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Upper Hutt City Fault Trace Project

by R. Van Dissen, N. Litchfield, J. Begg

Client Report
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EXECUTIVE SUMMARY

The area administered by Upper Hutt City Council is traversed by five active faults: (from most active to least), the Wellington, Akatarawa, Otaki Forks, Moonshine, and Whitemans Valley faults. In recognition of the surface rupture hazard posed by these faults, Greater Wellington Regional Council and Upper Hutt City Council commissioned the Institute of Geological & Nuclear Sciences Ltd to complete an earthquake fault trace survey of Upper Hutt City.

The Ministry for the Environment (MfE), New Zealand, has recently issued guidelines on planning for development of land on, or near, active faults. 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 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 active faults in Upper Hutt City, we have adopted the principles and methodology advanced in the MfE guidelines.

In the MfE 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. Fault avoidance zones have been defined around all known active faults in Upper Hutt City 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: Wellington fault – Recurrence Interval Class I (≤2000 years); Akatarawa and Otaki Forks faults – Recurrence Interval Class III (>3500 to ≤5000 years); Moonshine fault – Recurrence Interval Class IV (>5000 to ≤10,000 years); Whitemans Valley fault – Recurrence Interval Class V (>10,000 to ≤20,000 years).

The risk from 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 guidelines) to characterise building type/importance with respect to 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 formulate appropriate risk-based planning measures to mitigate the adverse and potentially life threatening effects of fault rupture.

1.0 INTRODUCTION

New Zealand lies within the deforming boundary zone between the Australian and Pacific tectonic plates. The area administrated by Upper Hutt City Council lies within one of the more active parts of this boundary zone. Upper Hutt City is underlain at depth 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 Wellington fault, Akatarawa fault, Otaki Forks fault, Moonshine fault, and Whitemans Valley fault (Figure 1). Data collected from these faults indicate that they 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.

At a regional scale, the active faults in Upper Hutt City have been most recently mapped by Begg & Mazengarb (1996; 1:50,000 scale geological map) and Begg & Johnston (2000; 1:250,000 scale geological map); however, the scale of this mapping is not refined enough to permit its use in site-specific land use planning. Fault features along several of the active faults in Upper Hutt City have been studied in detail (e.g. Wellington fault – Berryman 1990, Van Dissen *et al*. 1992, Van Dissen & Berryman 1996; Akatarawa fault – Van Dissen *et al*. 1998, Begg & Van Dissen 2000, Van Dissen *et al*. 2001; Whitemans Valley fault – Begg & Van Dissen 1998a, 1998b), and have allowed earthquake hazard parameters (e.g. fault location, earthquake size and recurrence) for these faults to be defined, to a greater or lesser extent. Other faults (e.g. Otaki Forks fault and Moonshine fault) have been studied in much less detail.

The Ministry for the Environment, New Zealand, has recently published guidelines on planning for development of land on, or near, active faults[1, 2] (Kerr *et al*. 2003, see also King *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 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 surface rupture of the fault.

[1] The Ministry for the Environment's guidelines "Planning for Development of Land on or Close to Active Faults" is available on both the Ministry for the Environment and the Quality Planning websites.
[2] Throughout the remainder of this report, the Ministry for the Environment's guidelines will be referred to as the MfE guidelines.

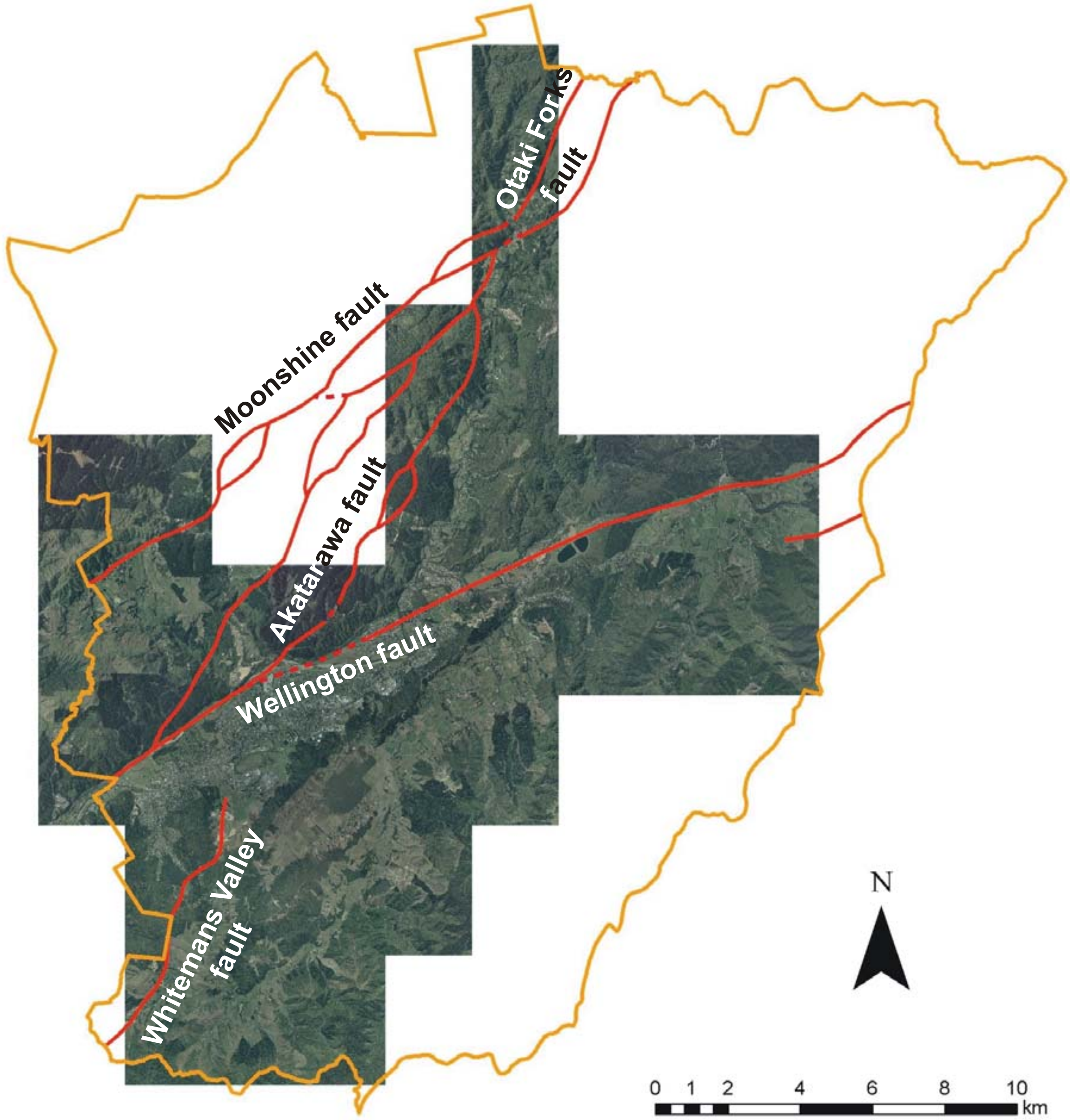

Figure 1 Active faults of Upper Hutt City

The MfE guidelines also advance a hierarchical relationship between fault 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 (i.e. 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 (i.e. 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 the 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; whereby, on a fault by fault basis, 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. We make some brief comment on how these two fault rupture hazard parameters, when combined with information on Building Importance Category (i.e. building type) and development status (i.e. previously developed, or "greenfield" site) can be used to formulate appropriate risk-based planning measures to mitigate the adverse and potentially life threatening effects of fault rupture. The report ends with a number of conclusions and recommendations.

The CD included with this report contains a copy of the report and tables (in PDF format) and figures (as TIFF images) together with the GIS data collated as part of this study in ESRI shapefile format (see Appendix 1 for details).

2.0 BACKGROUND, OBJECTIVE & SCOPE OF PROJECT

2.1 Background

Upper Hutt City is traversed by several active faults. While the ground shaking hazard posed by these faults cannot be avoided, damage or loss of life resulting from permanent displacement of the ground surface along the fault trace can be avoided by restricting or prohibiting development along the fault trace.

At present, the Wellington fault is the only fault included in the Upper Hutt District Plan and shown in planning maps. A standard 20 m buffer has been placed either side of the fault, regardless of the accuracy of its known location, to create a "fault band". Any new habitable building or structure to be erected within the fault band is a discretionary activity.

The Akatarawa, Otaki Forks, Moonshine, and Whitemans Valley faults are not included in the District Plan and there is, therefore, concern that District Plan rules do not provide an appropriate level of protection from fault rupture hazard.

This project aims to collate known fault location, complexity and recurrence interval data for Upper Hutt City at an appropriate level of detail for inclusion in the District Plan to enable robust planning measures to be put in place in keeping with the MfE guidelines.

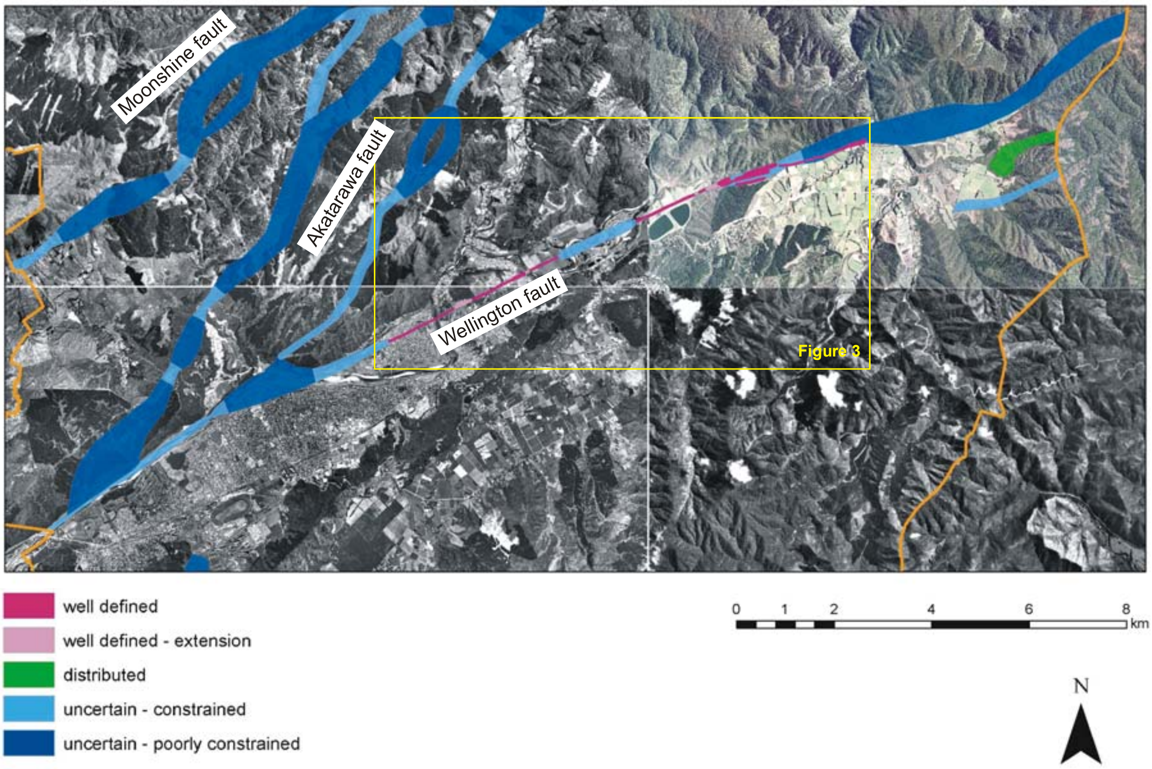

Figure 2. The Wellington fault showing Fault Avoidance Zones.

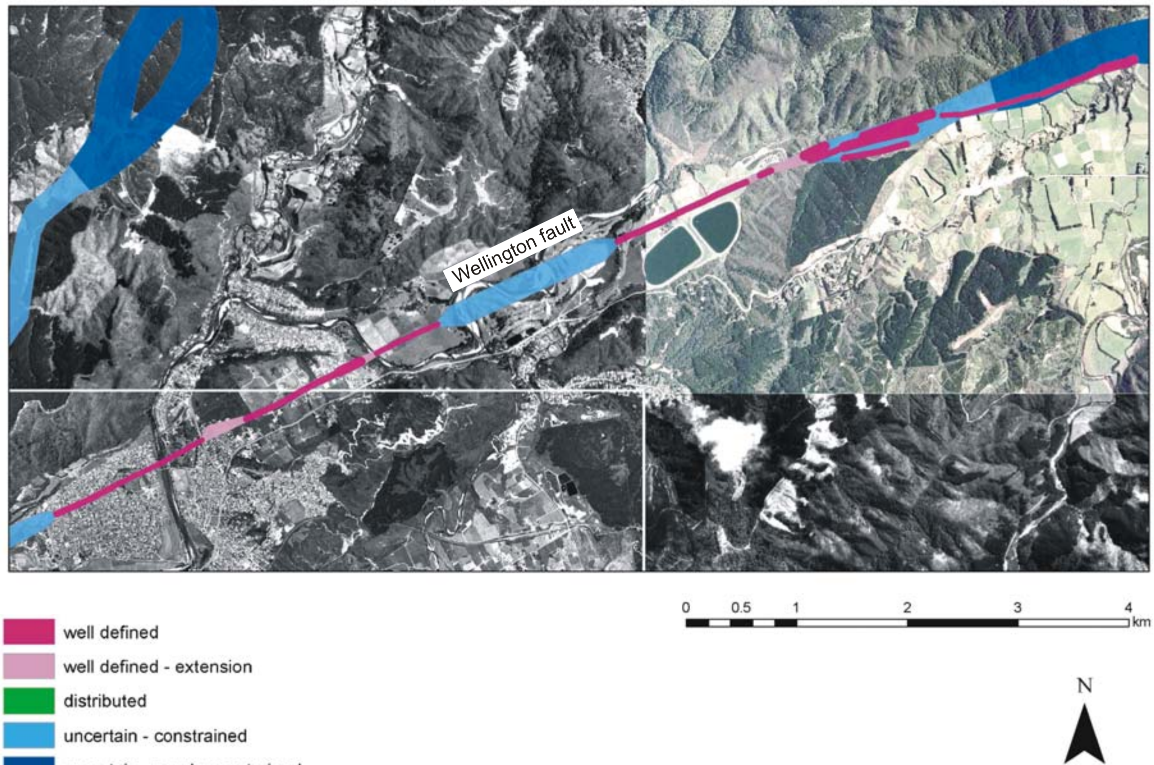

Figure 3. The Wellington fault (central) showing Fault Avoidance Zones.

2.2 Objective

The objective of this project is to provide robust and defensible data on the location, complexity and recurrence interval of active faults within Upper Hutt City that is as accurate as possible within the scope of the project.

2.3 Scope of Project

This study was undertaken on contract to Greater Wellington Regional Council and Upper Hutt City Council by the Institute of Geological & 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 MfE guidelines.

More specifically, the scope and key tasks of the project encompass the following:

1) identification of all known active fault traces in Upper Hutt City using relevant existing information, supplemented by aerial photography, LIDAR, and existing GPS data (where available).

2) mapping, as accurately as possible, all faults in Upper Hutt City, with priority given as follows:
   a. high priority (most attention given to accurately delineating fault location)
      - the length of the Wellington fault within Upper Hutt City (Silverstream bridge to Dobson Shelter)
      - Akatarawa fault at Hutt River (approximately R27:810-073 to R27:839-098)
      - Akatarawa fault at Cloustonville (approximately R26:875-181 to R26:890-200)
      - Otaki Forks fault at Cloustonville (approximately R26:889-202 to R26:894-215 and R26:890-200 to R26:896-203)
      - Moonshine fault at Cloustonville (approximately R26:879-194 to R26:889-202)
   b. moderate priority
      - Akatarawa fault between Hutt River and Whakatikei River (approximately R27:784-055 to R26:811-100)
      - Akatarawa fault at Karapoti Road (approximately R26:860-140 to R26:865-146)
      - Moonshine fault along Moonshine Road and Bulls Run Road (approximately R26:770-104 to R26:795-122 and R26:788-116 to R26:799-121)
      - Moonshine fault along Akatarawa River West (approximately R26:833-156 to R26:857-180)
   c. lower priority (least attention given to accurately delineating fault location)
      - the remainder of the Akatarawa, Otaki Forks and Moonshine faults (i.e. those

lengths of fault not described above)
- Whitemans Valley fault.

3) definition of Fault Avoidance Zones for the length of each fault within Upper Hutt City based on accuracy of location and surface rupture complexity, and classification as either *well defined*, *distributed*, *uncertain – constrained* or *uncertain – poorly constrained.*

4) description of the recurrence interval (i.e characterisation of Recurrence Interval Class, and associated uncertainty) of surface rupture faulting for each fault.

The results of this work are this report, and a GIS database of fault features (as points and lines with associated attributes) and Fault Avoidance Zones (as areas with associated attributes). The Fault Avoidance Zones are linked to tables pertaining to fault Recurrence Interval Class, and Building Importance Category. Maps derived from the GIS database are included in this report (Figures 2 - 6). These maps are provided to illustrate the methodology used and level of detail obtained in some areas; however, potential users are referred to the GIS data on the enclosed CD for complete coverage of the district. Any user of the GIS data should note the scale of capture and accuracy of the data and avoid using it inappropriately.

3.0 STUDY METHODOLOGY

The methodology outlined in the MfE guidelines was used in this project. The main steps in the process were:

1) identifying all known active fault traces, and related features, in Upper Hutt City
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 can then be used to formulate appropriate risk-based planning measures to mitigate the adverse effects of fault rupture.

3.1 Identification of Active Fault Traces

Details of known active fault features within Upper Hutt City were obtained from a number of sources, including: published papers and maps, unpublished GNS Science and Client reports, drill hole data, the Upper Hutt District Plan, and the authors' first-hand knowledge of the geology and active faulting in the district. Particularly relevant studies for this project include the paleoearthquake trenching investigations along the Wellington, Akatarawa, and Whitemans Valley faults (see reference list).

The above 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 Wellington fault (approximate scale of 1:4000).

Upper Hutt City supplied two sets of orthophotography for the purposes of this work. The urban area is covered by colour photography, flown in 2004 at 1:500 scale, with a pixel resolution of 0.125 m. The rural area, and the urban area too, is partly covered by a more extensive set of colour photography flown some years earlier at 1:5000 scale, which has a pixel size of 0.8 m. Figure 1 shows the coverage of the supplied 1:5000 scale photos. Outside this coverage, we had to use lower resolution orthophotography available through the LINZ web site which has a coarser pixel size (2.5 m) and reduced positional accuracy (±12.5 m). Also supplied for this study was LIDAR coverage of the Whitemans Valley fault areas with a resolution and accuracy comparable to the 1:500 scale orthophotography.

3.2 Capture of Fault Feature Coordinates

Previous studies of active faulting in Upper Hutt City 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, have 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. 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 Wellington fault, Akatarawa fault, and Whitemans Valley fault is very sharp and distinct (less than about 5-10 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 fault trace may be a broad or ill defined topographic feature (e.g. topographic saddle or fault-guided stream), expressed over a width of tens of metres or more. Without additional 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 to 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, for example in trenches that expose the fault plane. GPS or traditional survey techniques can be used to locate and capture the positions of these features to centimetre-scale accuracy. More typically for this project, 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 orthophotography. Where the fault feature is sharp and distinct, and could also be clearly seen on the Upper Hutt City 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 orthophotography, the accuracy of the captured location of the features is considered to be either *approximate* (± 10 m) or *estimated* (± 25 m to ± 250 m) depending on our subjective assessment as to our ability to constrain the location of the feature on the orthophotography and how precisely the feature constrains the location of the fault plane. No fault feature located using the LINZ orthophotography was ascribed an accuracy better than *estimated*.

In some of the developed areas of the district, fault scarps and other fault-generated features that are visible on pre-development aerial photography have been removed or significantly modified by subsequent engineering works, and cannot be located on the ground (e.g. the Te Marua Lakes area along the Wellington fault). As a consequence, these unrectified photographs are the only readily available 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.

The mapped fault features (points and lines) 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. Fault Avoidance Zones were subsequently delineated around the fault rupture zones, see Section 3.4 for more detail.

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 Upper Hutt City were used to categorise the fault rupture complexity for all parts of each active fault in the district. The MfE 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, 2003b):

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.

Subsequent to the release of the MfE guidelines, GNS has completed a fault trace mapping project for Kapiti Coast District Council (Van Dissen & Heron 2003, Van Dissen *et al*. 2004), and found it necessary to modify some of the original MfE Fault Complexity definitions. In particular, 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 (i.e. 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 the Kapiti Coast study, GNS chose a 300 m 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 m wide, then the Fault Complexity zone was defined as *uncertain - constrained*. For planning purposes, GNS recommended that *uncertain - constrained* Fault Complexity zones should be viewed in the same fashion as a *distributed* Fault Complexity zone.

For the current Upper Hutt City fault trace project we adopt the modified Fault Complexity terms as used in the Kapiti Coast District Council study. Below we list the Fault Complexity terms, and definitions, used 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 applies 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 the current Upper Hutt study, we chose 300 m 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 guidelines, 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 Upper Hutt City, and have attributed each Fault Avoidance Zone in the GIS database as either *well defined*, *well defined - extended, distributed*, *uncertain - constrained*, or *uncertain - poorly constrained* according to the fault complexity of the zone. Figures 3 - 6 show, in a general sense, the distribution of the Fault Avoidance Zones along all the active faults in the district.

Generally a given stretch of fault can be characterised by a single Fault Avoidance Zone. However, there are some regions in the district where two or more zones overlap. For example, there are places where a wide zone of deformation is anticipated, but within that zone, one or more distinct scarps can be identified. In such cases, we have mapped *well defined* zones around the distinct scarps, surrounded by a wider *uncertain - constrained* or *uncertain - poorly constrained* zone.

3.5 Building Importance Category

In the event of fault rupture, buildings constructed across the fault will experience significant stress and can suffer extensive damage. Buildings adjacent to the fault and within the Fault Avoidance Zone may also be damaged. The MfE 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 Interval 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 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 guidelines. Notwithstanding, a fault with a long recurrence interval typically poses less of a hazard than one with a short recurrence interval. In the MfE 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 3), there is one Recurrence Interval Class I fault in Upper Hutt City, the Wellington fault. The next two most active faults, the Akatarawa and Otaki Forks faults, are Recurrence Interval Class III faults.

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 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 relationship between fault activity (Recurrence Interval Class) and building type (Building Importance Category) is presented in Table 2.

The MfE 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 (see Table 2). 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. Also, 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.

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>

4.0 RESULTS

4.1 Wellington fault

The Wellington fault is one of the major earthquake-generating faults in the Wellington region. It extends east-northeastwards through the centre of Upper Hutt City. Trenching and other detailed earthquake geology studies on the Wellington fault have determined that the fault has a right-lateral slip rate of approximately 7 mm/yr, and an average recurrence interval of surface rupture earthquakes of approximately 650 years. It most recently ruptured the ground surface about 400 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 about 3-5 m of right-lateral displacement at the ground surface, and a lesser and variable amount of vertical displacement.

The Wellington fault passes through areas of urban, semi-rural, and rural development. In some areas (e.g. Totara Park) development has taken account of, and avoided, the location of the fault, but not so in other areas where houses may have been built on the fault. The Wellington fault passes under, or very near to, two important bridges that service Upper Hutt City (Silverstream and Moonshine bridges). Other vital engineering lifeline services (e.g. water, power, etc) cross the fault at a number of localities throughout the district.

Recurrence Interval Class

The average recurrence interval of approximately 650 years for the Wellington fault, and its relatively high slip rate, place the fault in Recurrence Interval Class I (≤2000 years) of the MfE guidelines with a high degree of confidence (Table 3, see also Van Dissen *et al*. 2003a).

Table 3. Recurrence Interval Classes of known active faults within Upper Hutt City. 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*
Wellington fault	I	≤2000 years	High
Akatarawa fault	III	>3500 years to ≤5000 years	Low
Otaki Forks fault	III	>3500 years to ≤5000 years	Low
Moonshine fault	IV	>5000 years to ≤10,000 years	Low
Whitemans Valley fault	V	>10,000 years to ≤20,000 years	Medium

*Relative confidence that the fault can be assigned to a specific fault-avoidance Recurrence Interval Class.
High - fault has a well constrained recurrence interval (usually based on fault-specific data) that is well within a specific Recurrence Interval Class, or fault has such a high slip rate that it can be confidently placed within the ≤2000 year Recurrence Interval Class.
Medium - uncertainty in average recurrence interval embraces a significant portion (> ~25%) of two Recurrence Interval Classes; the mean of the uncertainty range typically determines into which class the fault is placed.
Low - the range of uncertainty of the fault's recurrence interval embraces a significant portion of three or more Recurrence Interval Classes, 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). The mean of the recurrence interval uncertainty range typically determines into which class the fault is placed.

Fault Complexity

Parts of the Wellington fault fall into the *well defined*, *uncertain - constrained*, and *uncertain - unconstrained* Fault Complexity classes (i.e. Fault Avoidance Zone; see maps at end of report, Figures 2 & 3). Through Upper Hutt City, the location of the western and eastern thirds of the fault are generally less well constrained than the middle third.

Between the western boundary of the district, near Silverstream to Totara Park, the modern channel of the Hutt River follows the line of the fault. As such, most evidence of the fault's near-surface position has been obliterated by young river erosion and deposition. As a consequence, the precise location of the fault is rather poorly known, and the Fault Complexity (i.e. Fault Avoidance Zone) is either *uncertain - constrained*, or *uncertain – unconstrained*. At the western boundary of the district, the position of the fault is taken from the location provided by Wood (2003), though modified to encompass fault-rock (crush zone) exposures at Mains Rock that attest to the fault being at, or very close to, this location. Similar fault-rock exposures constrain the location of the fault immediately adjacent to the western abutment of the Moonshine Bridge. To the east of Moonshine Bridge, near the Whakatikei River/Hutt River confluence, the fault appears to side-step, or bend, to the left. Because of uncertainty as to the exact geometry of this side-step/bend the Fault Complexity (Fault Avoidance Zone) is *uncertain – unconstrained*.

Along the middle third of the fault's extent through Upper Hutt City, between Totara Park and Te Marua Lakes, the location of much of the fault is *well defined*, based on the presence of clear and distinct scarps (or as is the case near Te Marua Lakes, scarps that were clear and distinct prior to their destruction during construction of the two reservoirs). The major exception to the *well defined* nature of the middle third of the fault is between the Te Marua golf course and the stockcar track where young river action has removed evidence of the precise location of the fault. Here the position of the fault is *uncertain – constrained* because its location has had to be estimated based on extrapolation from *well defined* scarps to the west and east.

The eastern third of the fault is a combination of *well defined* Fault Avoidance Zones where there are distinct topographic scarps present, and *uncertain - constrained*, and *uncertain – unconstrained* zones where fault features such as saddles, fault-guided streams, and possible fault scarps provide less control as to the precise location of the fault. At the eastern boundary of the district, the Wellington fault side-steps to the left by about 2 km. Between the two traces that define the side-step, there is a zone of intense ridge renting, and we have designated this as a *distributed* Fault Avoidance Zone. Some long lengths of the Wellington fault, particularly in the Kaitoke area, 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.

4.2 Akatarawa fault

The Akatarawa fault comprises multiple strands, and is one of the regions important active faults. It splays from the Wellington fault near Riverstone Terraces, and strikes north-northeast through rough hill country to merge with the Moonshine and Otaki Forks faults in the Akatarawa Valley near Cloustonville. Geomorphic mapping and trenching of the fault trace in the Akatarawa Valley indicate that the fault has a minimum right-lateral slip rate of

0.4 mm/yr, and a maximum average earthquake recurrence interval of approximately 9000 years. However, given dating and measurement uncertainties, the actual slip rate may be considerably higher, and the recurrence interval may be considerably less (i.e. in the order of 3500 years or less).

Recurrence Interval Class

The Akatarawa fault's maximum recurrence interval of 3500-9000 years spans several Recurrence Interval Class boundaries defined in the MfE Guidelines. Considering that this estimate of recurrence interval is a maximum, it would appear appropriate to place the fault in Recurrence Interval Class III (>3500 years to ≤5000 years), towards the lower end of its maximum recurrence interval range, with a low degree of confidence (Table 3, see also Van Dissen *et al*. 2003a).

Fault Complexity

The Akatarawa fault is mapped as *uncertain - constrained* or *uncertain - poorly constrained* over most of its length (Figure 4). Its location is largely denoted by saddles, a few crush zones, offset drainages, and suspected fault-guided streams. Only along the floor of the Akatarawa Valley is a *well defined* fault trace mapped. This trace helps to constrain the fault's location to the southwest and northeast.

4.3 Otaki Forks fault

The Otaki Forks fault passes through Upper Hutt City in the hill country to the east of the Akatarawa Valley. It comprises two main strands, and is considered to be associated with the Akatarawa fault and ultimately the Wellington fault. Mapping of the Otaki Forks fault has yet to yield details on slip rate, and timing and size of recent rupture displacements. However, given the right-lateral sense of slip of the Akatarawa fault, and the geometry of its intersection with the Otaki Forks fault, it is reasonable to assume that slip on the Akatarawa fault is transferred onto the Otaki Forks fault. As such, we assume that the Otaki Forks fault has a slip rate and recurrence interval similar to that of the Akatarawa fault.

Recurrence Interval Class

There are no fault-specific data that constrain the recurrence interval of the Otaki Forks fault. However, based on its assumed close relation with the better studied Akatarawa fault, we place the Otaki Forks fault in Recurrence Interval Class III (>3500 years to ≤5000 years) with a low degree of confidence (Table 3).

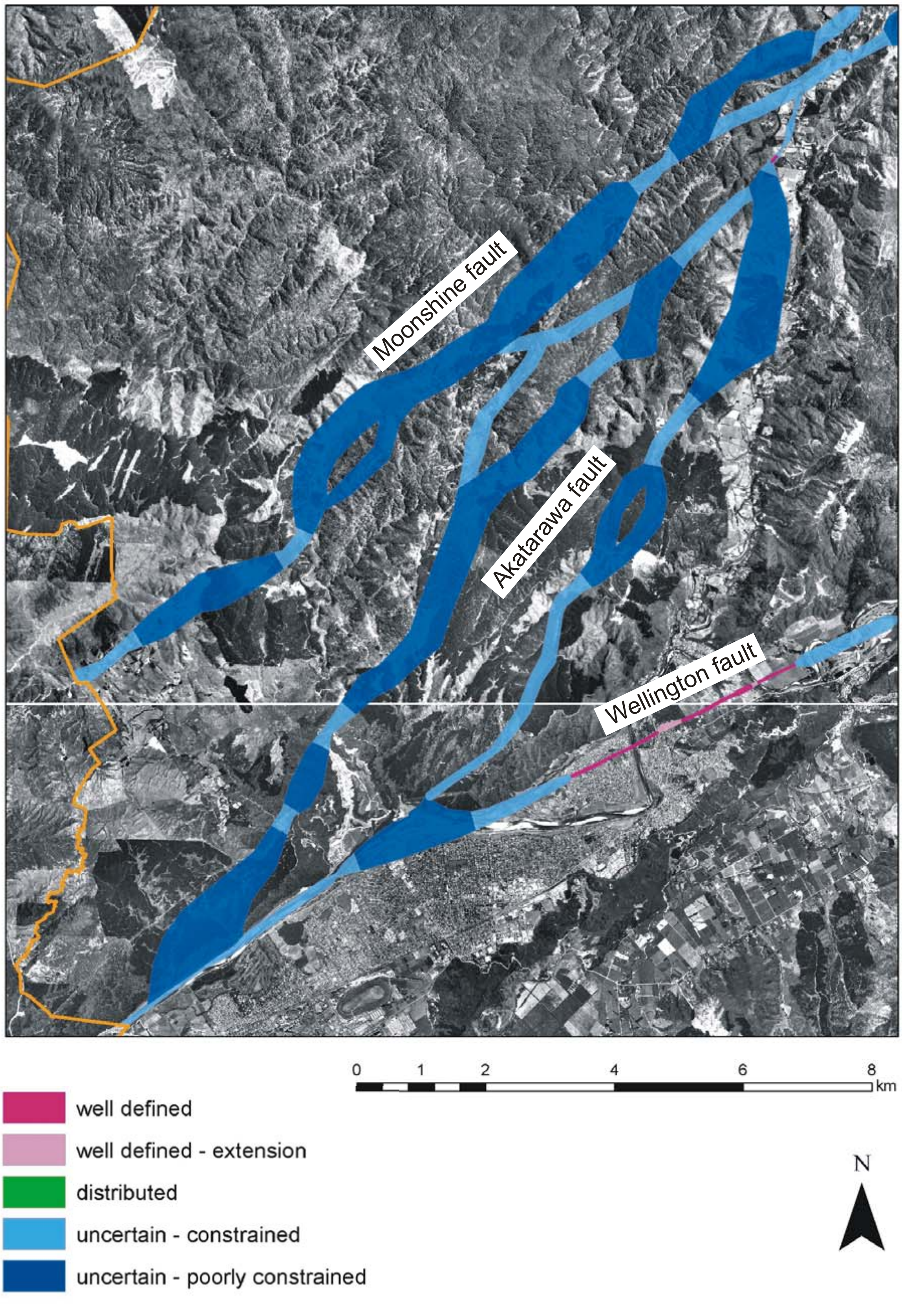

Figure 4. The Moonshine and Akatarawa faults showing Fault Avoidance Zones.

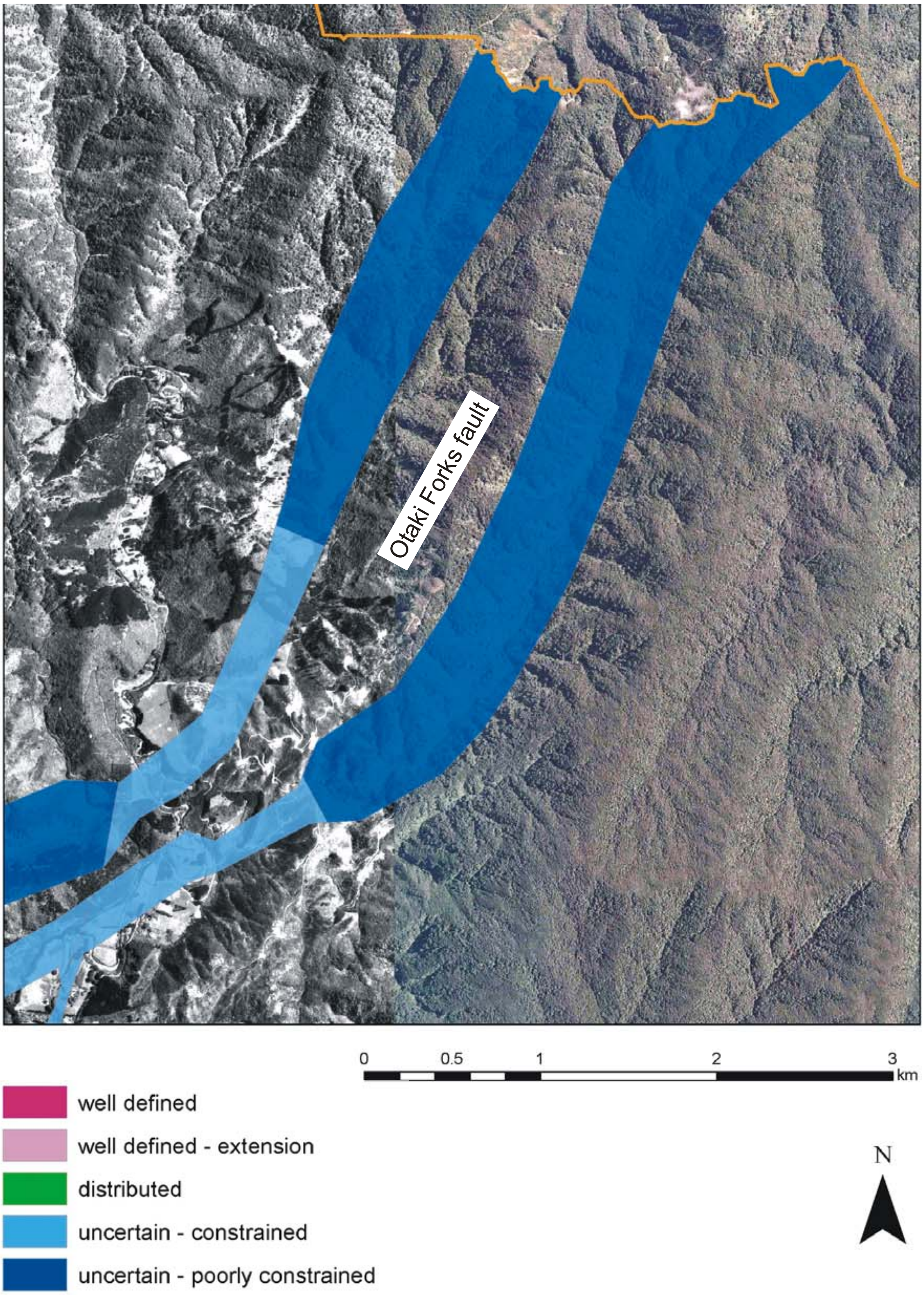

Figure 5. The Otaki Forks fault showing Fault Avoidance Zones.

Fault Complexity

The Otaki Forks fault is mapped as *uncertain - constrained* or *uncertain - poorly constrained* over most of its length (Figure 5). Its location is largely defined by saddles, and suspected fault-guided streams.

4.4 Moonshine fault

The Moonshine fault and the Otaki Forks fault appear to be part of the same geological structure, with the name Moonshine fault being applied southwest of the intersection with the Akatarawa fault, and the name Otaki Forks fault applying northeast of the intersection. There are no fault-specific data that constrain the Moonshine fault's slip rate, or recurrence interval. However, in general, the gross geomorphic expression of the Moonshine fault is less distinct and more subdued than that of the Otaki Forks fault. This is consistent with the notion that slip from the Akatarawa fault is transferred onto the Otaki Forks fault, but not the Moonshine fault. Of the known active faults in Upper Hutt City, the Moonshine fault is the one that we know the least about.

Recurrence Interval Class

As noted above, there are no fault-specific data that constrain the recurrence interval of the Moonshine fault. However, the topographic expression of the Moonshine fault is less distinct than that of the Otaki Forks fault, and the slip rate of the Otaki Forks fault is probably greater than that of the Moonshine fault (by an amount similar to the Akatarawa fault's slip rate). Based on these relationships we assume that the Moonshine fault is less active and has a longer recurrence interval than the Otaki Forks fault. As such, we tentatively place the Moonshine fault in Recurrence Interval Class IV (>5000 years to ≤10000 years) with a low degree of confidence (Table 3).

Fault Complexity

The Moonshine fault is mapped as *uncertain - poorly constrained* over most of its length (Figure 4), its location being largely denoted by saddles, and suspected fault-guided streams. Towards the western boundary of the district, near Bulls Run Road, we identified a subdued suspected fault scarp, which if proved to be of active fault origin, would better constrain the fault's location than its current *uncertain – constrained*.

4.5 Whitemans Valley fault

The Whitemans Valley fault is a "second order" active fault that strikes NNE-SSW through the southwestern portion of the district (Figure 1). Trenching of the fault has revealed that the most recent rupture of the fault probably took place less than 10,000 years ago, and produced a vertical displacement of approximately 2 m (approximately 3 m dip-slip reverse). The Whitemans Valley fault is considered capable of generating magnitude 6.7-7.3 earthquakes, and has an estimated recurrence interval of approximately 15,000-20,000 years.

Recurrence Interval Class

Based on the estimated recurrence interval of the Whitemans Valley fault of 15,000-20,000 years, and acknowledging the uncertainties and assumptions surrounding this estimate, we place the Whitemans Valley fault into Recurrence Interval Class V (>10,000 years to ≤20,000 years) with a medium level of confidence (Table 3).

Fault Complexity

The Whitemans Valley fault is mapped as either *uncertain - constrained* or *uncertain - poorly constrained* over most of its length (Figure 6). In these areas its location is marked primarily by saddles and suspected fault-guided streams. Only in the Johnsons Road area is a *well defined* scarp mapped.

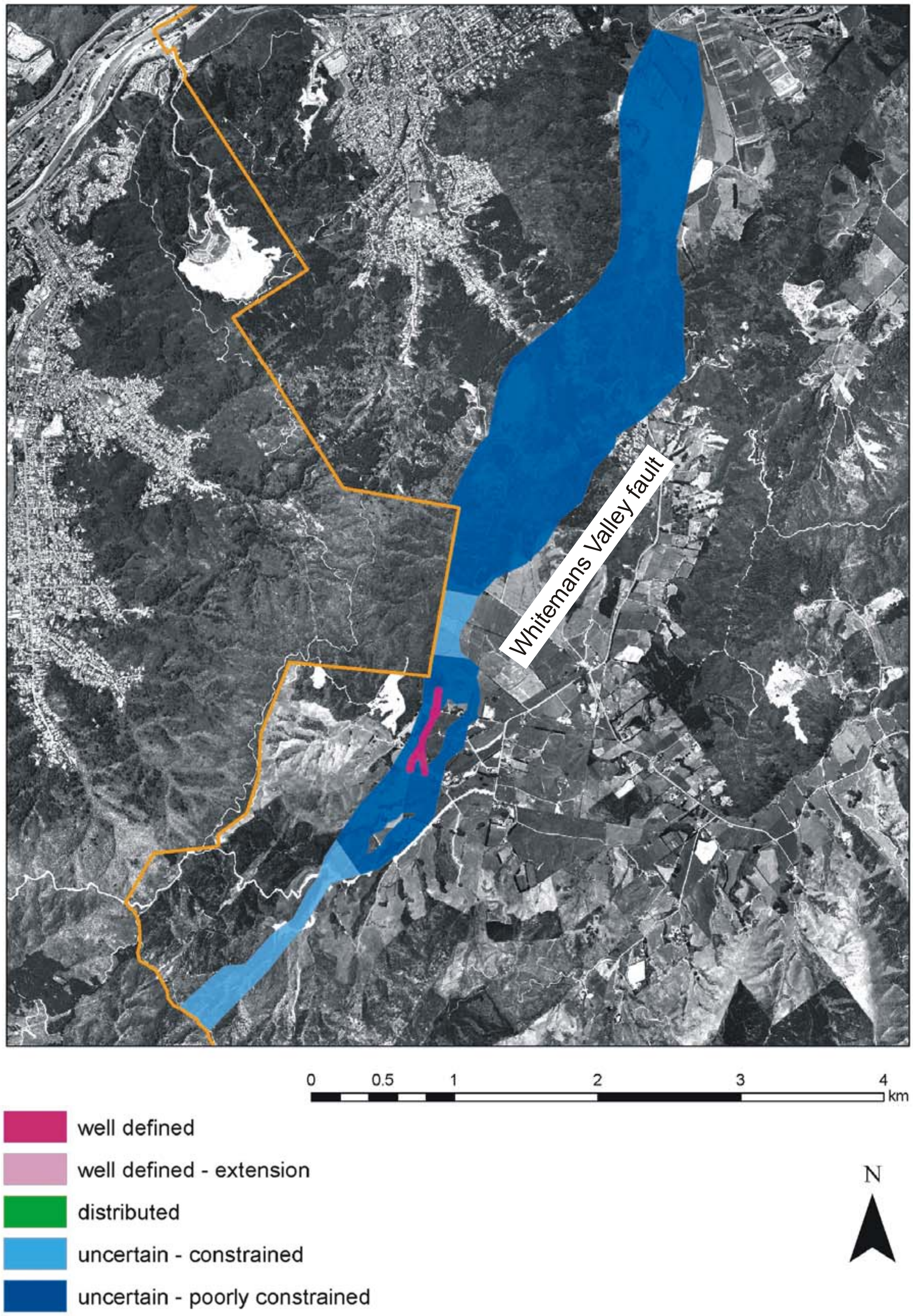

Figure 6. The Whitemans Valley fault showing Fault Avoidance Zones.

5.0 CONCLUSIONS & RECOMMENDATIONS

5.1 Conclusions

Fault Recurrence Interval Class, and Fault Avoidance Zones based on Fault Complexity have been defined for all known active faults in Upper Hutt City. 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.

5.2 Recommendations

1) *Get better constraints on Recurrence Interval Class:*

Using the terminology and definitions put forward in the MfE guidelines, the confidence of Recurrence Interval Classification for three of the active faults in Upper Hutt City is low. For the Akatarawa fault, presumably the second most active fault in the district, this is because the only estimate of recurrence interval is a maximum one, and the range of uncertainty of this maximum estimate spans a significant portion of two Recurrence Interval Classes. For the Akatarawa fault the lower end of the maximum recurrence interval range was used to guide its Recurrence Interval Classification. An alternative, and more conservative, approach would be to assign its Recurrence Interval Class based on the acknowledgement that the fault's recurrence interval could be shorter than the lower end of its maximum range. In this case, this would result in the Akatarawa fault being placed into the more hazardous/restrictive Recurrence Interval Class II. Recurrence Interval Classes for the Otaki Forks fault and the Moonshine fault are assigned largely based on subjective comparison with the Akatarawa fault.

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 that listed in Table 3. 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.

Also, less as a recommendation, but more as a comment, it needs to be acknowledged that with future geological work in Upper Hutt City, 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 both the Akatarawa and Whitemans Valley faults were only discovered within the last ten years.

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. mapping, 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 (i.e. Fault Avoidance Zone) may also warrant a re-think regarding decisions pertaining to development of that land.

It also needs to be acknowledged that there are some areas in the district (e.g. the *uncertain - poorly constrained* Fault Avoidance Zones) where expensive geological investigations 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) Formulation of planning policy and assessment criteria:

Fault Recurrence Interval Class, Fault Complexity, and Building Importance Category are the three key elements in the MfE guidelines 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 are summarised in Table 2. These interrelationships are expanded in tables presented in the MfE guidelines to incorporate Fault Complexity/Fault Avoidance Zones. These tables in the MfE guidelines also provide examples of Resource Consent Category suggestions for various combinations of Recurrence Interval Class, Fault Complexity, and Building Importance Category. Similar tables were also prepared for the Kapiti Coast District Council (see Van Dissen & Heron 2003) that take into account the modified definitions of Fault Complexity used in the current Upper Hutt study (see Section 3.3).

Determining appropriate fault rupture hazard mitigation strategies 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 mitigation strategies 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, such as those regarding the use, size, location and foundations of structures, to avoid or reduce the adverse effects of fault rupture.

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 fault rupture hazard at a site is not practicable, then planning and design measures need to be prescribed/incorporated to mitigate and accommodate the co-seismic surface rupture displacements anticipated at the site. The planning and 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 a re-assessment as to the most appropriate fault rupture hazard mitigation strategies applicable to the site.

With respect to planning for fault rupture, the Council will ideally want to apply one, or a number of strategies, which mitigates the hazard. These strategies should be tailored to suit the individual setting and requirements of the Council.

In light of the current study, the Council may wish to review objectives, policies and methods (which may include rules) in the District Plan that address fault rupture. The exact nature of these objectives, policies and methods will need to be determined in consultation with a number of relevant parties including within the Council itself, the community and other relevant organisations. A plan change may be required to incorporate these new elements into the document.

The Upper Hutt City District Plan already has a method relating to the "management of the location and use of buildings in close proximity to earthquake faults". The Council may now wish to review this method to incorporate the results of the current study, and to make it consistent with the recommendations put forward in the MfE guidelines. As part of the resource consents process, matters that the Council may wish to consider 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 the fault rupture.

If applying for a resource consent in a Fault Avoidance Zone, the District Plan should make provisions to ensure that the Council has the option of requiring applicants to provide evidence of the location for fault rupture hazard. Alternatively, if it is impractical to locate the fault to the accuracy that is necessary, then the developer should prove that the proposed building is resilient enough to withstand fault rupture, from a life safety standpoint.

4) *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.

6.0 ACKNOWLEDGMENTS

Quality control reviews of this report were provided by Julia Becker and David Heron.

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APPENDIX 1 – CD Contents

1: Report:

Upper Hutt Fault Trace Project. PDF Format.

2: Figures:

Figure 1. Active faults of Upper Hutt City. TIFF format.

Figure 2. The Wellington fault showing Fault Avoidance Zones. TIFF format.

Figure 3. The Wellington fault (central) showing Fault Avoidance Zones. TIFF format.

Figure 4. The Akatarawa and Moonshine faults showing Fault Avoidance Zones. TIFF format.

Figure 5. The Otaki Forks fault showing Fault Avoidance Zones. TIFF format.

Figure 6. The Whitemans Valley fault 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 fault feature observed, the landscape feature involved, 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 fault feature observed, the landscape feature involved, 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 complexity, the fault name, and the Recurrence Interval Class.

Data Dictionary and MetaData.

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