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
Geological Consultant	GNS Science
395 Trafalgar Street	PO Box 30368
Nelson	Lower Hutt

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EXECUTIVE SUMMARY

The Nelson urban area, comprising Nelson City and Richmond, is the South Island's third largest metropolitan area and one of only four in New Zealand known to be located on an active fault which has ruptured the ground surface (Wellington, Christchurch and Whakatane being the others). The Waimea-Flaxmore Fault System passes through Nelson City and Richmond and comprises active traces with mainly reverse displacements that formed during large magnitude surface-rupturing earthquakes. The size and timing of some of these prehistoric earthquakes have been estimated by geomorphological mapping and fault trenching at two sites. Three seismic events on the Waimea Fault have been bracketed in time by radiocarbon and optically stimulated luminescence (OSL) dates and occurred 15.3-20, 7.2-13.8 and 5.7-6.8 thousand years ago. The most recent earthquake on the Flaxmore Fault may also have occurred about 6 thousand years ago. Therefore, the time to the next large magnitude surface-rupturing earthquake on the Waimea-Flaxmore Fault System is likely to be significantly less than previously inferred. Cumulative vertical displacement of about 3.5 m accrued during large magnitude surface rupturing earthquakes on the Waimea Fault, with average slip/event and slip rates of approximately 1.2 m and 0.2 mm/yr respectively. Our analysis indicates that rupture of the Waimea and Flaxmore faults at the ground surface may be achieved during earthquakes of magnitudes 6.5-7.4.

The average recurrence interval for events on the Waimea Fault is about 6 thousand years and approximately equal to the elapsed time since the last surface-rupturing earthquake. Therefore, although earthquake activity of the fault system is relatively low, setback of building development from the main northeast-trending faults (Flaxmore, Waimea, Eighty-eight and Whangamoa faults) and three of the lesser faults (Hira, Grampians and Bishopdale) are recommended. A 10 m setback distance from the nearest active fault trace or fault zone is recommended with the option of reducing this value to 5 m where the fault is precisely located by geotechnical investigation.

To highlight the existence of the faults it is recommended that fault hazard overlays continue to be part of the two Councils resource management plans. Three types of overlay are proposed to identify sites along the faults with different land use or variations in quality of fault location information. These are: i) undeveloped (greenfield) land, ii) existing urban areas (i.e. developed sites) and iii) sites where the faults are deeply buried (e.g. >10 m) with poorly constrained locations which are unlikely to be improved by standard geotechnical investigations (e.g., test pitting).

In developed sites, residential buildings and similar structures may be constructed across a fault if it is within an existing building footprint and/or there is no alternative site. Resource consent for subdivisions of existing urban lots should not be granted if new building sites will be within the building setback. However, if after the appropriate level of geotechnical investigation the fault has not been identified, development can proceed without recourse to any setbacks.

If the fault is deeply buried, then the hazard of fault rupture can be dismissed for residential development. However, for the development of infrastructure or high occupancy multi-storied buildings, deep (e.g. >5-10 m) excavations or sub-surface geophysical investigations may be warranted. Where the fault is deeply buried and its approximate position is not known, no fault hazard overlay is recommended.

1.0 INTRODUCTION

Large magnitude earthquakes have the potential to generate seismic shaking and to rupture the ground surface which, in populated regions, can cause significant disruption to infrastructure and loss of life. To minimize the impact of seismic events it is prudent to identify potential sources of future large earthquakes, to estimate the magnitude and recurrence intervals of these events and to locate these faults as precisely as possible. This information is critical for seismic hazard assessment and provides essential guidance for land-use planning and urban development purposes.

The present report focuses on documenting the location of active faults and the paleoearthquake histories of the Waimea and Flaxmore faults in the Waimea-Flaxmore Fault System. The fault system extends northeast from the Alpine Fault near St Arnaud, through the eastern part of Tasman District and into Nelson City and Tasman Bay (Fig. 1). We report on a 45 km long section of the fault system within an area between the mouth of the Wairoa Gorge in the Tasman District to the lower Whangamoa valley in Nelson City's jurisdiction. In this area the fault system passes through the urban areas of Nelson and Richmond. While no historic large magnitude earthquakes have ruptured the Waimea-Flaxmore Fault System, field mapping reveals evidence of displacement of the ground surface on several faults and indicates that these faults experienced one or more large magnitude surface-rupturing earthquakes in the last 125 thousand years (Bruce, 1962; Johnston, 1979, 1981, 1982a, 1982b, 1983, 1990; Johnston et al., 1993; Rattenbury et al., 1998). The timing, frequency and magnitude of these events are poorly understood.

Nelson City and Tasman District councils, who are unitary authorities combining district and regional government responsibilities, recognise the hazard of fault rupture in their respective resource management plans. The fault hazard sections of the plans were largely based on reports by the Institute of Geological and Nuclear Sciences, now GNS Science, prepared for the councils in 1993 and 1995 (Johnston et al., 1993; Coote and Downes, 1995). As a consequence, the councils show fault hazard overlays in their resource management plans which contain known, or inferred, active faults within the Waimea-Flaxmore Fault System. These resource management plans require that for activities, such as subdivisions or building, active faults are, wherever possible, identified and, where feasible, structures are set back 5 m (Nelson City) or 10 m (Tasman district) from faults. Because it was not possible, with few exceptions, to precisely locate the faults at the time the GNS Science reports were prepared, fault overlays were introduced. By necessity the overlays were broad bands, up to 200 m wide, which alerted users of the approximate locations of active faults that could rupture the ground surface. Since the resource management plans were prepared, a considerable amount of new information has been collected on the faults in the northern part of the fault system administered by the Nelson City and Tasman district councils. In many cases, for example, the locations of the faults can now be determined with more precision than was previously achievable, and revision of the fault hazard overlays in the resource management plans is now possible.

The purpose of this report is threefold:

1.) New information for the last 20 thousand years on the timing, surface displacements, magnitudes and likelihood ground shaking during large magnitude surface-rupturing earthquakes are assessed for the Waimea and Flaxmore faults in the Waimea-Flaxmore Fault System. This information provides important constraints on the timing of these earthquakes, the recurrence interval between events and the size of earthquake slip.

2.) The locations of ground surface rupture during prehistoric large magnitude earthquakes have been revised. Newly available data on the locations of active faults has in many cases reduced the uncertainty in their locations and along significant sections of the Waimea and Flaxmore faults has allowed the widths of fault hazard overlays to be decreased. In several places, particularly southwest of Richmond, the widths have increased or new overlays have been recommended in light of new information.

3.) In light of new information on the width of the zones of ground surface deformation across active faults, we discuss, and recommend minor revisions to, fault setback distances.

To constrain the locations of active faults and paleoearthqauke attributes within the fault system we use a combination of mapping and surveying of active fault traces, trenching of these fault traces and the deposits that they displace, and dating of both faulted and unfaulted horizons, such as terraces (Fraser, 2005; Fraser et al., 2006; this study). Trenching was largely confined to a section of the Waimea Fault displacing a flight of river terraces on the south bank of the Wairoa River and to the Flaxmore Fault at Bishopdale (for locations see Fig. 1). In addition the report incorporates information from site specific geotechnical investigations undertaken by Geo-Logic Limited, Geotech Consulting Ltd, Golder Associates (NZ) Ltd, MWH New Zealand Ltd and Tonkin & Taylor Ltd, which provide information on the locations of active fault traces. The results build on previous estimates of active-fault locations and provide the first robust data set for paleoearthquakes in the Waimea-Flaxmore Fault System.

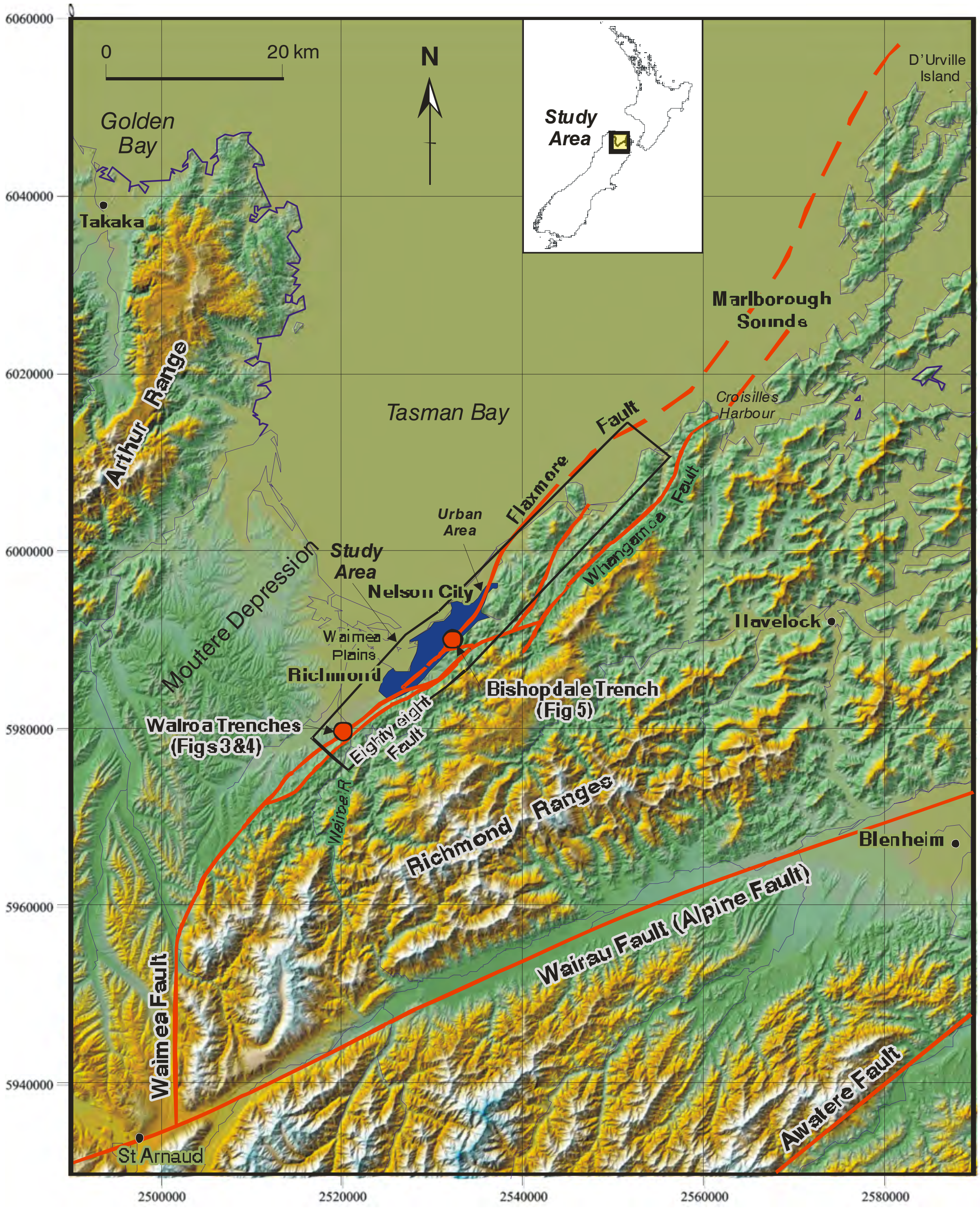


Figure 1 Digital elevation model showing the location of the Waimea-Flaxmore Fault System (which includes the Waimea, Flaxmore, Eighty-eight and Whangamoa faults) relative to the main urban areas of Nelson and Richmond. Locations of Figure 3 and the trenches (Figures 4 & 5) are shown. Figure modified from Fraser (2005).

2.0 GEOLOGY SETTING OF ACTIVE FAULTING

The surface traces of the Waimea-Flaxmore Fault System extend for ~90 km from near St Arnaud at Lake Roto-iti, where it branches off the Alpine fault, to the lower Whangamoa valley (Fig. 1). From the Whangamoa valley the system has been traced northeast, mostly offshore, to beyond D'Urville Island (Fig.1). The fault system, which includes the Bishopdale, Eighty-eight, Flaxmore, Grampion, Hira, Waimea and Whangamoa faults (Fig.2), separates the eastern Nelson Ranges from the Moutere Depression within which the Waimea Plains have formed. Cenozoic strata, including the Late Pliocene (~1.8-3 Ma in age) Moutere Gravel, are up to several kilometres thick within the depression adjacent to the fault system. The northern end of the depression is below sea level and forms Tasman Bay. East of the fault system Cenozoic rocks have been mainly eroded from the ranges exposing bedrock of Late Paleozoic-Mesozoic age (Rattenbury et al., 1998). In the Tasman District part of the study area, the topographic and structural boundary between the depression and the eastern ranges is mainly marked by the Waimea Fault which defines the western margin of the Nelson Ranges. Further north in Nelson City, the Flaxmore Fault generally defines the base of the range front. However, uplifted Tertiary rocks west of the fault occupy an intermediate altitude between the eastern ranges and the Moutere Depression.

The fault system comprises six main faults that generally trend northeast and numerous shorter faults trending at moderate to high angles (>40°) to the main structures. From west to east, the main faults exposed at the ground surface are the Flaxmore, Waimea, Eighty-eight and Whangamoa faults (Johnston, 1979, 1981, 1982a, 1982b 1983, 1990; Rattenbury et al., 1998). These faults are located on Fig. 2 and mainly distinguished because they separate contrasting rocks units, most of which constitute terranes. The Flaxmore and Waimea faults, for example, define the west and east (respectively) boundaries of the Brook Street terrane. The width of the terranes and the spacings of the main faults in the system vary considerably along strike (e.g., see Rattenbury et al., 1998). South of the Wairoa Gorge to within 20 km of the Alpine Fault the main faults are closely spaced, with a total system width of about 5 km and spacings between individual faults as little as 100 m. Northeast from about Richmond, the fault system widens to 12-15 km in Nelson City with typical spacings of 1-4 km for the main faults. In addition to these variations, lenses of basement terranes and Tertiary strata have been incorporated into some fault zones. The Waimea Fault, for example, comprises a fault zone which includes lenses of Eocene coal measures that are up to 500 m wide.

The main faults are mainly reverse slip with a variable, but apparently small, component of dextral strike-slip (Johnston, 1983; Pettinga and Wise, 1994). Fault outcrops indicate that they mainly dip steeply (~70º) southeast (Johnston, 1983; Fraser, 2005). In addition to the main faults there are a number of shorter faults, mainly trending approximately east-west, including the Bishopdale, Grampian and Hira faults (Fig. 2).

No historical (last 160 years) ground rupturing earthquakes have been reported on the Waimea-Flaxmore Fault System. In fact very few earthquakes have been recorded historically in, and immediately adjacent to, the study area at depths of less than 15km (Hatherton, 1980; Anderson and Webb, 1994; Reyners et al., 1997). Collectively these data suggest the presence of a low seismicity zone or "aseismic corridor" in the upper 15km of the crust, which encloses the Waimea-Flaxmore Fault System and provides few indications of its likely future seismic activity.

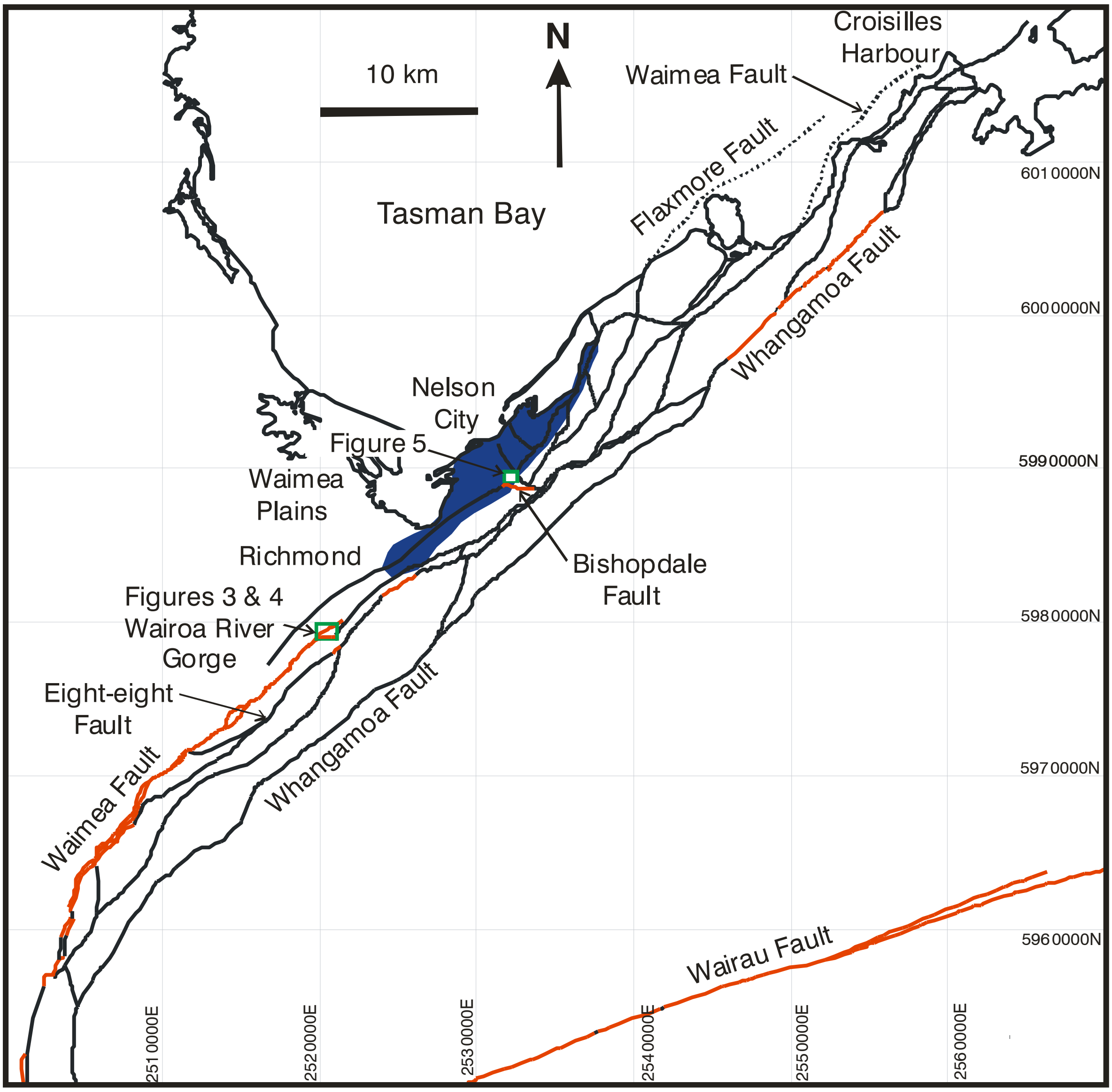


Figure 2 Locations and names of active fault traces and faults within the Waimea-Flaxmore Fault System. Red lines are active fault traces and black lines are faults without an active trace. Faults are from Rattenbury et al. (1998).

3.0 LOCATIONS AND GEOMETRIES OF ACTIVE FAULTS AND FOLDS

Active faults have been identified by the presence of scarps or steps in the land surface which, by analogy with historical large magnitude earthquakes elsewhere, form due to displacement of the ground surface during past earthquakes. In the study area, the Waimea-Flaxmore Fault System contains several active fault traces arising from fault rupture (see Fig. 2 red lines). Fault scarps are typically discontinuous and are most notably preserved on the Waimea Fault in the vicinity of the Wairoa Gorge, the Bishopdale Fault near Bishopdale, the

Eighty-eight Fault in the Barnicoat Range and the Whangamoa Fault in the Whangamoa valley. The scarps range in height from 1-2 m on the Bishopdale and Eighty-eight faults, to up to 3.5 m on the Waimea Fault immediately south of the Wairoa Gorge. Differences in scarp heights may arise in part due to variations in the numbers of surface-rupturing earthquakes recorded on each fault, with larger scarps requiring more earthquakes. Trenching, for example, reveals that the scarp on the Waimea Fault southwest of the Wairoa River formed in three events during the last 20 thousand years, while a < 1 m vertical displacement recognised in a trench across the Flaxmore Fault formed in one event about 6 thousand years ago (Fraser, 2005).

The longest scarp (i.e. active fault trace), which may be locally removed by erosion or buried, is along a 14 km long section of the Whangamoa Fault through the upper Whangamoa valley and south into the Whakapuaka valley (Fig. 2). Further south evidence of surface rupture is primarily limited to an approximately 2 km section of the Bishopdale Fault, which connects the Flaxmore and Waimea faults near Bishopdale, and to a 2.8 km length of the Eighty-eight Fault in the Barnicoat Range (Fig. 2) . South of the Wairoa Gorge beyond the study area, scarps on the Waimea Fault are largely continuous. Our trenching is consistent with the notion that the southward increase in continuity of the Waimea Fault partly arises because a greater number of earthquakes have ruptured the ground surface along the southern part of this fault in the last 20 thousand years. Further work is required to test this idea which, if true, suggests that the entire length of the Waimea Fault trace does not rupture in each earthquake on the fault.

To locate faults where they are not marked by a scarp arising from the rupturing of the ground surface, a combination of information from shallow sub-surface geotechnical investigations and geological mapping of bedrock has been used (e.g., Fraser, 2005; Fraser et al., 2006; this study). Test pits, trenches and drilling, primarily as part of geotechnical investigations for urban subdivisions have enabled short sections of the Flaxmore and Waimea faults to be accurately located where concealed by superficial deposits, such as fan gravel, scree and landslides. While surface mapping, in the absence of a fault scarp, rarely allows faults to be accurately located it can constrain their positions to varying degrees of accuracy. This is because the main northeast trending faults, and many of the lesser faults, typically separate different rock types. In most instances, mapping of the bedrock permits faults to be located within zones ranging in width from a few metres to several hundred metres. The width of the zones is therefore largely dependent on the density of rock outcrop and the scale at which the maps were produced. The spatial distribution of rock outcrop is strongly influenced by vegetation and the distribution of surficial deposits. Landslides, for example, may both bury faults and significantly displace bedrock units down slope resulting in faults being incorrectly located, as has previously occurred along the parts of the Waimea Fault at the toe of the Barnicoat Range in the vicinity of southern Hill Street and Hill Street South. The scale of fault mapping varies from 1:5000 in built up urban areas to 1:25000 in rural and mountainous regions. Increasing the mapping scale generally results in an increase in the width of the zone within which the fault is located.

Movement on a fault may manifest itself by deforming the ground surface over a broader area, producing a fold or warp instead of a well-defined scarp. Folding of the ground surface commonly occurs where an active fault is covered by thick (e.g., >5-10 m) unconsolidated deposits, such as alluvial gravel. In the absence of sub-surface information, these folds can be difficult to recognise, particularly where they are sub-parallel to other geomorphic features, which may include terrace risers or abandoned river channels. Nine topographic features on an 18 thousand year old (Last Glaciation) outwash terrace surface along the eastern margin of the Waimea Plains and up to 4 km north of the Wairoa River have been identified as possible folds (Fraser, 2005). The largest of these features defines a 10-15 m wide bank that extends about 1 km northeast from near the corner of Glover Road East and Haycock Road to the foot of the Barnicoat Range. The bank height diminishes from about 6 m in the southwest to zero near the Barnicoat Range where it is overtopped by fan colluvium and other deposits derived from higher ground. The bank is directly along strike from the fault scarp south of the Wairoa River and could have formed due to fault vertical displacement beneath the gravels. The spatial distribution of Tertiary bedrock is also consistent with the presence of a fault at this location, however, no active faults can be traced across inferred Holocene river terraces of the Wairoa River. Seismic reflection profiles have been collected across the inferred folds to determine their origin (Fraser, 2005). However, these data did not prove conclusive and determining whether undulations in the terrace surface are due to sedimentary or tectonic processes is not possible from the available information. Further work, including trenching, is required to determine the origin of these features. Given the uncertainty in the origin of these features they have been excluded from the fault hazard overlay maps (Appendix 1).

4.0 PALEOEARTHQUAKE SLIP AND TIMING

Nelson City and Richmond are particularly vulnerable to seismic hazard as the active Waimea-Flaxmore Fault System passes through these urban areas. This fault system has the potential to produce both displacement of the ground surface (rupture) and seismic shaking, yet very little is known about its past activity. Two sites, one on each of the Waimea and Flaxmore faults, were selected for detailed examination of the paleoearthquake history of the fault system (see Fig. 2 for locations). At a site southwest of the Wairoa River, the Waimea Fault displaces a flight of river terraces, which are schematically presented in Figure 3, and range in age from about 6 to 18 thousand years. The timing and slip of paleoearthquakes in this area have been estimated by dating and surveying the terraces and by excavating two trenches (referred to here as Wairoa-1 and Wairoa-2) across the fault scarp on two offset terraces (B & C). These terraces are displaced vertically by as much as ~3.5 m (Table 1) down to the northwest on a scarp about 600 m long (Figs 2 & 3). Trenching together with mapping of the active trace indicates that the fault displacing the Wairoa River terraces has a component of reverse slip (Fig. 3).

At a second site, at Bishopdale, an estimate for the timing of the last earthquake on the Flaxmore Fault has been constrained using data from a single trench (Bishopdale-1). The logs for all three trenches are presented in Figs 3 & 4. For further information on the collection and analysis of the information refer to Fraser (2005).

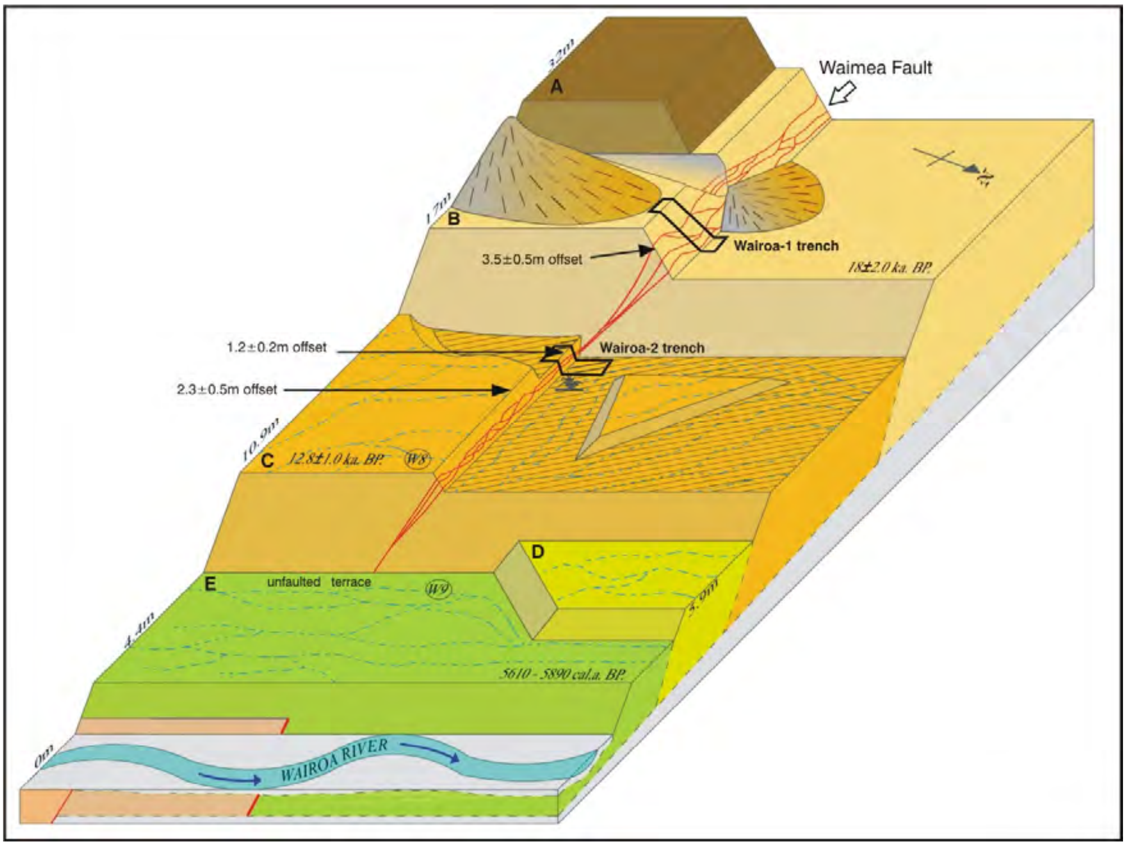


Figure 3 Schematic block diagram of the Waimea Fault where it displaces river terraces of the Wairoa River. Terraces A-E and their displacements and ages are labelled (Fraser, 2005). Numbers along the southeast margin (left) of the block diagram indicate approximate height of the terrace above the present Wairoa River bed. The locations of dated samples W8 (OSL) and W9 (radiocarbon) are shown. Figure from Fraser (2005).

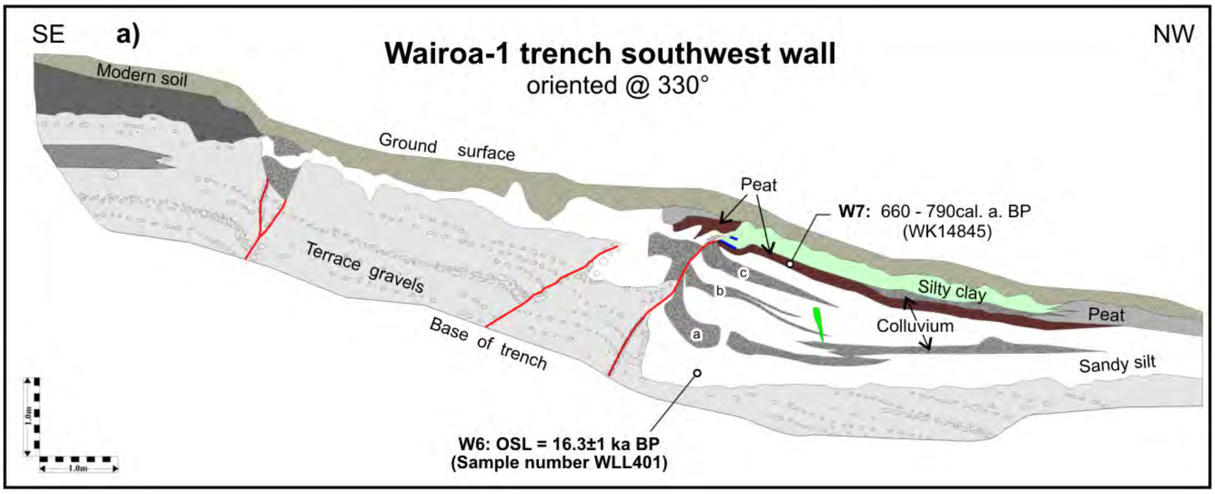
4.1 Slip per earthquake and Slip rates

At the Wairoa trenching site, vertical displacements and their ages indicate greater offsets for the older surfaces (Table 1). The displacement measurements are consistent with the occurrence of three surface-rupturing earthquakes. The average vertical slip per earthquake is about 1.2 m, while slip rates during the last 18 thousand years are typically about 0.2 mm/yr. These estimates of slip per earthquake and slip rates are likely to be minimum values because: i) reverse faults like the Waimea Fault may form at the ground surface in association with kilometre-scale folding and/or ii) other faults in the system may have ruptured during these earthquakes. The trenches and mapping of the ground surface revealed no evidence of horizontal displacement at the Wairoa trenching site. Elsewhere in the fault system there is limited evidence for horizontal movement. Beneath the Waimea Plains, for example, confined aquifers deposited by the Wairoa River are dextrally offset, although the amount and timing of the displacement is not known (Dicker et al., 1992). At Bishopdale the Flaxmore Fault appears to dextrally offset ridge crests by about 30 m. Nearby the ESE-trending Bishopdale Fault dextrally displaces ridges and creeks between 10 and 20 m (Bruce, 1962). The age of these ridges is unknown and therefore they cannot be used to calculate slip rates.

Table 1 Waimea Fault vertical displacements, horizon ages and slip rates determined from offset terraces on the south bank of the Wairoa River. Refer to Fraser (2005) for details of measurements.

Terrace displaced	Vertical displacement (m)	Horizon age (years BP)	Terrace dating method¥	Vertical slip rate (mm/yr)
E	0	5750±140	^{14}C	0
C*	1.2±0.2#	6230±580	^{14}C	0.19±0.04
C	2.3±0.5	12800±1000	OSL	0.18±0.05
B	3.5±0.5#	18000±2000	OSL	0.19±0.05

*Channel cut into terrace C. # Includes a component of folding. ¥^{14}C = radiocarbon date & OSL = Optically Stimulated Luminescence date.



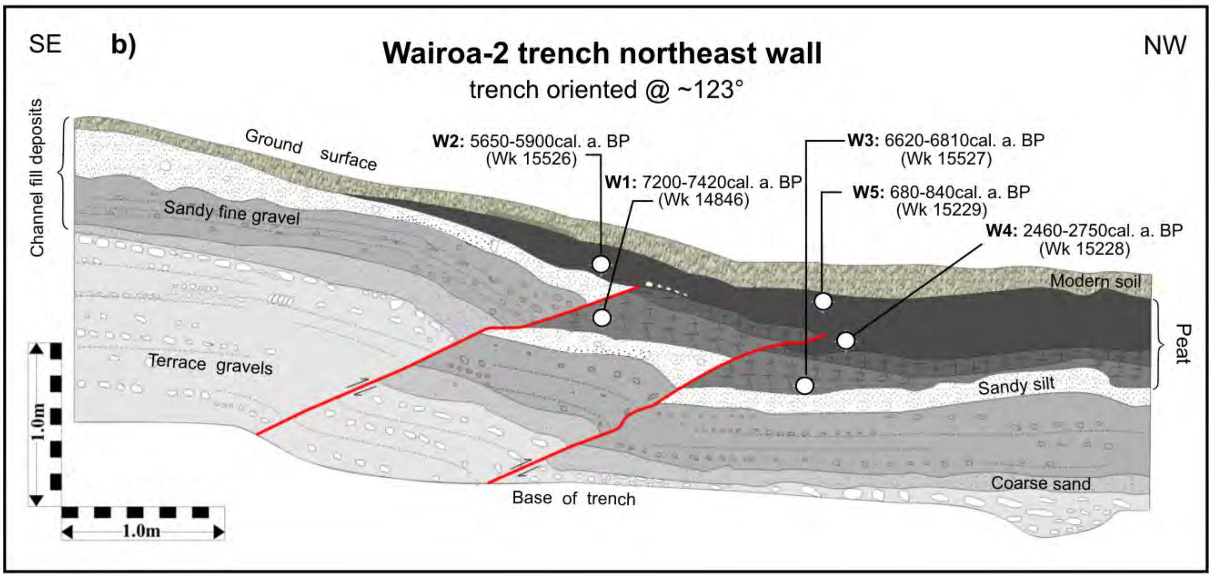


Figure 4 Wairoa-1 (a) and Wairoa-2 (b) trench logs which cross the Waimea Fault on the southwest bank of the Wairoa River (NZMS 262: Grid reference for Wairoa-1 is 2520200E, 5979070N and Wairoa-2 is 2520280E, 5979110N). See Figs 1 & 2 for approximate locations. Trench logs modified from Fraser (2005). The locations and two sigma age ranges of radiocarbon samples W1-W5 for peat are shown. Sample numbers (in brackets) are for the Waikato Radiocarbon Laboratory.

4.2 Timing of Events

Trenches excavated across the Waimea and Flaxmore faults reveal the timing of past earthquakes on these structures. The Wairoa-1 trench exposes the Waimea Fault where it displaces tilted gravels of terrace B and overlying grey silts (white fill in Fig. 4a) interbedded with thin (<30 cm) layers of angular colluvial gravels (grey units labelled a,b & c in Fig. 4a). Tilted gravels in the lower part of the trench are interpreted to have been folded across the fault during a surface-rupturing earthquake. Subsequent to this seismic event the fault scarp appears to have been eroded and buried by silt and angular colluvial fan gravels. The earliest recorded paleoearthquake in this trench dates from between the formation of the B terrace (~18±2 thousand years ago) and deposition of the 16.3±1 thousand year old silt which rests immediately on the terrace gravels (for further details of OSL date see Fraser, 2005). Further faulting is indicated by displacement and local folding of the beds of colluvium labelled *a*, *b* and *c,* which are inferred to have been deposited across the fault scarp during storm-driven fan aggradation (NB we cannot discount the possibility that these colluvium beds formed in response to earthquake shaking or rupture of the fault, however, the age of these beds has not been determined and cannot be used to constrain the timing of paleoearthquakes). Bed *a* is folded more than beds *b* and *c*, which we interpret to indicate that the lowest bed has experienced at least one more earthquake than the upper two beds. Therefore, at least three events on the Waimea Fault can be inferred from the Wairoa-1 trench. The timing of the youngest two events cannot be estimated from this trench.

To determine better the timing of these younger events a second trench was excavated about 60 m to the northeast of Wairoa-1. This trench, Wairoa-2, exposed the fault in a channel cut into the surface of terrace C and is shown in Fig. 4b. Here the fault comprises two main strands that displace channel gravels and the lower peat beds by about the same amount, but do not offset the top of the upper peat. These data suggest that the strata were faulted in a single event that occurred during peat accumulation. Radiocarbon dating of the peat (Fig. 4b) indicates that a paleoseismic event occurred between deposition of samples W2 (5650–5900 calibrated years BP) and W3 (6620–6810 calibrated years BP) giving an age of 5650–6810 calibrated years BP for the timing of the last surface-rupturing earthquake on the Waimea Fault.

The age of the ultimate and penultimate events on the Waimea Fault are further constrained by the ages of river terraces southwest of the Wairoa River (Fig. 3). The lowest of these terraces (E) is unfaulted and is therefore younger than the last surface-rupturing earthquake at this site. The timing of terrace abandonment has been constrained by a radiocarbon sample (Rafter Laboratory Sample number NZA 20095) collected from a soil layer which rests on terrace gravels and was buried by a ~15 cm thick sandy bed inferred to comprise over-bank deposits. These field relations together with the date from the sample indicate that the fault has not moved in the last 5610 to 5890 calibrated years BP. This date is consistent with the age of the unfaulted sample W2 in the Wairoa-2 trench. Displacements of terrace C are greater than those recorded on the gravels and lower peat in the Wairoa-2 trench and suggest that the penultimate event on this fault occurred after the formation of this terrace (12.8±1 thousand years ago; for further details of the OSL dates see Fraser, 2005), and before formation of the oldest peat in the trench (sample W1, 7200-7420 calibrated years BP, Fig. 4b). This event occurred somewhere between 7.2 and 13.8 thousand years ago. The proposed timing of paleoearthquakes on the Waimea Fault is summarised in Table 2.

Table 2 Summary for the timing and slip/event of paleoearthquakes on the Waimea Fault.

Seismic Event	Timing (years BP)	Slip/event (m)
1	5650–6810	1.2±0.2
2	7200–13800	1.1±0.7
3	15300–20000	1.2±1.0

The timing of the last surface-rupturing event on the Flaxmore Fault has been estimated from the Bishopdale-1 trench (Fig. 5, see Fig. 1 for location). The trench revealed faulted bedrock which is overlain by a poorly bedded cover sequence of locally derived angular gravels (containing variable amounts of silt) and paleosol layers. All but the lowermost portion of the cover beds are unfaulted, including a paleosol about 4.5-5.0 m below the ground surface which was dated at 4229-4421 calibrated years BP (sample F4, Rafter Laboratory Sample NZA21378). To further constrain the timing of this event we have used dates from samples F3 and F4 to calculate average sedimentation rates of 0.76-0.86 m/thousand years between the depths of about 1.8 and 4.9 m (i.e. along a vertical line that passes through sample F2). The type of sediment does not change across the F4 paleosol and if these rates also apply below sample F4, then faulted sediments resting immediately on basement would be about 5-6 thousand years old. Thus, the last event on this fault occurred between 4.2 and 6 thousand years ago. If correct this age estimate suggests that the timing of the last surface-rupturing earthquakes on the Flaxmore and Waimea faults are similar which could indicate that either each ruptured at the same time or they slipped in separate events no more than 1-2 thousand years apart. Discriminating between these two alternatives requires further investigation and will help to constrain better the magnitudes of paleoearthquakes over the last 10 thousand years.

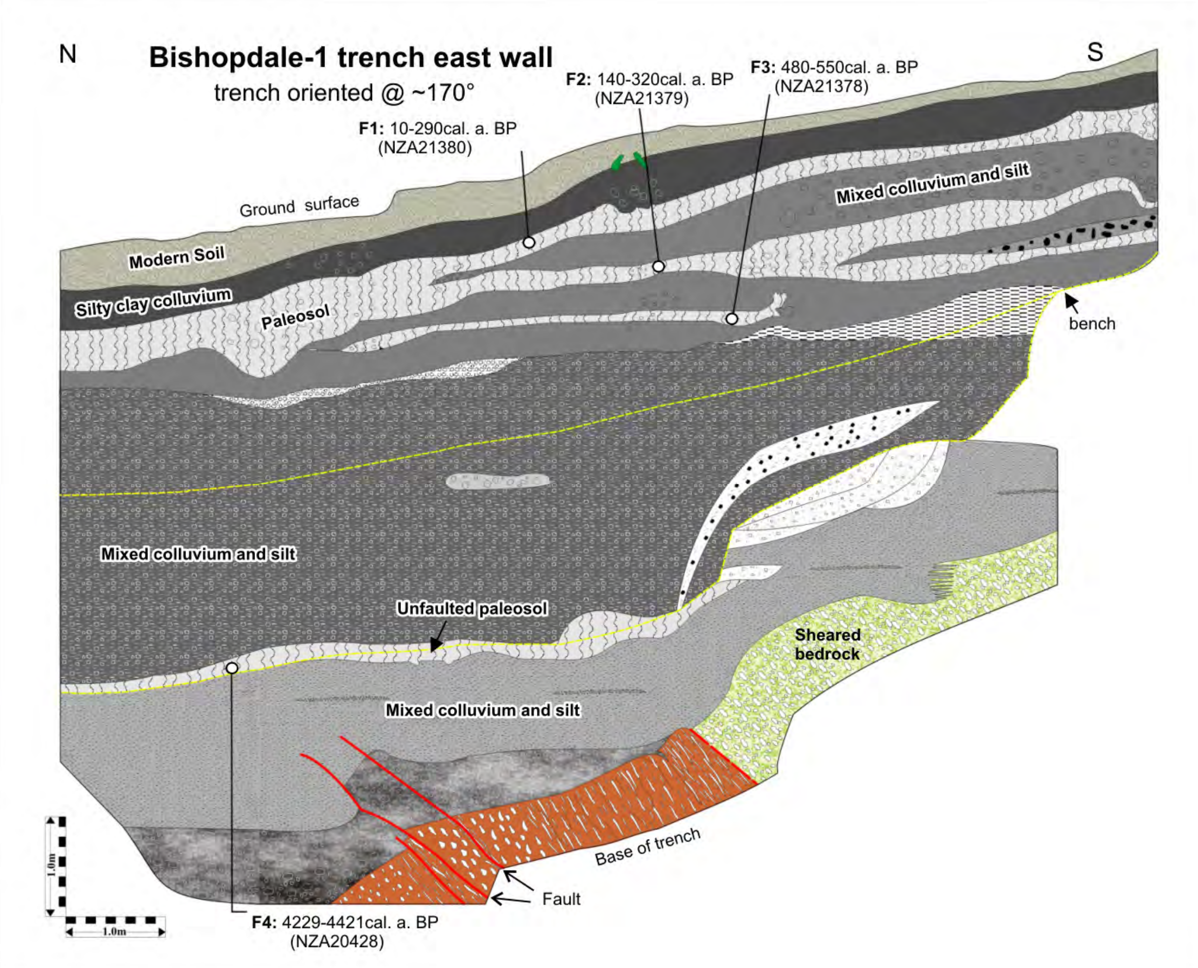


Figure 5 Bishopdale-1 trench excavated across the Flaxmore Fault near Nelson City (NZMS 262: Grid reference, 2531970E, 5989130N). See Fig. 1 for approximate location. Trench logs modified from Fraser (2005). The locations and two sigma age ranges of radiocarbon samples F1-F4 for charcoal in paleosols are shown. Sample numbers (in brackets) are for the GNS Rafter Radiocarbon Laboratory.

An average recurrence interval can be estimated for the Waimea Fault at the Wairoa Gorge site since the formation of terrace B. Based on the OSL age of 16.3±1 ka for silt resting directly on terrace B gravels and the elevated position of this terrace in the landscape we infer it to be a last glacial maxima surface. Therefore, this terrace surface has an estimated age of 18±2 thousand years and has experienced three events with an average recurrence interval of about 6 thousand years. This average value is a first-order estimate which carries uncertainties of about ±1.5 ka.

No data are available to constrain earthquake recurrence intervals for other faults in the Waimea-Flaxmore system. The 6 thousand year average recurrence interval for the Waimea Fault probably represents a maximum long-term average for the entire system (i.e. if other faults in the system ruptured at different times to the events on the Waimea Fault, then the system-wide recurrence interval would be less than 6 thousand years). This estimate of recurrence interval is significantly lower than the ca. 15 thousand years proposed by

Johnston et al. (1993) on the Waimea-Flaxmore Fault System further north in Nelson City. The average recurrence interval proposed in this report is approximately equal to the elapsed time since the last event (see Table 2). The similarity between the average recurrence interval and the elapsed time since the last event might be interpreted to indicate that surface rupture on the Waimea Fault is imminent. The data that constrain the timing of prehistoric earthquakes on the Waimea Fault are too imprecise to provide a reliable estimate of the variability of its earthquake recurrence intervals. Paleoearthquake studies of other faults in New Zealand (e.g., Howard et al., 2005) suggest, however, that large magnitude earthquakes on the Waimea Fault may not be evenly spaced in time. Based on present data, for example, recurrence intervals on the Waimea Fault could range from about 400 years to 12.8 thousand years. Therefore, while rupture of the Waimea Fault is likely over the next 1-2 thousand years we cannot discount the possibility that the next event occurs outside this time period.

5.0 PALEOEARTHQUAKE MAGNITUDES AND GROUND SHAKING

Earthquake magnitudes for prehistoric events can be estimated if information is available on the dimensions of the rupture surface, the amount of slip and the shear modulus of the rock volume enclosing the fault. Presently the most widely utilised magnitude scale is that for the Moment Magnitude (M_w) (Kanamori, 1977; Hanks and Kanamori, 1979). The formula used to determine the M_w proposed by Hanks and Kanamori (1979) is:

$$M_w = 2/3 \log M_o – 10.7 \qquad (1)$$

where M_o is the seismic moment, and $M_o = D\ A\ \mu$. D (cm) is the average slip per event across the fault surface (assumed to range from 0.3-2.4 m); A (cm^2) is the rupture area and μ is the shear modulus (3×10^{11} dyne/cm^2 or 30,000N/m^2). A is the product of the fault rupture length at the ground surface and the thickness of the seismogenic crust (in this case 15 km, for further information see Stirling et al., 2002).

Empirical relations from a global historical earthquake database are also used to estimate the magnitudes of prehistoric events. Here we use the empirical relation between magnitude and rupture area from Wells and Coppersmith (1994):

$$M = 3.98+1.02 \log A \qquad (2)$$

where A is again the rupture area (i.e. product of the fault rupture length at the ground surface and the thickness of the seismogenic crust).

The shear modulus and the thickness of the seismogenic crust have been derived from previous work (Hanks and Kanamori, 1979; Stirling et al., 2002), while the rupture lengths and average slip per event were estimated during this study. In the absence of evidence for the extent of surface rupture during individual earthquakes, we have selected a range of possible lengths within the system. In all cases the ends of each fault segment that may have ruptured during a single earthquake have been defined by changes in the strike of the faults or by intersection between two major faults. These estimates of rupture lengths are poorly constrained and provide an indication of what is possible rather than necessarily characterising the rupture length in future events. Average slip per event and their associated uncertainties were calculated from the range of displacements observed for the Waimea Fault on the terraces south of Wairoa River using a fault dip of 70°(see Table 1). Our estimates of average slip per earthquake do not explicitly take account of the possibility that some displacement at depth on the fault was accommodated by folding at the surface or that multiple faults within the system rupture in a single earthquake. The average slip per event in Table 1 are therefore likely to be minimum values.

Many variants on the above two equations are now in use. However, given the large uncertainties on the rupture dimensions and average slip/event of faults within the Waimea-Flaxmore Fault System, exploring these options is unwarranted until further detailed mapping and trenching more accurately constrains the fault-rupture lengths and average slip per event.

Table 3 Magnitude estimates for possible earthquake rupture lengths on the Waimea and Flaxmore faults. Rupture lengths represent a range of potential values and do not include all possible fault segments. See Fig. 2 for segment locations.

Fault	Segment description	Rupture length (km)	Moment Magnitude (M_w)*	Magnitude (M)
Waimea	St Arnaud - Bishopdale	70	6.6-7.2	7.1
Waimea	St Arnaud – D'Urville Island	150	6.8-7.4	7.4
Waimea	Bishopdale - Croisilles Harbour	40	6.5-7.1	6.8
Flaxmore	Stoke - Croisilles Harbour	50	6.5-7.1	6.9
Flaxmore	Stoke - D'Urville Island	90	6.7-7.3	7.1
Flaxmore	Croisilles Harbour-D'Urville Island	40	6.5-7.1	6.8

* Magnitude range due to range in dip slip/event of 0.3-2.4 m calculated from throws for fault dips of 70°.

Table 3 illustrates the range of earthquake magnitudes from 6.5–7.4 for the assigned rupture lengths. While the possible range of rupture lengths are likely to be captured in Table 3, the magnitudes of past earthquakes are not currently known with any certainty. Although the anastomosing nature of faults in the Waimea-Flaxmore Fault System and the common occurrence of fault intersections provide significant potential for rupture arrest, we cannot discount the possibility of the fault system rupturing along its entire length in a single earthquake. The estimates of earthquake magnitudes in Table 2 are consistent with the M7 magnitude, applied to this fault system in the New Zealand National Seismic Hazard Model (Stirling et al., 2002).

The intensity of ground shaking during earthquakes is dependent on a number of factors, including the magnitude of the event, distance from the earthquake focus, the local site conditions and the type of slip (e.g. reverse or strike-slip). Ground shaking can be assessed in a qualitative manner by recording the way in which it impacts on people, buildings (and fittings within these building) and the environment. These observations are collated for individual earthquakes and used to produce felt intensity distributions where levels of damage and disruption are contoured using isoseismals. The Modified Mercalli (MM) intensity scale has been used to map felt intensities for 122 earthquakes within, and close to, the New Zealand mainland (Downes, 1995). Of these earthquakes, six events ruptured to (or close to) the ground surface and had magnitudes of about 7, including the 1868 Cape Farewell, 1888 North Canterbury, 1929 Murchison, 1929 Arthurs Pass and 1968 Inangahua earthquakes. The six historical events display maximum felt intensities of MM 8-10 over areas which are typically at least twice the size of the combined Nelson and Richmond urban areas. Therefore, we concur with Johnston et al. (1993) in suggesting that felt intensities of MM 8-10 are likely to result from future large magnitude earthquakes in the Waimea-Flaxmore Fault System. Felt intensities of this order would cause damage to most buildings, cracking of the ground, liquefaction and widespread development of landslides on steep slopes, including one or more very large failures. Given the inferred Modified Mercalli values, it remains possible that many of the landslides along the range front were initiated or reactivated during earthquake events that produced surface ruptures on the Waimea-Flaxmore Fault System in the study area, including the last event about 6 thousand years ago. Many of the large landslides originating in the Barnicoat Range may be directly attributed to the earthquake that formed the scarp on the nearby Eighty-eight Fault. Unfortunately, neither the ages of the fault scarp nor the landslides are known.

6.0 PLANNING CONSIDERATIONS

The Waimea-Flaxmore Fault System is an active structure. Active fault guidelines for Nelson and Tasman resource management plans were developed using information from previous earthquake hazard reports Waimea-Flaxmore Fault System (Johnston et al., 1993; Coote and Downes, 1995). As a result of this work it was proposed that active faults, or zones of intense deformation that are likely to encompass the active fault when movement occurs, should not be built over. New information on the paleoearthquake potential of the Waimea-Flaxmore Fault System contained within this report together with the development of national guidelines for active faults in resource management plans (Kerr et al., 2003) provide a basis for reassessing the treatment of active faults in the Nelson and Tasman resource management plans.

Paleoearthquake investigations on the Waimea Fault suggest a recurrence interval of about 6 thousand years and place it in fault recurrence interval class IV of the national active fault guidelines (Kerr et al., 2003). These guidelines suggest that building within a fault avoidance zone (i.e. an area created by establishing a buffer zone either side of the known active fault trace), should be discouraged wherever possible. This recommendation applies even when a fault has a long recurrence interval (e.g., Waimea and Flaxmore faults), and the chance exists that the fault may move during the lifetime of a building (Kerr et al., 2003). For a fault recurrence interval class IV active fault, the guidelines recommend that where the fault is well-defined residential construction (i.e. building importance category 2 of Kerr et al., 2003) be permitted within fault avoidance zones for pre-existing developments and greenfield sites, but may be subject to the control or discretion of the local authority. Buildings of greater community value or higher occupancy would be discretionary (e.g., greenfields sites building category 3) or not permitted (building category 4). Because the average recurrence interval for the Waimea Fault is approximately equal to the elapsed time since the last earthquake on this fault, we suggest that discretion is exercised when granting permission to construct category 2 and 3 buildings (see Kerr et al., 2003). Consequently, unless unavoidable to do so, it is prudent that structures are not located across active or potentially active faults or fault zones in the Waimea-Flaxmore system. The most practical means of achieving this is to continue with the requirement that buildings and other structures are setback from the active faults. This does not mean that other faults in the fault system might not rupture but that there is currently no evidence to warrant a setback from them.

Establishing a building setback is not a simple exercise as, rather than well located and well-defined fault planes, the positions of the faults are generally imprecisely known or there are zones in which the intensity of deformation may gradually diminish away from the fault. The distance over which this diminution occurs can be highly variable and dependent on such factors as the composition of materials affected. This diminution cannot be easily resolved without intensive investigation of the faults along their entire lengths. Consequently, rather than trying to precisely define the faults along their entire lengths, it is more practical to firstly define planning hazard zones (i.e., fault avoidance zones) which are known to contain the faults.

6.1 Fault Hazard Planning Zones (or Overlays)

The objective of a fault hazard planning zone, or overlay, on resource management plans, is to advise that within them there is a hazard arising from rupture or other types of deformation of the ground surface as a result of fault movement (see Appendix 1 for hazard overlays along the Waimea-Flaxmore Fault System). This does not necessarily mean that entire fault hazard overlays are areas at high risk from fault rupture. Instead the overlays require that developments within them need to take cognisance of the risk of fault rupture and, if a risk exists then, where possible, mitigation measures should be implemented. The measures are primarily a building setback although it is possible that certain types of constructions could tolerate ground deformation adjacent to the plane of rupture better than others. Also the end use of the structure may be an important consideration. For example, it may be acceptable to build a lightweight storage structure across a fault but not a high rise/high occupancy building.

In theory, a planning overlay need not be any wider than the distance between the building setbacks as measured on opposite sides of a fault. In practice, because at most sites the location of a fault is generally imprecisely known, the planning zone will need to be wider to accommodate this uncertainty. Consequently, where the precise location of a fault is not known then a fault hazard planning zone should incorporate the ground inferred to contain the fault in addition to a setback from that fault. Where the fault zone has not been identified, the fault hazard zone can be centred on the median line between the surface features arising from fault movement or between other geological data, such as outcrops, which constrain the fault. For example, where there is a scarp arising from ground rupture along a fault, then the fault can be reasonably assumed to be somewhere within it and a fault hazard planning zone (or fault avoidance zone) could be defined by setbacks from the toe and top of the scarp. Once a zone has been defined, the hazard of fault rupture to any proposed structure within it, can be specifically assessed and setback an appropriate distance. While it is important that the fault hazard planning zone encompasses all ground where rupture or intense deformation can be anticipated, it is clearly desirable to keep the width of this zone to a minimum. Zones of excessive width will unnecessarily involve areas where rupture or severe ground deformation will not occur, potentially resulting in unnecessary delays and costs for any development.

It follows that where a single fault plane has been located, then the planning zone would be no less than the combined setback distances on either side of the plane. However, most faults do not consist of a single plane but instead may have multiple planes and/or comprise a zone of fault gouge or pug, which may or may not have clearly defined boundaries. In such circumstances, the fault planning zone will be correspondingly wider. Where the fault has been only broadly constrained by rock types then the planning zone will be between the outcrops plus the addition of a distance on either side of it equivalent to the building setback. Thus depending on the data available, a planning zone could be of variable or uniform width.

Where the fault is a well-defined single plane, the zone would be at a minimum twice the width of the building setback distance from the fault. In Nelson City, where the setback is currently 5 m, this results in a zone a minimum of 10 m wide. For the Tasman district, where the building setback is presently 10 m, the minimum width would be 20 m. Where the fault is poorly constrained, the width would increase in proportion to the degree of uncertainty in the position of the fault. In locations where detailed fault information is not available a zone of uniform width based on the maximum width can be used. While easier to prepare and define, and what is broadly shown on the current Nelson and Tasman resource management plans, this uniform maximum width has the major disadvantage that it will include ground that is unlikely to be faulted in future earthquakes.

6.2 Building Setbacks

Building setbacks should be measured from the nearest fault plane or, if a fault plane has not been identified, a fault scarp or other fault related feature. Building setbacks will be of a width that does not exceed that of the enclosing fault hazard overlay. The amount of the building setback should be sufficient to ensure that buildings or other structures are not directly affected by rupture along the fault or subject to intense ground deformation. However, it needs to be acknowledged that deformation of the ground away from a fault will not end abruptly and that the width of intense deformation may vary along the fault. Consequently, the definition of a setback is subjective and damaging ground deformation may extend beyond it. In some circumstances, the fault need not be located to determine that a structure is not sited across it. This is because most of the faults in the Waimea-Flaxmore Fault System separate contrasting bedrock types. Provided it can be demonstrated that a particular rock type extends across an entire site no further investigation is required.

6.2.1 Setback Distance

Currently, as required by the Nelson and Tasman resource management plans, the setback distances from the active faults are 5 m and 10 m respectively. The reasons for the figures being different are complex and resulted from a number of factors. One factor, for example, was that when the GNS Science assessment was done for the Nelson City Council in 1993 there was uncertainty as to whether the Flaxmore Fault was sufficiently active in the city to be of concern from a planning perspective. After much deliberation, it was recognised that it would be prudent not to build over this fault and also other faults that showed evidence of surface rupture or were considered to have an elevated risk of rupture, such as the Bishopdale, Whangamoa and Waimea faults. Subsequent investigations, summarised in this study, have demonstrated that this was a sensible decision although the question now arises as to what is an appropriate setback. A report prepared for Ministry for the Environment recommended a 20 m setback from active faults (i.e. a fault avoidance zone width of 40 m), which may be modified for variations in local site conditions and different levels of geotechnical investigation (Kerr et al., 2003).

From the limited work undertaken on the Waimea-Flaxmore Fault System, it appears that its constituent faults have a relatively narrow zone in which intense deformation occurs. Possible exceptions to this occur where faults offset thick alluvial deposits, such as the Last Glaciation outwash surface forming the Waimea Plains between Haycock Road and the toe of the Barnicoat Range. Taking this into account, it is considered that a minimum building setback of 10 m is prudent. However, because of the nature of the fault system, in particular where it separates bedrock units, it is possible that with site specific investigation the setback could be reduced at the discretion of the local authority, but should be no less than 5 m. In superficial deposits, such as gravel and scree where intense deformation may extend further from the plane of rupture, a minimum 10 m building setback would likely prevail and this is discussed further below.

A 10 m building setback would maintain the *status quo* in the Tasman District but it would mean a change for Nelson City. With Nelson and Tasman having residential land prices amongst the highest in New Zealand, any change in the setback distance would likely be a significant factor in any development straddling a fault within the Waimea-Flaxmore Fault System. However, specific investigation may allow the building setback to be decreased to half this distance both in Nelson City and in the Tasman District to as far south as the Wairoa Gorge.

6.3 Level of Geotechnical Investigation in Locating Faults

Recognising active or potentially active faults is dependent on two factors: the training and experience of the consultant involved and the level of geotechnical investigation. The first factor is not discussed here except that the consultant should be recognised as specialising in earthquake risk assessment. For buildings, expertise in seismic engineering design could also be appropriate. With respect to the second factor, it is not always possible to locate a fault, even following a level of geotechnical investigation expected as part of any application for resource or building consent. Such investigations would normally include test pitting or auger holes using a mechanical digger or similar machine. On hillsides, the depth to which test pits or auger holes can reach is rarely greater than 4 m. Consequently, it may not be possible to locate a fault because it is too deeply buried, such as beneath alluvium or landslide deposits, or the rocks are deeply weathered. In large subdivisions or other major developments, drilling may be undertaken. However, for subdivisions drilling is usually confined to only one or two holes and this may be insufficient to locate a fault. Despite this, even a single drill hole may, if bedrock is intercepted, provide firm data as to which direction a fault may lie and therefore whether the development straddles or avoids the fault. Additional, and generally costly, further work, such as an extensive drilling programme and/or geophysical surveys could narrow the zone of interest. There is also the additional uncertainty that even if the fault is located beneath a thick cover of alluvium, it may be difficult, as discussed above, to predict the likely plane of fault propagation to the surface. In such circumstances, any building setback would result in an excessively wide zone in which development could not occur.

Where, after investigation, the position of the fault remains uncertain, the current resource management plans allow the fault to be disregarded as part of any residential development. In addition, in the urban area of Nelson City between Iwa Road and Scotland Street (Appendix 1), where the Flaxmore Fault has not been located due to a thick alluvial cover, the Nelson Resource Management Plan allows low density residential development without any investigation whatsoever of the fault. This highlights the question of whether areas where a fault is deeply buried and/or have already been subdivided for urban development, should be treated differently from “greenfield sites” that have yet to be developed (see Kerr et al., 2003).

6.4 Greenfield versus Developed Land

Since the Nelson and Tasman resource management plans became operative, it has been shown that the rules referring to the implementation of building setbacks have not always been straightforward. Where land within the overlays is not developed for housing or other intensive use (such as in pasture or plantations), then it is simple to implement a building setback, provided the fault in question can be located. By taking cognisance of the presence of a fault when planning a housing subdivision, it is generally possible to locate dwelling sites that do not straddle the fault. However, it is impractical to avoid services such as roads, water mains and the like from crossing the fault.

Where the land is already developed, implementation of a fault setback is not always straightforward. As already mentioned, there are areas where long sections of some of the faults in the Waimea-Flaxmore Fault System, particularly the Flaxmore Fault in Nelson City and the Waimea Fault in Richmond, have been built on. In such areas where the faults have been built on then, in view of the relatively low activity on the fault system, and that only light weight structures are involved, it could be argued that the rupture hazard the fault presents should be dismissed. In other words, for dwellings within a fault hazard overlay, alterations or new construction could take place generally within the existing foot print without further investigation of the hazard of fault rupture. However, for any extensions significantly beyond the footprint or further subdivision for residential purposes would require an appropriate level of investigation before resource and/or building consents were considered by councils. Where more intensive development is proposed within a fault hazard overlay, such as a multiple storied high occupancy building, then irrespective of existing land use, a full assessment of the hazard of fault rupture would be required. The level of the investigation should be commensurate with the development proposed.

6.5 Possible ill-defined Ground Deformation arising from Fault Movement

Faults within the Waimea-Flaxmore Fault System appear to have relatively narrow zones of intense deformation. However, in the Haycock Road area of the Waimea Plains, as discussed above, a prominent bank and undulations in the 18,000 year old Last Glaciation outwash surface, have been identified as possible folds arising from movement on the Waimea Fault at depth (Fraser, 2005). While this inference is reasonable further collection of information is required to test the folding idea. Given that some uncertainty exists around the validity of the folding interpretation we have elected not to designate these possible folds fault hazard zones in the overlay maps. This decision may need to be reassessed as more geotechnical information is collected.

7.0 RECOMMENDATIONS

7.1 Fault Hazard Overlays and Building Setback Distances from Faults

It is recommended that the Nelson City and Tasman District councils:

1. Continue to recognise that the Waimea-Flaxmore Fault System is active and that,

where possible and practical to do so, the building of structures across its constituent faults that have an elevated risk of rupture during an earthquake is avoided. Based on the information presently available, the active faults are Flaxmore, Waimea, Heslington, Eighty-eight, Whangamoa, Bishopdale, Grampian and Hira.

2. Adopt a revised fault hazard overlay (presented in Appendix 1) incorporating the Flaxmore, Waimea, Heslington, Eighty-eight, Whangamoa, Bishopdale, Grampian and Hira faults.

    i. Where the Flaxmore, Waimea, Heslington, Eighty-eight, Whangamoa, Bishopdale, Grampian and Hira faults have already been precisely located, the fault hazard overlay shall have a width of no less than 20 m. The boundaries of the overlay shall be 10 m from the fault plane. However, as the fault planes are commonly not vertical it may not be possible to determine where to measure the 10 m from and a wider fault hazard overlay may result (hazard overlay zones 50-200 m wide are common – see Appendix 1). This is particularly so on sloping ground where superficial creep has shallowed the fault dip close to the ground surface. In such circumstances, the fault hazard overlay may be wider and/or the faults intersection with the surface may not be equidistant from the boundaries of the overlay. In addition, where there is more than one slip surface and/or a zone of fault gouge, the boundaries of the fault hazard overlay shall be measured from the outer margin of the fault zone or fault scarp.

    ii. Elsewhere where the position of the fault is only approximately known or inferred, the overlay should be wide enough to capture uncertainties in the fault location and should also include 10 m setback beyond the fault locations.

3. Adopt revised Building Setback Distances from Faults with elevated Risk of Movement

    i. Where a fault with an elevated risk of rupture can be located, and the likely future plane of movement on it identified, there should be a 10 m set back from it for buildings. As in the fault hazard overlay, allowance should be made for possible near-surface creep affecting the position of the fault.

    ii. For Nelson City and the Tasman District north of the Wairoa River the setback may be reduced to 5 m following specific assessment by a consultant specialising in earthquake risk assessment, including seismic engineering design. Such an assessment should address the likely levels and width of deformation that would arise during fault rupture.

4. Adopt Different Types of Fault Hazard Overlays

Depending on factors such as uncertainty in the position of the fault and/or where a concealed fault may propagate to the surface during movement, along with the type of land use, it is recommended that Councils adopt several categories of fault hazard overlay:

1) Overlays where the fault is at or close to the ground surface, including confirmed and inferred fault scarps.

   i. Undeveloped (Greenfield) Sites

      A geotechnical assessment by a consultant specialising in earthquake risk assessment and, where appropriate seismic engineering design, shall accompany any application for resource or building consent. The assessment shall likely include test pitting using a mechanical digger or mechanical auger. In some circumstances, such as large subdivisions, more extensive investigations may be appropriate and could include drilling and/or seismic reflection surveys. Also for large structures, such as high occupancy and/or high rise buildings or for crucial infrastructure facilities a more intensive appraisal of the fault, and the effect of fault rupture, may be warranted. If after investigation, the fault is defined then building sites shall be setback from it by the distance stated in Section 7.1.3 above. However, it is recognised that it may be unavoidable for structures, such as roads and pipelines, not to be constructed across a fault

      Where the fault is not located after the appropriate level of investigation, then development within any part of the overlay is allowed.

   ii. Existing Urban Areas

      a) Building consents

      In existing urban areas, rebuilding within the existing footprint is permitted without investigation of the hazard of fault rupture. If building beyond the existing footprint is proposed, then any application for building consent shall be accompanied by a site specific investigation of the fault. If the fault is identified then any building beyond the existing footprint shall be setback by the distances defined in Section 7.1.3.

      b) Subdivision

      Subdivision resulting in new lots within existing urban areas shall be accompanied by a geotechnical assessment by a consultant specialising in earthquake risk assessment. If the fault is located then any dwelling shall be set back from the projected plane of movement as required in 7.1.3 above. If a building cannot be setback as required by 7.1.3 the subdivision should not proceed. However, in cases where, after investigation, the fault plane is not located then subdivision consent can be granted.

2) The location of the fault is approximately known but is deeply buried or there

is a very wide zone within which movement could occur:

Where the fault cannot be expected to be located after standard geotechnical investigation, then any building involving low occupancy buildings and other similar developments, can proceed without geotechnical assessment of the hazard of fault rupture. Other structures, such as a high occupancy multi-storied buildings and/or infrastructure such as a water storage facility or power substation, shall be subject to detailed geotechnical investigation by a consultant specialising in earthquake risk assessment, including seismic engineering design. The investigation could include seismic-reflection surveys and/or drilling,

3) Deeply buried faults whose positions are not known:

   Where the position of the fault is not known or very poorly constrained, no fault hazard overlay is recommended,

4) As further work, in relation to specific geotechnical investigations and/or to an increase in knowledge of the Waimea-Flaxmore Fault System (see Section 7.2 below), will enable refinement of the width and location of the fault hazard overlays, the Councils should make provision for future amendments to these planning maps.

7.2 Further Work

The present research programme has provided important and potentially useful information on the size and timing of prehistoric earthquakes within the Waimea-Flaxmore Fault System. Despite these advances, key uncertainties remain regarding the magnitude and timing of past earthquakes within the system. Resolving these uncertainties will be important if Councils are to plan appropriately for future earthquakes in, and close to, the Nelson and Richmond urban areas. In particular, future work should focus on three main issues:

i) improving estimates of rupture lengths and magnitudes of past earthquakes,

ii) determining whether other faults in the system rupture at the same or different times to the Waimea or Flaxmore faults (if the faults rupture at different times then the recurrence interval for earthquakes in the entire fault system may be significantly shorter than the 6 thousand year average determined for the Western Branch of the Waimea Fault south of the Wairoa Gorge), and

iii) gaining a more precise measure of vertical and horizontal slip during individual earthquakes.

All of these issues can be addressed by:

1) Undertaking further trenching across active fault traces and by dating geomorphic surfaces offset by the fault. Four sites are recommended with a single trench across

each of the following faults: Whangamoa, Bishopdale, Eighty-eight and Waimea (south of Wairoa Gorge) faults.

2) A trench across the inferred fold/fault scarp at Clover Road East to confirm that the bank has arisen from multiple ruptures. This trench has the potential to determine whether the bank is sedimentary or tectonic in origin and, if the latter, whether it is the result of fault movement at depth or from multiple ground rupture along the Western Branch of the Waimea Fault.

3) Dating of terrace surfaces and other features displaced by these faults to help constrain the timing and magnitudes and of past earthquakes and the possibility of determining if the large landslides within Nelson City and the Barnicoat Range are the result of large magnitude events on the Waimea-Flaxmore Fault System.

8.0 CONCLUSIONS

The active Waimea-Flaxmore Fault System passes through Nelson City and Richmond and comprises active traces with mainly reverse displacements that formed during large magnitude surface-rupturing earthquakes. The fault system, which has not ruptured in historical times, has experienced at least three seismic events in the last 20 thousand years. These earthquakes occurred on the Waimea Fault at 15.3-20, 7.2-13.8 and 5.7-6.8 thousand years ago. The average recurrence interval for these events is about 6 thousand years and is approximately equal to the elapsed time since the last surface-rupturing earthquake. A total of about 3.5 m vertical displacement accrued during these events, with average slip/event and slip rates of about 1.2 m and 0.2 mm/yr respectively. Our analysis suggests that fault rupture of the ground surface may be accompanied by earthquakes with magnitudes of about 7. With the exception of the Flaxmore Fault at Bishopdale, no information is available for the timing of earthquake events on any of the other faults in the Waimea-Flaxmore Fault System.

Fault hazard overlays are defined along the main northeast-trending Flaxmore, Waimea, Eighty-eight and Whangamoa faults and the Hira, Grampians and Bishopdale faults which trend at approximately right angles to the main faults. The width of the overlay is directly proportional to the level of uncertainty in the location of the fault and/or its likely plane of future rupture. Where the fault comprises a single vertical or steeply dipping fault plane which is accurately located (and not affected by slope creep) a width of 20 m is recommended. Where the uncertainty is greatest the maximum width is 175 m.

Because the Waimea-Flaxmore fault System has a relatively low level of activity, three types of fault hazard overlays are recommended. These comprise overlays for undeveloped land (Greenfield sites), existing urban and parts of faults that are deeply buried or likely to be associated with a wide zone of potential movement. A building setback of 10 m from the nearest fault plane or projected plane of future movement is recommended. This setback may be reduced to 5 m where the fault is precisely located by geotechnical investigation.

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10.0 REFERENCES

Anderson, H. and Webb, T. (1994). "New Zealand seismicity; patterns revealed by the upgraded National Seismograph Network," *New Zealand Journal of Geology and Geophysics,* Vol. 37, pp. 477-493.

Bruce, J.G. (1962). "The geology of the Nelson City area," *Transactions of the Royal Society of New Zealand, Geology,* Vol. 1, pp. 157-181.

Coote, T.P. and Downes, G.L. (1995). Preliminary assessment of earthquake and slope instability hazards in Tasman District. Institute of Geological & Nuclear Sciences Client report, 1995/41430D.16. Institute of Geological & Nuclear Sciences Ltd.

Dicker, M.J.I.; Fenemor. A.D.; Johnston, M.R. (1992). Geology and Groundwater Resources of the Waimea Plains, Nelson. *New Zealand Geological Survey bulletin 106*. DSIR Geology and Geophysics.

Downes, G.L. (1995). Atlas of isoseismal maps of New Zealand earthquakes. Institute of Geological & Nuclear Sciences Monograph 11, 304 p., Lower Hutt, New Zealand: Institute of Geological & Nuclear Sciences Ltd.

Fraser, J.G. (2005). "Paleoseismic Investigation of the Waimea-Flaxmore Fault System, Nelson Region," *Unpublished M.Sc. Thesis, University of Canterbury.*

Fraser, J.G., Nicol, A., Pettinga, J.R., and Johnston, M.R. (2006). Paleoearthquake investigation of the Waimea-Flaxmore fault system, Nelson, New Zealand. In: Earthquakes and urban development: New Zealand Geotechnical Society 2006 Symposium, Nelson, February 2006. Institution of Professional Engineers. Proceedings of technical groups / Institution of Professional Engineers New Zealand 31(1), p. 59-67.

Hanks, T.C. and Kanamori, H. (1979). "Moment Magnitude Scale," *Journal of Geophysical Research,* Vol. 84, pp. 2348-2350.

Hatherton, T. (1980). "Shallow Seismicity in New-Zealand 1956-75," *Journal of the Royal Society of New Zealand,* Vol. 10, pp.19-25.

Howard, M., Nicol, A., Campbell, J.K. and Pettinga. J.R. (2005). Prehistoric earthquakes on the strike-slip Porters Pass Fault, Canterbury, New Zealand. *New Zealand Journal of Geology and Geophysics,* Vol. 48, pp 59-74.

Johnston, M.R. (1979). “Geology of the Nelson urban area 1:25,000 (1st ed.),” *New Zealand Geological Survey Urban Series Map 1,* Map 1 sheet, notes 52 pp., Urban series map, 1, Wellington, N.Z., Department of Scientific and Industrial Research.

Johnston, M.R. (1981). “Part sheet O27 - Dun Mountain 1st ed,” *Geological Map of New Zealand 1:50,000,* Map 1 sheet, notes 39 pp., Wellington, N.Z., Department of Scientific and Industrial Research.

Johnston, M.R. (1982a). “Part sheet N27 - Richmond 1st ed,” *Geological Map of New Zealand 1:50,000,* Map 1 sheet, notes 31 pp., Wellington, N.Z., Department of Scientific and Industrial Research.

Johnston, M.R. (1982b). “Sheet N28 BD - Red Hills 1st ed,” *Geological Map of New Zealand 1:50,000*, Map 1 sheet, notes 47 pp., Wellington, Department of Scientific and Industrial Research.

Johnston, M.R. (1983). “Sheet N28 AC – Motupiko,” *Geological Map of New Zealand 1:50,000,* Map 1 sheet, notes 40 pp., Wellington, N.Z., Department of Scientific and Industrial Research.

Johnston, M.R. (1990). “Sheet N29 - St Arnaud,” *Geological Map of New Zealand 1:50,000, Map 1 sheet, book 119 pp., New Zealand Geological Survey*, 99, Wellington, N.Z., Department of Scientific and Industrial Research.

Johnston, M.R., Hull, A.G. and Downes, G.L. (1993). Earthquake, landslide and coastal hazards in Nelson City. Institute of Geological & Nuclear Sciences Client report, 413399.21. Institute of Geological & Nuclear Sciences Ltd.

Kanamori, H. (1977). “Energy-Release in Great Earthquakes,” *Transactions-American Geophysical Union,* Vol. 58, pp. 438-438.

Kerr, J., Nathan, S., Van Dissen, R., Webb, P., Brunsdon, D and King, A. (2003): Planning for Development of Land on or close to Active Faults. Report for the Ministry for the Environment by the Institute of Geological & Nuclear Sciences. Institute of Geological & Nuclear Sciences Client report 2002/124 440W103301, July 2003.

Pettinga, J.R. and Wise, D.U. (1994). “Paleostress adjacent to the Alpine Fault; broader implications from fault analysis near Nelson, South Island, New Zealand,” *Journal of Geophysical Research, B, Solid Earth and Planets,* Vol. 99, pp. 2727-2736.

Rattenbury, M.S., Cooper, R.A. and Johnston, M.R. (1998). “Geology of the Nelson area,” *Institute of Geological and Nuclear Sciences, 1:250000 Geological Map 9*, 1 map (1 sheet), booklet 67 pp., Lower Hutt, N.Z., Institute of Geological & Nuclear Sciences.

Reyners, M., Robinson, R. and McGinty, P. (1997). “Plate coupling in the northern South Island and southernmost North Island, New Zealand, as illuminated by earthquake focal mechanisms,” *Journal of Geophysical Research, B, Solid Earth and Planets,* Vol. 102, 15 pp.

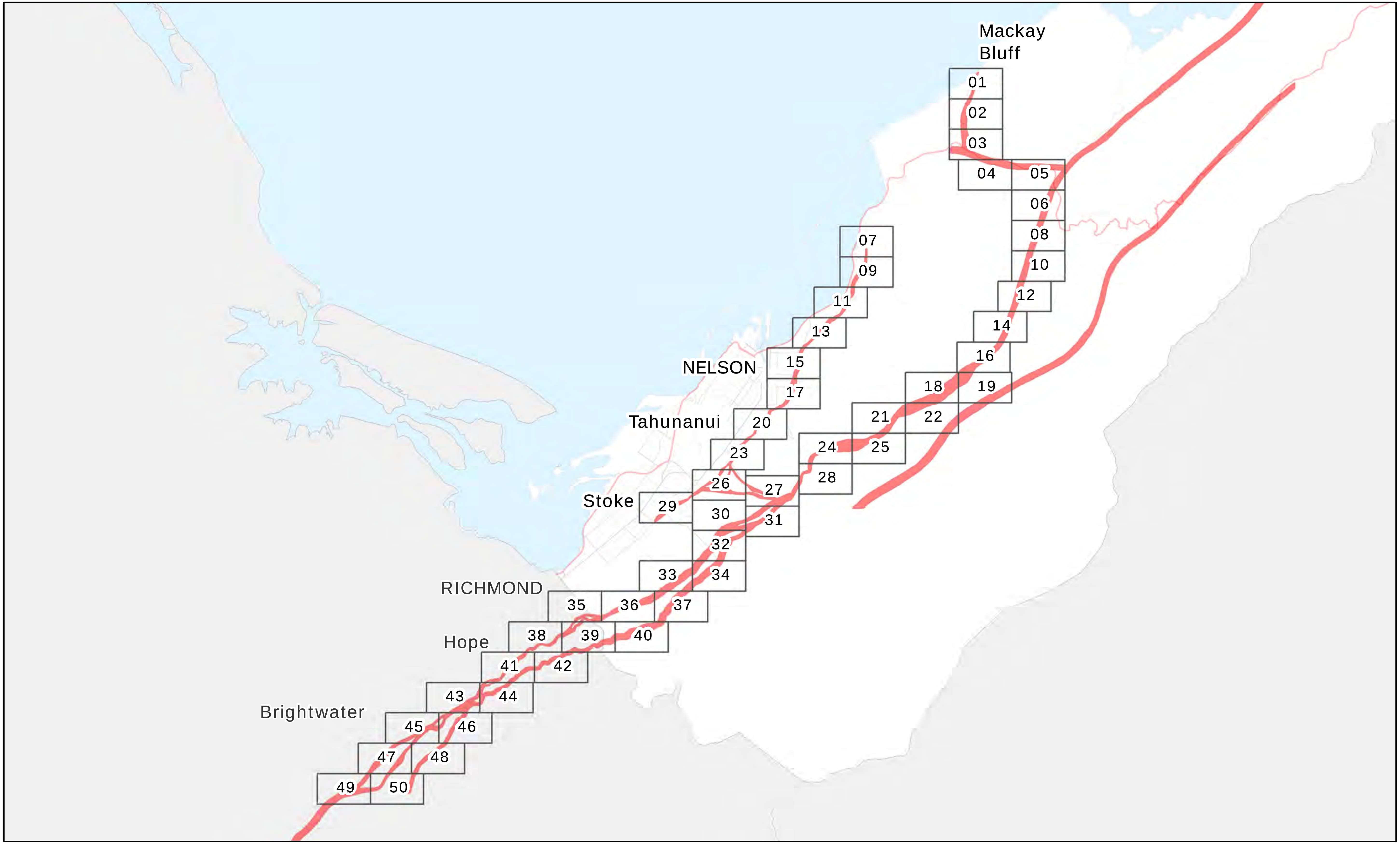
Stirling, M.W., McVerry, G.H. and Berryman, K.R. (2002). “A new seismic hazard model for New Zealand,” *Bulletin of the Seismological Society of America,* Vol. 92, pp. 1878-1903.

Wells, D.L. and Coppersmith, K.J. (1994). “New empirical relationships among magnitude, rupture length, rupture width, rupture area, and surface displacement,” *Bulletin of the Seismological Society of America,* Vol. 84, pp. 974-1002.

APPENDIX 1 — FAULT HAZARD PLANNING ZONES (OR OVERLAYS)

The fault hazard overlay maps have been plotted onto orthomaps, containing cadastral information at a scale of 1: 5 000. In defining the various fault hazard overlays, the faults within them or points constraining the positions of the faults, were firstly plotted onto the cadastral maps although the accuracy of this is dependent on existing information. Much of the information was transferred from aerial photographs (Johnston 1981, 1982a, b). Subsequently, as part of this study, the position of some of the faults, or the points constraining them, were fixed using a handheld GPS with an accuracy of ±5 m. In a few areas the faults, mostly as a result of geotechnical investigations, have been accurately fixed by surveying. Once the positions of the faults were constrained within these limits, the boundaries of the fault hazard overlays were drawn to encompass the points constraining the position of the faults. In all cases fault hazard planning zones are marked by red polygons. The widths of the hazard overlays are of variable width (ranging from ~20 m to ~400 m), being narrowest where the faults have been identified and their positions accurately surveyed. Elsewhere, the width is dependent directly on the information constraining the position of the faults.

New fault hazard overlay zones, as recommended by this report, are shown on the following 51 maps. The first of these maps shows the locations of 50 detailed maps.



Overview Map

Recommended Revised Fault Hazard Overlay

Nelson City Council
te kaunihera o whakatū

0 2.5 5 7.5 10 km

Scale 1:120,000

N

August 2013

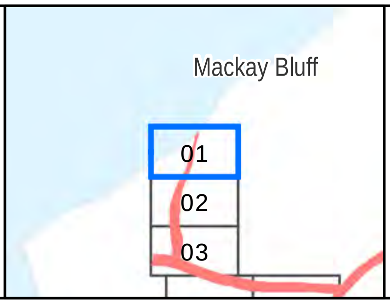
File Ref: 1201892
SER. Original map size A3.

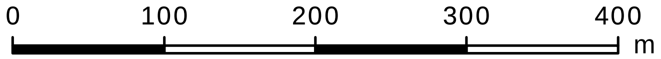
Map 01

Recommended Revised Fault Hazard Overlay

Nelson City Council
te kaunihera o whakatū

🟥 Recommended Revised Fault Hazard Overlay
(Source: GNS Science)





Scale 1:5,000

N

August 2013

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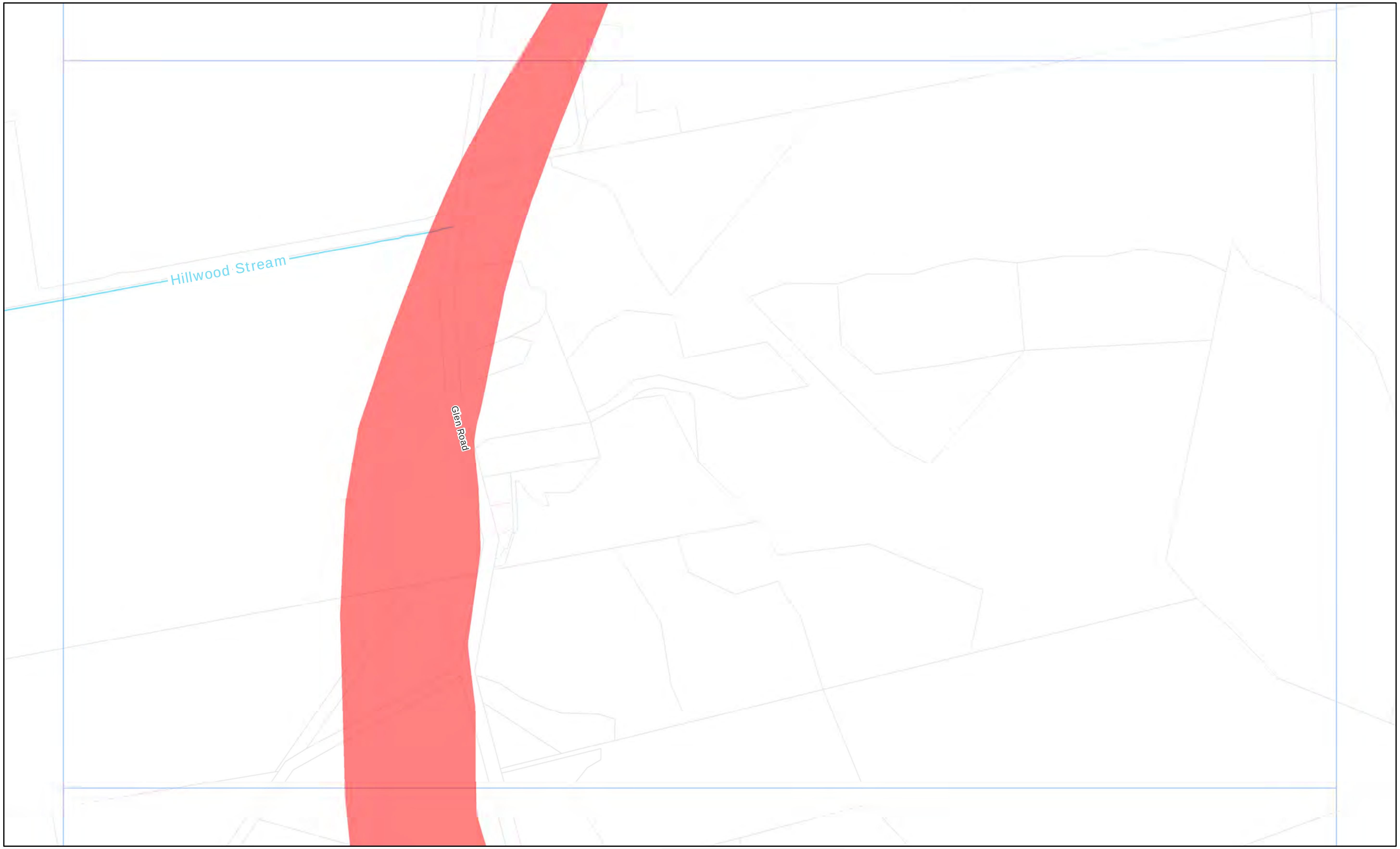
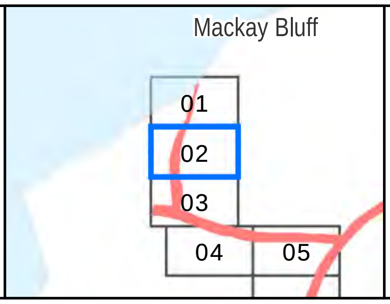


Map 02

Recommended Revised Fault Hazard Overlay

Nelson City Council
te kaunihera o whakatū

🟥 Recommended Revised Fault Hazard Overlay
(Source: GNS Science)



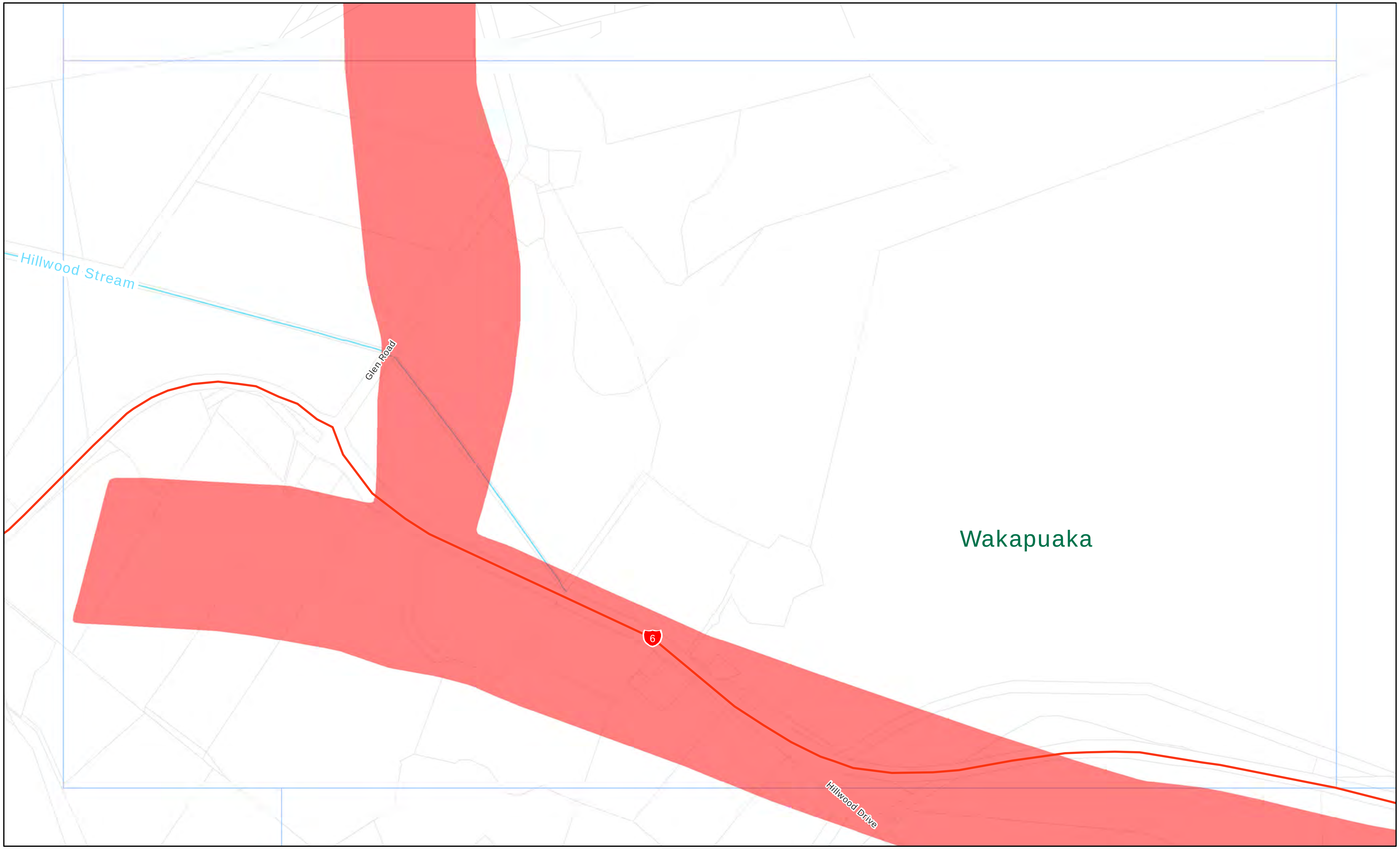
0 100 200 300 400 m

Scale 1:5,000

N

August 2013

File Ref: 1201892 SER. Original map size A3.

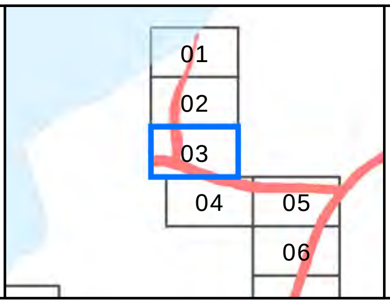


Map 03

Recommended Revised Fault Hazard Overlay

Nelson City Council
te kaunihera o whakatū

🟥 Recommended Revised Fault Hazard Overlay
(Source: GNS Science)



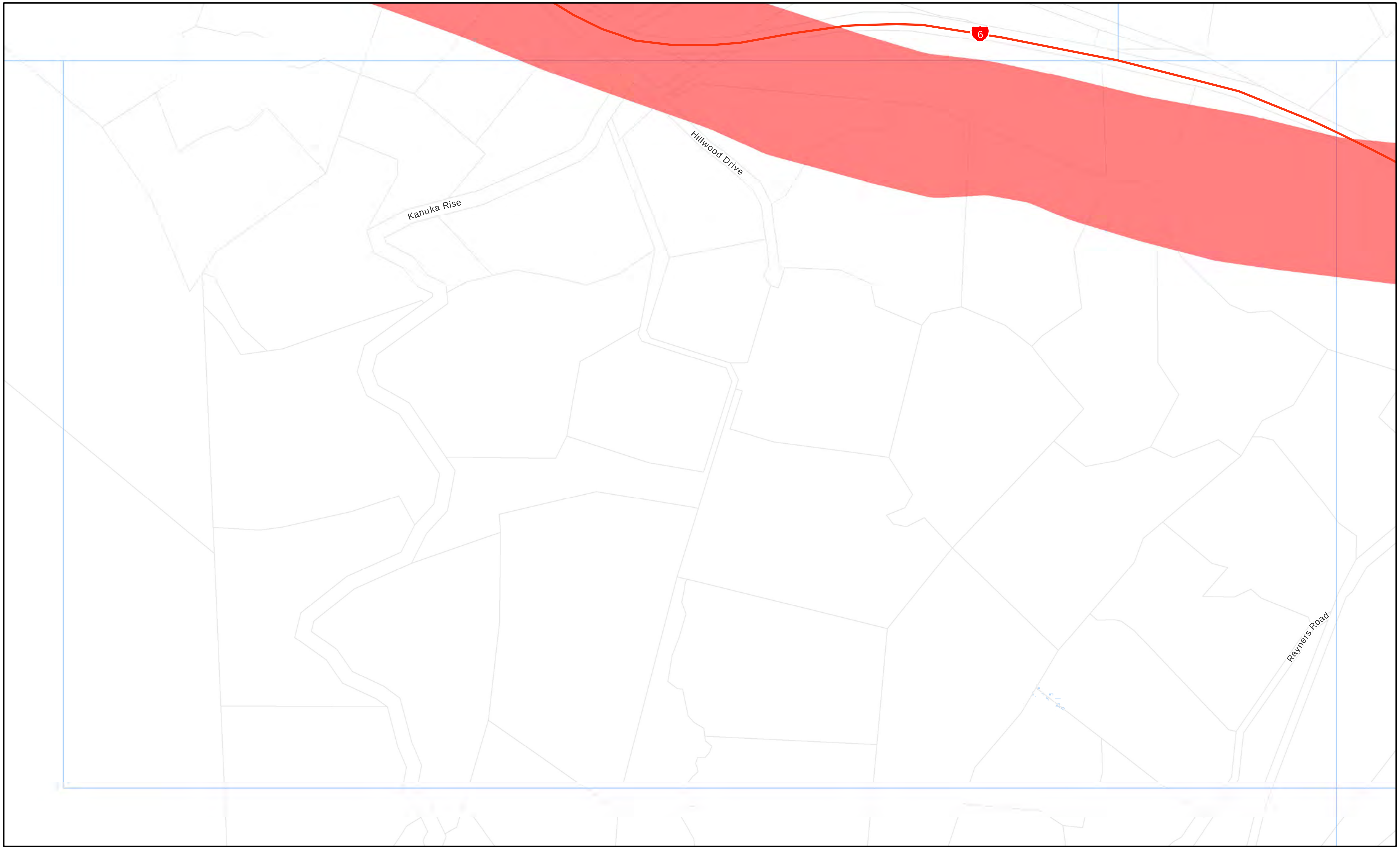
0 100 200 300 400 m

Scale 1:5,000

N

August 2013

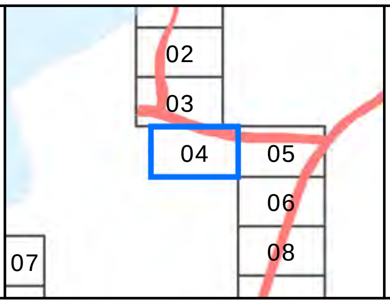
File Ref: 1201892 SER. Original map size A3.



Map 04

Recommended Revised Fault Hazard Overlay

Nelson City Council
te kaunihera o whakatū



🟥 Recommended Revised Fault Hazard Overlay
(Source: GNS Science)

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Scale 1:5,000

N

August 2013

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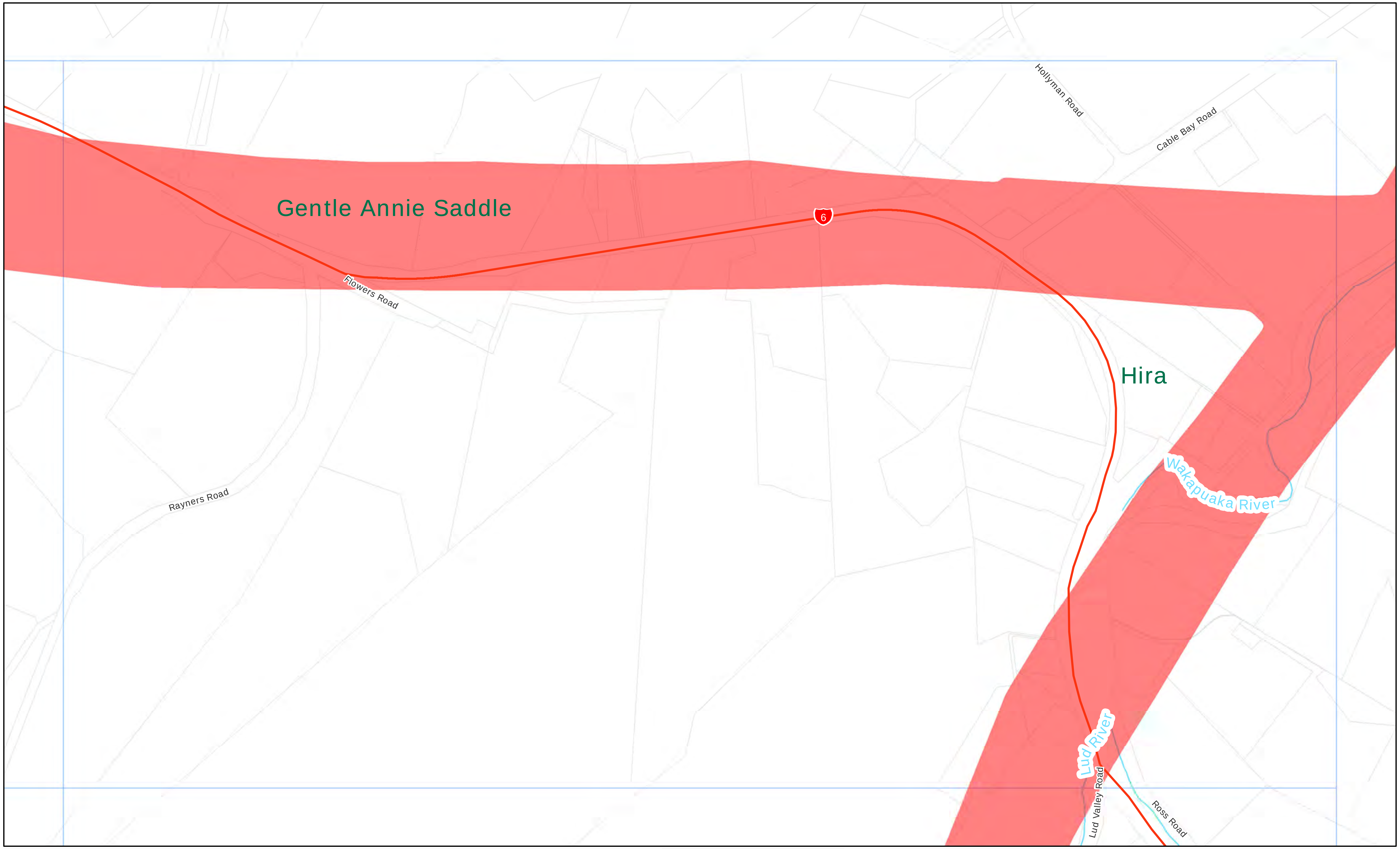
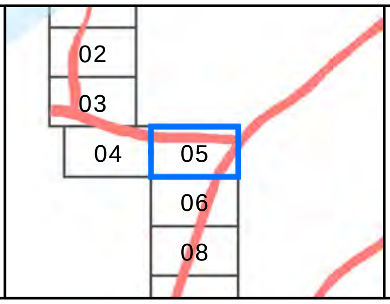


Map 05

Recommended Revised Fault Hazard Overlay

Nelson City Council
te kaunihera o whakatū

🟥 Recommended Revised Fault Hazard Overlay
(Source: GNS Science)



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Scale 1:5,000

N

August 2013

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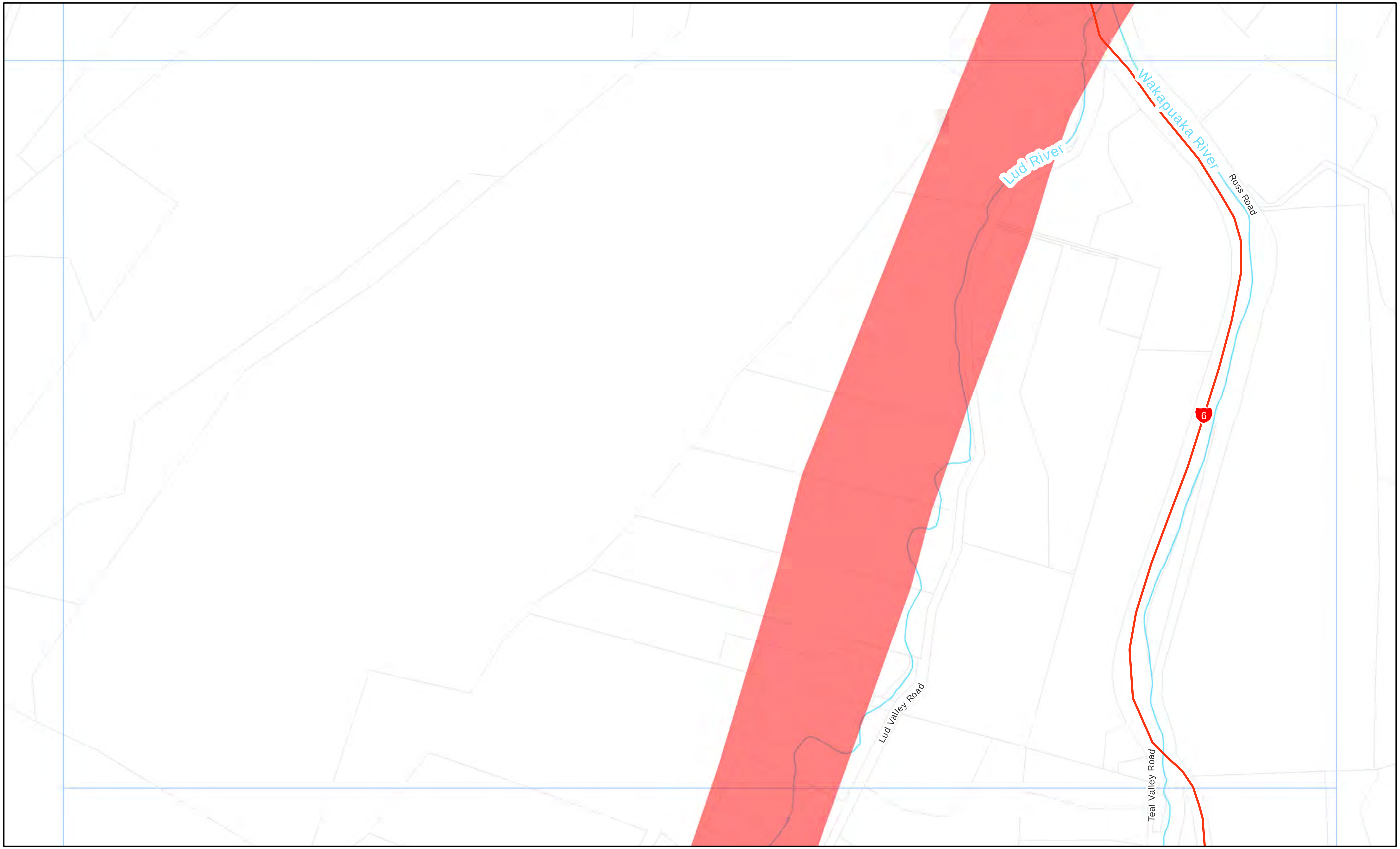
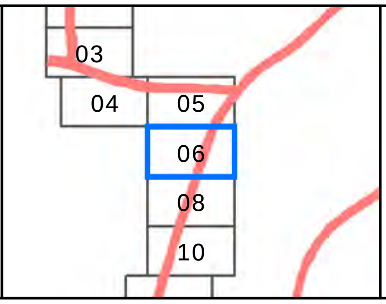


Map 06

Recommended Revised Fault Hazard Overlay

Nelson City Council
te kaunihera o whakatū



🟥 Recommended Revised Fault Hazard Overlay
(Source: GNS Science)

Scale 1:5,000

N

August 2013

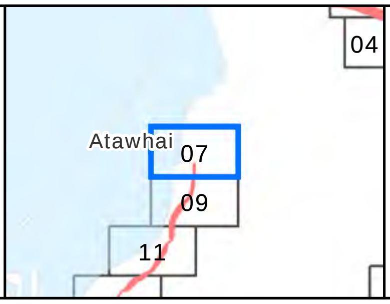
File Ref: 1201892
SER. Original map size A3.

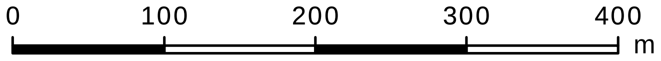
Map 07

Recommended Revised Fault Hazard Overlay

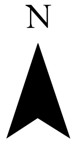
Nelson City Council
te kaunihera o whakatū

🟥 Recommended Revised Fault Hazard Overlay
(Source: GNS Science)





Scale 1:5,000



August 2013

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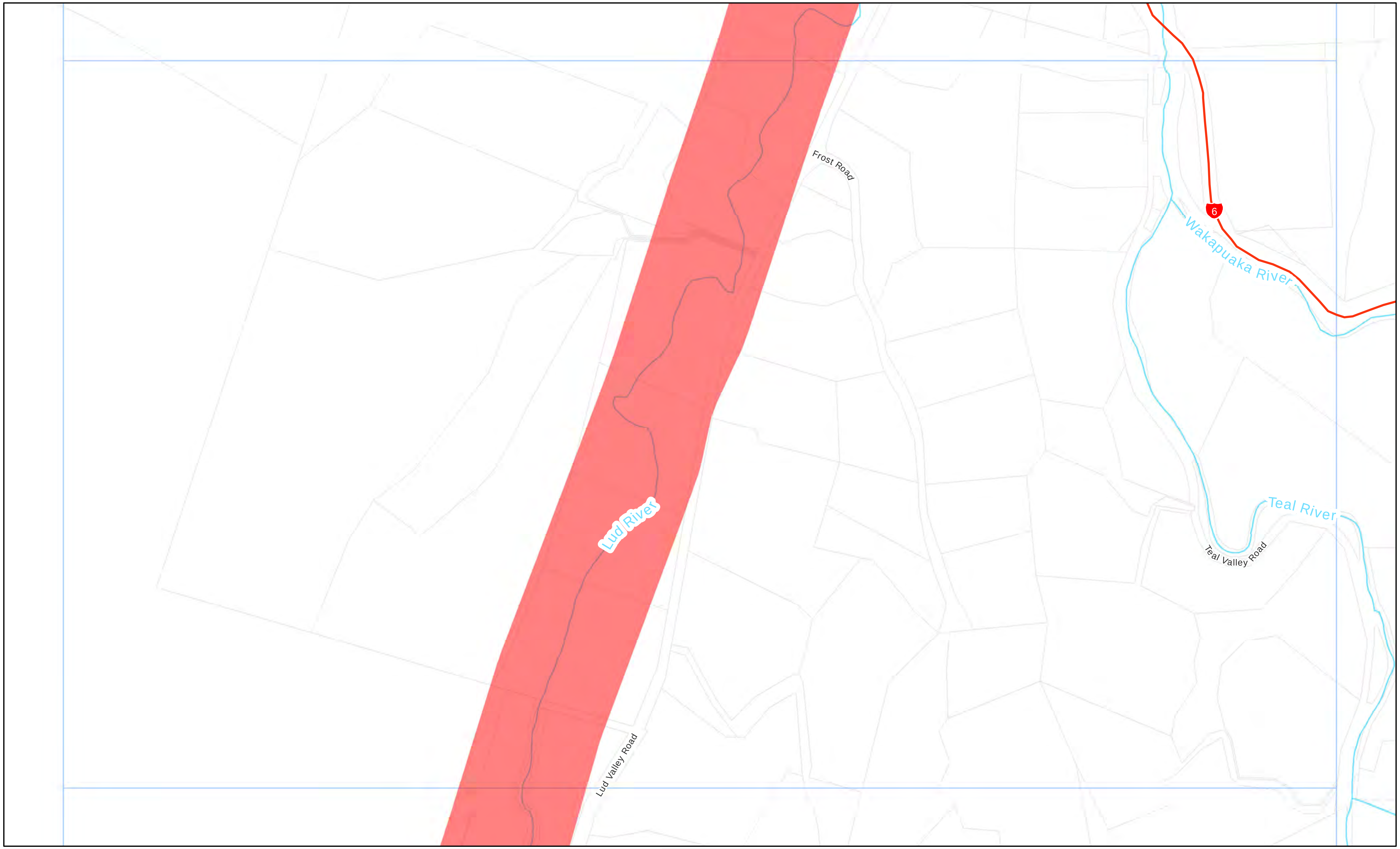
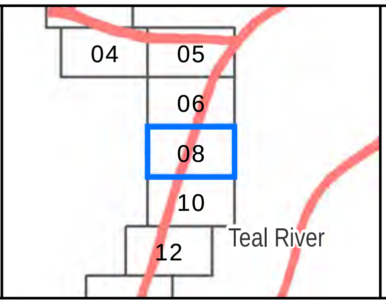


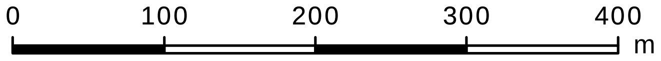
Map 08

Recommended Revised Fault Hazard Overlay

Nelson City Council
te kaunihera o whakatū

🟥 Recommended Revised Fault Hazard Overlay
(Source: GNS Science)





Scale 1:5,000

N

August 2013

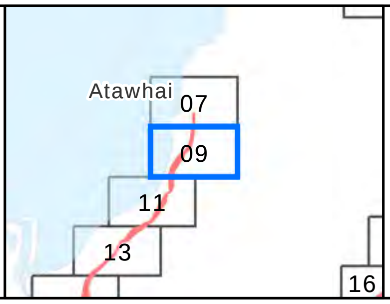
File Ref: 1201892
SER. Original map size A3.

Map 09

Recommended Revised Fault Hazard Overlay

Nelson City Council
te kaunihera o whakatū

🟥 Recommended Revised Fault Hazard Overlay
(Source: GNS Science)



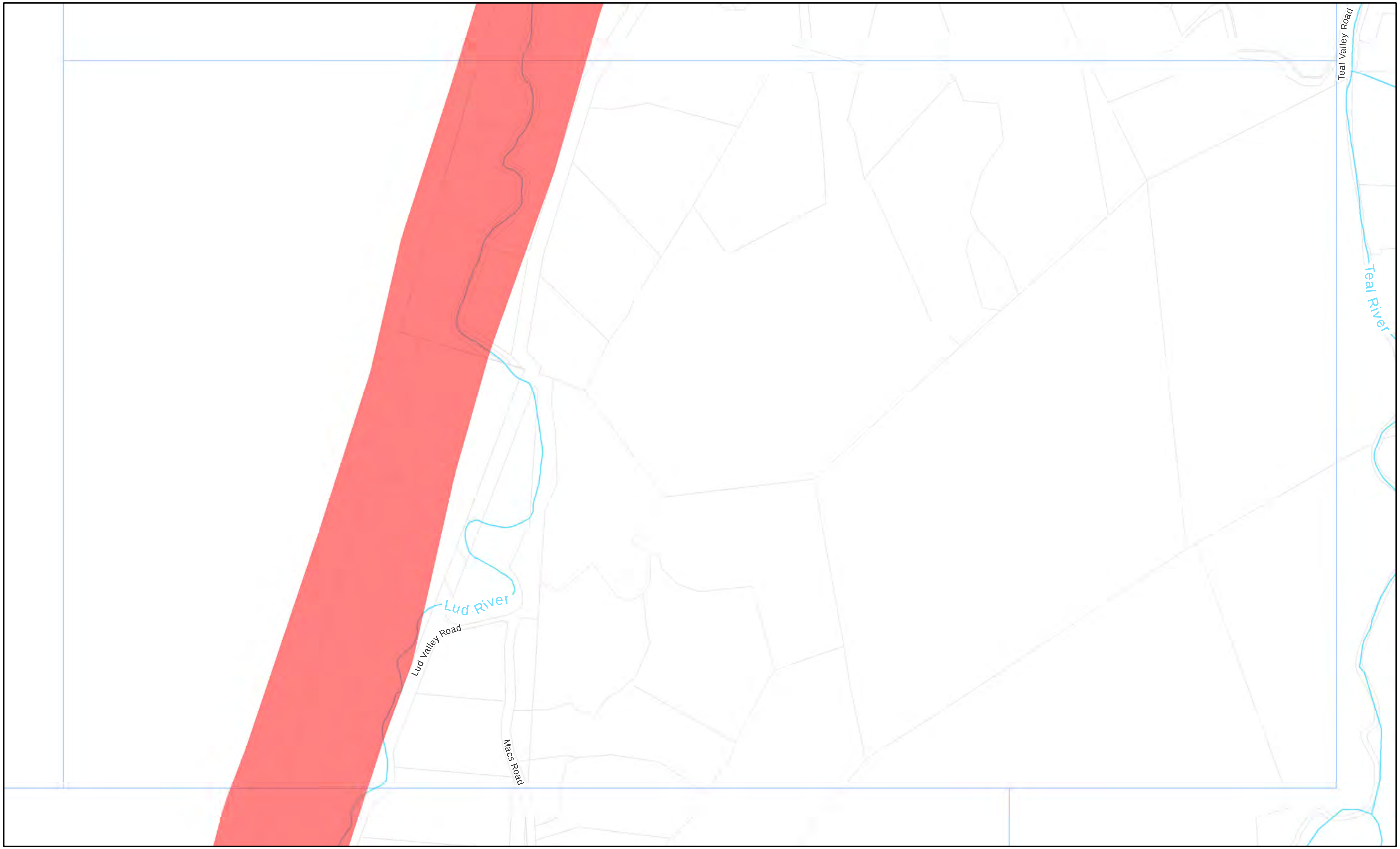
0 100 200 300 400
m

Scale 1:5,000

N

August 2013

File Ref: 1201892
SER. Original map size A3.

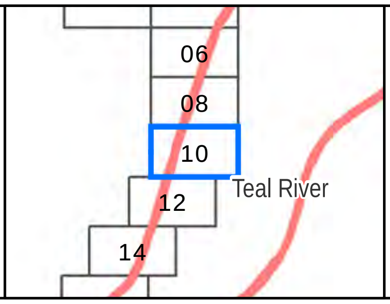


Map 10

Recommended Revised Fault Hazard Overlay

Nelson City Council
te kaunihera o whakatū

🟥 Recommended Revised Fault Hazard Overlay
(Source: GNS Science)



0 100 200 300 400 m

Scale 1:5,000

N

August 2013

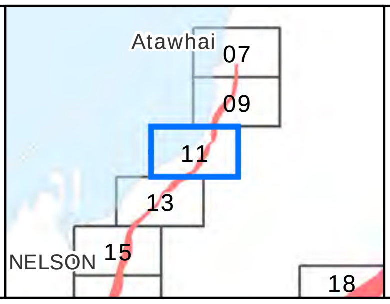
File Ref: 1201892 SER. Original map size A3.

Map 11

Recommended Revised Fault Hazard Overlay

Nelson City Council
te kaunihera o whakatū

🟥 Recommended Revised Fault Hazard Overlay
(Source: GNS Science)



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Scale 1:5,000

N

August 2013

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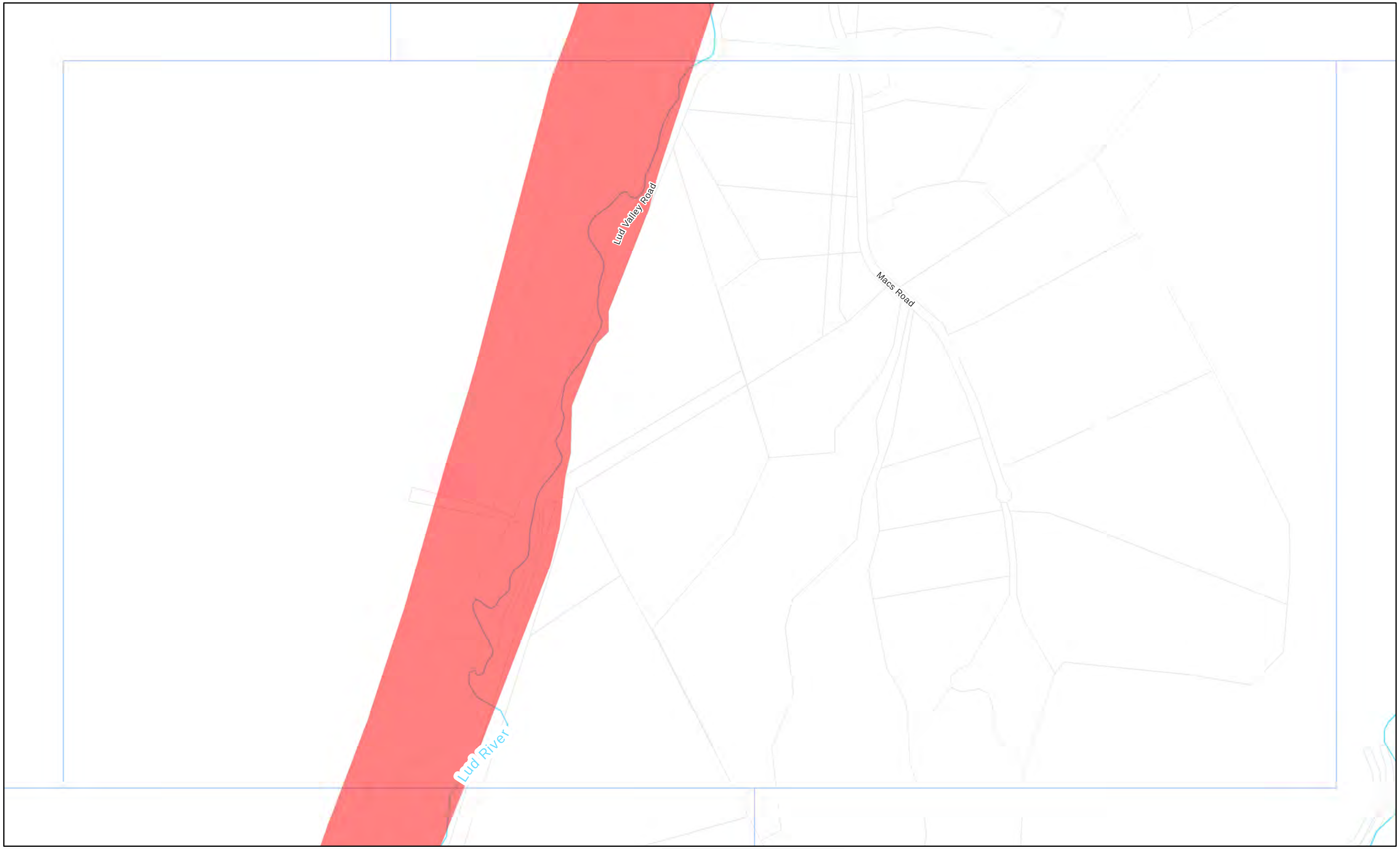
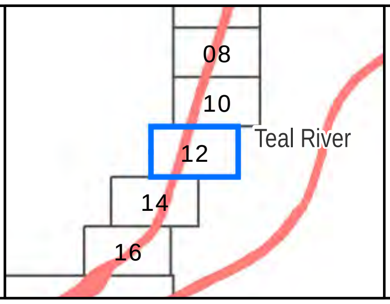


Map 12

Recommended Revised Fault Hazard Overlay

Nelson City Council
te kaunihera o whakatū

🟥 Recommended Revised Fault Hazard Overlay
(Source: GNS Science)



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Scale 1:5,000

N

August 2013

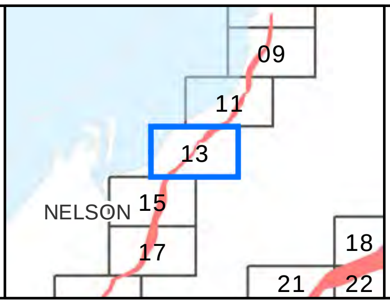
File Ref: 1201892 SER. Original map size A3.

Map 13

Recommended Revised Fault Hazard Overlay

Nelson City Council
te kaunihera o whakatū

🟥 Recommended Revised Fault Hazard Overlay
(Source: GNS Science)



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Scale 1:5,000

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August 2013

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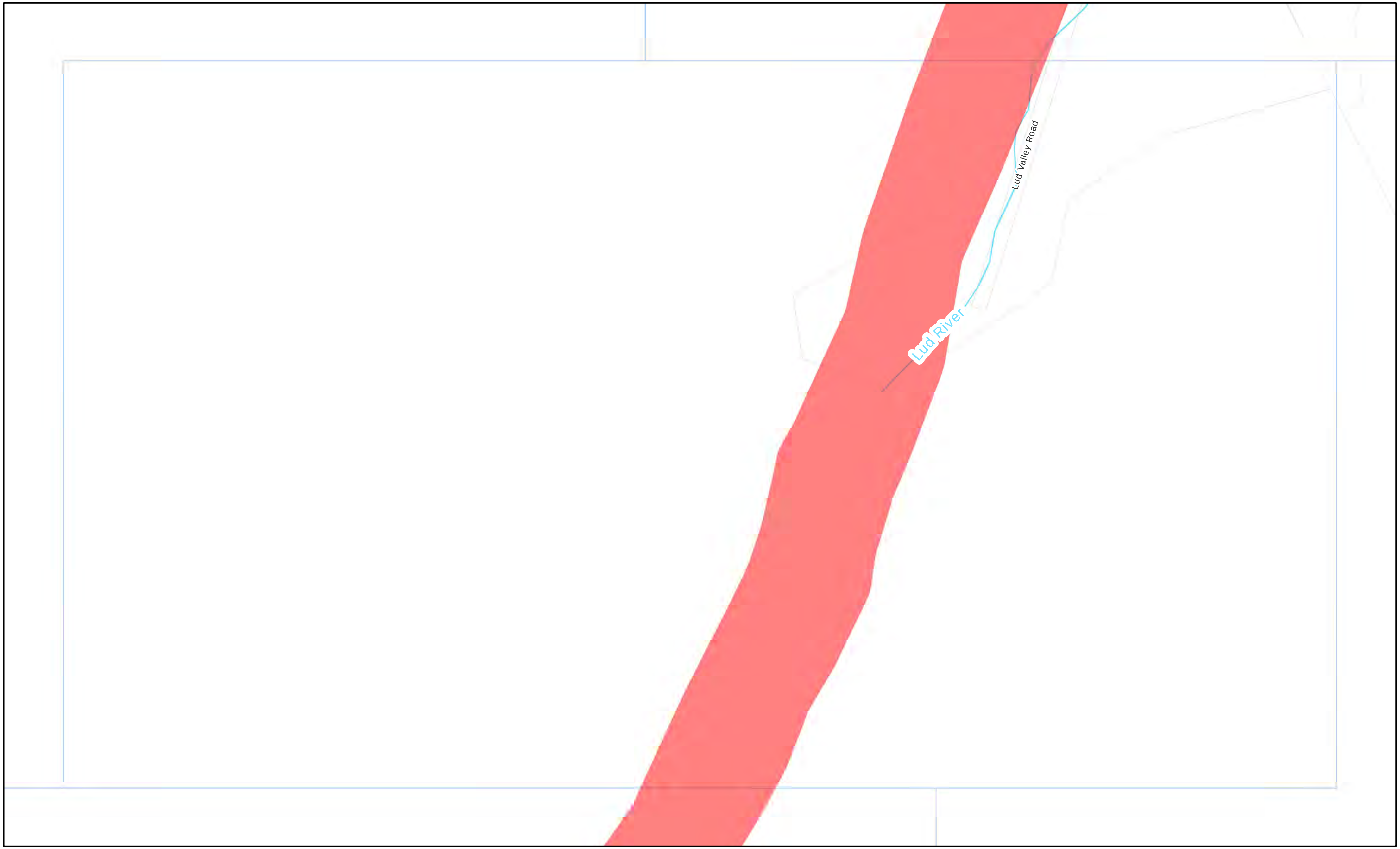
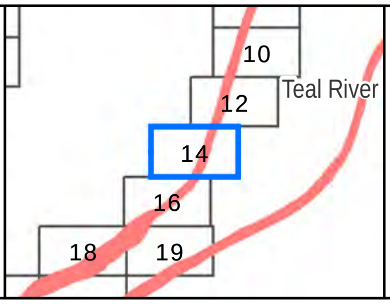


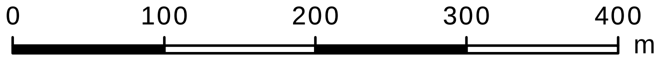
Map 14

Recommended Revised Fault Hazard Overlay

Nelson City Council
te kaunihera o whakatū

🟥 Recommended Revised Fault Hazard Overlay
(Source: GNS Science)





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August 2013

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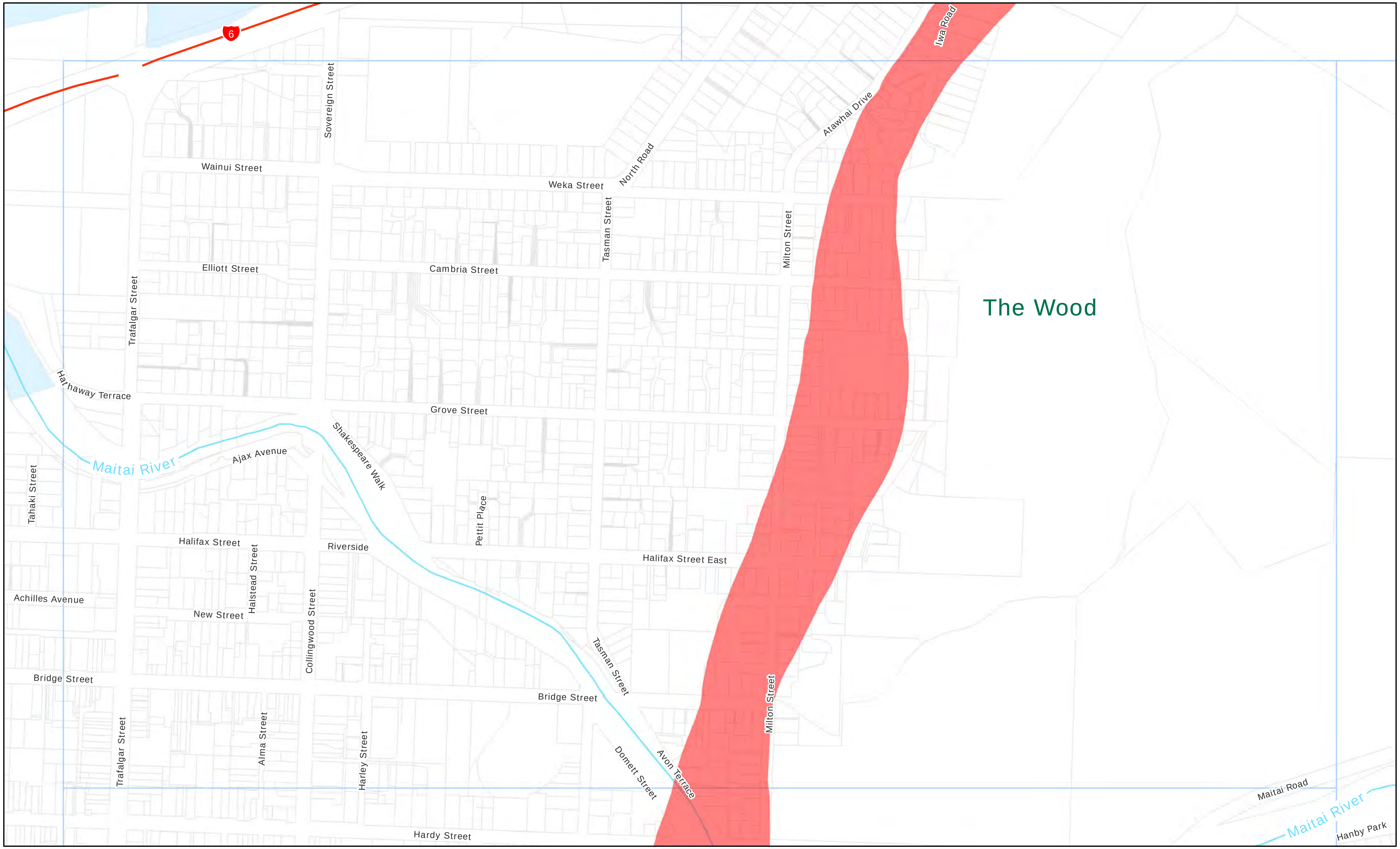
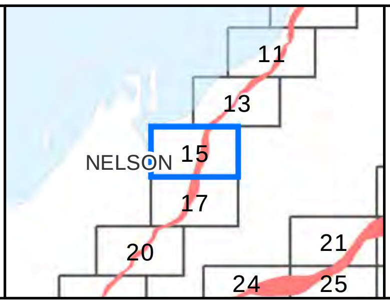


Map 15

Recommended Revised Fault Hazard Overlay

Nelson City Council
te kaunihera o whakatū

🟥 Recommended Revised Fault Hazard Overlay
(Source: GNS Science)



0 100 200 300 400
m

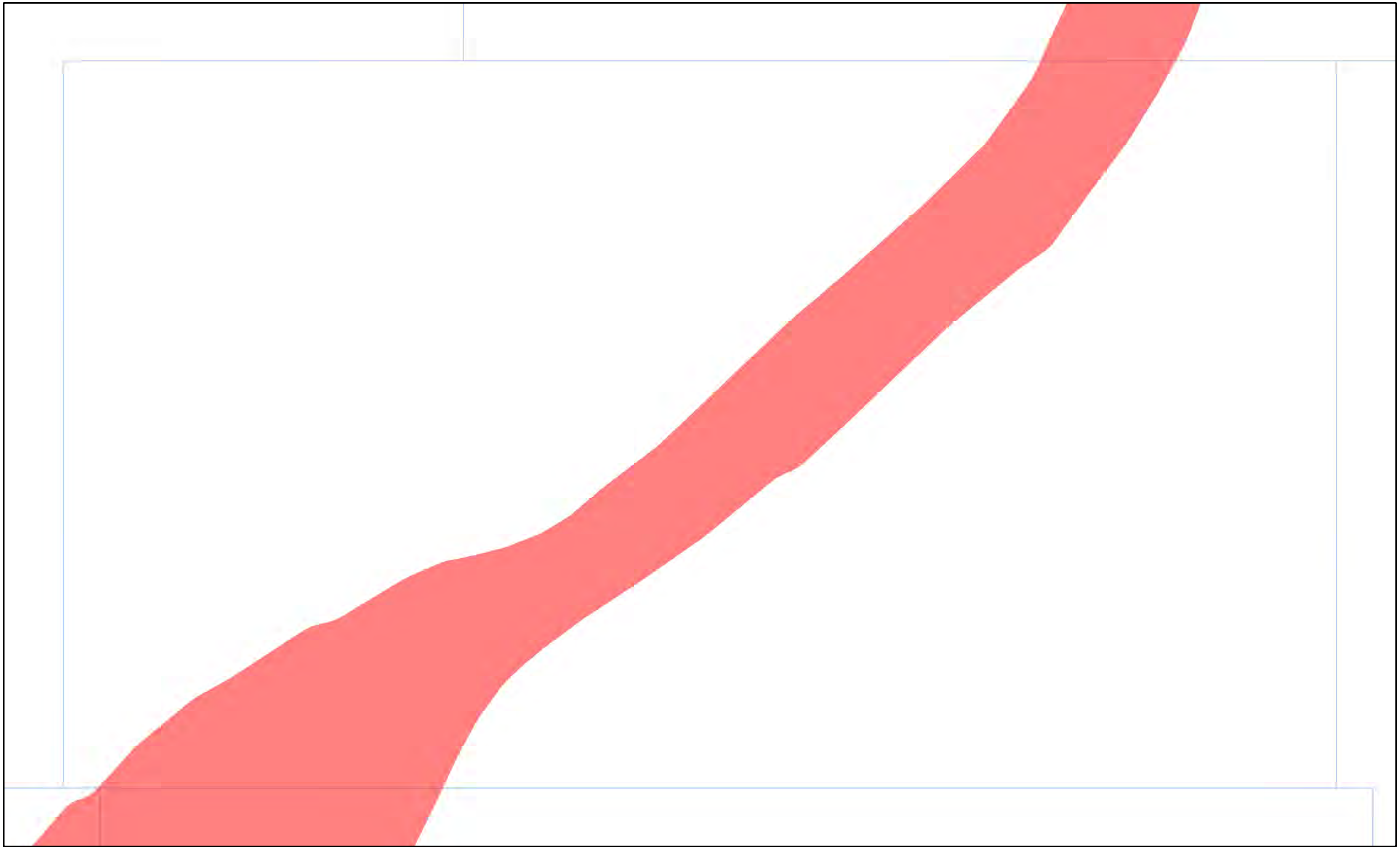
Scale 1:5,000

N

August 2013

PO Box 645 Nelson 7040 New Zealand PH 03 5460200 www.nelsoncitycouncil.co.nz

File Ref: 1201892
SER. Original map size A3.

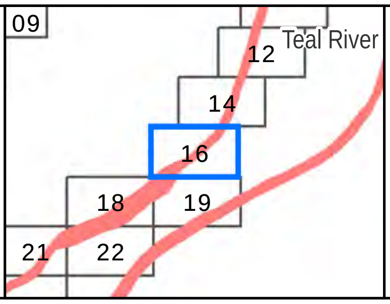


Map 16

Recommended Revised Fault Hazard Overlay

Nelson City Council
te kaunihera o whakatū

🟥 Recommended Revised Fault Hazard Overlay
(Source: GNS Science)



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August 2013

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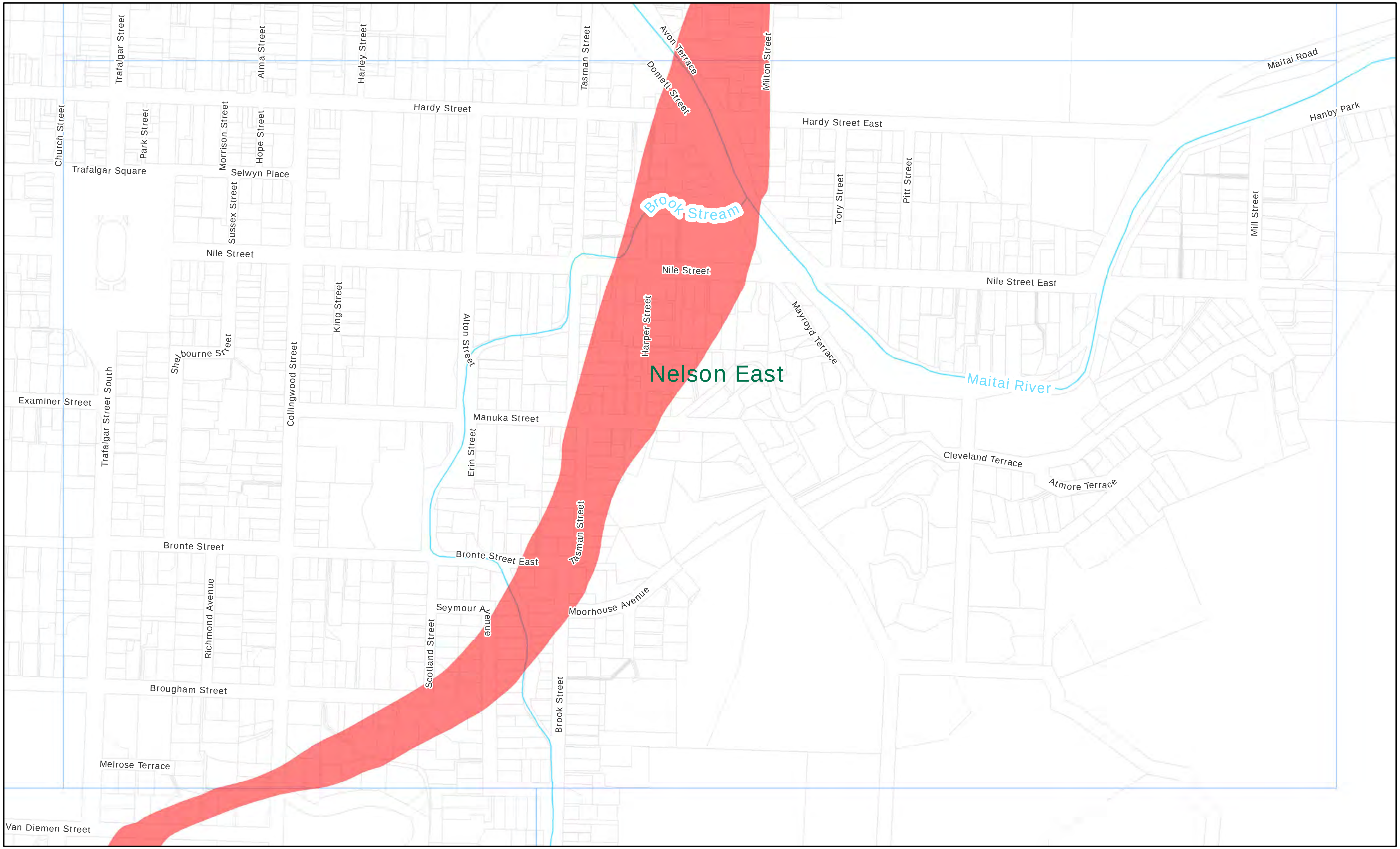
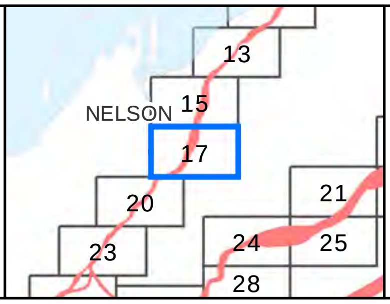


Map 17

Recommended Revised Fault Hazard Overlay

Nelson City Council
te kaunihera o whakatū

🟥 Recommended Revised Fault Hazard Overlay
(Source: GNS Science)



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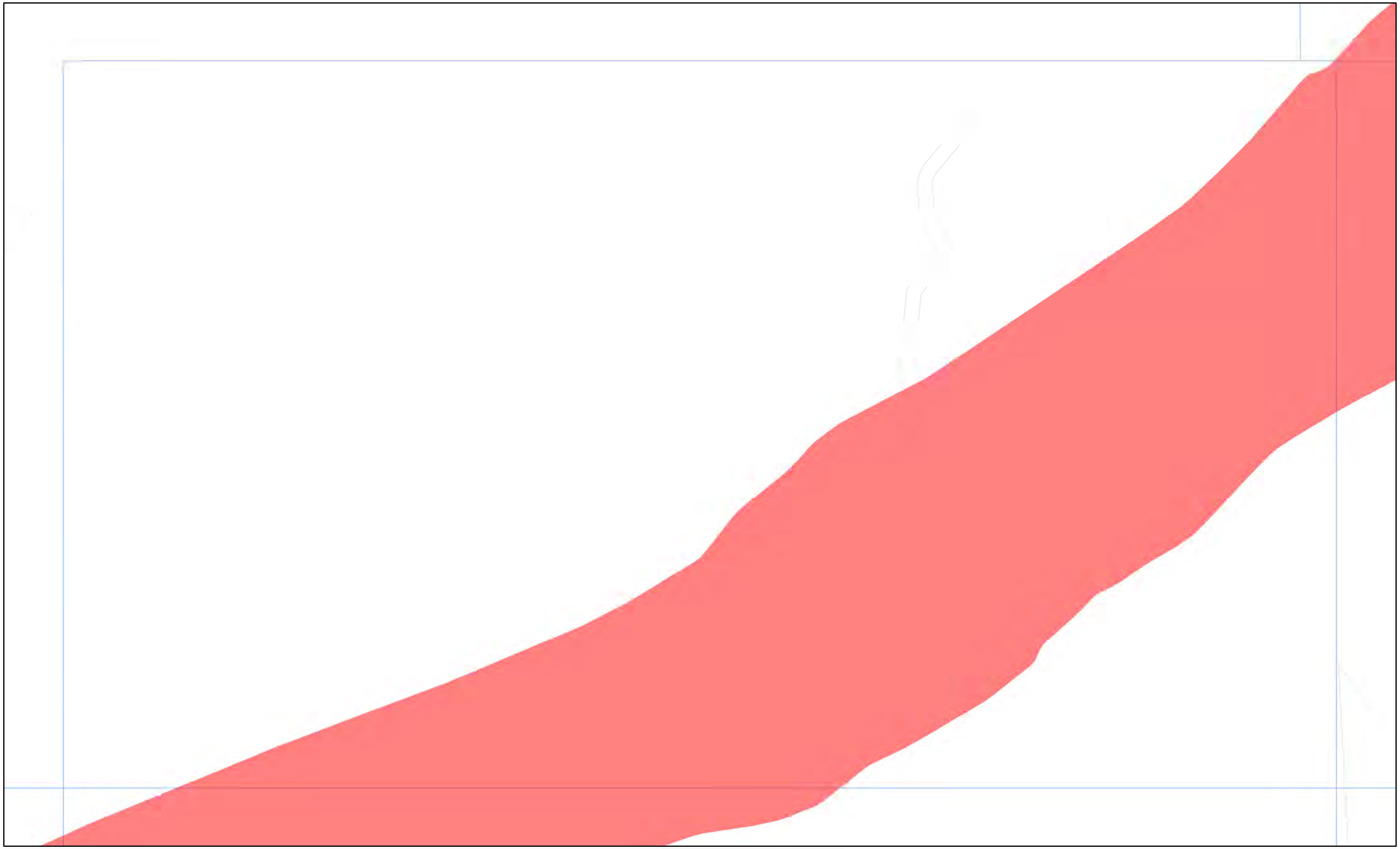
Scale 1:5,000

N

August 2013

File Ref: 1201892 SER. Original map size A3.

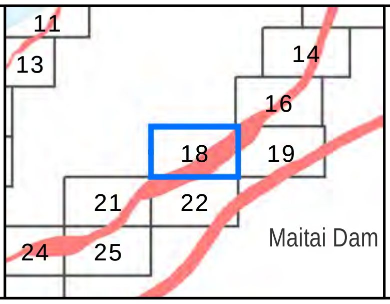


Map 18

Recommended Revised Fault Hazard Overlay

Nelson City Council
te kaunihera o whakatū

🟥 Recommended Revised Fault Hazard Overlay
(Source: GNS Science)



0 100 200 300 400 m

Scale 1:5,000

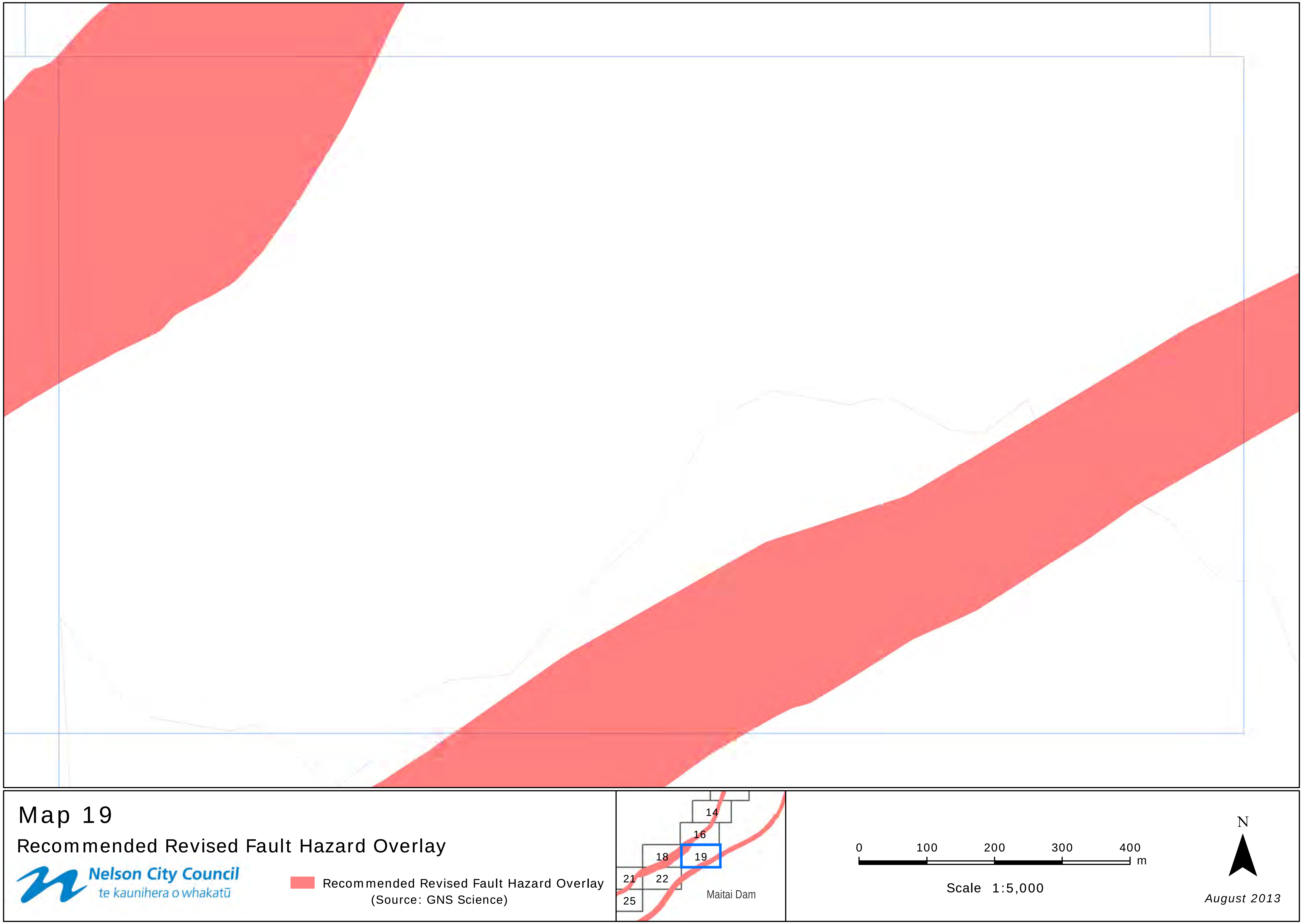
N

August 2013

File Ref: 1201892
SER. Original map size A3.

Map 19

Recommended Revised Fault Hazard Overlay



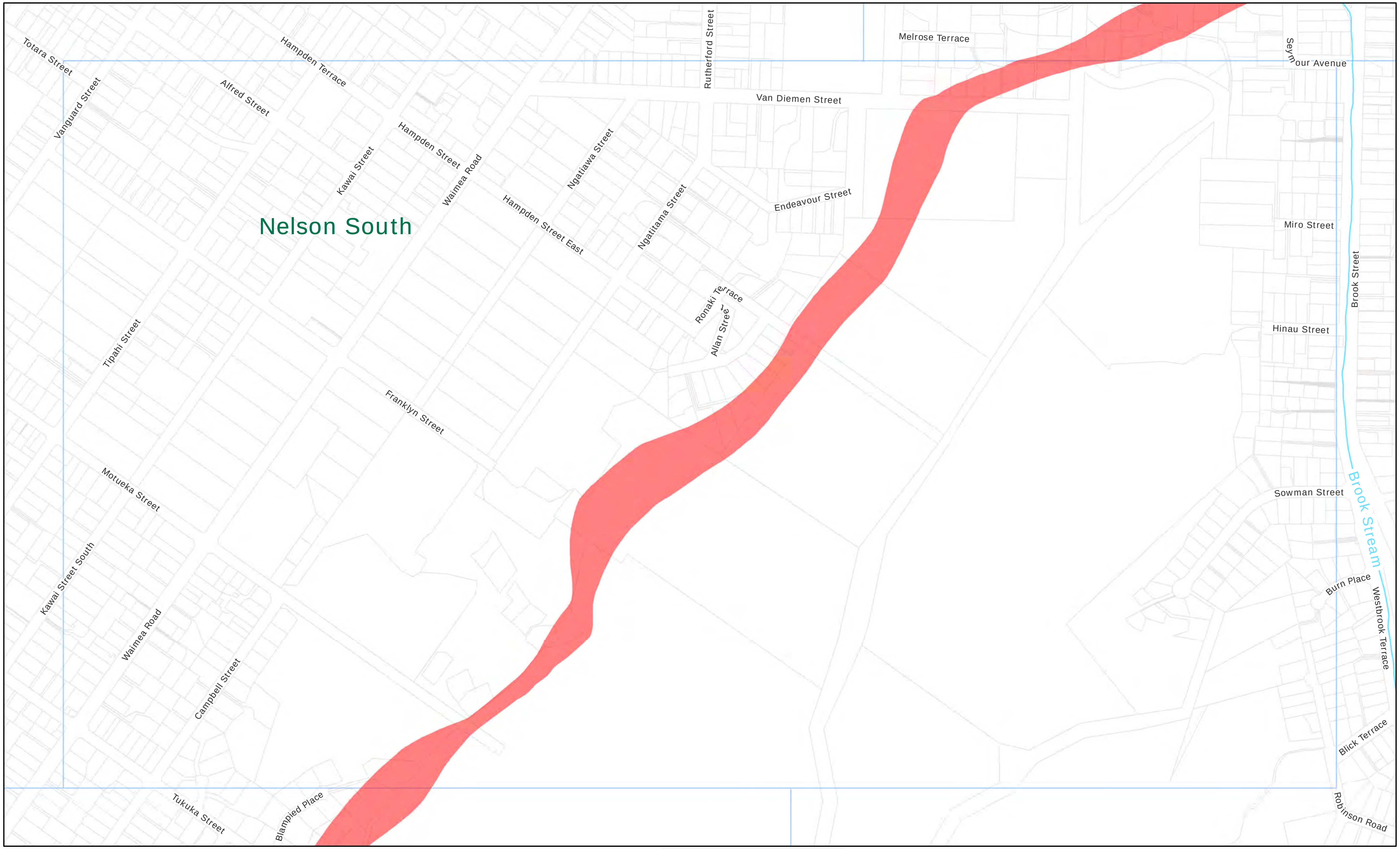
Nelson City Council
te kaunihera o whakatū

🟥 Recommended Revised Fault Hazard Overlay
(Source: GNS Science)

Scale 1:5,000

August 2013

File Ref: 1201892
SER. Original map size A3.

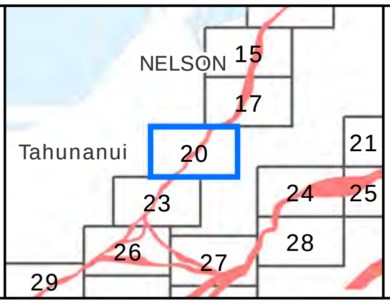


Map 20

Recommended Revised Fault Hazard Overlay

Nelson City Council
te kaunihera o whakatū

🟥 Recommended Revised Fault Hazard Overlay
(Source: GNS Science)

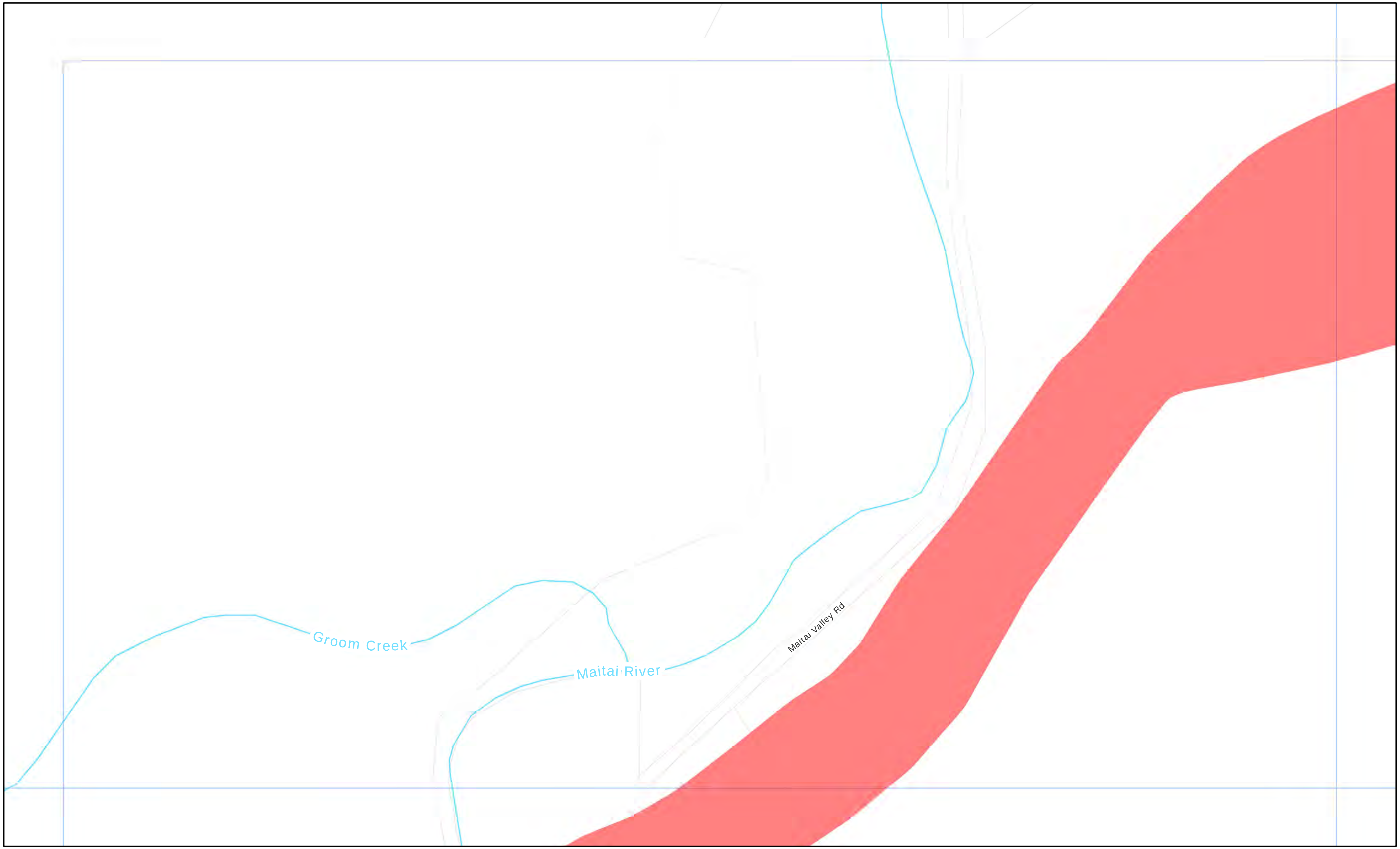


Scale 1:5,000

N

August 2013

File Ref: 1201892 SER. Original map size A3.

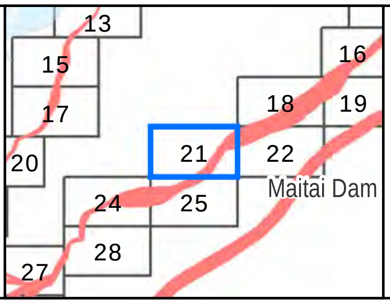


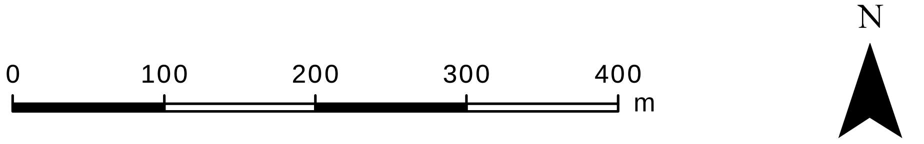
Map 21

Recommended Revised Fault Hazard Overlay

Nelson City Council
te kaunihera o whakatū

🟥 Recommended Revised Fault Hazard Overlay
(Source: GNS Science)

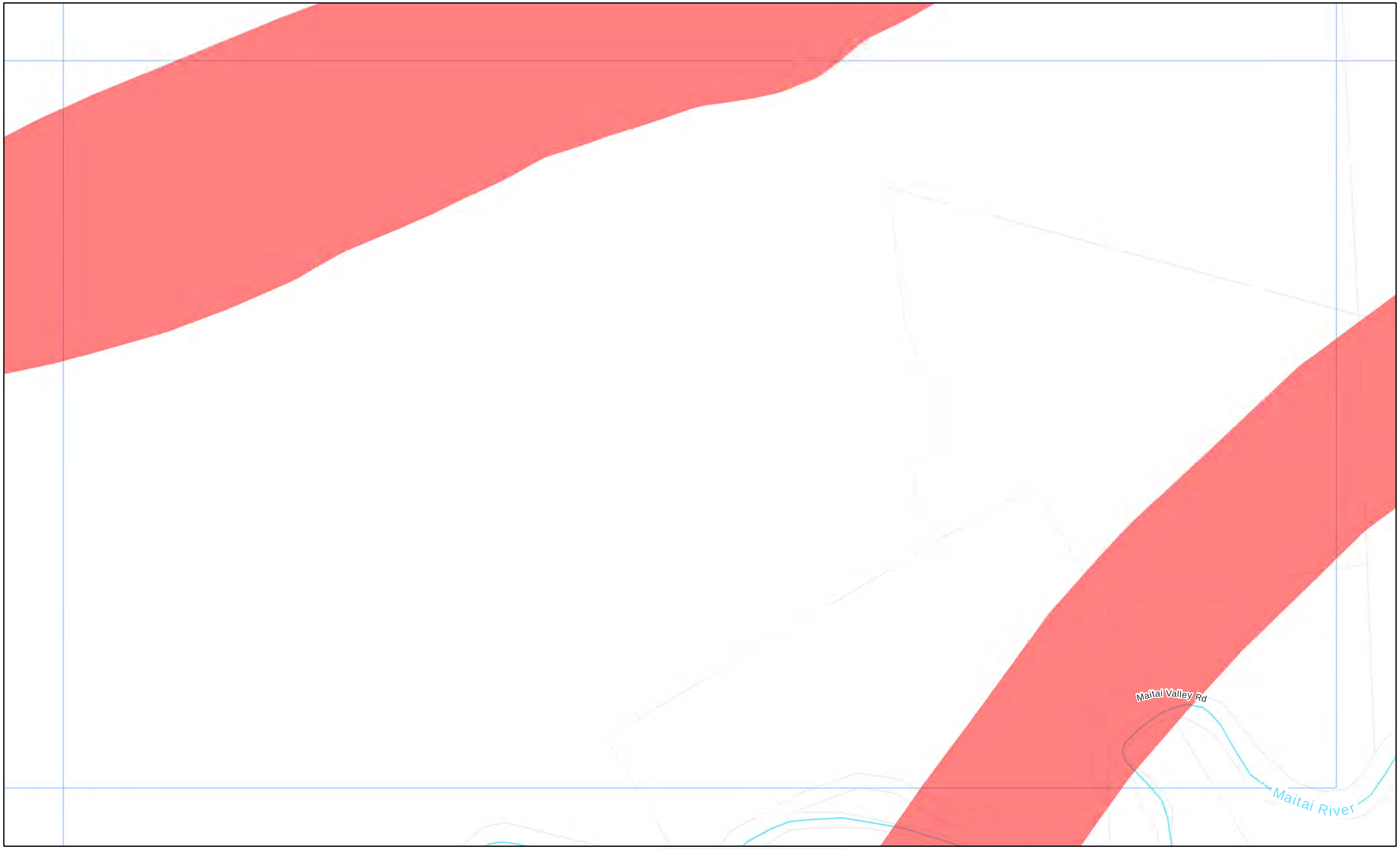




Scale 1:5,000

August 2013

File Ref: 1201892 SER. Original map size A3.

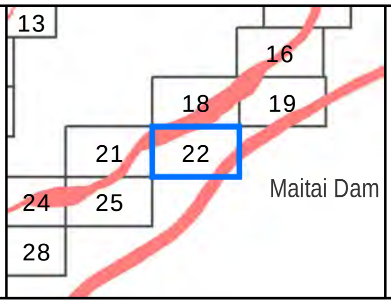


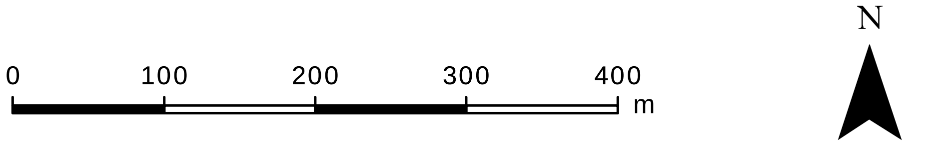
Map 22

Recommended Revised Fault Hazard Overlay

Nelson City Council
te kaunihera o whakatū

🟥 Recommended Revised Fault Hazard Overlay
(Source: GNS Science)





Scale 1:5,000

August 2013

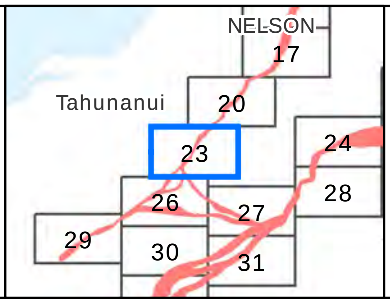
File Ref: 1201892 SER. Original map size A3.

Map 23

Recommended Revised Fault Hazard Overlay

Nelson City Council
te kaunihera o whakatū

🟥 Recommended Revised Fault Hazard Overlay
(Source: GNS Science)



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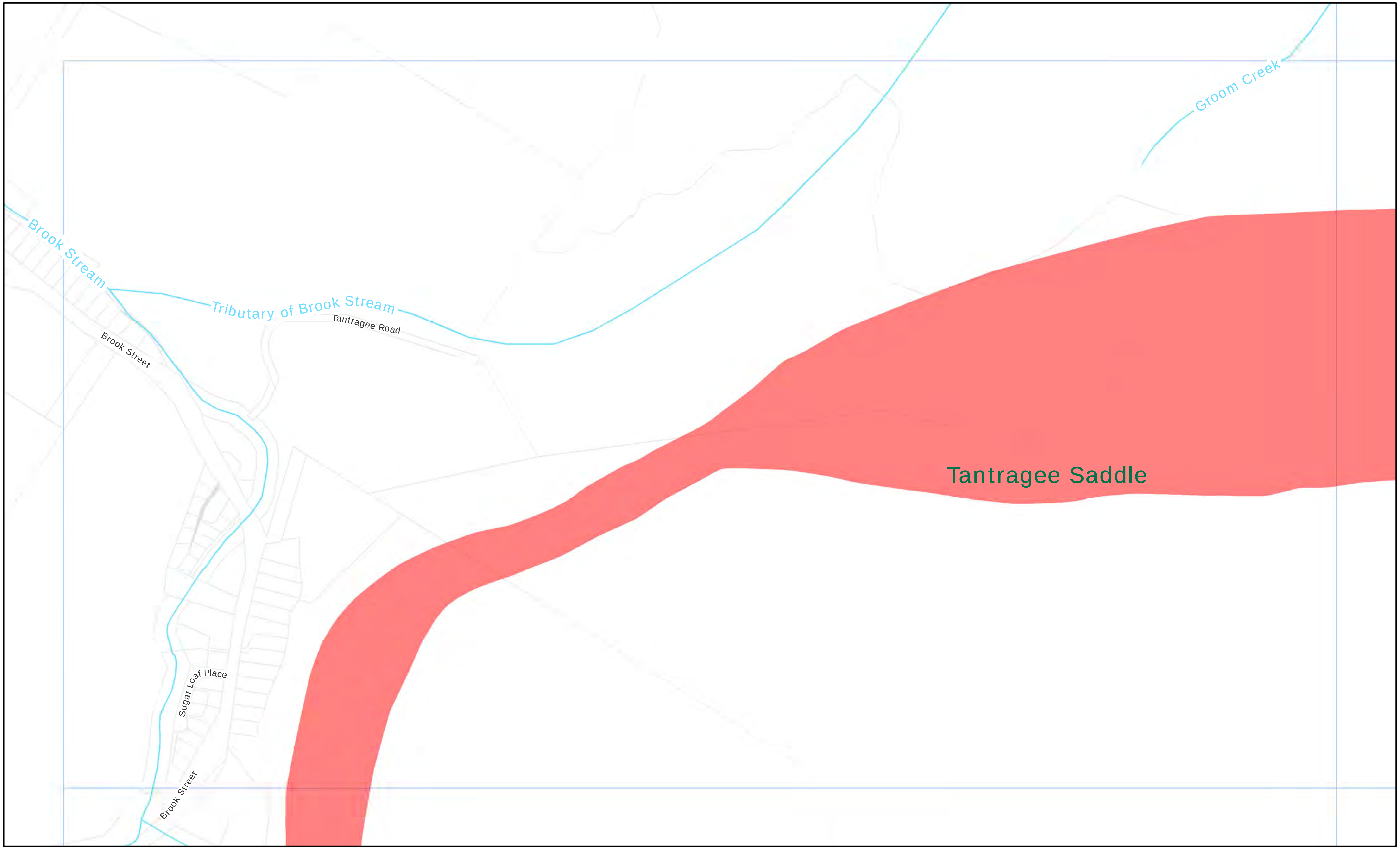
Scale 1:5,000

N

August 2013

File Ref: 1201892 SER. Original map size A3.

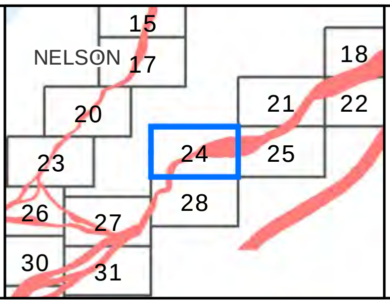


Map 24

Recommended Revised Fault Hazard Overlay

Nelson City Council
te kaunihera o whakatū

🟥 Recommended Revised Fault Hazard Overlay
(Source: GNS Science)



Scale 1:5,000

August 2013

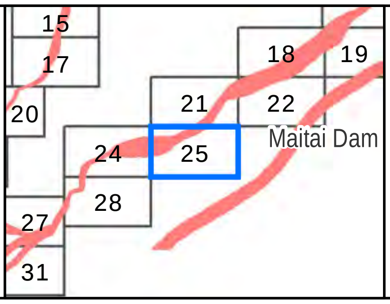
File Ref: 1201892 SER. Original map size A3.

Map 25

Recommended Revised Fault Hazard Overlay

Nelson City Council
te kaunihera o whakatū

🟥 Recommended Revised Fault Hazard Overlay
(Source: GNS Science)



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Scale 1:5,000

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August 2013

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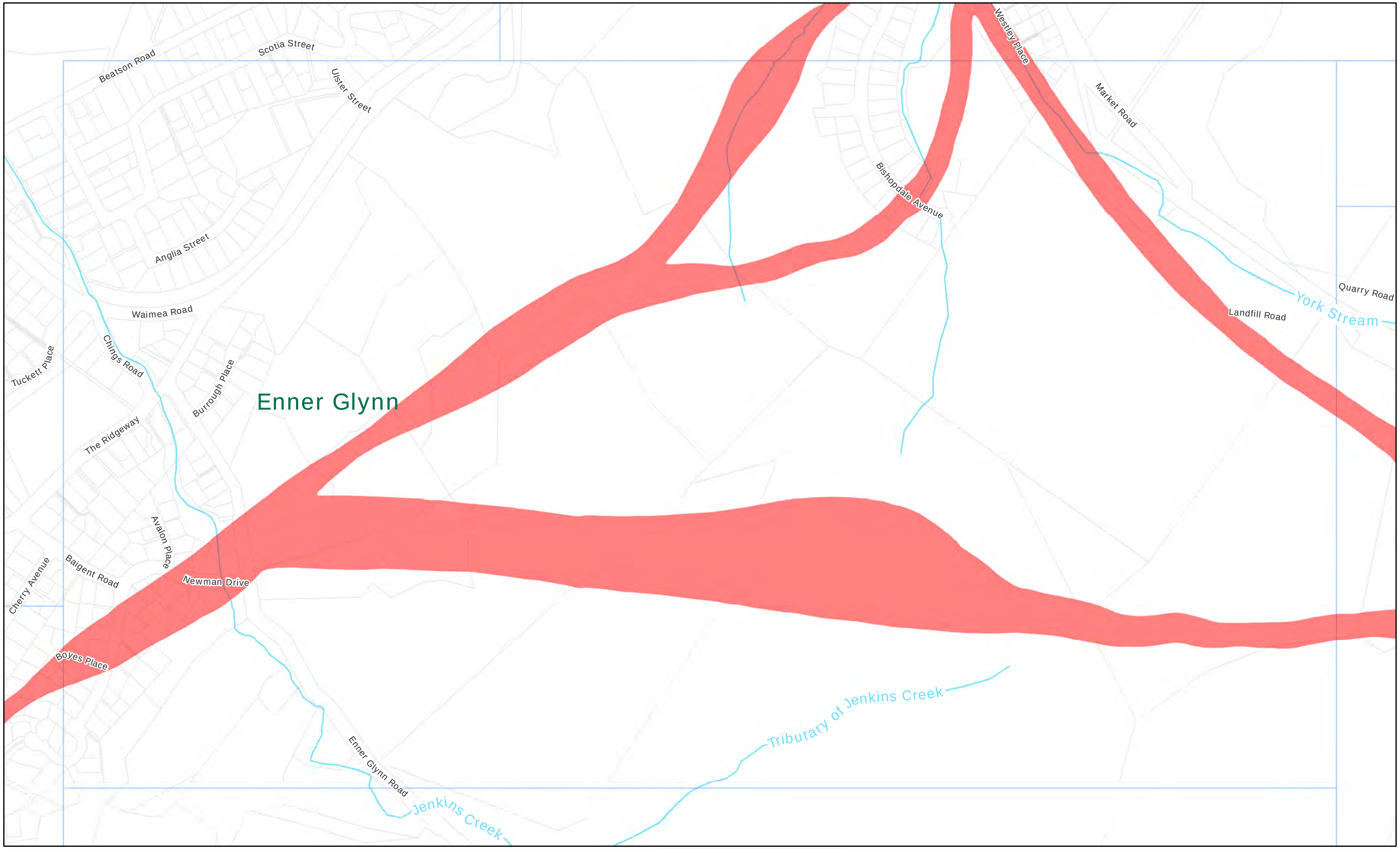
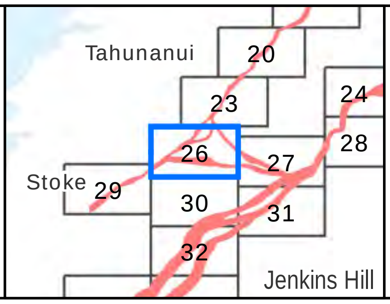


Map 26

Recommended Revised Fault Hazard Overlay

Nelson City Council
te kaunihera o whakatū

🟥 Recommended Revised Fault Hazard Overlay
(Source: GNS Science)



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Scale 1:5,000

N

August 2013

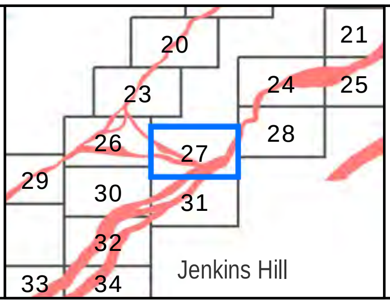
File Ref: 1201892
SER. Original map size A3.

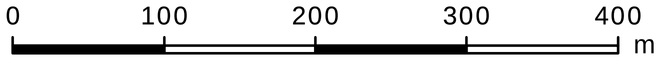
Map 27

Recommended Revised Fault Hazard Overlay

Nelson City Council
te kaunihera o whakatū

🟥 Recommended Revised Fault Hazard Overlay
(Source: GNS Science)





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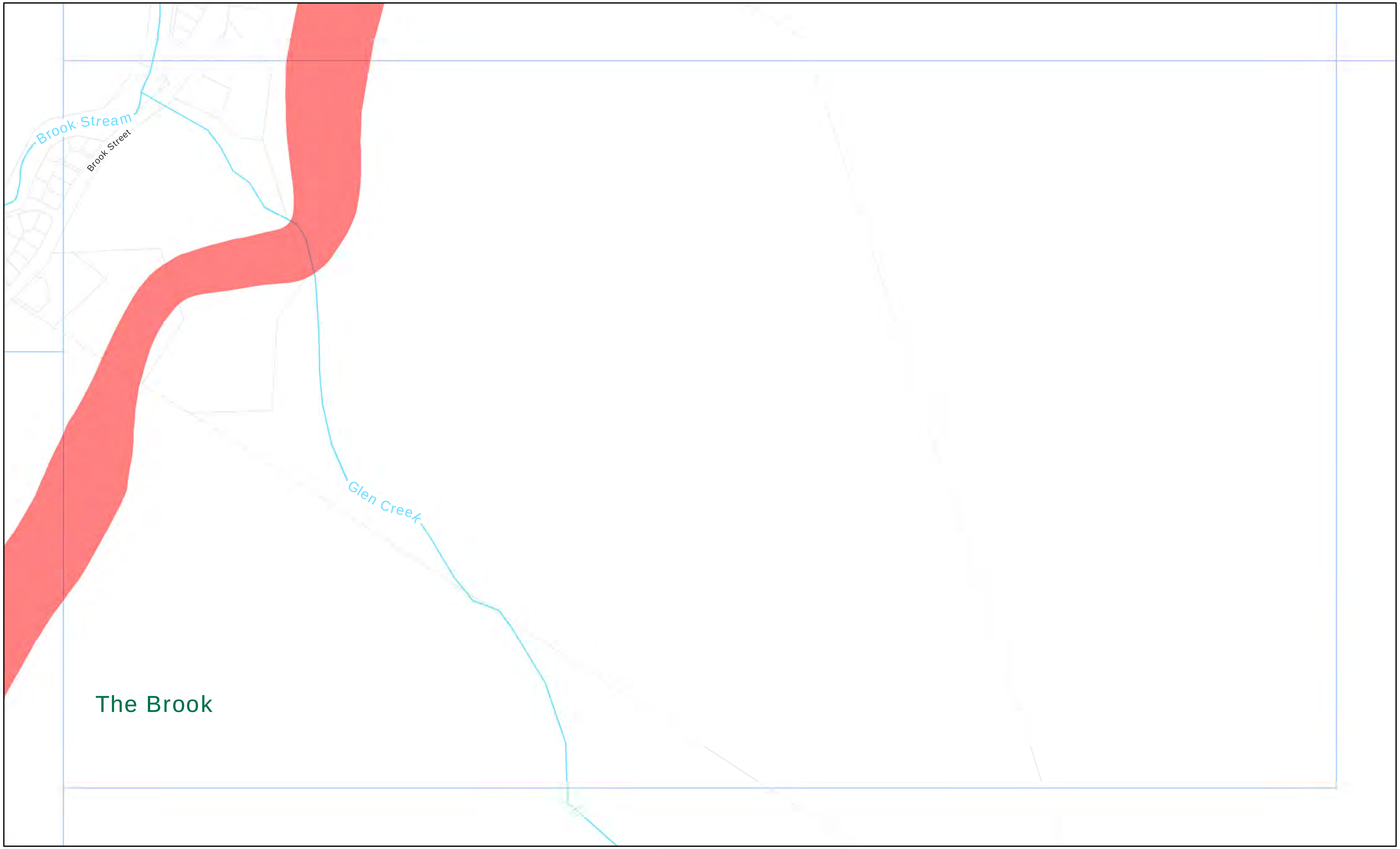
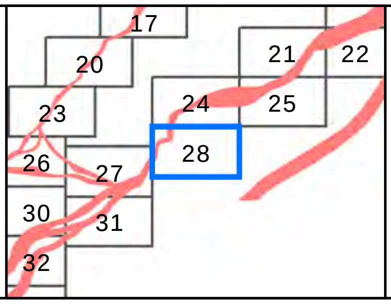


Map 28

Recommended Revised Fault Hazard Overlay

Nelson City Council
te kaunihera o whakatū

🟥 Recommended Revised Fault Hazard Overlay
(Source: GNS Science)



0 100 200 300 400 m

Scale 1:5,000

N

August 2013

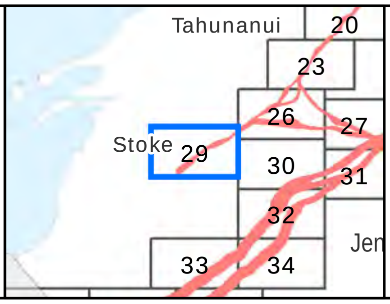
File Ref: 1201892 SER. Original map size A3.

Map 29

Recommended Revised Fault Hazard Overlay

Nelson City Council
te kaunihera o whakatū

🟥 Recommended Revised Fault Hazard Overlay
(Source: GNS Science)



0 100 200 300 400 m

Scale 1:5,000

N

August 2013

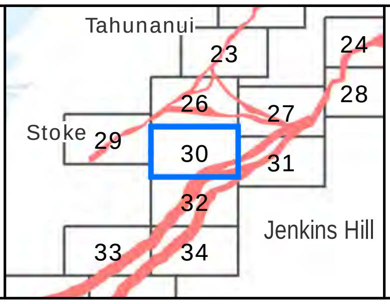
File Ref: 1201892 SER. Original map size A3.

Map 30

Recommended Revised Fault Hazard Overlay

Nelson City Council
te kaunihera o whakatū

🟥 Recommended Revised Fault Hazard Overlay
(Source: GNS Science)



0 100 200 300 400 m

Scale 1:5,000

N

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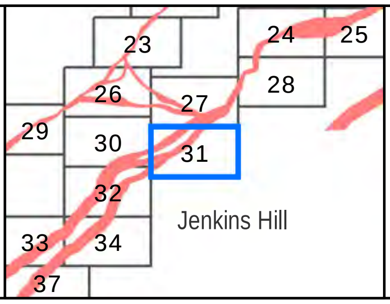
File Ref: 1201892
SER. Original map size A3.

Map 31

Recommended Revised Fault Hazard Overlay

Nelson City Council
te kaunihera o whakatū

🟥 Recommended Revised Fault Hazard Overlay
(Source: GNS Science)



0 100 200 300 400 m

Scale 1:5,000

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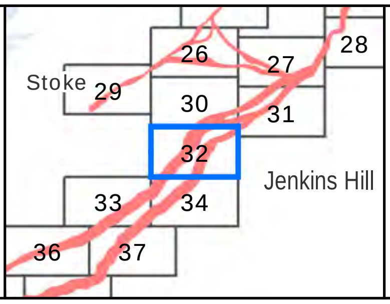
Map 32

Recommended Revised Fault Hazard Overlay

Nelson City Council
te kaunihera o whakatū

🟥 Recommended Revised Fault Hazard Overlay
(Source: GNS Science)



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Scale 1:5,000

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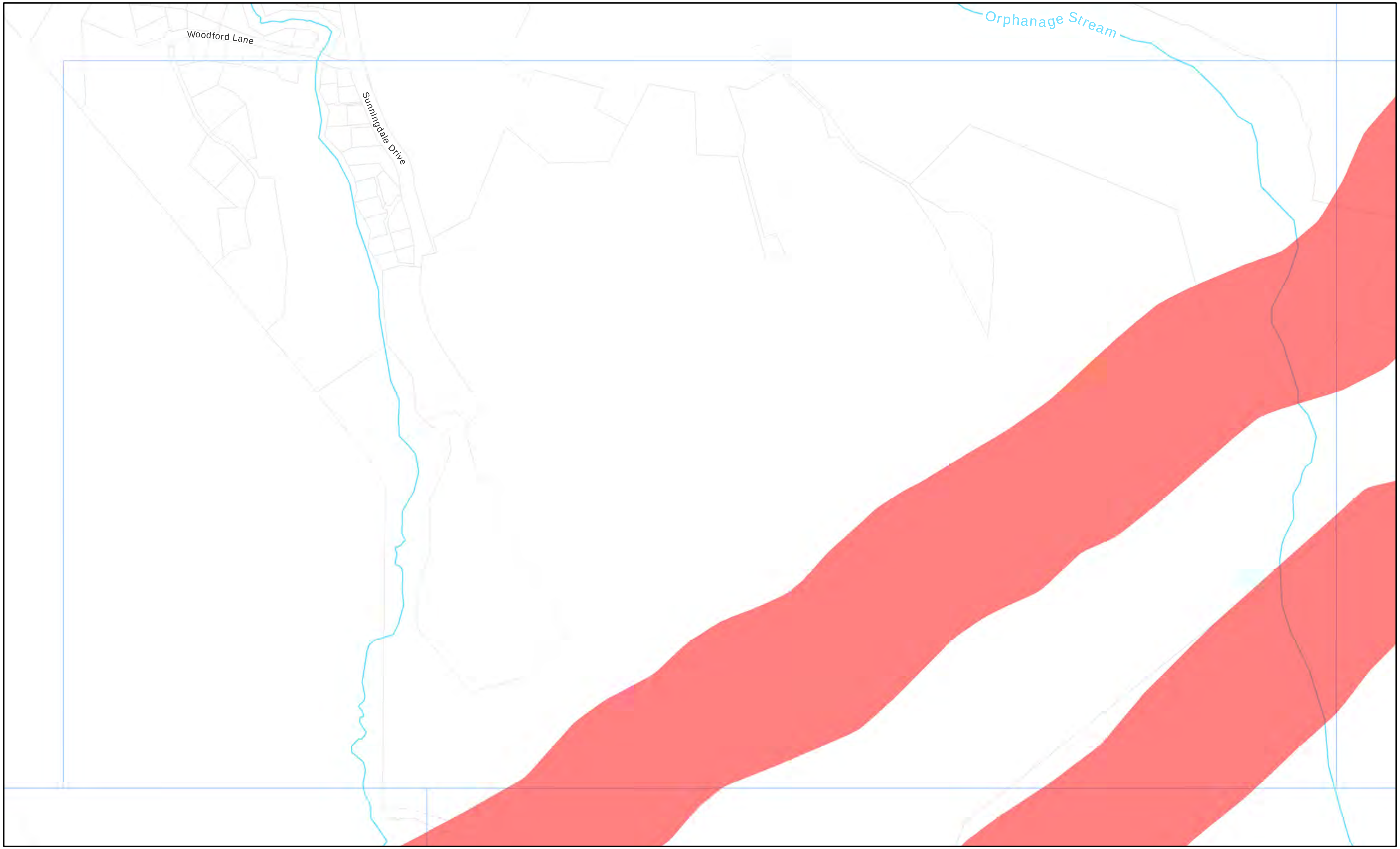
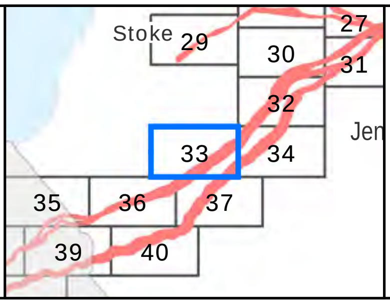


Map 33

Recommended Revised Fault Hazard Overlay

Nelson City Council
te kaunihera o whakatū

🟥 Recommended Revised Fault Hazard Overlay
(Source: GNS Science)



0 100 200 300 400 m

Scale 1:5,000

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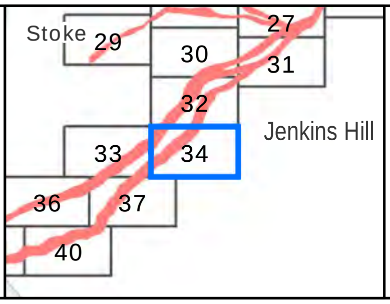
File Ref: 1201892 SER. Original map size A3.

Map 34

Recommended Revised Fault Hazard Overlay

Nelson City Council
te kaunihera o whakatū

🟥 Recommended Revised Fault Hazard Overlay
(Source: GNS Science)



0 100 200 300 400 m

Scale 1:5,000

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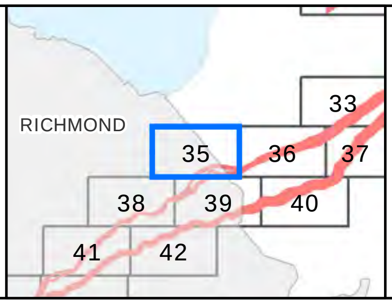
Map 35

Recommended Revised Fault Hazard Overlay

Nelson City Council
te kaunihera o whakatū



🟥 Recommended Revised Fault Hazard Overlay
(Source: GNS Science)

Scale 1:5,000

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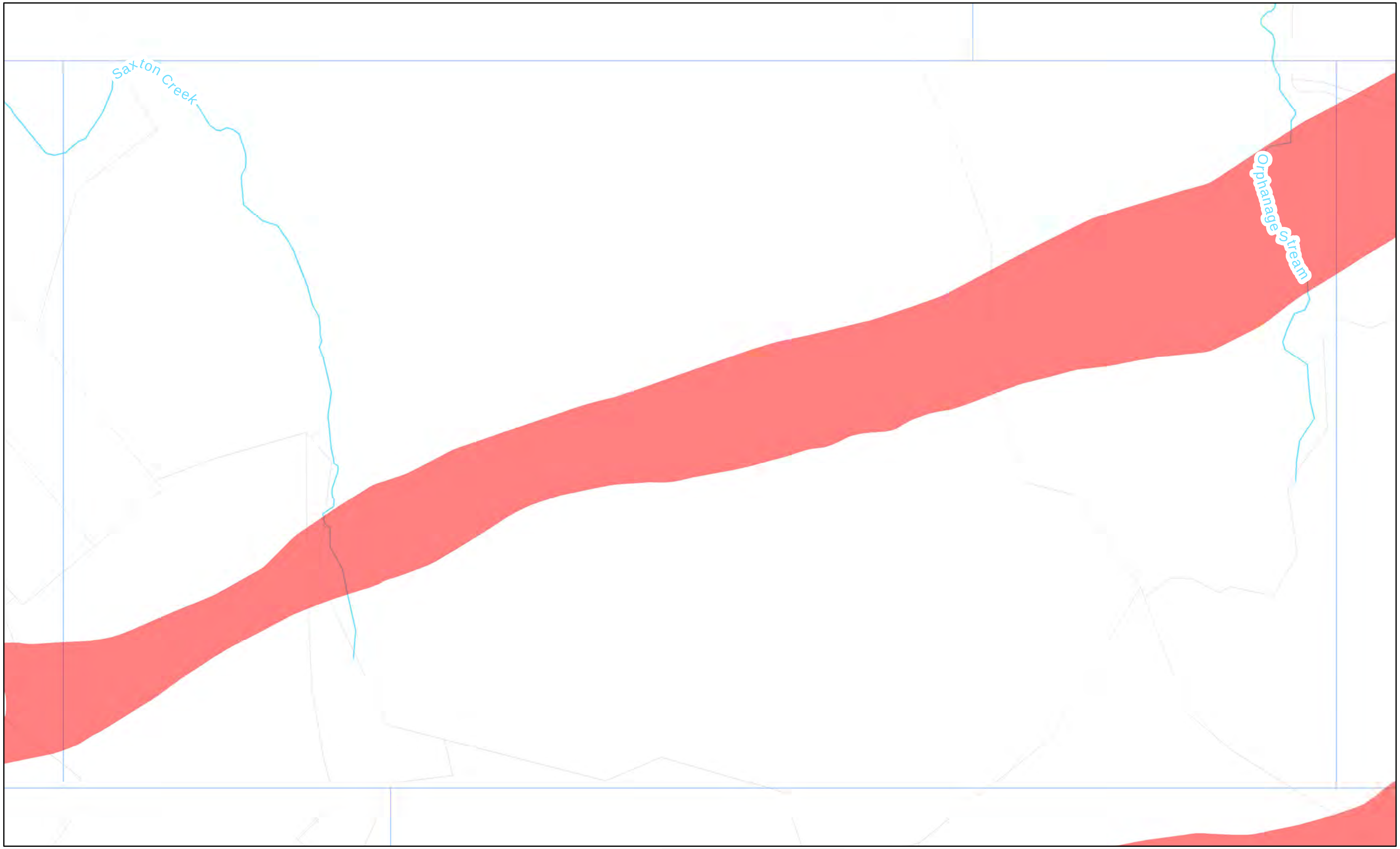
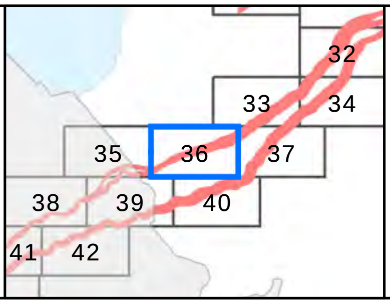


Map 36

Recommended Revised Fault Hazard Overlay

Nelson City Council
te kaunihera o whakatū

🟥 Recommended Revised Fault Hazard Overlay
(Source: GNS Science)



0 100 200 300 400 m

Scale 1:5,000

N

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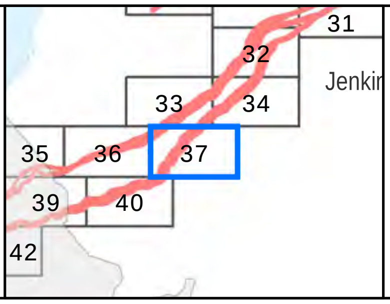
File Ref: 1201892
SER. Original map size A3.

Map 37

Recommended Revised Fault Hazard Overlay

Nelson City Council
te kaunihera o whakatū

🟥 Recommended Revised Fault Hazard Overlay
(Source: GNS Science)



0 100 200 300 400 m

Scale 1:5,000

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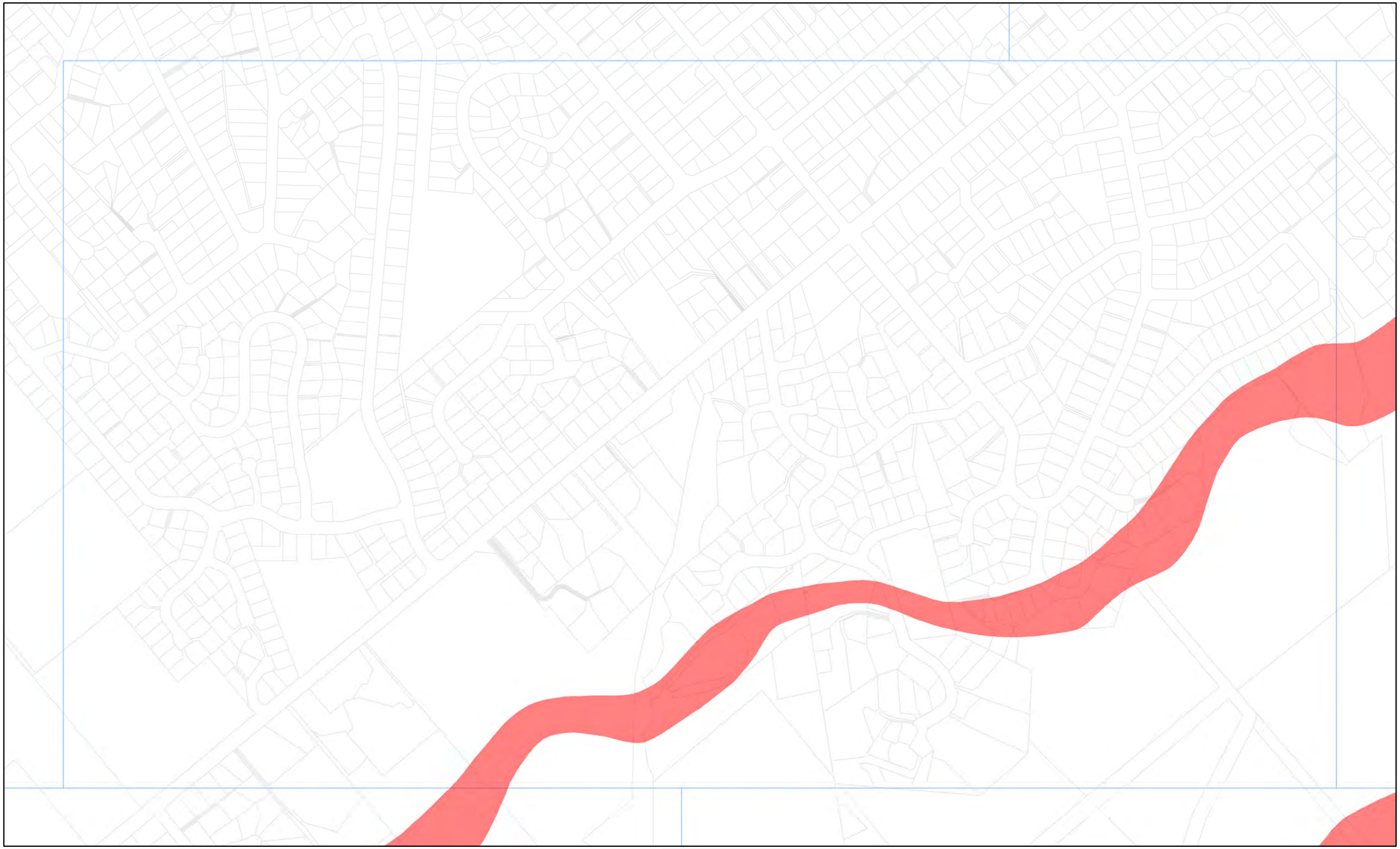

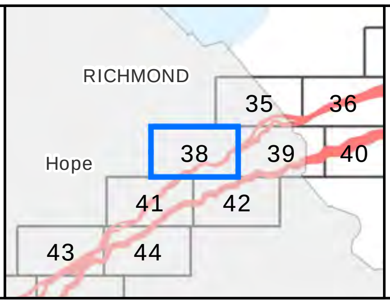

Map 38

Recommended Revised Fault Hazard Overlay

Nelson City Council
te kaunihera o whakatū

🟥 Recommended Revised Fault Hazard Overlay
(Source: GNS Science)

0 100 200 300 400 m

Scale 1:5,000

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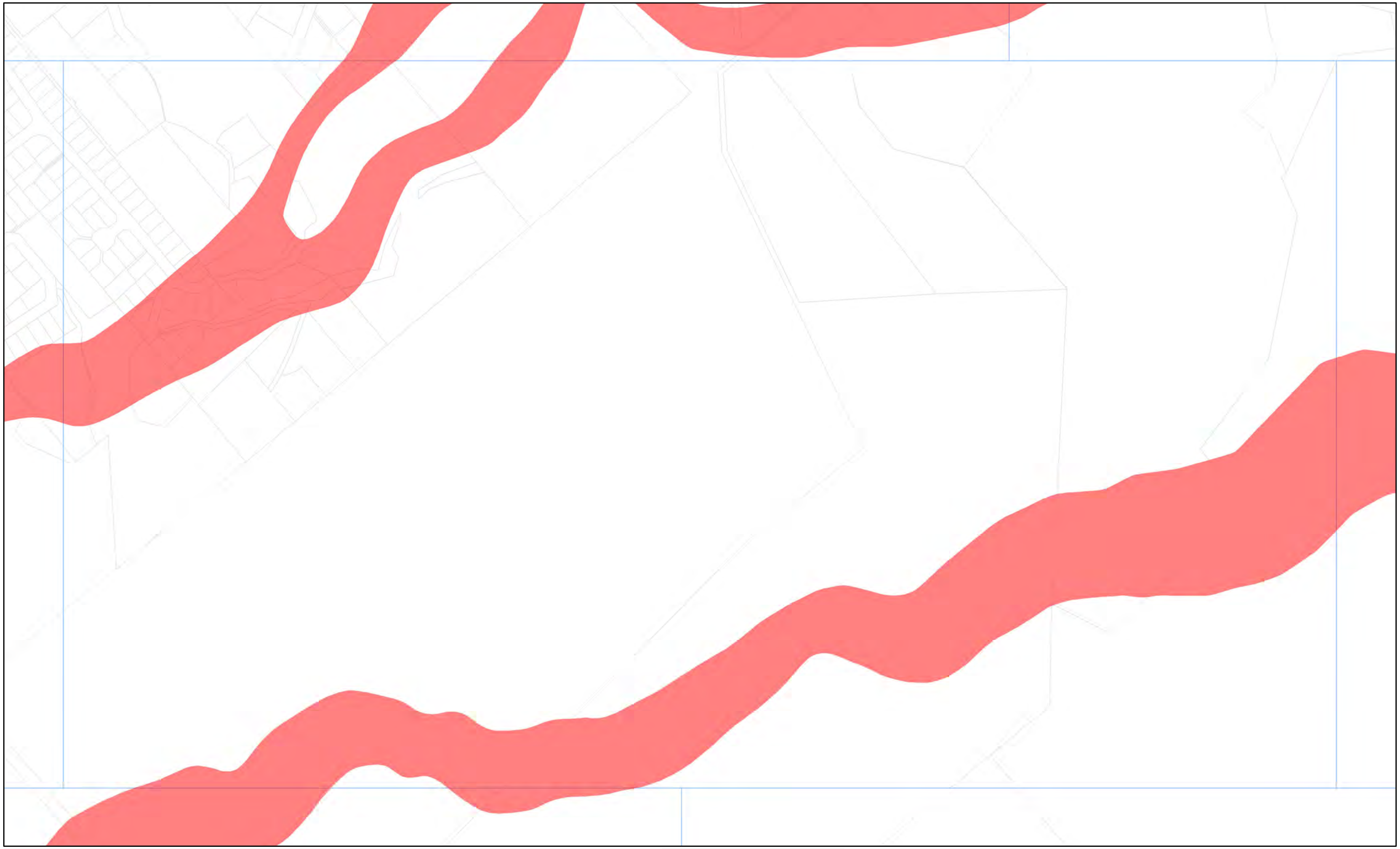
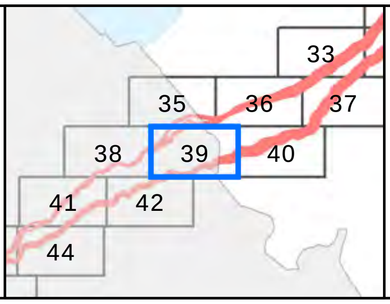


Map 39

Recommended Revised Fault Hazard Overlay

Nelson City Council
te kaunihera o whakatū

🟥 Recommended Revised Fault Hazard Overlay
(Source: GNS Science)



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Scale 1:5,000

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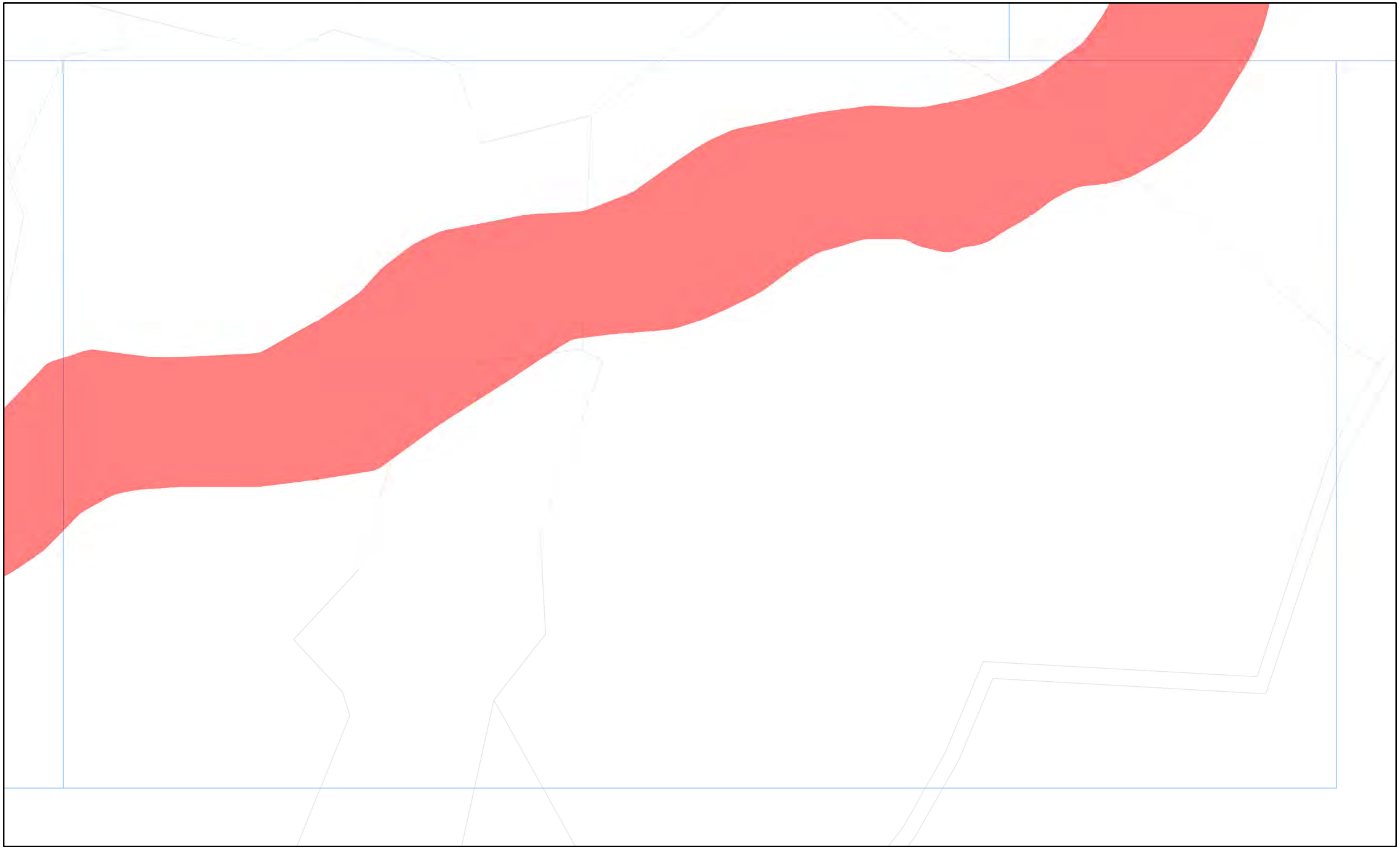
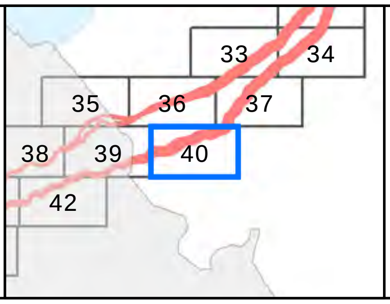


Map 40

Recommended Revised Fault Hazard Overlay

Nelson City Council
te kaunihera o whakatū

🟥 Recommended Revised Fault Hazard Overlay
(Source: GNS Science)



0 100 200 300 400 m

Scale 1:5,000

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File Ref: 1201892
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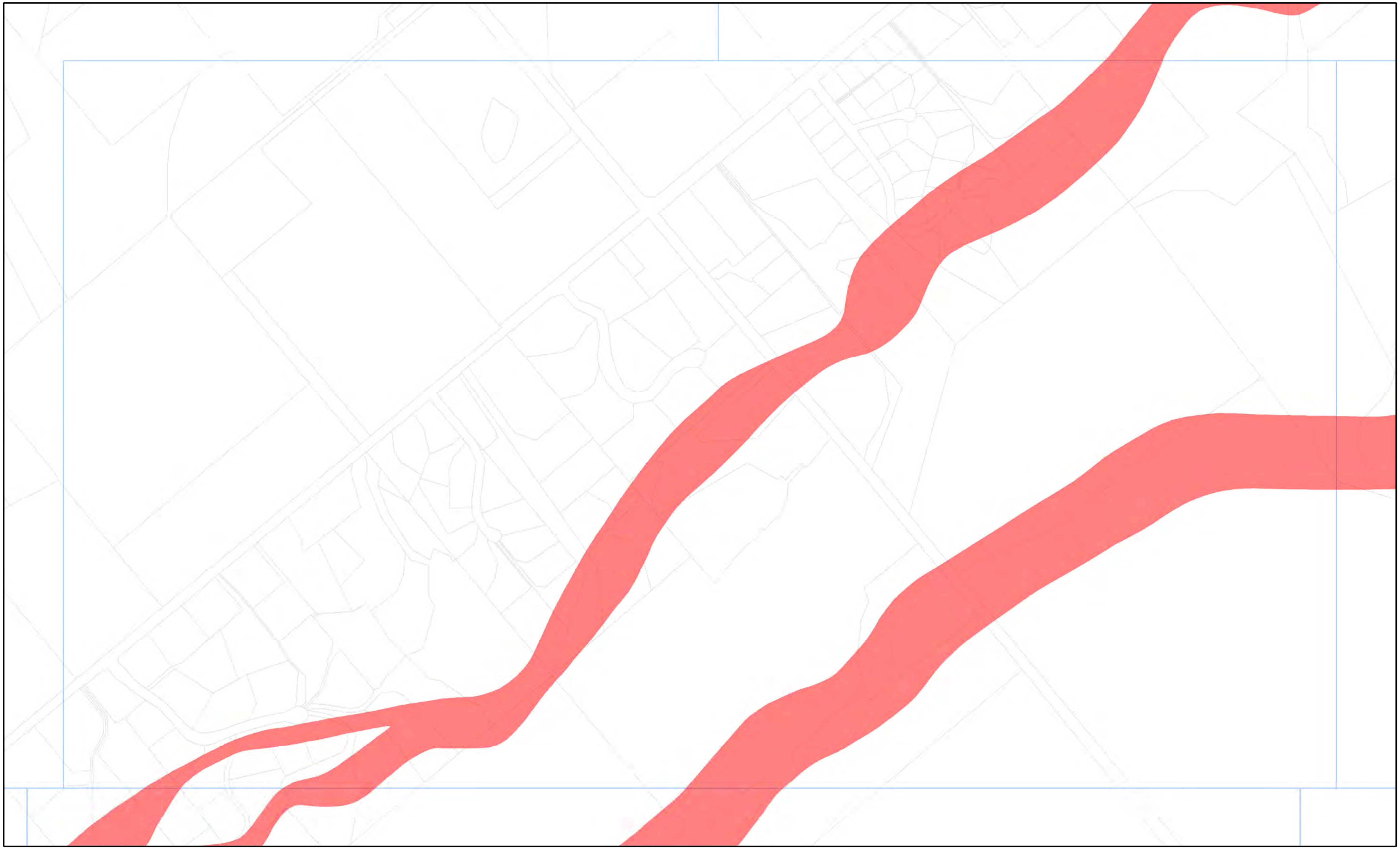
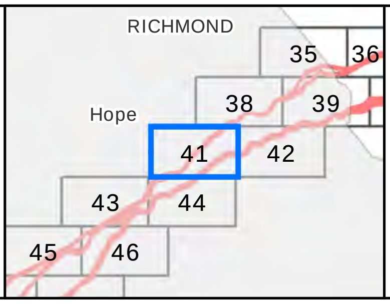


Map 41

Recommended Revised Fault Hazard Overlay

Nelson City Council
te kaunihera o whakatū

🟥 Recommended Revised Fault Hazard Overlay
(Source: GNS Science)



0 100 200 300 400 m

Scale 1:5,000

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August 2013

File Ref: 1201892
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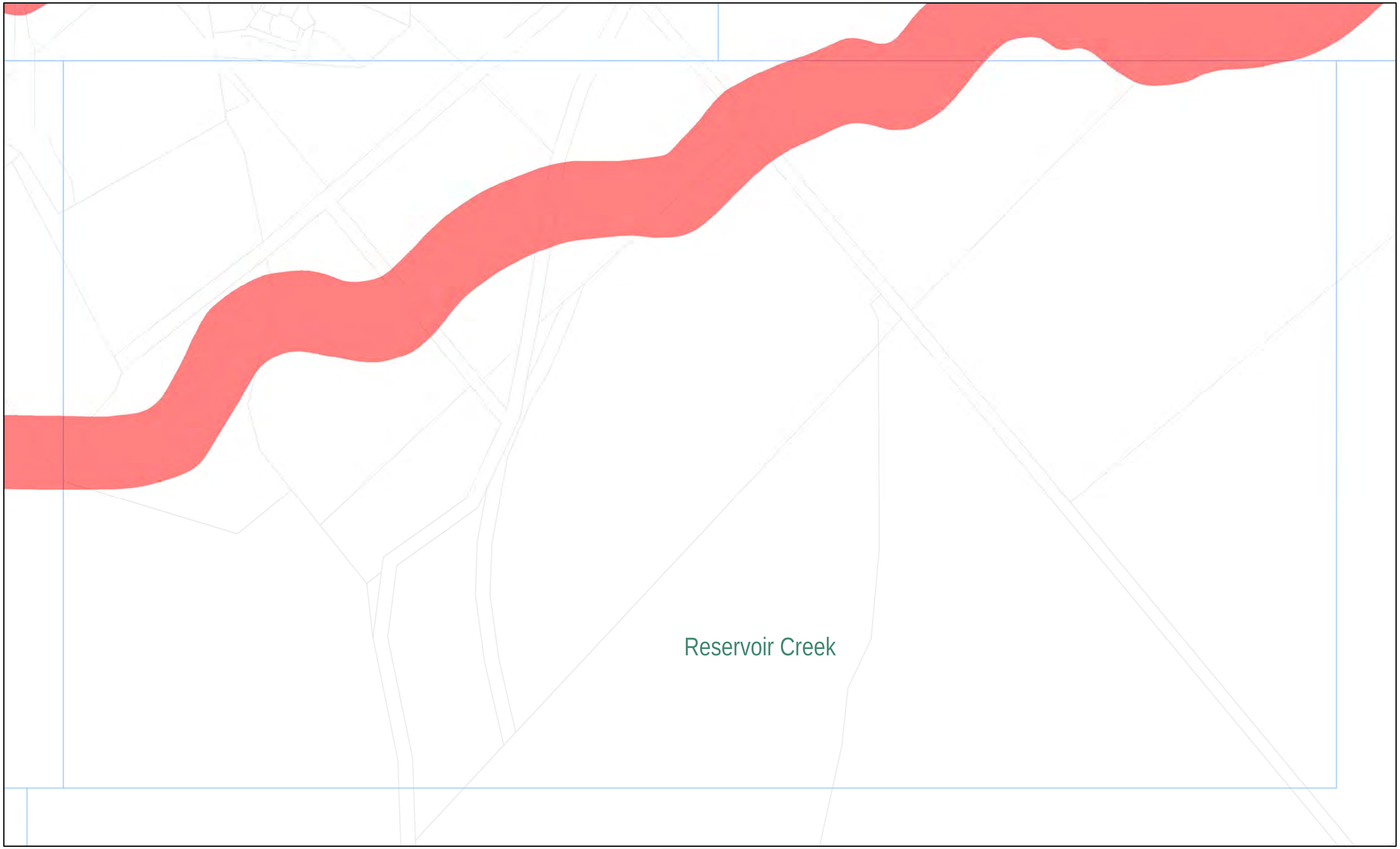
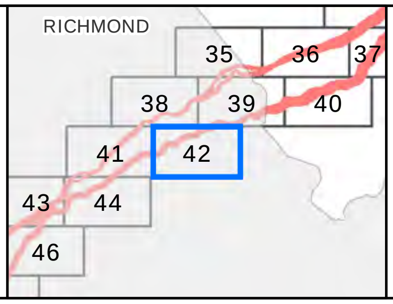


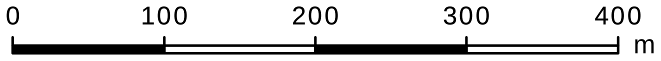
Map 42

Recommended Revised Fault Hazard Overlay

Nelson City Council
te kaunihera o whakatū

🟥 Recommended Revised Fault Hazard Overlay
(Source: GNS Science)





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August 2013

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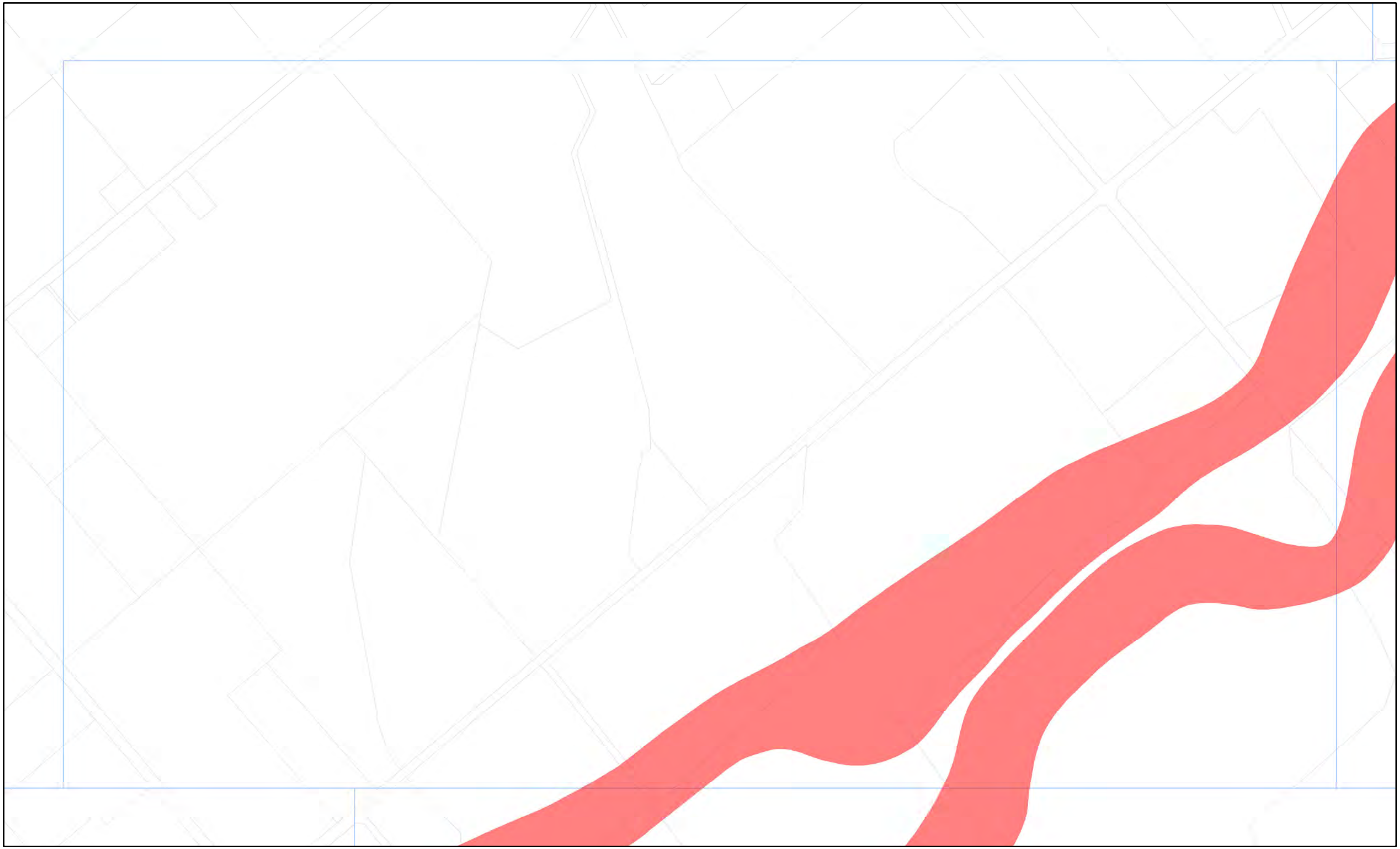
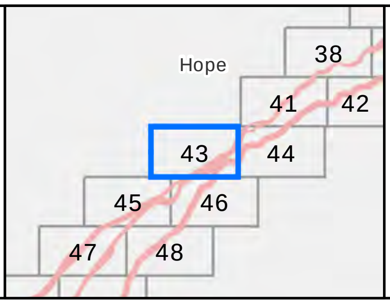


Map 43

Recommended Revised Fault Hazard Overlay

Nelson City Council
te kaunihera o whakatū

🟥 Recommended Revised Fault Hazard Overlay
(Source: GNS Science)



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Scale 1:5,000

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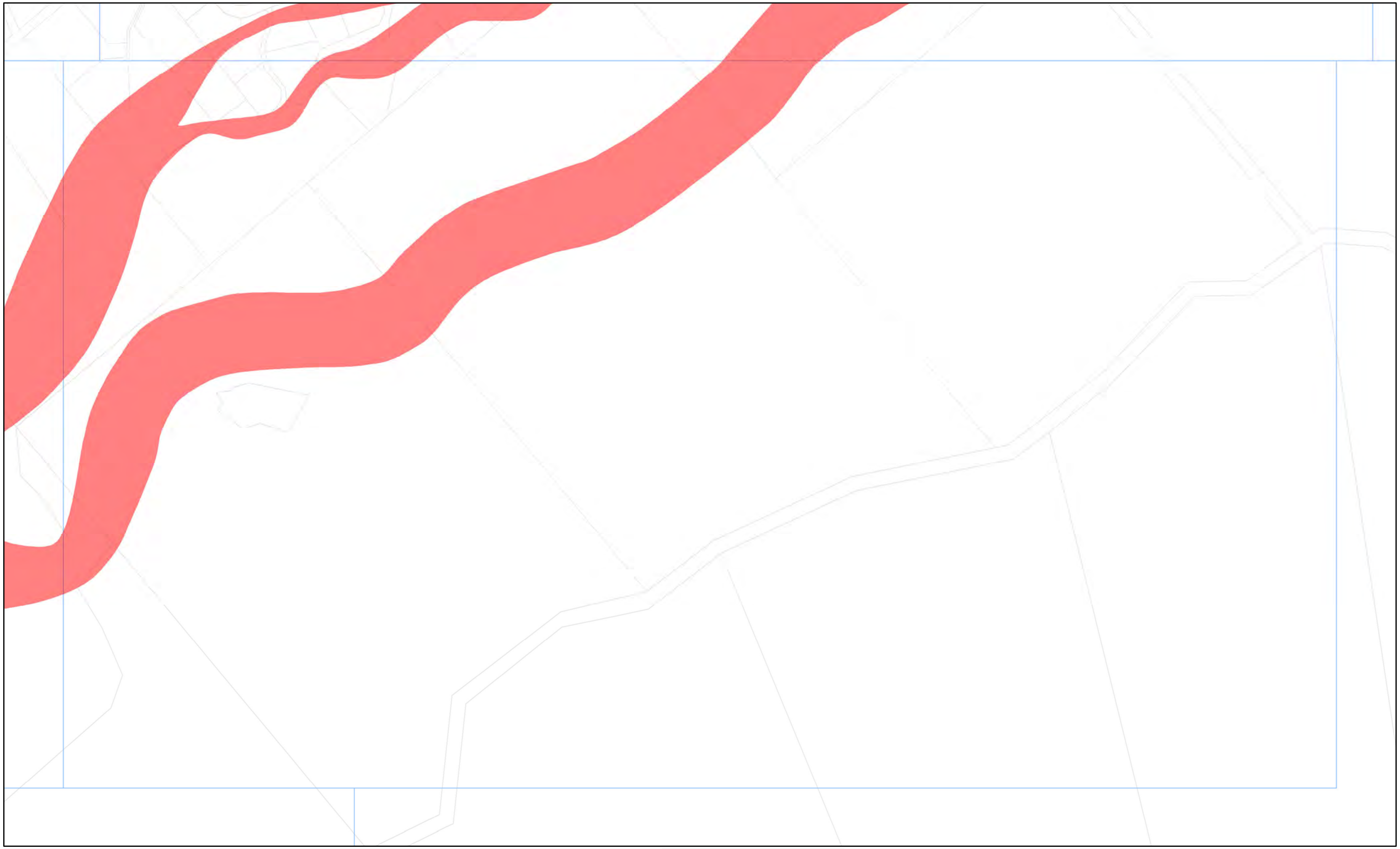
August 2013

File Ref: 1201892 SER. Original map size A3.

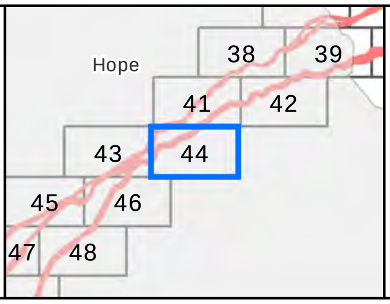


Map 44

Recommended Revised Fault Hazard Overlay

Nelson City Council
te kaunihera o whakatū

🟥 Recommended Revised Fault Hazard Overlay
(Source: GNS Science)



0 100 200 300 400 m

Scale 1:5,000

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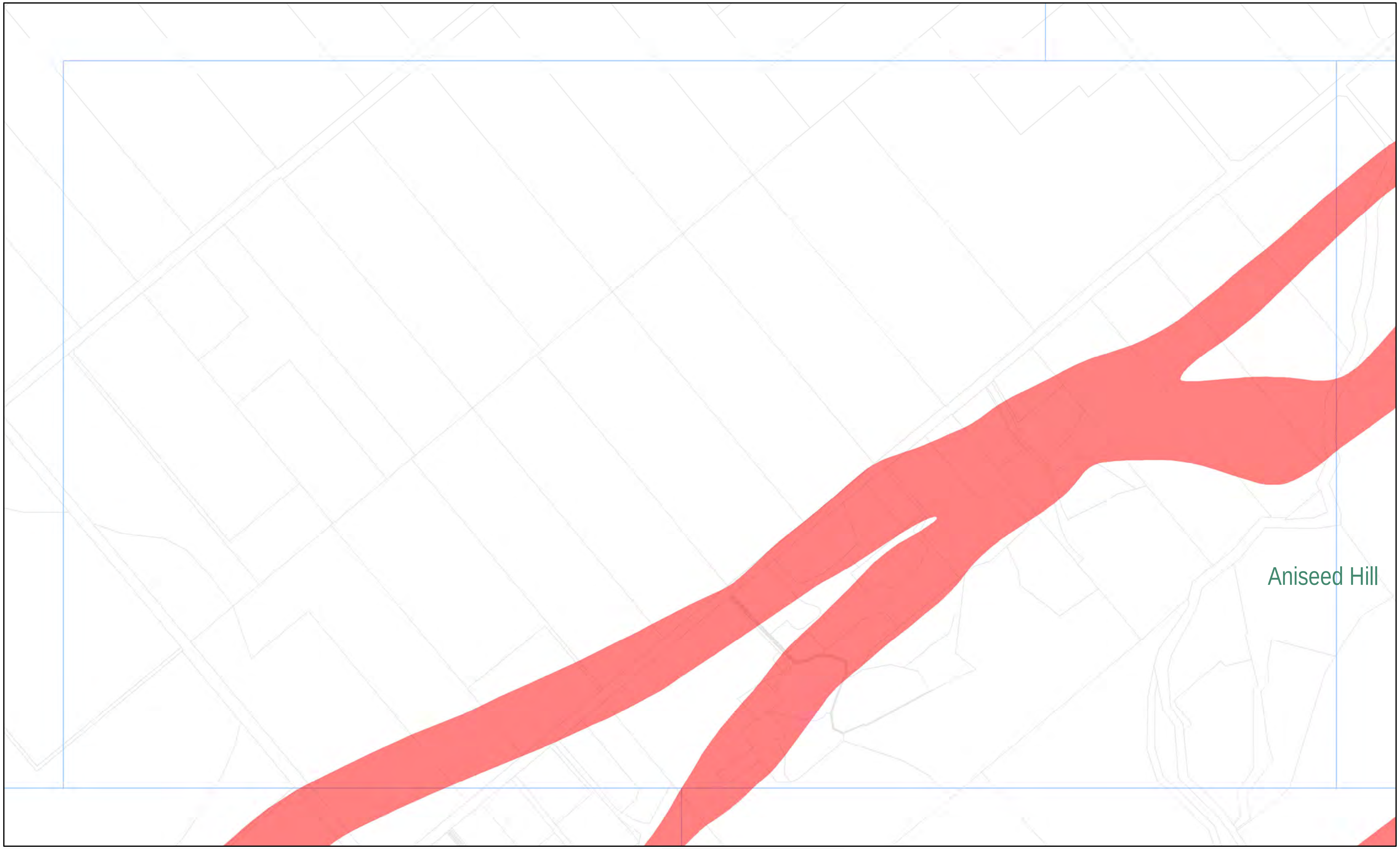
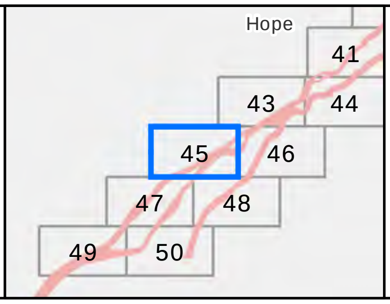


Map 45

Recommended Revised Fault Hazard Overlay

Nelson City Council
te kaunihera o whakatū

🟥 Recommended Revised Fault Hazard Overlay
(Source: GNS Science)



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Scale 1:5,000

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August 2013

File Ref: 1201892
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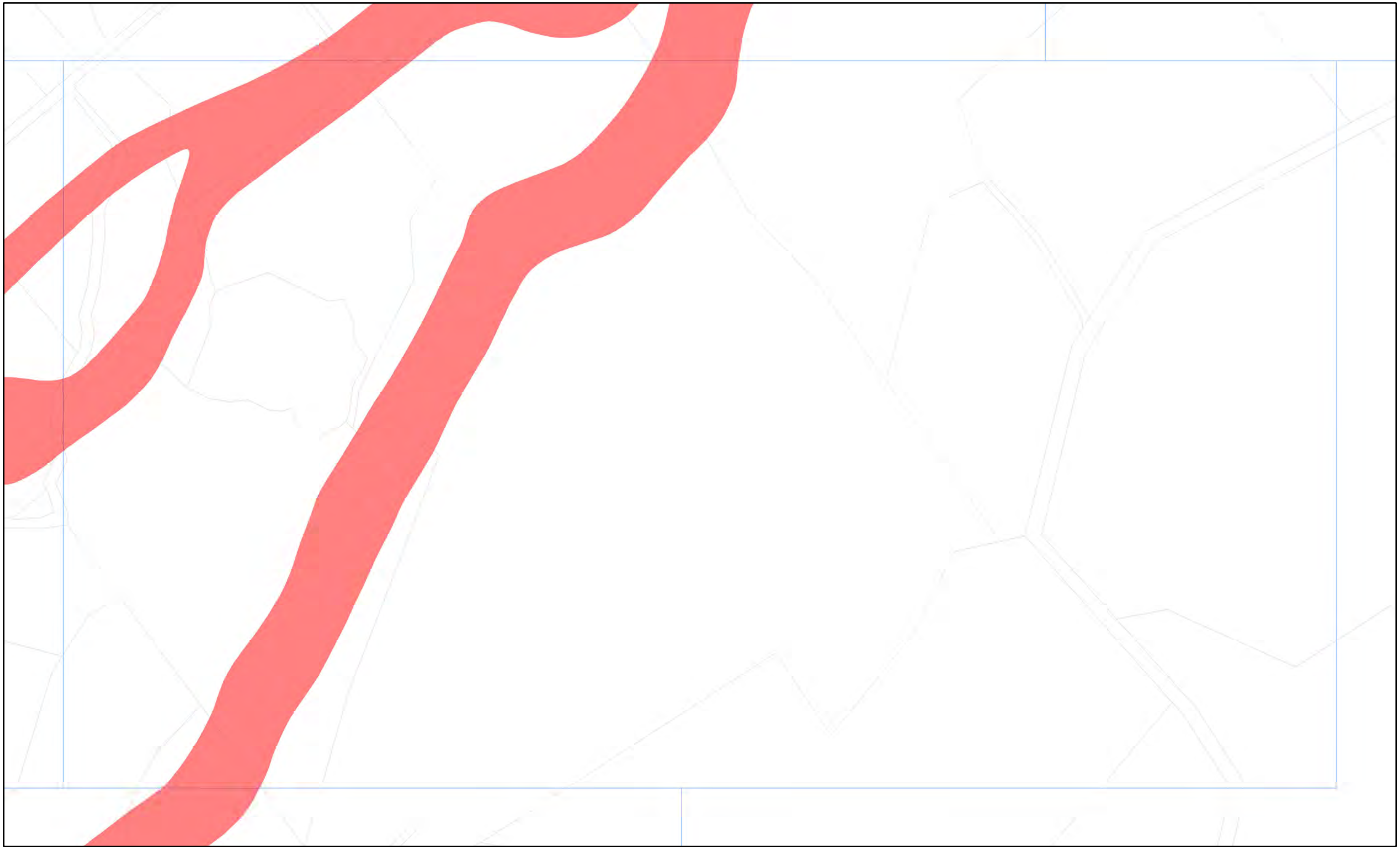
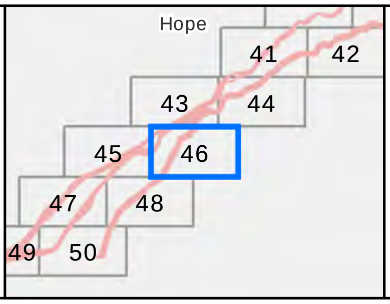


Map 46

Recommended Revised Fault Hazard Overlay

Nelson City Council
te kaunihera o whakatū

🟥 Recommended Revised Fault Hazard Overlay
(Source: GNS Science)



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Scale 1:5,000

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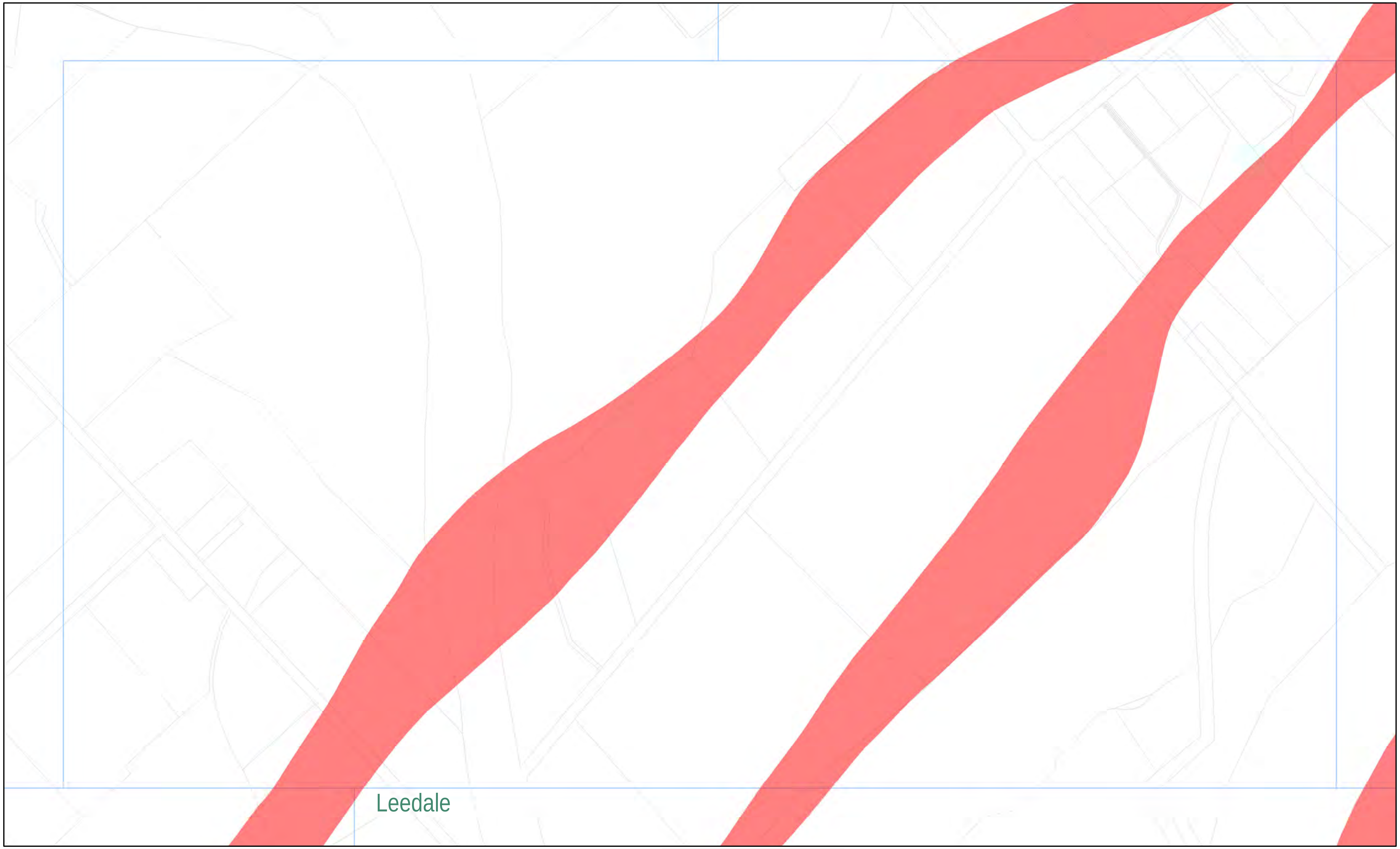
August 2013

File Ref: 1201892
SER. Original map size A3.

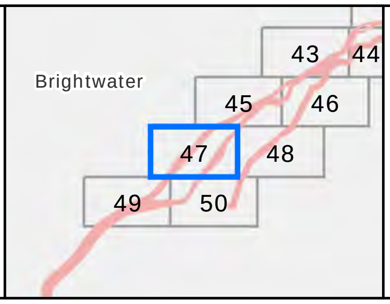


Map 47

Recommended Revised Fault Hazard Overlay

Nelson City Council
te kaunihera o whakatū

🟥 Recommended Revised Fault Hazard Overlay
(Source: GNS Science)



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Scale 1:5,000

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August 2013

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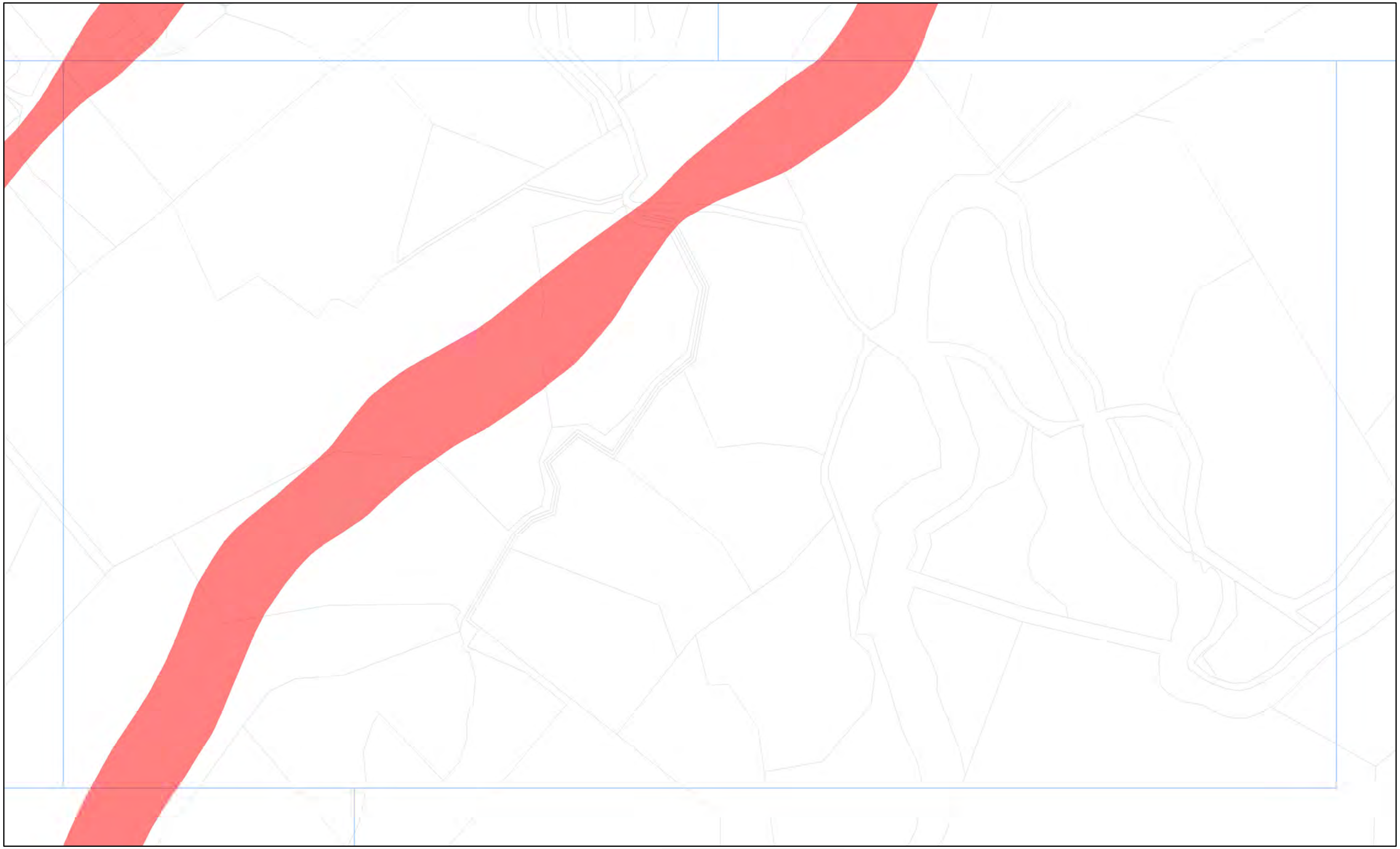
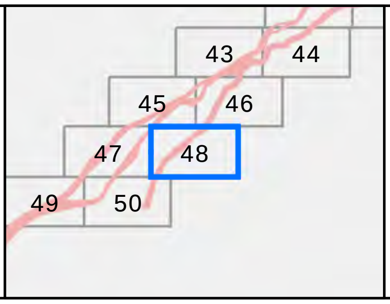


Map 48

Recommended Revised Fault Hazard Overlay

Nelson City Council
te kaunihera o whakatū

🟥 Recommended Revised Fault Hazard Overlay
(Source: GNS Science)



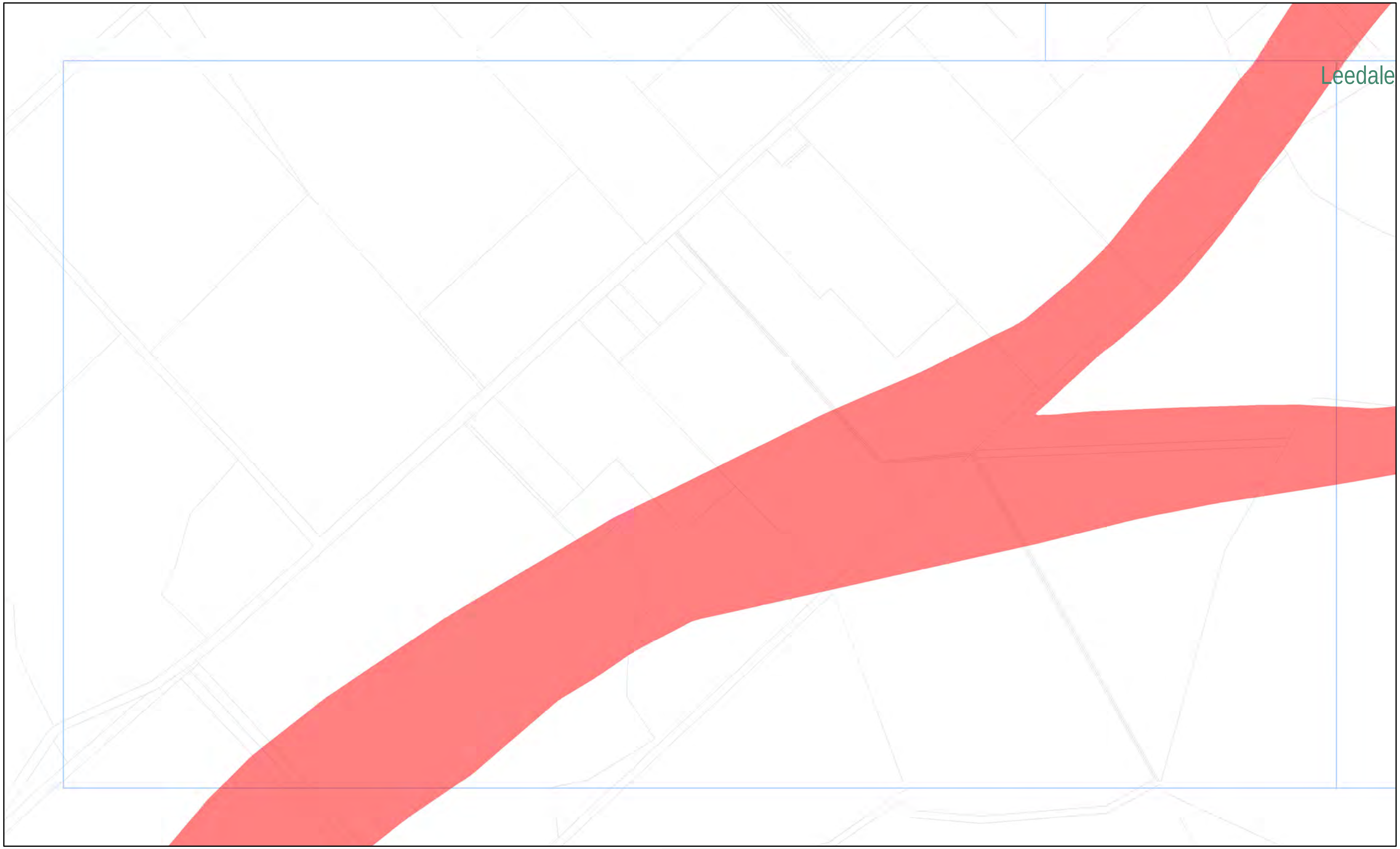
0 100 200 300 400 m

Scale 1:5,000

N

August 2013

File Ref: 1201892
SER. Original map size A3.

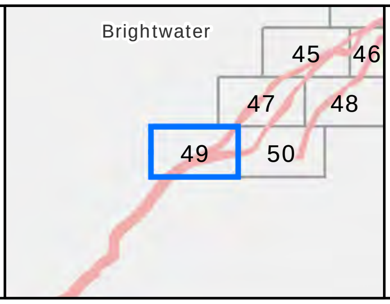


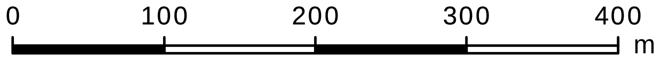
Map 49

Recommended Revised Fault Hazard Overlay

Nelson City Council
te kaunihera o whakatū

🟥 Recommended Revised Fault Hazard Overlay
(Source: GNS Science)





Scale 1:5,000

N

August 2013

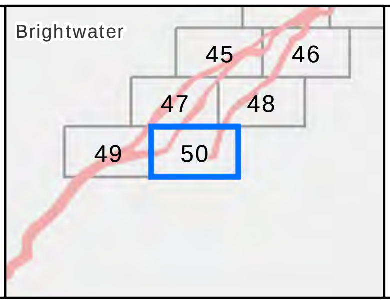
File Ref: 1201892
SER. Original map size A3.

Map 50

Recommended Revised Fault Hazard Overlay

Nelson City Council
te kaunihera o whakatū

🟥 Recommended Revised Fault Hazard Overlay
(Source: GNS Science)



0 100 200 300 400 m

Scale 1:5,000

N

August 2013

File Ref: 1201892
SER. Original map size A3.