Non-Complying
Notes: * - Where the fault trace is uncertain, specific fault studies may provide more certainty on the location of the fault. *Italics*: The use of italics indicates that the Resource Consent Category of these categories is more flexible. For example, where *discretionary* is indicated, *controlled* may be considered more suitable by Council, or vice versa.					

APPENDIX 2 GIS LAYERS

ArcMap Shapefiles of features mapped between the Waiho River and Stony Creek including the township of Franz Josef-Waiau. (See attached CD).