Mapping and fault rupture avoidance zonation for the Alpine Fault in the West Coast region

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EXECUTIVE SUMMARY

The Alpine Fault is an active dextral-reverse fault that forms the major plate boundary structure between the Australian and Pacific plates through much of the South Island. In this study, the Alpine Fault has been mapped according to the Ministry for the Environment's Guidelines - "Planning for Development of Land on or Close to Active Faults" (i.e. MfE Guidelines; Kerr et al. 2003) for the entire length of West Coast region through all three districts of the region. The Alpine Fault will generate large to great earthquakes in the future with the potential to rupture to the Earth's surface, causing damage to built structures across or adjacent to the fault zone. The Alpine Fault is classified as a Recurrence Interval Class I (RI <2000 yr) fault along its entire length, and has an average recurrence time of c. 300-500 yr.

The main purpose of the MfE Guidelines is to avoid future loss of life from surface faulting. For life safety purposes, the Guidelines focus on: (i) the location and complexity of faulting; (ii) the characterisation of recurrence interval of surface faulting; and (iii) the Building Importance Category (BIC) with respect to land zonation for a site. Fault traces have been mapped to produce Fault Avoidance Zones (FAZ) surrounding the active traces at a scale suitable for the purposes of cadastral zoning. A number of priority areas have been defined for the West Coast region, where the Alpine Fault traverses open, accessible land where development pressures may overlap upon areas of potential future surface rupture.

Mapping of the Alpine Fault and Fault Avoidance Zones about the rupture trace has been undertaken using a Geographic Information System (GIS) utilising a number of mapping resources. These are principally: QMap geological maps (which include active fault line data), University of Otago online Alpine Fault mapping; RTK-GPS topographic maps and sketch maps from student theses and scientific papers. In addition a considerable amount of linework review has been undertaken by the authors using these sources, aerial photographs and orthophotographs. In addition to GIS-based mapping some field fault checking has been undertaken to confirm fault locations in some key areas. Several paleoseismic trenches have been excavated across the Alpine Fault during the last 12 years, as part of research and thesis studies into the activity of the fault. These trenches generally confirm the location and activity of the Alpine Fault as shown in the GIS.

Several case studies of priority areas show how the Fault Avoidance Zones are created. These areas are located where the Alpine Fault traverses near Maruia River, Haupiri River, Inchbonnie, Toaroha River, Franz Josef and Haast. The GIS dataset on the accompanying CD, provides coverage at the appropriate scale and includes cadastral information, with respect to fault location[1].

Typically, the data in this report has been mapped in a GIS at a scale of c. 1:10,000. In general, a line which approximates the location of surface faulting has been mapped in the GIS along the length of the Alpine Fault. Information related to the type and quality of the mapping data is stored within an Attribute Table in the GIS. The exact location of the fault has some inherent uncertainties. In this project the Horizontal Location uncertainty (i.e. where the fault represented by a line is) has been categorised by values of ± 20, ± 30, ± 50,

[1] Maps in the text of this report should not be used for planning purposes. They act as examples of the data that resides on the GIS CD.

and ± 100 m. These values are broadly correlated with the terms *Well-Defined, Distributed and Unconstrained* that relate to fault complexity in the MfE Guidelines. An additional value of uncertainty (± 20-100 m) has been added to the southeast, uplifting side of the fault along most of the length of the Alpine Fault, to account for the possibility of the uneven distribution of deformation on the hangingwall side of the fault.

Finally, a 'margin of safety' buffer of ± 20 m is added to these zones. The final widths of the Fault Avoidance Zones along the fault are therefore either: ± 100, ± 130, ±190, or ± 340 m in width, reflecting the overall confidence in the location and width of fault deformation along the length of the fault. As a result of this study, data on faults in the GNS Active Faults database (http://data.gns.cri.nz/af/index.jsp) will be updated and improved.

According to the MfE Active Fault Guidelines, for RI Class I faults in either a "Greenfield" or Developed setting, all BIC structures of BIC 2b or higher should be Non-Complying resource consent activities. BIC 2a structures, e.g. residential timber-framed single-storey dwellings have a Non-complying to Discretionary Resource Consent Activity.

We recommend that the mapping and zonation within this report be adopted by West Coast Regional Council and its three Territorial Land Authorities on the West Coast (Buller, Grey and Westland Districts). The Fault Avoidance Zones defined in this study act as a guide to the presence of the Alpine Fault within those areas. FAZ's could be reduced in width through more detailed mapping, trenching studies or surveying that better locate and define the nature of surface deformation. This may be particularly useful for the placement and consent of future developments.

Consideration should be given to fault mapping and zonation of other active faults in West Coast region in future. In future, individual active fault mapping studies could be undertaken for: Buller and Grey Districts - focusing on faults of the Paparoa Tectonic Zone, and faults of the Marlborough Fault System west of the Main Divide); and in Westland District, where more attention needs to be paid to the Alpine Fault in the vicinity of the town of Franz Josef.

1.0 INTRODUCTION

1.1 Scope of the Study

This study was undertaken on contract to West Coast Regional Council (WCRC) by the Institute of Geological and Nuclear Sciences Ltd (GNS Science) and was funded through the FRST Envirolink program. The purpose of the study was to help the WCRC to formulate and implement appropriate guidance for its Districts' (and their plans) pertaining to development in areas on, or close to, the active faults in its region. In particular, this study deals with the Alpine Fault (Fig. 1), which is the fastest moving, onland fault in New Zealand, and, according to the Ministry for the Environment's Active Fault Guidelines[2] is a Class I Recurrence Interval fault (RI <2000 years) along its entire length (Kerr et al. 2003; Van Dissen et al., 2003). These Guidelines cover issues related to the hazard posed by future surface rupture of active faults.

To facilitate this, the principal aims of the study were to:

1) more accurately define the location of the Alpine Fault in the West Coast region using the best available data, focusing on moderate to high impact areas along the fault;

2) develop surface rupture avoidance (Fault Avoidance) zones for the Alpine Fault that are based on the level of accuracy contained by the data; and

3) present the results of the study in a fashion that is compatible with the MfE Active Fault Guidelines.

In the contract, the GNS study was required to undertake:

- A literature search and review that defines the best sources of active fault mapping across the region;
- An assessment of aerial photographs, orthophotographs and other available imagery;
- Accurate mapping of active fault traces using the best available fault location data, placed into a Geographic Information System (GIS) format;
- Limited field work to verify and more accurately define fault locations in specific areas;
- To write a report and supply GIS Shapefile data that presents this material.

A number of specific geographic priority areas were discussed by GNS Science and WCRC. These are located on Figure 2 and include urban areas traversed by the fault (e.g. Franz Josef); land cleared of forest for farming and lifestyle blocks (e.g. Inchbonnie), and Dept. of Conservation (DoC) areas (e.g. Marble Hill). Active faults in other parts of West Coast region, e.g. the Paparoa Tectonic Zone, have not been addressed in this study.

The results of this work are this report, and a GIS database of fault features (as lines and points with associated GIS attribute tables) and Fault Avoidance Zones (as buffers with associated GIS attributes). The Fault Avoidance Zones are linked to Resource Consent Categories via Fault Recurrence Interval Class and Building Importance Category (BIC) as described in Kerr et al. (2003). Maps derived from the GIS database are included in this

[2] These guidelines will generally be referred to as the MfE Guidelines throughout this report.

report. These maps are provided to illustrate the methodology used and level of detail obtained in some areas, but do not show all areas where similar detail is present. Potential users are referred to the GIS data on the enclosed CD for complete coverage of the study area.

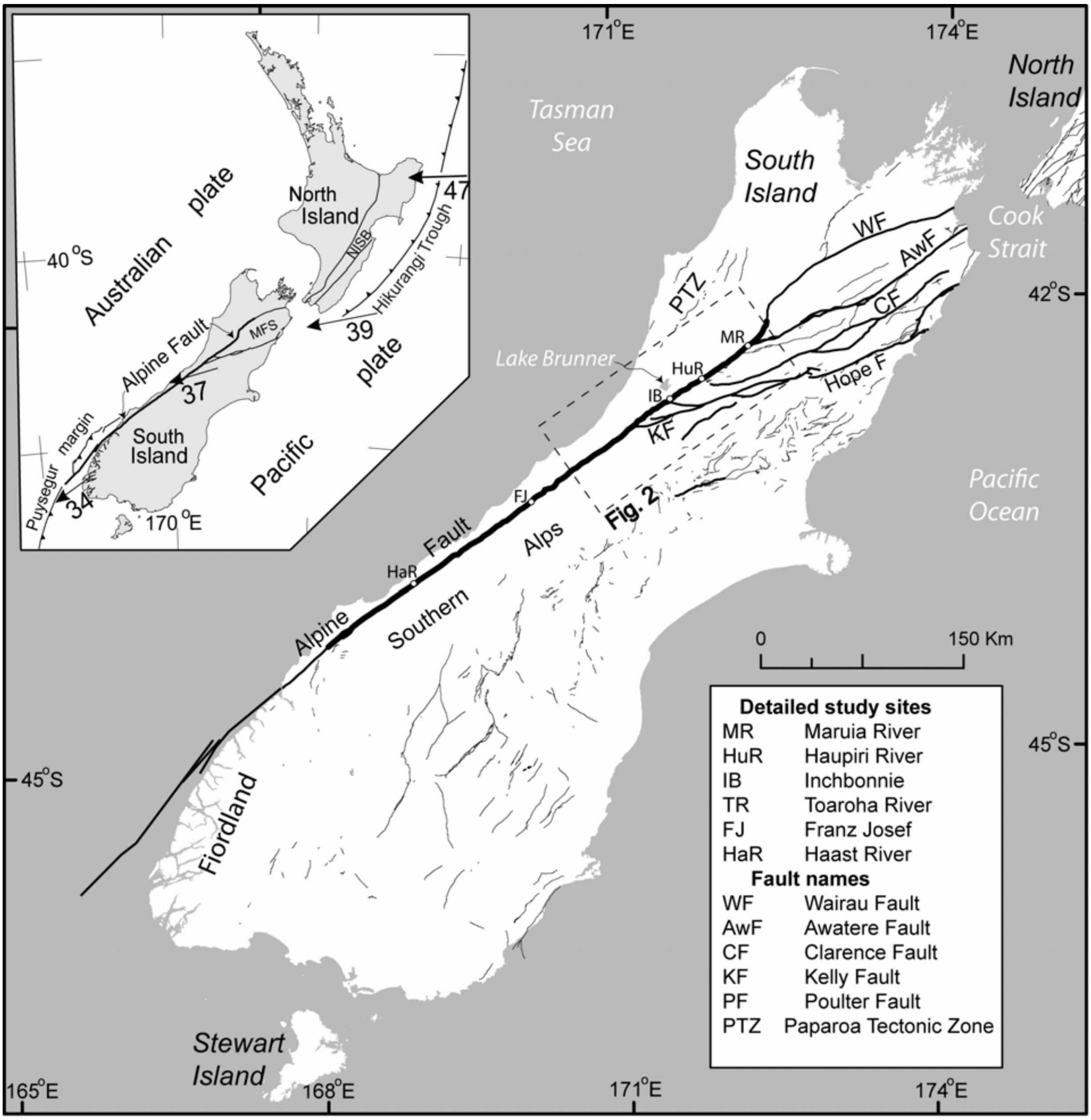

Figure 1 Active fault map (black & grey lines) of South Island highlighting the Alpine Fault (bold within West Coast region). Fault names and detailed mapping localities are shown in the legend. Inset: Plate tectonic setting of New Zealand, including the locations of subduction margins and Marlborough Fault System (MFS). Relative motion between the Pacific and Australian plates is shown in mm/yr from De Mets et al. (1994).

The report ends with a number of recommendations and conclusions. The included CD contains a copy of the report and tables (in PDF format) and figures together with the data collated as part of this study in ESRI Shapefile format (i.e. the GIS information; see Appendix I for details).

1.2 Neotectonics of the Alpine Fault

New Zealand lies within the deforming 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 tectonic boundary zone. The Alpine Fault forms the main plate boundary structure through 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). These faults are not, however, the focus of this study.

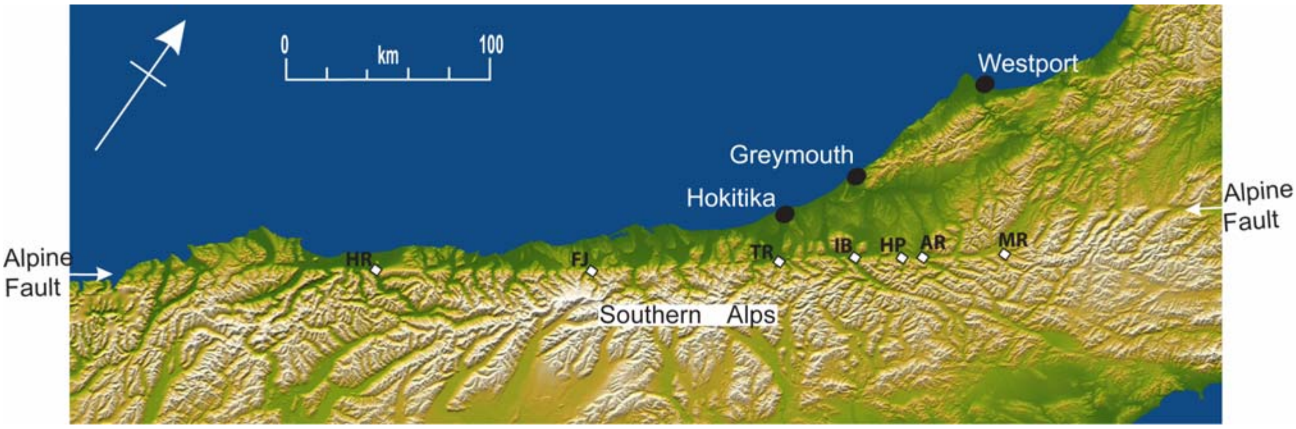

Figure 2 Topography of the West Coast region which clearly shows the trace of the Alpine Fault between Milford Sound and Nelson Lake (tips of white arrows). The main urban centres of West Coast are shown along with a number of moderate to high impact 'priority' areas along the fault that will suffer surface faulting in the next large to great Alpine Fault earthquake. The priority areas 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 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, over a distance of c. 500 km (Fig. 2). To the east of the Nelson Lakes, the Alpine Fault is now referred to as the Wairau Fault, though long term bedrock displacements have occurred across the combined Alpine-Wairau Fault. The Alpine Fault also continues offshore to the southwest of Milford Sound as an active strike-slip fault across the continental shelf of Fiordland (e.g. Barnes 2009). Despite this level of knowledge, the Alpine Fault is 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 have occurred on the fault several times during the last millennia (Adams 1979; Berryman et al. 1992). Consensus at this time points towards a large earthquake rupture at c. AD 1717 (±2 yr), with other large rupture events having occurred at c. AD 1620 (±5 yr), c.

AD 1425 and 1220 (Yetton 2000; Rhoades and Van Dissen, 2003; Berryman et al. in review Wells et al. 1999, 2001). The average recurrence interval for rupture events (i.e. large earthquakes ≥ M_w 7.8) along the Central segment of the fault, i.e. between Milford Sound and Hokitika (Fig. 2), using average values for displacement of c. 9 m and a slip rate of 27 mm/yr is c. 333 years.

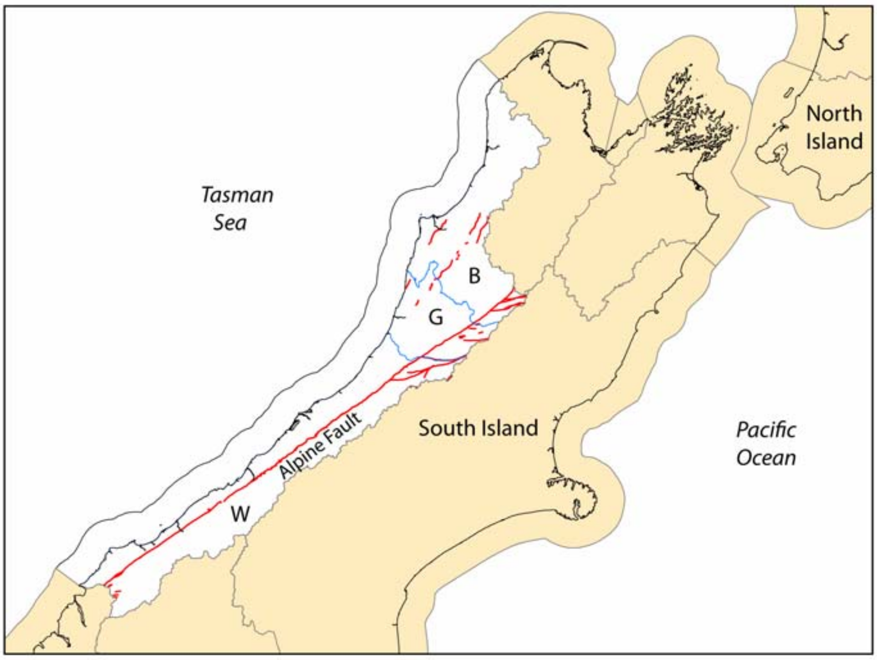

Figure 3 The Alpine Fault (and other active faults; red lines) in the West Coast region (in white). The Alpine Fault strikes southwest-northeast through all three Territorial Local Authorities, i.e. W, Westland; G, Grey; and B, Buller Districts, of the region. *Source*: GNS Science Active Faults database (http://data.gns.cri.nz/af/).

The Alpine Fault spans the entire length of the West Coast region (Fig. 3) and is characterised by right–lateral (horizontal) slip, with a component of vertical movement which brings about uplift to the southeast of the fault trace (Cooper and Bishop 1979) (Fig. 2). The expected horizontal displacement in a single, large-magnitude 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., 2010). The long term result of this movement is c. 470 km dextral displacement of bedrock terranes along the fault (Wellman 1953; Sutherland et al. 2006) and the uplift of the Southern Alps (Adams 1979; Wellman 1979). From the Hokitika area to Milford Sound (Central segment), the Alpine Fault has an 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., 2010).

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. 1999; Langridge et al. 2002). These events have highlighted the potential for similar surface rupture of faults in New Zealand and the possibility that loss of life and damage to infrastructure can result from surface ruptures here (see King et al. 2003; Kerr et al., 2003 and next section). 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, e.g. c. 8-10 m horizontal and c. 1-2 m vertical displacement.

Fault rupture is a distinct hazard, compared to the local to regional ground shaking that will result from a large to great earthquake 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. Therefore, one of the main purposes of this study is to develop a strategy for future land use around the Alpine Fault, one which is aligned with the MfE Guidelines and outlined below.

1.3 The MfE Active Fault Guidelines

The Ministry for the Environment has published Guidelines on “Planning for Development of Land on or Close to Active Faults[3] (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 promote a risk-based 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.

As described above, the Alpine Fault is the most active onland fault in New Zealand and has a high slip rate and short recurrence interval. From the available paleoseismic data, there is little doubt that 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 during the next 2000 (or probably much less) years (Rhoades & Van Dissen 2003; Berryman et al. 1992; Van Dissen et al., 2003). Consequently, rather than discuss the evidence for the activity of the Alpine Fault in great detail, the greater part of this report is devoted to accurately mapping the location of the future rupture zone of the fault and its uncertainty.

The MfE Active Fault Guidelines also advance a hierarchical relationship between fault-avoidance recurrence interval and building importance, such that the greater the importance of a built structure, with respect to life safety, the longer the avoidance recurrence interval (see Table 6, and Appendix I 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 contrast, 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. In this regard, the recommendations of this report will be simple and clear, in that, a rupture zone or setback area around the Alpine Fault should generally be avoided, as the probability of a surface rupturing earthquake in the foreseeable future is reasonably high.

[3] 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.

1.4 Fault mapping and priority areas

Along much of its length the Alpine Fault is covered by native forest and in areas that are maintained by the Department of Conservation (DoC). Areas that have been cleared of native bush and have undergone some level of development are termed in this study “medium and high impact” priority areas. Not by coincidence, these areas often correspond with sites where roads and/or rivers cross the Alpine Fault, and where detailed neotectonic studies have taken place, (e.g. Berryman, 1975; Yetton, 2000). The priority areas (Figs. 2, 4), serve the purpose of identifying important areas of active faulting that coincide with developed and developing land use areas. A brief description of the priority areas and the data which exists for them, follows.

Maruia River: Near Springs Junction, the Alpine Fault strikes northeast-southwest and traverses the Maruia River, Calf Paddock, the Lewis Pass highway (National Route 7; approximate NZ grid ref. L31/457725) and the farmland managed by Lewis Pass Motels. Due to its openness this stretch represents a moderate impact area (Figs. 2, 4d). The area of Calf Paddock is particularly well-studied due to the presence of the Alpine Fault wall, constructed across the fault in 1964. The fault trace is clearly identified here by a northwest-facing scarp and by a series of dextrally-displaced river terrace risers, i.e. former river banks of the Maruia River. Recent research includes paleoseismic studies (Yetton 2002), ground penetrating radar (GPR) and shallow seismic studies (McClymont et al., 2008; Kaiser et al., 2009), in addition to surveying of the fault and terraces by GNS Science (Langridge et al., unpublished data). While the fault can be mapped with greater confidence at Calf Paddock, this area is maintained by DoC and will probably not come under development pressure in the future.

Southwest of the highway the fault truncates a series of alluvial fan surfaces near the Lewis Pass Motels. The nature of the faulting in this area is shown by a front-on sketch by Berryman (1975). Reconnaissance mapping along this portion of the fault confirmed a pattern of left-stepping fault traces with individual fault scarps that grow in height toward their mid point. These traces are typically separated by young alluvial fans that bury the smaller ends of these scarps (Langridge et al. unpublished data). Ten km to the southwest, along Palmer Road, the Alpine Fault is well expressed in open country on either side of the Blue Grey River (Fig. 4d). In addition to orthophotographs and the QMAP Greymouth sheet data (Nathan et al. 2002), maps in Yetton (2002) have been geo-referenced within the GIS and used to improve fault location mapping.

Ahaura River: Near the village of Haupiri the Alpine Fault strikes northeast-southwest across the Ahaura River (Fig. 2). This is an area where Yetton (2000) presents sketch maps and trenches of the fault. A sketch map in the area, of a pair of tributary streams has been added to the project GIS to aid fault trace mapping (approximate NZ grid ref. L32/136488)[4]. Nevertheless, two parallel fault traces are identified in this sketch map and both are considered to be active traces of the Alpine Fault.

Haupiri River: The Haupiri River area (Fig. 2) refers to a mapped stretch of the Alpine Fault where the river crosses the Alpine Fault (approximate NZ grid ref. L32/055440). This is another area where Yetton (2000) presents sketch maps and a trench exposure of the fault. The sketch map has been added to the project GIS to aid in the interpretation of the fault location through this area.

[4] One of these creeks is incorrectly named Coates Creek in this thesis (it is an unnamed creek that emanates from Mt. Newcombe)

<u>Inchbonnie:</u> The Alpine Fault is well-mapped through the area of Inchbonnie (Figs. 2, 4), between the Taramakau River in the southwest and Lake Poerua in the northeast (Berryman 1975; Langridge and McSaveney 2008; Berryman et al. 1992; Langridge et al. 2010). Maps of differing scale and accuracy from these studies have been added to the GIS. Fault traces on the Harris farm between Inchbonnie and Lake Poerua have been trenched by GNS Science (Langridge et al. 2010) and confirm that a complex pattern of faulting occurs in stepover zones along the fault here, i.e. the fault trace in this area consists of c. 1 km long single-trace fault scarps separated by 80-100 m wide stepover zones (Fig. 4c). A similar stepover zone is mapped at the southeast corner of Lake Poerua, extending to the edge of the lake there (Berryman 1975; Langridge & McSaveney 2008). Such subsurface control provides a clear justification for the style of fault mapping and buffering that has been used in this area.

Development pressures along the shore of Lake Poerua (see Langridge and Hancox 2006; Langridge and McSaveney 2008) was one of the original drivers to better map the Alpine Fault through West Coast region and to provide Fault Avoidance zones that planners at the District level could apply to future potential developments along the fault (Kerr et al. 2003). The Fault Avoidance buffering strategy that is described below was in part developed by considering the likely fault deformation along the eastern edge of Lake Poerua close to the Alpine Fault.

To the southwest of the Taramakau River the Alpine Fault is mapped along the front of the range, subparallel to the Arthur’s Pass highway (National Route 73). Fault traces are shown along this rangefront in Berryman et al. (1992) striking toward the Taipo River (Fig. 4c).

<u>Styx to Hokitika River</u>: Between the Taipo and Styx Rivers, much of the trace of the Alpine Fault occurs along a steep, bush covered and relatively inaccessible area (Fig. 2). Conversely, one of the more open and intensively used portions of the fault occurs between the Styx and Hokitika Rivers, southeast of Hokitika. This area has also received a large amount of attention from geologists interested in the neotectonics of the fault. In this area, Yetton (2000) presents detailed maps of the Kokatahi to Toaroha River portions of the fault at several scales. Paleoseismic trenches have been excavated near these two latter rivers, confirming the location and activity of the Alpine Fault there (Fig. 4b; Yetton et al. 1998). More recently, new paleoseismic studies have been undertaken on the Staples farm on the True Left side of Toaroha River (Langridge et al. 2009). These studies confirm that the two traces mapped through this area are both active and Class I recurrence interval faults.

The fault is mapped with less certainty between the Toaroha and Hokitika Rivers. However, the fault occurs along the rangefront of the Southern Alps in this area. Along this rangefront a large debris avalanche (landslide) collapsed from the peak of Round Top to the NW across the trace of the Alpine Fault. The Round Top debris avalanche has an age of c. 930 AD and is believed to have occurred as a consequence of co-seismic shaking caused by the Alpine Fault (Wright 1998). Weak, linear fault traces can be mapped along the large scarred rangefront which was evacuated by the debris avalanche, implying that further surface rupture has occurred on the Alpine Fault since the Round Top event.

There is typically poor control on the mapped location of the fault between the Hokitika River and the township of Franz Josef Glacier – a distance of c. 78 km - due to dense vegetation cover, increasing distance from population centres, a lack of development, and preservation of the original landscape in DoC lands. This part of the fault has been described as the "central Westland section" of the fault (Berryman et al. 1992) and is poorly characterised. The main sources of line data over the central Westland section included in this study come from GNS Science QMAP mapping (Cox and Barrell 2007; Nathan et al., 2002; Rattenbury et al. 2010) and University of Otago mapping (see web address below[5]).

Franz Josef: The trace of the Alpine Fault strikes northeast-southwest through the town of Franz Josef in Westland District (Fig. 2). Franz Josef is by far the largest community that has been built in the vicinity of the trace of the Alpine Fault and thus, is most at risk from the hazard of surface rupture of the Alpine Fault in future large to great earthquakes. Therefore, it is of some importance that an active fault map is designed for the town that contains a strategy for understanding the effects of surface faulting, alleviating the future risk to established built structures, and providing guidance for future development near the fault. Neotectonic research has typically been limited within the township due to the location of the fault with respect to pre-existing development and lands being administered by DoC.

Southwest of the village, the Alpine Fault traverses from the Waiho River through the grounds of the National Park headquarters and onward through the town of Franz Josef, to the beginning of the Tartare Track walk. From there, the fault progresses to the northeast through native bush within the edge of the DoC estate, behind the town, to the Tartare Stream. The fault continues to the northeast of the Tartare Stream along the rangefront. The fault is buried beneath the youngest terraces and active floodplains of Tartare Stream and the Waiho River. To the southwest of the Waiho River, the fault is mapped for several km as a rangefront structure that is covered by native bush (Norris and Cooper 1995).

Haast: The Haast area has also been a focus of interest for neotectonic and paleoseismic research due to the ease of access in this area (Figs. 2, 4). Locally, the Alpine Fault occurs away from the rangefront of the Southern Alps and crosses young alluvial surfaces between the range and the coast (Rattenbury et al., 2010). In particular, the fault has been clearly mapped across the Haast, Okuru and Turnbull River floodplains by Berryman et al. (in review 2010) (Fig. 4a). In these areas, a number of fault scarps and dextral displacements have been identified and paleoseismic trenches have been excavated to investigate the paleoseismic history of the fault. In addition, RTK-GPS topographic maps have been surveyed at the Haast and Okuru Rivers to accurately locate the fault and to measure the dextral displacements at these sites (Berryman et al. 2010 in review). At the Haast River, the trace of the fault is c. 3.4 km southwest of Haast village. In future, there is a possibility that development will encroach closer toward the fault trace there, and at the Okuru and Turnbull Rivers.

1.5 Field reconnaissance investigations of the Alpine Fault

Limited reconnaissance and research trips to 'ground truth' traces of the Alpine Fault were undertaken between 2008-2010. These trips were typically related to other field research related to the Alpine Fault and were generally funded through GNS Sciences' PLT research program. These projects are described briefly below as they add important information on the location and parameters of the Alpine Fault, e.g.:

(i) Shallow geophysical studies of the Alpine Fault at Calf Paddock, Maruia River. The lead author has been working with geophysicists from ETH Zurich who use Ground Penetrating Radar (GPR) and shallow seismic techniques to image the fault in the

[5] http://www.otago.ac.nz/Geology/research/structural_geology/alpinefault/index.html

subsurface. This work has led to new assessments of the structure of the fault and the fault dip (e.g. McClymont et al. 2008; Kaiser et al., 2009). These studies have helped to understand the geometry of the fault traces beneath the site, and importantly the dip and dip direction of the fault there. In addition, the fault was walked out through beech forest between the Calf Paddock terraces and Highway 7 to review different interpretations of the fault there (c.f. Yetton 2002).

(ii) In January 2010, a neotectonic study of the displaced terraces at Maruia River was undertaken. Students from Western Washington University worked with GNS Science to construct a very detailed RTK-GPS map of the terraces and the Alpine Fault. In addition, four pits were excavated into different terraces to ascertain the stratigraphy of the terraces and to find material to date them. OSL and radiocarbon samples were extracted from the pits for dating. In addition, reconnaissance mapping was undertaken along the fault between Highway 7 and the Lewis Pass Motel to investigate the location and geomorphic style of the fault. This mapping has been incorporated into the GIS of this project.

(iii) Studies of Lake Poerua and the location of the Alpine Fault in the vicinity of the lake, 2 km northeast of Inchbonnie (Fig. 2). GNS Science was contracted to assess geological work done for a proposed subdivision along the shore of Lake Poerua (Langridge and Hancox 2006; Langridge and McSaveney, 2008). A number of tree stumps were located on the floor of the lake and sampled for radiocarbon dating. The outermost rings of these stumps yielded young ages, i.e. < c. 500 yr that imply that the lake rose dramatically about 500 yr ago, drowning former forests (Langridge and Basili, unpublished research). It is surmised that these lake level changes occurred as a result of an Alpine Fault rupture event.

(iv) Paleoseismic trenching at Inchbonnie. Five trenches were excavated on the Harris farm at Inchbonnie to assess the rupture history of the Alpine Fault there. Following on from this work, geophysicists from ETH Zurich have undertaken GPR and shallow Seismic experiments across this area. The combined efforts of trenching and landscape change studies in the Inchbonnie area have led to a paper on the slip rate and kinematics of the Alpine Fault there (Langridge et al. 2010)

(v) As a direct result of reconnaissance fieldwork related to this project, new paleoseismic studies have been undertaken at the Toaroha River site, southeast of Hokitika. Three trenches were excavated there in concert with some detailed topographic mapping using a RTK-GPS system (Fig. 4b). The microtopographic map has been added to the GIS project database. The trenches were open for the visit of a large group of scientists prior to the Deep Drilling workshop held in Franz Josef in March 2009.

(vi) Some further reconnaissance of the Franz Josef area at the time of the Deep Drilling Workshop in March 2009. This involved a bush reconnaissance between Franz Josef township and Tartare Stream. In this area the fault scarp can be followed and dextrally-offset features can be recognised in some places. It is hoped that in future both LiDAR mapping and paleoseismic trenching can be undertaken along this length of the fault as it offers one of the only such opportunities along the Central Westland section of the fault.

2.0 METHODOLOGY OF FAULT MAPPING

The methodology outlined in the MfE Active Fault Guidelines for mapping faults and developing hazard zones (Fault Avoidance Zones) was used in this work (e.g. Kerr et al. 2003). With respect to the Alpine Fault, the main steps in the process were:

1) collating and selecting the best available active fault mapping for the Alpine Fault throughout the West Coast region from multiple data sources, listed in Section 2.1 below;
2) adding the fault data into a Geographic Information System (GIS) database;
3) editing and revising the location of some of the fault trace data along the Alpine Fault;
4) characterising the uncertainty of fault location and other forms of uncertainty (see Section 2.3);
5) defining Fault Avoidance Zones for fault traces, considering the effects of hangingwall (uplifted) vs. footwall block deformation along the Alpine Fault.

These data are then combined with standard tables for Building Importance Category (see Table 2 in Chapter 4) and Development Status (Table 3) to determine appropriate Resource Consent Categories for proposed development of land on, or close to the Alpine Fault across West Coast region (Table 4).

2.1 Sources of mapping data

This mapping project was greatly aided by the fact that accurate mapping datasets for the Alpine Fault were already freely available and could be amalgamated in a GIS to develop an accurate fault trace map of the Alpine Fault along the entire length of the West Coast region. The available products included: University of Otago on-line fault mapping; GNS Science QMAP mapping (e.g. Nathan et al. 2002; Cox and Barrell 2007), a comprehensive PhD study of the Alpine Fault by Yetton (2000), unpublished site specific RTK-GPS micro-topographic maps made by the GNS Science earthquake geology team, scientific papers with maps, e.g. Berryman et al. (1992), and older Geological Survey reports that contain detailed sketch maps of specific areas, e.g. Berryman (1975); Berryman and Cutten (1985).

This data has been assembled and geo-referenced in a GIS and has been quality-control reviewed by the authors of this report. That is, we have inspected mapping data for the Alpine Fault along its length and have reviewed or revised the data based on our assessment. That assessment has also relied upon the use of geo-referenced aerial photos, and orthophotographs within the GIS. Fault trace data presented here is assumed to represent the location of future earthquake ruptures, i.e. there is an expectation that the line of the Alpine Fault in the GIS represents the fault plane intersecting the Earth’s surface. As such, a large part of the review component of this work has been in assessing what the line data represents and how accurate it is.

To some extent the quality of data is very much scale dependent. For example, QMAP data is mapped at a scale of 1:50,000 on NZMS 260 sheets, and is later summarised to a scale of 1:250,000 (see for example, Nathan et al., 2002; Cox and Barrell, 2007). While every effort is made to map ‘accurately’, this scale of mapping is not adequate for use at the cadastral or property scale. However, over the vast majority of the length of the Alpine Fault through West

Coast region, the fault is under native bush on land that is designated as Department of Conservation forest or park lands. Therefore, in most cases, this level of mapping accuracy is sufficient for these areas, as there is a low probability that the land use status of these areas will change significantly in the foreseeable future.

The distribution of the data sources used to constrain the location of the Alpine Fault is shown in map view in Figure 4. An example of how the data sources can be stacked within the GIS is shown in Figure 5. The following paragraphs summarise the data sources used in this study:

1. University of Otago mapping – A comprehensive project was undertaken by the University of Otago, led by Professors Richard Norris and Alan Cooper to construct a detailed strip map of the Alpine Fault (see web reference in footnote[6]). The mapping has been undertaken by Norris and Cooper and a number of graduate students (e.g. Wright 1994) who undertook individual mapping and paleoearthquake studies along the Alpine Fault. Twenty maps, mapped at a scale of c. 1:50,000 are presented on the website, providing one of the major sources of data for this project. The maps show semi-continuous data coverage between the Styx River (their map 1) in the northeast and the Arawhata River (their map 20) areas. These maps include data on the location of active strike-slip traces of the Alpine Fault, active thrust or reverse-slip traces, inactive traces, cataclasite and gouge zones, and the mylonite transition, the latter of which is a bedrock marker contact. For the purposes of this project, we are interested in the most recent active traces of the Alpine Fault that are interpreted to have a surface rupture potential.

2. GNS Science QMAP mapping program – as described above, this data has been used along a considerable length of the fault in concert with the University of Otago mapping as the major sources of line data, particularly in West Coast bush country, where more detailed neotectonic studies have not been undertaken. The main references for these areas are Nathan et al. (2002) (Greymouth sheet) and Cox and Barrell (2007) (Aoraki sheet). Another portion of the Alpine Fault exists on the soon-to-be-published Haast sheet (Rattenbury et al. 2010). This data was also available for assessment and incorporation into the project GIS for this study.

3. Mark Yetton PhD thesis maps - Mark Yetton completed a significant body of research on the Alpine Fault in 2000. This work included mapping, trenching and seismic hazard assessment of the Alpine Fault (Yetton 2000; Yetton et al. 1998). Several site maps were included in this thesis from the Styx to Toaroha River area (Figs. 4b, 5), Crane Creek, Coates Creek and Haupiri River areas. These maps were scanned and geo-referenced into the project GIS for comparison to other data sources.

4. GNS Earthquake Geology Leica RTK-GPS maps – a number of GNS Science earthquake geology projects have been undertaken along the Alpine Fault during the last decade, during which time, the use of RTK-GPS has been in wide use as a means to create accurate micro-topographic maps. As part of work in South Westland, Berryman et al. (2010 in review) have created survey maps of the Alpine Fault at the Okuru and Haast Rivers. Langridge et al. (2010) have developed topographic maps in the Taramakau valley near Inchbonnie and Lake Poerua (see also Langridge and McSaveney 2008). Further topographic surveying has been

[6] http://www.otago.ac.nz/geology/research/structural_geology/alpinefault/index.html

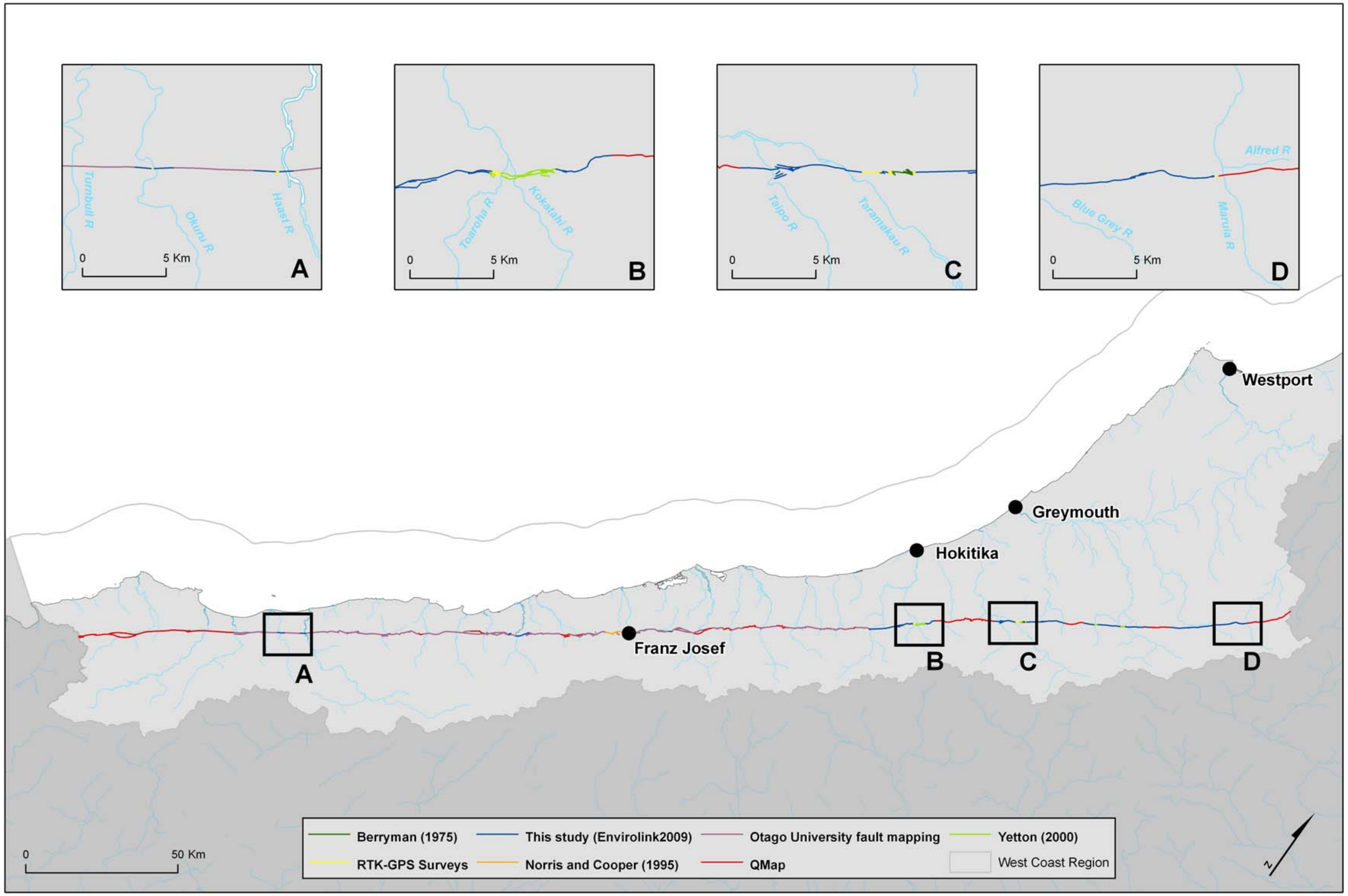

Figure 4 Map of the Alpine Fault in West Coast region and the data sources used in this mapping study (shown by colour). QMAP mapping data is predominant at the northeast and southwest ends of the fault, while Otago University mapping is the predominant source from Hokitika to Haast. Four windows A to D have been created to show areas of detailed active fault studies and the complexity of fault traces in these areas where the fault is relatively well expressed. Windows are: A, Haast River area; B, Styx to Toaroha River area; C, Inchbonnie-Taramakau River area; and D, Maruia River area.

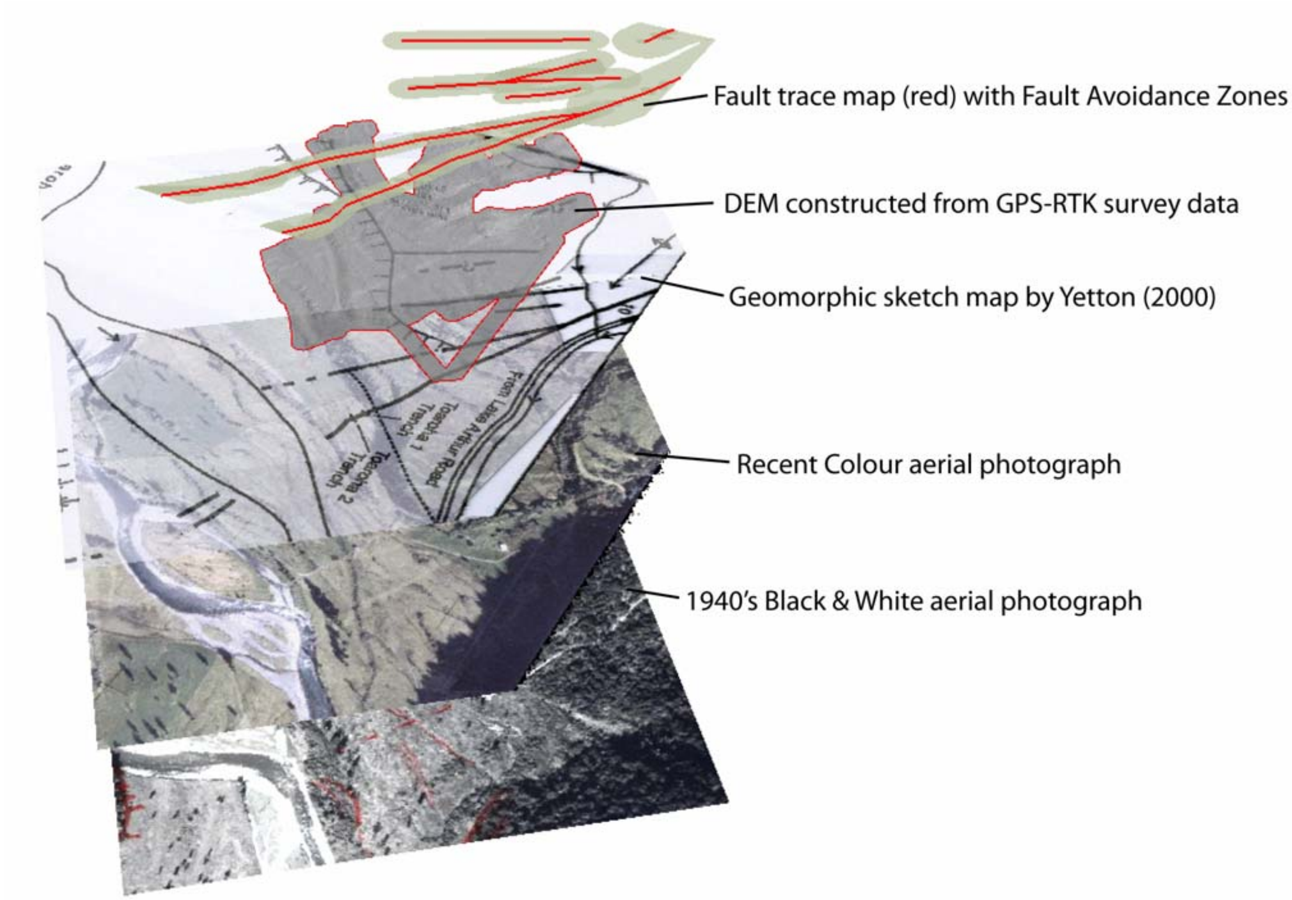

Figure 5 Data layers within the project GIS at the Toaroha River - one of the more open, data-rich areas along the Alpine Fault. Data sources there include aerial photographs, sketch maps, RTK-GPS microtopographic data (see Figure 4). The output of mapping includes a fault trace map (red lines) with Fault Avoidance buffers (green) about them. The main fault traces here have been confirmed here through the excavation and logging of paleoseismic trenches (Yetton 2000; Langridge et al. 2009).

undertaken at the Toaroha River site (Fig. 5) and at the Maruia River (Calf Paddock) (Langridge et al. 2009; unpublished data). These maps have also been uploaded into the project GIS.

<u>5. Other sketch maps</u> – these include figures from papers and Geological Survey Immediate Reports. These sources are: Norris and Cooper (1995), Berryman et al. (1992), Berryman (1975), and Berryman and Cutten (1985). Several of these maps are sketches that show the fault geomorphology and offsets, but are poorly georeferenced. Where these maps can be georeferenced, they have been added to the project GIS as a comparison to other scales of mapping.

2.2 Accuracy of mapping data sources (Horizontal Location Uncertainty)

A level of mapping accuracy has been assigned to each of the data sources. The level of mapping accuracy ranges from ± 20 m to ± 100 m and can be thought of as a "Horizontal Location Uncertainty". These values are defined by our level of confidence that the data can be used to define the fault location. In other words, how sure are we that the fault is exactly where it has been mapped?

The method of applying uncertainty to fault location in this study is not exactly as prescribed in the MfE Guidelines (Kerr et al., 2003), which instead sets out to describe the Fault Complexity, rather than the uncertainty associated with the fault location. In the MfE Guidelines, fault complexity refers to "the width and distribution of the deformed land around the fault trace", and is described as either: *Well-defined, Distributed, or Uncertain*. What has been undertaken in this study is to attempt to wed these three terms with the level of uncertainty that is assigned to each form of mapping data (see Figure 6 for comparison). Our strategy is better suited to the goals of this project, which are to map and buffer the entire length of the fault within West Coast region over c. 400 km.

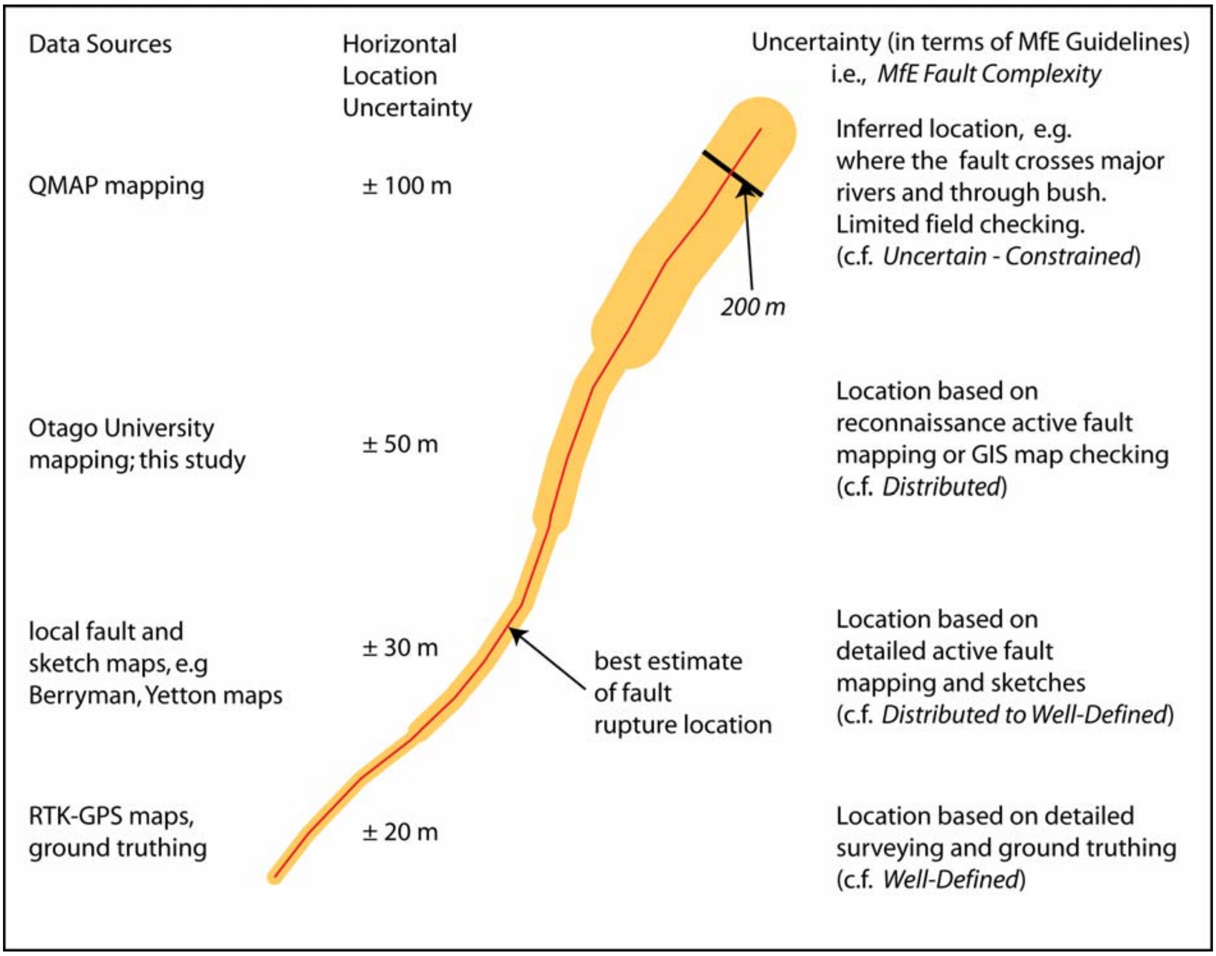

Figure 6 Fault (or Horizontal) Location Uncertainty strategy for the Alpine Fault. The uncertainty is an estimate of how well-mapped or located the fault is at any given point, based on the type of data that has been used in this study. These uncertainty levels have been wed to terms in the MfE Guidelines that describe Fault Complexity, e.g. ± 100 m equates to an *Uncertain – Constrained*, while ± 20 m equates to a *Well-Defined* fault complexity.

The lowest accuracy or highest uncertainty (± 100 m) is applied to QMAP mapping data. This (± 100 m) equates to a mapping uncertainty of 1 in 100,000, i.e. 1mm = 100 m) and is roughly comparable to the definition of *Uncertain – Constrained*, according to the MfE Guidelines and subsequent studies (Kerr et al, 2003; see also King et al. 2003; Van Dissen and Heron, 2003) (Fig. 6). QMAP data covers the entire length of the Alpine Fault within West Coast region (at a scale of 1:250,000), so is the only continuous mapping dataset. For about one third of the fault presented in this study (c. 125 of 400 km), QMAP line data is used (Fig. 4). Where more accurate fault information exists, the QMAP line data is superseded.

Otago University fault mapping data has been assigned an uncertainty of ± 50 m in this study. We equate this level of uncertainty with the term *'Distributed'* fault complexity in the MfE Guidelines (Fig. 6). The 'Otago' mapping was undertaken by several different mappers in rugged terrane along the majority of the Central segment of the Alpine Fault between Hokitika and Fiordland. While the mapping was done at a similar scale to the base mapping for QMAP (i.e. 1:50,000), a large part of the fault was field checked by University of Otago Geology graduate students and/or Professors Richard Norris and Alan Cooper. This equates to a mapping uncertainty of 1 in 50,000, i.e. 1mm = 50 m). This provides one of the main differences in the perceived uncertainty between QMAP and 'Otago' mapping, i.e. the Otago mapping has been done with the aim of locating the Holocene trace of the Alpine Fault. The Otago mapping data is used over approximately half of the study area (c. 180 of 400 km; Fig. 4). In reality, much of the line work adopted by QMAP comes from the mapping of Otago University students and professors, therefore, it is realistic that where available we use the on-line Otago mapping data and assign a lower uncertainty to it.

Fault mapping and checking done as part of this study (sometimes referred to as Envirolink 2009) is also assigned a Horizontal Location Uncertainty of ± 50 m (c.f. *Distributed* fault complexity; Fig. 6). Some of this fault checking is achieved within the GIS database using scanned aerial photographs and through interpreting the differences between QMAP fault traces and fault morphology on aerial photographs. Some of the fault checking is achieved through field reconnaissance studies described in Section 1.5.

Large-scale sketch maps, such as those made by Yetton (2000) and Berryman (1975) have been assigned an uncertainty of ± 30 m and are equated with a fault complexity in the MfE Guidelines of *Distributed* to *Well-Defined*. While these are detailed fault maps, the certainty of their location is less certain than for RTK-GPS topographic maps as they are either sketch or traced maps, or that they have few geographic points on them for geo-referencing into the GIS.

RTK-GPS topographic maps are assigned an uncertainty of ± 20 m and are equated with a fault complexity of *Well-Defined*. In practice, this means that the scarp of the fault is well located and relatively narrow – the scarp is a linear bump or height change across surfaces and hillslopes that marks the location of the fault. Normal practice in defining Fault Avoidance Zones for *Well-Defined* faults would be to map the top and bottom of the scarp, which could be metres to tens of metres wide, and to add a buffer of ± 20 m to account for uncertainty in future surface ruptures (Kerr et al., 2003). In this study, our strategy only provides a ± 20 m wide zone around the fault line (rather than a scarp). However in the following sections additional buffers and levels of uncertainty will be introduced that keep their definition more in keeping with the MfE Guidelines and the real level of uncertainty.

2.3 Specific types of Uncertainty related to locating fault features

The width of the Fault Avoidance Zones (FAZ) developed in this study is assigned based on the uncertainty of mapping sources (Section 2.2), which has been equated with *Fault Complexity*. The FAZ is also considered to include: (i) the uncertainty on the location of the rupture plane within the fault scarp; (ii) the asymmetry of surface deformation that occurs on faults that have reverse dip-slip movement; and (iii) data transfer uncertainties.

2.3.1 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 geologic faults (Fig. 7). 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 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 shows increased damage in the hangingwall side of the fault (Fig. 5). This phenomenon is described in more detail below.

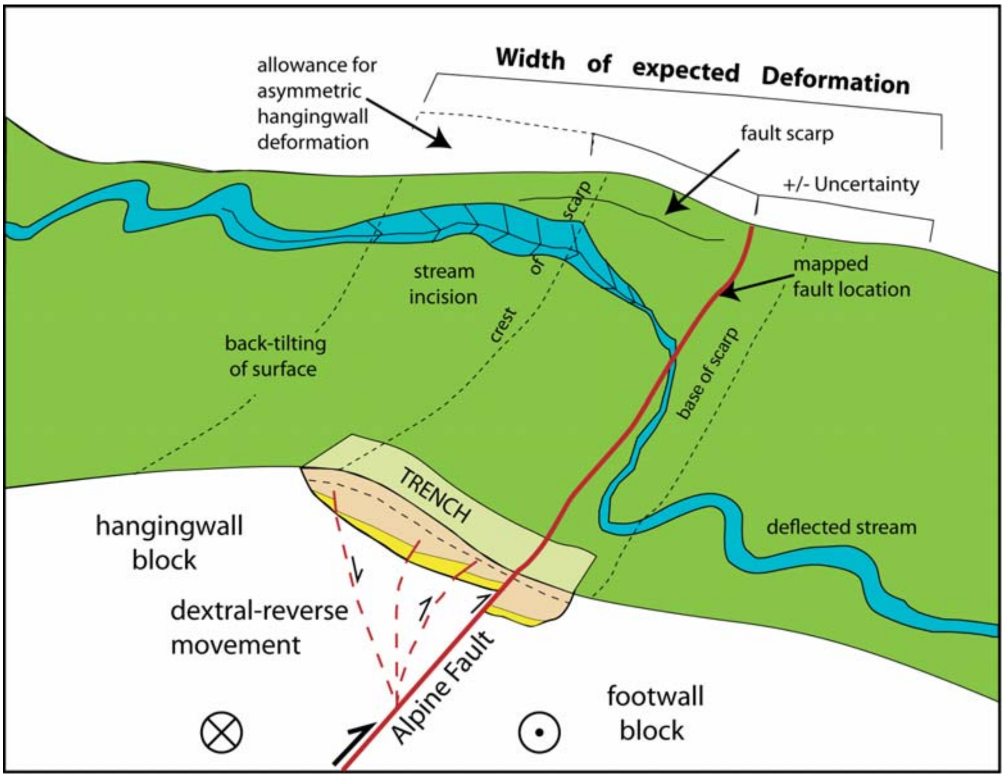

Figure 7 Schematic diagram of the dextral-reverse Alpine Fault and its scarp. In this case the mapped fault trace (rupture surface; bold red line) is located near the base of the scarp. The dominant movement on the fault is horizontal as shown by circle symbols at the base of the figure (arrow away/towards). 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.

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. It is likely that for the dextral-reverse Alpine Fault, that the ruptures occur in the middle to lower part of the scarp. This assumption is corroborated from trench data, for example, see Alpine Fault trenches in Yetton (2002); Yetton (2000); Berryman et al. (in review), and Langridge et al. (2010).

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 alluvial terrace. 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. In these cases, the fault location is inferred because it is not certain exactly where it occurs on the ground.

2.3.2 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. 7). 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 above them. This essentially adds a second level of *Fault Complexity* to that which is described under the Horizontal Location Uncertainty.

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 7 and 8 graphically document this kind of asymmetric deformation.

Due to the effect of more 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 Horizontal Location uncertainty on the hangingwall (typically southeast) side of the Alpine Fault (Figs. 5, 7).

Figure 8 Photograph taken of a surface rupture related to the 1999 Chi-Chi earthquake fault, Taiwan. The view is looking toward the fault, which has ruptured through a road. The man is standing on the footwall side of the fault. The hangingwall has been overthrust and warped over and across the footwall block toward the camera.

In the southernmost part of Westland District, however, the Alpine Fault is understood to approach a vertical dip (c. 90°) and even changes dip direction (to the northwest) southwest of the Cascade River. Therefore, in the southwestern part of the region we have simply applied a symmetric location uncertainty strategy about the fault traces.

2.3.3 Data and data transfer uncertainties

Another type of uncertainty relates to the transfer of line data from one media into the GIS and also the georeferencing of data uploaded into the GIS. A few examples of this type of uncertainty are listed below:

- Precise RTK-GPS maps constructed by GNS Science are sometimes not tied into a georeferenced benchmark. This means that the reference point for the survey is obtained from the GPS rather than fixed with respect to the NZ National Grid. The error on maps constructed without a benchmark reference is probably 5-10 m (N. Palmer, personal communication 2009), which is a tolerable uncertainty given the total of ± 20 m uncertainty that we have ascribed to this type of data.
- Scanning of sketch maps and georeferencing them into the GIS, e.g. those in Yetton (2000). We noticed that there was a certain amount of distortion between these maps and other georeferenced layers including the national Orthophotograph or NZMS 260 topographic maps. We had to georeferenced the sketch maps and then use the distorted fault traces that ensued from the data.

In this study, we have accepted that the uncertainties related to data transfer into the GIS are small enough compared to the Horizontal Location Uncertainty and the buffer for Asymmetric deformation to be considered within the bounds of these larger uncertainties.

2.4 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 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. 9).

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 could 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 (Figs. 9, 10).

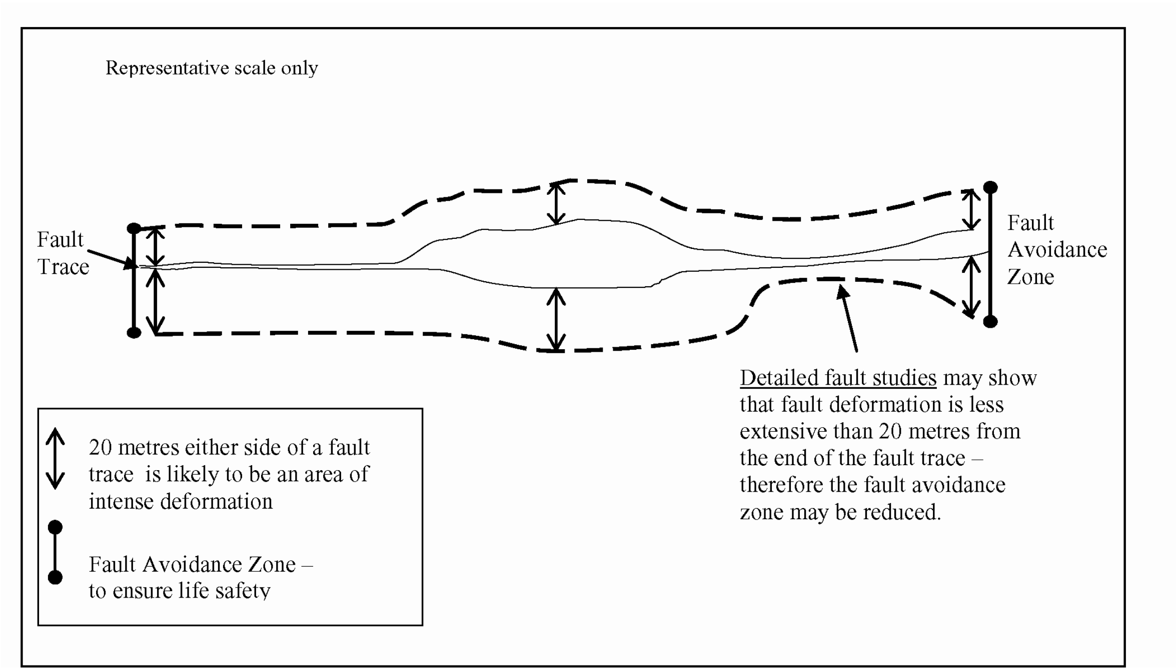

Figure 9 Original caption from Kerr et al (2003) – 'A fault avoidance zone on a district planning map'. In the case of the Alpine Fault, after trenching and mapping work it could be possible to narrow the Fault Avoidance Zone by better understanding the width of the deformation and fault location.

We have constructed a regional scale Fault Avoidance Zone (FAZ) for the Alpine Fault, and have created an Attribute File that holds the FAZ in the GIS database. Figures 11 and 13 show the new line data for the Alpine Fault at the Maruia, and Haupiri Rivers, respectively. Figure 7 shows the interpretation of the topography and structure of an active oblique–slip fault and its related Fault Avoidance Zone. Figure 10 shows a generic example of the relation between the position of mapped fault features and the subsequent definition of Fault Avoidance Zones and Figure 12 shows a real example of the application of a Fault Avoidance Zone in the Maruia River priority area. Table 1 shows the relationship between the uncertainty related to the Horizontal Location and the final width of the FAZ.

Figure 10 shows how the results of this study are presented within the GIS. 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 + Asymmetric buffer zones (= blue). Where the Horizontal Location uncertainty is low (e.g. ± 20 m) the total FAZ is narrowest at 100 m in width (i.e. 3 x 20 m + 2 x 20 m). Conversely, where the base uncertainty of the fault rupture location is high (e.g. ± 100 m), the total FAZ is set at 340 m in width (i.e. 3 x 100 m + 2 x 20 m), as shown in cross-section in the Inset of Figure 10.

Table 1 Development of Fault Avoidance Zone (FAZ) widths for mapped data along the Alpine Fault.

Fault Complexity terminology	Horizontal Location Uncertainty (m)	Asymmetric Buffer Width (m)	Margin of Safety Buffer (m)	Total Width of Fault Avoidance Zone (FAZ) (m)
Well-Defined	± 20	+ 20	± 20	100
Distributed to Well-Defined	± 30	+ 30	± 20	130
Distributed	± 50	+ 50	± 20	190
Uncertain - Constrained	± 100	+ 100	± 20	340

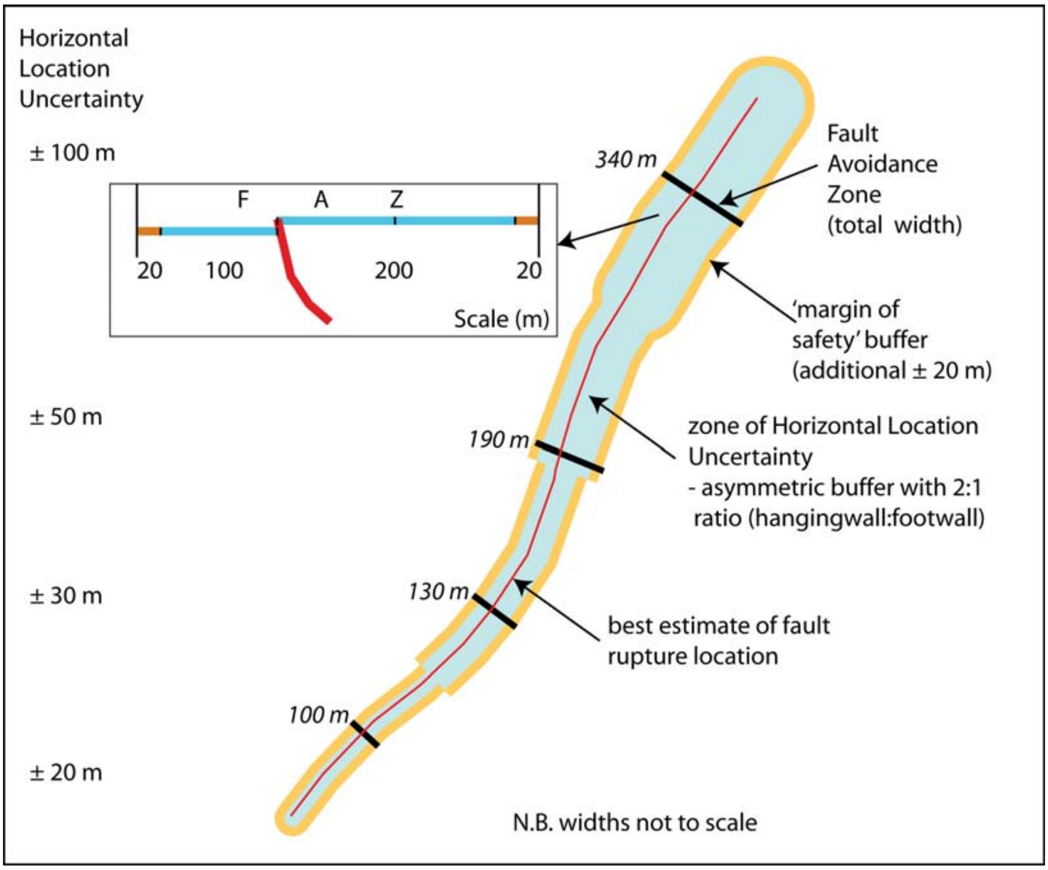

Figure 10 Fault Avoidance Zones (FAZ) for the Alpine Fault. Each FAZ consists of the fault trace (red line), plus a base (Horizontal Location) uncertainty. This uncertainty is doubled on the hangingwall side of the fault, creating the 'Asymmetric buffer' (blue). Added to this buffer is the 'margin of safety' buffer of ± 20 m (orange). Note: this example is applicable to a SE-dipping Alpine Fault. Inset: A cross section of the elements that make up the FAZ for the case of ± 100 m Horizontal Location uncertainty.

The FAZ should be considered as a zone where the Alpine Fault will rupture 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 likely presence of fault deformation. This level of buffering may be considered quite conservative in many areas with respect to the actual faulting and deformation that will occur. However, it is conservative due to the nature of the uncertainties in locating the fault and its deformation. Kerr et al. (2003) in defining Fault Avoidance Zones (FAZ) for the MfE Guidelines outline that if detailed fault studies are undertaken within an FAZ, then it may be possible to better define the fault zone and therefore reduce the overall width of the FAZ in these specific areas (see Fig. 9).

3.0 RESULTS AND CASE STUDIES

In this section, we present five examples of the results from priority areas along the Alpine Fault as maps. These case studies show in detail, examples of: (i) the re-mapping of fault traces along the Alpine Fault zone, (ii) the assignment of uncertainty according to the quality of the data or mapping, and (iii) the definition of Fault Avoidance Zones around these fault traces and their uncertainty zones. Figures shown in the following chapter have been extracted from the GIS file for this project. The GIS shows the Alpine Fault and its Fault Avoidance Zone in its entirety and should be used as the reference by Territorial Authorities, rather than the figures in this section.

3.1 Case studies and examples from Priority Areas

3.1.1 Maruia River area

The Maruia River area is an important example of the results of this study within Buller District (Figs. 3, 4) as shown in Figures 11 and 12. Figure 11 shows the mapped location of the Alpine Fault either side of the Lewis Pass Highway (State Highway 7) near Springs Junction. This (red) line represents the best estimate of the location of future ruptures of the Alpine Fault using a variety of data sources (described in Section 2.1).

Under bush cover northeast of, and also crossing the Maruia River, the fault location is poorly expressed. In these cases, the location is *Inferred and* we relied on the QMAP line data, which carries an associated uncertainty of ± 100 m. Across the faulted alluvial terraces of Calf Paddock, several maps including a RTK-GPS micro-topographic have been constructed (Langridge et al., unpublished data). This allows us to map the fault quite precisely and assign a fault location uncertainty of ± 20 m.

Between the Calf Paddock terraces and Highway 7, the fault trace is located within the forest. This area has been field checked (ground truthed) and we have applied an uncertainty of ± 30 m to it. Southwest of the highway, we used the orthophotographs in the GIS database to re-assess the fault location and attach an uncertainty of ± 50 m to this linework. The margin of safety of ± 20 m is added to the Asymmetric Deformation Buffer to produce the Fault Avoidance Zone (FAZ), which combines all of the uncertainties around the fault trace (Fig. 12). Note that although the FAZ has a total width of 190 m in the vicinity of the Lewis Pass Motels and the associated farmhouse (green oval on Fig. 11), that none of these buildings actually fall within the FAZ.

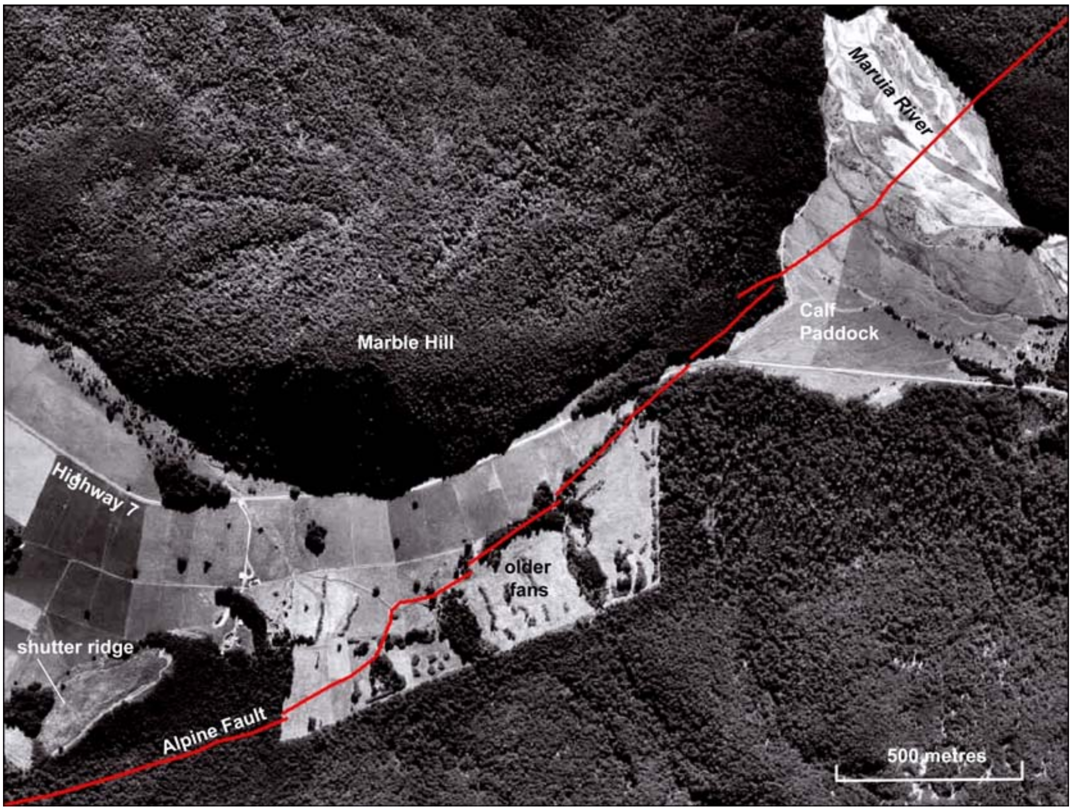

Figure 11 The Alpine Fault (as mapped) in the Springs Junction-Maruia River area, Buller District (scale extracted from GIS at 1:10,000). The fault strikes NE-SW across the Maruia River and the alluvial terraces at Calf Paddock. Southwest of State Highway 7, the fault truncates, or is buried by, a series of alluvial fans from the rangefront.

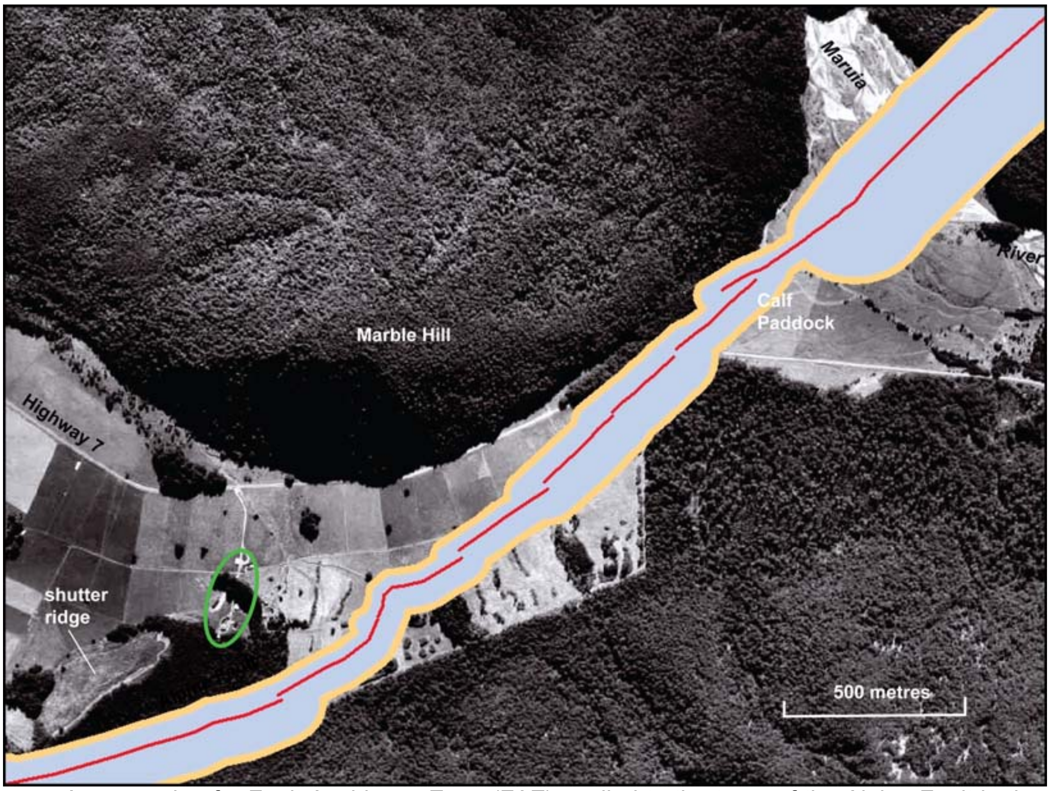

Figure 12 An example of a Fault Avoidance Zone (FAZ) applied to the trace of the Alpine Fault in the Springs Junction-Maruia River area (scale c. 1:10,000). The blue strip represents the Horizontal Location Uncertainty and the Asymmetric Deformation buffer, i.e. twice the width on the hangingwall side of the fault. The total Fault Avoidance Zone (FAZ) for this area includes the orange 'margin of safety' (± 20 m) about the blue strip. The Lewis Pass Motels occur directly to the NE of the shutter ridge within the green oval.

3.1.2 Haupiri River area

Figures 13 and 14 show the Alpine Fault and its Fault Avoidance Zone as mapped in this study near the Haupiri River in Grey District. This is an area of open land adjacent to the Alpine Fault, and is thus considered a priority area where detailed fault mapping and zonation would prove useful for future planning and land development issues. Figure 13 documents the fault crossing alluvial terraces of the Haupiri River. A sketch map of the area with details of the main fault and secondary fault traces has been geo-referenced and added to the GIS from Yetton (2000). The mapping on this sketch is quite precise due to the large scale of the sketch and we assigned an uncertainty of ± 30 m to this dataset.

One important feature that needs to be stressed is that in the process of geo-referencing and rectifying this sketch map to other geographic information, e.g. the national orthophotograph, some distortion does occur. This means that one or both of the items loaded in the GIS have georeferencing or rectification issues, i.e., some uncertainty is created within the GIS compared to the real earth. Therefore, the lines shown in Figure 9 show the main trace of the Alpine Fault (and secondary traces) according to a georeferenced, but distorted large-scale sketch map. If this creates a difference between the 'real' Earth and the GIS then this needs to be realised and accounted for. In this project, the additional 'margin of safety' (orange) buffer of ± 20 m, is assumed to be sufficient to cover this uncertainty (Fig. 11).

In those areas beyond the alluvial terraces of the Haupiri River where the fault trace traverses fans and the rangefront we re-assessed the fault location and assigned an uncertainty of ± 50 m.

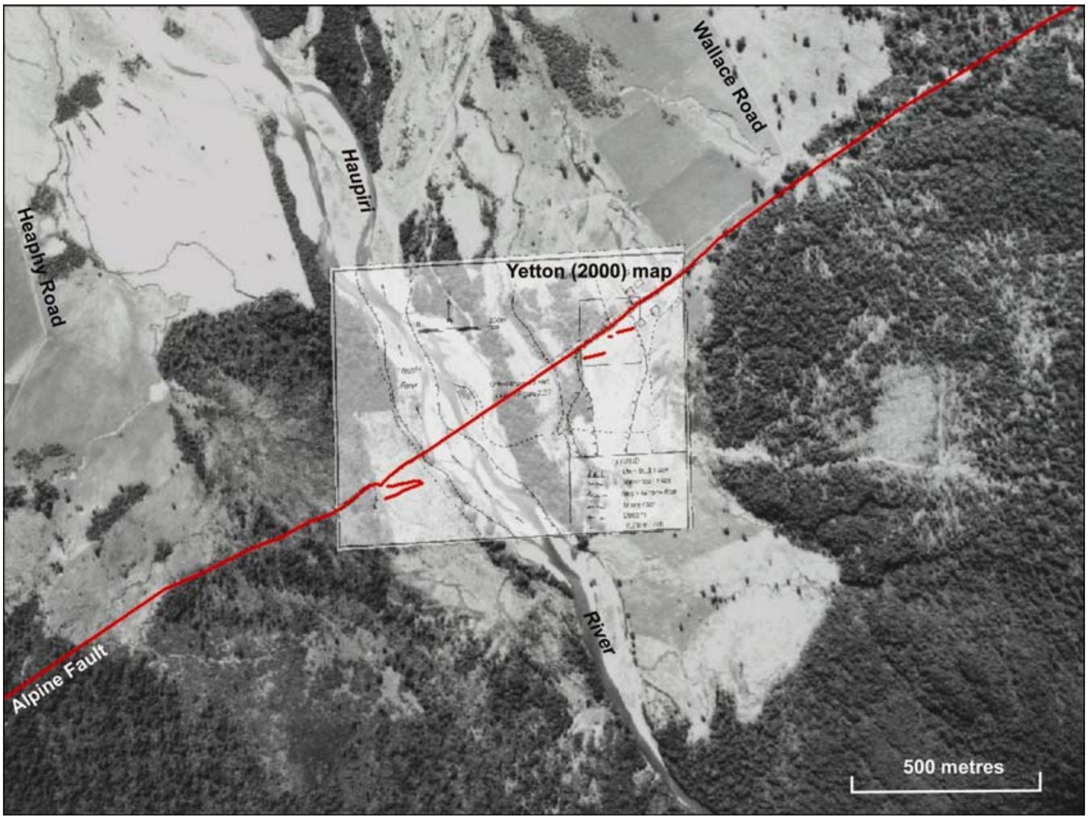

Figure 13 The Alpine Fault (as mapped) in the Haupiri River area, Grey District (scale extracted from GIS at 1:10,000). The fault strikes NE-SW across the Haupiri River. A sketch map from Yetton (2000) has been added to show the detail provided by such maps across alluvial terraces. Also note the distortion of this sketch map that occurred due to the geo-rectification process.

Figure 14 The Fault Avoidance Zone (FAZ) applied to the trace of the Alpine Fault in the Haupiri River area (scale c. 1:10,000). The extent of the orange strip represents the FAZ results that are presented to WCRC in the GIS. In this example, secondary fault traces mapped by Yetton (2000) have been included and buffered separately to the main trace of the fault. Note how the total FAZ broadens about secondary traces.

3.1.3 Inchbonnie area

The settlement of Inchbonnie and surrounds in Grey District is one of the most open and accessible areas along the Alpine Fault due to land clearance and the network of roads and railway. The fault can be accurately mapped across alluvial terraces between the Taramakau River and Lake Poerua, beyond which to the northeast, its trace is buried by young alluvial fans along the rangefront of the Southern Alps (Fig. 15) (Berryman et al. 1992; Langridge et al., 2010). Inchbonnie constitutes a priority area in terms of developing a Fault Avoidance Zone strategy with regards to the Alpine Fault.

Figure 15 shows the Alpine Fault as a complex pattern of traces in the area from Inchbonnie to Lake Poerua. Here, the fault consists of c. 1 km long traces, which are separated by c. 80 m wide stepover zones. While the fault is relatively simple in the longer trace sections, the stepover zones are complex, consisting of multiple short, subparallel traces that form a parallelogram with overall positive topography (Berryman 1975; Langridge et al, 2010). These features are often called compressional stepovers or bulges. While there are more fault traces within these stepovers, the overall deformation is expected to be conserved, i.e. equivalent, compared to the straight sections of the fault here. Therefore, in a single earthquake rupture each trace will have a relatively smaller amount of displacement. This is sometimes described as 'Distributed' deformation. We expect that each of these traces could rupture in the next earthquake and each trace should be considered individually as a Class I active fault (i.e. rupture recurrence <2000 yr) (Kerr et al. 2003; Langridge and McSaveney 2008).

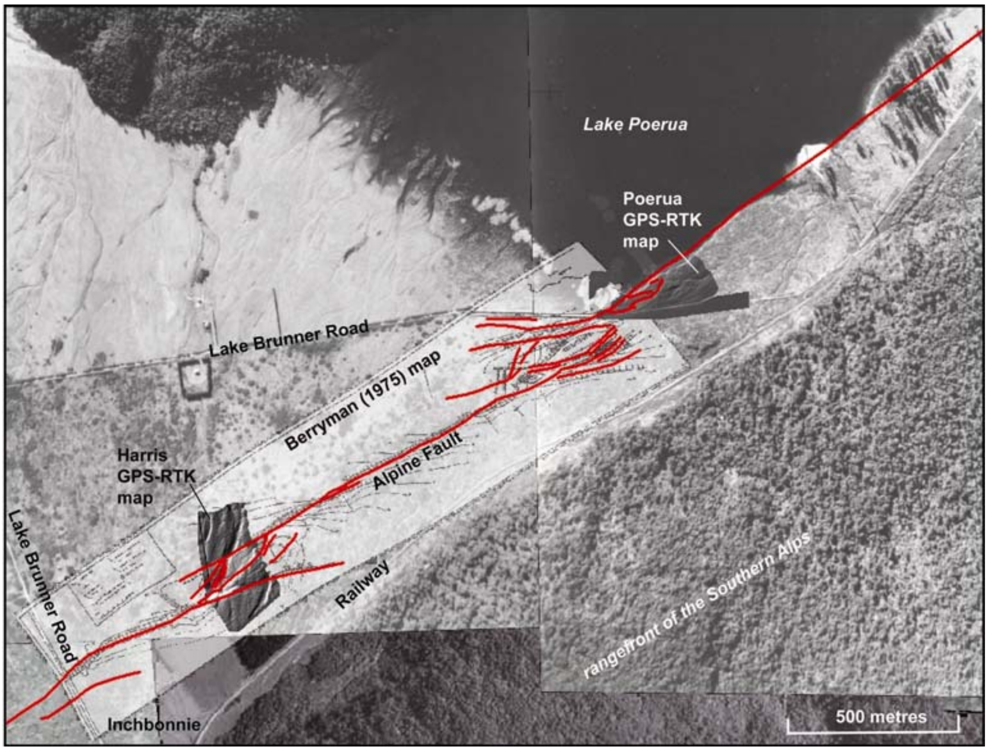

Figure 15 The Alpine Fault (as mapped) in the Inchbonnie – Lake Poerua area, Grey District (scale extracted from GIS at 1:10,000). Aerial photos were geo-referenced and rectified with respect to the ortho-photograph (at back/ bottom). A total station survey map from Berryman (1975) was used as a basemap for the area. Greater detail was provided by two RTK-GPS microtopographic maps at Harris' farm and at Lake Poerua.

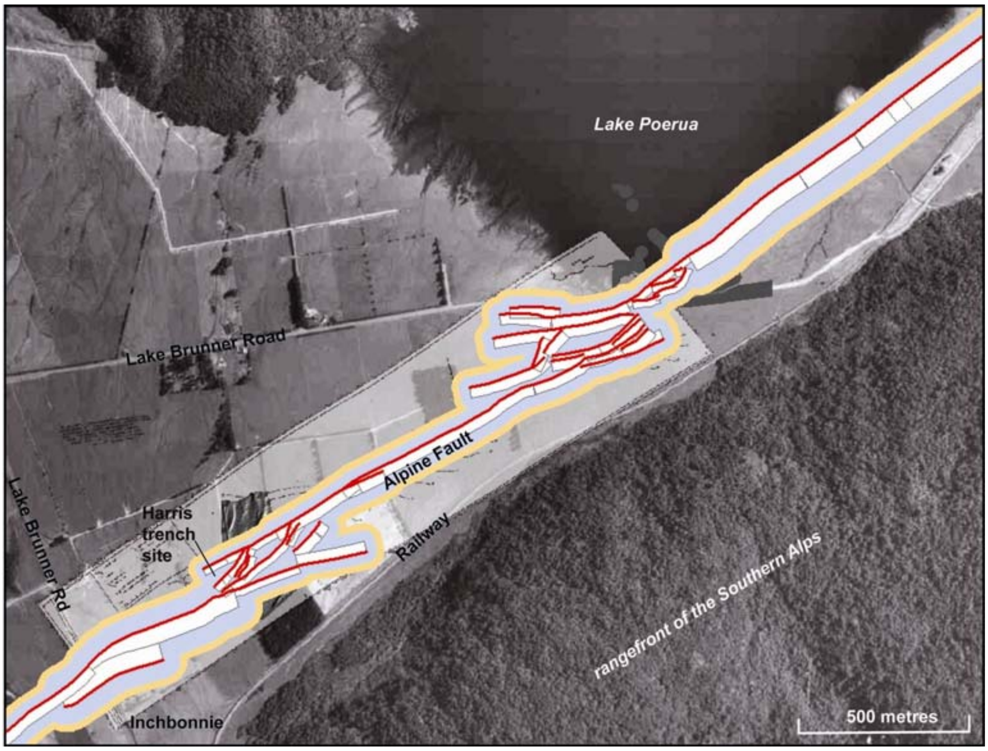

Figure 16 The Fault Avoidance Zone (FAZ) developed for the Alpine Fault in the Inchbonnie area (scale c. 1:10,000). In this example, three secondary 'backthrust' fault traces have been buffered oppositely to the others because they dip to the northwest (white panels on NW side). The area within and including the orange 'margin of safety' strips represents the complete FAZ for this area. N.B Only this total area carries any planning significance.

Another feature of the compressional stepovers are backthrust scarps. In cross-section these correspond with secondary faults that dip oppositely (back) toward the main trace of the fault, allowing for upward extrusion of the material within the stepover. In the Inchbonnie area, three traces have been given a NW dip direction and have been buffered according to that dip, i.e. their individual hangingwall is to the NW, rather than SE. This effectively narrows the overall FAZ along its SE edge, as faulting associated with those three traces will likely focus deformation within the stepover, rather than outside it.

In future, consideration will have to be given to the size and extent of the FAZ presented in this study, versus the size and extent of the FAZ presented by Langridge and McSaveney for the Lake Poerua area in Grey District. This test case is currently under Commissioners' review, but marks an example where detailed geologic and surveying work have been used to narrow the width of the FAZ. Such detailed studies take precedence over the broader-scaled FAZ constructed in this report.

3.1.4 Styx - Toaroha area

Like Inchbonnie, the Styx to Toaroha River area is one of the more open and consequently best studied parts of the Alpine Fault. The Fault Avoidance Zone for this area typically covers two main fault traces and subsidiary traces. The data used to develop the current fault map comes from sketch maps in Yetton (2000), a RTK-GPS map of the Staples trench site on the True Right bank of the Toaroha River, and through ground truthing and review undertaken during this study (Fig. 17).

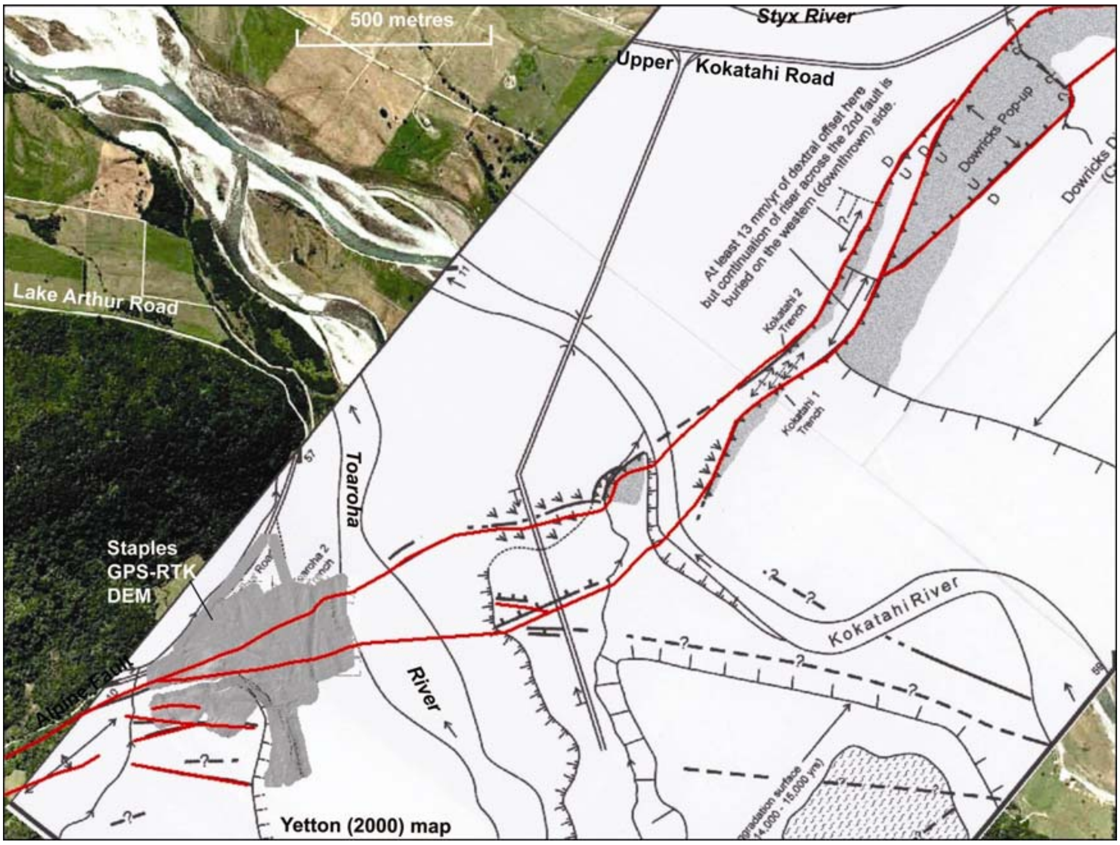

Figure 17 The Alpine Fault (as mapped) in the Styx–Toaroha area, Westland District (scale extracted from GIS at 1:10,000). The underlay of this image is a colour orthophotograph. Some of the uncertainties created by georeferencing can be seen between the mapped fault trace (red) and the Yetton (2000) sketch map. At bottom left, a DEM (grey) of the Staples trench site area is shown.

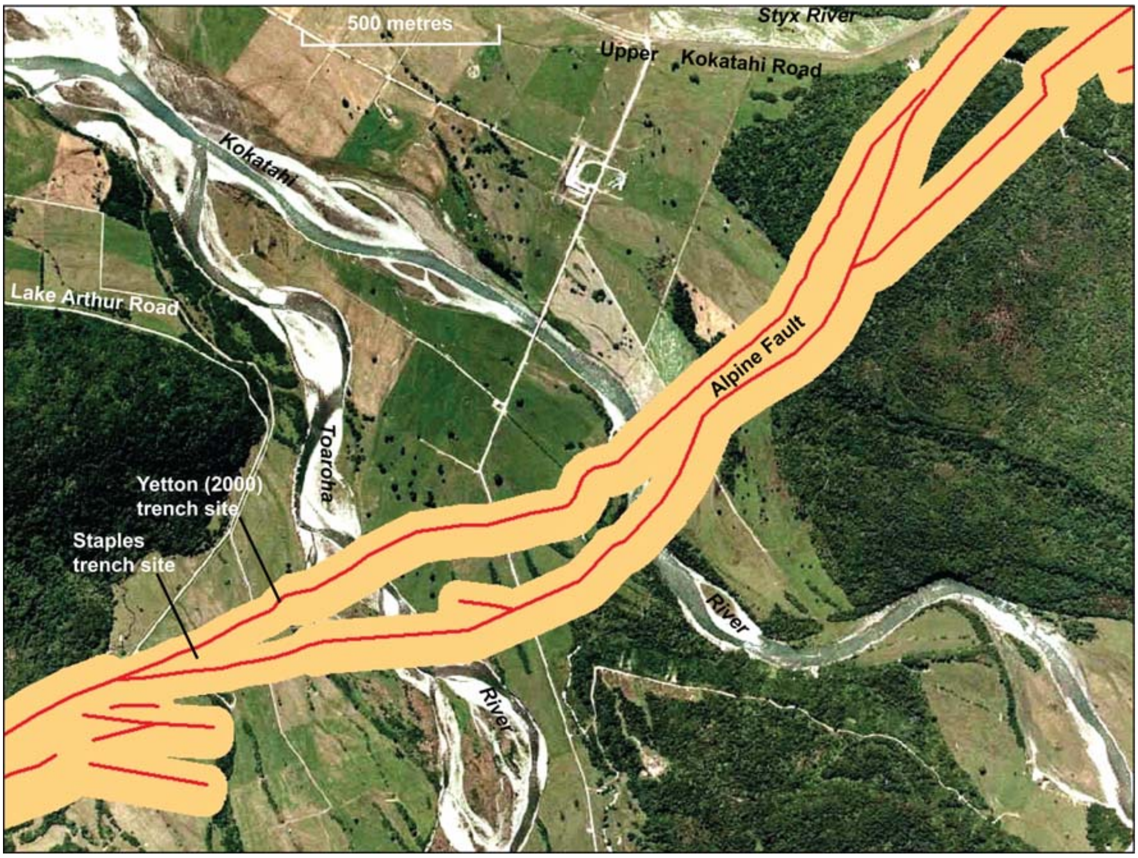

Figure 18 The Fault Avoidance Zone for the Alpine Fault in the Styx–Toaroha area, Westland District (scale c. 1:10,000). The underlay of this image is a colour orthophotograph. The orange bands represent the entire FAZ here.

3.1.5 Franz Josef area

It has long been known that the trace of the Alpine Fault runs obliquely through the township of Franz Josef in Westland District (Fig. 19) – the largest community built adjacent to the fault. This is precisely the type of 'urban' case example that the MfE Guidelines (Kerr et al., 2003) were intended to be used for. During the next fault movement, multi-metre surface displacements across the Alpine Fault will cause severe damage to houses, hotels, and businesses through Franz Josef. The implications of the fault being within the town and recommendations on how current and future developments could proceed in Franz Josef are outlined in Chapter 4 and the conclusions.

There is a significant difference between the fault mapping at the southwest edge of Franz Josef by Otago University and that which is currently shown as the location of the fault by WCRC (see Fig. 19). This reflects differing interpretations of the mapped or inferred fault location. Where the fault scarp is clear, e.g. at the Mobil petrol station, there is little variance in the fault location. It is clear that the town represents an area of high importance with respect to future surface faulting and that further work needs to be done to characterise the nature (width, extent) of faulting and deformation. At present, we have produced a FAZ with a total width of 190 m for Franz Josef (Horizontal Location uncertainty ± 50 m; Asymmetric buffer for the hangingwall side of the fault; margin of safety of ± 20 m (Figs. 10, 20). This width encompasses both the Otago and WCRC line data. Therefore, the FAZ should contain the Alpine Fault in the vicinity of the town. More detailed surveying or geologic studies should in future be undertaken as part of consent applications to better locate the fault trace (Fig. 9).

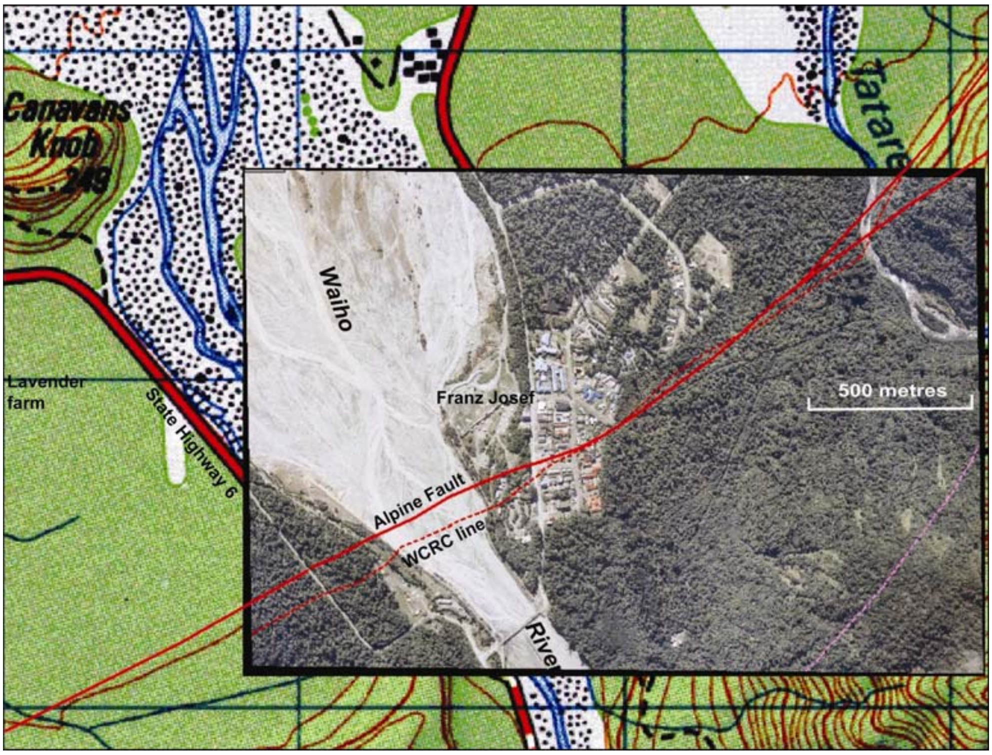

Figure 19 The Alpine Fault (as mapped) in the Franz Josef area, Westland District (scale extracted from GIS at 1:11,000). The background image is the NZMS 260 topographic sheet, as there is no orthophotograph coverage in this part of New Zealand. The solid red line is the fault trace as derived from Otago University mapping, while the dashed line is one currently used by West Coast Regional Council. Significantly, these two fault trace line sets show some difference in interpretation, especially in the southwest part of the town and across the Waiho River.

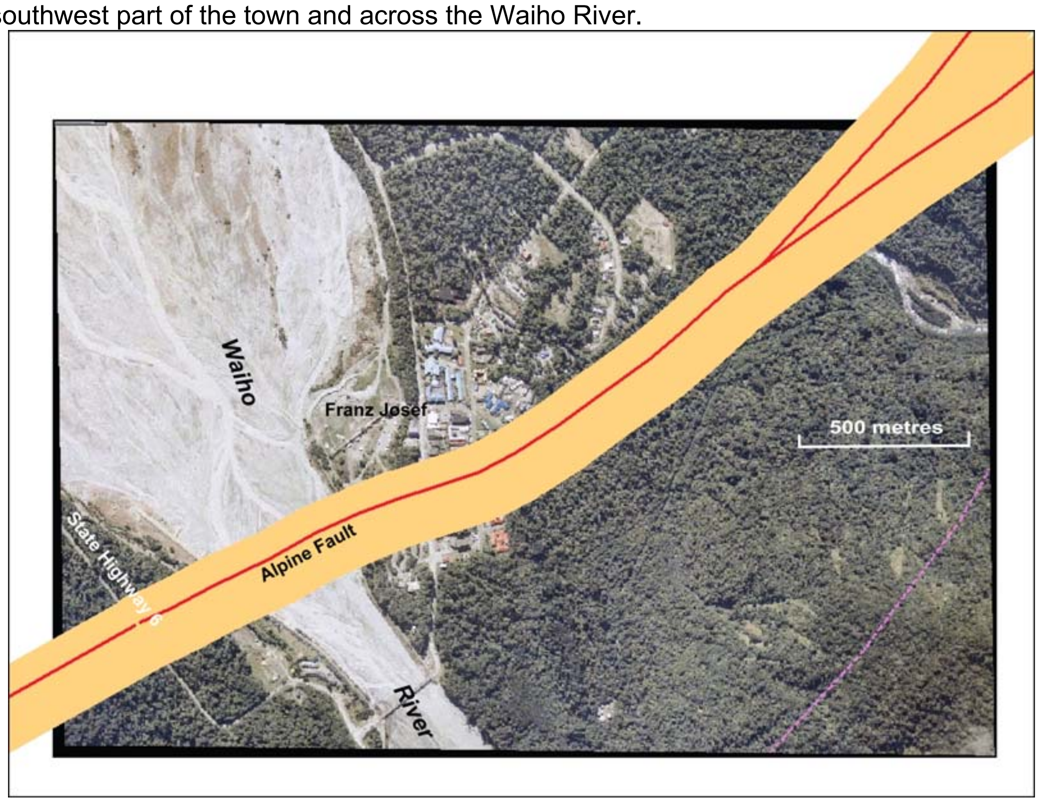

Figure 20 The Fault Avoidance Zone (FAZ) for the Alpine Fault in the Franz Josef area (scale extracted from GIS at 1:9000). Both the new mapped fault trace and the dashed WCRC line occur within the FAZ. In terms of future planning and consenting, a zone of width of 190m is currently placed through the town until better mapping data becomes available.

4.0 FAULT AVOIDANCE ZONES AND CONSENTING

In this section, we combine the results of fault trace mapping and recurrence interval estimates with land use and the Building Code to define the Resource Consent activities from the MfE Active Fault Guidelines (Kerr et al. 2003). First we outline the nature of the Building Importance Categories and their relationship to the Fault Recurrence Interval Classes.

4.1 Building Importance Category

In the event of fault rupture, buildings constructed on a fault line will suffer significant stress and can suffer extensive damage. Buildings adjacent to the fault and within the Fault Avoidance Zone may also be damaged. The MfE Active Fault Guidelines define five Building Importance Categories (BIC; Table 2) derived from the New Zealand Building Code. These five BIC categories can be wed with levels of accepted risk for damage or collapse considering the building type and its use and level of occupancy. This categorisation is weighted towards life-safety, but also allows for the importance of critical structures, e.g. schools or post-disaster facilities, and the need to locate these wisely.

Table 2 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

4.2 Relationship between Recurrence Interval and Building Importance Class

As noted earlier, the hazard posed by fault rupture is quantified using two parameters: a) Fault Complexity and its incorporation into the mapping of Fault Avoidance Zones, and b) the average recurrence interval of surface rupture or active faulting. The average recurrence interval of surface rupture is the average number of years between successive surface rupture earthquakes along a specific section/length of fault. Typically, the longer the average recurrence interval of surface rupture of a fault, the less likely the fault is to rupture in the near future. In the MfE Active Fault Guidelines, active faults are grouped according to Recurrence Interval Class (Table 2; Kerr et al. 2003, see also Van Dissen et al. 2003), such that the most hazardous faults, i.e. those with the shortest recurrence intervals, are grouped within Recurrence Interval Class I (RI Class 1 = <2000 yr). It has been stated above that the Alpine Fault is a RI Class I fault along its entire length (Van Dissen et al. 2003).

The MfE Guidelines advocate a risk-based approach to dealing with development of land on, or close to active faults. The risk at a site, of fault rupture is a function not only of the location and activity of a fault, but also the type of structure/building that may be impacted by rupture of the fault. For a site on, or immediately adjacent to an active fault, risk increases both as fault activity increases (i.e. fault recurrence interval and Recurrence Interval Class decrease) and Building Importance Category increases. In order to maintain a relatively constant/consistent level of risk throughout the region, it is reasonable to impose more restrictions on the development of sites located on, or immediately adjacent to highly active faults, compared to sites located on, or immediately adjacent to low activity faults. This hierarchical relation between fault activity (Recurrence Interval Class) and building type (Building Importance Category) is presented in Table 3.

Table 3 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.

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

The MfE Active Fault Guidelines also make a pragmatic distinction between previously subdivided and/or developed sites, and undeveloped “Greenfield” sites, and allows for different conditions to apply to these two types of sites of differing development status (Tables 3, 4). The rationale for this is that in the subdivision/development of a Greenfield area, a change of land usage is usually being sought, and it is much easier, for example, to require a building setback distance from an active fault, or to plan subdivision of land around the location of an active fault. However, in built-up areas, buildings may have been established without knowledge of the existence or location of an active fault, and the community may have an expectation to continue to live there, despite the potential danger.

Table 4 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). Note: In this example the Permitted activities have been highlighted.

Developed and/or Already Subdivided Sites					
Fault Recurrence Interval Class I # **(average recurrence interval ≤2000 years)**					
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.

In addition, existing use rights under the Resource Management Act mean that where an existing building over a fault is damaged, it can be rebuilt, even after the hazard/risk has been identified. The distinction between previous or new developments is incorporated into Table 4. Nonetheless, with regards to RI Class I faults like the Alpine Fault there is almost no difference in the Consenting Tables with regards to Greenfield or Previously subdivided situations.

4.3 Resource Consent Categories

Fault Recurrence Interval Class, Fault Complexity, and Building Importance Category are the three key elements, that when brought together, enable a risk-based approach to be taken when making planning decisions about development of land on, or close to active faults. Understanding the interrelationships between these key parameters is critical to the development of consistent, risk-based objectives, policies and methods to guide development of land that may be impacted by surface rupture faulting. The critical relationships between Recurrence Interval Class, and Building Importance Category have already been summarised in Table 3. These interrelationships are expanded in Table 4 to incorporate Fault Complexity. Table 4, extracted directly from the MfE Active Fault Guidelines also provide examples of Resource Consent Category guidelines for various combinations of Recurrence Interval Class, Fault Complexity, and Building Importance Category (see Kerr et al. 2003).

Determining the appropriate Resource Consent Category for different scenarios/ combinations of Recurrence Interval Class, Fault Complexity, and Building Importance Category is a complex task, especially when trying to anticipate the level of risk that a community may or may not be willing to accept. Certainly, as the risk increases, the Resource Consent Category should become more restrictive, and the range of matters that Council needs to consider increases. Ultimately, the Council needs to be able to impose consent conditions to avoid or mitigate the adverse effects of fault rupture, by requiring allotments to be subject to requirements such as to the use, bulk, location and foundations of any structure.

The WCRC through its Districts will wish to apply Resource Consent Categories depending upon their own requirements/ circumstances. The principal issue is to ensure that Councils have the ability to address fault rupture hazard/risk when assessing a resource consent application. Tables 3 and 4 show that the only Permitted Resource Consent Activity on, or adjacent to a Class I fault (e.g. Alpine Fault) is a BIC 1 structure. However, it is worth stating again that specific fault studies at or near the site may provide more certainty as to the fault's location, and thus allow the Fault Avoidance Zone to be reduced in width (see Fig. 9). Where detailed geologic studies are undertaken, e.g. mapping, trenching and/or surveying, it may be possible to narrow the zone of uncertainty about the zone of faulting and deformation associated with a fault.

Moreover, according to the MfE Guidelines, for a RI Class I fault such as the Alpine Fault, all BIC structures of BIC 2b or higher should be Non-Complying resource consent activities. BIC 2a structures, e.g. residential timber-framed single-storey dwellings have a Non-complying (when Well-Defined) or Discretionary (when Distributed or Uncertain) Resource Consent Activity. Councils may wish to seek more advice on the location or Complexity of the Alpine Fault when specific enquiries are submitted.

It is important to remember that surface fault rupture is a seismic hazard of relatively limited geographic extent, compared to strong ground shaking, and can, in many cases, be avoided. If avoidance of surface rupture fault hazard at a site is not practicable, then planning/ design measures need to be prescribed/ incorporated to mitigate/ accommodate the co-seismic surface rupture displacements anticipated at the site. The planning/ design measures need to also be consistent with the appropriate combination of Fault Complexity, Recurrence Interval Class, and Building Importance Category relevant to that site.

4.4 Outcomes of this work: Some Frequently Asked Questions

1. Are the MfE Guidelines legally binding, or are they part of the Resource Management Act? The MfE Guidelines are neither part of the RMA as they were written in 2003, nor are they legally binding. They act as guidelines for councils, planners and developers to use in regards to future consenting.

2. What can I build in a place like Franz Josef, where the fault and an FAZ are mapped through town?

First, in the case of new 'Greenfield' resource consent applications, no consenting restriction on new developments need to be considered outside of the mapped Fault Avoidance Zone in this report (with respect to fault rupture and deformation). Second, the FAZ should be used as an indicator that surface fault rupture and deformation may occur within that zone. If a new Greenfield site is located within the FAZ, the developers will need to either: (i) limit themselves to BIC 1 structures; or (ii) undertake further surveying and/or geologic studies to better understand the exact location of the fault and fault deformation (see Fig. 9). Development is not prohibitive within the FAZ, it merely acts as an indicator that fault deformation resides somewhere within the confines of the FAZ.

3. My house occurs within the Fault Avoidance Zone at Inchbonnie. What can I do? The MfE Guidelines have been written so as not to penalise the owners or builders of properties that have unknowingly been built on or adjacent to an active fault. Existing land use rights apply to sites within a FAZ. The likelihood of life-threatening fault displacement (to a structure) should decrease away from the mapped fault trace (approximate middle) of the FAZ.

4. Can I undertake renovations to my house, or re-build it following an earthquake? If the Land Use Status within a FAZ is maintained or not changed, then existing land use rights imply that renovations or re-building are permissible activities. As discussed, fault rupture can occur within the FAZ along and adjacent to the mapped trace of the fault. Surface rupture is a likely event along the Alpine Fault and could cause the complete destruction of built structures. The MfE Guidelines are designed for the purposes of Life Safety, i.e. to mitigate against casualty in the built environment. Following fault rupture, it would be appropriate (though not compulsory) to set back new structures from the zone of fault rupture. Notwithstanding, in the case of an Alpine Fault rupture, the shape of property boundaries themselves will be altered by displacements of c. 8 ± 1 m horizontally. Imagine that in Franz Josef township!

5. Won't my property values plummet because of these Guidelines? First, the main purpose of the Guidelines is to mitigate against casualties related to surface rupture along faults. However, it is understood that in the minds of many, in the medium term, that house prices play a more significant role in people's concerns. Some research into this question points to this perception being flawed, i.e. there is no long term impact to Real Estate values where earthquake hazard information has been disclosed (Palm, 1981, 1985).

5.0 SUMMARY AND RECOMMENDATIONS

- Active fault line data has been collated and mapped for the Alpine Fault along its entire length within the West Coast region at a scale applicable to the Guidelines of the Ministry for the Environment's "Planning for Development of Land on or Close to Active Faults" (MfE Guidelines). We have defined Fault Avoidance Zones around the Alpine Fault that encompass the area of possible surface rupture and ground deformation associated with active fault traces, and its uncertainty. We have undertaken some reconnaissance mapping and field checking to confirm fault locations in key areas.
- Mapping of the fault zones has been undertaken using a Geographic Information System (GIS) in conjunction with rectified aerial photographs and other map data sources. Each of these data media have an intrinsic level of uncertainty for mapping.
- For Land Use and Life Safety purposes, the "MfE Active Fault Guidelines" focus on: (i) the location and characterisation of surface deformation related to faulting; (ii) the characterisation of the recurrence interval of faulting, and (iii) the building importance category (BIC) of the proposed structures. The Alpine Fault is a Recurrence Interval Class I (RI Class I) fault along its entire length, i.e. surface rupture <2000 years.
- The fault has been classified according to its expression at the ground surface, with the information stored in an Attribute Table in the GIS. In general, a line which approximates the location of surface faulting has been mapped along each fault trace. Attached to that trace is a location error based on the uncertainty of the exact location of the fault (Horizontal Location uncertainty), and the media used, e.g. QMAP data vs. RTK-GPS topographic map, to capture the line on a map.
- Due to the asymmetric distribution of surface deformation associated with dextral-reverse faulting (with more deformation on the upthrown, hangingwall block compared to the downthrown, footwall block), we have developed an asymmetric zone of deformation for the Alpine Fault. In addition to the Horizontal Location uncertainty and the asymmetric buffer, a ± 20 metre 'margin of safety' buffer is added to create the full Fault Avoidance Zone.
- According to the MfE Active Fault Guidelines, for RI Class I faults in a "Greenfield" setting, all BIC structures of BIC 2b or higher should be Non-Complying resource consent activities. BIC 2a structures, e.g. residential timber-framed single-storey dwellings have a Non-complying (when well-defined) or Discretionary (when Distributed or Uncertain) Resource Consent Activity.
- For developed or already subdivided areas, the Resource Consent Activity status for RI Class I faults, e.g. the Alpine Fault is almost identical to the Greenfield situation, i.e. all BIC structures of BIC 2b or higher should be Non-Complying resource consent activities. BIC 2a structures, e.g. residential timber-framed single-storey dwellings have a Non-complying (when well-defined) or Discretionary (when Distributed or Uncertain) Resource Consent Activity. The only difference in the Resource Consent Activity status is for BIC 4 structures where the Fault Complexity is Well-defined.
- Construction of a new BIC Class 1 structure is the only permissible resource consent activity on or adjacent to the Alpine Fault, i.e. within the zone of immediate surface rupture. The Fault Avoidance Zone presented for the Alpine Fault in this report is an indicator of the likely position of the fault and future fault deformation.
- The figures displayed in this report, i.e. 1:10,000 scale, should not be used for planning purposes. They are meant as a guide. The GIS data on the enclosed CD contains the relevant fault location information at the scale we undertook the mapping for cadastral purposes, i.e. c. 1: 10,000, and also displays the Fault Avoidance Zones.

<u>Further to this summary, we recommend that:</u>

- Our new mapped fault locations and Fault Avoidance Zones should be adopted by the West Coast Regional Council and its Territorial Land Authorities for planning purposes. The mapping and FAZ's are of an appropriate scale (cadastral; 1: c. 10,000) and are in keeping with the recommendations of the Ministry for the Environment's Active Fault Guidelines (Planning for Development of Land on or Close to Active Faults; Kerr et al. 2003).
- Other active faults in West Coast region should also be considered for future fault mapping and zonation. These include areas along the extensions of the Marlborough Fault System west of the Main Divide and parts of the North Westland area, e.g. Paparoa Tectonic Zone, and in particular, concerning faults near the town of Blackball. This work could be funded through 3 individual (district by district) studies looking at the faults of Buller, Grey and Westland Districts. Improved fault location and definition of an FAZ through Franz Josef township for planning purposes must also be of a high priority.
- Fault Avoidance Zones defined in this study could be reduced in width through more detailed mapping, trenching studies or surveying that locates and defines the nature of surface deformation. This may be particularly useful for the placement and consent of future developments.

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APPENDIX

APPENDIX 1 – CD CONTENTS

1: Report:

Mapping and fault rupture avoidance zonation for the Alpine Fault in the West Coast region. GNS Science Consultancy Report 2009/18. (PDF Format).

2: GIS Data:

Line Fault Features – line.shp. Shapefile format. These are line features representing observed line fault features such as scarps, degraded scarps, guided drainage, and ridge rents. Details are provided on the fault name, the landscape feature involved, the fault feature observed, a statement concerning the accuracy of location, and an estimate of the accuracy in metres.

Fault Avoidance Zone – zone.shp. Shapefile format. These are polygon features representing the Fault Avoidance Zones developed for this study. Details are provided on the fault name, the fault complexity, the recurrence interval class, and suggested Resource Consent Category.