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Earthquake Fault Trace Survey Kapiti Coast District

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Client Report
2003/77

August 2003

Earthquake Fault Trace Survey
Kapiti Coast District

by

R. Van Dissen & D. Heron

Prepared for

Kapiti Coast District Council

CONFIDENTIAL

Institute of Geological & Nuclear Sciences client report 2003/77
Project Number: 430W6910

The data presented in this Report are available to GNS for other use from
August 2003

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EXECUTIVE SUMMARY

The area administered by the Kapiti Coast District Council is traversed by five active faults: the Ohariu, Northern Ohariu, Gibbs, Otaki Forks, and Southeast Reikorangi faults. In recognition of the surface rupture hazard posed by these faults, the Kapiti Coast District Council commissioned the Institute of Geological & Nuclear Sciences Ltd to complete an earthquake fault trace survey of the district.

The Ministry for the Environment (MfE), New Zealand, is about to circulate Interim MfE Interim Guidelines on planning for development of land on, or near, active faults. The aim of the MfE Interim 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 Interim 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 our survey of the active faults in the Kapiti Coast District, we have adopted the principles and methodology advanced in the MfE Interim Guidelines.

In the MfE Interim Guidelines, the surface rupture hazard of an active fault is characterised by two parameters: 1) the location/complexity of surface rupture of the fault, and 2) the activity of the fault, as measured by its average recurrence interval of surface rupture. Surrounding all parts of all known active faults in the Kapiti Coast District, Fault Avoidance Zones have been defined based on the fault's location and complexity. Fault Avoidance Zones are attributed as *well defined*, *distributed*, *uncertain - constrained*, or *uncertain - poorly constrained*, and range in width from about 40 m to greater than 300 m. Also, each active fault has been placed into a specific Recurrence Interval Class based on existing data relevant to its recurrence interval: Ohariu & Northern Ohariu faults – Recurrence Interval Class II (>2000 to ≤3500 years); Gibbs & Otaki Forks faults – Recurrence Interval Class III (>3500 to ≤5000 years); Southeast Reikorangi fault – Recurrence Interval Class IV (>5000 to ≤10,000 years).

The risk of fault rupture at a site is a function not only of the location and activity of a fault, but also on the type of structure/building that may be impacted by rupture of the fault. Building Importance Category is used here, and in the MfE Interim Guidelines, to characterise building type/importance with respect of life safety. By combining Building Importance Category, with fault rupture hazard parameters, and with development status of a site (i.e. previously developed site, or undeveloped "greenfield" site) it is possible to define appropriate, risk-based Resource Consent Categories for development of land on, or close to the active faults. Determining the appropriate Resource Consent Category for different scenarios/combinations of Recurrence Interval Class, Fault Complexity, and Building Importance Category is a complex task, and we present a number of tables depicting the interrelationships of these parameters based on examples in the MfE Interim Guidelines.

1 INTRODUCTION

New Zealand lies within the deforming boundary zone between the Australian and Pacific tectonic plates. The area administrated by the Kapiti Coast District Council lies within one of the more active parts of this boundary zone. The Kapiti Coast District is underlain by the subducting Pacific plate, and the district is traversed by a number of significant active faults that break and rupture the ground surface, including the Ohariu fault, Northern Ohariu fault, Otaki Forks fault, and Gibbs fault (Figure 1). Data collected from these faults indicate that some have relatively high rates of activity (i.e. relatively short recurrence intervals of surface rupture), and are capable of generating large (i.e. metre-scale) single event surface rupture displacements.

Surface rupture along these active faults will result in a zone of intense ground deformation as opposite sides of the fault move past each other during an earthquake. Property damage can be expected and loss of life may occur where buildings, and other structures, have been constructed across the rupturing fault.

Fault features along several of the active faults in the Kapiti Coast District have previously been mapped in detail (e.g. *Ohariu fault* – Miyoshi *et al*. 1987, Van Dissen & Berryman 1996, Heron *et al*. 1998, Heron & Van Dissen 1992a; *Northern Ohariu fault* – Van Dissen *et al*. 1999, Palmer & Van Dissen 2002). This work included walking the entire length of each fault, and on the Ohariu fault detailed surveys (Heron 1993, 1994a, 1994b, 1996) and trenching at a number of locations (Heron *et al*. 1998, Litchfield *et al*. 2001, Litchfield *et al*. 2003, Van Dissen *et al*. 2003b). Other faults (e.g. *Gibbs fault, Otaki Forks fault* – Begg & Van Dissen 2000, Van Dissen *et al*. 1998; *Southeast Reikorangi fault*) have been mapped in lesser detail. In only a few locations along the Ohariu fault (Waikanae and Nikau valley) have mapped fault features in the Kapiti Coast District previously been used to define zones within which future surface fault rupture is considered likely to occur.

The Ministry for the Environment, New Zealand, is about to circulate Interim Guidelines on planning for development of land on, or near, active faults[1, 2] (Kerr at al. 2003, see also King *et al*. 2003). The aim of the MfE Interim 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 Interim Guidelines provide information about active faults, specifically fault rupture hazard, and promote a risk-based approach when dealing with

[1] The Ministry for the Environment's Interim Guidelines "Planning for development of land on, or near, active faults: An interim guidelines to assist resource management planners in New Zealand" will soon be available on both their main website and their Quality Planning website. The Ministry for the Environment invites public comment on these Interim Guidelines, and intends to update the "interim" version accordingly.

[2] Throughout the remainder of this report, the Ministry for the Environment's Interim Guidelines will be referred to as the MfE Interim Guidelines.

development in areas subject to fault rupture hazard. In the MfE Interim 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 surface rupture of the fault. In this report, these two fault rupture hazard parameters are collated for the five known active faults in the Kapiti Coast District.

The MfE Interim Guidelines also advance a hierarchical relationship between fault-avoidance recurrence interval and building importance, such that the greater the importance of a structure, with respect to life safety, the longer the avoidance recurrence interval (see Tables 1 & 2, and Section 3.6 for more detail). For example, only low hazard structures, such as farm sheds and fences (e.g. Building Importance Category 1 structures), are allowed to be built across active faults with average recurrence intervals of surface rupture less than 2000 years. In contrast, in a "greenfield" (i.e. undeveloped) setting, more significant structures such as schools, airport terminals, and large hotels (Building Importance Category 3 structures) should not be sited across faults with average recurrence intervals shorter than 10,000 years.

In the report that follows, we first outline the scope of study and its objectives. We then discuss, in some detail, the methodology used to achieve the study's objectives. Following this, we present the results of the study; on a fault by fault basis, whereby, for each fault we define Fault Avoidance Zones based on fault rupture location and complexity, and Recurrence Interval Class based on the fault's average recurrence interval of surface rupture. Combining these two fault rupture hazard parameters, with information on Building Importance Category (i.e. building type) and development status (i.e. previously developed, or "greenfield" site) an appropriate, risk-based Resource Consent Category can be defined for land on, or close to the active faults in the Kapiti Coast District. The report ends with a number of recommendation and conclusions.

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

2 SCOPE OF STUDY

This study was undertaken on contract to Kapiti Coast District Council (KCDC) by the Institute of Geological and Nuclear Sciences Ltd (GNS). Ultimately, the Council's goal is to formulate and implement appropriate controls within the District Plan pertaining to development in areas on, or near, the active faults in the district. To facilitate this, the two principle aims of GNS' study were to: 1) more accurately define the location of the active faults in the district, and 2) present the results of the study in a fashion that is wholly compatible with the soon to be released MfE Interim Guidelines. In the contract, the GNS study was required to:

1) Identify all known active fault traces in the Kapiti Coast District.
2) Accurately map as many fault traces as possible to within ± 5 metres.
3) Provide relevant information/explanations on faulting in the district with respect to (a) level of certainty of location, (b) fault recurrence interval, (c) horizontal and vertical displacement.

In addition, the above information has been used to define Fault Avoidance Zones classified in terms of the MfE Interim Guidelines. The goal being to provide examples of appropriate, risk-based Resource Consent Categories for land that lies within Fault Avoidance Zones based on the Recurrence Interval Class of the fault, the current development status of the land, and the proposed building type (i.e. Building Importance Category) (see Tables 3, 4 & 6 - 9).

The results of this work are this report, and a GIS database of fault features (as lines and points with associated attributes) and Fault Avoidance Zones (as areas with associated attributes). The Fault Avoidance Zones are linked to Resource Consent Category via tables pertaining to fault Recurrence Interval Class, and Building Importance Category. Maps derived from the GIS database are included in this report (Figures 2 - 8). 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 district.

3 STUDY METHODOLOGY

The methodology outlined in the MfE Interim Guidelines was used in this work. The main steps in the process were:

1) identifying all known active fault traces, and related features, in the Kapiti Coast District
2) mapping and defining the positional coordinates of the fault traces, and related features
3) classifying all parts of a fault in terms of the fault complexity of surface rupture
4) defining Fault Avoidance Zones for each of these parts
5) determining the average recurrence interval of surface rupture faulting (i.e. Recurrence Interval Class) for each fault

These data are then combined with standard tables for Building Importance Category (see Table 1) and Development Status (see Table 2) to determine appropriate Resource Consent Categories for proposed development of land on, or close to active faults in the Kapiti Coast District (see Tables 3, 4 & 6 - 8).

3.1 Identification of Active Fault Traces

Details of known active fault features within the Kapiti Coast District were obtained from a number of sources, including: published papers, unpublished GNS Science and Client reports, drill hole data, previous GNS clients and sub-contractors (Pritchard Group and Cuttriss Consultants), the Kapiti Coast District Plan, and the authors' first-hand knowledge of the geology and active faulting in the district, including trenching studies along the Ohariu fault (see reference list).

This information was supplemented with air photo interpretation of the district using GNS's extensive collection of commercially flown vertical aerial photography dating from 1945 (pre-subdivision) to the present (approximate scales ranging from 1:16,000 to 1:40,000), as well as modern purpose-flown low level vertical and oblique aerial photography along the Northern Ohariu fault, the Gibbs fault, and portions of the Ohariu fault (approximate scale of 1:4000).

KCDC supplied two sets of orthophotography for the purposes of this work. The urban area is covered by colour photography, flown in 2003 with a pixel resolution 0.25 m and an accuracy of ± 0.25 metres. The rural area is covered by black and white photography with a pixel resolution of 1 m and an accuracy of ± 3 metres.

3.2 Capture of Fault Feature Coordinates

Previous studies of active faulting in the Kapiti Coast have produced extensive data on the location and type of fault-generated features present in the district. However, these data are often site specific in nature, and, until this study, had not yet been compiled to provide comprehensive coverage of the District as a whole. The identified fault-generated features, such as fault scarps, offset river terraces, fans, spurs, and streams, guided drainages, crush zones, and aligned saddles are point or line features that assist in locating the position of faults, and provide evidence as to the timing and size of previous surface rupture earthquakes along these faults.

The accuracy with which the location of a fault feature can be captured into a database is influenced by two types of uncertainty or error. The first is the error associated with how accurately the feature can be located on the ground. The second is the error associated with capturing that position into the database.

While a major active fault is typically a near-continuous geological structure, surface features generated by past surface ruptures of the fault are often intermittent. In some areas where fault features should exist, they can not be seen. On hill slopes, for instance, geological processes such as landslides and slope wash can quickly destroy or modify topographic fault features. River processes such as erosion and sediment deposition can destroy fault features on the river valleys and plains. Also, fault ruptures are seldom preserved in the coastal plain where the young age and mobility of the dune and swamp sediments often obscure evidence of faulting. It almost goes without saying that it is along the stretches of an active fault where fault features are not preserved that uncertainty as to the fault's precise location is greatest.

Where features are preserved, the accuracy with which the fault can be located on the ground depends on the type of feature. A fault scarp is one of the more definitive features that can be used to define the location of a fault. In places, the scarp of the Ohariu fault and Northern Ohariu fault is very sharp and distinct (less than about 5 m wide), and here it is possible to define the location of the fault quite accurately (to within several metres). However, in other places, the scarp is a broad topographic rise 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 the fault cannot be significantly more accurate than the distinctness/sharpness of the topographic expression of the fault feature. So, even when topographic fault features are preserved, the ability to use these features to define the precise location of the fault, and therefore future surface rupture hazard, varies according to the distinctness of topographic expression of the feature.

An additional uncertainty with regard to using topographic fault features to define the location of past, and future, surface rupture and hazard, is that the preservation potential of fault scarps, and other fault-generated topographic features, typically varies according size. That is, a large scarp, or displacement, is more likely to be preserved in the landscape than a small scarp, or displacement. So, even when one can identify a distinct fault feature at a site, one cannot be entirely sure that smaller, but still life-threatening displacements did not once extend through the site, but are now no longer preserved. Thus, the identified fault feature may not indicate/record the true scale of fault rupture hazard at a site. As is discussed in more detail in Section 3.4, this type of uncertainty is typically addressed by prescribing a "set-back" distance either side of the fault.

In limited instances, active faults and fault-related features can be located absolutely as in the trenches that have been excavated across the Ohariu fault. GPS or traditional survey techniques have been used to locate and capture the positions of these features to an accuracy of ± 0.1 m, and they are attributed as *surveyed* in the GIS database. More typically, however, once a fault feature was identified on the ground, or on air photos, whether the feature be distinct or otherwise, its position was captured/defined using the KCDC orthophotography. Where the fault feature is sharp and distinct, and could also be clearly seen on the KCDC orthophotography, the accuracy of the captured location of these features is considered to be ± 5 m and they are attributed as *distinct* in the database. Where the fault feature is either less distinct, and/or not clearly visible on the KCDC orthophotography, the accuracy of the captured location of the features is considered to be either ± 10 m (*approximate*) or ± 25 m (*estimated*) depending on our subjective assessment as to our ability to constrain the location of the feature on the KCDC orthophotography.

In some of the urban areas of the district, fault scarps and other fault-generated features that are visible on pre-subdivision aerial photography have been removed or significantly modified by subsequent development, and cannot be located on the ground. As a consequence, these unrectified photographs are the only record of the location of the fault feature, and the position of the fault. In these cases, and where possible, the pre-subdivision photos were rectified and the position of the fault features captured/defined. The lack of good control points on the pre-subdivision aerial photography resulted in the accuracy of the captured location of features defined by this technique to be in the order of ± 10 m, and are attributed as *approximate* in the database. In places where a lack of control points prevented any attempt to rectify the pre-subdivision aerial photography, adjacent topographic and cultural features were used to infer the location on the KCDC orthophotography, and the location was captured at a lesser accuracy. The accuracy of location of the fault features is dependent on the proximity, number, and nature of these reference points, and the captured features were attributed as either *approximate* (± 10 m) or *estimated* (± 25 m).

The mapped fault features (lines and points) were used to construct fault rupture zones (zones within which future rupture is likely to cause intense ground deformation). In some areas, these zones are based on the position of a simple linear fault-line, and the width of the zones reflects the accuracy of capture. In other 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 or uncertainty of the fault location on the ground, and the accuracy of capture. In specific cases, detailed fault studies (trenching) could be used to reduce the uncertainty of fault location and thereby reduce the width of the fault rupture zone.

3.3 Fault Complexity of Surface Rupture

Surface rupture Fault Complexity is an important parameter used in defining rupture hazard at a site. When fault rupture deformation is distributed over a wide area, the amount of deformation at a specific locality within the distributed zone is less compared to where the deformation is concentrated on a single well-defined trace. The relative fault rupture hazard/risk is therefore less within a zone of distributed deformation than within a narrow well defined zone. The fault feature data compiled for the Kapiti Coast were used to categorise the fault rupture complexity for all parts of each active fault in the district. The MfE Interim Guidelines define Fault Complexity of surface rupture using the following terms (Kerr *et al*. 2003; see also King *et al*. 2003, and Van Dissen *et al*. 2003a, 2003c):

Well defined: fault rupture deformation is well defined and of limited geographic width (e.g. metres to tens of metres wide).

Distributed: fault rupture deformation is distributed over a relatively broad geographic width (e.g. tens to hundreds of metres wide), and typically comprises multiple fault traces and/or folds.

Uncertain: the location of fault rupture deformation is uncertain usually because the fault has not been mapped in detail, or because evidence of deformation has been either buried or eroded away.

In compiling the data for the Kapiti Coast District it was necessary to extend the definition of *well defined* to include areas where the fault had been either buried or eroded over short distances but its position is tightly constrained (e.g. its location can be constrained to within metres to tens of metres) by the presence of nearby distinct fault features. In these cases we define the Fault Complexity as *well defined - extended* (see below). It was also necessary to subdivide the definition of *uncertain* into two categories: *uncertain - constrained* and *uncertain - poorly constrained*. The former term, *uncertain - constrained*, was required to allow for areas where the location of fault rupture is uncertain because evidence has been either buried or eroded away but where the location can be constrained to a reasonable geographic extent (e.g. tens of metres to hundreds of metres wide). In this study, we chose a 300 metre width, the width of the wider identified *distributed* fault complexity zones, as the cut-off between *uncertain - constrained*, and *uncertain - poorly constrained*. That is, if the position of a length of active fault was uncertain, but could be constrained to lie within a region ≤300 metres wide, then the fault complexity zone was defined as *uncertain - constrained*. For planning purposes, we consider that *uncertain - constrained* fault complexity zones should be viewed in the same fashion as a *distributed* fault complexity zone. The remainder of the text, and specifically Tables 3 & 4, reflect this opinion.

Below we list the Fault Complexity terms, and definitions, that we use throughout the rest of the report, including tables and figures.

Well defined & well defined - extended: fault rupture deformation is well defined and of limited geographic width (e.g. metres to tens of metres wide), including areas where fault rupture deformation has been either buried or eroded over short distances but its position is tightly constrained by the presence of nearby distinct fault features.

Distributed & uncertain - constrained: The location of fault rupture deformation can be constrained to lie within a relatively broad geographic width (e.g. tens to hundreds of metres wide). *Distributed* Fault Complexity applied to areas where fault rupture deformation is distributed over a relatively broad, but defined, geographic width (e.g. tens to hundreds of metres wide), typically as multiple fault traces and/or folds. *Uncertain - constrained* Fault Complexity applies to areas where the location of fault rupture is uncertain because evidence has been either buried or eroded but where the location of fault rupture can be constrained to a reasonable geographic extent (≤300 m). In this study, we chose 300 metres as the maximum width of a region that is mapped as *uncertain - constrained*.

Uncertain - poorly constrained: the location of fault rupture deformation is uncertain and cannot be constrained to lie within a zone less than 300 m wide, usually because evidence of deformation has been either buried or eroded away, or the features used to define the fault's location are widely spaced and/or very broad in nature.

3.4 Defining Fault Avoidance Zones

Generally, a fault is a zone of deformation rather than a single linear feature. The zone may range in width from metres to hundreds of metres. Structures sited directly across an active fault, or near a fault, are in a potentially hazardous area, and could be damaged in the event of fault rupture. As is suggested in the MfE Interim Guidelines (Kerr *et al*. 2003, see also King *et al*. 2003), a Fault Avoidance Zone is created by defining a 20 m buffer around the likely fault rupture zone. We have done this for all the active faults in the Kapiti Coast District, and have attributed each Fault Avoidance Zone in the GIS database as either *well defined*, *distributed*, *uncertain - constrained*, or *uncertain - poorly constrained* according to the fault complexity of the zone. Figure 2 shows a detailed example of the relation between the position of mapped fault features and the subsequent definition of Fault Avoidance Zones for a stretch of the Ohariu fault near MacKays Crossing. Figures 3 - 8 show, in a more general sense, the distribution of the Fault Avoidance Zones along all the active faults in the district.

3.5 Building Importance Category

In the event of fault rupture, buildings constructed on the fault 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 Interim Guidelines define five Building Importance Categories (Table 1) based on accepted risk levels for building collapse considering building type, use and occupancy. This categorisation is weighted towards life-safety, but also allows for the importance of critical structures and the need to locate these wisely.

Table 1 Building Importance Categories and representative examples. For more detail see Kerr *et al*. (2003), and King *et al*. (2003).

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

3.6 Relationship between Fault Recurrence Class and Building Importance Category

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 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. Likelihood of rupture is probably also a function of other variables such as elapsed time since the last rupture of the fault, and the size, style and timing of large earthquakes on other nearby faults; however, these variables are not used to define rupture hazard in the MfE Interim Guidelines. Notwithstanding, a fault with a long recurrence interval typically posses less of a hazard than one with a short recurrence interval. In the MfE Interim Guidelines, active faults are grouped according to Recurrence Interval Class (Table 2; Kerr *et al*. 2003, see also Van Dissen *et al*. 2003a), such that the most hazardous faults, i.e. those with the shortest recurrence intervals, are grouped within Recurrence Interval Class I. The next most active group of faults are those within Recurrence Interval Class II, and so on. As will be discussed later in the report (Section 4; see also Table 5), there are no known Recurrence Interval Class I faults in the Kapiti Coast District. The two most active, hazardous, faults in the district are here judged to be the Ohariu fault and the Northern Ohariu fault, and both are Recurrence Interval Class II faults.

The MfE Interim Guidelines advocate a risk-based approach to dealing with development of land on, or close to active faults. The risk at a site to 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 district, it appears 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 2.

The MfE Interim Guidelines also make a pragmatic distinction between previously subdivided and/or developed sites, and undeveloped “greenfields” sites, and allows for different conditions to apply to these two types of sites of differing development status (Table 2, see also Tables 3, 4 & 6-8). The rational for this is that in the subdivision/development of a greenfields 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. Also, existing use rights under the RMA mean that where an existing building over a fault is damaged, it can be rebuilt, even after the hazard/risk has been identified.

Table 2 Relationships between Recurrence Interval Class, Average Recurrence Interval of Surface Rupture, and Building Importance Category for Previously Subdivided and Greenfield Sites. For more detail see Kerr *et al*. (2003), and King *et al*. (2003).

<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>

3.7 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 2. These interrelationships are expanded in Tables 3 & 4 to incorporate Fault Complexity. Tables 3 & 4 also provide examples of Resource Consent Category suggestions for various combinations of Recurrence Interval Class, Fault Complexity, and Building Importance Category.

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 Council will want to apply Resource Consent Categories depending upon their own requirements/circumstances. The principle issue is to ensure that the Council has the ability to address the issues of fault rupture hazard/risk when assessing a resource consent application. When dealing with controlled and discretionary activities, the matters over which the Council reserves control or restricts its discretion are important. For these categories, the matters the Council may need to consider include: the proposed use of the building; the site layout including building setback and separation distance; building height and design; construction type (note only for resource management purposes); and financial contributions such as reserve contributions.

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.

Also worth reiterating is that when a Fault Avoidance Zone is classified as, for example, *uncertain - poorly constrained*, 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 and reclassified to, for example, *well defined* or *uncertain - constrained*. Commensurate with a reclassification of Fault Avoidance Zone, is reclassification of Resource Consent Category at the site.

Table 3 **Example of relationships between Resource Consent Category, Building Importance Category, fault Recurrence Interval Class, and Fault Complexity for developed and/or already subdivided sites, based on the MfE Interim Guidelines (for more detail see Kerr *et al*. 2003).**

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*	Prohibited
Distributed, & Uncertain - constrained	Permitted	*Discretionary*	*Non-Complying*	*Non-Complying*	Non-Complying
Uncertain - poorly constrained	Permitted	*Discretionary*	*Non-Complying*	*Non-Complying*	Non-Complying
Fault Recurrence Interval Class II *(average recurrence interval >2000 years to ≤3500 years)*					
Building Importance Category	**1**	**2a**	**2b**	**3**	**4**
Fault Complexity	**Resource Consent Category**				
Well Defined	Permitted	Permitted*	*Non-Complying*	*Non-Complying*	Prohibited
Distributed, & Uncertain - constrained	Permitted	Permitted	*Discretionary*	*Non-Complying*	Non-Complying
Uncertain - poorly constrained	Permitted	Permitted	*Discretionary*	*Non-Complying*	Non-Complying

Table 3 – *continued on next page*

Table 3 – continued. Example of relationships between Resource Consent Category, Building Importance Category, fault Recurrence Interval Class, and Fault Complexity for developed and/or already subdivided sites, based on the MfE Interim Guidelines.

Fault Recurrence Interval Class III (average recurrence interval >3500 years to ≤5000 years)					
Building Importance Category	**1**	**2a**	**2b**	**3**	**4**
Fault Complexity	**Resource Consent Category**				
Well Defined	Permitted	Permitted*	Permitted*	*Non-Complying*	Non-Complying
Distributed, & Uncertain - constrained	Permitted	Permitted	Permitted	*Discretionary*	Non-Complying
Uncertain - poorly constrained	Permitted	Permitted	Permitted	*Discretionary*	Non-Complying
Fault Recurrence Interval Class IV (average recurrence interval >5000 years to ≤10,000 years)					
Building Importance Category	**1**	**2a**	**2b**	**3**	**4**
Fault Complexity	**Resource Consent Category**				
Well Defined	Permitted	Permitted*	Permitted*	Permitted*	Non-Complying
Distributed, & Uncertain - constrained	Permitted	Permitted	Permitted	Permitted	Non-Complying
Uncertain - poorly constrained	Permitted	Permitted	Permitted	Permitted	Non-Complying

Notes:
[#] No faults of Recurrence Interval Class I have been identified in the Kapiti Coast District.
* Indicates that the Resource Consent Category is permitted, but could be controlled or discretionary given that the fault location is well defined.
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.

Table 4 **Example of relationships between Resource Consent Category, Building Importance Category, fault Recurrence Interval Class, and Fault Complexity for Greenfield sites, based on the MfE Interim Guidelines (for more detail see Kerr *et al*. 2003).**

Greenfield 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*	Prohibited
Distributed, & Uncertain - constrained	Permitted	*Discretionary*	*Non-Complying*	*Non-Complying*	Non-Complying
Uncertain - poorly constrained	Permitted	*Discretionary*	*Non-Complying*	*Non-Complying*	Non-Complying
Fault Recurrence Interval Class II (average recurrence interval >2000 years to ≤3500 years)					
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

Table 4 – *continued on next page*

Table 4 – continued. Example of relationships between Resource Consent Category, Building Importance Category, fault Recurrence Interval Class, and Fault Complexity for Greenfield sites, based on the MfE Interim Guidelines (for more detail see Kerr *et al*. 2003).

Fault Recurrence Interval Class III (average recurrence interval >3500 years to ≤5000 years)					
Building Importance Category	**1**	**2a**	**2b**	**3**	**4**
Fault Complexity	**Resource Consent Category**				
Well Defined	Permitted	Permitted*	*Non-Complying*	*Non-Complying*	Non-Complying
Distributed, & Uncertain - constrained	Permitted	Permitted	*Discretionary*	*Discretionary*	Non-Complying
Uncertain - poorly constrained	Permitted	Permitted	*Discretionary*	*Discretionary*	Non-Complying

Fault Recurrence Interval Class IV (average recurrence interval >5000 years to ≤10,000 years)					
Building Importance Category	**1**	**2a**	**2b**	**3**	**4**
Fault Complexity	**Resource Consent Category**				
Well Defined	Permitted	Permitted*	Permitted*	*Non-complying*	Non-Complying
Distributed, & Uncertain - constrained	Permitted	Permitted	Permitted	*Discretionary*	Non-Complying
Uncertain - poorly constrained	Permitted	Permitted	Permitted	*Discretionary*	Non-Complying

Notes:
[#] No faults of Recurrence Interval Class I have been identified in the Kapiti Coast District.
* Indicates that the Resource Consent Category is permitted, but could be controlled or discretionary given that the fault location is well defined.
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.

4 RESULTS

4.1 Ohariu fault

The Ohariu fault is one of the major earthquake-generating faults in the Wellington region. It extends approximately 70 km north-northeastwards from offshore of the Wellington south coast, through Porirua, to at least Waikanae (e.g. Heron *et al*. 1998, Begg & Johnston 2000). North of Waikanae, the name of the Ohariu fault changes to the Northern Ohariu fault which extends northward to near Palmerston North.

Trenching and other detailed studies on the Ohariu fault (e.g. Heron *et al*. 1998, Litchfield *et al*. 2003) have determined that the fault has a right-lateral slip rate of approximately 1-2 mm/yr, and an average recurrence interval of surface rupture earthquakes of 1500-5000 years. It most recently ruptured the ground surface about 1000 years ago, and is capable of generating earthquakes in the order of magnitude 7.5. Individual surface rupture earthquakes along the fault are expected to generate 3-5 metres of right-lateral displacement at the ground surface, and a lesser and variable amount of vertical displacement.

The Ohariu fault passes through areas of urban, semi-rural, and rural development. In some areas (e.g. Nikau Valley and Waikanae Downs) development has taken account of, and avoided, the location of the fault, but not so at Waikanae where houses have been built on the fault.

Recurrence Interval Class

The recurrence interval of 1500-5000 years for the Ohariu fault spans several Recurrence Interval Class boundaries defined in the MfE Interim Guidelines (Kerr *et al*. 2003). Based on the mean of this range (3250 years), the fault is placed in Recurrence Interval Class II, >2000 years to ≤3500 years (Table 5, see also Van Dissen *et al*. 2003a).

Fault Complexity

Parts of the Ohariu fault fall into the *well defined*, *uncertain - constrained*, and *uncertain - unconstrained* fault complexity classes (see maps at end of report, Figures 2 - 4). In the south, on the edge of the Kapiti Coast District in Transmission Gully the fault is *well defined*. Just south of the district boundary, trenching confirmed the location of the fault (Heron *et al*. 1998). Further north, the fault complexity (i.e. Fault Avoidance Zone) is *uncertain - constrained* based on the location of guided streams and offset spurs. In the vicinity of Mackays Crossing the fault is well defined where it offsets alluvial fans. At Mackays Crossing the fault was trenched, and RTK GPS was used here and to the north and south to capture the fault location (Figure 2; Van Dissen *et al*. 2003b). To the north of MacKays Crossing, through the Valley Road area to the upper part of Nikau Valley, a few short lengths of fault scarp allow the fault position to be *well defined*. Elsewhere in this area the fault complexity is *uncertain - constrained* based on the position of saddles, springs, and breaks in slope. In Nikau Valley, trenching and surveying of the fault prior to subdivision (Heron 1994a, 1994b; Litchfield *et al*. 2001) allows the position of the fault to be *well defined*. North through the Scenic Reserve, through the hills above Waikanae Downs, and across the Waikanae River, the fault complexity is *uncertain - constrained* based on the location of springs and saddles. In places, short scarps are *well defined* and possible scarps are also present. Through Waikanae, the fault is *well defined* on pre-subdivision photographs but becomes *uncertain - constrained* and then *uncertain - poorly constrained* as fault features become more widely distributed as it passes north into the hills. Just south of Hadfield Road, the close proximity saddles and springs allow the fault to be classified as *uncertain - constrained*. In the hills above Hadfield Road, the Ohariu fault appears to join two short southwest-trending faults, one which is *well defined* across the fan surface but becomes *uncertain - poorly constrained* as it approaches State Highway One. To the northeast, the Ohariu fault is *uncertain - constrained* judged by a series of springs and saddles. Further northeast, the fault's location is *uncertain - poorly constrained* and no definite fault features are known beyond Best Road.

Some long lengths of the Ohariu fault are classified as *uncertain - constrained* or *uncertain - poorly constrained*, and more detailed mapping may allow the location of the fault to be more tightly constrained. However, these areas are largely above 100 m elevation and unlikely to be subject to development, and, therefore, detailed mapping may be of little practical benefit.

Proposed Resource Consent Categories

Table 6 shows examples of Resource Consent Categories for both developed and/or already subdivided sites, and greenfield sites along the Ohariu fault accounting for various combinations of Building Importance Category, and Fault Complexity. Figure 2 presents an example of linkages between this table and the Fault Avoidance Zone polygons in the GIS database.

Table 5 Recurrence Interval Classes of known active faults within Kapiti Coast District. For more detail see Kerr *et al*. (2003), and Van Dissen *et al*. (2003a).

Fault Name	Recurrence Interval Class	Recurrence Interval Range of Respective Recurrence Interval Class	Confidence of Recurrence Interval Classification
Ohariu fault	Class II	>2000 years to ≤3500 years	Low*
Northern Ohariu fault	Class II	>2000 years to ≤3500 years	Low*
Otaki Forks fault	Class III	>3500 years to ≤5000 years	Low*
Gibbs fault	Class III	>3500 years to ≤5000 years	Low*
SE Reikorangi fault	Class IV	>5000 years to ≤10,000 years	Low*

Note:
* As defined in the MfE Interim Guidelines, a Low confidence of recurrence interval classification is assigned to an active fault when the range of uncertainty of the fault's recurrence interval embraces a significant portion of three or more Recurrence Interval Classes (e.g. Ohariu and Northern Ohariu faults), or when there are no fault-specific data available for the fault to enable an estimation of its fault-specific recurrence interval (i.e. Recurrence Interval Class is assigned based only on subjective comparisons with other better studied faults) (e.g. Otaki Forks, Gibbs, and SE Reikorangi faults).

Table 6 **Examples, based on the MfE Interim Guidelines, of Resource Consent Category for both developed and/or already subdivided sites, and greenfield sites along the Ohariu fault and Northern Ohariu fault accounting for various combinations of Building Importance Category, and Fault Complexity.**

OHARIU FAULT and NORTHERN OHARIU FAULT (based on Fault Recurrence Interval Class II, >2000 to ≤3500 years)					
Developed and/or Already Subdivided Sites					
Building Importance Category	**1**	**2a**	**2b**	**3**	**4**
Fault Complexity	**Resource Consent Category**				
Well Defined	Permitted	Permitted*	*Non-Complying*	*Non-Complying*	Prohibited
Distributed, & Uncertain - constrained	Permitted	Permitted	*Discretionary*	*Non-Complying*	Non-Complying
Uncertain - poorly constrained	Permitted	Permitted	*Discretionary*	*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:

* Indicates that the Resource Consent Category is permitted, but could be controlled or discretionary given that the fault location is well defined.

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. See Table 9 (Recommendations Section) for an example of alternative Resource Consent Category classifications for the Ohariu and Northern Ohariu faults.

4.2 Northern Ohariu fault

The Northern Ohariu fault is also one of the major earthquake-generating faults in the Wellington region. It is probably the northern continuation of the Ohariu fault. The Northern Ohariu fault extends approximately 60 km northwards from near Otaki to just south of Palmerston North (e.g. Van Dissen *et al*. 1999, Begg & Johnston 2000, Palmer & Van Dissen 2002). Studies along the Northern Ohariu fault (e.g. Van Dissen *et al*. 1999, Palmer & Van Dissen 2002) have determined that the fault has a right-lateral slip rate of approximately 1-3 mm/yr, and an average recurrence interval of surface rupture earthquakes of 1000 years to several thousand years. Both slip rate and recurrence interval appear similar to that of the Ohariu fault. The Northern Ohariu fault most recently ruptured the ground surface between several hundred years ago and about 1000 years ago, and is capable of generating earthquakes in the order of magnitude 7.5. Individual surface rupture earthquakes along the fault are expected to generate 3-4 metres of right-lateral displacement at the ground surface, and a lesser and variable amount of vertical displacement.

Recurrence Interval Class

The Northern Ohariu fault's recurrence interval of 1000 to several thousand years spans several Recurrence Interval Class boundaries defined in the MfE Interim Guidelines (Kerr *et al*. 2003). Based on the approximate mean of the fault's recurrence interval range, and its apparent similarities with the Ohariu fault, the Northern Ohariu fault is placed in Recurrence Interval Class II, >2000 years to ≤3500 years (Table 5, see also Van Dissen *et al*. 2003a).

Fault Complexity

Parts of the Northern Ohariu fault fall into the *well defined*, *distributed*, *uncertain - constrained*, and *uncertain - poorly constrained* fault complexity classes (Figure 5). In the north, on the edge of the Kapiti Coast District near Waitohu Quarry, several *well defined*, semi-parallel faults traces are recognised. The area between these traces may be subject to deformation and is mapped as *uncertain - constrained*. Immediately south across Waitohu Stream, the fault is *well defined* across a terrace surface but further south towards Ringawahiti Road, fault features are more difficult to recognise with certainty both on the ground and using aerial photography. Modification of the land surface during subdivision development has degraded fault features in this area. In this area, the fault is mapped as *uncertain - constrained* with portions mapped as *well defined* were possible. In the vicinity of the Otaki River, no features are preserved across the youngest river terraces and the fault is mapped as *uncertain - constrained* based on the locations of the well defined fault traces either side of the river. To the southwest, the fault is *well defined* just west of Harper Road and Old Hautere Road. After crossing Old Hautere Road, the faults becomes *distributed* as it nears State Highway One at Te Horo, although, within this zone, *well defined* parts are recognised. No fault features are recognised to the southwest, as the sediments become younger (young alluvium, dune sand, and swamp deposits) and the fault is mapped as *uncertain - constrained* for several hundred metres and then as *uncertain - poorly constrained*.

The Northern Ohariu fault passes through areas of semi-rural and rural development. South and east of Otaki, houses have been built on or in close proximity to the fault.

Proposed Resource Consent Categories

Table 6 shows examples of Resource Consent Categories for both developed and/or already subdivided sites, and greenfield sites along the Northern Ohariu fault accounting for various combinations of Building Importance Category, and Fault Complexity.

4.3 Gibbs fault

The activity and location of the Gibbs fault is less well constrained than either the Ohariu fault or the Northern Ohariu fault. The fault probably branches from the Ohariu fault at MacKays Crossing and extends 30 km north-northeastwards to within 3-4 km of, and possibly joining with, the Otaki Forks fault near Otaki Forks. Studies on the Gibbs fault (e.g. Van Dissen *et al*. 1998) have speculated that the fault has a right-lateral slip rate less than that of the Ohariu fault and Northern Ohariu fault (i.e. less than about 1-2 mm/yr). No information on average recurrence interval or the timing of the last rupture is available. The Gibbs fault is probably capable of generating earthquakes in the order of magnitude 7.

Recurrence Interval Class

The topographic expression of the Gibbs fault is less distinct than that of the Ohariu fault and the Northern Ohariu fault. This suggests that it has a longer recurrence interval of faulting than these two faults. Based on this, the Gibbs fault is placed in Recurrence Interval Class III, >3500 years to ≤5000 years (Table 5, see also Van Dissen *et al*. 2003a).

Fault Complexity

Few distinct fault features are preserved along the Gibbs fault, and it is mapped as *uncertain - poorly constrained* for most of its length (Figure 6). In these areas, its location is marked by saddles and a few crush zones. Near the Waikanae River, a *well defined* trace is mapped in the hills above Reikorangi Road. The trace and detailed mapping to the southwest helps constrain the location of the fault here. To the northeast, the location of the fault is *uncertain - constrained* to Kapakapanui Stream valley where a short *well defined* trace is preserved. Further to the north, aligned saddles allow the fault to be mapped as *uncertain - constrained*, except for a short length just northeast of Kapakapanui Stream where fault features are lacking and the fault's position cannot be constrained. *Well defined* fault traces are present in the Waikanae River to the northeast near the Mangaone Walkway. The fault trends east beyond this point in the Pukehinau Stream valley and its location is *uncertain - constrained* based on the presence of aligned saddles and offset spurs. To the east, the fault's location cannot be constrained due to a lack of fault features.

For the most part, the Gibbs fault is mapped as uncertain – poorly unconstrained. Where the fault is below the 100 m contour, it has been mapped as *well defined* or *uncertain - constrained*. The Gibbs fault passes mostly through rural areas and hill country. At Waikanae, it crosses river flats which may be subject to future development.

Proposed Resource Consent Categories

Table 7 presents examples of Resource Consent Categories for both developed and/or already subdivided sites, and greenfield sites along the Gibbs fault accounting for various combinations of Building Importance Category, and Fault Complexity.

Table 7 **Examples, based on the MfE Interim Guidelines, of Resource Consent Category for both developed and/or already subdivided sites, and greenfield sites along the Gibbs fault and Otaki Forks fault accounting for various combinations of Building Importance Category, and Fault Complexity.**

GIBBS FAULT and OTAKI FORKS FAULT (based on Fault Recurrence Interval Class III, >3500 to ≤5000 years)					
Developed and/or Already Subdivided Sites					
Building Importance Category	**1**	**2a**	**2b**	**3**	**4**
Fault Complexity	**Resource Consent Category**				
Well Defined	Permitted	Permitted*	Permitted*	*Non-Complying*	Non-Complying
Distributed, & Uncertain - constrained	Permitted	Permitted	Permitted	*Discretionary*	Non-Complying
Uncertain - poorly constrained	Permitted	Permitted	Permitted	*Discretionary*	Non-Complying
Greenfield Sites					
Building Importance Category	**1**	**2a**	**2b**	**3**	**4**
Fault Complexity	**Resource Consent Category**				
Well Defined	Permitted	Permitted*	*Non-Complying*	*Non-Complying*	Non-Complying
Distributed, & Uncertain - constrained	Permitted	Permitted	*Discretionary*	*Discretionary*	Non-Complying
Uncertain - poorly constrained	Permitted	Permitted	*Discretionary*	*Discretionary*	Non-Complying

Notes:
* Indicates that the Resource Consent Category is permitted, but could be controlled or discretionary given that the fault location is well defined.
Italics: The use of italics indicates that the Resource Consent Category – activity status of these categories is more flexible. For example, where *discretionary* is indicated, *controlled* may be considered more suitable by Council, or vice versa.

4.4 Otaki Forks fault

The Otaki Forks fault passes through the Kapiti Coast District in the hill country to the east some 10-15 km from the developed coastal plain. Initially considered to be part of a larger fault system (Moonshine-Otaki-Mangahao) branching from the Ohariu fault near Johnsonville (Van Dissen *et al*. 1988), it is now considered to be associated with the Akatarawa fault and ultimately the Wellington fault (Begg & Van Dissen 2000). Mapping of the Otaki Forks fault has yet to yield details on slip rate, and timing and size of recent rupture displacements. Based on comparisons with other active faults in the Wellington region, it appears reasonable to suggest that the Otaki Forks fault is capable of generating metre-scale single event surface rupture displacements, and earthquakes in the order of magnitude 7 or greater.

Recurrence Interval Class

There are no fault-specific data that constrain the recurrence interval of the Otaki Forks fault. However, the topographic expression of the Otaki Forks fault is less distinct than that of the Ohariu fault, and the slip rate and recurrence interval of the Akatarawa fault, which joins with and becomes the Otaki Forks fault, appears to be no faster than the Ohariu fault. Based on these observations, the Otaki Forks fault is placed in Recurrence Interval Class III, >3500 years to ≤5000 years (Table 5).

Fault Complexity

The Otaki Forks fault is mapped as *uncertain - poorly constrained* over most of its length (Figure 7). Its location is largely denoted by saddles, a few crush zones, and offset drainages. Near the Otaki River, two *well defined* fault traces are mapped crossing terraces behind Parawai Lodge. These traces help to constrain the fault's location to the southwest and northeast. A possible fault trace has been seen on aerial photos near the Plateau in Arapito Creek and is used to constrain the fault's location in this vicinity.

Proposed Resource Consent Categories

Table 7 presents examples of Resource Consent Categories for both developed and/or already subdivided sites, and greenfield sites along the Otaki Forks fault accounting for various combinations of Building Importance Category, and Fault Complexity.

4.5 Southeast Reikorangi fault

The Southeast Reikorangi fault extends for 20 km in the hills east of the Kapiti Coast. It probably branches from the Gibbs fault in Mangakotukutuku Valley, swings east-northeast then north-northeast to rejoin the Gibbs fault in the upper Waikanae River. Of the known active faults in the Kapiti Coast District, the Southeast Reikorangi fault is the one that we know the least about.

Recurrence Interval Class

Few fault activity data have been collected on the Southeast Reikorangi fault. However, based on the fault's subdued topographic expression, it appears to be the least active of the five known active faults in the district. Consequently, we place the Southeast Reikorangi fault into Recurrence Interval Class IV, >5000 years to ≤10,000 years, which implies a lower rate of activity compared to the other active faults in the district (see Table 5).

Fault Complexity

The Southeast Reikorangi fault is mapped as *uncertain - poorly constrained* over almost all of its length (Figure 8). In these areas its location is marked by saddles and offset drainages. Only in the south where it branches from the Gibbs fault in Mangakotutuku Stream valley are any distinct features mapped. Here, a distinct scarp is visible offsetting slopes to the northeast. All of the fault is above the 100 m contour.

Proposed Resource Consent Categories

Table 8 presents examples of Resource Consent Categories for both developed and/or already subdivided sites, and greenfield sites along the Southeast Reikorangi fault accounting for various combinations of Building Importance Category, and Fault Complexity.

Table 8 **Examples, based on the MfE Interim Guidelines, of Resource Consent Category for both developed and/or already subdivided sites, and greenfield sites along the Southeast Reikorangi fault accounting for various combinations of Building Importance Category, and Fault Complexity.**

SOUTHEAST REIKORANGI FAULT (based on Recurrence Interval Class IV, >5000 to ≤10,000 years)					
Developed and/or Already Subdivided Sites					
Building Importance Category	**1**	**2a**	**2b**	**3**	**4**
Fault Complexity	**Resource Consent Category**				
Well Defined	Permitted	Permitted*	Permitted*	Permitted*	Non-Complying
Distributed, & Uncertain - constrained	Permitted	Permitted	Permitted	Permitted	Non-Complying
Uncertain - poorly constrained	Permitted	Permitted	Permitted	Permitted	Non-Complying
Greenfield Sites					
Building Importance Category	**1**	**2a**	**2b**	**3**	**4**
Fault Complexity	**Resource Consent Category**				
Well Defined	Permitted	Permitted*	Permitted*	*Non-Complying*	Non-Complying
Distributed, & Uncertain - constrained	Permitted	Permitted	Permitted	*Discretionary*	Non-Complying
Uncertain - poorly constrained	Permitted	Permitted	Permitted	*Discretionary*	Non-Complying

Notes:
* Indicates that the Resource Consent Category is permitted, but could be controlled or discretionary given that the fault location is well defined.
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.

4.6 Other faults

In the Horowhenua, near Levin and further north, some active faults at depth are expressed as gentle broad-scale warps/folds of the ground surface (e.g. Levin anticline, Shannon anticline, Himatangi anticline). The age of the warped surfaces are at least 70,000 – 128,000 years old. Most of the sediments forming the coastal plain of the Kapiti Coast are significantly younger (some less than 28,000 years old with the majority less than 6500 years old) and can not be used to measure such gentle deformation. The few remnants of older sediments that are preserved are too small to provide any evidence of similar buried faults. Also, broad-scale warping/folding of the ground surface, even if the result of earthquake rupture, typically does not represent a life-safety hazard to buildings. As such, active folds have not been mapped in the Kapiti Coast District as part of this earthquake fault trace survey.

Correlation of subsurface units in the numerous drill holes logged on the Kapiti Coast indicate significant changes in depth of both basement and near-surface units across relatively short distances (Tony Edwards, Stratigraphic Solutions Ltd, pers comm.). This suggests the presence of faults beneath the coastal plain. In general, these faults appear to have a low level of activity and may not have moved in the last 50,000 years. Accurately locating the position of the faults over any distance and confidently determining the recurrence interval can not be done without further subsurface investigation.

Ridge rents are uphill-facing fault scarps that extend parallel to ridge crests. They are typically thought to result from shaking-induced gravity collapse of ridge crests. A number of ridge rents, and a diffuse area of faulting between the Ohariu fault and the Gibbs fault near the southern boundary of the district, have been identified (Figure 9). The locations of the features are included in the GIS database, and Fault Avoidance Zones have been defined around them. A Recurrence Interval Class is difficult to ascribe to these features, but we have assigned them based on that of the nearest most active fault. The vast majority of these features lie above the 100 m contour.

5 CONCLUSIONS & RECOMMENDATIONS

Conclusions

Fault Recurrence Interval Class, and Fault Avoidance Zones based on Fault Complexity have been defined for all known active faults in the Kapiti Coast District. These fault rupture hazard parameters, when brought together with Building Importance Category enable a risk-based approach to be taken when making planning decisions about development of land on, or close to active faults. Through an understanding of the interrelationships between these key parameters it is possible to develop consistent, risk-based objectives, policies and methods to guide development of land that may be impacted by surface rupture faulting.

Recommendations

1) Get better constraints on Recurrence Interval Class:

Using the terminology and definitions put forward in the MfE Interim Guidelines, the confidence of Recurrence Interval Classification for all active faults in the Kapiti Coast is low. For the two most active faults in the district, the Ohariu and Northern Ohariu faults, this is because the range of uncertainty of the recurrence interval estimates for these faults spans a significant portion of three Recurrence Interval Classes. For both the Ohariu fault and the Northern Ohariu fault, the mean of the range of their respective recurrence interval estimates are used to define their Recurrence Interval Class. An alternative, and more conservative, approach would be to assign Recurrence Interval Class based on the minimum value of the fault's recurrence interval range, as opposed to the mean. In the cases of the Ohariu fault and Northern Ohariu fault this would result in both faults being placed in the more hazardous/restrictive Recurrence Interval Class I. Recurrence Interval Class for the other three active faults in the district is assigned, largely based on subjective comparison with the better studied Ohariu and Northern Ohariu faults.

Additional paleoearthquake studies on these faults could yield data that would better constrain their respective recurrence intervals. This may warrant a re-assessment of the fault's Recurrence Interval Class, compared to what is listed in Table 5, and a consequent re-classification of Resource Consent Categories along the fault. Regardless if new work leads to the re-classification of a fault's Recurrence Interval Class, better constrained recurrence interval data will allow Recurrence Interval Class to be assigned with more confidence. This would ensure that the Resource Consent Categories ascribed to the various Fault Avoidance Zones along the fault are the most appropriate.

Also, less as a recommendation, but more as a comment, it needs to be acknowledged that with future geological work in the Kapiti Coast area, new active faults may be discovered, and evidence may be uncovered to show that faults now regarded as not active, may, in fact, be active. In this regard, it is fitting to remember that the Northern Ohariu Fault was discovered less than ten years ago.

2) Reduce the width of some fault avoidance zones:

Some of the Fault Avoidance Zones defined in this study are quite wide, largely owing to uncertainty in the location of the fault. Detailed fault studies (e.g. trenching and other forms of subsurface investigation) could provide better constraints on the fault's location in some of these areas, and consequently the width of the Fault Avoidance Zones could be reduced. This would mean fewer properties would fall within Fault Avoidance Zones, and, consequently, fewer properties would need consideration by Council with regard to fault rupture hazard.

Additionally, with better constraints on fault location, and a possible reduction in width of a Fault Avoidance Zone, the zone may warrant reclassification, for example, from *uncertain - poorly constrained* to *uncertain - constrained*. Depending on Building Importance Category, a reclassification of Fault Complexity may also warrant a reclassification of Resource Consent Category.

Complimentary to this topic, is the need to acknowledge that not all fault location studies aimed at mitigating rupture hazard, need to be focused on locating the fault. For example, detailed geological studies at a site may prove that the site, and its immediate surrounds, have not been subjected to active fault rupture. Thus, the Recourse Consent Category of the site would warrant reclassification, even though the fault was not located.

It also needs to be acknowledged that there are some areas in the district (e.g. the *uncertain - poorly constrained* Fault Avoidance Zones defined around the Ohariu and Northern Ohariu faults where they are inferred to extend across the coastal plain southwest of State Highway 1, near Mary-Crest, and Hadfield Road Peka Peka) where expensive subsurface investigations (i.e. geophysical seismic surveys) may be the only methods available to better constrain the fault's location. The results of these surveys may still leave uncertainty as to the precise location of the fault, particularly with respect to the location of future surface rupture. In these areas, it may be more expedient to mitigate rupture hazard by appropriate assessment criteria (e.g. the degree to which the proposed building, structure or design work can accommodate/mitigate the effects of fault rupture), rather than by locating the fault.

3) *Reassign Resource Consent Categories for uncertain - poorly constrained Fault Avoidance Zones for greenfield sites on the Ohariu and Northern Ohariu faults, compared to examples based on the MfE Interim Guidelines*

Table 6 presents examples, based on the MfE Interim Guidelines, of relationships between Resource Consent Category, Building Importance Category, fault Recurrence Interval Class, and Fault Complexity for both previously developed sites, and greenfield sites along the Ohariu fault and Northern Ohariu fault. Early in the report, we outlined the need to subdivide the *uncertain* Fault Complexity term used in the MfE Interim Guidelines, into *uncertain - constrained*, and *uncertain - poorly constrained*. It is fair to say that, as envisioned by those who developed the MfE Interim Guidelines, the width of an *uncertain* Fault Avoidance Zone was not as wide as we have mapped many *uncertain - poorly constrained* Fault Avoidance Zones in the Kapiti Coast District. Thus, for the two most active faults in the district, the Ohariu and Northern Ohariu faults, the Resource Consent Categories listed under *uncertain - poorly constrained* Fault Complexity in Table 6 for greenfield sites are probably too restrictive for Building Importance Category 2a, and 2b structures. This is because there is, typically, an inverse relationship between the width of a Fault Avoidance Zone, and the level of rupture hazard within that zone (i.e. the wider the zone, the less likely it is that fault rupture will impact any specific locality within that zone). Accordingly, in the table that follows, Table 9, we present an alternative to Table 6 that Council may wish to consider adopting. This new table, Table 9, lists more permissive Resource Consent Categories for Building Importance Category 2a and 2b structures for greenfield sites in *uncertain - poorly constrained* Fault Avoidance Zones.

The Resource Consent Categories listed in Tables 7 & 8 for the other “less active” faults in the Kapiti Coast District are considered appropriate, as too are the Resource Consent Categories listed in Table 6 for previously developed sites. As such, we do not present alternatives to Tables 7 & 8, or the portion of Table 6 that deals with previously developed sites.

Table 9 **Alternative examples of Resource Consent Category for greenfield sites along the Ohariu fault and Northern Ohariu fault accounting for various combinations of Building Importance Category, and Fault Complexity. This table differs from Table 6 only in the Resource Consent Categories listed for Building Importance 2a, and 2b structures on greenfield sites within uncertain - poorly constrained Fault Complexity areas.**

OHARIU FAULT and NORTHERN OHARIU FAULT (based on Fault Recurrence Interval Class II, >2000 to ≤3500 years)					
Developed and/or Already Subdivided Sites					
Building Importance Category	**1**	**2a**	**2b**	**3**	**4**
Fault Complexity	**Resource Consent Category**				
Well Defined	Permitted	Permitted*	*Non-Complying*	*Non-Complying*	Prohibited
Distributed, & Uncertain - constrained	Permitted	Permitted	*Discretionary*	*Non-Complying*	Non-Complying
Uncertain - poorly constrained	Permitted	Permitted	*Discretionary*	*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	*Controlled*	*Discretionary*	*Non-Complying*	Non-Complying

Notes:
* Indicates that the Resource Consent Category is permitted, but could be controlled or discretionary given that the fault location is well defined.
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.

4) Formulation of planning policy and assessment criteria:

It is a complex task to determine the appropriate Resource Consent Categories for different scenarios/combinations of Recurrence Interval Class, Fault Complexity, and Building Importance Category. In this report, we present a number of tables that depict interrelationships of these parameters based on examples in the MfE Interim Guidelines.

An equally complex task is determining the elements of development that Council wishes to have discretion over, and determining appropriate assessment criteria. This task will no doubt involve consultation and input from a number of relevant parties. Of course, before any rules are developed in the District Plan that limit development of land on, or close to active faults, appropriate objectives and policies relating specifically to fault rupture hazard need to be developed.

Assessment criteria should be contained within District Plans to make clear the key matters that Council will consider when assessing resource consents. Matters may include:

- the risk to life, property and the environment posed by fault rupture hazard
- the likely frequency and size of displacement
- the type, scale and distribution of potential effects from surface rupture
- the combined effects of ground shaking and displacement caused by earthquakes
- the distance of the proposed structure from the fault itself
- the degree to which the building, structure or design work can avoid or mitigate the effects of fault rupture

The assessment criteria should either give evidence of the location for fault rupture hazard (or show that the fault is not within 20 metres of the proposed development), or if the fault's location remains uncertain, (i.e. Council has not located it and/or the developer does not wish to locate it) then the developer should be able to prove that the proposed building is resilient enough to withstand fault rupture.

5) Consistency of policy throughout region:

Natural hazards, including fault rupture hazard, do not stop at local authority boundaries. It is important to consider how the district plan will co-ordinate with other adjoining local authorities that share the same hazards, to ensure that hazard avoidance and/or mitigation issues can be suitably integrated across councils.

Greater Wellington (i.e. the regional council) would appear well placed to facilitate interactions with local authorities aimed at maintaining/ensuring consistency of policy throughout the region. A useful approach at the regional level would be for Greater Wellington to develop specific fault rupture hazard policy within the Natural Hazards section of the Regional Policy Statement.

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APPENDIX 1 – CD Contents

1: Report:

Earthquake Fault Trace Survey, Kapiti Coast District. PDF Format.

2: Figures:

Figure 1	Active faults of the Kapiti Coast District. TIFF format.
Figure 2a	Ohariu Fault, Mackays Crossing. TIFF format.
Figure 2b	Fault Avoidance Zones developed for the Ohariu fault at MacKays Crossing. TIFF format.
Figure 3	The Ohariu fault (southern end) showing Fault Avoidance Zones. TIFF format.
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Figure 9	Ridge rents and zone of diffuse area of faulting in the hills south of MacKays Crossing showing Fault Avoidance Zones. TIFF format.

3: GIS Data:

Point Fault Features – point.shp. Shapefile format. These are point features representing observed point fault features such as saddles, springs, crush zones, and faults observed in trenches. 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.

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.

Data Dictionary and MetaData.

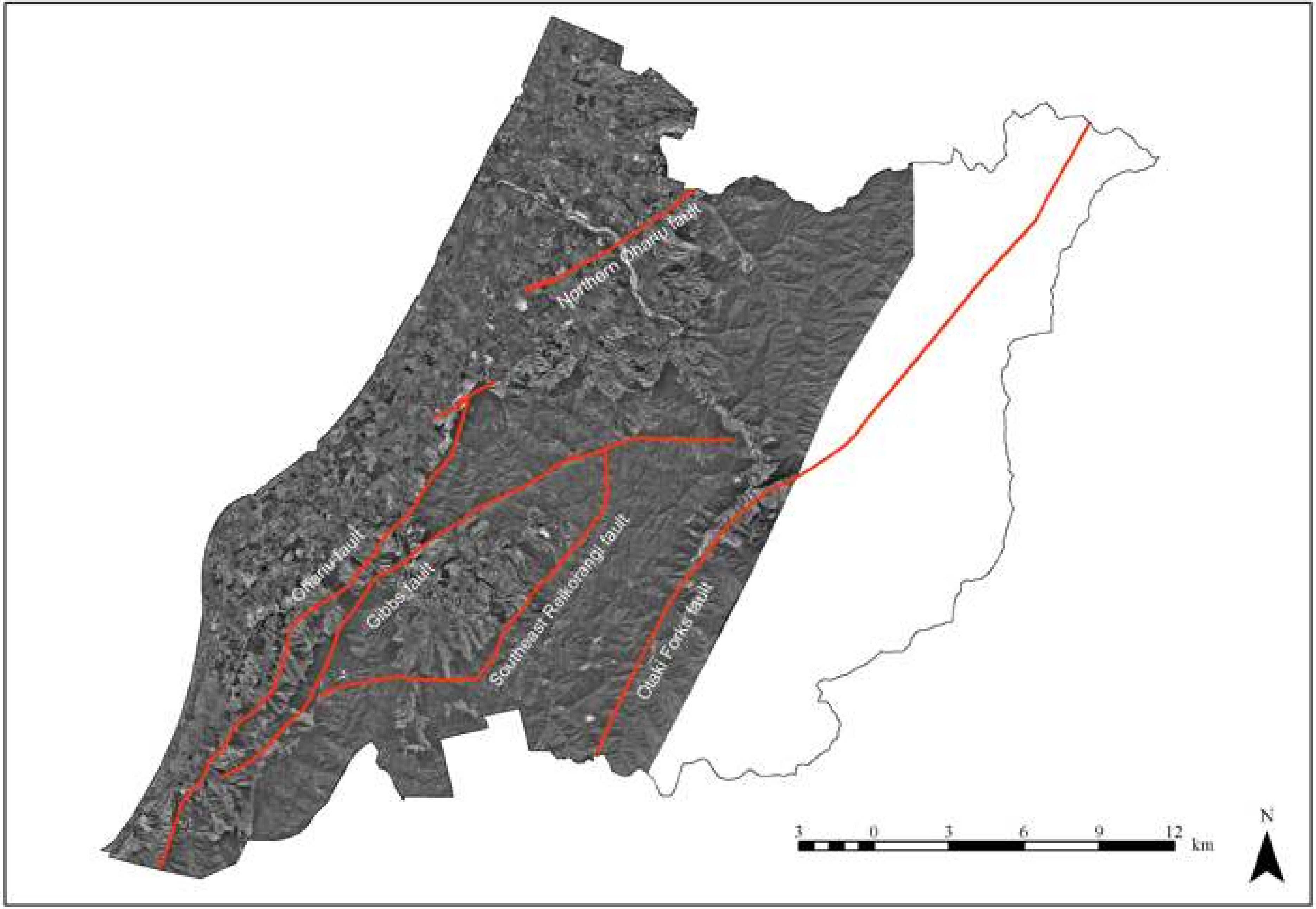


Figure 1. Active faults in the Kapiti Coast District.

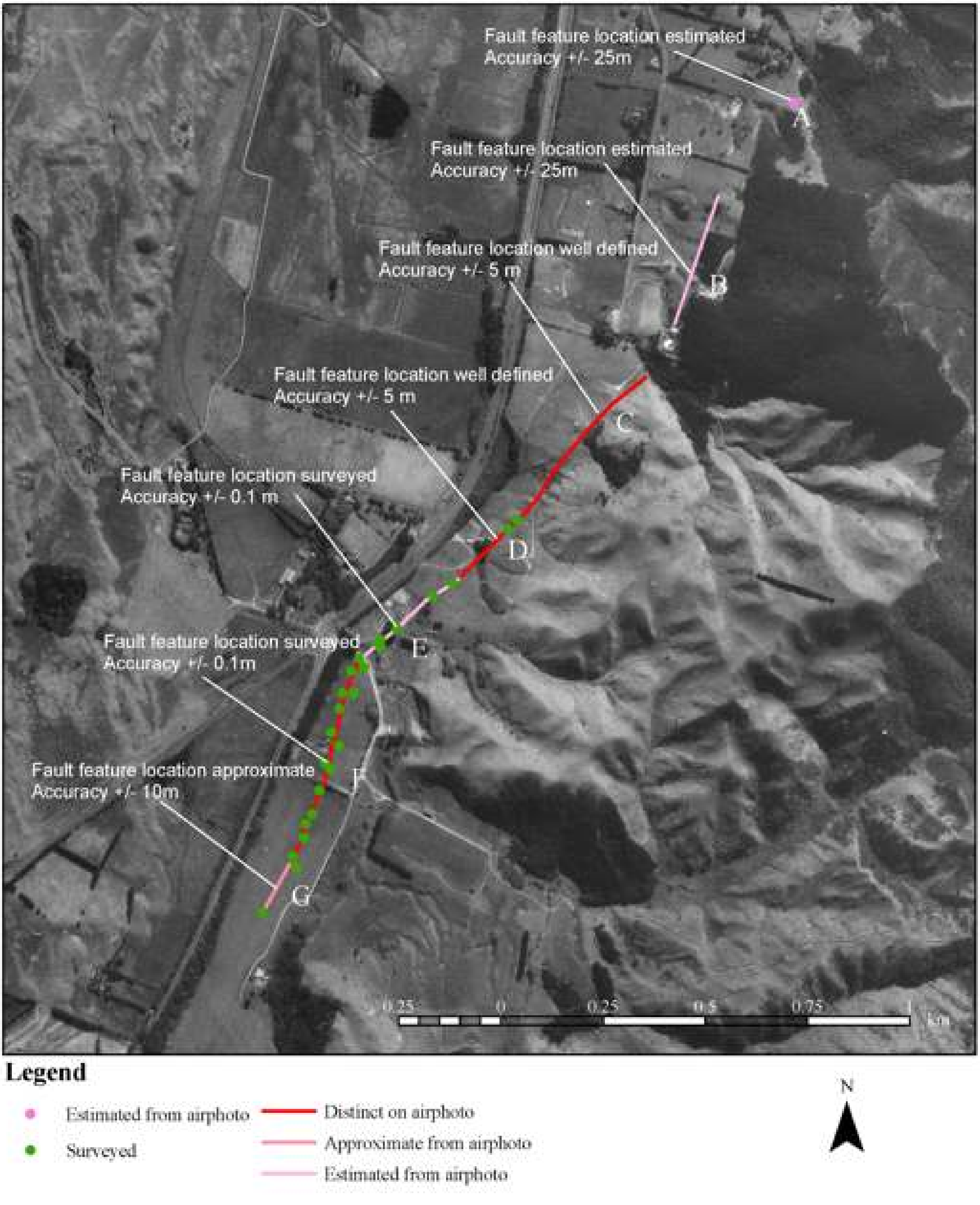


Figure 2a. Ohariu fault at MacKays Crossing showing mapped fault features and associated accuracy.

In the north a damaged spur (A) is located with an accuracy of +/- 25 m. Some 400 m to the south a series of aligned springs (B) are located with a similar accuracy. A well defined scarp (C) seen on air photos was captured with an accuracy of +/- 5 m. Surveying of the scarp at a number of locations (D,E,F) reduced this error. In one location (E), where the fault scarp has a very subtle expression, trenching and surveying allowed accurate location of the fault. To the south (G), where the fault has a subtle expression, the location could not be accurately captured from either the air photos or by surveying, and is recorded as approximate with an accuracy of +/- 10m.

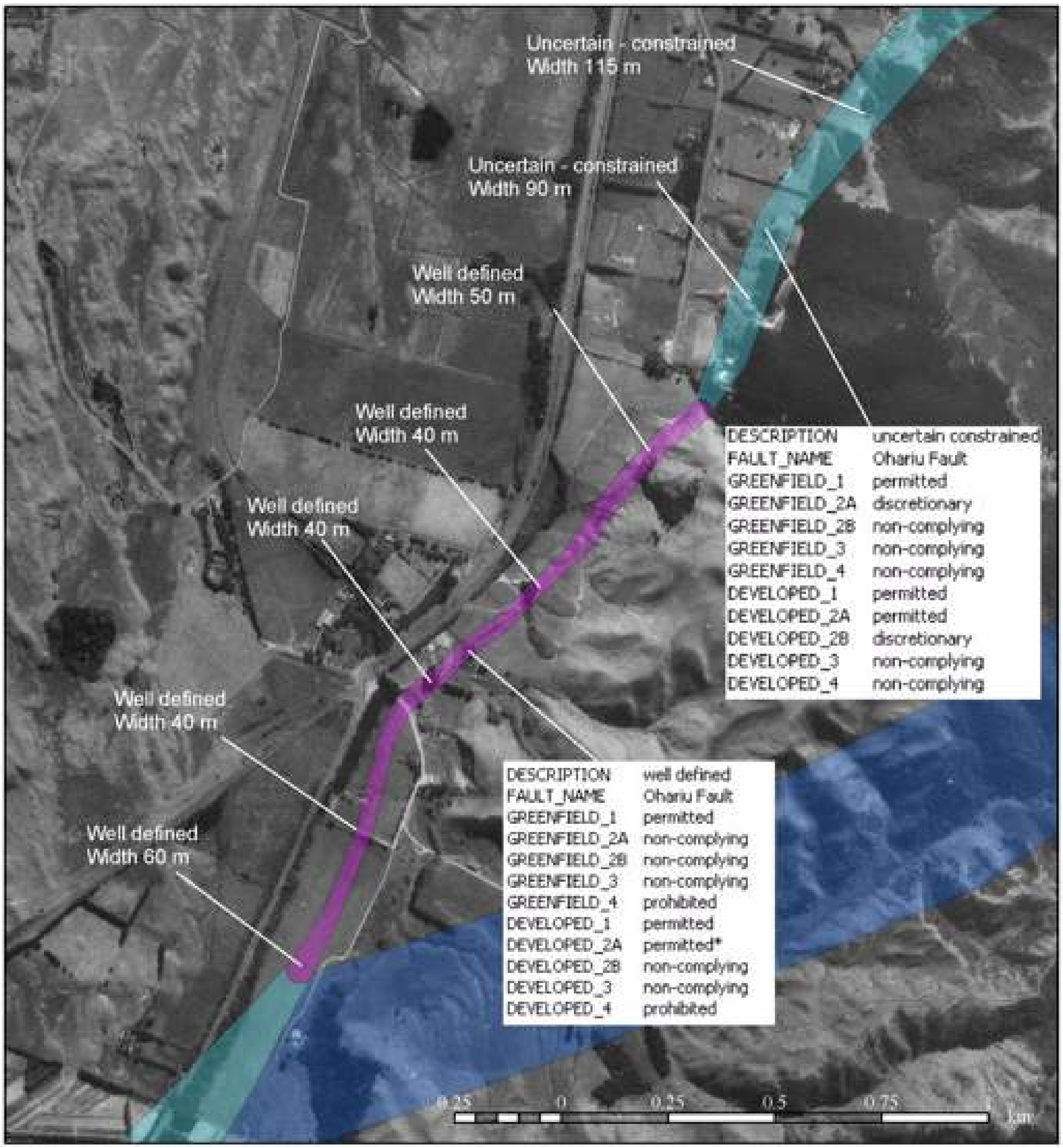
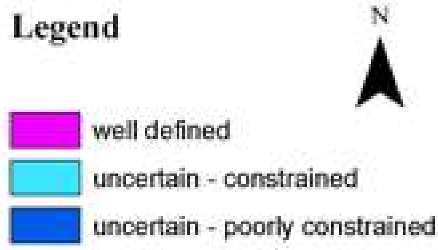


Figure 2b. Fault Avoidance Zones developed for the Ohariu fault at MacKays Crossing. The zones were defined on the basis of the accuracy of location and Fault Complexity (see Fig. 2a).



The Resource Consent Category suggested in the MfE Interim Guidelines associated with two of the zones based on the Building Importance Category (Table 1) and current site status (ie, 'greenfield' or 'developed') is shown in the text boxes on the figure.

The dark blue Fault Avoidance Zone is associated with the Gibbs fault. In this locality it is classified as 'uncertain - poorly constrained'.

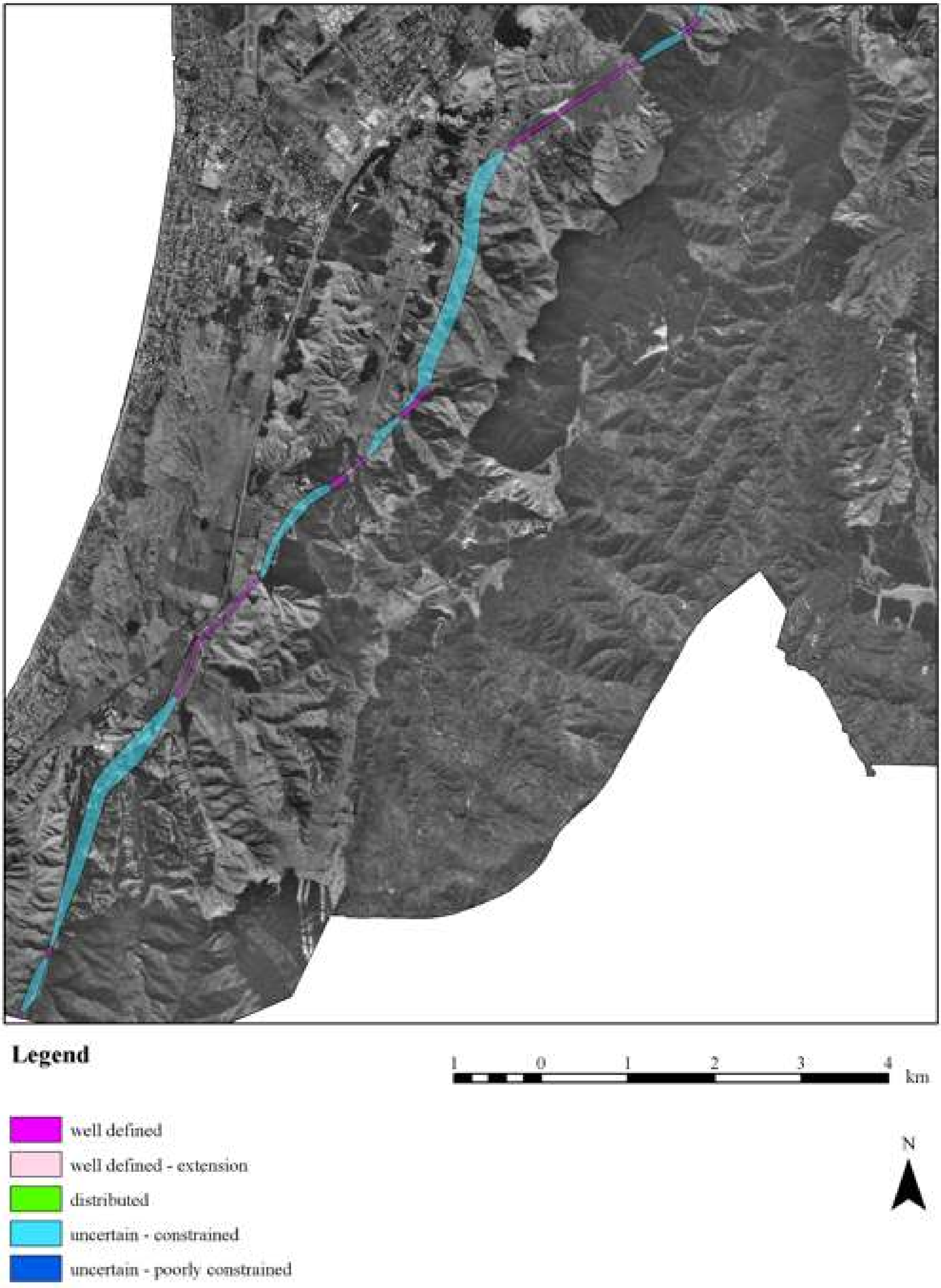


Figure 3. The Ohariu fault (southern end) showing Fault Avoidance Zones.

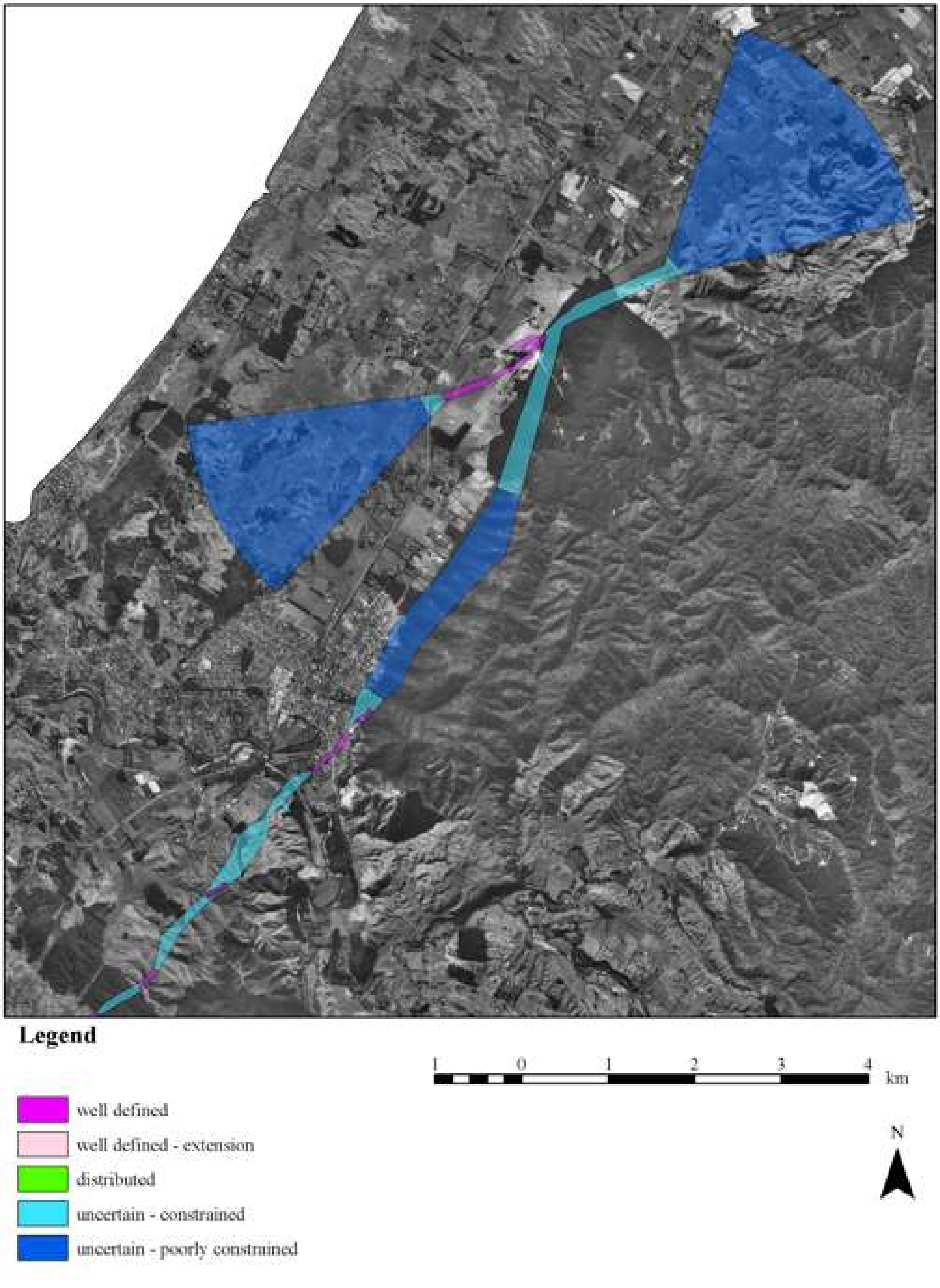


Figure 4. The Ohariu fault (northern end) showing Fault Avoidance Zones.

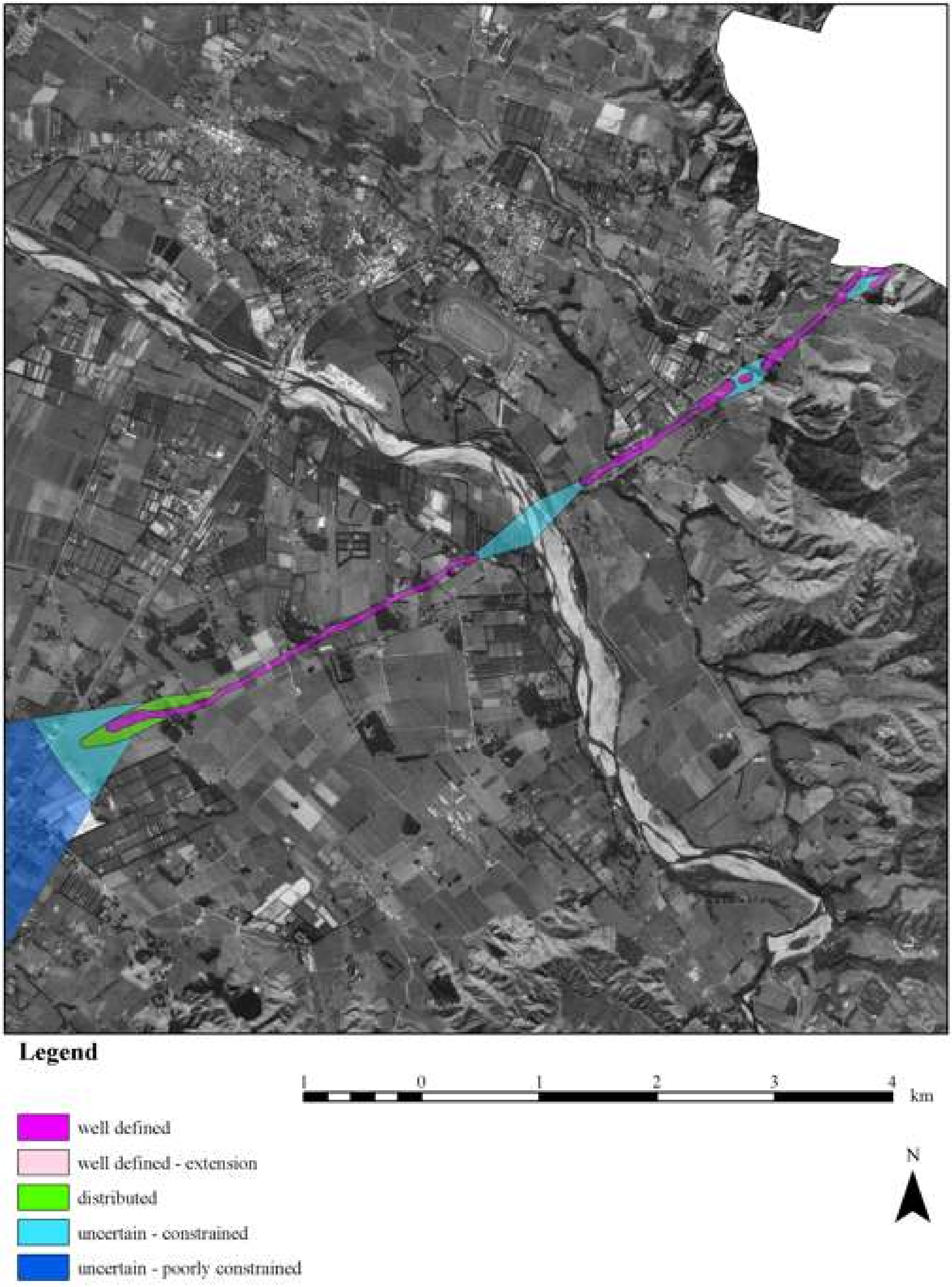


Figure 5. The Northern Ohariu fault showing Fault Avoidance Zones.

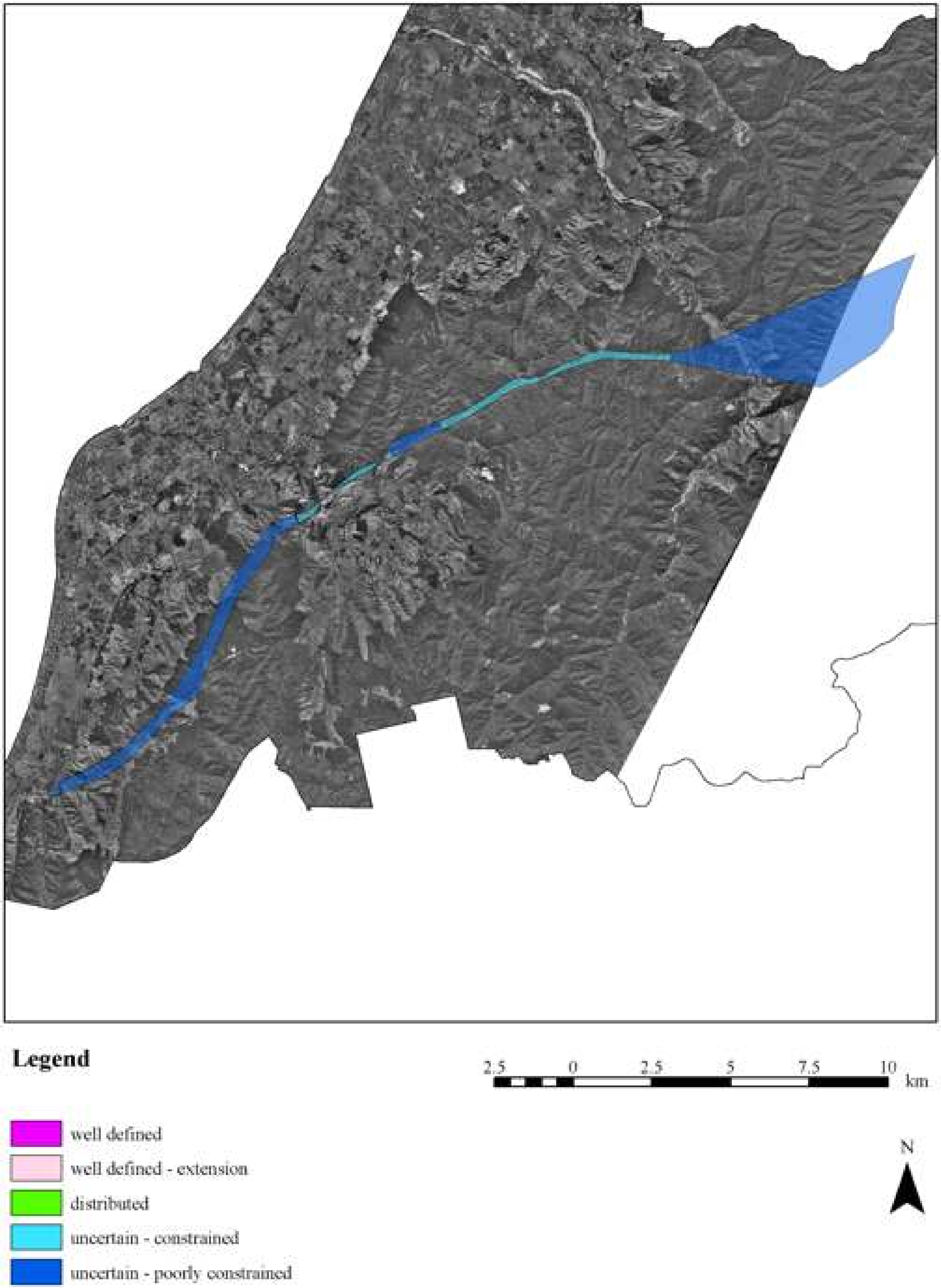


Figure 6. The Gibbs fault showing Fault Avoidance Zones.

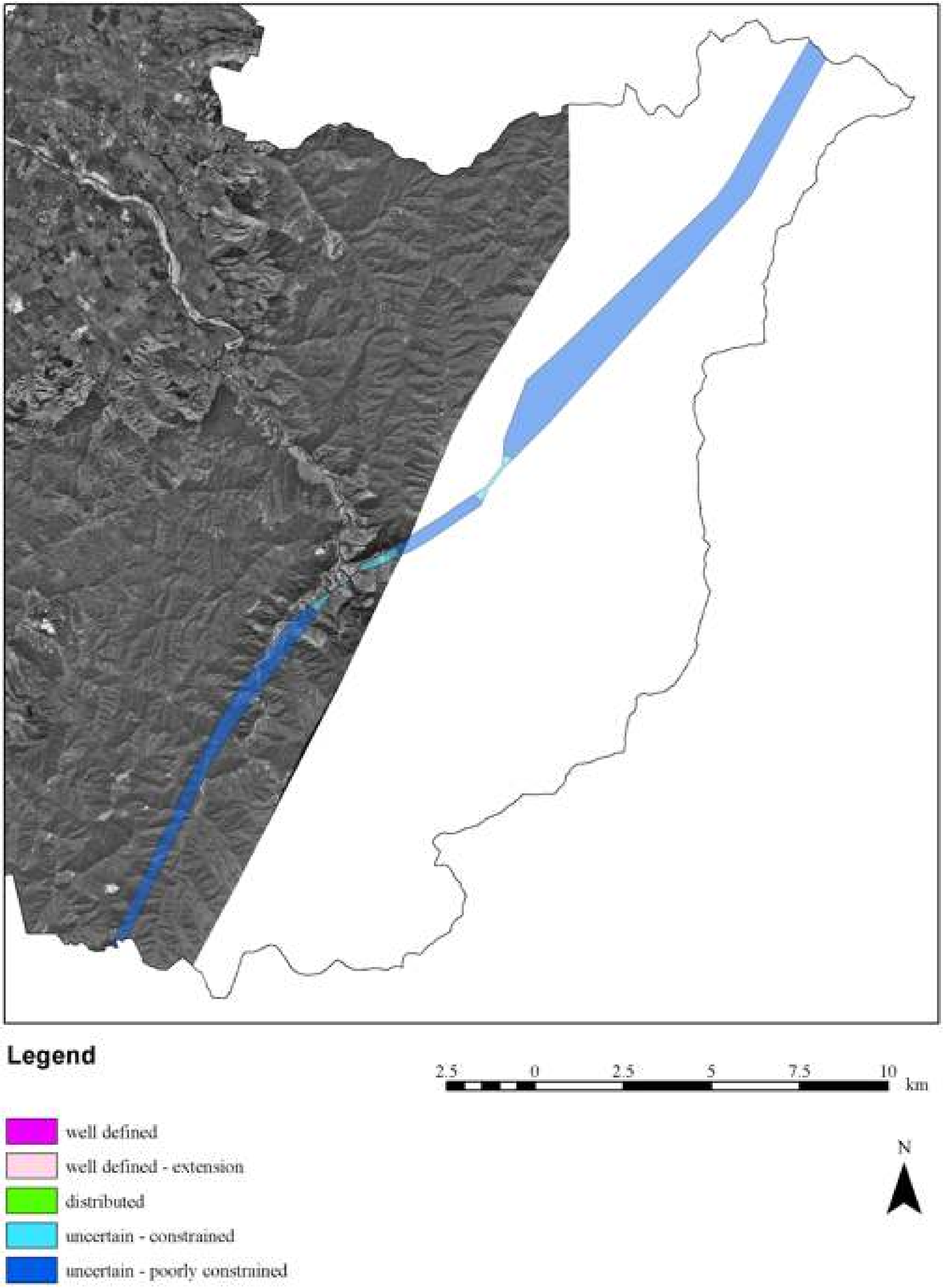


Figure 7. The Otaki Forks fault showing Fault Avoidance Zones.

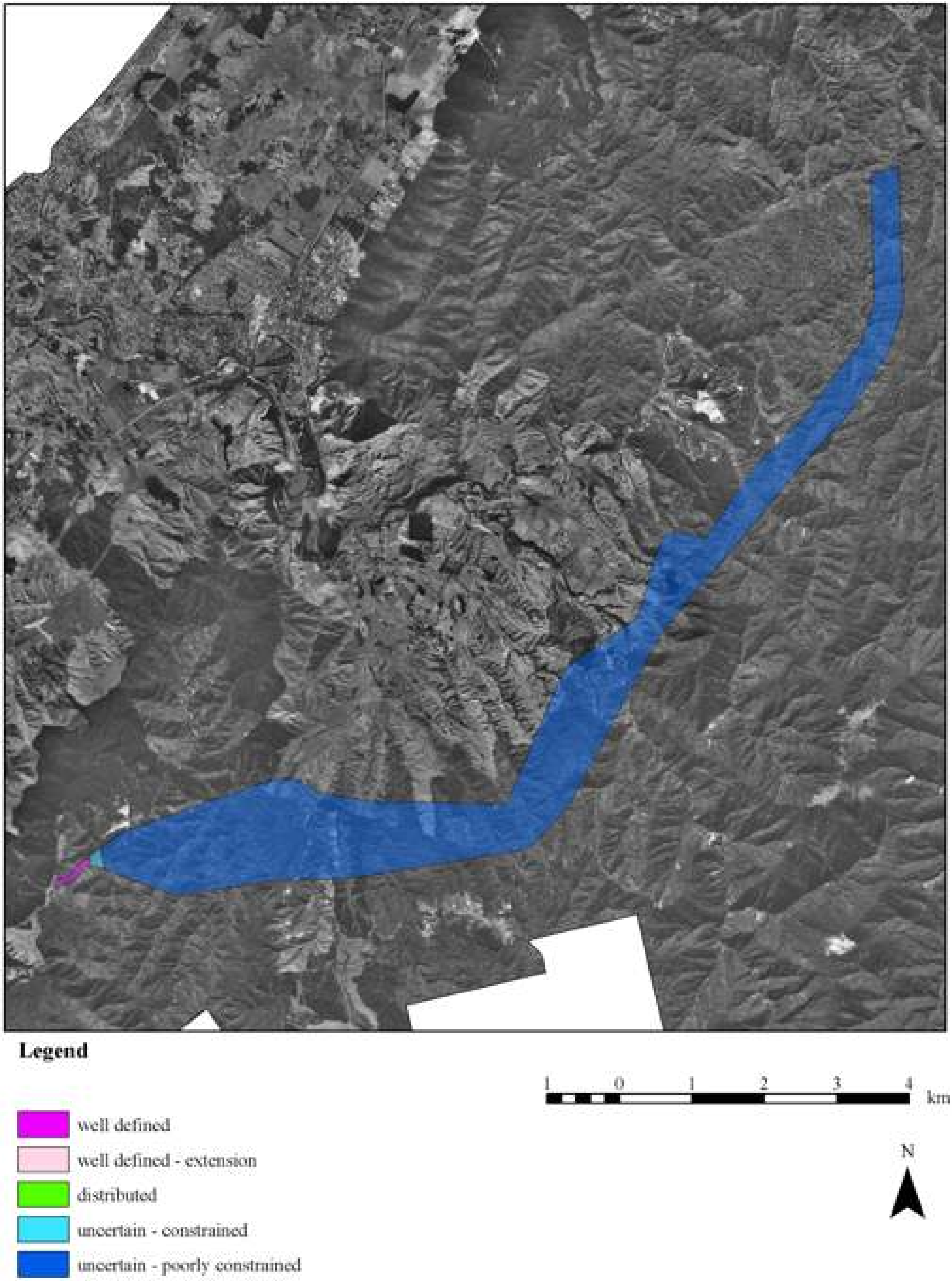


Figure 8. The Southeast Reikorangi fault showing the Fault Avoidance Zones developed.

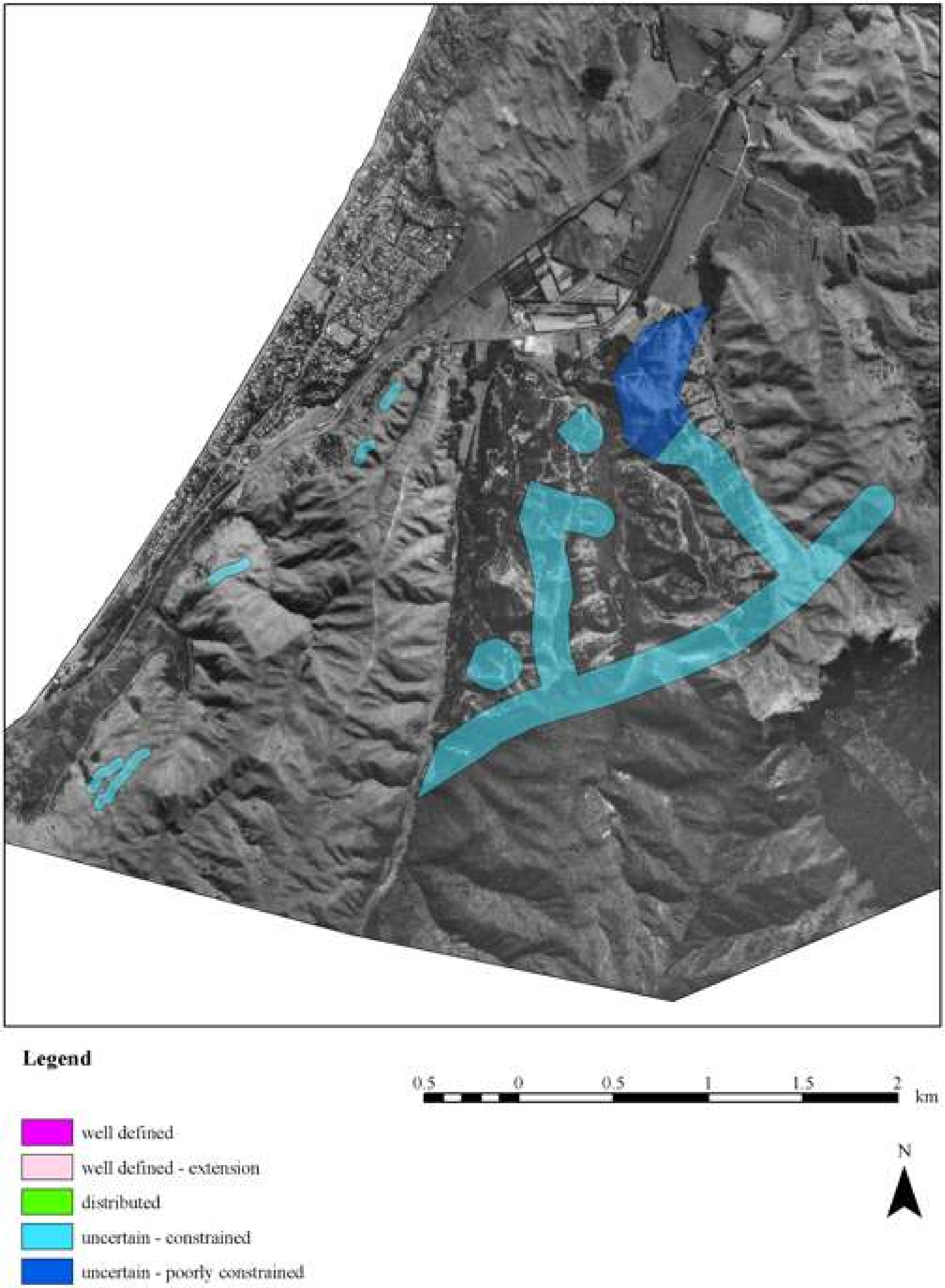


Figure 9. Ridge rents and zone of diffuse area of faulting in the hills south of MacKays Crossing showing Fault Avoidance Zones.

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