Mapping of Active Faults and Fault Avoidance Zones for Wairoa District: 2016 Update

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GNS Science Consultancy Report 2016/133
January 2017

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Clark, K.J.; Ries, W.F. 2017. Mapping of Active Faults and Fault Avoidance Zones for Wairoa District: 2016 Update, *GNS Science Consultancy Report* 2016/133. 35 p.

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EXECUTIVE SUMMARY

The Wairoa district is traversed in the west by a series of active strike-slip faults that form part of the North Island Fault System. In the eastern part of the district there are several short (<4 km long) traces of active faults. Following the Ministry for the Environment's (MfE) Guidelines – "Planning for Development of Land on or Close to Active Faults" active faults in the Wairoa District have been mapped to produce Fault Avoidance Zones surrounding the active faults. For life safety purposes, the MfE active fault guidelines focus on: (i) the location and complexity of faulting; (ii) the characterisation of recurrence interval of surface faulting, and (iii) the building importance category with respect to land zonation for a particular site.

An update of geographic information systems (GIS) data describing the locations and activity of known active faults in the Wairoa District is presented. Active fault mapping was undertaken for the district using, regional scale orthophotographs, regional scale 10 m ground pixel resolution Digital Terrain Model (DTM) and derivative hillshade model, and also a review of active fault linework from produced by QMAP (GNS Science 1:250 000 geological map series), the New Zealand Active Fault Database (NZAFD), and other local fault mapping reports. This work builds upon and supersedes previous active fault mapping and Fault Avoidance Zones developed for parts of the district by Langridge et al. (2011). The fault mapping has been undertaken at scales between 1:50,000 to 1:250,000.

Augmenting the geospatial data, attributes, including Fault Name, Accuracy, and Recurrence Interval (RI) Class accompany the active fault linework. Recurrence intervals for surface rupture (faulting) have been defined for the named faults within the Wairoa District. The Whakatane Fault, Rangiora Fault and part of the Waimana Fault are assigned Recurrence Interval Class I (RI ≤2000 years); the Waiohau, Waiotahi, and Koranga faults and part of the Waimana Fault are assigned RI Class II (>2000 to ≤3500 years). Three short fault traces on Mahia Peninsula are RI Class IV (>5000 to ≤10,000 years) and several short active fault traces in the eastern Wairoa District could not be assigned a RI Class due to insufficient information and are designated RI Class "unknown". Fault Avoidance Zone widths vary within the Wairoa District from 290 to 540 m.

We recommend that the active fault linework and Fault Avoidance Zone data presented here as digital geospatial data be adopted by Wairoa District Council to be used as standard practice for planning and consenting in the Wairoa District. These fault traces should be incorporated within district plan maps where possible, or within council GIS databases, in order to set rules for the mitigation of ground-surface fault rupture hazard in a fashion that is consistent with the MfE active fault guidelines. These data should supersede previous versions of active fault linework, attributes and Fault Avoidance Zones. We also recommend that active fault linework and Fault Avoidance Zones should be updated every 10 years, or as more Light Detection and Ranging (LiDAR) survey data becomes available, and our estimation of recurrence intervals on specific faults improves. This is particularly important for areas that are undergoing, or are envisioned to undergo, land-use change leading to increased exposure to hazard associated with active faulting.

1.0 INTRODUCTION

The east coast of the North Island, New Zealand, lies within the Hikurangi subduction margin, the plate boundary where the Pacific Plate subducts beneath the Australian Plate at ~40 mm/yr (Figure 1.1). The area administrated by Hawke's Bay Regional Council (HBRC) is underlain by the subduction interface and is also crossed by many active faults that are associated with distributed plate boundary deformation. Surface rupture of an active fault in a large earthquake (magnitude greater than about M 6.5) will result in a zone of intense ground deformation as opposite sides of the fault move past or over 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. The 2010 Darfield (Canterbury) earthquake is a recent example of impacts of ground surface rupture along faults (Van Dissen et al., 2011).

In this report we map active faults in the Wairoa District for the purposes of producing Fault Avoidance Zones suitable for land-use planning. The faults with the highest rates of activity in this district are in the west: the Waiohau, Whakatane, Waimana and Waiotahi faults (Figure 1.1 and Figure 2.1). There are also several short traces of possible active faults in the low hill country to the northeast of Wairoa township. Active faults in some parts of the Wairoa District were previously mapped by Langridge et al. (2011) but in the five years since that report, methodology for active fault attributing has slightly changed and new fault mapping and interpretation for the western part of the Wairoa District (not covered by Langridge et al., 2011) is available in the GNS Science 1:250 000 geological maps of Hawke's Bay (Lee et al., 2011) and Rotorua (Leonard et al., 2010). This report updates the active fault mapping the whole of the Wairoa District, including an update of the areas covered by Langridge et al. (2011); it provides GIS data for active fault linework and Fault Avoidance Zones in a manner consistent with recent work in Hastings District and Central Hawkes Bay District (Langridge and Ries, 2014; 2015).

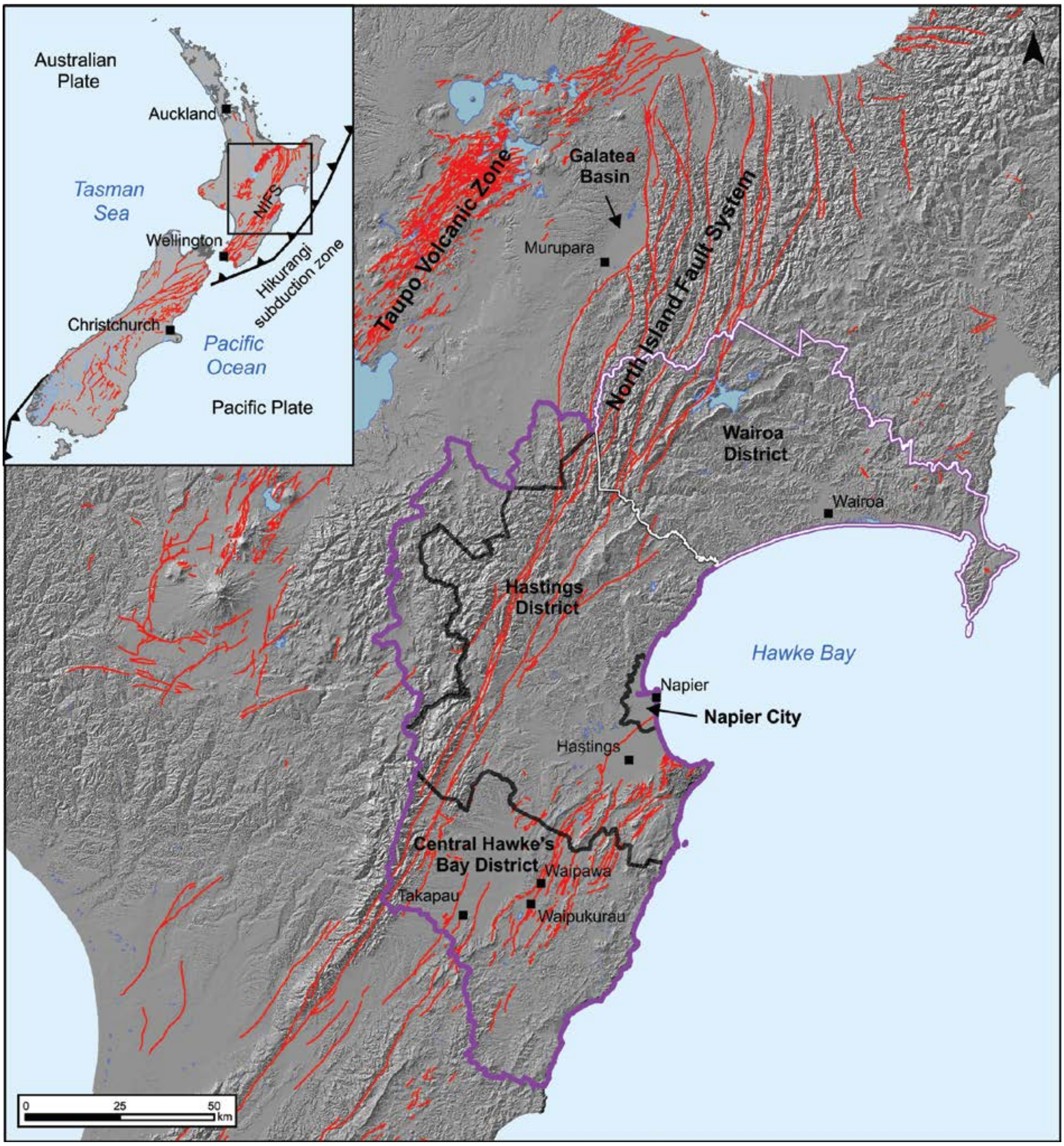

Figure 1.1 Active faults (red) within the Hawke's Bay region (inside purple line). The study area of Wairoa District is within the white line. Inset: Simplified map of North Island plate tectonic boundary zone. NIFS = North Island Fault System.

1.1 SCOPE OF WORK

GNS Science was commissioned by Hawke's Bay Regional Council (HBRC), to provide an update of mapping of active faults within Wairoa District. The main objective for this work is to provide HBRC with updated GIS-based active fault location data and Fault Avoidance Zones for Wairoa District. This includes the production of high-quality GIS maps suitable for planning use across Wairoa District at scales that are relevant to the current and expected future land use requirements. The project will provide relevant information with regard to the Ministry for the Environment guidelines "Planning for Development on or Close to Active Faults" (Kerr et al., 2003), to assist in future land use planning, particularly with regard to building on "Greenfield" (i.e., previously undeveloped land) sites, or in the renovation of buildings in areas adjacent to active faults.

To improve the understanding of ground-surface fault rupture hazard and to update the quality of fault mapping within Wairoa District the scope of work is as follows:

- Review and assess existing map and data quality across the district;
- Accurately map active fault traces into a GIS database where airborne LiDAR coverage exists (1:5,000 to 1:10,000 scale);
- Update previous active fault linework and assessment of fault attribute data;
- Review and incorporate new active fault linework from QMap Hawke's Bay (1:50,000 to 1:250,000 scale);
- Provide a completion report for HBRC and presentation of results to Wairoa District Council staff.

In the appendices we have placed useful information that is repeated from the Hastings District active fault mapping study of Langridge and Ries (2015). This information has not changed since the 2015 study.

- Appendix A1.1: What is an active fault? This appendix provides background material on what active faults are, their styles of movement, and frequency of movement (recurrence interval).
- Appendix A1.2: Fault location uncertainty, attributes and Fault Avoidance Zones This appendix provides a description of how we develop, map and define the attributes, uncertainties and Fault Avoidance Zones for the active faults in the Wairoa Disctrict, and the Hawkes Bay region in general.

1.2 PREVIOUS ACTIVE FAULT MAPPING

Active faults of the Wairoa District have been mapped in the QMAP geological map series (Mazengarb and Speden 2000; Leonard et al., 2010; Lee et al., 2011), in the New Zealand Active Faults Database (Langridge et al., 2016), and in a fault mapping report for Hawkes Bay Regional Council by (Langridge et al., 2011). All of these sources of active fault information are used in this report, and here we explain each data source:

1.2.1 QMAP geological map series

The QMAP geological map series includes a GIS layer of active faults; information provided by QMAP includes the type of fault, activity and sense of movement. Rattenbury and Isaac (2012) state "*the general QMAP approach to active fault portrayal was to extrapolate and interpolate between known active traces, consistent with the observation that faults which rupture to the surface typically propagate over many kilometres*".

1.2.2 New Zealand Active Faults Database (NZAFD) and NZAFD250:

GNS Science maintains the New Zealand Active Faults Database (NZAFD), a national database of information on active faults that have deformed onshore New Zealand during the Late Pleistocene and Holocene (125,000 years to the present day, http://data.gns.cri.nz/af/, Langridge et al., 2016). This NZAFD GIS database consists of line features that represent the location of past surface fault rupture and geological information about each active fault. The data in the NZAFD vary in locational accuracy because of the variety of methods used in data capture (e.g., aerial photo interpretation, theodolite surveying, differential GPS), the scale of capture, and the reasons for which the data were recorded. Recently, the NZAFD250 was launched; this GIS database provides quality-controlled active fault line work at a scale of 1:250,000. NZAFD250 was developed to address some inconsistencies between the depictions of active faults in the NZAFD and in the QMAP series (Rattenbury and Isaac 2012). The NZAFD250 view is constructed using GIS data from: (1) the NZAFD; (2) QMAP; (3) recent active fault mapping reports at a local to regional scale (e.g., Langridge et al., 2011); and (4) new GIS data compiled during the review process that occurred through the development of the NZAFD250. The NZAFD250 differs slightly from the active fault component of QMAP. Faults shown in QMAP often represent generalised boundaries between geological units; the accuracy of the fault locations in the NZAFD250 have been improved through additional interpretation of remote imagery to include all features of the active surface trace (e.g., where the fault trace is expressed across youthful landscapes, rather than following a geological boundary). In this current report, we will use data from the NZAFD and NZAFD250.

1.2.3 Fault Avoidance Zone Mapping for Wairoa District, Napier City and surrounds (Langridge et al., 2011).

In 2010–2011 a study of active faults in parts of the Wairoa District and Napier City was undertaken by GNS Science for Hawkes Bay Regional Council. This report consisted of a literature review, analysis of aerial photographs, orthophotographs and LiDAR digital terrain models, mapping of fault traces in a GIS, and application of the MfE Guidelines to produce Fault Avoidance Zones. It is important to note that although the report title implies that the entire Wairoa District was surveyed, actually only a subset of areas within the district were considered for active fault mapping (Figure 1.2). These were: (1) a coastal strip from Wairoa township to Mahia Peninsula (the extent of this area was defined by the extent of existing LiDAR coverage); (2) the area north of the coastal strip up to the district boundary (this area was selected as it was known previously to contain a relatively high number of short active fault traces); (3) Mahia Peninsula; (4) the area including the Rangiora Fault in the southwest of the district. The current report revisits these four areas mapped by Langridge et al. (2011) and evaluates if there is any new information for refining the existing active fault mapping.

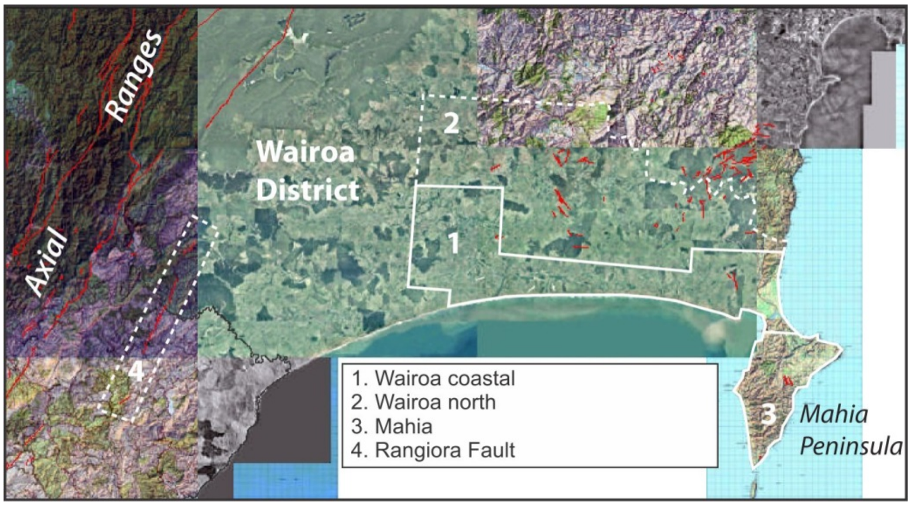

Figure 1.2 Areas of the Wairoa District covered by the active fault mapping report of Langridge et al. (2011). Note the major strike slip faults in the west of the Wairoa District were not covered by the earlier report (Figure taken directly from Langridge et al. (2011).

1.3 MfE GUIDELINES FOR DEVELOPMENT OF LAND ON OR CLOSE TO ACTIVE FAULTS

The Ministry for the Environment (MfE) published guidelines on "Planning for Development of Land on or Close to Active Faults (Kerr et al., 2003), hereafter referred to as the MfE Guidelines. 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 that are subject to fault rupture hazard.

The main elements of the risk-based approach presented by the guidelines are:

1. Fault characterisation relevant to planning for development across fault lines which focuses on: (a) accurate location of faults (including its "fault complexity", i.e., the distribution of deformation around a fault line); (b) definition of Fault Avoidance Zones, and; (c) classification of faults based on their recurrence interval (time between large earthquakes on the same fault), which is an indicator of the likelihood of that fault rupturing in the near future. Faults with the highest activity fall into RI Class I; these faults have an average recurrence interval of ≤2000 years. The least active class of faults is RI Class VI which includes faults that have an average recurrence interval of 20,000 to 125,000 years.
2. The Building Importance Category (BIC), which indicates the acceptable level of risk of different types of buildings within a Fault Avoidance Zone. The Building Importance categories are based on risk levels for building collapse according to the building type, use and occupancy. Category one is least importance; category four is most importance. For example, a farm shed is BIC 1, medical emergency facilities and emergency shelters are BIC 4.
3. The MfE Guidelines advance a hierarchical relationship between 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 needs to be for that building to be permissible. For example, only low occupancy, or low risk, structures, such as farm sheds and fences (e.g., BIC 1 structures), are recommended as being permissible to be built across active faults with average recurrence intervals of surface rupture less than 2000 years. In a "Greenfield" (i.e., undeveloped) setting, more significant structures such as schools, airport terminals, and large hotels (BIC 3 structures) should not be sited across faults with average recurrence intervals shorter than 10,000 years (i.e., RI Class ≤ IV).

2.0 ACTIVE FAULTS IN WAIROA DISTRICT: FAULT MAPPING AND RECURRNCE INTERVALS

Within Wairoa District two broad geomorphic zones can be identified: (1) the Axial Ranges zone in the west, dominated by strike-slip faulting associated with the North Island Fault System (Figure 1.1); (2) the eastern or coastal zone, which is generally characterised by low rates of deformation and, consequently, has only a few short-length traces of normal faults. In the following section we describe the fault mapping in these two zones. For Fault Avoidance Zone mapping, following the MfE Guidelines (Kerr et al., 2003), the important factors are: (1) fault location and its accuracy, (2) fault recurrence interval (for further detail, see Appendix A1.1.2). In this section we discuss each fault that has been mapped; we describe the fault location, information about its slip rate and recurrence interval, and discuss how our revised mapping compares with previous active fault maps (see Section 1.2). Figure 2.1 shows a map of all known active faults, classified by RI Class, in the Wairoa District. Where significant differences occur between the active fault linework of this report and previous active fault mapping we have included detailed comparative maps that show the differences (white boxes on Figure 2.1, and Figure 2.3–Figure 2.9).

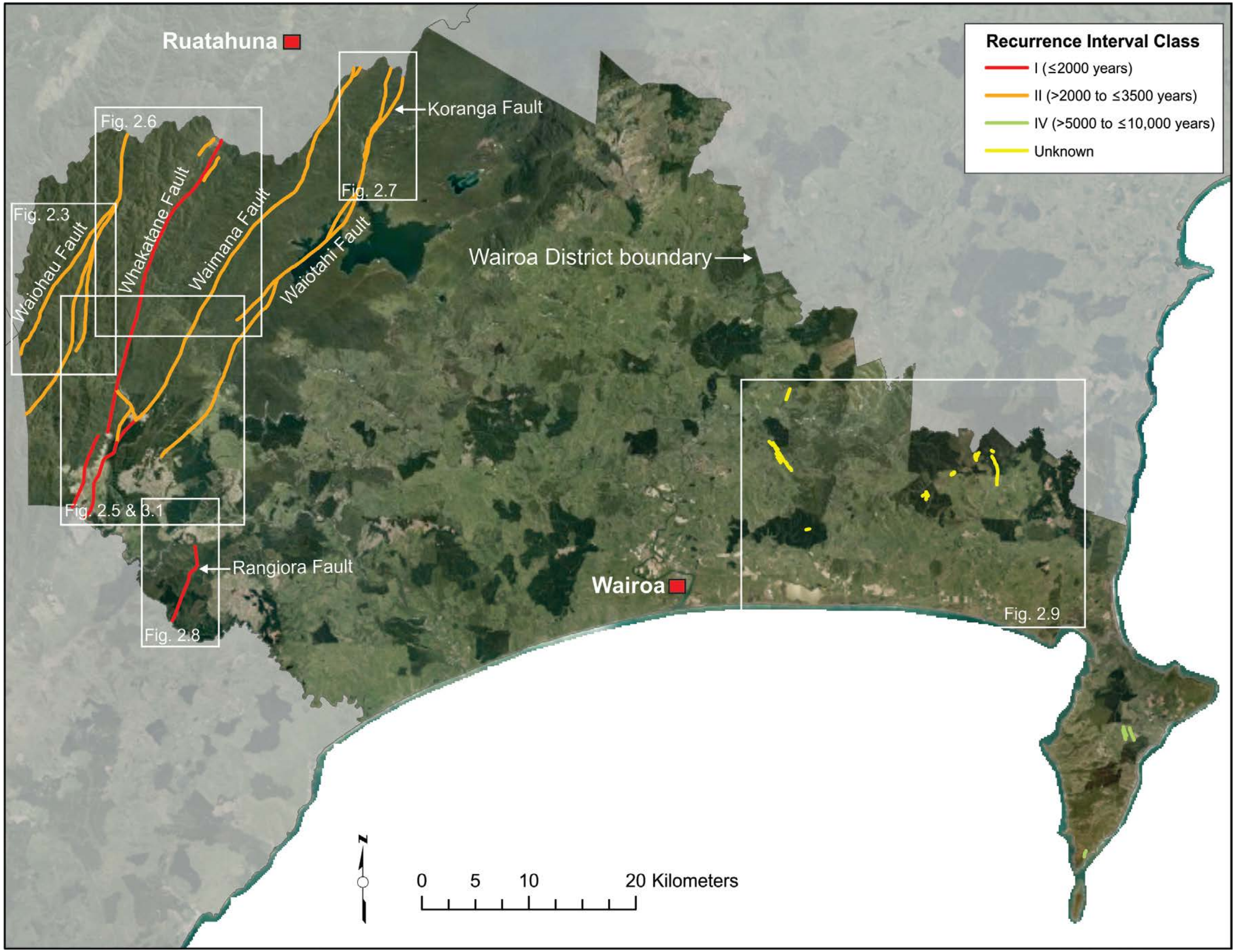

Figure 2.1 Overview of areas of active faulting in the Wairoa District. Active faults are colour coded by displayed by Recurrence Interval Class.

2.1 STRIKE-SLIP FAULTING OF THE NORTH ISLAND FAULT SYSTEM

Strike-slip faults are prevalent in the west of the Wairoa District within the Axial Ranges geomorphic zone (west of Lake Waikaremoana; Figure 2.1 and Figure 2.2); these faults are part of a broader tectonic system called the North Island Fault System (NIFS, Figure 1.1). The NIFS is a series faults running onshore from Wellington to the Bay of Plenty; the faults accommodate ~15–20 mm/yr of plate motion in the Wellington area and this decreases to ~4 mm/yr in the Bay of Plenty (Mouslopoulou et al., 2009). South of the Mohaka River, the NIFS is expressed mainly by the northeast-southwest striking Wellington-Mohaka Fault and the Ruahine Fault; motion on these faults is dominantly right-lateral strike-slip (Figure 2.2; see Appendix A1.1.1 for information on the styles of fault movement). North of the Mohaka River the faults of the NIFS start to bend to a more north-south strike and they bifurcate into five strands; accompanying this change in orientation is a change in the motion on the faults as they accommodate more dip-slip motion (i.e., "pulling apart") to become transtensional. In the Wairoa District, the faults of the NIFS are dominantly strike-slip but as they head toward the Bay of Plenty, they turn into dominantly normal faults; the Wairoa District essentially covers a transitional zone in the style of faulting on the NIFS (Figure 2.2; see Appendix A1.1.1 Styles of fault movement). Here we describe each of the faults in the Wairoa District from west to east.

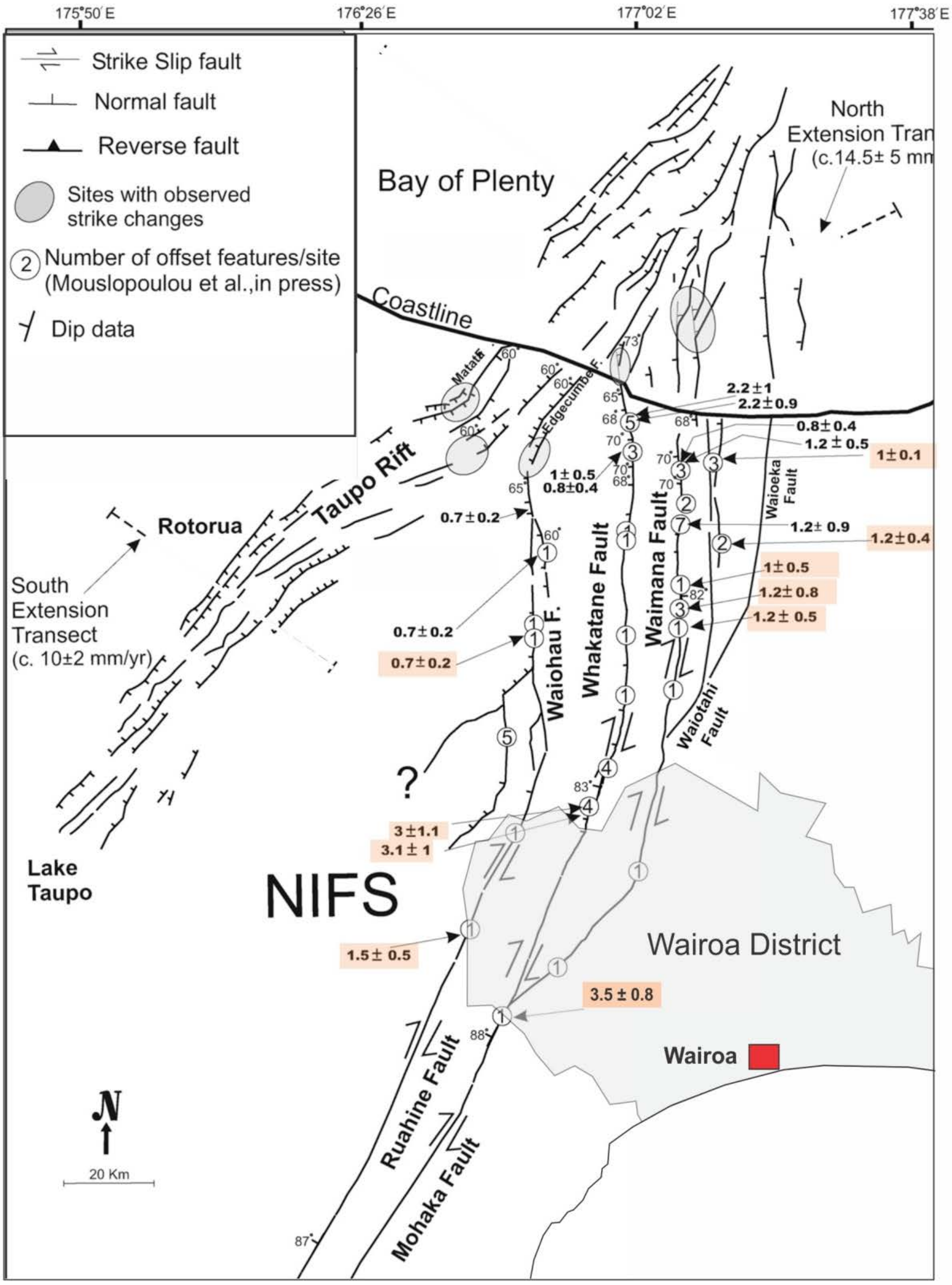

Figure 2.2 Simplified map of the major faults of the North Island Fault System (NIFS). This map shows how the main faults in the central North Island (Ruahine Fault and Mohaka Fault) bifurcate and start to strike north-south through the Wairoa District (shaded grey). Also notable is the change in fault style from dominantly strike-slip in the south to normal faulting in the Bay of Plenty. The slip rates shaded in orange are cited in this report and are listed in mm/yr. This figure has been adapted and simplified from Mouslopoulou et al. (2007a).

2.1.1 Waiohau Fault

The Waiohau Fault is the northern extension of the Ruahine Fault (Figure 2.1 and Figure 2.2). The Ruahine Fault was described in Langridge and Ries (2015); it has a slip rate of 1–2 mm/yr, a single-event displacement (i.e., relative ground movement across the fault in a single earthquake) of 2–5 m, and a recurrence interval of 1000–5000 years (Beanland and Berryman, 1987; Hanson, 1998). About 15 km south of the Hastings-Wairoa District boundary, the Ruahine Fault splits into two strands and from there northwards is called the

Waiohau Fault. The two strands of the Waiohau Fault run sub-parallel to each other through the Wairoa District (Figure 2.1 and Figure 2.3). They merge together about 6 km south of the Wairoa-Whakatane District boundary, and the fault becomes better-defined in the landscape northwards from there. The style of faulting on the Waiohau Fault transitions from strike-slip in the south to normal in the north, corresponding with a decrease in the net slip rate from approximately 1.5 ± 0.5 mm/yr in the south to 0.7 ± 0.2 mm/yr in the north (Mouslopoulou et al., 2007b). The paleoearthquake history of the Waiohau Fault has been summarised by Mouslopoulou et al. (2009) and, like the slip rate, earthquake recurrence interval appears to vary along the fault from 2300 ± 1300 years in the south (this data is from the north end of the Ruahine Fault, ~60 km south of the Wairoa District) to 5000 ± 1300 at the Galatea Basin (near Murapara, 25 km north of the Wairoa District) and 3600 ± 1200 years at Waiohau (50 km north of the Wairoa District). Estimates of the recurrence interval of the Waiohau Fault have not been obtained from within the Wairoa District. Where the Waiohau Fault traverses the Wairoa District we assign it to RI Class II (>2000 to ≤3500 yr) which is consistent with the RI Class of the Ruahine Fault in the Hastings District, and consistent with the available data on recurrence interval from north and south of the district (Mouslopoulou et al., 2009).

QMAP and the NZAFD250 portray the Waiohau Fault in the same location through the Wairoa District. We reviewed this mapping using regional scale orthophotographs and the 10 m DTM and agree with the fault mapping for most of the length of the fault. However, because of the intended scale for usage of the data in this report, we made some minor adjustments to the fault linework at the southern end of the western strand to make the linework more compatible with geomorphic evidence of the fault trace (Figure 2.3). Near the northern merging point of the two strands of the Waiohau Fault the NZAFD has a 10 km-long splay fault to the east of the eastern strand and three other minor (<4 km length) fault traces in the area. Our review found no geomorphic evidence on the available imagery for the three minor fault traces so we did not include them in our fault mapping. However, we do agree with the geomorphic evidence of the 10 km-long eastern splay fault, so we have retained this feature (Figure 2.3). We include this as a strand of the Waiohau Fault and assign it the same attributes as the main trace.

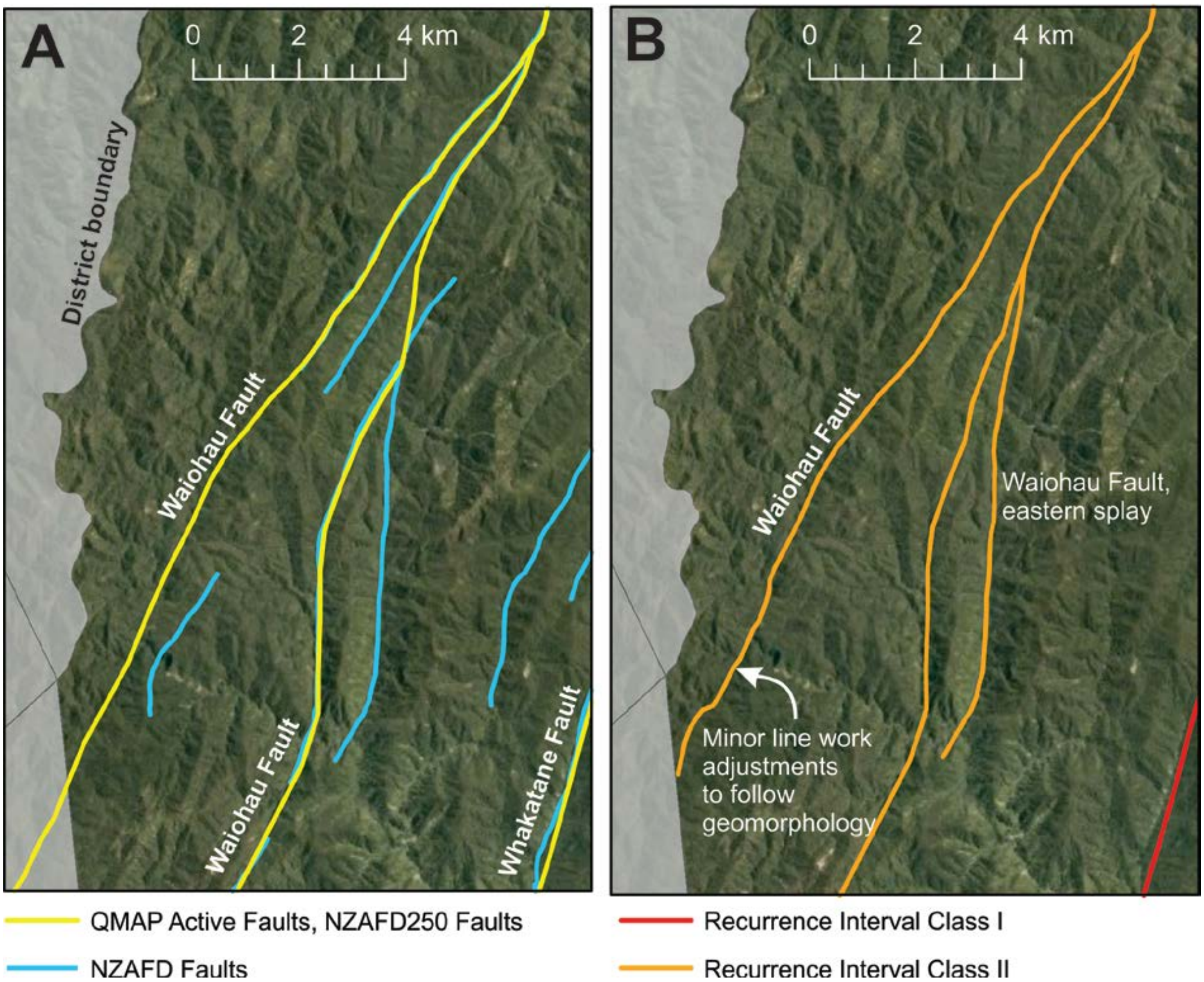

Figure 2.3 Detail of the Waiohau Fault line mapping. (A) Existing mapping of the Waiohau Fault in QMAP (same linework as NZAFD250) and the NZAFD. (B) Revised line work in this report; note, we have removed three minor fault traces and retained the 10-km long eastern splay fault.

2.1.2 Whakatane Fault

Just 3 km south of the Hastings-Wairoa District boundary the Mohaka Fault splits into two strands: the Whakatane Fault (western strand) and the Waimana Fault (eastern strand) (Figure 2.1 and Figure 2.2). The Mohaka Fault was described by Langridge and Ries (2015); it has an average recurrence interval of approximately 1000 years and there is geomorphic evidence of single event displacements of 3–5 m; it was classified as a RI Class I fault (i.e., RI ≤2000 years). The Whakatane Fault carries most of the activity from the Mohaka Fault and in the Wairoa District has a slip rate of 3.0 ± 1.1 mm/yr. This slip rate was derived from a study site at Ruatahuna, 10 km north of the Wairoa-Whakatane District boundary (Figure 2.4; Mouslopoulou et al., 2007b). Through the Wairoa District, the Whakatane Fault is dominantly strike-slip and north of Ruatahuna it has an increasing amount of normal fault movement.

There are no direct determinations of earthquake recurrence interval on the Whakatane Fault within the Wairoa District. We therefore use data from Ruatahuna (Figure 2.1 and Figure 2.4), where two paleoseismic trenches were studied by Mouslopoulou et al. (2009). At Ruatahuna there have been two earthquakes in the past 2500 years, then a 5000 year hiatus with no ground surface rupturing earthquakes, then another two earthquakes in the interval between 7500 and 9500 years before present. These four paleoearthquakes over 9500 years give a recurrence interval of ~2375 years (= RI Class II, >2000 to ≤ 3500 yr), but if only the two most recent events are considered this yields a recurrence interval of ~1250 years (= RI Class I, ≤ 2000 yr). Given the Whakatane Fault carries most of the slip from the Mohaka Fault, which is a RI Class I fault, we assign an RI Class of I to the Whakatane Fault in the Wairoa District.

Figure 2.4 Oblique aerial photograph of the Whakatane Fault (white arrows point to fault trace) running through the Ruatahuna basin. The photo perspective is looking southward toward the Wairoa District. Photo credit: Dougal Townsend, GNS Science.

Our revised mapping of the Whakatane Fault follows the QMAP and NZAFD250 fault linework for most of the length of the fault within the Wairoa District. In the south we have made some minor adjustments to the fault linework to better follow the geomorphology and have removed some short (<2 km) fault traces (Figure 2.5). There is a change in nomenclature between our mapping and that of QMAP and the NZAFD250; south of Te Hoe Rd, both QMAP and the NZAFD250 called the two fault strands the Mohaka Fault and then north of Te Hoe Rd they were called the Whakatane Fault (eastern strand) and Waimana Fault (western strand). Here we have followed the precedent set by Langridge and Ries (2015) who called the faults “Whakatane” and “Waimana” northward of the bifurcation point roughly at the Mohaka River at the northern margin of the Hastings District.

On the northern part of the Whakatane Fault in the Wairoa District our fault mapping follows the linework of QMAP and the NZAFD250, except for the addition of two minor fault traces near the northern boundary of the Wairoa District. There are some significant differences from the fault traces mapped in the NZAFD (Figure 2.6): we have neither retained several splay faults nor the sinuous fault trace near the northern boundary of the Wairoa District. Our assessment of the geomorphology from the orthophotographs is that the sinuous line of the NZAFD follows steams and valleys which could possibly be fault controlled, but the clearer evidence for the Whakatane Fault trace is to the east where there are multiple offset gullies and ridges along a straighter geomorphic feature, as mapped by QMAP and the NZAFD250 (Figure 2.6).

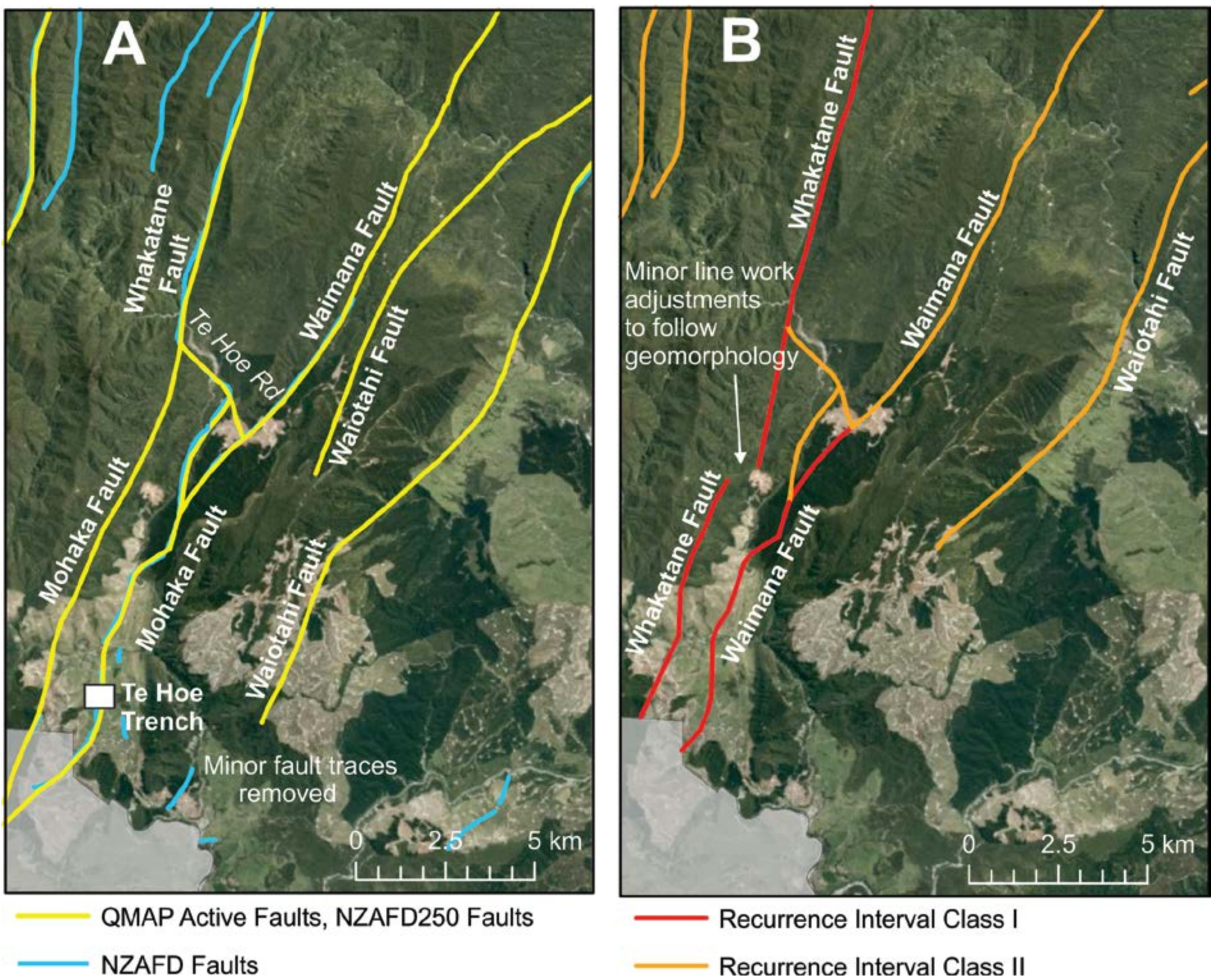

Figure 2.5 Detail of the Whakatane Fault and Waimana Fault in the southern part of the Wairoa District. (A) Existing fault mapping in QMAP (same linework as NZAFD250) and the NZAFD. (B) Revised line work in this report; note we have removed some minor fault traces splaying from the Whakatane Fault and adjusted the fault location in the south. We have renamed strands of the Mohaka Fault south of Te Hoe Rd as the Whakatane and Waimana faults. We have also decreased southward extent of the Waiotahi Fault.

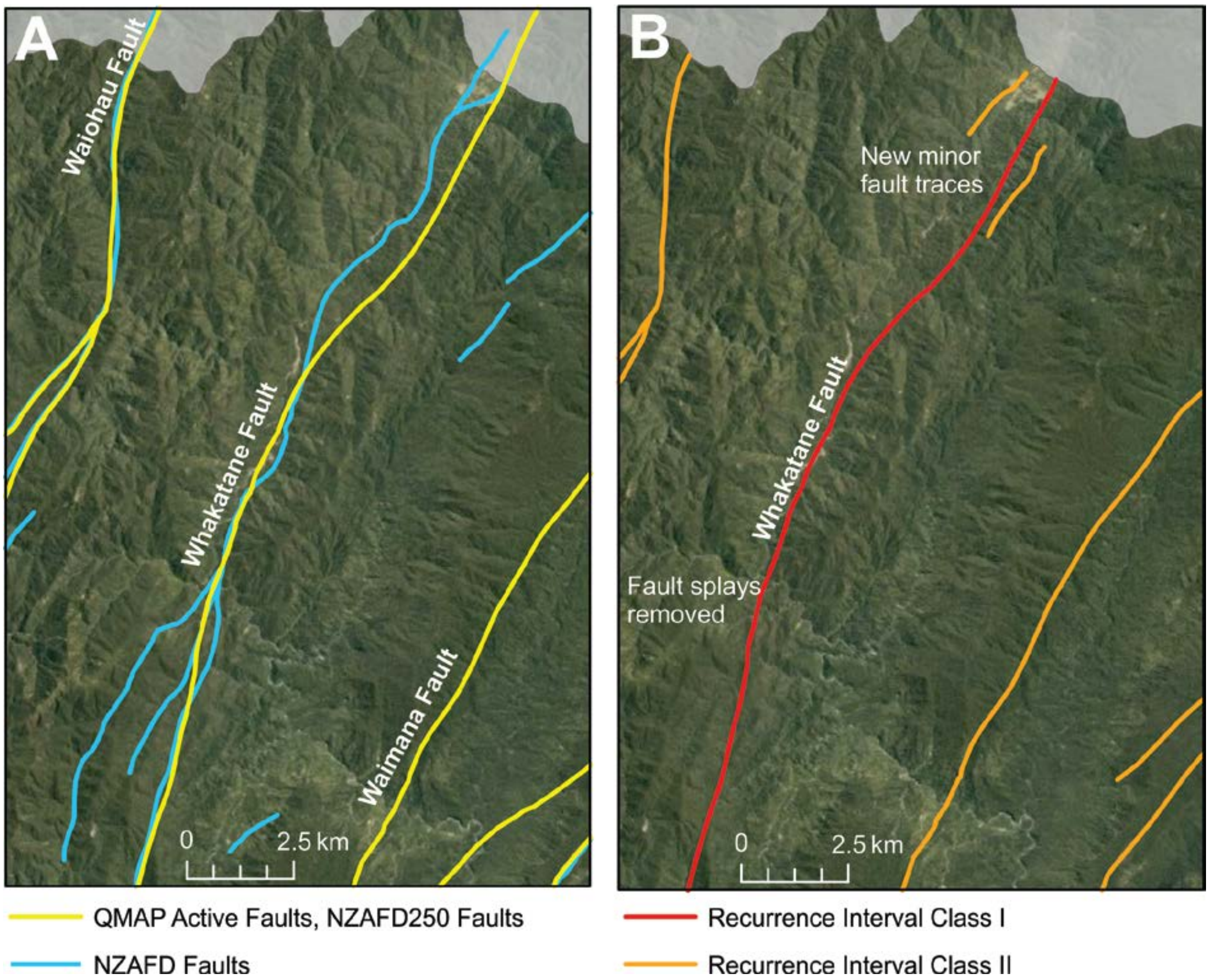

Figure 2.6 Detail of the Whakatane Fault and Waimana Fault in the northern part of the Wairoa District. (A) Existing mapping in QMAP (same linework as NZAFD250) and the NZAFD. (B) Revised line work in this report; note we have removed some minor fault traces splaying from the Whakatane Fault and added two minor fault traces near the northern Wairoa District boundary.

2.1.3 Waimana Fault

The Waimana Fault runs continuously on a northeasterly strike through the Wairoa District (Figure 2.1). Our revised mapping of this fault agrees entirely with the QMAP and NZAFD250 mapping. The geomorphic expression of the fault is not strong through most of the district and the fault mapping appears to be largely based on the geological contact between late Cretaceous sandstone (Tinui Group) in the west and Miocene mudstone (Tolaga Group) in the east. The Waimana Fault does become clearer in the topography north of the Wairoa District boundary where it forms the north-south oriented Tauranga River valley. The NZAFD did not have a trace of the Waimana Fault in its currently mapped position but it was mapped at the southern end near Te Hoe Road (Figure 2.5).

There is no data on the slip rate or paleoearthquake history of the Waimana Fault derived from within the Wairoa District so we rely on data from the northern part of the Waimana Fault, at locations ≥ 30 km north of the district boundary (Mouslopoulou et al., 2007b; 2009). The slip rate of the Waimana Fault north of the Wairoa District is about 1 mm/yr (Mouslopoulou et al., 2007b). This rate is probably applicable to the fault in the Wairoa District because the sum of the slip rates for the Waimana (~1 mm/yr) and Whakatane (~3 mm/yr) faults should *approximately* equal the slip rate of the Mohaka Fault (3–4 mm/yr, Langridge et al., 2016). It should also be noted that the fault changes in character from dominantly strike-slip in the south to normal in the north; in the Wairoa District it is dominantly strike-slip but at the northern locations, where data has been collected, it is dominantly normal (Figure 2.2).

The recurrence interval of the Waimana Fault can be calculated from the timing of paleoearthquakes identified both within and north of the Wairoa District. At the southern end of the Waimana Fault a study site called, called the Te Hoe trench (Figure 2.5A), revealed six earthquakes in the past 9500 years yielding a recurrence interval of 1500 years (= RI Class I, ≤ 2000 years; Hull 1983). This contrasts with information from the northern Waimana Fault where, at Te Ahirau (~30 km north of the Wairoa District boundary), at least three three earthquakes in the past 13,000 years were determined giving a maximum recurrence interval of 4300 years (= RI Class III, >5000 to ≤10,000 yr). However, this recurrence interval is a minimum because the paleoseismic trench did not preserve evidence of earthquakes between ~3000 to 8000 years BP (Mouslopoulou et al., 2009). A third site located ~25 km north from Te Ahirau records 4 earthquakes in 13,000 years and yields a recurrence interval of 3250 years (= RI Class II: >2000 years to ≤3500 years; Mouslopoulou et al., 2009). Given the varying information baring on the recurrence interval for the Waimana Fault, we assign the southern end of the fault (encompassing the segment on which the Te Hoe fault trench was located) to RI Class I (≤2000 yr), and the rest of the fault (north of Te Hoe Road, Figure 2.5) is assigned to RI Class II (>2000 to ≤3500 yr).

An un-named active fault trace was present in the NZAFD in the northern part of the Wairoa District in between the Whakatane and Waimana faults. We reviewed the orthophotos and DTM in this area but could see no strong evidence of a fault so we have not retained it as an active fault trace.

2.1.4 Waiotahi Fault and Koranga Fault

The Waiotahi Fault runs from ~20 km south of Lake Waikaremoana, to the northeast, beyond the Wairoa District boundary. At 6 km south of the Wairoa District boundary a fault, named the Koranga Fault, branches from the Waiotahi Fault (Figure 2.1). Little is known about the slip rates of either of these faults and they have not been the subject of any paleoearthquake investigations. At locations north of the Wairoa District slip rates of about 1 mm/yr have been obtained on the Waiotahi Fault (Mouslopoulou et al., 2007b). Given that the fault has approximately the same slip rate as the Waimana Fault we assign the Waiotahi Fault an RI Class of II (>2000 to ≤3500 yr), although acknowledge that without any paleoearthquake data this has a high degree of uncertainty. Slip rates have not been obtained from the Koranga Fault so, like the Waiotahi Fault, we assign a RI Class of II but this has a high degree of uncertainty. The Koranga Fault is generally less well-expressed in the topography than the Waiotahi Fault so may have a lower slip rate and longer recurrence interval, however, considering the data uncertainties we consider it prudent at this time to be conservative, and assign the same (shorter) RI Class to the Koranga Fault as we assign to the Waiotahi Fault (i.e., RI Class II).

Our mapping of the Waiotahi Fault and Koranga Fault generally follows the same linework as QMAP and NZAFD250, and these do not differ significantly from mapped fault traces in the NZAFD. At the southern end of the Waiotahi Fault there are two fault traces; our revised mapping has not extended these as far southwards as the QMAP and NZAFD250 mapping because we cannot see any geomorphic expression of these faults with the available imagery (Figure 2.5). At the northern end of the Waiotahi Fault our fault mapping is slightly different from that of QMAP, NZAFD250 and the NZAFD (Figure 2.7). We have shifted the linework to better follow the geomorphic expression of a fault trace and we have added a short (<2 km) fault trace just south of the junction of the Waiotahi and Koranga faults.

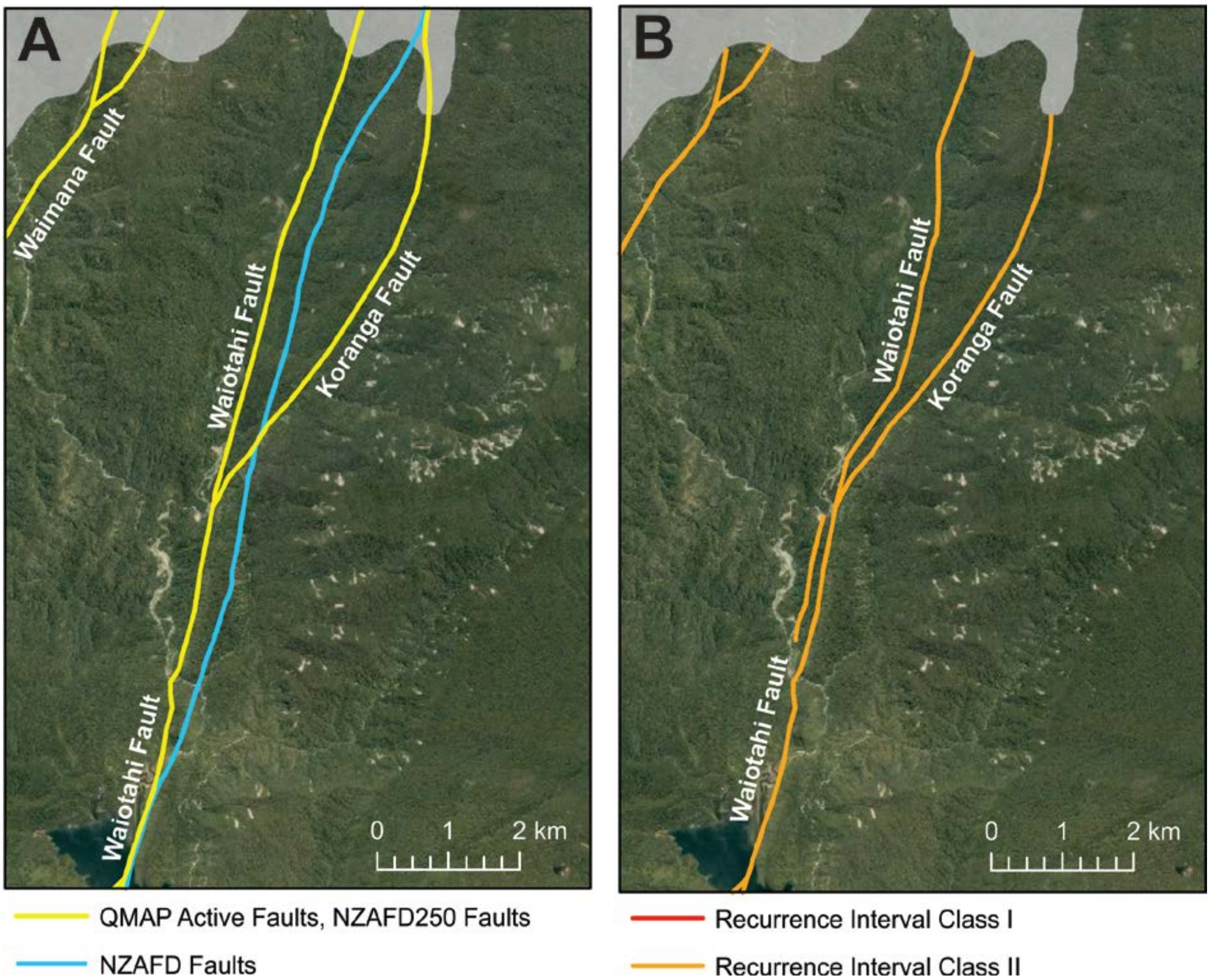

Figure 2.7 Detail of the northern part of the Waiotahi Fault and the Koranga Fault in the Wairoa District. (A) Existing mapping in QMAP (same linework as NZAFD250) and the NZAFD. (B) Revised line work in this report; note we have adjusted the location of the Waitohai Fault in the north and mapped a new fault trace just south of Waiotahi-Koranga Fault junction.

2.1.5 Rangiora Fault

Near the southern boundary of the Wairoa District is the northern end of the Rangiora Fault. This was previously mapped by Langridge et al. (2011) and our revision of the fault linework has not changed the location, nor is there any updated information on the fault slip rate or paleoearthquake history. From the Hastings-Wairoa District boundary northward, approximately 4.5 km of the Rangiora Fault is well expressed in the topography but then the remaining 3 km (from Extension Road to 1.5 km south of the Mohaka River, Figure 2.8) the fault traces are less clear, and this may reflect a diminishing amount of total fault movement toward the northern end of the Rangiora Fault. The most up-to-date information on the slip rate and paleoearthquake history of the Rangiora Fault is derived from Cutten et al. (1988). Langridge et al. (2011) used the information from Cutten et al. (1988) to calculate a slip rate of ~4.4 ± 1 mm/yr, an average recurrence interval of c. 570 yr, and a RI Class of I (<2000 yr). The fault mapping of QMAP and NZAFD250 both had a trace of the Rangiora Fault for 4.5 km northward from the Hastings-Wairoa District boundary; the fault linework was slightly offset (by ~40 m eastward) from the more detailed mapping of Langridge et al. (2011)

(Figure 2.8). We use the linework as mapped by Langridge et al. (2011), and adopt the ~3 km northward fault trace (from Extension Road to 1.5 km south of the Mohaka River, Figure 2.8).

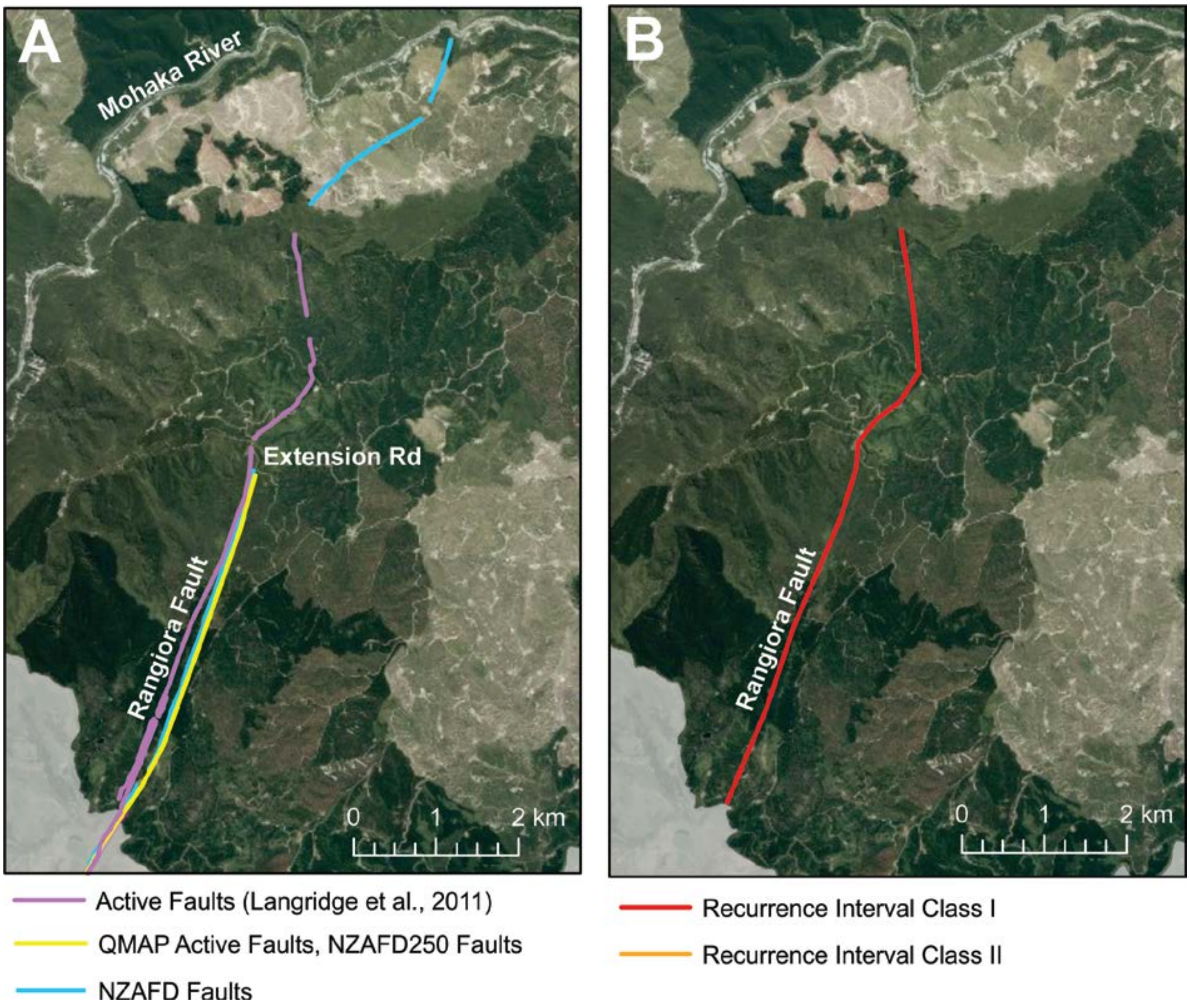

Figure 2.8 Detail of the Rangiora Fault in the southern part of the Wairoa District. (A) Existing mapping of the Rangiora Fault in QMAP (same linework as NZAFD250), NZAFD, and Langridge et al. (2011). (B) Revised line work in this report; note we largely adopted the trace mapped by Langridge et al. (2011).

2.2 EASTERN WAIROA DISTRICT

2.2.1 Northeastern Wairoa

In the low hill country in the eastern part of the Wairoa District numerous short traces of active faults had been previously mapped (NZAFD), but revisions of the active fault mapping has reduced the number of traces (Langridge et al., 2011, QMAP and NZAFD250). QMAP has only four short (<2 km long) fault traces and the NZAFD and Langridge et al. (2011) map approximately 20 short (0.3–3 km) traces (Figure 2.9). For this report we adopt all the fault traces mapped by Langridge et al. (2011) because they utilised aerial photos as a means of identifying active fault traces, and the imagery we have available for this report cannot improve on the aerial photos used previously by Langridge et al. (2011). We are relatively confident of the active fault identification for the set of northwest-striking lineations approximately 16 km northeast of Wairoa township, near the junction of Mangapoike Rd and Hereheretau Rd (circled in Figure 2.9B). The remainder of the active fault traces have a high degree of uncertainty regarding whether they are actually active faults, or possibly other geomorphic features such as landslides scarps (which still pose a land movement hazard) or bedrock lineaments. This could probably only be resolved through field visits and/or scrutiny of higher resolution imagery such as LiDAR. The recurrence intervals of the fault traces in the eastern Wairoa District are unknown, and until additional focused investigations are undertaken, that will remain the case.

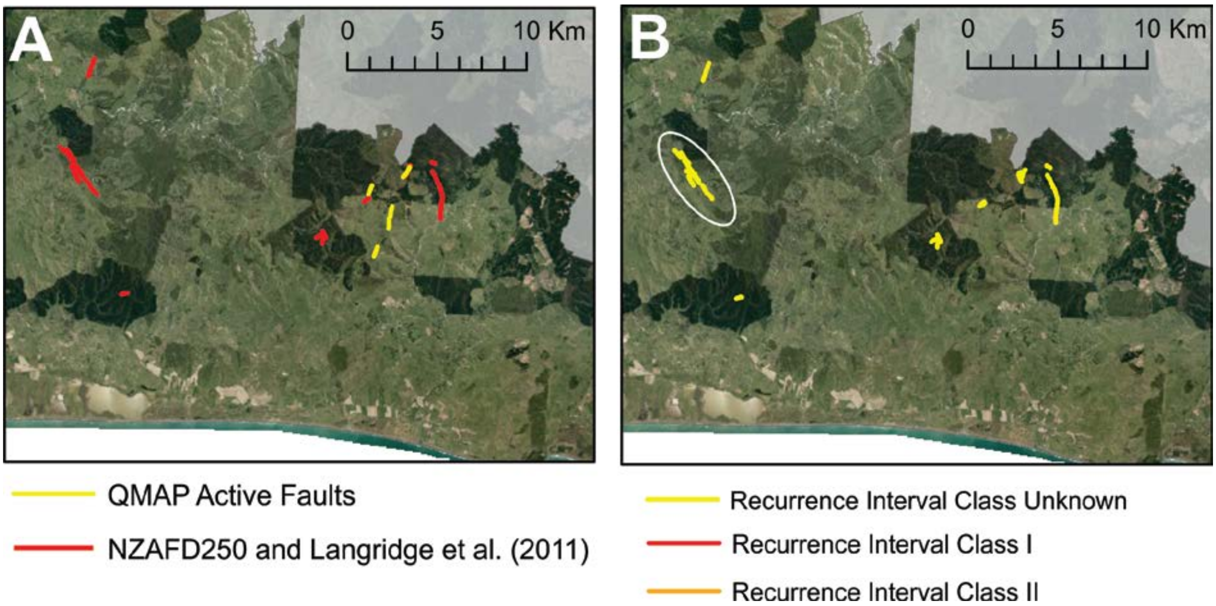

Figure 2.9 Detail of active fault traces in northeastern Wairoa District. (A) Existing mapping in QMAP, Langridge et al. (2011), and NZAFD250. (B) Revised line work in this report; note we adopt the same linework as Langridge et al. (2011). The fault circled in white (near the junction of Mangapoike Rd and Hereheretau Rd) is the only fault trace that is confidently mapped and identified as an active fault, the remainder have a high degree of uncertainty as to whether they are actually active faults.

2.2.2 Mahia Peninsula

There are four short (<2 km) traces of active faults on the Mahia Peninsula (Figure 2.1). Our fault mapping agrees with that of Langridge et al. (2011) and no further information on fault parameters have been obtained since the time of that report (see Section 3.1.3 in Langridge et al., 2011). These fault traces are likely to be secondary tectonic features related to the rapid uplift of Mahia Peninsula; the faults offset marine terrace surfaces that are ~128,000 years old and Langridge et al. (2011) assigned them a RI Class of IV. QMAP does not have any active faults mapped on the Mahia Peninsula but the NZAFD250 has three traces that are in approximately same locations as the four traces mapped by Langridge et al. (2011).

2.3 SUMMARY OF ACTIVE FAULTS IN THE WAIROA DISTRICT

Table 2.1 shows a summary of the active fault parameters for the main faults of the Wairoa District. The strike slip faults that form part of the NIFS have slip rates of between 1 and 5 mm/yr with the Whakatane and Rangiora faults having the highest slip rates and correspondingly lower RI Class of I (<2000 yr). The remainder of the strike slip faults (Waiohau, Waimana, Waiotahi and Koranga) are assigned RI Class II faults (>2000 to ≤3500 yr), except for the southern part of the Waimana Fault which is RI Class I. Very little is known about the short segments of active faults in the eastern Wairoa District, and we are unable to assign them a slip rate, recurrence interval, or RI Class for Fault Avoidance Zone mapping. Three short fault traces on Mahia Peninsula have been assigned RI Class IV.

Table 2.1 Summary of the main known active faults in Wairoa District.

Fault Name	Fault style	RI Class†	References
Waiohau	dextral	II	Mouslopoulou et al. (2007, 2009)
Whakatane	dextral	I	Mouslopoulou et al. (2007, 2009)
Waimana	dextral	I-II	Hull (1983); Mouslopoulou et al. (2007, 2009)
Waiotahi	dextral	II*	Mouslopoulou et al. (2007)
Koranga	dextral	II*	This report
Rangiora	dextral	I	Cutten et al. (1988)
NE Wairoa**	normal	ND	This report
Mahia Peninsula**	normal	IV	Langridge et al. (2011)

Notes

* Preliminary result based on comparing the expression of similar, nearby faults.

** No formal fault names are given, this describes the geographic location of the faults

† RI Class from on Kerr et al. (2003). RI Class I: ≤2000 years; RI Class II: >2000 to ≤3500 years; RI Class IV: >5000 to ≤10,000 years. ND: no data.

3.0 FAULT AVOIDANCE ZONE MAPPING

Fault Avoidances Zones have been produced around all mapped active faults in the Wairoa District. A Fault Avoidance Zone includes the **fault rupture hazard zone**, and the **buffer zone**. The MfE Guidelines recommend that the buffer zone is 20 m. The width of **fault rupture hazard zone** depends on the accuracy of the fault mapping, which is influenced by:

- the **data source**
- the **scale** at which the fault has been digitised
- the fault **complexity** (i.e., how well the fault can be recognised from its geomorphic expression).

In practice, for the Wairoa District, the **data source** and **scale** dictate the width of **fault rupture hazard zone** because the uncertainty introduced by fault complexity is much less than the amount of uncertainty introduced by the data source and scale. We have therefore not included a fault complexity factor in Tale 3.1. Further information on fault location uncertainty, attributes and fault avoidance zones is in Appendix A1.2. The widths of Fault Avoidance Zones for this study are presented in Table 3.1.

All faults in the Wairoa District have an accuracy of “Uncertain” because they have all been mapped from QMAP, NZAFD, 10 m DTMs or orthophotos. In previous reports for the Hawkes Bay Regional Council (Langridge et al., 2014; 2015) strike slip and normal faults that have been assigned an accuracy of “Uncertain” (i.e., mapped from QMAP, NZAFD, orthophotos, and 10 m DTM) have a Fault Avoidance Zone width of 290 m (= fault rupture hazard zone of ±125, and ±20 buffer). However, for this report we introduce an additional factor of “Terrain” in our calculation of the Fault Avoidance Zone width (Table 3.1).

- For faults mapped in areas of cleared land and/or on gentle to flat topography we use a **fault rupture hazard zone** of ±125 m (Table 3.1). This brings the total Fault Avoidance Zone width to 290 m (Table 3.1).
- For faults mapped in forested and steep topography we double the width of the **fault rupture hazard zone** to ±250 m. This brings the total Fault Avoidance Zone width to 540 m (Table 3.1).

The reason for increasing the fault rupture hazard zone to ±250 m in areas of forested, steep topography is simply that these faults are significantly harder to locate in this terrain, therefore the uncertainties are larger. Our use of a ±250 m fault rupture hazard zone contrasts with the Fault Avoidance Zone widths used by Langridge et al. (2014; 2015), however, the wider fault rupture hazard zone is justified in the Wairoa District for two reasons: (1) the main strike slip faults of the Wairoa District traverse through the axial ranges, rather than traversing the less steep and less forested eastern margins of the ranges as they typically do further to the south, therefore the faults are more difficult to map; (2) the main strike slip faults of the Wairoa District are in a transitional zone in terms of fault style (i.e., changing from dominantly strike slip to normal) and strike (i.e., changing from northeast-southwest striking, to north-south striking. These transitions mean that the faults are less well expressed in the landscape than they are both south and north of the Wairoa District.

The strike slip faults of the NIFS (Waiohau, Whakatane, Waimana, Waiotahi and Koranga) that traverse the axial ranges have a Fault Avoidance Zone width of 540 m. The Rangiora Fault is largely in cleared land, and was mapped using orthophotos by Langridge et al.

(2011); it therefore has a Fault Avoidance Zone width of 290 m The faults of northeastern Wairoa and Mahia Peninsula also have Fault Avoidance Zone widths of 290 m because they are located in cleared land and gentle topography, and were mapped from orthophotos by Langridge et al. (2011). An example of the Fault Avoidance Zones for parts of the Whakatane, Waimana and Waiotahi faults in the southern part of the Wairoa District is shown in Figure 3.1.

Table 3.1 Widths of Fault Avoidance Zones for Wairoa District.

Slip Type	Data Source	Map Scale	Accuracy	Terrain	Fault Rupture Hazard Zone (m)	Buffer (m)	Fault Avoidance Zone width (m)
Strike slip and normal	Orthophoto +10-m DTM	1:20,000	Uncertain	Cleared land / gentle to flat topography	±125	±20	**290**
	10-m DTM + QMAP, NZAFD250	1:250,000	Uncertain	Cleared land / gentle to flat topography	±125	±20	**290**
	10-m DTM + QMAP, NZAFD250	1:250,000	Uncertain	Forested, steep topography	±250	±20	**540**

Figure 3.1 Detail of the Whakatane Fault and Waimana Fault in the southern part of the Wairoa District. Revised line work in this report and Fault avoidance Zones

4.0 SUMMARY

- Active fault traces have been mapped in a GIS database across Wairoa District using a national scale 10 m resolution DTM and orthophotograph basemap, QMAP active fault linework, the NZAFD and the NZAFD250. This work builds on and supersedes previous fault linework and avoidance zones for parts of the Wairoa District produced by Langridge et al. (2011). In this report, Fault Avoidance Zones and GIS attributes, including Fault Name, Accuracy, and Recurrence Interval Class are presented along with the active fault linework.
- Recurrence intervals for surface faulting have been defined for the named faults of the North Island Fault System in the west of the Wairoa District. There are two RI Class I faults (Whakatane and Rangiora faults) and several RI Class II faults (Waiohau, Waimana, Waiotahi and Koranga faults) in the district. There are three fault traces on the Mahia Peninsula of RI Class IV and several fault traces in the eastern Wairoa District for which an RI Class could not be assigned.
- Fault Avoidance Zones have been defined based on the accuracy of mapping, and an additional setback zone in accordance with the MfE Guidelines.
    - Faults mapped across cleared land, or in areas of gentle to flat topography, using QMAP and NZAFD250 linework, 10 m DTMs and orthophotos have a fault rupture hazard zone of ±125 m and a buffer of +20 m, this yields Fault Avoidance Zone widths of 290 m.
    - Faults mapped across forested and steep topography using QMAP and NZAFD250 linework, 10 m DTMs and orthophotos have a fault rupture hazard zone of ±250 m and a buffer of +20 m, this yields Fault Avoidance Zone widths of 540 m.

5.0 RECOMMENDATIONS

- We recommend that the updated fault linework and Fault Avoidance Zones presented as digital geospatial data be adopted by Wairoa District Council, and should supersede previous versions of active fault linework, attributes and Fault Avoidance Zones provided by GNS Science.
- We recommend that the MfE Guidelines regarding active faulting should be used as standard practice for planning and consenting in Wairoa District, and that these fault traces be incorporated within District Plan maps where possible, or within Council GIS databases.
- We also recommend that active fault linework and Fault Avoidance Zones should be updated every decade, or when new LiDAR coverage becomes available. Given the large locational uncertainties for the faults of the Wairoa District, we recommend LiDAR surveys in areas of urban and rural development to facilitate more precise fault mapping.

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APPENDICES

A1.0 APPENDIX 1: ACTIVE FAULT DESCRIPTIONS AND ATTRIBUTES

In the appendices we have placed useful information, with regards to active fault mapping and the MfE Guidelines, that is repeated from the Hastings District active fault mapping study of Langridge and Ries (2015). This information has not changed since the 2015 study and has been minimally altered for this report. .

A1.1 WHAT IS AN ACTIVE FAULT?

Active faults are those faults considered capable of generating strong earthquake shaking and ground surface fault rupture, causing significant damage. Ground surface-rupturing earthquakes are typically of magnitude M_w >6.5. An active fault in New Zealand is generally defined as one which has deformed the ground surface within the past 125,000 years (Langridge et al., 2016).This is defined in part for practical reasons as those faults which deform marine terraces and alluvial surfaces that formed during the 'Peak Last Interglacial period' or Marine Isotope Stage (MIS) 5e, or younger (MIS 1–4; e.g., Alloway et al. 2007).

The purpose of this chapter is to introduce how active faults express themselves, i.e., their behaviour, styles of deformation, activity and geomorphic expression. Active faults are expressed in the landscape as linear traces displacing surficial geologic features which may include hillslopes, alluvial terraces and fans. The age of these displaced features can be used to define how active a fault is. Typically in New Zealand, alluvial terraces are associated with the contemporary river drainages, and therefore they are typically <30,000 years old. Hillslopes are mainly formed in bedrock and in New Zealand these surfaces have generally been modified by glacial or cold climate processes during the peak of the Last Glacial period. This means that well-defined, linear fault traces that cut across bedrock hillslopes are probably also <30,000 years old.

Active faults are often defined by a fault scarp. A fault scarp is formed when a fault displaces or deforms a surface and produces an abrupt linear step, which smooths out with time to form a scarp (Figure A1.1). In some cases, where a fault moves horizontally, only a linear trace or furrow may be observed. Traditionally, faults have been mapped from aerial photographs using stereoscopy, i.e., pairs of overlapping aerial photographs that can be used to visualise the ground surface in 3-D. Airborne LiDAR and detailed Digital Elevation Models (DTM's) have greatly improved the accuracy to which active fault traces can be mapped.

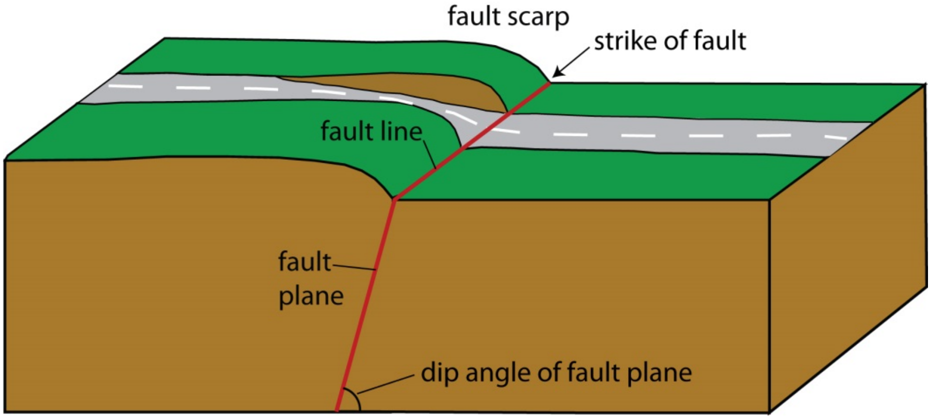

Figure A1.1 Block model of a generic active fault. Fault displacement produces a scarp along the projection of the fault plane at the Earth's surface (fault line or trace).

A1.1.1 Styles of fault movement

Faults can be categorised as: strike-slip faults, where the dominant style (sense) of motion is horizontal (movement in the strike direction of the fault), and dip-slip faults, where the dominant sense of motion is vertical (defined by movement in the dip direction of the fault). Strike-slip faults are defined as either right-lateral (dextral), where the motion on the opposite side of the fault is to the right (Figure A1.2), or, left-lateral (sinistral) where the opposite side of the fault moves to the left.

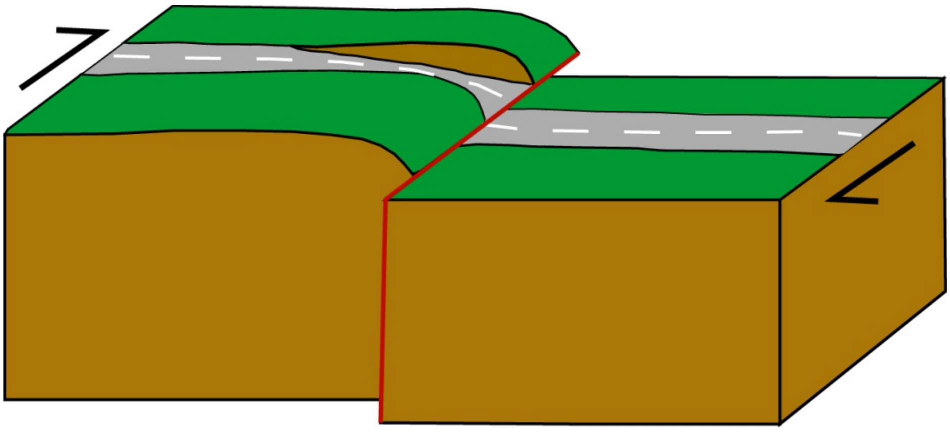

Figure A1.2 Block model of a strike-slip faultFigure A (red line). The fault is a right-lateral fault as shown by the black arrows and by the sense of movement across the two blocks and a right separation across the road.

Most strike-slip faults in New Zealand, such as the Alpine, Hope, Wairarapa and Wellington faults, have a mainly right-lateral sense of movement (Berryman and Beanland 1991). Right-lateral strike-slip faults predominate within and on the boundaries of the main Axial Ranges in the western part of Wairoa District, and include the Whakatane and Waiohau faults.

Dip-slip faults can be divided into reverse faults, formed mainly under contraction (where the hangingwall block of the fault is pushed up; Figure A1.3) and normal faults, formed under extension (where the hangingwall block of the fault drops down; Figure A1.4). No reverse faults have been mapped onshore in the Wairoa District, although there are some offshore of Mahia Peninsula (Barnes et al., 2002). Short traces of normal faults have been mapped in the east of the Wairoa District.

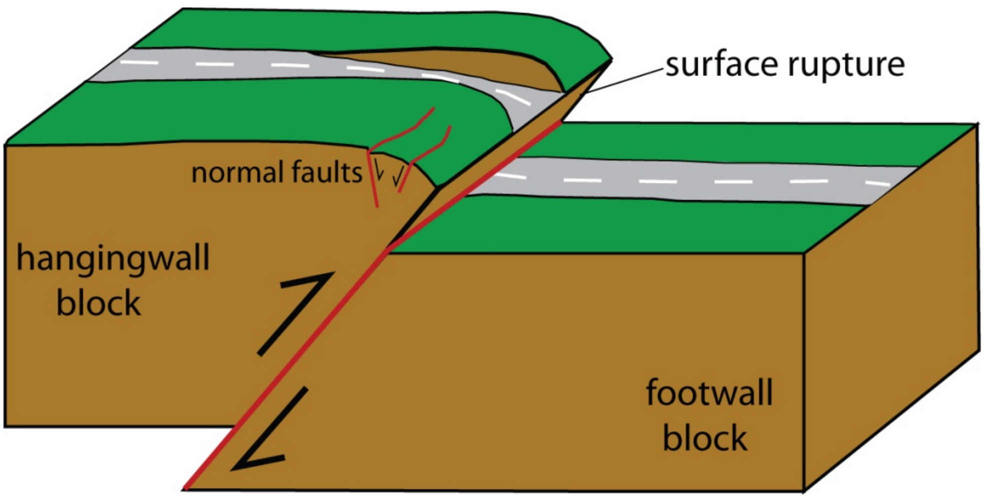

Figure A1.3 Block model of a reverse dip-slip fault that has recently ruptured. Movement of the blocks is vertical and in the dip direction of the fault plane. In this case, the hangingwall block has been pushed up over the footwall block. Folding and normal faulting are common features of deformation in the hangingwall block of reverse faults.

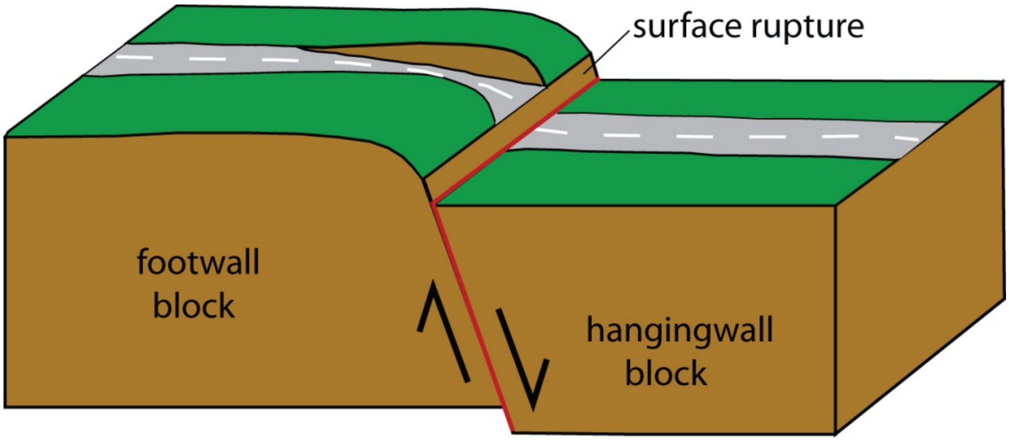

Figure A1.4 Block model of a normal dip-slip fault.Figure A The relative movement of the blocks is vertical and in the dip direction of the fault plane. The hangingwall block has dropped down, enhancing the height of the fault scarp.

A1.1.2 Active fault parameters: recurrence interval, slip rate and single-event displacement

An important parameter in terms of the hazard posed by an active fault is its recurrence interval. This term refers to the average amount of time between earthquakes large enough to rupture the Earth's surface along the fault. The MfE Guidelines define six recurrence interval classes of active faults based on recurrence times (Table A1.1). In general, the recurrence interval classes were defined to offer levels of collapse prevention (i.e., life-safety) compatible with levels prescribed in the New Zealand Building Code. Faults with the highest activity fall into RI Class I; these faults have an average recurrence interval of ≤2000 years. The least active class of faults is RI Class VI which includes faults that have an average recurrence interval of 20,000 to 125,000 years (Table A1.1). Planning restrictions developed from the MfE Guidelines typically increase with a decrease in the Recurrence Interval Class of the fault.

Table A1.1 Average Recurrence Interval of Surface Rupture, RI Classes and examples of New Zealand faults that fall in each RI Class.

Recurrence Interval Class	Average Recurrence Interval of Surface Rupture	NZ examples (faults); Wairoa District examples in bold
I	≤2000 years	Alpine, Hope, Awatere, Wellington, **Whakatane**, **Rangiora**
II	>2000 years to ≤3500 years	Ostler FZ, Ohariu, Makuri, Rangipo, **Waiohau, Waimana**
III	>3500 years to ≤5000 years	Lake Heron, Poutu
IV	>5000 years to ≤10,000 years	Dalgety, Esk, Karioi
V	>10,000 years to ≤20,000 years	Pisa, Greendale, Martinborough
VI	>20,000 years to ≤125,000 years	ND

Notes: Faults with average recurrence intervals >125,000 years are not considered active. FZ = Fault Zone.

When the timing of individual past surface rupturing earthquake events needs to be defined, paleoseismic trenches are excavated at sites where the fault and its relationship with recent sediments can be exposed. These sediments offer the opportunity to separate out the evidence for discrete paleoseismic or past surface-rupturing earthquakes.

In the absence of paleoseismic trenching, slip rate and single-event displacement data in combination with geomorphic landscape assessment forms the basis of how faults are defined according to Recurrence Interval Class for the MfE Guidelines. Careful measurement of well-dated and displaced geomorphic features can be used to calculate a slip rate or displacement rate for a particular fault. A slip rate is the velocity of the fault measured over time, i.e., displacement divided by time. For example, Whakatane Fault has a moderate slip rate of c. the 3 ± 1 mm/yr. (or 3 metres per thousand years). In reality, fault displacement occurs in steps during large earthquakes that shift the Earth on either side of the fault by metres at a time (Figure A1.2). Thus, when there is no data available from trenches, the recurrence interval can be defined through the combination of slip rate and single-event displacement data. These latter calculations are often limited by a lack of data and sometimes rely on assuming the age of a faulted surface or the likely amount of displacement in a single event along a fault and hence the designated recurrence interval is defined as tentative.

A1.2 FAULT LOCATION UNCERTAINTY, ATTRIBUTES AND FAULT AVOIDANCE ZONES

For this study, the location and attributes pertaining to active faults have been assembled in a Geographic Information System (GIS) and recorded in a digital geospatial database (provided as supplementary to this report). A detailed description of the attributes assigned to fault locations is contained in Appendix A1.3.

The digitising of active faults requires expert recognition of fault-influenced geomorphic landforms and an understanding of the local geology. The most obvious landform feature associated with surface fault rupture is a fault scarp (Figure A1.1). Fault scarps are steps in the land surface that coincide with the locations of faults. They can extend for hundreds of metres to many kilometres in length and are often many metres wide. Therefore, representing a scarp as a line within a GIS is problematic. In practice, a line within a GIS database has a width of zero and is meant to represent the location where it is estimated the fault would rupture the ground surface. Active faults are more appropriately defined as zones rather than lines. This is because of the location uncertainty of digitising or surveying a line, the lack of knowledge on the exact location of the fault plane (unless the fault plane is exposed in, for example, an excavation or a river bank), and because the surface area that will be deformed by faulting is likely to be somewhat wider than the main fault plane.

The accuracy with which the location of a fault feature can be represented in a GIS is influenced by three main types of uncertainty. The first is the uncertainty of the source data relative to a global datum. This uncertainty can be quantified and is differentiated in this study with the attribute in the field **DATA_SOURCE**. The second is resolution of the source data, (i.e., the scale at which a geomorphic landform is able to be resolved from the data). This can be expressed as an average scale at which the fault has been digitised and has been attributed in the field **SCALE**. The third is the uncertainty associated with how accurately the feature can be identified from a geomorphic study and the complexity of the surface deformation associated to a given fault feature. This is also a reflection of the expression of a tectonic (fault-related) feature and is defined as ‘Fault Complexity’ in the MfE Guidelines. Fault complexity is an important component in the definition of planning consent categories. In this study the **ACCURACY** attribute encompasses this expression uncertainty.

These distinctions concerning locational uncertainty are important because of: (i) how they relate to the accuracy of the fault linework; (ii) how we build Fault Avoidance Zones from that linework; (iii) how this fault data is applied by Councils; and, (iv) how the scale and accuracy affect individual land and building owners.

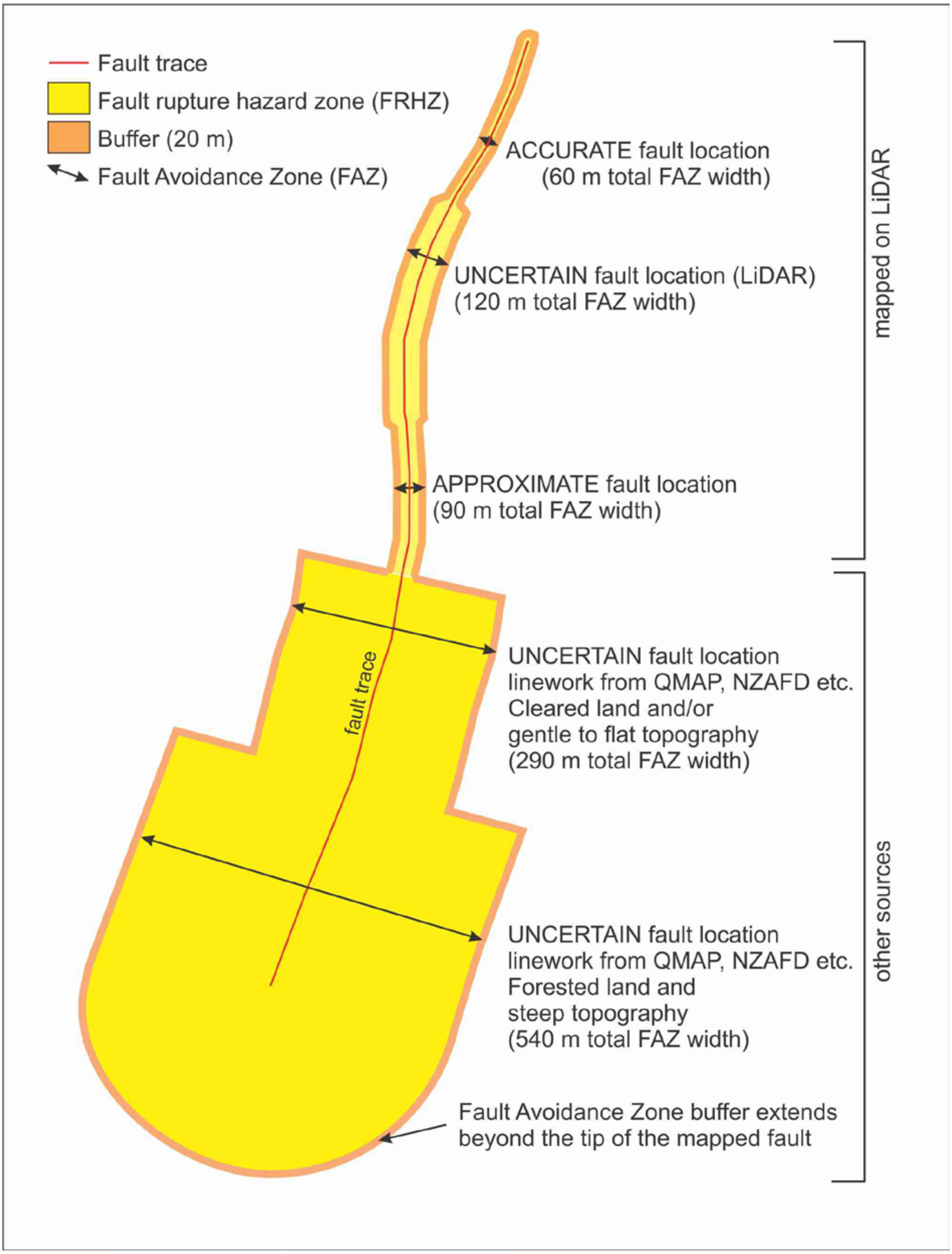

Figure A1.5 Fault Avoidance Zones (FAZ, sum of yellow and orange) for hypothetical strike-slip or normal faults with varying Fault Location accuracy along strike. The zones at the ends of fault traces are extended and rounded to account for the possibility of deformation extended beyond their tips. This figure shows that the FAZ widths can be narrowed significantly if LiDAR is acquired.

Once a fault trace location has been identified, attributes to describe the fault allow for the calculation of Fault Avoidance Zones (FAZ's) that reflect the uncertainty regarding the position of surface faulting. The attributes from the fields **DATA_SOURCE, MAP_SCALE** and **ACCURACY**, are used to define the width of one side of FAZs and is assigned a value in metres in the field **FRHZ.** A visual representation of the varying width of a FAZ is presented in Figure A1.5.

The style of faulting (**SLIP_TYPE**) can also influence the width of the zone of surface rupture. For strike-slip and normal faults an equal width either side of the fault is used to develop a FAZ because there is no geological preference toward distributed deformation on one side. However, for reverse faults, it has been demonstrated that the hangingwall block (or uplifted side) of the fault has an increased amount of fault deformation relative to the footwall side.

In addition, the MfE Guidelines recommend that a *Buffer* of +20 m be included as part of the FAZ. This buffer gives some assurance that there is unlikely to be any fault deformation outside the entire width of the Fault Avoidance Zone. The widths of Fault Avoidance Zones for this study are presented in Table 3.1.

A1.3 GIS DATA

This study includes digital data supplied as two ESRI shapefiles, consisting of a polyline shapefile of mapped faults and a polygon shapefile of Fault Avoidance Zones. These data and their attributes are described below.

File Name: WairoaDC_Faultlines_CR_2016_133
Type: Polyline
Projection: NZGD 2000 New Zealand Transverse Mercator.prj

Each mapped fault trace is represented as a series of features that have been attributed with the following information:

FAULT_NAME: A fault name is supplied for faults that are long or connected enough to have been given a distinct name in previous studies, i.e., they have an established geological name, e.g., Mohaka Fault or Waipukurau Fault Zone. Many short fault traces or unconnected pieces have yet to be given names.

SECTION: The name given to a fault section. In some cases a fault may be subdivided into distinct sections, where there is a geographical or structural break in the fault. A fault section will typically consist of several to many individual fault traces.

DATA_SOURCE: Refers to the source of the data used to map the fault trace. For this study the data source is limited to:

Clark et al., 2016: Data from this report

Langridge et al., 2011: Data from previous Wairoa fault mapping report

QMAP: Data from QMAP geologic mapping program of New Zealand

NZAFD: Data from New Zealand Active Fault Database (NZAFD)

NZAFD250: Data from New Zealand Active Fault Database (NZAFD250). Scale 1:250 000

SCALE: The scale at which the feature was digitised.

ACCURACY: Refers to the ability to identify and clearly map fault-related features from the available imagery and is limited to three possibilities.

Accurate: Where a fault scarp can be clearly mapped.

Approximate: Where the fault/trace is not as clearly expressed but there is clear geomorphic evidence of a surface fault rupture.

Uncertain: Where the fault is concealed (buried) or eroded away i.e., where a fault crosses an active river or floodplain.

FRHZ (Fault Rupture Hazard Zone): Is a number value in metres with which we consider to be the maximum mapped location uncertainty for a fault line. These values are used for defining the widths of Fault Avoidance Zones.

For this study the values used are based on the **DATA_SOURCE, SCALE** and **ACCURACY** attributes as explained in the text.

±*125 m*: All linework from sources mapped at a scale greater than 1:10,000, i.e., QMAP, regional DTM or the NZAFD, in areas of cleared land, and/or areas of gentle to flat topography. A value of ±125 m is used regardless of whether its location is considered accurate, approximate or uncertain.

±*250 m*: All linework from sources mapped at a scale greater than 1:10,000, i.e., QMAP, regional DTM or the NZAFD, in areas forested, steep topography. A value of ±250 m is used regardless of whether its location is considered accurate, approximate or uncertain.

SLIP_TYPE: Refers to the dominant sense of movement on a fault. These are as described in Chapter 2 and include:

Dextral (right-lateral), *Sinistral* (left-lateral), *Reverse*, *Thrust, and Normal*

The terms *strike-slip*, *dip-slip* and *<Null>* are sometimes used when the style of movement is unclear.

DOWN_QUAD: Refers to the compass quadrant that is downthrown relative to the strike of the fault. They are limited to the following attributes:

N, S, E, W, NW, NE, SW, SE

RI_CLASS: relates to the recurrence interval of faulting. The MfE Guidelines (Kerr et al., 2003) define six recurrence interval classes (RI Classes I-VI) depending on the activity of the fault.

Class I:	≤2000 yr
Class II:	>2000 to ≤3500 yr
Class III:	>3500 to ≤5000 yr
Class IV:	>5000 to ≤10,000 yr
Class V:	>10,000 to ≤20,000 yr
Class VI:	>20,000 to ≤125,000 yr

File Name: WairoaDC_FAZ_CR_2016_133
Type: Polygon
Projection: NZGD 2000 New Zealand Transverse Mercator.prj

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