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REVIEW OF FAULT RUPTURE HAZARD CORRIDORS, NELSON CITY

Prepared for Nelson City Council

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1. INTRODUCTION

1.1 Nelson City, and indeed the greater Nelson urban area, is traversed by the major Waimea-Flaxmore Fault System. Although the whole fault system, which in the city consists of five major northeast-trending faults – Tahunanui[1], Flaxmore, Waimea, Eighty-eight and Whangamoa – and numerous lesser faults – is active, only a few of the faults show evidence of ground rupture. These have been interpreted as the most active and fault hazard overlays encompassing them were incorporated into the Nelson Resource Management Plan and a similar exercise was completed in the adjoining part of the Tasman District. These overlays were very broad and simply indicated that somewhere within them was a fault that had, within the greater urban area or its environs, showed evidence of displacing the present ground surface. Since the Nelson plan became operative, additional information, particularly from geotechnical investigations and a specific assessment by GNS Science of the fault system in Nelson City and Tasman District[2], has constrained the faults in a number of places as well as providing data on the level of seismic risk. This allowed the overlays to be reduced in width and the outcome has been distinguished as fault corridors. More appropriately these should be referred to as "Hazard of Fault Rupture Corridors".

1.2 The Nelson City Council requested that the maps showing the current Fault Hazard Corridors be reviewed with the objective of incorporating any new information pertaining to them. As a consequence a letter was sent to all known geotechnical practitioners working in the city asking if they had any such information (Appendix One). This resulted in three specific, and one more general, responses.

1.3 A draft report was forwarded to the City Council in July 2018 and after discussions with council staff on 18 April 2019 it was agreed that the report be finalised.

2. LOCALITIES FOR WHICH INFORMATION WAS RECEIVED

The three responses received from the geotechnical practitioners involved the Flaxmore Fault at Kakenga Road, Brooklands and Brougham Street. Independent of this, information was obtained on the Waimea Fault in the Lud valley.

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[1] A fault, which is responsible for the western edge of the Port Hills has long been inferred as lying somewhere concealed beneath Tasman Bay and the low-lying ground extending from Tahunanui Beach southwards through Stoke. The fault, which has in recent years been broadly constrained by drilling for groundwater in the Stoke area, separates the rocks exposed in the Port Hills in the east from Moutere Gravel in the west. However, its characteristics and position are not known sufficiently to define a fault hazard corridor. The fault has been formally named in a paper *Geological Mapping and Structural Analysis of the Waimea-Flaxmore Fault System in the Nelson-Richmond Urban Area (South Island, New Zealand): seismotectonic implications* by F. Ghisetti, M. R. Johnston and P. Wopereis and which was submitted in May 2019 to the *New Zealand Journal of Geology and Geophysics*.

[2] *Assessment of the location and paleoearthquake history of the Waimea-Flaxmore Fault System in the Nelson-Richmond area with recommendations to mitigate the hazard arising from fault rupture of the ground surface* (M. R. Johnston & A. Nicol). GNS Science Consultancy Report 2013/186 August 2013.

2.1 Kakenga Road

The Flaxmore Fault in the Kakenga Road-View Mount area separates Port Hills Gravel to the southeast from older Tertiary rocks of the Wakatu Formation, locally with lenses of the View Mount Limestone member, and what was formerly mapped as Bishopdale Conglomerate formation[3]. The fault, dipping steeply to the southeast, was temporarily exposed when subdivisions comprising 43 to 47 View Mount and 7 Kakenga Road were developed. Geo-Logic Ltd advised that it had undertaken a site investigation with respect to the fault at 23 Kakenga Road. Its report, including *Site Plan 1 Faulting Hazard Assessment 23 Kakenga Road, Nelson*, was submitted to Council as part of building consent BC101154. As part of the site investigation the fault was not located but the distribution of the various rock types on this and adjacent properties has allowed the fault hazard corridor to be further constrained, albeit in a minor way, from 21 Kakenga Road to 44 View Mount, as shown on Map 1.

2.2 Brooklands

GEOadvice Ltd forwarded three geotechnical reports prepared for a staged subdivision between Brooklands Road and the northern end of Davies Drive[4]. As part of an extensive investigation, involving ground surface mapping, test pitting, trenching and drilling, the Flaxmore Fault was located at six places and its position was constrained elsewhere. The fault, which separates Drumduan Group and Port Hills Gravel to the southeast and northwest respectively, has been well constrained in Davies Drive and to a lesser extent off Paremata Street. In amending the fault corridor, in the light of the GEOadvice information, allowance has been taken of the fact that where the fault plane was identified within the subdivision it has a relatively shallow dip to the southeast. This relatively shallow dip is here attributed to superficial creep resulting from slow downward superficial movement of hillside. Should the fault rupture then the plane of intersection with the ground surface is anticipated to be upslope of where the fault was exposed as part of the GEOadvice investigation. This has been taken into consideration in amending the fault hazard corridor. As distance from the places where the fault was exposed increases so does the uncertainty in its position, viz. subject to any localities where the rocks on either side of it have been determined (Map 2). While the fault appears to lie within the existing Fault Hazard Corridor the boundary of the amended corridor has in one place been extended further

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[3] The Bishopdale Conglomerate was introduced (Johnston 1979: Geology of the Nelson urban area. *NZ Geological Survey Urban Series Map 1*) for conglomerate in the Nelson South-Enner Glynn area. The conglomerate occurs within the Tertiary sequence and as a strip on the northwest side of the Flaxmore Fault. It has subsequently been determined that there are two conglomerates – one within the Tertiary sequence and the other, the strip along the fault. The latter is now known to be the more extensive, is of probable Late Cretaceous age, and the name Bishopdale has been extensively applied to it. For the other conglomerate, within the Tertiary sequence, the name Kawai Formation has been proposed by Ghisetti et al. in the paper referred to footnote 1 above.

[4] GEOadvice Ltd (ref. 14149) *Geotechnical Investigation Report, Brooklands Way Subdivision*, January 2015; *Geotechnical Investigation Report, Brooklands Way Subdivision, Stage 2 – Rev 1*, March 2016; *Geotechnical Investigation Report, Brooklands Way Subdivision, Nelson – Stage 4*, 26 January2017.

upslope to accommodate potential uncertainties where its position is less constrained.

2.3 Brougham Street

Swanney Geotechnical and Civil Engineering has provided a report, dated 30 September 2104, on an investigation at 54A Brougham Street. Two 3 m auger holes within the existing corridor did not encounter bedrock although a DSIR drill hole on the northwest corner of Brougham and Scotland streets had bottomed in Bishopdale Conglomerate[5]. The eastern end of Brougham Street is complicated by a relatively large ancient landslide. Its western boundary intersects Brougham Street at about St Johns Drive but the eastern boundary is ill-defined. On reviewing the corridor, its northwestern boundary could be shifted slightly southeastwards although, being in road reserve, the consequences of this are minimal. As locating the fault beneath the landslide deposit would require deep drilling, properties sited entirely on it, viz. 46, 48, 50, 52, 52A and 54A Brougham Street, should be treated in a similar manner as the properties between Seymour Avenue and Weka Street currently are in the Nelson Resource Management Plan.

2.4 Lud Valley

The owner of 190 Lud Valley Road was in discussion with Nelson City Council regarding the construction of a garage on the property. The garage had been erected within the fault hazard corridor containing the Waimea Fault. In the valley the fault separates two contrasting rock units, namely Brook Street Volcanics and Maitai groups to the west and east respectively although at the head of the valley a large fault sliver of Richmond Group occurs between the Brook Street and Maitai rocks. Because of alluvium filling the valley the fault had not been precisely located in the middle part of the valley containing the property in question. The owner of 190 Lud Valley contacted me about the fault hazard corridor but, due to my contractual arrangement with Council, I was not able to assist. I did, however, forward to Council a broad assessment of the risk posed to the garage should rupture of the Waimea Fault occur in the Lud Valley and also some general comments on the hazards, in addition to ground rupture, posed by an earthquake originating on the Waimea-Flaxmore Fault System in the greater Nelson urban area. The owner also indicated that rock was exposed in Lud River on the property. The property was subsequently sold and with the agreement of the new owner, these outcrops were examined and confirmed as Maitai Group showing that the Waimea Fault must lie to the west of them.

The Waimea Fault was exposed in the northwest corner of 134 Lud Valley as part of a geotechnical investigation as depicted on Golder Associates Site Plan showing *Test Pit and Scala Test Locations* (Ref L0878320334/01) dated January 2008 and the corridor had been previously reduced in width to incorporate this information. Additional site inspections were made at 138, 180, 250 and 312 Lud Valley Road. Although the Waimea Fault was not observed, the various outcrops,

[5] Position of drill hole shown on Nelson urban area geological map (Johnston 1979).

along with that seen at 190 Lud Valley Road, has allowed the fault corridor to be significantly constrained south of 134 Lud Valley Road. It appears probable that the fault lies close to the boundary of the residential lots on the valley floor and the steep slopes to the west.

As the western boundary of the existing corridor largely aligns with the inferred position of the fault, it is recommended that it be moved further west as originally recommended in the GNS report. The alteration in the corridor from that shown in the GNS report was made to coincide its western boundary, as much as possible, with cadastral boundaries. At 138, 140, 144 and 146 Lud Valley Road it is recommended that the western boundary of the corridor, which as depicted in the GNS report is already within these properties, be moved further west. This more accurately reflects the likely position of the fault based on rock outcrops. Such an alteration will not impinge on any house sites but by shifting of the eastern boundary, as part of a reduction in the width of the corridor in the middle Lud valley, the house on 138 Lud Valley will be excluded. The change in position of the eastern boundary of the corridor will also exclude a number of other houses and substantial buildings. The recommended position of the fault corridor between 126 and 312 Lud Valley Road is shown on Map 3 (four sheets).

2.5 Iwa Road

Iwa Road sits on a moderately large landslide whose age is not known but it is old as the sea has cut a cliff into its toe. The landslide is apparently stable although there have been subsequent shallower movements on the sea cliff, particularly where excavations have over-steepened slopes, as well as along its northern margin where there is an active earthflow, and from its head scarp. As the landslide deposit and subsequent deposits of material eroded from its head scarp obscures the Flaxmore Fault there is little prospect of locating it by type of geotechnical investigation that would be undertaken in an urban environment. Consequently it is recommended that the area within the fault hazard corridor from the end of Weka Street to the north boundary of 21 Iwa Road be treated in the same manner as the corridor south from Weka Street.

3. THE FLAXMORE FAULT SOUTH OF POORMAN VALLEY STREAM

3.1. Except where concealed, notably beneath the alluvial deposits of the Maitai River and The Brook and locally elsewhere, the Flaxmore Fault in Nelson City has been mapped or its position relatively closely constrained from The Glen southwest to the southern end of Kakenga Road. As referred to above it separates different rock units, which allows its position to be constrained, to varying degrees of accuracy, even where the fault itself has not been exposed. In floors of Marsden Valley and the valleys of Jenkins Creek and Orphanage Stream it has long been known that there is a change in the altitude of the fan gravel ground surface on or about the inferred position of the fault. Whether this depicts the offsetting of the valley floors by a now much eroded scarp of the fault or reflects the presence of fan gravel surfaces of different ages has yet to be resolved. However, it is understood that a Victoria University student is undertaking an

investigation of the terraces and when completed this is likely to provide further relevant information on this question.

3.2. Further confirmation of the approximate position of the fault on the south side of Orphanage Stream is the long abandoned Leighton's Shaft depicted on the geological map accompanying the geological bulletin "Dun Mountain" (Bell et al. 1911). The existence of the shaft indicates that traces of coal were located in the nearby creek but it was, until recently, uncertain as to whether this was Marsden Coal Measures, commonly found as slivers along some of the major faults in the Nelson area, or merely lignite bands within the nearby younger Port Hills Gravel. Following storm events, erosion by the creek has exposed discontinuous outcrops of both the coal measures and the Cretaceous Bishopdale Conglomerate thereby constraining, but not accurately fixing, the position of the Flaxmore Fault. However, if the different heights in the nearby fan gravel surface are confirmed as being due to fault displacement then this will significantly constrain its position.

3.3. Further north, Bishopdale Conglomerate was exposed in 235-239 The Ridgeway, when that area was subdivided, and *in situ* Port Hills gravel is exposed at the end of Songer Street. Although the conglomerate is gravity displaced within the Greenmeadows Landslide, it and the Port Hills Gravel constrain the position of the fault.

3.4. What could be a highly modified fault scarp trends southwest along the eastern edge of Isel Park and tapers out into a fan gravel deposit centred on the end of Songer Street. If a fault scarp then the fault must swing in a more southerly direction to trend east of Bishopdale Conglomerate at 235-239 The Ridgeway.

3.5. A better defined scarp extends from just south of the corner of Saxton and Suffolk roads southwestwards until it merges into young Stoke Fan Gravel deposited by Saxton Creek. In the opposite direction there is a difference in ground height but this could be the result of land sliding.

3.6. Other than the possible scarps referred to above, no fault scarps have been identified on the Flaxmore Fault anywhere along its exposed length although there is the possibility of offset fan gravel terraces in Jenkins Creek. However, between the creek and Marsden Valley bed rock is close to the surface and any scarp should have been preserved. At View Mount a prominent change in slope lies some distance to the east of the fault as defined by the various different rock units that were exposed during the subdivision of land at the end of View Mount. Alternatively the last rupture may have been on the segment of the fault from Marsden Valley to south of Saxton Road. Such a rupture may be responsible for the major landslides that buries much of this segment of the fault. This includes the Greenmeadows failure, which extends from just south of the end of Songer

Street to about Covent Terrace, and the Suffolk Road landslide from about 389 Suffolk Road to Northgate Way[6].

3.7. If one or more of the scarps referred to above are confirmed as resulting from fault rupture then a question that will need to be considered is whether to extend the Fault Hazard Corridor from Marsden valley south to almost Champion Road. It should be noted that, as described above, along much of this distance the fault is apparently deeply buried beneath extensive landslide deposits (Greenmeadows and the Suffolk Road failures as well lesser land sliding to the south of Northgate Way). In the narrow floors of the valleys of Orphanage and Poorman Valley streams, where highly modified fault scarps may exist, the land is largely built on. The feature from just to the south of the eastern end of Saxton Road towards the Saxton Creek fan deposit is worthy of further investigation, including trenching, to determine its origin. Should it be confirmed as a fault scarp then it should be incorporated within a fault corridor.

3.8. If a corridor was introduced for the Saxton Road scarp, or any of the other scarps referred to above, then how to deal with the intervening areas will also require discussion. If the intervening area was to become part of a fault hazard corridor, then it would be more appropriate to treat most, if not all, of it in the same manner as the corridor containing the fault between Seymour Avenue and Weka Street. Alternatively, it may be simpler to confine the corridors to the valley floors containing the fault scarps and exclude the thick landslide deposits.

3.9. Because of the uncertainty with regard to this segment of the Flaxmore Fault there are two options for Mardsen Valley. That is leave the corridor as it is south of Marsden Valley Road, even though it may need to be broadened westward, or terminate it at Marsden Valley Road and deal with the whole segment, between Marsden Valley and Champion roads, when more is known about the fault.

3.10. In concluding this section of the report, it is suffice to note that further investigation of this segment of the Flaxmore Fault, including origin of the features referred to in this section of the report, is necessary in order to resolve the uncertainties described above.

4. FAULT HAZARD CORRIDORS – DISCUSSION

4.1 The prime objective of delineating corridors is to advise that an active fault, which may result in rupture of the ground surface, likely lies somewhere within them. In places the faults, and their likely plane of future movement, have been identified, usually in temporary excavations such as trenches. Because the major faults, and many of the lesser faults within the Waimea-Flaxmore Fault System separate different rock types this, where the position of the faults remains uncertain, constrains where they can be to a level of accuracy commensurate with

[6] Extensive geotechnical remediation has allowed Greenmeadows landslide to be subdivided for residential use. The Suffolk Road landslide has apparently reached stability and displays no evidence of continuing deep-seated movement.

the density and location of rock outcrops. Thus where the fault has been identified as a single plane then the corridor is narrow being 20 m wide[7]. This width expands as uncertainty in the position of the fault or its likely plane of future movement increases. In is important to ensure that the variable widths of the corridors signify nothing more than this.

4.2 Because a fault may constitute a wide crush zone, or a zone containing slivers of other rock types incorporated along it, it may not be possible in such circumstances to come to any conclusion as to where it might rupture in the future.

4.3 It is important that cognizance of the activity on the fault system is taken into account. The risk of rupture on any fault within the Waimea-Flaxmore Fault System is low but nevertheless real. This has been recognized in the GNS Report, on which the Fault Hazard Corridors are based, which recommends that where possible to do so structures should not be sited over the fault, particularly if the likely plane of future movement can be identified. As already stated, this cannot always be achieved, even when the fault is exposed, if it consists of a very wide crush zone or there are slivers, maybe up 100 m or more wide, of other rocks caught up along the fault. In such circumstances it may be impossible to identify the likely plane of future movement.

4.3 Recommendation 7.1.4 1) (i), in the GNS report, states that where a fault has not been located after the appropriate level of [geotechnical] investigation then [from a geotechnical perspective] development within any part of the overlay [corridor in current terminology] can be allowed. If this recommendation is adopted, then building consent can be granted, subject to the geotechnical conditions that Council may adopt at the time it accepts geotechnical certification of the subdivision.

4.4 Data from several investigations in recent years indicate that earthquakes originating on the Waimea-Flaxmore Fault System are separated by long time intervals. For example, the Waimea Fault near Brightwater shows three ruptures in the last 20,000 years. The evidence is not precise enough to determine if rupture occurs at regular intervals but from the nature of the fault system this would appear to be unlikely.

4.5 Although the Waimea-Flaxmore Fault System comprises a large number of faults, geological evidence suggests that, in Nelson city, past ruptures during an earthquake event have been along a relatively short section of a fault rather than involving a significant number of faults or even a long length (tens of kilometres) of any individual fault.

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[7] The GNS report (Sec 7.1 .3) states that this offset can be reduced from 10 to 5 m from the fault plane if so recommended by a suitably qualified consultant specialising in earthquake risk..

4.6 While a number of the faults in the Waimea-Flaxmore Fault System are known to be active it is not possible to include all of their lengths in fault hazard corridors because where deeply buried their locations are not known. To incorporate them, and the Tahunanui Fault is a prime example, would result in a very wide fault corridor without necessarily any knowledge of the activity of that fault. To determine where the fault is would be expensive and even if this was done, uncertainty would likely remain as to how it would propagate to the surface should rupture occur. When this, and the activity on the fault system is taken into account, coupled with not knowing which fault may rupture next, means that the introduction of corridors in such circumstances would be very hard to justify. Other faults within the Waimea-Flaxmore Fault System, whose position is relatively well-known, show no evidence of ground rupture but may in fact rupture in the future. Nevertheless, including all of these faults within fault corridors would again be difficult to justify.

4.7 That the position of the faults, or sections of them, are not known and that earthquakes originating within the fault system are infrequent led GNS to make the recommendations contained in Section 7.1 of its 2013 report.

4.8 The hazard of rupture needs to be kept in perspective with the other damage that would result if an earthquake originates on the Waimea-Flaxmore Fault System within or close to Nelson City. Fault rupture may offset the ground within a relatively few properties but the other damage will be widespread. This will include severe ground shaking, deformation of the ground for varying distances on either side of the fault that ruptures, liquefaction in soils susceptible to this phenomenon and major slope failures (up to the size of the Tahunanui Slump is possible), particularly on steep hillsides. In addition, if rupture extends offshore, and/or there is a major slope failure into the sea, then there is a tsunami risk.

4.9 The fault hazard corridors are based on information available at the time they were compiled. Further investigation will undoubtedly enable the boundaries to be further refined and in some instances it may be that new data indicates the rupture may occur outside of a corridor. An example of the latter may be where it is shown that large scale gravity collapse has significantly displaced the fault and during a future earthquake the fault straightens itself by "cutting the corner". Also while geological evidence indicates that the faults in the corridors, where they separate bedrock units, tend to have repeated movement along the same plane this might not necessarily be so during a future rupture. Furthermore, the boundaries of the corridors are based on existing geological mapping and it is possible that, because of poor exposure, severe crushing and/or intense weathering, bedrock units adjacent to the faults may have been locally misidentified. The only alternative is to have very wide corridors, which the activity and nature of the fault system scarcely warrants.

4.10 The prime aim of the overlays/corridors is to make known that within them are faults that show evidence of geologically young movement and can be

expected to rupture in future (but bearing in mind that there are other faults in the city not so identified, for a variety of reasons, that could rupture). Even though the risk of rupture is low, structures where possible to do so should avoid straddling the faults or be so designed to minimise as much as possible damage.

4.11 After assessing the risks involved, both from fault rupture and the more widespread other forms of earthquake damage that will result, potential purchasers or developers of properties within the fault corridors will be better placed to make an informed decision.

5. RUBY BAY-MOUTERE FAULT

5.1. Attention of the Nelson City is drawn to the existence of the Ruby Bay-Moutere Fault that parallels the Waimea-Flaxmore Fault System. Although to the west of the city this blind fault (it has no known surface expression) is considered to be active with the potential to generate similar magnitude earthquakes to those that could originate on the Waimea-Flaxmore Fault System. The likely frequency of earthquakes on the Ruby Bay-Moutere Fault is assessed as lower than for the Waimea-Flaxmore Fault System[8].

6. RECOMMENDATIONS

It is recommended that:

6.1. The fault hazard corridors in the vicinity of 23 Kakenga Road, Brooklands Road, and the Lud Valley Road and be modified as shown on Maps 1, 2 and 3 respectively.

6.2. When the Nelson Resource Management Plan is amended that it be made clear that the corridors are solely dealing with the possibility of fault rupture, a low probability event in terms of the life of any structures within them, and does not address other damage that will occur during a major earthquake centred in or close to the Nelson urban area.

6.3. Where a building site, particularly one for residential development, has been certified by a geotechnical practitioner and the fault or the likely plane of fault movement has not been identified as part of that certification then no further investigation with regard to the fault should be necessary unless there are reasons to the contrary.

6.4. Where the fault is concealed by moderately large landslide deposits, such as at Iwa Road and Brougham Street, these areas be treated in a similar manner to the corridor between Seymour Avenue and Weka Street.

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[8] Ghisetti, F., Johnston, M.R., Wopereis, P & Sibson, R.H. 2018: Structural and morpho-tectonic evidence of Quaternary faulting within the Moutere Depression, South Island, New Zealand. *New Zealand Journal of Geology and Geophysics 61 (4)*: 1-19.

6.5. Consideration is given to as how far south the corridor encompassing the Flaxmore Fault should extend and bearing in mind that further information on this section of the fault is likely to become available in the next few years

ACKNOWLEDMENTS

I record my appreciation of the geotechnical practitioners who assisted by providing information relevant to this review. In particular I thank Paul Denton, Carol Foote, Jeff Swanney, Paul Wopereis and, for supplying base maps, Steve Read formerly of the Nelson City Council. I also acknowledge the assistance provided by several residents of the Lud Valley.

LIMITATIONS

This assessment has been prepared solely for the Nelson City Council and is based on information currently available to the author. Only very limited site specific investigations have been undertaken (in the Lud valley).

Maps:

Recommended amendments to boundaries of Fault Hazard Corridors

Map 1 – Kakenga Road

Map 2 – Brooklands

Map 3 – Lud Valley (4 sheets).

Appendix One

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19 April 2018

Dear Fellow Geotechnical Practitioners

As many of you are aware I have an ongoing commitment to provide advice to the Nelson City Council on the Fault Hazard Overlays/Fault Hazard Corridors in relation to the Waimea-Flaxmore Fault System. This fault system includes a several major northeast-trending faults (within the city these are, from east to west, Whangamoa, Waimea, Eighty-eight, Flaxmore and Tahunanui) and a large number of "cross faults") one of which, Bishopdale, has an active trace. Council has adopted fault hazard overlays, currently being revised as fault hazard corridors, over the major northeast-trending faults where they can be identified - the Tahunanui Fault, west of the Port Hills, is, for example, totally concealed and therefore, as far as the overlays/corridors are concerned, it is ignored. Similarly the "cross faults" are, except where there is known rupture of the ground surface or there is other evidence to suggest they are active (e.g. Hira, Grampian faults), are excluded even though this does not imply they may not rupture in the future - there is simply insufficient data to classify them as active. For further information on the fault system see: *Assessment of the location and paleoearthquake history of the Waimea-Flaxmore Fault System in the Nelson-Richmond area with recommendations to mitigate the hazard arising from fault rupture of the ground surface* (M. R. Johnston & A. Nicol) GNS Science Consultancy Report 2013/186 August 2013 and Appendix[9]. Section 7.1 of the report is of particular relevance.

Council is now finalising the fault hazard corridors as part of its revision of the Nelson Resource Management Plan. It should be noted that basically the aim of the corridor is to make people aware that there are active faults present within the city and to avoid unnecessarily placing structures over the planes along which fault rupture may occur. It is also recognised that should a segment of the fault system rupture within or close to the city there will be widespread damage away from the rupture itself, including a variable width of ground distortion either side of the rupture and, depending on such things as subsurface materials and topography, liquefaction and mass slope movement.

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[9] Johnston, M. R.; Nicol, A. 2013: *Assessment of the location and paleoearthquake history of the Waimea-Flaxmore Fault System in the Nelson-Richmond area with recommendations to mitigate the hazard arising from fault rupture of the ground surface*. GNS Science Consultancy Report 2013, August 2013. Note: both are available on the Nelson City Council.

It is not always possible to identify planes of likely future movement because depth of burial of the fault, the width of fault zones (although where "basement rocks" - including Port Hills Gravel - are involved the zone is commonly narrow and on which there is evidence of repeated movement on it) etc. Also the amount of investigation, taking into account the infrequency of movement on individual faults in the fault system and, in greater Nelson urban area, the relatively short fault scarps that are preserved, is largely governed by the ultimate use of the land involved - e.g. a housing subdivision with individual dwellings compare compared to a high rise hospital block.

In order to exclude as many properties as possible from the proposed fault hazard corridors, it would be very much appreciated if you would advise, from any investigations that you may have undertaken, where the fault corridors (accessible at nelson.govt.nz/environment/nelson-plan/natural-hazards/faults-line) can be further refined. Even if you have no information, a response to this effect would also be appreciated. I am happy to call in at your respective offices if that would be more convenient for you

Thank you for any your assistance you may be able to provide

With best wishes

Mike Johnston