Update of hazard Information for 2015 Lifelines Risk & Responsibilities Report

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DISCLAIMER

Use of Data:

Date that GNS Science can use associated data: May 2016

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EXECUTIVE SUMMARY

The Manawatu-Wanganui Lifelines Advisory Group is undertaking a project to update its 2005 *Risks and Responsibilities* report. This report presents and describes the updated hazards information provided to Horizons Regional Council by GNS Science for use by the Manawatu-Wanganui Lifelines Advisory Group and includes the following items as per the scope of work agreed with Horizons Regional Council:

1. Peak Ground Acceleration (PGA) modelling.
2. Inferred earthquake ground shaking site sub-soil class information.
3. PGA estimates incorporating inferred site sub-soil class information.
4. Basic liquefaction hazard mapping.
5. Digitisation of existing landslide information.
6. Volcanic hazard mapping updates.

NZS1170.5 site sub-soil class has been inferred from the 1:250,000 Geological Map of New Zealand (Heron, 2015) and presented as a map and GIS file. The site sub-soil class information has been combined with the National Seismic Hazard Model (Stirling et al., 2012) to produce a 0.05° by 0.05° grid of PGAs that take into account the estimated site sub-soil class for return periods of 500, 1000 and 2500 years.

A regional scale liquefaction hazard map has been compiled from consideration of the latest 1:250,000 Geological map of New Zealand and accounts of liquefaction from historical earthquakes. The liquefaction hazard map gives a five-level classification of liquefaction hazard identifying areas as having very high, high, moderate, low or no liquefaction hazard. The map is suitable for assessing where further investigation of liquefaction might be required as part of a package of work to improve the resiliency of assets and infrastructure.

Landslide data shown on Figure 1 of Dellow and Dymond (2008) has been extracted and supplied in digital format to Horizons Regional Council.

Five scenario eruption events have also been modelled. Eruption scenarios of 0.1 km^3, 0.5 km^3 and a maximum credible event (MCE) of 1 km^3 for Mt Taranaki, and a 0.01 km^3 and an MCE of 0.1 km^3 for Mt Ruapehu have been produced.

Volcanic ashfall maps for T = 100, 500 and 2500 year return periods for three volcanic centres (Mt Taranaki, and the Tongariro National Park volcanoes Ruapehu and Tongariro and Taupo) have been produced.

Metadata accompanies the digital datasets supplied as part of this contract.

1.0 INTRODUCTION

The Manawatu-Wanganui Lifelines Advisory Group is undertaking a project to update its 2005 *Risks and Responsibilities* report. The lifelines vulnerability study is being updated in a similar manner to that followed by other lifelines groups within New Zealand.

This report presents and describes the updated hazards information provided to Horizons Regional Council by GNS Science for use by the Manawatu-Wanganui Lifelines Advisory Group and includes the following items as per the scope of work agreed with Horizons Regional Council:

1. Peak Ground Acceleration (PGA) modelling: Horizontal PGA estimates will be calculated from GNS Science's "New Zealand Seismic Hazard Model" for return periods T = 500, 1000, and 2500 years for a grid covering the Horizons region.
2. Inferred earthquake ground shaking site sub-soil class information: Site class (NZS1170 Site Class B rock, Site Class C shallow soil, and Site Class D deep or soft soil) will be inferred from 1:250,000 geological mapping by matching shear-wave velocity estimates to the geological unit based on geological structure, unit description and age.
3. PGA estimates incorporating inferred site sub-soil class information: The PGA estimates determined in 1 above will be adjusted to take into account the site sub-soil classes found within the Horizons Region as derived in 2 above.
4. Basic liquefaction hazard mapping: Basic liquefaction maps will be produced that rank areas within the Manawatu-Wanganui region on a five-fold liquefaction scale (none, low, moderate, high, very high), drawing on 1:250,000 geological maps as source data.
5. Digitisation of existing landslide information: Locations of existing landslides will be extracted and digitised from Figure 1 in Dellow and Dymond (2008).
6. Volcanic hazard mapping updates: A summary of the existing information on volcanic hazard within the Manawatu-Wanganui region considering T = 100, 500, and 2500 year return periods will be prepared. Volcanic ashfall contours will be prepared for the return periods and estimates of maximum credible ashfall will be provided.

2.0 PEAK GROUND ACCELERATION MODELLING

PGA hazard estimates are determined for the Manawatu-Wanganui region using GNS Science's National Seismic Hazard Model (NSHM; Stirling et al., 2012) incorporating the non-magnitude-weighted application of the McVerry et al. (2006) ground motion prediction equation (GMPE). The horizontal PGA is calculated from the NSHM for each point on a 0.05° grid for the requested annual exceedence probabilities for each of the NZS1170.5 site classes in the region. The latitudinal/longitudinal extents of this grid were defined by the client prior to running the NSHM, but the final results are clipped to the Horizons Council boundary.

The return period (in years) for different levels of Modified Mercalli (MM) shaking intensity for the eighth largest urban areas in the Horizons Region is provided as a link to enable some comparison with previous work (Table 1). A correlation between MM shaking intensity values and PGA values is provided in Table 2.

2.1 INFERRED SITE SUB-SOIL CLASS

Site class is usually assigned by evaluating geotechnical data and depth profiles based on criteria outlined in NZS1170.5 (Standards New Zealand, 2004). However, as this information is not widely available and cannot be obtained from a regional-scale geological map, site class must be inferred by making assumptions that correlate NZS1170.5 site class criteria to described characteristics and ages of the mapped geological units. Perrin et al. (2015) developed an NZS1170.5 site class map for New Zealand based on the geological data released as part of the 1:250,000 Geological Map of New Zealand (Heron, 2015). This map by Perrin et al. (2015) has been used to assign site sub-soil class at the regional scale for this study with a resolution no better than ~200 m (Nick Perrin, pers. comm.). Therefore, it is important to note that the resulting maps provided for this study are also only suitable for regional-scale use. Site-specific information including the soil profile with depth is not included in this analysis.

The data is clipped to the Horizons Council boundary and is presented on Figure 1.

2.2 INCORPORATION OF SITE CLASS IN PGA ESTIMATES

The horizontal PGA estimates (see 2.0 above) were incorporated with the New Zealand inferred site sub-soil class information (see 2.1 above) to produce maps and datasets that show, at a regional scale, the estimated PGAs across the region with annual exceedence probabilities of 1 in 500 (Map 2), 1 in 1000 (Map 3) and 1 in 2500 (Map 4). No PGA model is available for Site Sub-Soil Class E materials and these were treated as Site Class D in the preparation of the maps and datasets. Note that PGAs are less sensitive to site class than longer-period measurements of earthquake ground shaking, such as the response spectral acceleration at 1s period. The PGAs are strongest for Class C shallow soil, followed at low acceleration values by Class D deep or soft soil and then Class B rock, with the order of Classes D and B interchanging for stronger PGAs. At long spectral periods, the strongest motions will be for Class D, followed by Class C and then Class B.

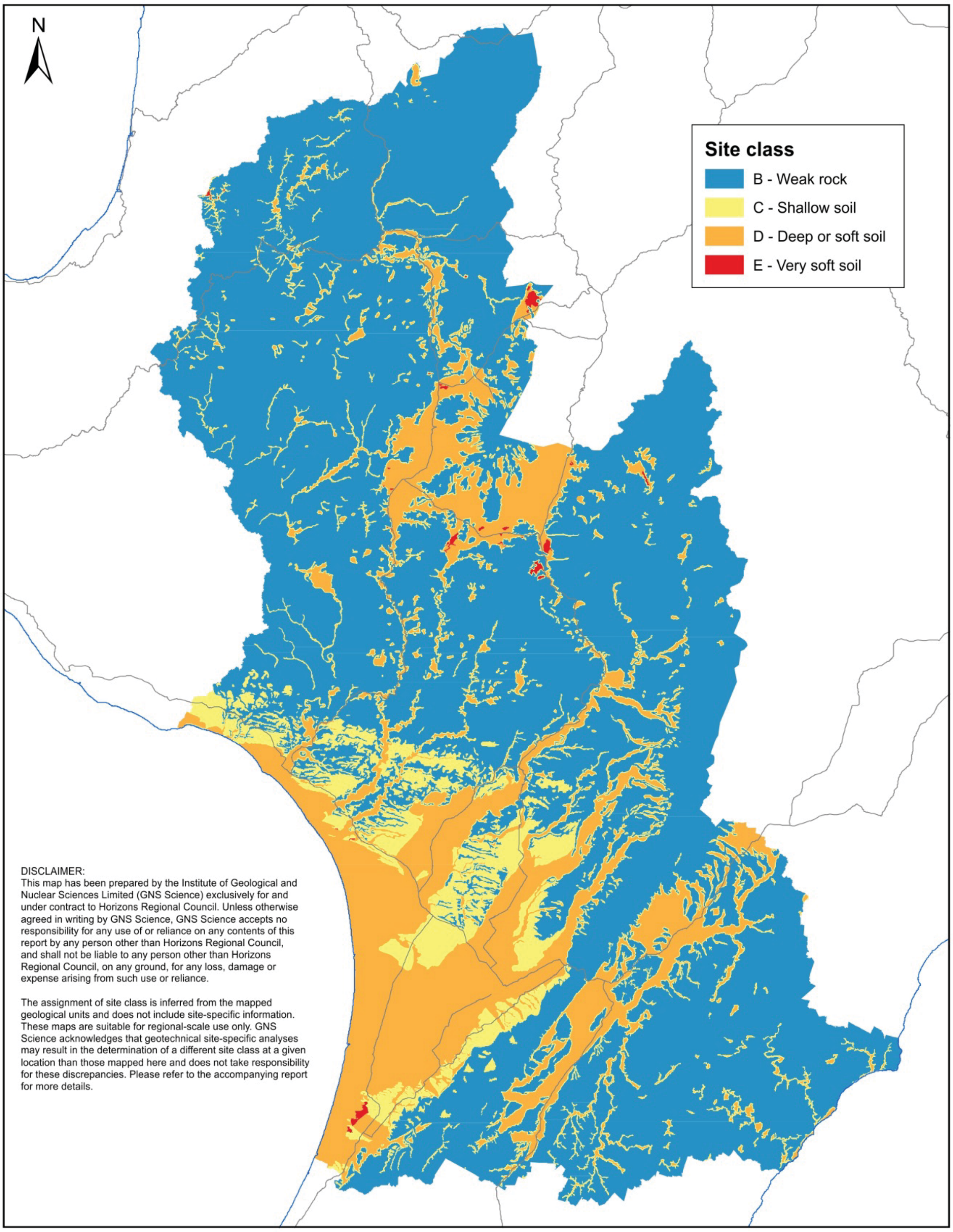
Given the resolution constraints on the PGA and geological data described in the previous sections (2.0 and 2.1), the maps and data produced for this study are useful at a regional level only, and should not be used in place of site-specific studies. GNS Science acknowledges that geotechnical site-specific analyses may result in the determination of a different site sub-soil class at a given location than those mapped here and does not take responsibility for these discrepancies.

Table 1 Modified Mercalli Shaking Intensity Return Periods (in years) for the main urban areas in the Horizons Region.

Town	MM7	MM8	MM9	MM10
Palmerston North	26	113	625	4237
Wanganui	40	278	3448	58824
Dannevirke	25	107	521	5000
Fielding	28	134	905	9804
Levin	25	103	502	3650
Taihape	36	201	1639	23256
Ohakune	47	208	684	3155
Taramaranui	101	750	7194	125000

Table 2 Correlation between Modified Mercalli (MM) Shaking Intensity and Peak Ground Acceleration (PGA) from Hancox et al. (2002).

MM Intensity	PGA (Peak Ground Acceleration, g)
5	0.03-0.04
6	0.05-0.08
7	0.10-0.15
8	0.18-0.25
9	0.3-0.5
10	>0.5



SCALE BAR: 0 25 50 km

EXPLANATION:

Inferred site class derived from 1:250,000 scale geology as described by Perrin et al. (2015). Areas classified as site class E by Perrin were treated as site class D. For more information read the accompanying report.

PROJECTION: NZGD 2000 New Zealand Transverse Mercator

SCALE: 1:800,000

DRW: BL, DWH

CHK: GHM

GNS SCIENCE TE PŪ AO

Horizons Region

Site Class

MAP 1

REPORT: GNS 2016/08 LR

DATE: February 2016

Figure 1 Site sub-soil class as per NZS 1170.5 (2004).

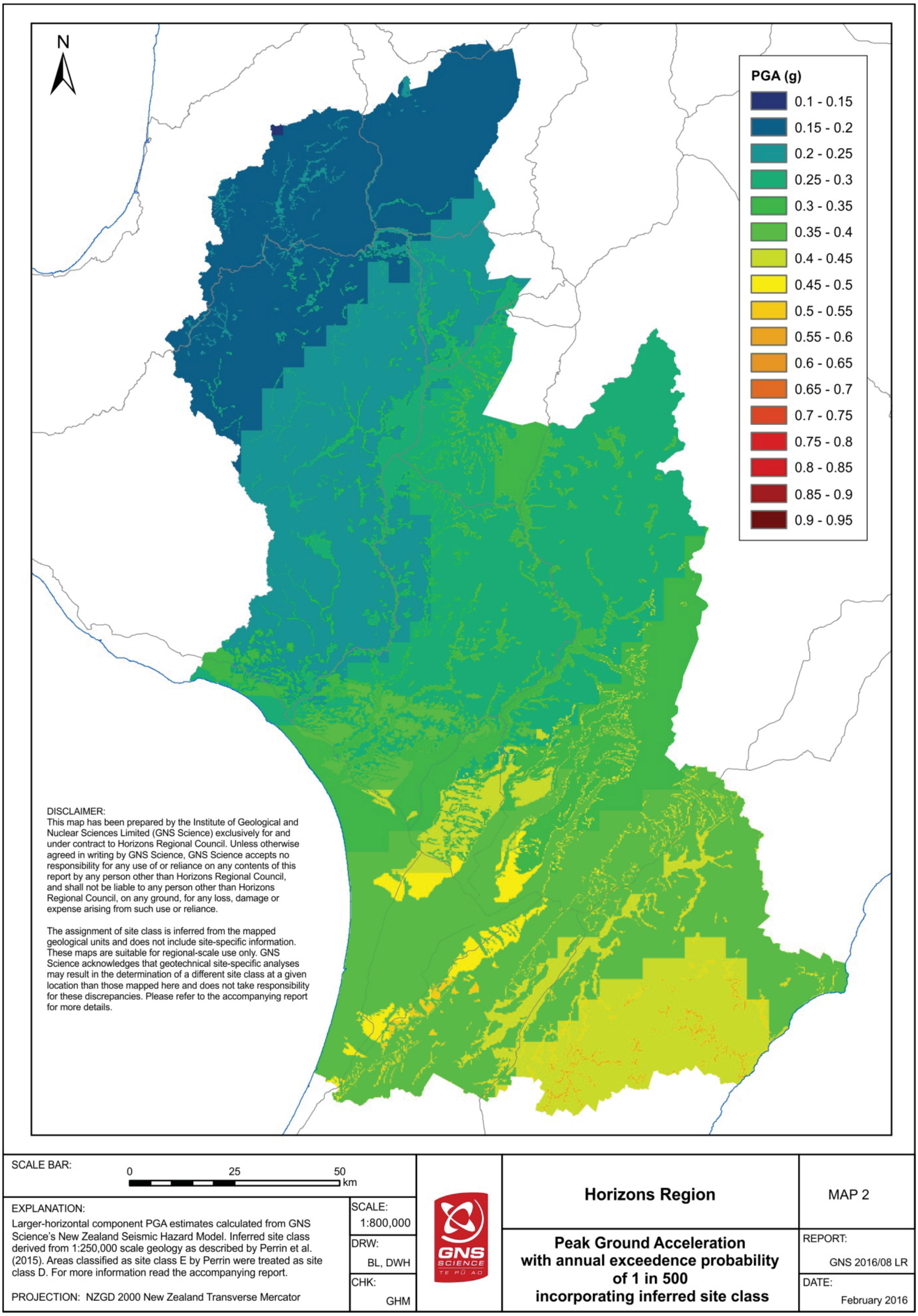


Figure 2 Peak Ground Acceleration with an annual exceedence probability of 1 in 500 incorporating NZS 1170.5 site sub-soil class.

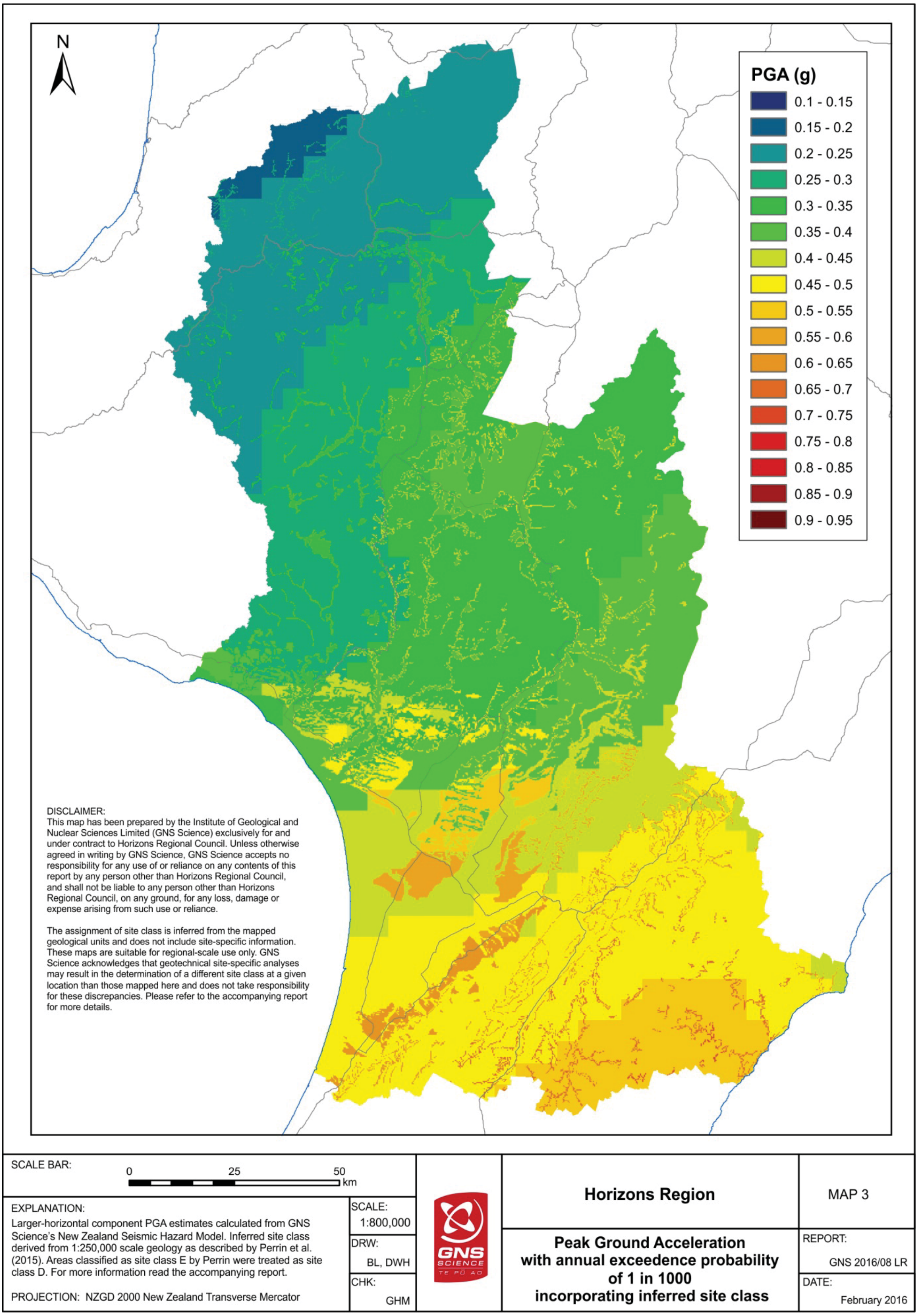


Figure 3 Peak Ground Acceleration with an annual exceedence probability of 1 in 1000 incorporating NZS 1170.5 site sub-soil class.

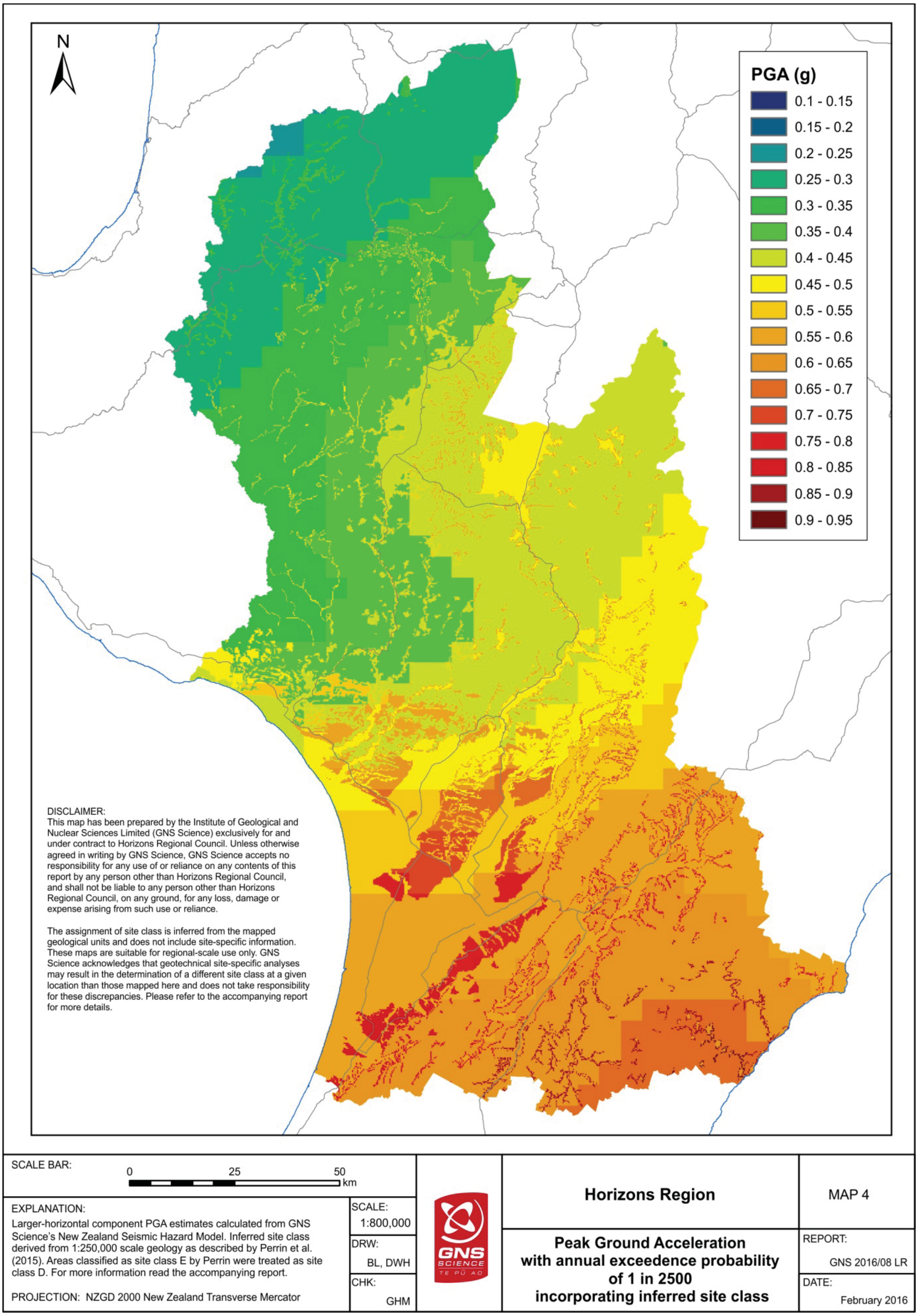


Figure 4 Peak Ground Acceleration with an annual exceedence probability of 1 in 2500 incorporating NZS 1170.5 site sub-soil class.

3.0 BASIC LIQUEFACTION HAZARD MAPPING

The first regional liquefaction map of the Horizons Region was prepared in 1994 (Dellow et al., 1994). This work used 1960's era geological maps (Grindley, 1960; Hay, 1967; Kingma, 1962; Kingma, 1967; Lensen et al, 1959) as a base for determining the liquefaction hazard in the region. Subsequently, more localised studies have been completed for Wanganui (Beetham et al., 1998) and Palmerston North (Beetham et al., 2011).

Since 1994, when the initial liquefaction susceptibility mapping was undertaken, new geological mapping at the regional scale has been completed (Heron, 2014). This new mapping in conjunction with more detailed knowledge of the historical earthquake record and the liquefaction response during these earthquakes (Downes et al., 1999; Downes et al., 2001; Grapes and Downes, 1997; Hancox et al., 2002) provide an opportunity to update liquefaction hazard maps for the Horizons Region.

Liquefaction is a process that leads to a soil suddenly losing much of its strength, most commonly as a result of strong ground shaking during a large earthquake. Not all soils, however, can liquefy in an earthquake. The following are particular features of soils that potentially can liquefy:

- The soils need to be composed of loose sand and/or silt with very little or no clay. Such soils do not stick together the way clayey soils do.
- The soils need to be saturated (i.e. located below the water table) so all of the space between the grains of sand and silt is filled with water. Dry soils above the water table do not liquefy.

This simplifies the identification of sediments (soils) that are vulnerable to liquefaction. The sediments must be relatively young (typically less than ~10,000 years old) and deposited in a low energy environment (e.g. settle out of suspension). Thus the places most likely to accumulate sediments prone to liquefaction are lagoons and estuaries near the coastline where sand and silt suspended in flood waters can settle out of suspension. Other locations are overbank silt deposits (again silt settling out of suspension from floodwaters), and point bar and channel deposits in meandering river systems.

The new, regional-scale liquefaction hazard map (Figure 5 - Figure 7) for the Horizons Region was developed by first extracting a spreadsheet containing a line for each individual map polygon for all the mapped geological units in the region. Each geological unit, as defined in recent (1996-2012) 1:250,000 scale geological maps, also included identifiers such as unit code and various descriptors including material type and age. Geological units older than Holocene (i.e. more than 10,000 years old) were identified and removed from the spread-sheet. This eliminated more than ninety per cent of the land area of the Horizons Region. The material types of the remaining units were then considered and any that were gravel or clay dominated were removed.

Any geological units left after this were considered to potentially contain liquefiable materials. Individual map units were then examined and subdivided if they were considered to contain both liquefiable and non-liquefiable areas. The polygons considered for subdivision were invariably large polygons of modern alluvial materials that stretched from the coast up into the headwaters of the larger rivers.

The division of these polygons into liquefiable and non-liquefiable areas was based primarily on river gradient. Inland areas having a steeper gradient and consequently a higher-energy depositional environment and coarser sediment component, (i.e. gravel dominated) were considered non-liquefiable. Coastal areas with a low river gradient and consequently a lower-energy depositional environment and finer sediment component, (i.e. sand and silt dominated) were considered potentially liquefiable.

The final step was to compare the identified areas with the accounts of historical liquefaction in the region. Although the location of historical liquefaction is often imprecise, the historical accounts were in good agreement with the areas identified through the mapping process, including both Wanganui and Palmerston North cities where liquefaction has been investigated in more detail (Beetham et al., 1998; Beetham et al., 2011).

The liquefaction hazard map supplied with this report is a regional scale map that identifies areas where liquefaction might be damaging to buildings and infrastructure. It is not suitable for use as a site-specific analysis of liquefaction, but it may be used to identify and prioritise areas where a site-specific analysis of liquefaction hazard is warranted. For Wanganui and Palmerston North more detailed liquefaction hazard maps are available (Beetham et al., 1998; Beetham et al., 2011) and these should be used in these areas to identify areas for further site-specific investigation of liquefaction in preference to this map.

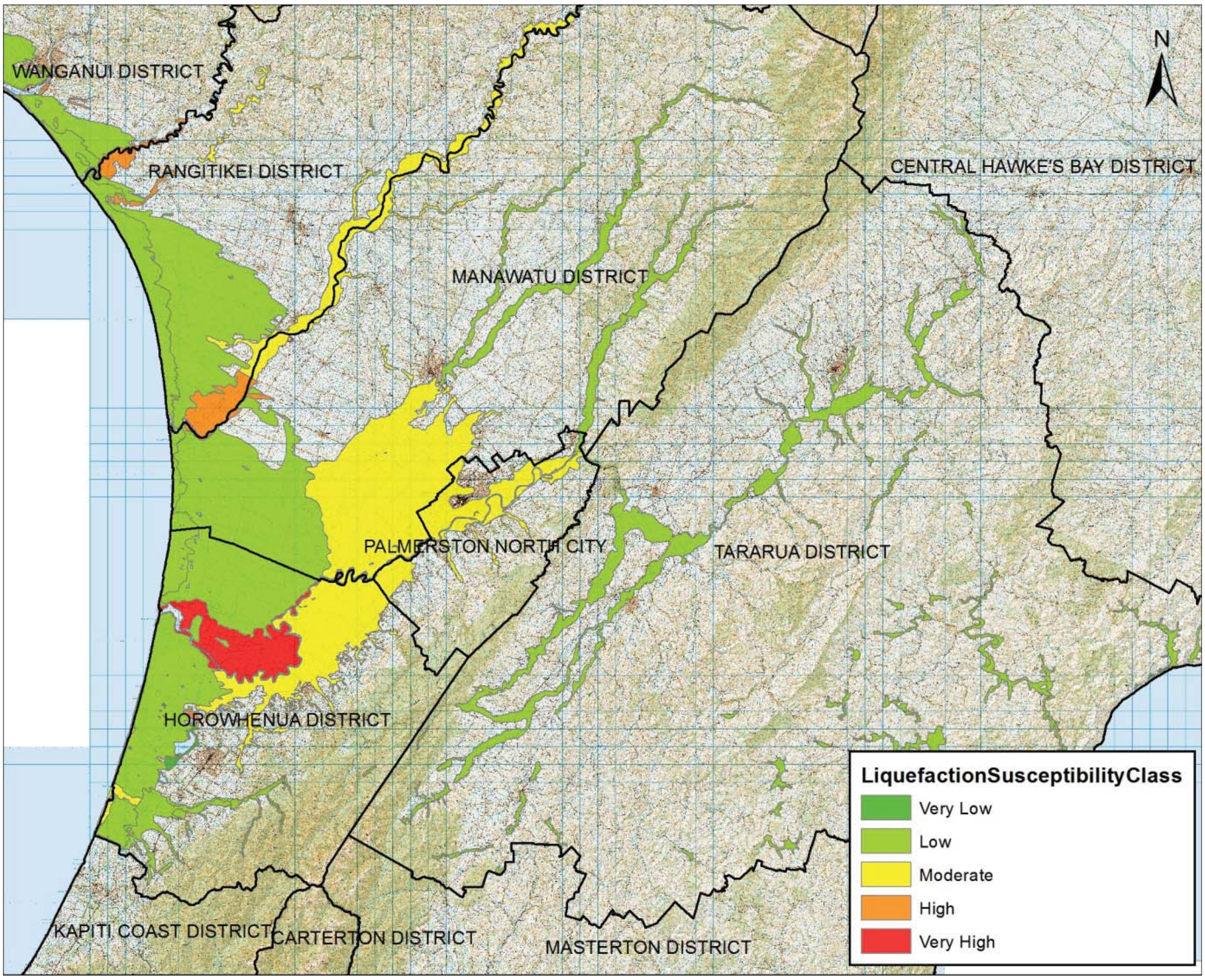


Figure 5 Liquefaction hazard map for Horowhenua District, Tararua District, Manawatu District and Palmerston North City.

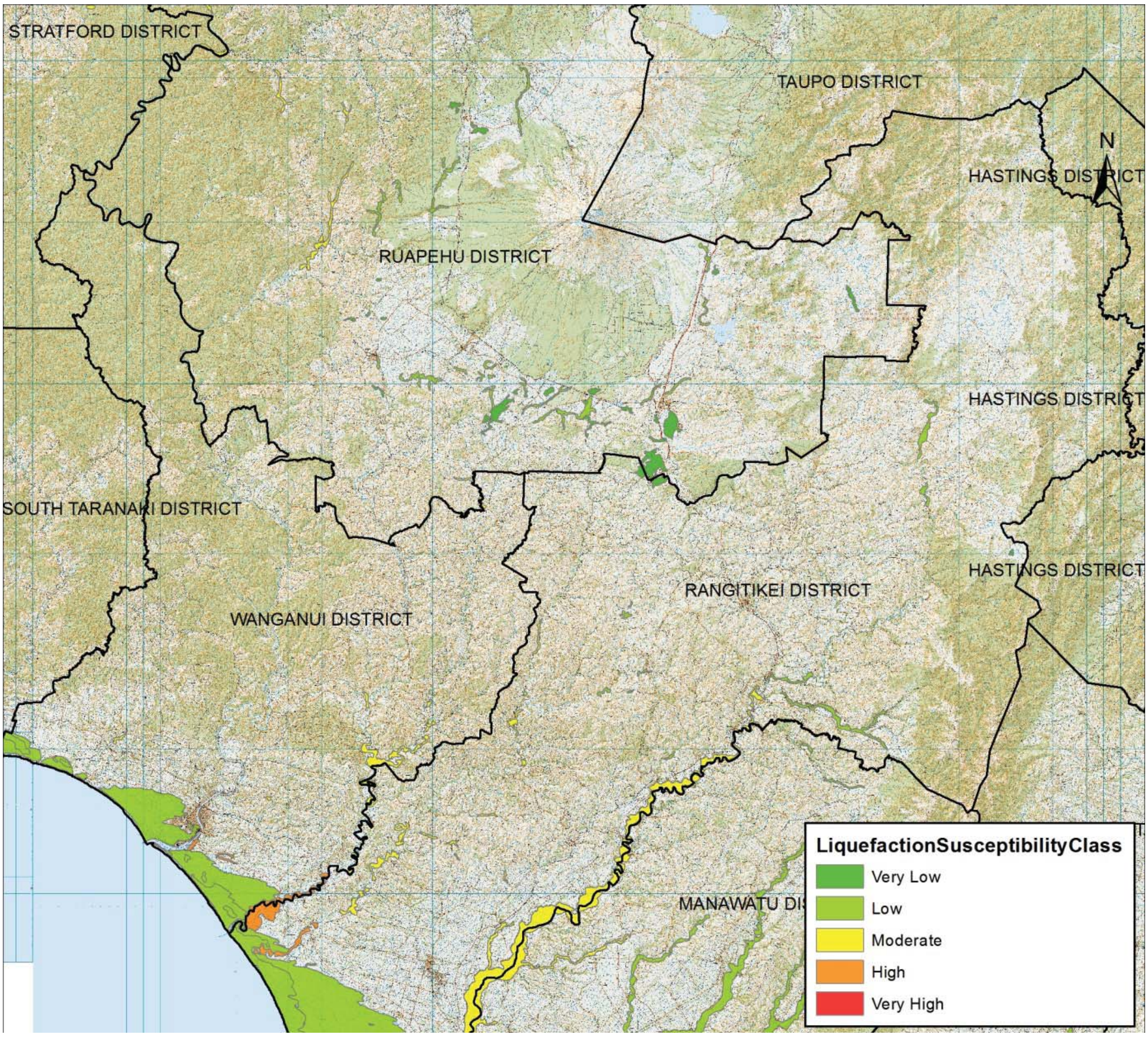


Figure 6 Liquefaction hazard map for Rangitikei District and Wanganui District.

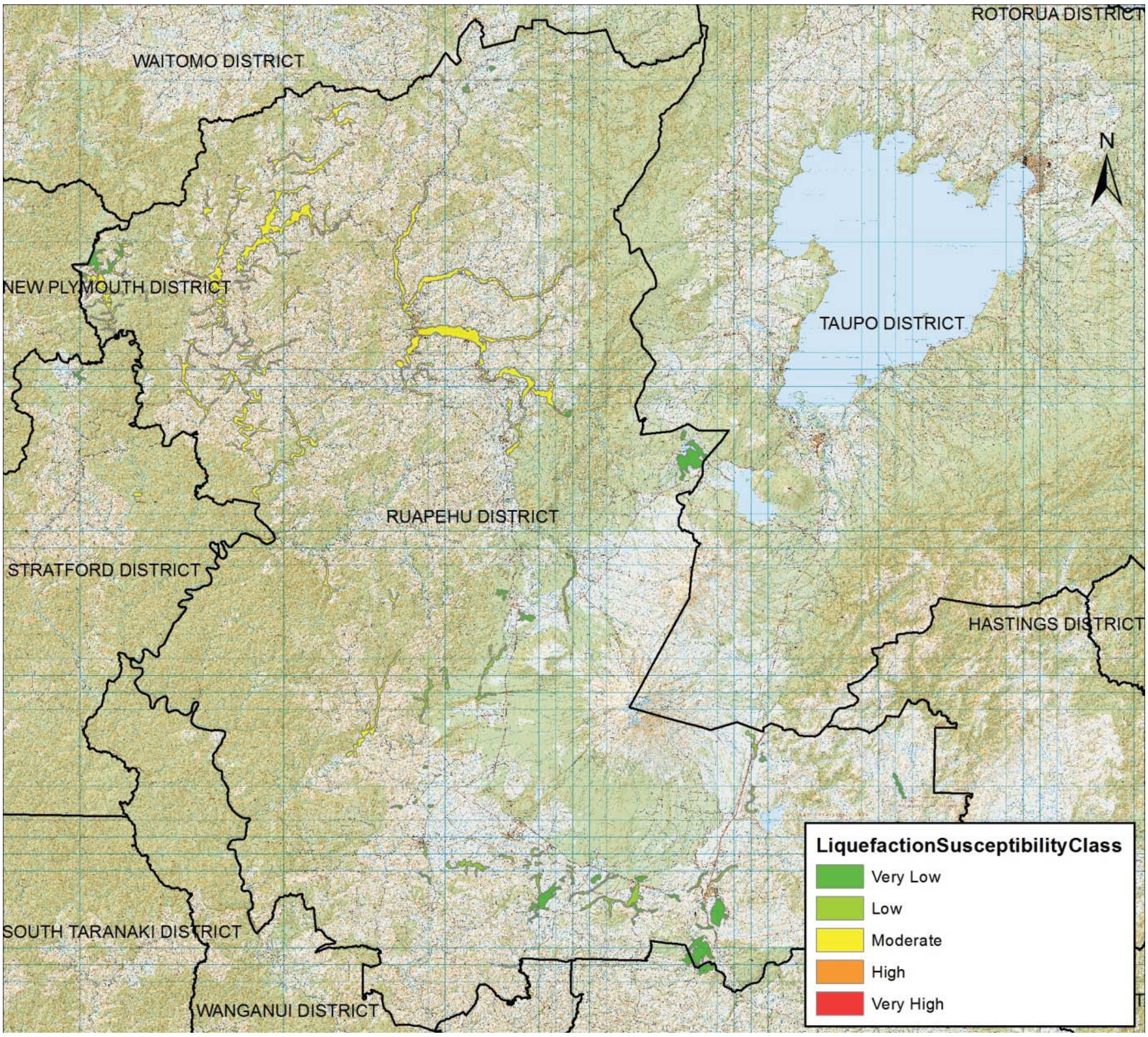


Figure 7 Liquefaction hazard map for Ruapehu District.

4.0 DIGITISING OF EXISTING LANDSLIDE INFORMATION

Dellow and Dymond (2008) presented a map that included 2159 GIS polygons for pre-existing landslides in the Horizons Region (their Figure 1, reproduced in Figure 8). These large, pre-existing landslides (or the remains of a landslide) can often be identified in the landscape from geomorphic features.

For the Horizons region, pre-existing landslides have been identified by examining vertical aerial photographs and plotting the landslides observed onto NZMS 260 1:50,000 topographic maps. The landslides drawn on these maps have then been digitised to provide a dataset of polygons representing the boundaries of large pre-existing landslides. This data has not been field checked.

The 2159 landslide polygons identified in the Horizons region have been provided as a digital dataset accompanying this report. Accompanying the digital data is a metadata statement and a data dictionary.

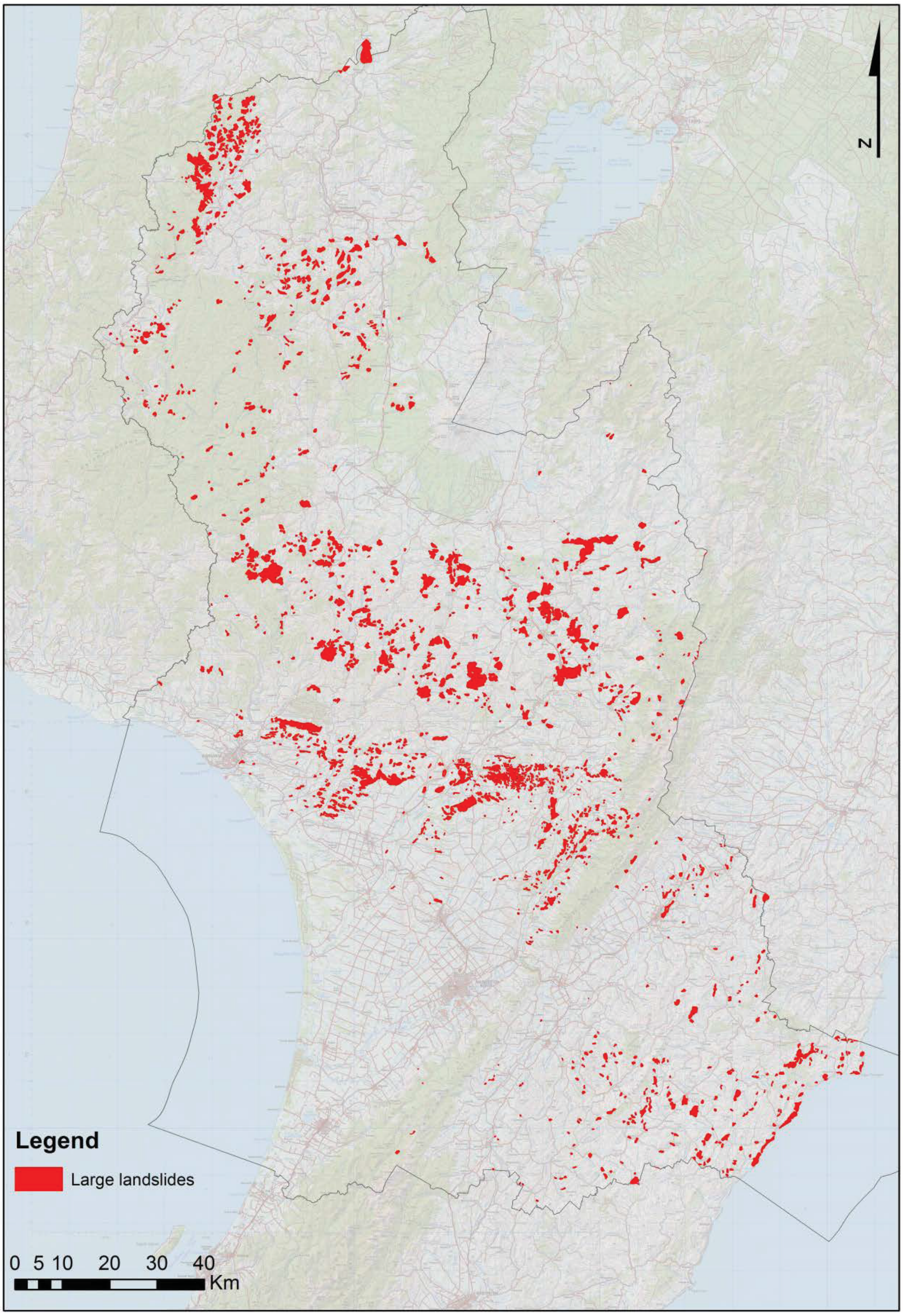


Figure 8 Large landslides mapped in the Horizons Region (Dellow and Dymond, 2008).

5.0 VOLCANIC HAZARD MAPPING UPDATES

5.1 INTRODUCTION

The Manawatu-Wanganui Region is unique in that it flanks and includes a portion of the Taupo Volcanic Zone (home to many active volcanoes) and lies downwind of another volcanic complex, Taranaki. This relative positioning confirms there is an exposure to volcanic hazards. Aspects of volcanic hazards and the relationship to lifelines have been covered by Hodgson and Houghton (1995), Horizons (2005) and Morris (2014).

5.2 ACTIVE VOLCANIC CENTRES

There are three primary volcanic centres that could affect the Manawatu-Wanganui Region; Tongariro National Park volcanoes (Ruapehu, Ngauruhoe and Te Maari), Taupo Volcanic Centre and Taranaki volcano (Figure 9). Each of these has varying styles of eruption, at varying intervals with a large range of sizes involved. As a consequence the impacts of volcanic activity will be variable in the Region.

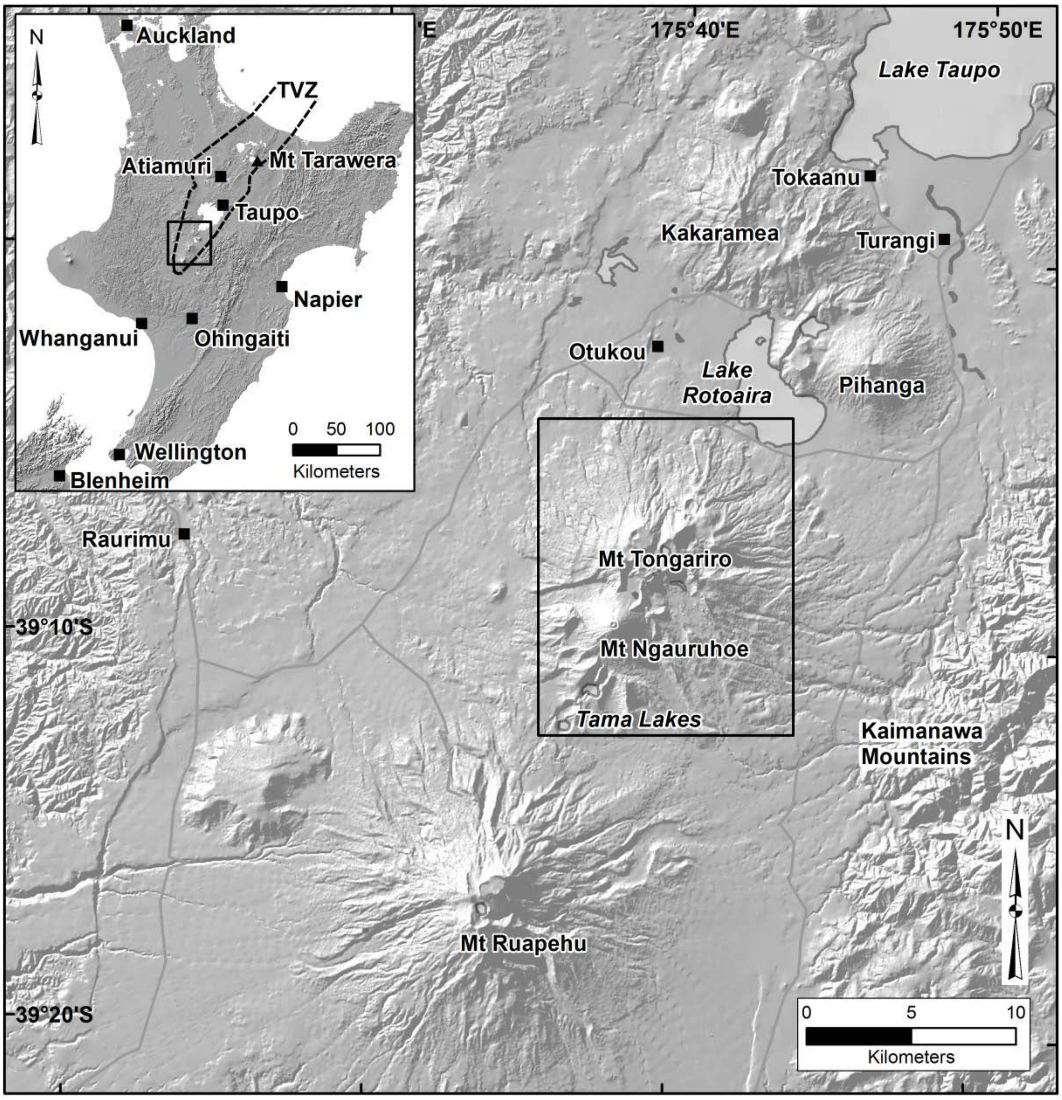


Figure 9 Volcanic centres with the potential to affect the Horizons Region during eruptive episodes.

5.2.1 Taupo Volcanic Centre

Taupo Volcanic Centre is one of two active caldera volcanoes in the Taupo Volcanic Zone (Leonard et al., 2010). Okataina lies to the north and Taupo to the south. Taupo Volcanic Centre (TVC) is used to encompass the eruptive vents that have been recognised in the Taupo area. Activity has been recognised for at least 200,000 years, however to be consistent with the other volcanic centres discussed in this project only the last 27,000 years are considered. In that period 28 eruptions are recognised (Wilson, 1993, Leonard et al., 2010). Eruption volumes from TVC show wide variations, ranging from 0.01 to 45 km^3. Four of these eruptions have had volumes larger than 1 km^3. The latest eruption in the sequence is also the largest by a considerable margin at 45 km^3, while the other three are 16, 4.8 and 1.4 km^3 respectively. A further complication is that eruptions have occurred from a north east trending vent zone about 20 km long along the eastern side of the modern lake. This gives the rather distorted view of the typical Taupo eruption.

Eruptions greater than 1 km^3 therefore occur about once every 6700 years, while eruptions greater than 0.5 km^3 (including those over 1 km^3) number 8 in the last 27,000 years; therefore occur about once in about 3400 years. There are 14 eruptions greater than 0.2 km^3; hence they occur about once in 1900 years, but range in size from 0.2 to 45 km^3. The 14 eruptions smaller than 0.2 km^3 from Taupo volcano average 0.07 km^3 in size and these range in size from 0.01 to 0.15 km^3. Not being any larger than the moderate to large eruptions from Taranaki or Tongariro Volcanic Centre. The average period between known eruptions is about 960 years.

For planning purposes the T = 2500 year eruption would be in the range 0.2 to 0.5 km^3 while the T = 500 year event would be in the range 0.1 to 0.2 km^3 (Figure 16). Near source eruption impacts will be restricted to 5-15 km, hence not directly impact the Manawatu-Wanganui Region. Depending on wind direction, eruption column height and volume, ashfall could be experienced in the Region. An eruption of 0.5 km^3 (largest T = 2500) would produce ashfall up to about 5 mm thick, while an eruption of 0.2 km^3 (largest T = 500) would produce ashfall up to about 100 mm, but only if the weather conditions are such that the wind direction is towards the Horizons Region.

5.2.2 Taranaki Volcano

Mt. Taranaki (Egmont volcano) is a basaltic to andesitic-dacitic volcano that rises in near perfect conical form to 2,518 m above sea level (Figure 10). It is the western most expression of current volcanic activity within New Zealand. Although currently in a state of quiescence, recent studies (Alloway et al., 1995; Turner et al., 2008, 2009, 2011) have shown it to have been very active. Moderate to large eruptions are interspersed with relatively smaller scale explosive and lava extrusion episodes. Turner et al. (2008) noted that there appears to be no significant relationship between eruption size and the following (or prior) repose period. Approximately 15% of the estimated volumes are greater than 0.1 km^3, with the largest at 0.94 km^3.

The date of the most recent eruption from Mt. Taranaki is uncertain. Druce (1966) used dendrochronology to date a local ash within the soil profile at AD 1755. Paleovegetation studies and pollen evidence (Lees and Neall, 1993) indicated an event was around AD 1860. Recent stratigraphic and geochemical evidence confirms that two post AD 1755 events occurred at c. AD 1800 and 1854 (Platz et al., 2007).

Turner et al. (2009) have merged all available data sets to build an eruptive record for the last 10,000 years. They document 138 eruptions that have produced ashfall deposits that are preserved on and about the volcano, ranging in age from between 96 and 10150 year BP. This gives a very good indication of the size and style of eruption that are likely to impact the Manawatu-Wanganui Region from a Taranaki source. The largest event has an eruptive volume of 0.94 km^3, while only 15% have volumes greater than 0.1 km^3. This eruption size data provides constraints on the size of expected eruptions and therefore the likely impacts. Green et al. (2016) have applied a statistical approach to estimate volumes based on the sparse geological data set. They conclude the geological record will include all eruptions greater than 0.1 km^3. From this they derive a dataset that indicates about 85% of the eruption volumes range from 0.02 to 0.26 km^3.

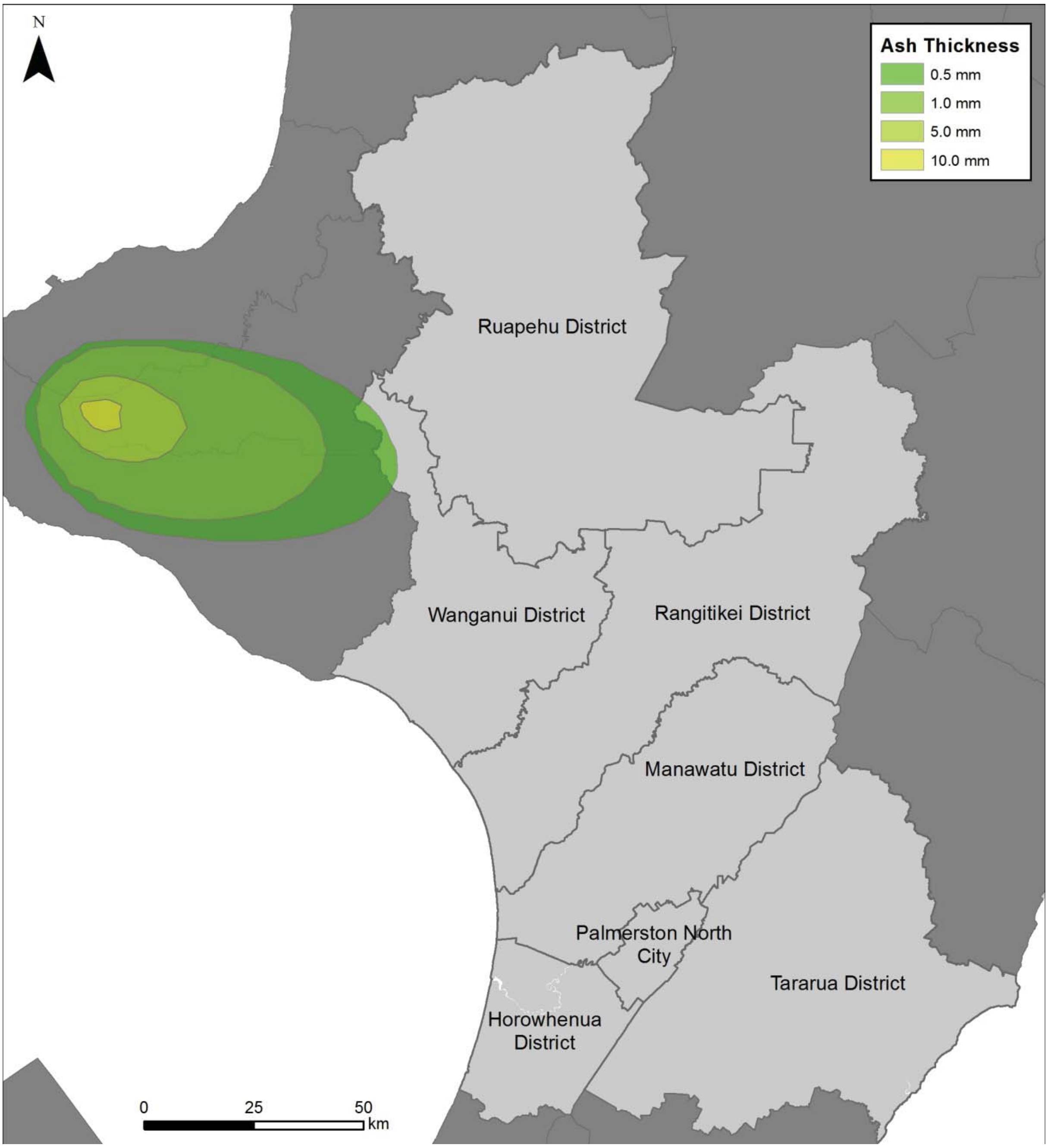


Figure 10 Ashfall depths for a scenario where approximately 0.1 km^2 of material is erupted from Mt Taranaki. In the Horizons Region maximum ashfall depths are expected to be less than 0.5 mm and only affect a small area of northern Wanganui District.

In summary the maximum credible eruption would be of the order of 1 km^3 of erupted material. As only 15% of the eruptions in the last 10,000 years are greater than 0.1 km^3 it is very likely the next events will be less than that. The sizes of the events less than 0.1 km^3 are poorly known due the poor preservation of the deposits. The statistical analysis of Green et al. (2016) indicates they range in size from 0.02 to 0.26 km^3. From a planning perspective it is recommended that the likely 'normal' eruption is taken as one of about 0.05 km^3. The average time between eruptions in the last 10,000 years is about 70 years and can be taken as the T = 100 event (Figure 15). While the larger 'likely' size is greater than 0.1, but less than 0.25 km^3 and could be considered to represent the T = 500 event (Figure 10 and Figure 16). Figure 11 shows the T = 1000 event. The T = 2500 event is closer to the maximum credible event of about 1 km^3 (Figure 12 and Figure 17).

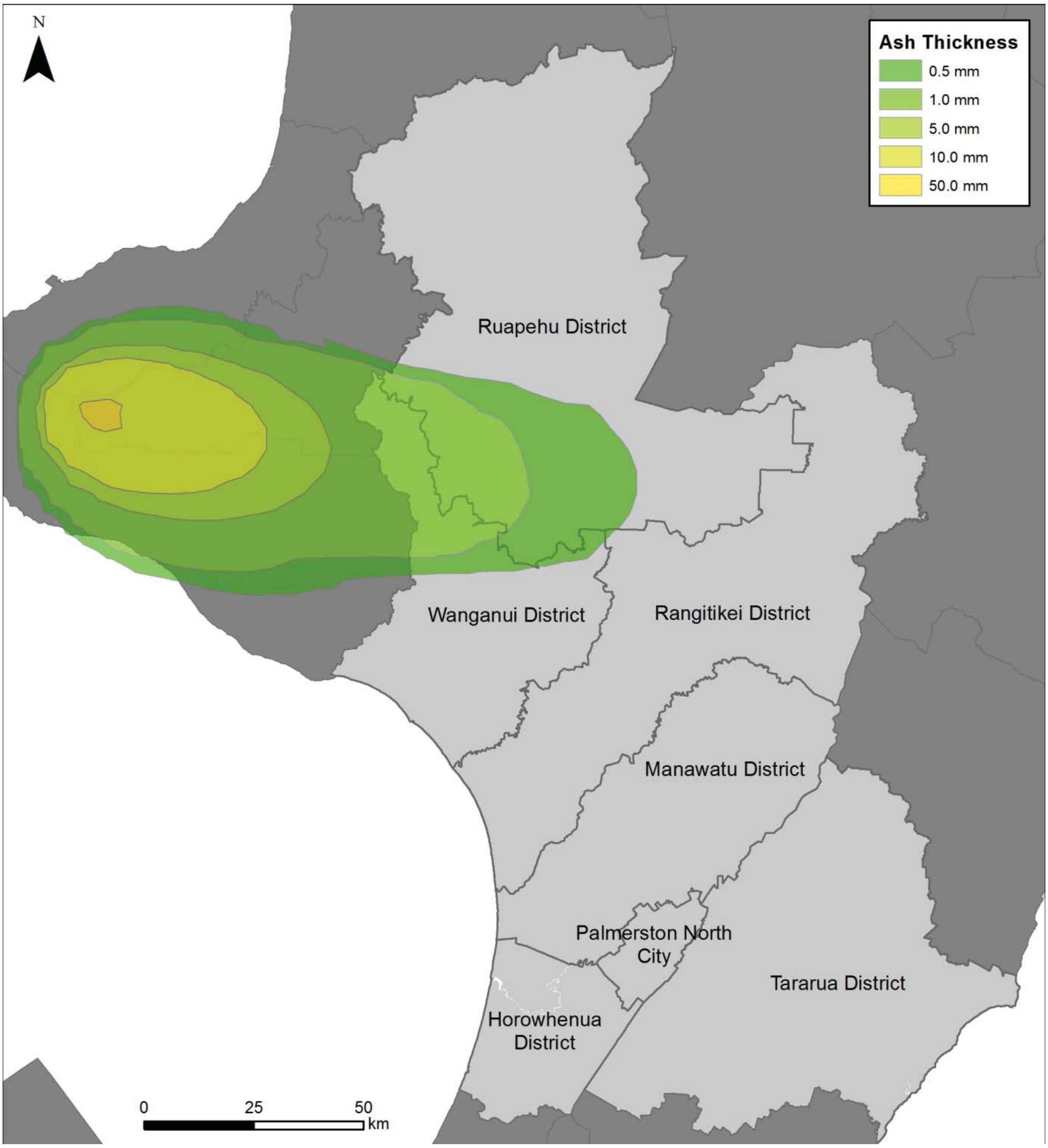


Figure 11 Ashfall depths for a scenario where approximately 0.5 km^2 of material is erupted from Mt Taranaki. In the Horizons Region maximum ashfall depths are expected to be less than 1.0 mm and only affect a small area of northern Wanganui District and southern parts of Ruapehu District.

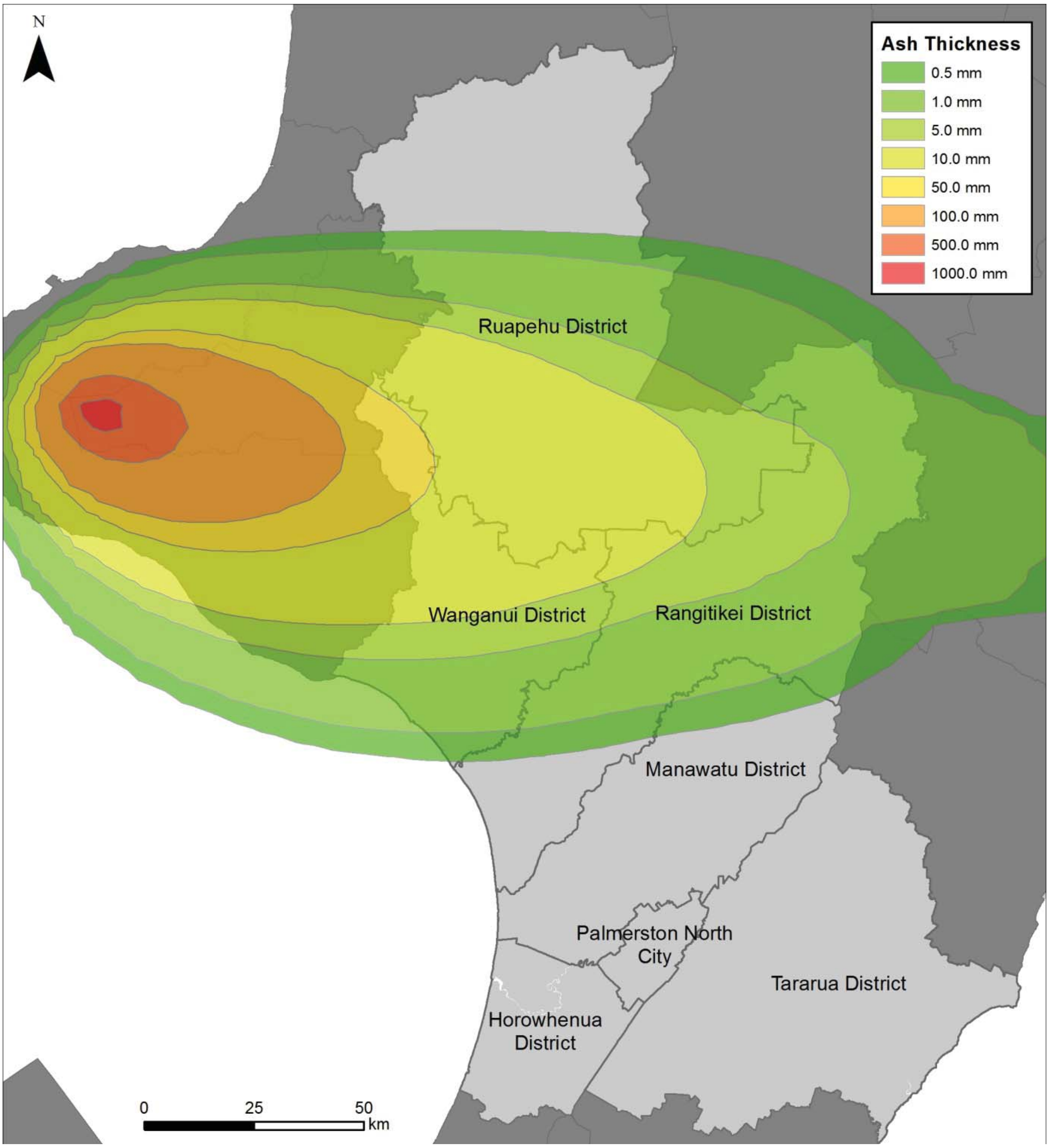


Figure 12 Ashfall depths for the maximum credible event for Mt Taranaki where approximately 1 km^2 of material is erupted. In the Horizons Region maximum ashfall depths are expected to be 50 mm. Most of the northern half of the Horizons Region will be affected by ashfall ranging from 0.1 to 50 mm in thickness.

5.2.3 Tongariro National Park Volcanoes

Two volcanic complexes are present in Tongariro National Park, Ruapehu in the south and Tongariro in the north. Mounts Tongariro and Ruapehu are part of the larger Tongariro Volcanic Centre (TgVC) and are positioned in the southern most portion of the Taupo Volcanic Zone (Cole, 1990; Hobden et al., 2002; Figure 9). TgVC, as defined by Cole (1990), includes the four large andesite volcanoes - Kakaramea, Pihanga, Mt. Tongariro and Mt. Ruapehu.

Only two, Mts. Ruapehu and Tongariro have been active historically and through the Holocene (Hobden et al., 1999; Moebis et al., 2011; Scott, 2013; Scott and Potter, 2014).

Mt. Ruapehu is the largest TgVC edifice (Hackett and Houghton, 1989; Gamble et al., 2003) and is surrounded by an extensive ring plain formed by collapse events and lahars (Cronin and Neall, 1997). Historical Ruapehu eruptions have always been through the summit Crater Lake vent where c.10 million m^3 of water is held in the lake (Scott, 2013). Donoghue et al. (1997) inferred that the Crater Lake has existed for at least 3000 cal. years, and earlier vents are identified north of it (Hackett and Houghton, 1989). Petrological studies of Ruapehu lavas show that they are mantle-derived volcanic arc magmas that have interacted with the lower crust before migrating to the surface through a complex plumbing system containing several small individual magma storage bodies and dyke-systems. The younger tephra producing eruptions have been summarised by Donoghue et al. (1995), Donoghue et al. (1997), (2007) and Moebis et al. (2011). Historic activity is catalogued by Scott (2013).

Mt. Tongariro is a less distinctive complex than Mt. Ruapehu, comprising more than 17 overlapping vents, which collectively cover an area of 5 by 13 km (Hobden et al., 1999). Mt Tongariro has erupted a variety of lavas including andesites, basaltic andesites, and dacite within several recognised eruption episodes (210-220 ka, 130-70 ka and 25 ka to present; Hobden et al., 2002; Price et al., 2005. Topping (1973, 1974) and Hobden (1997) have developed the volcano stratigraphy and a model of magma petrogenesis for the older activity. Mt. Ngauruhoe, the frequently active cone is named separately (Scott and Potter 2014), however it is geologically considered part of Mt. Tongariro and forms its highest peak (Figure 9). The Ngauruhoe lava is considered to have a different source of magma to other recently active Tongariro vents based on geochemical analysis (Moebis et al., 2011). Underlying Mt. Tongariro is a substantial vapour-dominated geothermal system that is capped by a thick condensate layer (Walsh et al., 1998). Surface manifestations at Red Crater, Central Crater, Upper and Lower Te Maari craters, and Ketetahi Hot Springs are linked to this geothermal system.

Topping (1974) developed a model of the tephra stratigraphy for the Tongariro Volcanic Centre. Donoghue et al. (1995), Donoghue et al. (1997, 2007) developed one for Ruapehu. Eruptions in the on-going (long-term) eruptive episode at Tongariro have occurred from Ngauruhoe, Upper Te Maari crater, Red Crater, Blue Lake, and Tama Lakes (Topping, 1973, 1974; Nairn et al., 1998; Moebis et al., 2011). These have been expanded on by Moebis et al. (2011) who investigated the tephra stratigraphy of TgVC. That study has identified 205 discrete tephra deposits from Ruapehu, Ngauruhoe and Red Crater in the last 12,000 years. 127 are assigned to Ngauruhoe, while 16 eruptions have occurred from Red Crater in the last 300 years, and 62 are from Mt. Ruapehu. Age control shows the eruptions started at Ngauruhoe about 7000 years, old than previously thought. The activity of Mt. Ngauruhoe is characterised by frequent eruptions with small volumes (< 0.1 km^3) implying eruption of small and short-lived magma batches (Hobden et al., 1999). Red Carter activity appears to be a similar size or smaller.

Historic eruptions have occurred from Ruapehu, Ngauruhoe, Red Crater and Te Maari (Gregg et al., 1960; Cole and Nairn, 1975; Scott, 2013; Scott and Potter, 2014). Activity at Ruapehu has been characterised by many small eruptions through the Crater Lake. The larger produce lahars and about once every 25-30 years the lake is removed and explosive ash eruptions occur (Scott, 2013). Ngauruhoe has been characterised by explosive activity and occasionally lava flows have occurred (1870, 1949, and 1954). Some of the eruptive episodes producing explosive activity have been long lasting (months to years; Gregg et al., 1960). The stronger periods of explosive activity have also produced pyroclastic density currents (PDCs) down the flanks of the cone. PDCs are a form of volcanic avalanche. Historic eruptions from Te Maari and Red Crater have occurred, all been small with limited duration or ash production.

The studies of the tephra stratigraphy provide an insight into the longer term eruptive history from the Tongariro Volcanic Centre (Topping, 1973, 1974; Donoghue et al., 1995, 1997, 2007). Donoghue et al. (1997) estimate the volumes for the larger eruptions in the last 1850 years are less than 0.1 km^3. In total they recognised 18 eruptive episodes. The work of Moebis et al. (2011) has identified 205 eruptions in the last 12,000 years from Ruapehu, Ngauruhoe and Red Crater. This work has established information on frequency and source, but size of eruption data is still weak. Although not stated but it is implied that none of the 205 eruptions identified by Moebis et al. (2001) are larger than those identified in the Tufa Trig Formation (Donoghue et al., 1997). Donoghue et al. (1997) estimate the volumes for the larger eruptions in the last 1850 years are less than 0.1 km^3. This implies the largest eruptions from the TgVC on the last 12000 years are less than 0.1 km^3. Based on this observation the maximum credible event would be an eruption of about 0.1 km^3.

In terms of the eruption size and return periods this is difficult to assess as the number of events is well known but the size isn't. The maximum credible event is of the order 0.1 km^3 and this could be assigned as the T = 2500 year event. Nairn et al. (1998) estimated the size of the larger eruptions in October 1995 as 0.01 and 0.02 km^3 (Figure 16). The total ash from the 1995-1996 eruptive episode is of the order 0.04 km^3 and this size eruption occurs about once every 50 years (Scott 2013). Hence an eruption of this size can be considered as the T=100 year event (Figure 15). The T = 500 year event is more difficult to assess and is assigned as about 0.06 km^3 as a guide for planning.

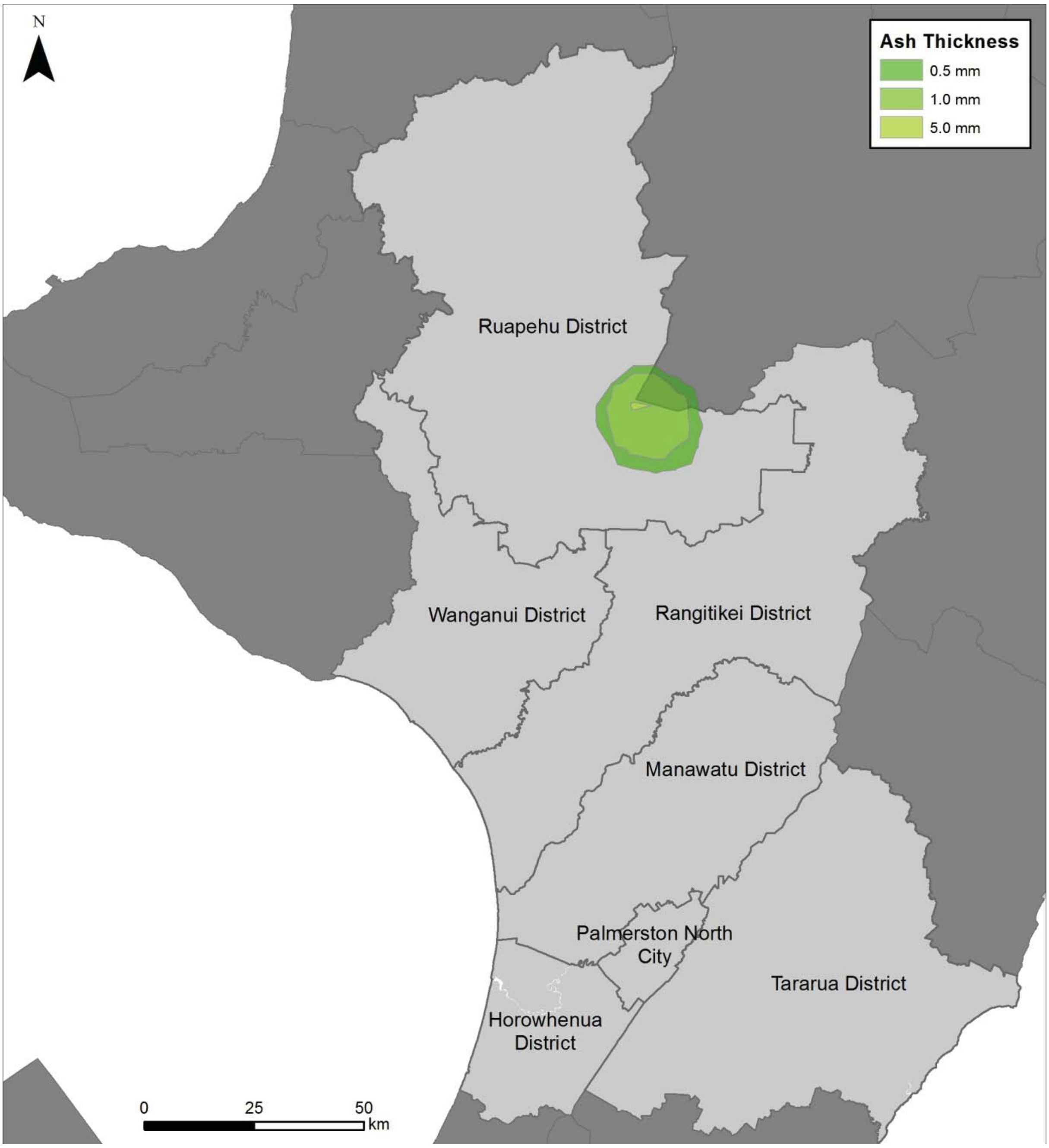


Figure 13 Ashfall depths for a scenario where approximately 0.01 km^2 of material is erupted from Mt Ruapehu. In the Horizons Region maximum ashfall depths are expected to be less than 5.0 mm and only affect a small area of Ruapehu District.

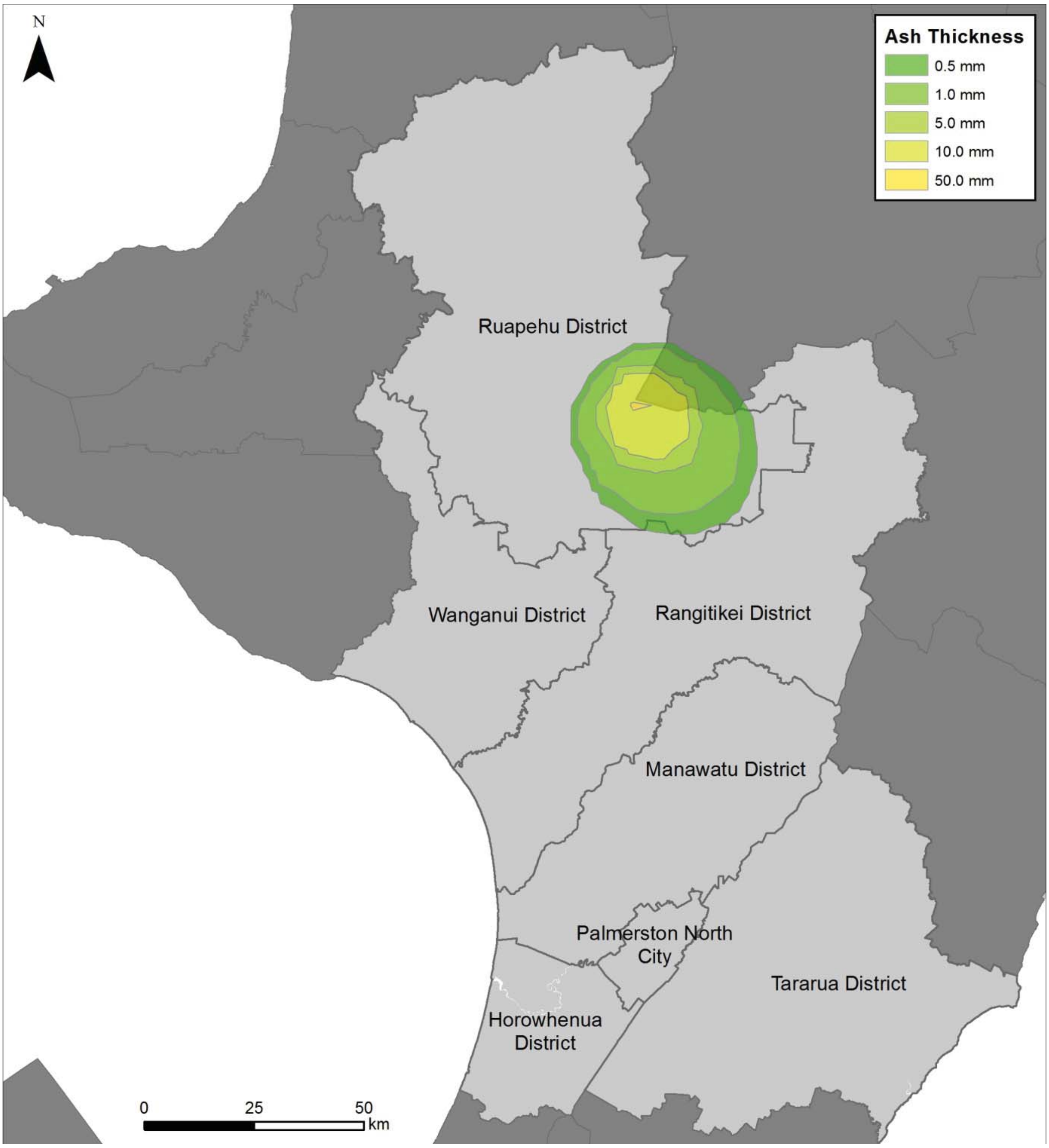


Figure 14 Ashfall depths for a maximum credible scenario where approximately 0.1 km^2 of material is erupted from Mt Ruapehu. In the Horizons Region maximum ashfall depths are expected to be less than 50.0 mm and only affect a small area of Ruapehu District.

5.3 ASHFALL THICKNESS

Many parameters contribute to the estimation of ashfall thickness. These include the eruption source parameters like mass ejected, the rate of ejection, the duration, the elevation of the vent and the height attained above the vent. Also contributing is the wind field (velocity and elevation).

Supplied with this report are modelled ashfall thicknesses for various return periods from the three volcanic centres that could impact the Manawatu-Wanganui Region (Figure 15, Figure 16 and Figure 17). The return periods vary from volcano to volcano and are matched to eruption histories from each of the volcanic centres. They are presented as circles around the volcano as on the day the ash could be distributed into any sector, depending on the weather conditions. These give guidance as to expected thickness. Also included are five 'scenario' ashfalls (Figure 10 - Figure 14 above). Two of the scenarios are from Mt Ruapehu for eruptions of 0.01 km^3 and 0.001 km^3 and three from Taranaki for eruptions of 0.2 km^3, 0.5 km^3 and 1.0 km^3.

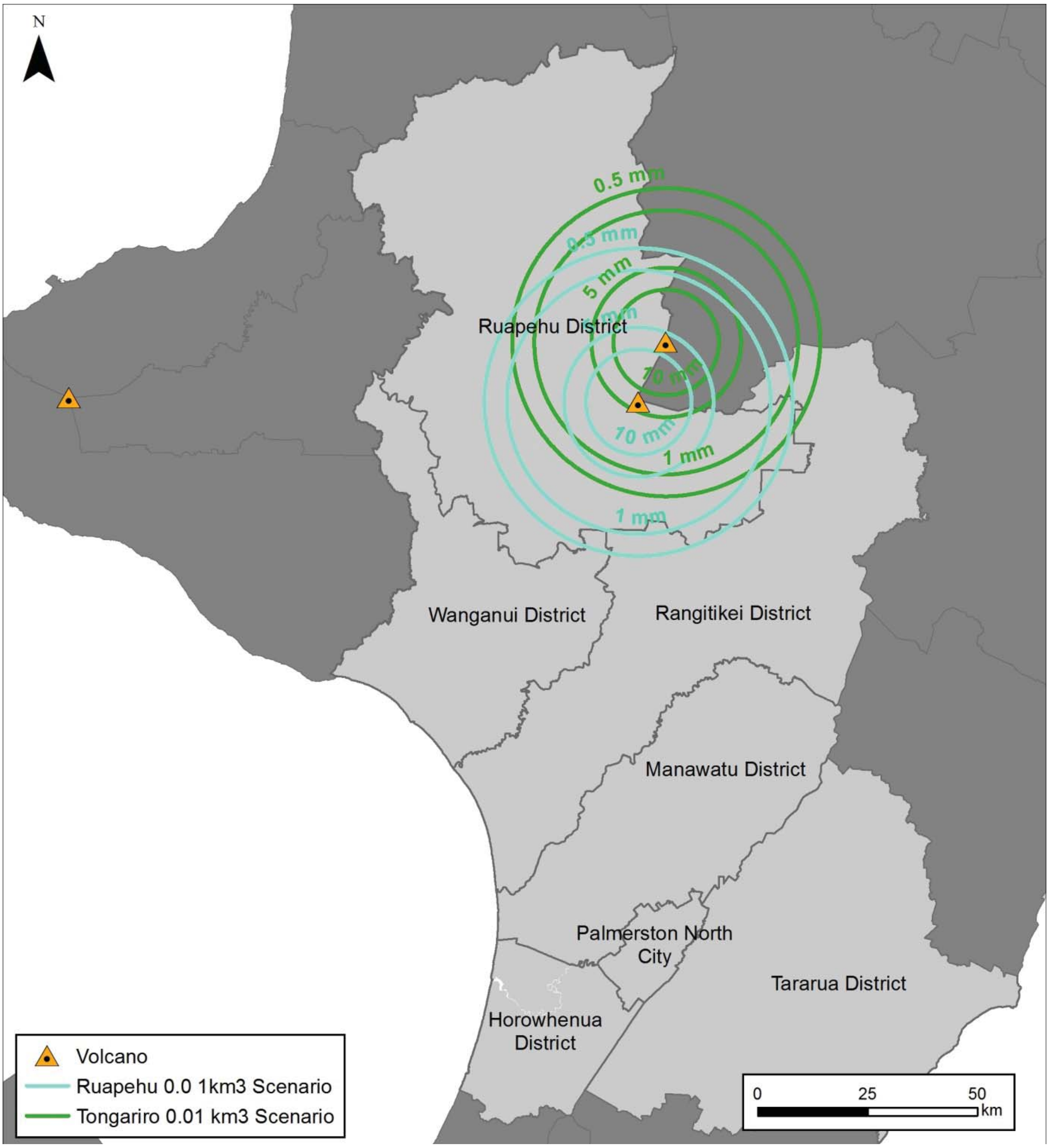


Figure 15 The 0.01 km^3 eruption volume (representative of the 100 year return period ashfall event) for Tongariro and Ruapehu volcanoes. Under most conditions the impacts are limited to Ruapehu District.

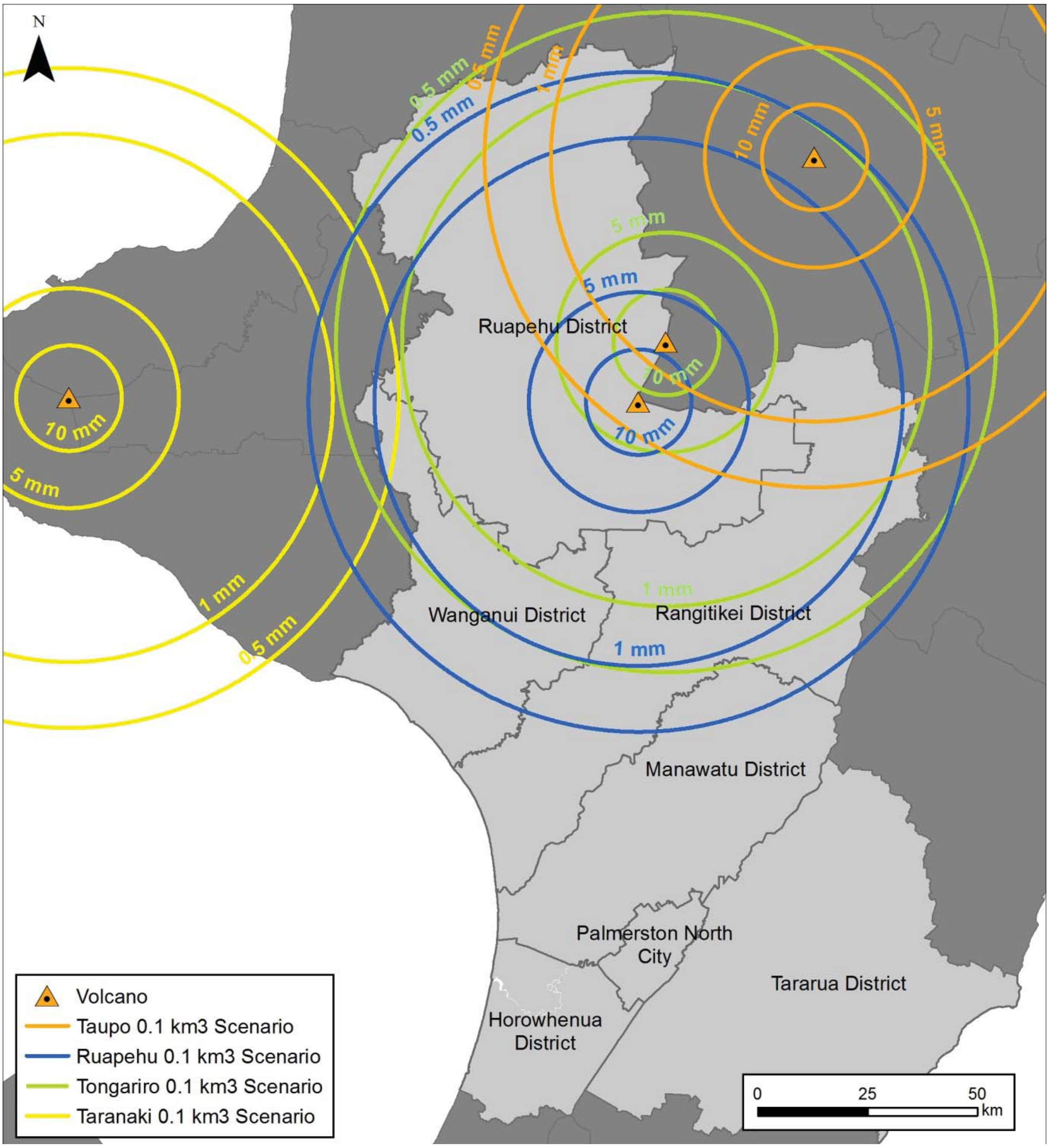


Figure 16 Ashfall contours for eruption volumes of 0.1 km^3 for Tongariro, Ruapehu, Taupo and Taranaki volcanoes. For Tongariro and Ruapehu volcanoes this is equivalent to the 2500 year return period event and is also the likely maximum credible event (MCE) for these volcanoes. For Mt Taranaki and Taupo this event is equivalent to the 500 year return period event and only has a very minor impact on the Horizons Region under favourable weather conditions. Under most conditions the major impacts from Ruapehu and Tongariro are at the 2500 year return period and are limited to Ruapehu District with some thin ashfall occurring in Wanganui and Rangitikei Districts when weather conditions are conducive.

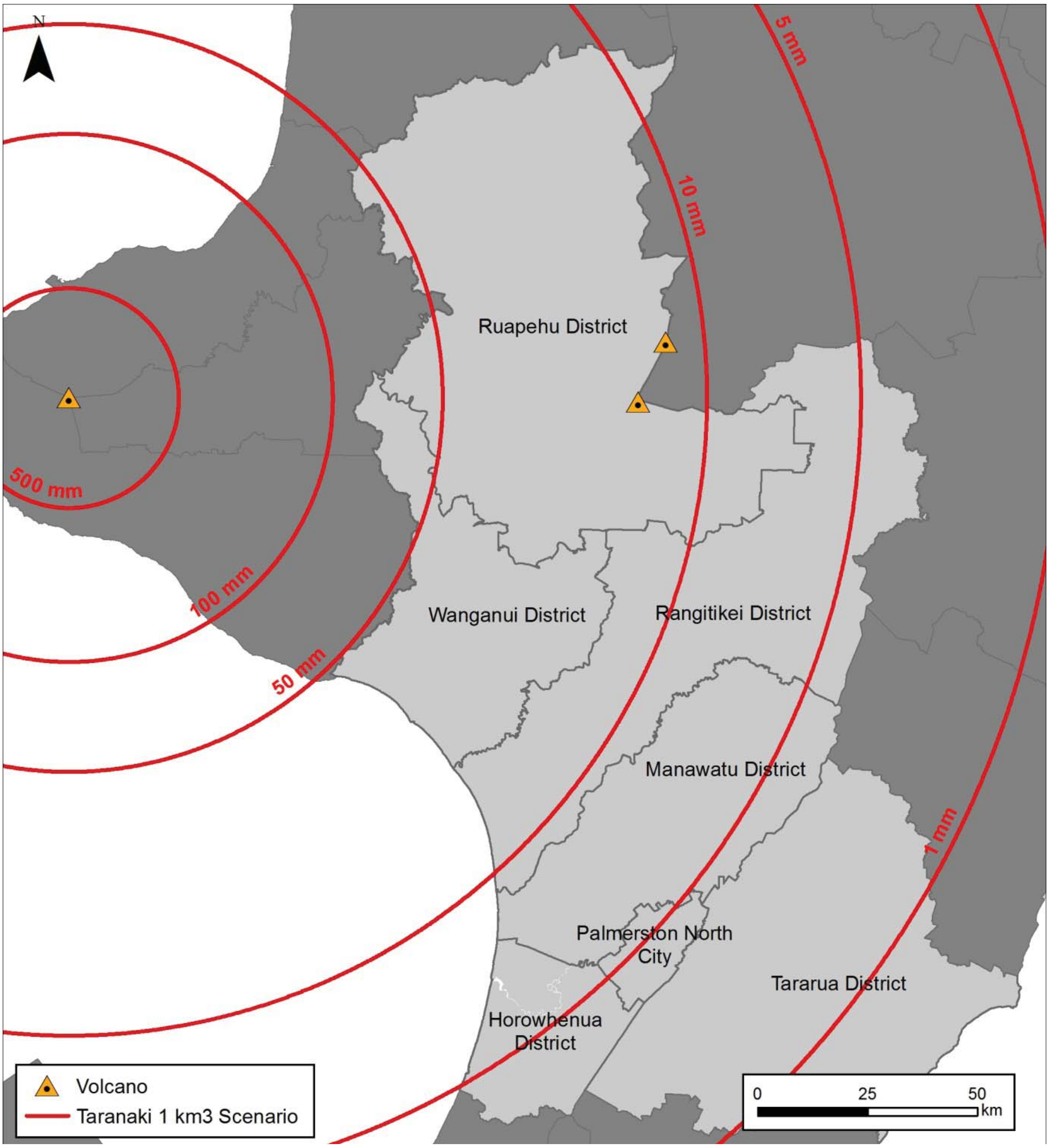


Figure 17 Ashfall contours for an eruption volume of 1.0 km^3 from Mt Taranaki. For Mt Taranaki this is equivalent to the 2500 year return period event and is also the likely maximum credible event (MCE) for this volcano. Under westerly wind conditions the impacts from the 2500 year return period eruption from Mt Taranaki will impact all of the Horizons Region to some degree with ashfall thicknesses potentially varying from 0.5 to 100 mm.

5.4 ASHFALL IMPACTS

Wilson et al. (2014) have summarised the impacts of volcanic ash on infrastructure. They review and documented disruption and physical damage to critical infrastructure elements resulting from volcanic hazards (tephra fall, pyroclastic density currents, lava flows and lahars). This is based on documentation and analysis of eruptions in the last 100 years. They report of common trends and vulnerabilities, providing an insight to the exposure of critical infrastructure like energy production and distribution, water supply, waste water, communications, transport and airports.

6.0 SUMMARY

NZS1170.5 site sub-soil class has been inferred from the 1:250,000 Geological Map of New Zealand (Heron, 2015) and presented as a map and GIS file. The site sub-soil class information has been combined with the National Seismic Hazard Model (Stirling et al., 2012) to produce a 0.05° by 0.05° grid of PGAs that take into account the estimated site sub-soil class for return periods of 500, 1000 and 2500 years.

A regional scale liquefaction hazard map has been compiled from consideration of the latest 1:250,000 Geological map of New Zealand and accounts of liquefaction from historical earthquakes. The liquefaction hazard map gives a five-level classification of liquefaction hazard identifying areas as having very high, high, moderate, low or no liquefaction hazard. The map is suitable for assessing where further investigation of liquefaction might be required as part of a package of work to improve the resiliency of assets and infrastructure.

Landslide data shown on Figure 1 of Dellow and Dymond (2008) has been extracted and supplied in digital format to Horizons Regional Council.

Five scenario eruption events have also been modelled. Eruption scenarios of 0.1 km^3, 0.5 km^3 and a maximum credible event (MCE) of 1 km^3 for Mt Taranaki, and a 0.01 km^3 and an MCE of 0.1 km^3 for Mt Ruapehu have been produced.

Volcanic ashfall maps for T = 100, 500 and 2500 year return periods for three volcanic centres (Mt Taranaki, Tongariro National Park volcanoes (Ruapehu, Ngauruhoe and Te Maari) and the Taupo Volcanic Centre).

Metadata accompanies the digital datasets supplied as part of this contract.

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