2 Natural hazards in the Wairarapa

2.1 INTRODUCTION

This chapter brings together scientific and historical information on the natural hazards potentially able to harm engineering lifelines in the Wairarapa. The hazards have been grouped into sections covering earthquake, tsunami, meteorological, flooding, landslides, wildfire and volcanic ash hazards. Earthquake and meteorological hazards both provide triggering mechanisms for several separate hazards, and have been further divided. For example, earthquake hazards cover ground shaking, liquefaction, fault rupture and ground settlement. Flooding hazards are treated separately from meteorological hazards as they are a significant hazard in their own right. Both landslides and tsunami can be triggered by several mechanisms, so are also treated separately.

Each individual hazard has been described as follows:

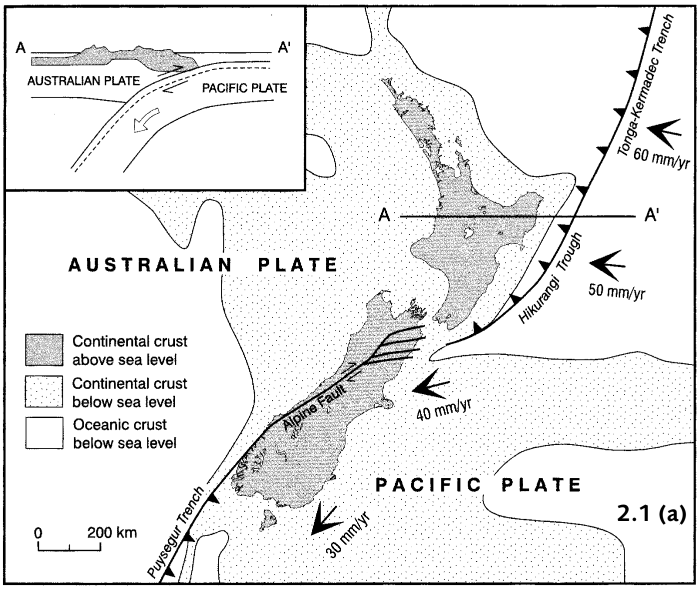
- *Hazard definition* defines and summarises the nature of the hazard. This includes a discussion of the general causes and effects of the hazard;
- *Wairarapa context* discusses the hazard as it relates to the Wairarapa. It covers the geological and historical history of the occurrence of the hazard in the Wairarapa. Scientific reports specifically studying the hazard in the Wairarapa are also summarised;
- *Specific example* where a particular example further illustrates the effects of the hazard in the Wairarapa, a highlighted section is provided.
- *Further reading* directs the reader to the sources referenced in the report, to obtain more detail on both the hazard and its Wairarapa context. To view copies of the references and reports mentioned, contact the Wellington Regional Council's Wairarapa Hazards Section.

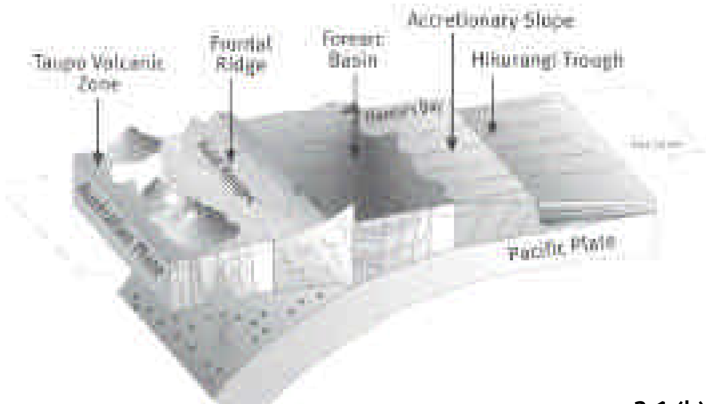
2.2 EARTHQUAKE HAZARDS

(1) Tectonic setting

Earthquakes are a common occurrence in the Wairarapa and throughout New Zealand, due to the country's location along an active tectonic plate boundary.

The Pacific Plate is sliding (subducting) underneath the Indo-Australian Plate (**Figure 2.1 a and b**). In the Wairarapa region, the Pacific Plate is moving, in a relative sense, towards the Australian Plate at a rate of 40-50 millimetres per year. This movement is occurring at an oblique angle. Strain and crustal deformation are concentrated along the boundary zones between these plates.





2.1 (b)

Figure 2.1 (a) Offshore from the Wairarapa, the Pacific Plate subducts (slides under) the Australian Plate. Source: Aitken (1999). **(b)** Geological structure of the North Island. The relative motion between the plates is absorbed through fault movements in the frontal ridge and forearc basins. There is no volcanic chain at the latitude of the Wairarapa. The Tararua/Rimutaka Ranges mark the edge of the frontal ridge. *Source: McConchie et al (2000).*

The Hikurangi Trough, 150 kilometres off the eastern Wairarapa Coast, represents the plate boundary. From the trough, the interface of the two plates dips under the North Island. It is approximately 25 kilometres deep under Wellington City.

Folding and faulting within the Wairarapa area is largely a result of the forces generated by the subduction process. The Wairarapa is made up of several northeast/southwest trending features including the eastern hills (frontal ridge), the Wairarapa Valley (forearc basin), the Tararua Ranges (axial ranges) and a series of faults.

The Wairarapa Fault bounds the eastern side of the Tararua Ranges. Numerous other active faults occur in the Wairarapa Valley and eastern hills. **Table 2.1** lists the known active faults in the Wairarapa along with their estimated segment length, return period, and probable magnitude. Active faults are defined as those which have moved in the past 100,000 years. The Masterton and Carterton faults are discussed in more detail later in this section.

Fault name	Length	Average period (years) return	Probable earthquake magnitude
Ohariu- south	25	3300	7.2
Ohariu - central	30	2000	7.1
Northern Ohariu	60	2000	7.3
Wellington – Hutt Valley	75	590	7.5
Wellington – Tararua	50	590	7.4
Wairarapa – 1855	105	1500	7.9
Wairarapa – Alfredton	20	670	7.1
Saunder Rd	35	3000	7.3
Mokonui	25	2000	7.0
Masterton*	15	1000	6.8
Carterton*	40	1000	7.0
Tinui	10	5000	6.6
Otaraia	45	10000	7.2
Dry River	75	5000	7.3
Mangatoetoe	12.5	10000	6.8
Ngapotiki	12	5000	6.8
Flat Point	25	10000	7.0
Palliser - north	55	2000	7.4
Palliser - south	50	2000	7.4
Mataikona	25	2700	7.1
Uruti	85	3300	7.5
Opouawe - Uruti	90	3300	7.5
Pahaoa - south	75	3300	7.4
Pahaoa - north	65	3300	7.4
Wairarapa Subduction	150	2500	8.2

Table 2.1 Characteristics of faults in or close to the Wairarapa region *(From Berryman et al 1998)*. * From Begg et al 2001.

FURTHER READING:

1. Aitken, J J, *Rocked and Ruptured: Geological Faults in New Zealand*, Reed Publishing (NZ), Auckland, 1999.
2. Aitken, J J, *Plate Tectonics for Curious Kiwis*, Institute of Geological and Nuclear Sciences, Wellington, 1996.
3. Begg, J G and Mazengarb, C, *Geology of the Wellington area*: sheets R27, R28, and part Q27, scale 1:50 000, Institute of Geological & Nuclear Sciences geological map 22, Lower Hutt, 1996.
4. Berryman, K, Villamor, P and Cheriton, M, *Probabilistic Earthquake Ground Motion Study of the Wairarapa Region. IGNS Client Report 1998/43621B.10*, Institute of Geological and Nuclear Sciences, Wellington, 1998.

(2) Ground shaking

HAZARD DEFINITION

Ground shaking is the ground vibration associated with an earthquake.

Vibrations produced by movement on a fault radiate out in all directions from the source. These vibrations are usually felt more strongly close to the source and weaken (attenuate) with distance. However, the strength of shaking also depends on the physical ground conditions, particularly for more distant earthquakes. Certain types of soils may dramatically increase the level and duration of shaking. For instance, buildings on soft, unconsolidated sediments, such as sands and gravels, usually shake more vigorously and for longer than buildings built on rock. The type and extent of damage is related to the strength of shaking, the duration of shaking, and the response of the structure to the type of ground shaking.

Earthquakes are usually recorded in two ways: by the Richter Magnitude (M) and by the Modified Mercalli Intensity (MMI) scales. The magnitude (M) is a measure of the total energy of the earthquake released at the source, derived from instrumental records. On the other hand, the MMI results from a field examination of the earthquake area. It is a way of grading the strength of an earthquake based upon its effects. The MMI scale, which measures from 1 to 12, describes the effects of an earthquake on people, man-made structures and on the earth's surface. A summary of the scale is presented in **Table 2.2**.

Ground shaking can be a threat to lifelines and critical facilities through structural failure, settlement of bridge approaches, buckling of poles and pylons and failure of buried services.

Modified Mercalli Intensity Scale (1996)	
MM I	Not felt except by a very few people.
MM II	Felt by people at rest or on the upper floors of buildings.
MM III	Felt indoors. Hanging objects may swing slightly; vibrations similar to passing of light trucks.
MM IV	Felt indoors, but generally not outside. Dishes rattle and the walls may creak.
MM V	Felt outside, sleepers wakened, some crockery broken, hanging pictures move.
MM VI	Generally felt by everyone, furniture moves, objects fall from shelves, plaster cracks, some minor chimney damage.
MM VII	General alarm, difficult to stand up, noticed by vehicle drivers. Damage to weak masonry buildings, small slides and rock-falls, unrestrained water cylinders may move and leak, windows crack.
MM VIII	General alarm approaching panic, steering vehicles difficult. Non-reinforced chimneys fall, stone and brick walls damaged, possibly collapse, some damage to non-ductile pipes. Moderate landslides, ground cracks, liquefaction.
MM IX	Panic, serious damage to masonry buildings, some destroyed, many partially collapse, ground cracks, some houses shift off their foundations, permanent damage to buildings and structures built before 1970, some damage to non-ductile pipes.
MM X	General panic, masonry buildings destroyed, wooden buildings seriously damaged, moderate damage to buildings and structures built after 1970, some damage to seismically designed buildings (built after 1980). Landslides widespread, rivers slop over banks, severe liquefaction.
MM XI	General panic, partial collapse of buildings and structures built after 1970, minor to moderate damage to seismically designed buildings (built after 1980). Broad ground cracks, soil slumps, great damage to most underground pipes, few buildings remain standing.
MM XII	General panic, objects thrown up in the air. Total destruction of most buildings, moderate damage to seismically designed buildings (built after 1980).

Table 2.2. Modified Mercalli Intensity Scale. Modified from Aitken (1999).

WAIRARAPA CONTEXT

Historical earthquakes

Since European arrival there have been several damaging earthquakes in the Wairarapa. In 1855 the Wairarapa Fault ruptured, causing New Zealand's largest recorded earthquake, with a magnitude of 8.1-8.2 on the Richter scale. MM X and MM IX shaking was felt over much of the Wairarapa (**Figure 2.2**). There was extensive damage in both Wellington and the Wairarapa. The Wairarapa Fault was displaced up to 6 metres vertically and 13 metres horizontally *(Grapes and Downes, 1997)*. The ground shaking caused extensive fissures in the Wairarapa, with many cracks over 2 metres long *(Grapes, 2000)*. Four people were reported killed in the Wairarapa when their whare collapsed on top of them. At Waihakeke in the Wairarapa Valley, Charles Borlase found that although his house was still standing, it was "…somewhat out of perpendicular" and that the roof had been "…entirely dislodged, and must be put on again before winter". *(Grapes, 2000)*. The damage to property would have been more widespread if the region had been more heavily populated at the time.

The 1904 Cape Turnagain Earthquake (M 6.7) caused shaking between MM VI and MM VIII throughout the Wairarapa. An earthquake in 1917 caused fallen chimneys, broken crockery, smashed windows, and cracked brickwork in Masterton. In Te Ore Ore, Wangaehu, Bideford, Taueru, and Tinui some buildings were destroyed and crockery and furniture destroyed *(Rogers 1996)*.

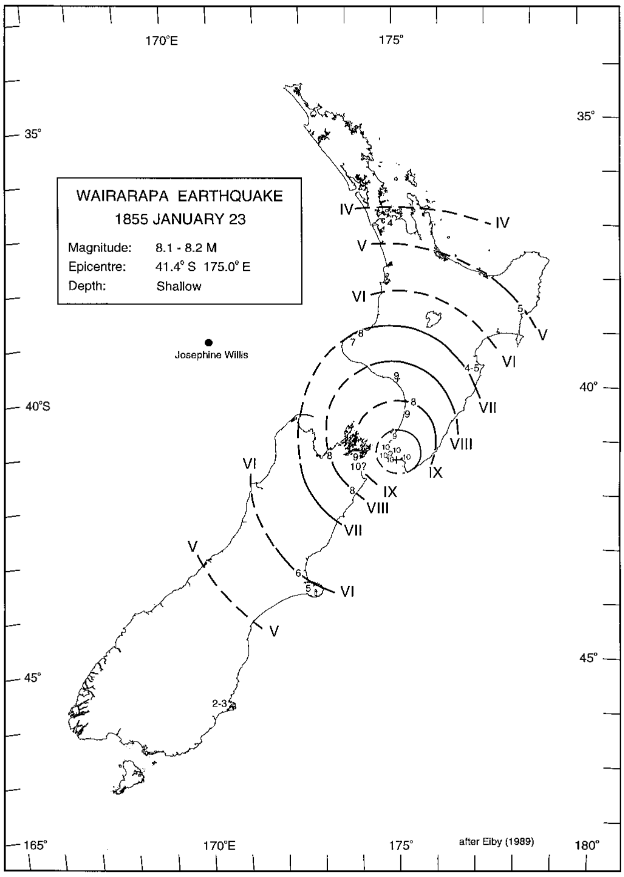


Figure 2.2. Isoseimals from the 1855 Wairarapa Earthquake. Source: Downes (1995).

The 1934 Pahiatua Earthquake (M 7.6 ~20 kilometres deep) is the fourth largest known to have occurred in New Zealand in the last 160 years *(Downes et al, 1999)*. It caused MM IX shaking as far south as Bideford. Most of the Wairarapa region, including the main centres of Masterton, Carterton, Greytown, Featherston and Martinborough, experienced MM VII shaking. Heavy chimney damage as well as damage to parapets and non-reinforced brick walls were reported. Lifelines affected in the Wairarapa included cracking of the road between Alfredton and Masterton and twisting of tracks on the Masterton – Woodville Railway. Electricity, telephone and water services in Pahiatua were disrupted. Heavy gales in the two days following the earthquake caused problems in electricity restoration.

However, the most damaging earthquakes to Wairarapa property both occurred in 1942. On June 24, a magnitude 7.2 earthquake 15 kilometres deep caused MMVIII ground shaking around Masterton and MMVII shaking through the rest of the Wairarapa *(Downes et al, 2001) (see* **Figure 2.5***)*. The damage was widespread throughout Masterton and the Wairarapa (see the local example below). The second earthquake, on August 2, was smaller, with a magnitude of 7.0, and deeper, at 43 kilometres. It caused shaking of MMVI to MMVII over the Wairarapa with damage less severe due to its deeper focal point and lower shaking intensities.

Even small earthquakes can be damaging. A shallow (31 kilometres), magnitude 5.4 earthquake on March 30, 2000, was centred 10 kilometres northwest of Greytown. Ground shaking intensities were estimated to be MMV *(Perrin and Wood, 2000)*. It was that year's most damaging earthquake in New Zealand, with nearly 600 claims totalling $610,000 made to the Earthquake Commission *(Wairarapa Times-Age, 2 Jan 2001)*.

It is not only earthquakes centred near the Wairarapa that can cause significant ground shaking. Ground shaking will be highest near the centre of the earthquake, but significant shaking can occur some distance from the epicentre. For example, the 1931 Napier Earthquake caused ground shaking of MMVIII-MMX in Hawke's Bay, and MMV and MMVI in the Wairarapa. The 1968 Inangahua Earthquake in 1968, centred near Westport in the South Island, caused MM IV shaking throughout the Wairarapa.

Ground-shaking studies

In June 1997, WELA commissioned IGNS to carry out a strong ground-shaking study of the Wairarapa region based on the use of probabilistic methods. The results of the study are published in an IGNS report by Berryman *et al* (1998).

The reason for adopting probabilistic methods rather than the traditional scenario events used in earlier lifelines studies such as that of Wellington, was the large area involved in the Wairarapa study. A probabilistic basis gives equivalent risk of exceedence for all points in the region. The hazard study was performed using a US Geological Survey-sourced computer package with input to the hazard model consisting of:

i. a catalogue of 432 shallow earthquakes of magnitude $\geq$ 4, from the period 1840 to 1991, that are interpreted to be within the upper plate;
ii. 369 deep earthquakes, from the period 1840 to 1991, that are interpreted to be within the lower plate;
iii. location, maximum magnitude and recurrence data from 25 active fault sources;
iv. the earthquake parameters for the subduction zone beneath the Wairarapa coast.

The earthquake hazard results were computed for ground motions with a 10 percent probability of exceedence in 15 years, and a 10 percent probability in 50 years. These probabilities correspond to events with return periods of 142 years and 475 years respectfully. The 475 year event corresponds to the nominal return period of the earthquake design level of the New Zealand loadings code NZS 4203 for many structures and may be likened to a Design Level Event. The 142 year event is one that can be expected with a reasonably high probability and is sometimes likened to an Operating Base Event. The Operating Basis Event can be expected with reasonably high probability and where minor damage could be expected, but not to the extent that lives, functionality of a structure, or services are impaired.

The results of the study indicate that the variation of estimated strong ground shaking across the Wairarapa region for the 475 year return period event to be MMI 9 to 10 and a peak ground acceleration (PGA) of 0.5 g to 0.7 g (**Figure 2.3 and 2.4**). For the 142 year return period event, the region may experience MMI of about 8.0 to 8.5 and a PGA of 0.33 g to 0.35 g.

It should be noted that the PGA and MM intensity figures in the GNS report are based upon "average" soil conditions. Such soils are generally accepted to be compact fine to coarse alluvial gravel up to 200 metres thick, usually with lenses of finer materials (sands, silts, peat, etc), and with moderate to high standard penetrometer test (SPT) values N=20>60. They correspond to Zone 2 soils used in the Wellington microzoning studies. Other soil zones with progressively finer and softer soils and possibly high water tables, Zones 3, 4, and 5 are known to amplify the level of shaking and the duration of shaking. The characteristics of the rock and soils in the zones are set out in **Table 2.4**.

To date no amplification or microzoning studies have

		MM Intensity	Peak ground acceleration (g)
Scenario 1			
Zone 1		V-VI	0.02 – 0.06
Zone 2-4		VI-VII	0.02 – 0.1
Scenario 2			
Zone 1	Featherston	VIII	0.3 – 0.6
	Masterton	VII	0.1 – 0.3
Zone 2-4	Featherston	VIII – IX	0.3 – 0.6
	Masterton	VII – VIII	0.1 – 0.3

Table 2.3. Results of the Earthquake Ground Shaking Hazard Assessment of the Wairarapa *(van Dissen, 1992)*. The results are based on earthquakes centred outside the Wairarapa.

been carried out in the Wairarapa area and all the soil hazard studies for the Welligton Regional Council have focussed on a narrow strip of the central part of the Wairarapa Valley floor where most of the urban population and infrastructure is located.

New Zealand-based attenuation expressions have been used throughout the study. Hazard estimates produced by the model are generally insensitive to reasonable variations in input parameters at the 142 year return period, but are increasingly sensitive at longer return periods. Variation in aspects of earthquake attenuation, particularly in relation to the standard deviation of the regression of the attenuation relationship, and maximum magnitudes of some fault sources are the main factors most likely to cause variations in hazard estimates. For the 475 year event, the variation is about one half an MMI unit, and up to 0.1 g for the PGA. The earthquake ground motions derived in this study provide a regional revision of the nationally based earthquake hazard calculations of Smith and Berryman (1986, 1992).

In 1992 the Department of Scientific and Industrial Research (DSIR) completed a report on the earthquake ground shaking hazard of the Wairarapa *(van Dissen, 1992)*. The report analysed only the Wairarapa Valley from Martinborough and Featherston up to Masterton.

Based on comparison with ground-shaking studies from Californian earthquakes and recently completed studies for the Hutt Valley and Porirua, two soil types particularly vulnerable to ground shaking from distant earthquake sources were identified in the Wairarapa. Zone 1 consists of solid bedrock that is expected to experience a low level of shaking during an earthquake. The second zone, labelled Zone 2-4 in the report, consists of coarse-grained alluvium and compact gravels and sands, which are expected to have a higher level of shaking during an earthquake.

Two scenario earthquakes were used to model earthquake shaking. The first scenario involves a shallow earthquake of magnitude 7.0 centred about 100 kilometres from the Wairarapa. Scenario 2 was an earthquake centred on the Wellington City-Hutt Valley segment of the Wellington fault. The earthquake was assumed to be of magnitude 7.5 and to be associated with up to 5 metres of horizontal fault displacement.

The effects of the two earthquake scenarios are summarised in **Table 2.3**.

Using the same scenario earthquakes, a Works Consultancy Services (Works) report assessed the potential casualties and building damage induced by ground shaking *(Davey & Shephard, 1995)*. The report estimated that a Scenario 1 earthquake would cause minor injuries to people, and building damage totalling $10.4 million. Only minor injuries were expected if the scenario 2 earthquake occurred at night. If the earthquake occurred during the daytime, casualties would be slightly greater. A Scenario 2 earthquake would cause about $50 million of building damage. Building damage values includes damage to residential and commercial properties, but not the cost of repairing lifelines.

Two main limitations to the DSIR and the Works reports limit their usefulness for the Lifelines study. First, the area studied covered only the Wairarapa Valley floor, not the entire Wairarapa region. Second, both scenario earthquakes were some distance from the region. The effect of a more local earthquake involving rupture of a Wairarapa fault would be greater than either of the scenarios studied.

The probabilistic study predicted the ground-shaking hazard for the average to firm alluvium that is common throughout the Wairarapa Valley. Local variations in ground shaking will occur for different soil and rock types (See **Table 2.4**), so the values predicted in the probabilistic study can only be estimates. The predictions are also constrained by limited historical and geologic data. The estimates of ground shaking are likely to change with more complete data sets, as more detailed studies of Wairarapa faultlines are undertaken, and as national estimates of probabilistic ground-shaking are subsequently refined.

More detail on the estimates of ground-shaking, methodology used, sources of earthquake and the study's limitations are provided in the 'Probabilistic Ground Motion Study of the Wairarapa Region' *(Berryman et al, 1998)*.

Hazard zone	Soil foundation condition	Soil category	Engineering description of soils/rock	SPT N values	Shear wave velocity m/s	Typical ground failure resulting from earthquakes
1	Effective rock	Greywacke bedrock or equivalent	andy silt/clay gravels moderately hard rock – hard rock	5-150 >100 >120 >120	Approx. 500 500-750 750-1000 1000-2000	On moderately sloping ground, little, if any, damage is expected. Local to widespread failures on steep slopes and unsupported batters >2m.
2	Stiff sediment	Alluvial deposits	Dense gravels Clay/silt with gravel Clayey gravels Silt/sandy gravels Clay and organic layers	20-60 30-70 30-100 15-30 approx. 10		Little significant damage expected. Local failures of river banks. Cracking and lateral spreading likely adjacent to rivers and streams. Liquefaction with sand boils. Minor settlement and collapse of saturated materials.
3-4	Transition	Transition zone of thicker alluvial deposits	Fine-grained sediments (fine sand, silt, clay and peat) with alluvial gravel Alluvial gravel	<20 20 to >60		Some damage expected. Some local cracking and sand boils. As for zone 2.
5	Soft	Soft "flexible" deposits	Fine sand, silt, clay and peat 10-30m thick. Loose rocks and hydraulic fill. Loose sand, gravel, and non-cohesive silt.	0-35 typically 5 5-60 typically 20	90-175 50-150 150-200	Damage widespread due to liquefaction effects (sand boils, cracking, lateral spreading and settlement). Serious damage adjacent to rivers.

Table 2.4 Typical ground failure as a result of earthquakes in varying soil foundation conditions from hard rock to soft sediment. Damage will be more widespread in soft "flexible" deposits than in hard rock.

FURTHER READING:

1. Aitken, J J, Rocked and Ruptured: *Geological Faults in New Zealand*, Reed Publishing (NZ), Auckland, 1999.
2. Berryman, K, Villamor, P and Cheriton, M, *Probabilistic Earthquake Ground Motion Study of the Wairarapa Region, IGNS Client Report 1998/43621B.10*, Institute of Geological and Nuclear Sciences, Wellington, 1998.
3. Davey, R A and Shephard, R B, *Earthquake Risk Assessment Study: Study Area 5 – Wairarapa*, Works Consultancy Services Report, Wellington, 1995.
4. Dowrick, D J, *The Modified Mercalli Earthquake Intensity Scale – Revisions Arising from Recent Studies of New Zealand Earthquakes*, Bulletin of the New Zealand National Society for Earthquake Engineering. Vol. 29 no. 2, pp 92-106, Wellington, 1996.
5. Downes, G, Dowrick, D, Smith, E and Berryman, K, *The 1934 Pahiatua Earthquake sequence: analysis of observational data*, BNZEE, Vol. 32, No. 4, Wellington, 1999.
6. Downes, G L, *Atlas of Isoseismal Maps of New Zealand Earthquakes*, Institute of Geological and Nuclear Sciences Monograph 11, New Zealand: Institute of Geological and Nuclear Sciences, Lower Hutt, 1995.
7. Downes, G L, Dowrick, D J, Van Dissen, R J, Taber, J J, Hancoz, G T and Smith E G C, *The 1942 Wairarapa, New Zealand, Earthquakes: Analysis of observational and instrumental data*, Bulletin of the New Zealand Society for Earthquake Engineering, vol. 34 no. 2, p125-157, Wellington, 2001.
8. Grapes, R, *Magnitude Eight Plus: New Zealand's Biggest Earthquake*, Victoria University Press, Wellington, 2000.
9. Grapes, R and Downes, G, *The 1855 Wairarapa Earthquake, New Zealand, Earthquake – Analysis of Historical Data*, Bulletin of the New Zealand Society for Earthquake Engineering vol. 30 no. 4, p271-368, Wellington, 1997.
10 McLaren, J, *A night of Terror - Wairarapa's 1942 Earthquake*, Wairarapa Archive, Masterton, 2002.

Predicted Modified Mercalli Shaking in the Wairarapa for a 1 in 475-year earthquake event

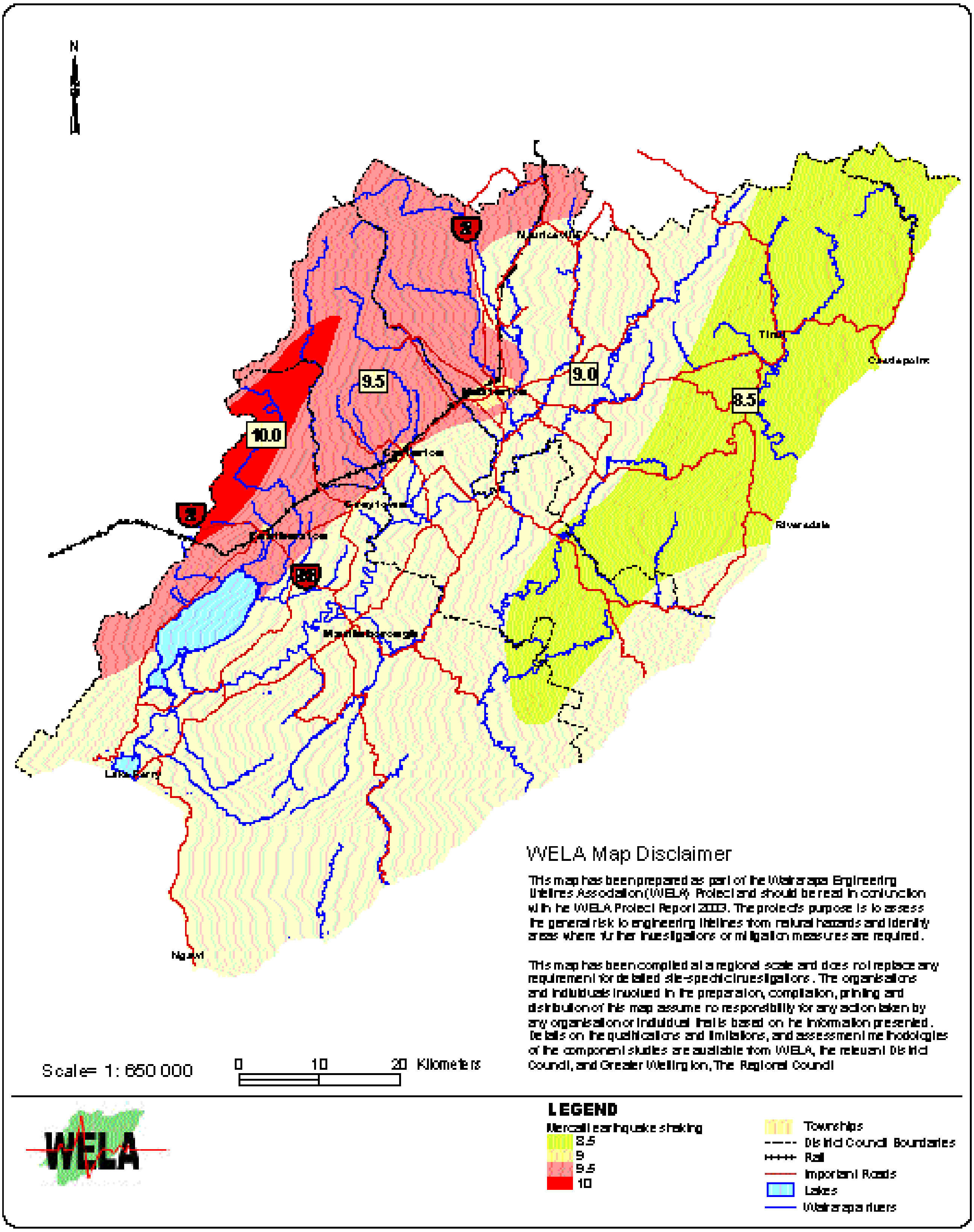


Figure 2.3. Predicted Modified Mercalli Shaking in the Wairarapa for a one in 475 year earthquake event. The predicted values of MMI are for average ground conditions, such as the firm alluvium that underlies many of the towns in the Wairarapa.

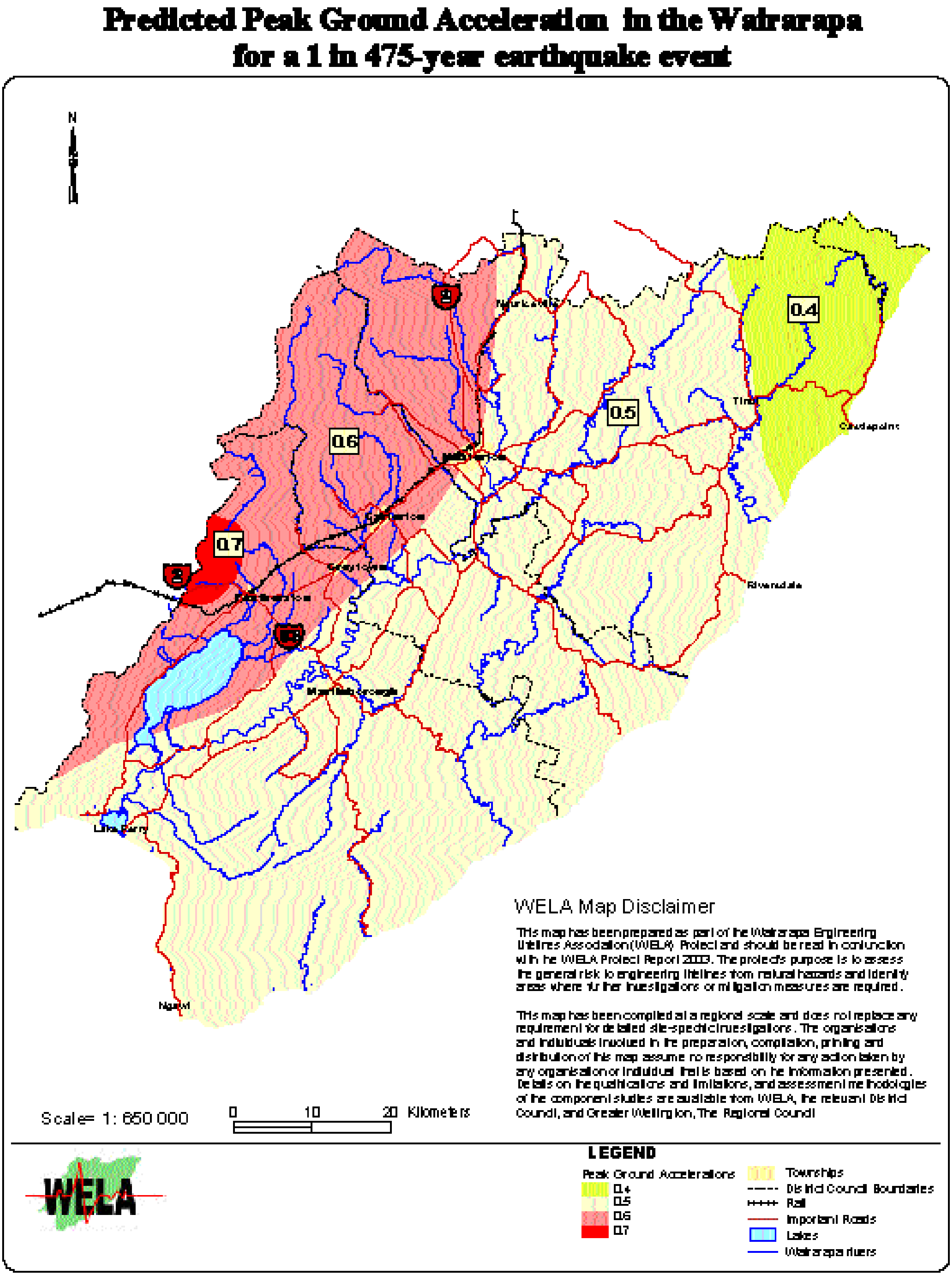


Figure 2.4. Predicted peak ground acceleration in the Wairarapa for a one in 475 year event. The predicted values of PGA are for average ground conditions, such as the firm alluvium that underlies many of the towns in the Wairarapa.

1942 Wairarapa Earthquakes

In the midst of World War II, the last thing New Zealand needed was destruction on the home front. At 11:17 pm on 24 June 1942, an earthquake of magnitude 7.2 on the Richter Scale shook the Wairarapa and Wellington. The earthquake, centred about 20 km ENE of Masterton and 15 kilometres deep, caused MM VIII shaking over most of the northern Wairarapa, and MM VII shaking over the rest of the Wairarapa (**Figure 2.5**) *(Downes, 1996)*.

There was extensive damage in Masterton. Houses swayed, chimneys fell, electricity was cut, and broken water mains flooded houses. Up to £500,000 damage occurred. Fortunately no one was injured in the town *(Rogers, 1996)*. St. Matthew's Anglican Church looked like a bomb had hit it. Its eastern wall collapsed, the organ was destroyed and many windows shattered (**Figure 2.6**). The damage was so bad the Army had to demolish the church with explosives. Several stores, including Bullick & Blackmore in Queen St, lost their entire frontages (**Figure 2.7**). In one case the upstairs living quarters were completely exposed. A 40,000 gallon water tank toppled through the Farmers Co-operative building, causing much damage *(Rogers, 1996)*.

Figure 2.6. 1942 Earthquake damage to St Matthew's church in Masterton. Unable to be repaired, the church was later demolished by the Army. *Source*: Alexander Turnbull Library.

Figure 2.7. Many stores, including Bullick and Blackmore in Masterton (pictured here) were severely damaged by the 1942 Masterton earthquake. *Source*: Alexander Turnbull Library.

The northern approach to Masterton's Colombo Road bridge over the Waipoua River settled (**Figure 2.8**). The bridge was unusable and traffic had to be diverted. Ammonia pipes at the Waingawa freezing works burst, damaging the freezing chambers.

Houses and shops were damaged in towns throughout the rest of the Wairarapa. Most houses lost their chimneys. Houses built on silt, river (alluvial) deposits and filled ground generally suffered more damage than those built on solid ground. Many houses built on alluvial deposits slipped off their foundations and suffered extensive structural damage. In contrast, at least one house built on solid limestone was unscathed. Carterton's post office and fire station were badly damaged; the post office so badly it had to be demolished. In Martinborough the roof of the oldest general store, Pain & Kershaw Ltd, was dislodged. It was 1948 before the roof was repaired. For six years the shop traded with windows open to the rain (Rogers, 1996).

To make matters worse, heavy rain on 13-14 July 1942 brought flooding to the Wairarapa. Damaged buildings in Masterton easily let in floodwaters, compounding the damage.

Just after midnight on August 2 1942 a magnitude 7.0 earthquake caused MM VII shaking throughout the Wairarapa. Chimneys suffered again, cracks widened, and some buildings which had survived the June shake failed during the August earthquake and its aftershocks.

In total, both earthquakes caused over £2 millon worth of damage in Wairarapa, Wellington and Manawatu. The combined damage of the two earthquakes plus the effect of wartime delays meant that it was 12 years later in 1954 before the last traces of the earthquake were removed *(Rogers, 1996)*.

11. Perrin, N D and Wood, *P R, Immediate Report Earthquake Reconnaissance 20 March 2000*, Institute of Geological and Nuclear Sciences, Wellington, 2000.

12. Rogers, A, *New Zealand Tragedies: Earthquakes*, Grantham House Publishing, Wellington, 1996.

13. Smith, W D and Berryman, K R, *Earthquake hazard in New Zealand: Inferences from seismology and geology*, Royal Society of New Zealand Bulletin 24: 223-243, Wellington, 1986.

14. Van Dissen, R J, *Earthquake Ground Shaking Hazard Assessment of the Wairarapa, New Zealand Contract Report No 1992/10,* Department of Scientific and Industrial Research, Wellington, March 1992.

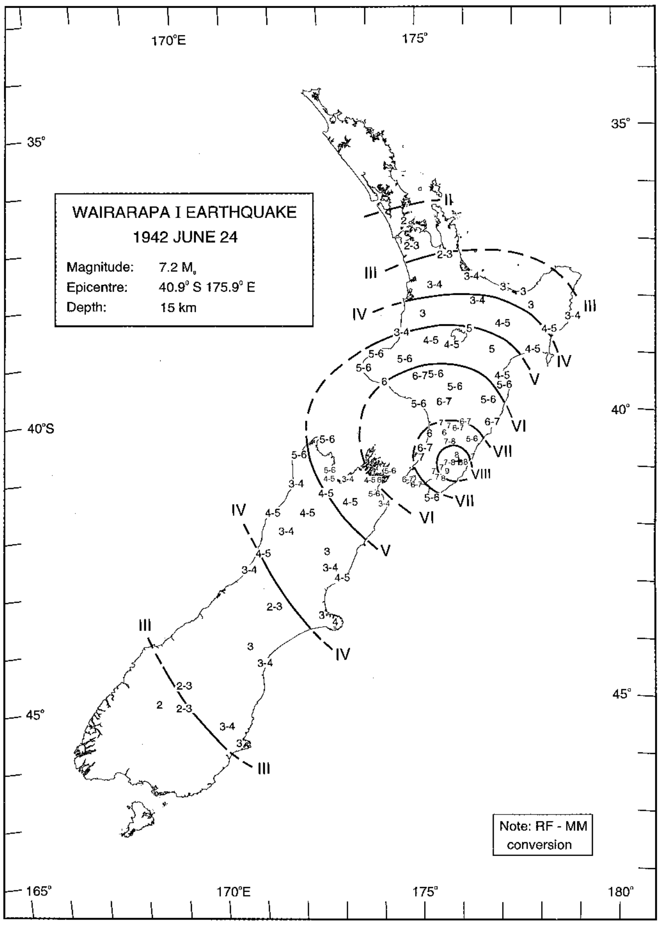


Figure 2.5. Isoseismals (lines joining points of equal shaking intensity) from the June 24, 1942 Masterton Earthquake. *Source*: Downes (2001).

(3) Liquefaction

HAZARD DEFINITION

Liquefaction is the conversion of material from a solid state into fluid state, as a consequence of seismic shaking.

Sand boils are ejections of sediment (sand or mud) and water on the ground surface, through cracks or

Figure 2.8. The approach to Masterton's Colombo Road bridge over the Waipoua River subsided 1/2 metre, so that traffic had to be diverted. *Source*: Alexander Turnbull Library.

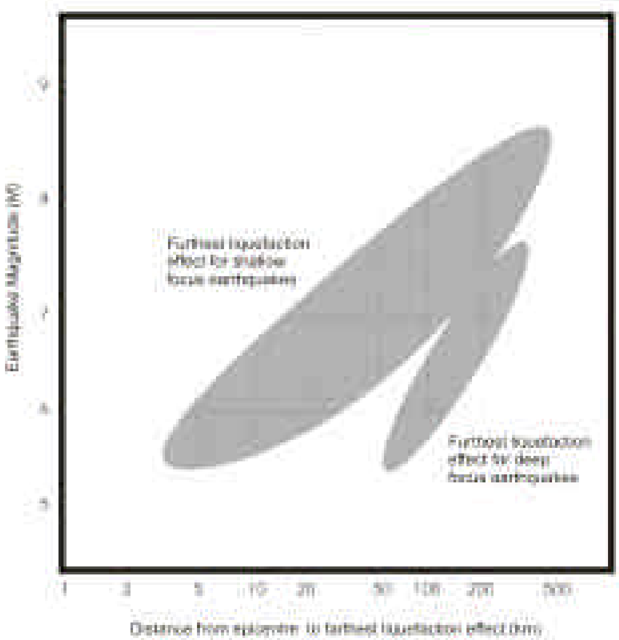


Figure 2.9. Liquefaction phenomena (sand boils and liquefaction) during historical New Zealand earthquakes are related to both distance from source (epicentre) and MM intensity shaking. Modified from Hancox *et al*, (1997).

fissures. Sand boils, which resemble miniature volcanos, are the most common and clear indicator that liquefaction has occurred.

Lateral spreading is the lateral displacement of surface blocks of sediment as a result of liquefaction in a subsurface layer. Lateral spread most commonly occurs on gentle slopes that range between 0.3° and 3.0° (Tinsley *et al*, 1985), such as river banks. Liquefaction is brought about by earthquake shaking. With sufficient shaking, pore water pressures in saturated sediments increase to match the shear strength of the sediment. The sediment then behaves like a liquid until the excess pressure is released. Maximum pore pressure is reached at the time when the peak ground acceleration occurs. Slow excess pore water dissipation can mean that failures occur some time after the end of strong ground motion *(Christensen, 1995)*. Sediments that have undergone liquefaction tend to become more compact afterwards. This often results in subsidence of the overlying land.

Liquefaction is most likely to occur in relatively uniform, loose, fine sands, silty sands, or coarse silts in areas where the water table is within five metres of the ground surface. Susceptible sandy and silty sediments may occur in estuarine flats, small pockets of river sands and silts, reclaimed ground and other fill structures such as bridge approaches, stopbanks and other artificial earthworks composed of fine material where the water table is high. Hancox *et al*, (1997) reported that although liquefaction phenomena may occur at lesser levels, liquefaction ground damage, including fissuring and lateral spreading, is most common at MM VIII shaking and above. The threshold for sand boils is MM VII and above. Both may occur at one intensity level lower in highly susceptible soils *(Hancox et al, 1997)*. **Figure 2.9** shows how the different liquefaction phenomena (sand boils and lateral spreading) relate to distance from source and MM intensity shaking.

Liquefaction can cause foundation failure in buildings and other structures, causing them to settle (sink) and tilt. Buried structures such as pipes and tanks that are of lower density than the liquefied soil will float upward. If the area is on a gentle slope, or close to a free face such as an incised river channel, then lateral spreading failures can occur. Lateral spreading can result in the deformation or failure of foundations and piles, horizontal displacement of structures, and ground settlement. Lateral spreading typically affects stopbanks, bridge approaches, abutments and piers. Liquefaction of a confined sub-surface layer can cause large vertical and lateral displacements of the ground surface or possibly only minor effects such as sand boils and water ejection's on otherwise unaffected surfaces.

WAIRARAPA CONTEXT

Historical information

Accounts of the Wairarapa earthquakes of 1855, 1904, and 1942 record several observations of liquefaction in the Wairarapa region. The sites of observed liquefaction phenomena are shown in **Figure 2.10**. At the time of these earthquakes the phenomenon of liquefaction was poorly understood. Because of this several cases of liquefaction in the region have probably gone unrecognised or have been overshadowed by more spectacular earthquake-induced failures. The first definite reports of liquefaction in the Wairarapa from the 1855 earthquake included:

> *"[The area around the confluence of the Ruamahanga and Waiohine Rivers] for many square miles, is rent in every direction: cracks in the ground of many feet in length, and from a few inches to several feet deep…twelve of which opened and shut with violence during the shock, and threw water to a considerable height over the surrounding bushes. I saw the water, cracks, sand and mud, which were thrown up…." (Anon 1855 quoted in Grapes and Downes, 1997).*

Liquefaction was also observed at Pihautea (now Pahautea) near Martinborough, near the house of Charles Bidwell. The morning after the earthquake the Bidwells found many fissures from which blue mud had been ejected *(Grapes, 2000)*.

> *"Fissures in the ground were sometimes three or four feet in width and Mrs Bidwell walked about examining these cracks but was unable to reach the bottom of them with the longest flax stick." (Grapes and Downes, 1997)*

Observations of liquefaction resulting from the 1904 Cape Turnagain earthquake were reported at Gladstone. A report in the Manawatu Evening Standard stated:

> *"Following the earthquake shock and a fall of earth off the cliffs at Gladstone, innumerable small holes appeared on the flat adjacent, spouting bluish mud and sand like miniature geysers. They eased when the shake was over."*

The article went on to report that:

> *"The approaches to the bridge [Gladstone Bridge] are somewhat rifted, but the bridge itself appears uninjured. The flat presents an interesting spectacle, being punctured by a number of small volcano-like craters, through which the mud and water spouted."*

Several cases of liquefaction were also reported as a result of the 1942 Masterton earthquakes. The Press (29 June 1942) reports that:

"As a result of the earthquake a strange sight was discovered on Thursday morning on the farm of Mr George Seymour, at Opaki, a few miles from Masterton. Over an area of nearly half a mile [square] funnel shaped holes appeared in the ground. Through these sand and water had been thrown up, and judged by the area covered, had spouted to considerable height."

Mr Jim Bicknell observed sand boils in a swampy area at Papawai, near the confluence of the Ruamahanga and Waiohine Rivers. They were of varying size and spouted high enough to cover the lower branches of full-grown willow trees.

Lateral spreading during the 1942 Earthquakes damaged the Tuhitarata Bridge over the Ruamahanga River south of Martinborough. The base of one pier on the approach spans was displaced by 13 inches (330 millimetres) due to lateral spreading. The damage to several can still be seen today on the west (right) bank of the river. Repair work on the joint between the pier and the bridge deck beams is also evident.

LIQUEFACTION STUDIES

Two reports have been commissioned to specifically study liquefaction in the Wairarapa. In 1993, Works Consultancy Services was commissioned by the Wellington Regional Council to investigate liquefaction in part of the Wairarapa. The study area included the Wairarapa Valley floor from just north of Masterton, south to include Featherston and Martinborough, but north of Lake Wairarapa *(McMinn et al 1993)*. The scenario earthquakes used for the liquefaction study were the same as those used in the DSIR's Ground Shaking Hazard study *(van Dissen 1992)* shown in the Table on page 11.

Using data from only four boreholes, the report concluded liquefaction would probably only occur near Featherston and Carterton during a Scenario 2 earthquake. Liquefaction was unlikely to occur during a distant Scenario 1 earthquake or in Masterton during a Scenario 2 earthquake. The report notes that dense sandy and silty gravels, which have little liquefaction potential, underlie the majority of the Wairarapa study area. Liquefiable soil layers are only present in relatively small areas; hence the extent of liquefaction is likely to be limited. The report concludes that with limited information, liquefaction hazard maps of the Wairarapa were inappropriate at the time.

Given that there have been several historical cases of liquefaction, WELA commissioned a more detailed study on liquefaction in the Wairarapa *(Wick, 2000)*. The study used Cone Penetrometer Testing (CPT) of sub-surface sediments at 19 sites (**Figure 2.10**) to assess liquefaction potential.

The study sites were selected based on the following criteria:

- The significance of the site to key engineering lifelines;
- Whether the site was typical for the lifeline being assessed;
- Evidence of historical liquefaction during past earthquakes;
- Classification of the site from mapping of sediments that may be liquefiable (**Figure 2.10**).

To determine liquefaction potential, the CPT results were analysed using four different liquefaction models. Sites were assigned a level of liquefaction potential based on the number of models predicting liquefiable soil conditions. The defined levels of liquefaction potential used were:

1. ***High potential***, in which the measured cone resistance plotted below all four of the models' cone resistance curves.
2. ***Moderate to high potential***, in which the measured cone resistance plotted below three of the models' cone resistance curves.
3. ***Some degree of potential***, in which the measured cone resistance plotted below two of the models' cone resistance curves.
4. ***Possible potential***, in which the measured cone resistance plotted below just one of the model's cone resistance curves.
5. ***Little potential***, in which the measured cone resistance plotted below none of the models' cone resistance curves.

Additional CPT testing is planned at potentially liquefiable sites in the future, to further extend the knowledge of areas prone to liquefaction in the Wairarapa.

The results of the CPT testing to study liquefaction are presented in **Table 2.5**.

Note: *The data for sites 1, 6, 7, 8, and 17, classified as 'little liquefaction potential', are limited because the CPT could not penetrate shallow gravel layers. It is possible that liquefiable deposits underlie the gravels, and therefore the classification should be treated with caution. A review of groundwater bore logs near sites 1 (Upper Plain Rd Water Main) and 8 (Carterton Sewage Treatment Plant) has indicated that there may be liquefiable layers beneath the gravel. These sites thus require further investigation.

FURTHER READING:

1. Beetham, R D and Hancox, *G T, Assessment of Liquefaction and Ground Failure Hazards in the Greater Wellington Region, 1992-1993 IGNS Contract Report No 1992/84*, Institute of Geological and Nuclear Sciences, Wellington,

Category		Lifeline	Remarks
High liquefaction potential			
5	Tinui Bridge	Bridge	Silts appear non-plastic, therefore liquefiable
9	Gladstone Bridge	Bridge / historic liquefaction	Liquefaction observed in 1904 and 1942
10	Papawai	Historic liquefaction	Sand boils observed in 1942
13, 14	Blundell Barrage	Flood protection	Degree and effect of soil cohesion unknown
15, 16	Kahautara Bridge, Tuhitarata	Bridge / historic liquefaction	Lateral spreading in 1942
Moderate to high liquefaction potential			
3	Goodland's Bridge	Bridge / 33kV line	Liquefiable deposits between 2-7 m depth
11	Waihenga Bridge Ruamahanga River, Martinborough	Bridge	Predicts liquefaction to 6 m
18	Pukio	Stopbank – flood control	Susceptible in times of high water table
Some degree of liquefaction potential			
4	Homebush, Masterton	Masterton main sewer line gravel at 3 m	Susceptible material 0.5-2.5 m; probe stopped in
19	Lake Onoke pumping station	Drainage/ flood control susceptibility could be higher than this.	Plasticity of soils not well determined,
Possible liquefaction potential			
12	Featherston railway bridge	Railway bridge	Depends on water table
Little liquefaction potential			
1	Upper Plain Rd, Masterton	Masterton water main	Unable to penetrate surface gravel
2	Paierau Road Bridge at Patton's Bush	Bridge	
6	Kopuaranga	Road and Rail	Unable to penetrate gravel layer at 1.5 m
7	Belvedere Rd, Carterton		Unable to penetrate gravel layer at 2.6 m
8	Carterton sewage treatment station	Sewage treatment plant	Unable to penetrate gravel layer at 1.0 m
17	Masterton Oxidation Ponds	Sewage Treatment Plant	Unable to penetrate surface gravel

Table 2.5. Results of the CPT (cone penetration test) Liquefaction Study (Wick, 2000). The study site locations are shown on Figure 2.10. Those classified as having little liquefaction potential require further investigation as the tests where limited because the CPT could not penetrate shallow gravel layers.

1992.

2. Brabhaharan, P and Jennings, D N, *Liquefaction Hazard Study Wellington Region: Study Area 5 – Wairarapa*, Works Consultancy Services Report, Wellington, 1993.
3. Christensen, S A, *Liquefaction of Cohesionless soils in the March 2, 1987 Edgecumbe Earthquake, Bay of Plenty, New Zealand, and other earthquakes*, Department of Civil Engineering, University of Canterbury Research Report 95/1, Christchurch, 1995.
4. Grapes, R and Downes, G, *The 1855 Wairarapa Earthquake, New Zealand, Earthquake – Analysis of Historical Data*, Bulletin of the New Zealand Society for Earthquake Engineering vol 30 no 4, pp271-368, Wellington, 1997.
5. Hancox, G T, Perrin, N D, and Dellow, G D, *Earthquake-Induced Landsliding in New Zealand and Implications for MM Intensity and Seismic Hazard Assessment – EQC Research project 95/196*, Institute of Geological and Nuclear Sciences, Wellington, 1997.
6. McMinn, J et al, *Liquefaction Hazard Study Wellington Region: A Review of Historical Records of Liquefaction*, Works Consultancy Services Report, Wellington, 1993.
7. Tinsley et al, in Ziony J I (Ed), *Evaluating Earthquake Hazard in the Los Angeles Region – An Earth Science Perspective*, US Geological Survey Professional Paper, 1985.
8. Wick, H, *Liquefaction Susceptibility of Selected Lifeline sites in the Wairarapa Region*, University of Canterbury Civil Engineering Department, Christchurch, 2000.

Liquefaction in the Wairarapa

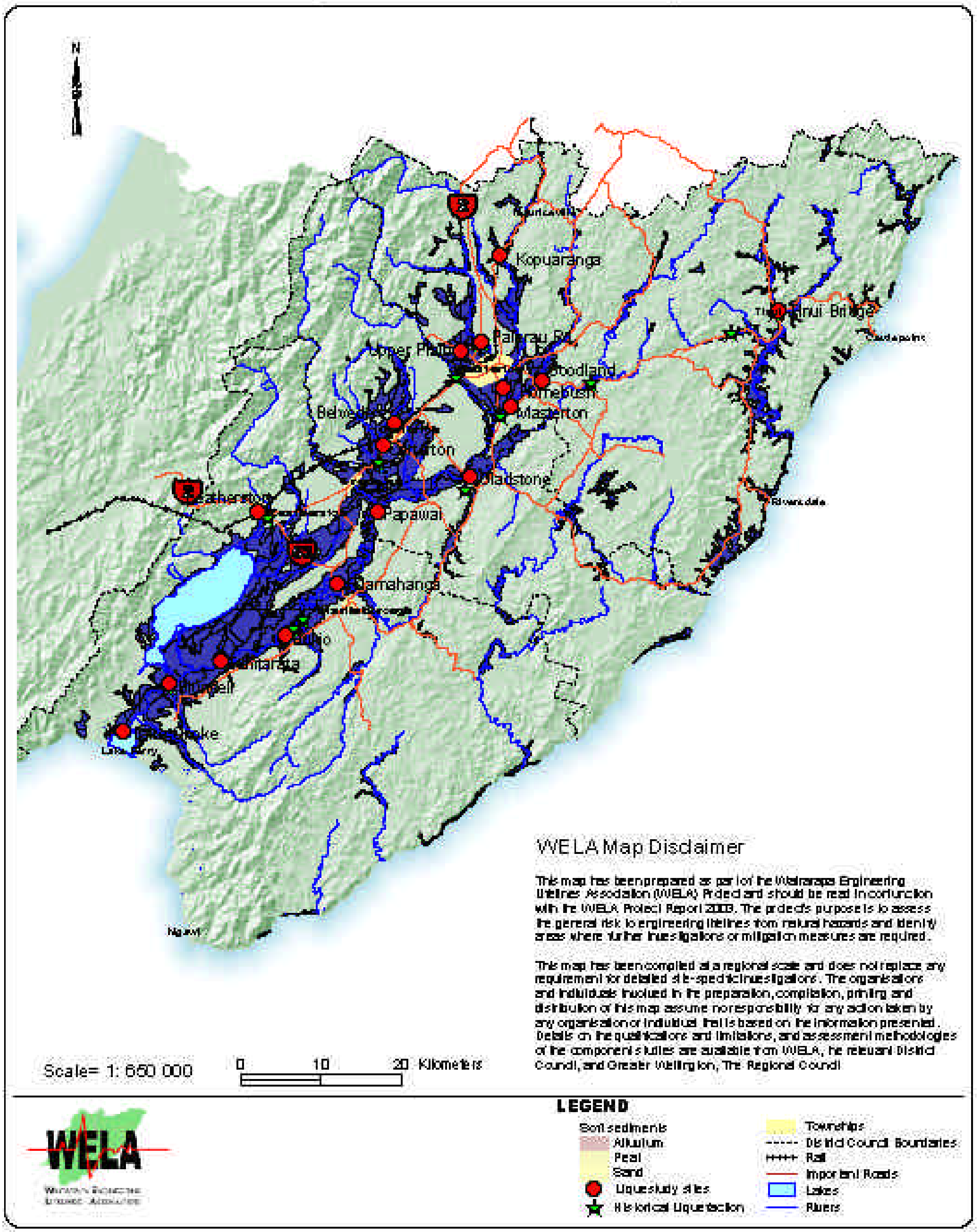


Figure 2.10. Map indicating potential liquefaction in the Wairarapa. The soft sediments shown on the map represent areas potentially at risk. The map also shows sites of historical liquefaction, and the sites studied by Wick in 2000. Note: not all the soft sediments on the map are susceptible to liquefaction. Some of the sites of historic liquefaction are not in areas of predominantly soft sediments.

(4) Fault displacement and ground settlement

HAZARD DEFINITION

Fault displacement is the displacement, horizontally and/or vertically of the sides of the fault fracture or fracture zone, relative to one and other. ***Ground settlement*** is the change in level, positive or negative, of the ground surface due to seismic induced compaction, folding, or tilting of the Earth's surface (**Figure 2.11**).

Figure 2.11. Surface rupture of the Edgecumbe Fault from the 1987 Edgecumbe Earthquake. Note the relatively confined linear area of disturbance. *Source*: Aitken (1999).

Fault displacement is a hazard because the rate and amount of ground displacement can instantaneously destroy or weaken foundations and structures which straddle the fault zone.

Lifelines crossing the fault can break and be rendered unserviceable (**Figure 2.12**). This can delay emergency responses and may compound recovery throughout the area affected by the earthquake.

Surface rupture is usually restricted to earthquake faultlines, and hence occurs in known locations. Buildings and services straddling the fault line can be destroyed, but structures next to the fault may remain unscathed despite near-fault effects and intense ground-shaking (**Figure 2.13**). Although fault traces can be mapped, there is a chance that unmapped faults may re-activate or new faults may appear.

Vertical surface displacement may result in tilting of structures and progressive disruption, but instantaneous destruction of structures is unlikely unless the fault passes through them. However, changes in surface elevations can affect roads, railways, pipelines, stopbanks, and drainage lines. Sewerage that relies on gravity flow can be especially affected.

Figure 2.12. Lifeline services can be destroyed where they cross the fault rupture as illustrated by service pipes disrupted during the 1999 Taiwan Earthquake. *Source*: Dave Brunsdon.

WAIRARAPA CONTEXT

Several faults with the potential to rupture are present in the Wairarapa (**Figure 2.14**). The main faults that cross the Wairarapa's major engineering lifelines are the Wairarapa, Carterton, Masterton, and Mokonui (**Figure 2.15**) faults. Of particular concern is the Masterton fault, which runs through the centre of Masterton. Since fault rupture is a localised hazard restricted to ground damage around the fault, offshore faults and faults outside the Wairarapa are not a fault rupture hazard to the Wairarapa's lifelines. The only reported fault rupture event in the Wairarapa was during the 1855 earthquake (**Figure 2.16**). The Wairarapa fault ruptured over a distance of approximately 72 km. Immediately following the earthquake there were many reports of vertical displacement of the fault. All reports indicate that the Rimutaka side of the fault was uplifted relative to the Wairarapa valley floor.

The maximum uplift reported was about five metres at Turakirae Head, Palliser Bay in the south. The amount of uplift decreased to the north, where it was about 1.8 metres near Featherston *(Grapes and Downes, 1997)*. Mr Jackson travelled to Wellington over the Rimutaka Hill the day after the earthquake and commented on fault rupture near Featherston.

> *"When I got to the ascent of the [Rimutaka] hill behind the Hotel [Burling's Hotel at Featherston] I found that road over the Rimutaka hill broken in two and one part raised six feet (1.8 m) above the other" (Grapes and Downes, 1997)*

Figure 2.13. Damage due to fault rupture is limited to the area of fault rupture as illustrated by the undamaged petrol station next to a fault that ruptured (to the right of the photo) during the 1999 Taiwan Earthquake. Note the lean on the power pylon. Source: Dave Brunsdon.

However, the majority of movement of the fault was horizontal, with up to 12 metres measured, although this was not recognised until the 1950s *(Grapes and Downes, 1997)*. The most obvious evidence of horizontal fault movement is where man-made structures are displaced across a fault. The only recorded man-made feature that crossed the fault in 1855 was a track to Wellington. As the track crossed the fault obliquely, any horizontal movement would have been difficult to observe.

Evidence of the 12 metre horizontal movement has been determined from displaced streams and river terraces (**Figure 2.17**). The vertical and horizontal movements of the Wairarapa fault recognised in older displaced surfaces are of a similar size to those attributed to the 1855 earthquake *(Grapes and Wellman, 1988; Grapes and Downes, 1997)*.

Fault rupture during the June 1942 earthquake was reported by Ongley (1943). Ongley visited the Wairarapa immediately following the earthquake and reported a number of fissures in that region which he interpreted as tectonic surface rupture on the fault. However, more recent work *(Downes et al, 1999)* indicates that the 1942 earthquakes were not caused by rupture of the Masterton fault and hence could not have produced surface fault rupturing. The fissures observed by Ongley (1943) have since been attributed to the 1855 earthquake *(Grapes and Wellman, 1998; Grapes and Downes, 1997)* and reinterpreted as probable landslide features rather than faulting *(Zachariasen et al, 2000)*.

To provide more detailed information, WELA commissioned the Institute of Geological and Nuclear Sciences (IGNS) to study the Masterton and Carterton faults *(Zachariasen et al, 2000)*. The first stages of the project involved reviewing and summarising existing reports and detailed mapping of the faults using both aerial and photographic analysis and field checks. The detailed maps are available from the Wellington Regional Council.

Figure 2.15. Double Bridges, Opaki. The active Mokonui fault crosses the road and the rail line close to the rail crossing in the distance.

The study recognises both horizontal and vertical displacements on the Carterton fault. The horizontal movement was estimated to average 2-4 millimetres per year , with a probable single event displacement of about 6 metres. The vertical movement is estimated at a rate of 0.1-0.5 millimetres per year. This data has now been updated and is discussed below.

Based on data collected from Berryman *et al*, (1998), Zachariasen et al, (2000) and Begg *et al,* (2001) (discussed below), **Table 2.5** shows information about fault rupture along the main faults in the Wairarapa.

The study was a follow-on from Zachariasen (2000) and was undertaken to better understand the geological context and slip rates of the faults. The study involved fault trenching to determine the structural style of the faults and provide information on past individual earthquake events (**Figure 2.18**). A trench across the

Wairarapa Faultlines

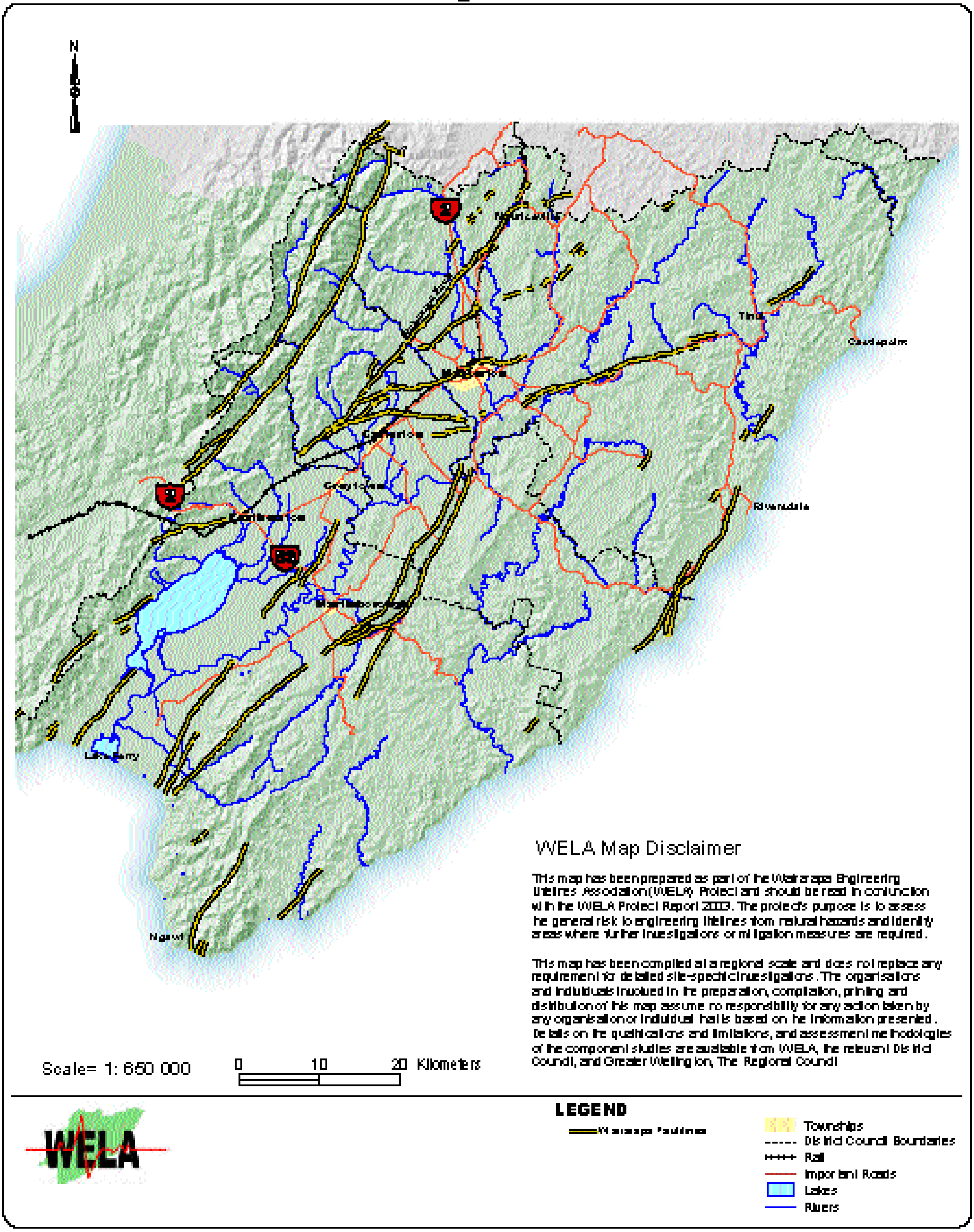


Figure 2.14. Map showing the location of the major faultlines in the Wairarapa.

Fault name	Length (km)	Average single event displacement (m)	Average vertical slip rate (mm/yr)	Average horizontal slip rate (mm/yr)	Average return period (years)
Wairarapa – 1855	105	12	-	8	1500
Mokonui*	25	2	-	1	2000
Masterton**	15	0.5	0.3	>0.3	1000 (M 6.7)
Carterton**	44	2	0.15	2	1000 (M 7.0
Tinui ***	10	2	-	0.4	5000

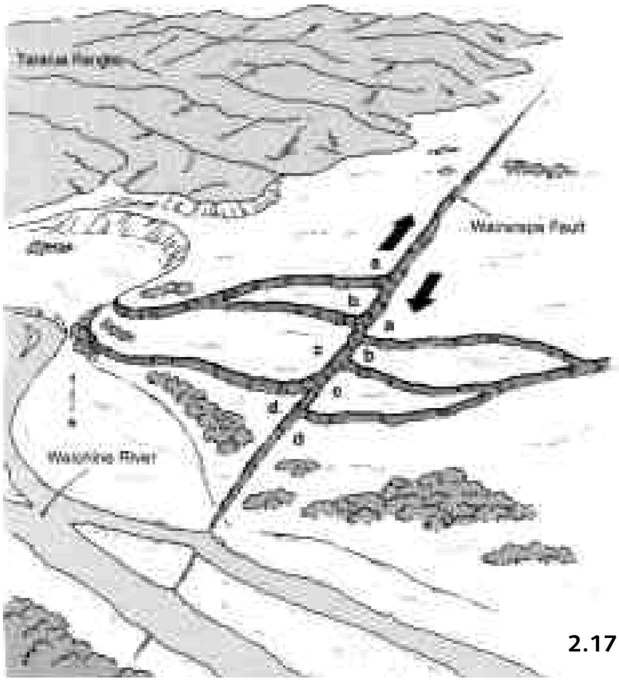
Table 2.6. Fault rupture data for faults of interest in the Wairarapa. *Source*: Berryman et al (1998), except where noted.

*From Berryman et al, 1998. **Data presented by Begg et al, (2001), as discussed below. ***The Tinui fault may be an extension of the Carterton fault. However, a 20 km gap in the fault trace suggests that it may rupture separately.

Masterton fault was excavated, although individual fault rupture events could not be discriminated due to the dominance of gravels and lack of material suitable for carbon dating. However, Begg *et al*, (2001) suggest there may have been two or more earthquake events in the late Holocene Period. Although the data from this fault were not ideal, estimates of characteristics may range between 0.3-0.7 metres for a single event displacement, >0.7 millimetres per year for slip rate and c. 1000 years for return period.

The trench near Cobden Road on the Carterton Fault revealed datable material in the late Holocene part of the trench which allowed discrimination of at least two late Holocene rupture events. These results are presented in **Table 2.6**. A slip rate of two millimetres per year and average single event displacement of two metres was estimated for the Carterton Fault. These estimates yielded a return period of 1000 years.

2.16



2.17

Figure 2.16. The Wairarapa fault, Western Lake. The Wellington to Woodville railway traverses the fault scarp in the centre of the photograph. The fault is evident in the foreground.

Figure 2.17. Displaced terraces near the Waiohine River show the repeated vertical and horizontal movement of the Wairarapa fault. The oldest terrace (a) was formed 20,000-15,000 years ago and has since been displaced by more than 120 metres horizontally and 15 metres vertically. The 12 metre horizontal and 3 metre vertical movement of terrace (d) accompanied the fault rupture of the 1855 Wairarapa earthquake. *Source*: (i) Aitken (1999).

Figure 2.18. Trench near Cobden Road exposing displaced units and revealing the Carterton fault. The position of the fault is marked by the dotted line.

2.18

FURTHER READING:

1. Ansell, R and Taber, J, *Caught in the Crunch*, Harper Collins, Auckland, 1996.
2. Begg, J G, Villamore, P, Zachariasen, J and Litchfield, N, *Palaeoseismic assessment of the active Masterton and Carterton Faults*, Wairarapa, Wellington, 2001.
3. Berryman, K, Villamor, P and Cheriton, M, *Probabilistic Earthquake Ground Motion Study of the Wairarapa Region IGNS Client Report 1998/43621B.10*, Institute of Geological and Nuclear Sciences, Wellington, 1998.
4. Grapes, R, *Magnitude Eight Plus: New Zealand's Biggest Earthquake*, Victoria University Press, Wellington, 2000.
5. Grapes, R and Downes, G, *The 1855 Wairarapa Earthquake, New Zealand, Earthquake – Analysis of Historical Data, Bulletin of the New Zealand Society for Earthquake Engineering* Vol. 30 no 4, p271-368, 1997.
6. Zachariasen, J, Villamor, P, Lee, J, Lukovic, B, and Begg, J. *Late Quaternary Faulting of the Masterton and Carterton Faults, Wairarapa, New Zealand IGNS Client Report 2000/71*, Institute of Geological and Nuclear Sciences, Wellington, 2000.

2.3 TSUNAMI

HAZARD DEFINITION

Tsunami is a Japanese word meaning *'harbour wave'* or *'waves'*. A tsunami is a fast-moving, long-period wave resulting from a sudden movement of the sea floor. This sudden impulse produces a movement of the water column, and thereby the water surface, which develops into a tsunami. In deep water, tsunami have a wave length anywhere between 200 and 700 kilometres and a wave period of 15-60 minutes.

Triggering events for tsunami include earthquakes (normally Richter M>5.0), submarine landslides, or underwater volcanic eruptions. These events may be from a local or distant source anywhere in the Pacific basin. The displacement of the sea surface initiates a series of waves radiating outwards from the initial disturbance. Locally generated waves may arrive at the coast within minutes, whereas it can take about 16 hours for a tsunami to travel from South America to New Zealand.

Tsunami vary in height from small, unrecognisable waves, to waves higher than 10 metres. The height of the wave depends on the energy of the initial event, distance from source (local sources will have higher energy and probably bigger wave height), bathymetry (undersea topography), coastal topography and setting (open bays are more prone than closed sounds), and direction of the tsunami waves.

The effects of tsunami are generally confined to low-lying coastal areas. The area affected depends on the size of the wave, the elevation and slope of the coastal margin and the surface roughness of the run-up area. Tsunami flood low-lying areas and can cause severe erosion of the beach and nearby infrastructure. Sediment and debris carried in the tsunami wave increases its damage potential, causing scouring, 'sand-blasting' and destruction of light structures. **Figures 2.19 and 2.20** show the damage capable of a locally generated tsunami. The tsunami shown occurred in 1993 and devastated the island of Okushiri in Japan. Maximum run-up heights were estimated to be 31 metres above sea level.

Figure 2.19. Damage following the 15 to 30 metre tsunami to hit Okushiri Island in Japan in 1993. A large fishing boat was carried inland and deposited against a fire engine. Note the toppled lighthouse in the background. *Photo George Butcher.*

WAIRARAPA CONTEXT

While there have been some studies on the effect of tsunami on Wellington Harbour and the south coast of Wellington City, no studies have specifically focused on the tsunami hazard in the Wairarapa. Goff *et al* (2001) have completed a tsunami hazard scoping project for the whole of the Wellington region which summarises the tsunami hazard and risk for the Wairarapa, the south coast and the west coast of Wellington. The eastern Wairarapa coast appears to have the highest risk to tsunami. A return period for a 5-10 metre tsunami in the eastern Wairarapa has been estimated by Goff *et al* (2001) to be 100-150 years.

Between 1840 and 1982, 32 tsunami have been recorded in New Zealand *(de Lange and Healy, 1986)*. However, this record only reflects areas where there are recording devices and/or human habitation. Most of these have been small and have caused little damage *(de Lange and Healy, 1986)*. Two of these tsunamis were observed in the Wairarapa.

The 1855 earthquake generated a large tsunami consisting of three waves that affected the Wairarapa coast. In Palliser Bay, the tsunami was at least nine metres high. At Te Kopi, on the eastern side of Palliser Bay, bales of wool ready for shipment to Wellington and several coastal whares and their contents were washed away. Fortuitously the wool bales were brought back inland by the third wave.

A sailor, who had experienced a tsunami in South America, recognised the approaching wave. He was able to warn a boatman's family and make sure they reached safety *(Grapes, 2000)*. The tsunami wave is also reported to have travelled up the east coast of the Wairarapa "...having done much injury." *(Grapes and Downes, 1997; Grapes, 2000)*.

Figure 2.20. Reinforced concrete block wall destroyed by the 1993 Okushiri tsunami. Much of the damage in the background was caused by fires following the tsunami. *Photo George Butcher.*

Barnett *et al*, (1991) reported that the faulting and uplift that occurred during the 1855 earthquake were sufficient to generate a tsunami of the size reported. However, the death of pressure-sensitive bottom-dwelling fish in Cook Strait suggests submarine landsliding accompanied the earthquake *(Grapes and Downes, 1997)*. This submarine landslide was possibly a contributing source to the 1855 tsunami.

A tsunami from the August 13, 1868 Chilean earthquake was recorded at Castlepoint. The effects at Castlepoint were minor. Two high tides three hours apart were observed. The most recent tsunami to have been recorded in Wellington occurred on 23 June 2001 and arrived at the New Zealand coast from Peru, 16.5 hours after an earthquake on the South American coast. The tsunami was only minor and no damage was reported. Tide recorders at Riversdale and in Wellington Harbour recorded the event. Wave heights were less than 30 centimetres in these areas. The largest response occurred in Lyttelton Harbour where a range of 56 centimetres was recorded in less than one hour.

There are several major active faults off the Wairarapa coast and in Cook Strait that could act as potential tsunami sources (**Figure 2.21**). Many of the faults identified in Cook Strait appear to be related and are probably continuations of large on-shore faults. The Wairarapa fault continues south of Southern Wairarapa into Cook Strait and may continue on to join the Clarence fault in southern Marlborough. Several other large fault structures have been identified off the Wairarapa's east coast. These include Palliser-Kaiwhata, Opouawe-Uruti, and Pahaua faults. The Palliser-Kaiwhata fault may be related to, or a continuation of, the Hope fault in southern Marlborough.

Very little information is known on the rupture history and potential magnitude of earthquakes that these faults are capable of producing. However, given the length of the fault traces and their probable relation to large on-shore faults, rupture of many of these faults is likely to produce large earthquakes and hence tsunamis.

Sources for potentially large tsunami generated by submarine landslides is also present near the Wairarapa coast. Both the Cook Strait Canyon and the deep Hikurangi Trough are potential landslide sources because of their steep underwater slopes. However, there has been little study of these features as potential tsunami sources.

The coastal communities of Castlepoint, Riversdale, Lake Ferry, Te Kopi, and Ngawi are potentially at risk from tsunami. The lifelines servicing those communities such as roads, electricity, water supply and sewerage are also at risk.

FURTHER READING:

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Figure 2.21. Map showing the Wairarapa's offshore faults and bathymetry (marine topography). Tsunamis could be generated from movement of the faults or landslides in the Cook Strait Canyon or Hikurangi Trough. *Source*: Barnes and Audru (1999).

2.4 METEOROLOGICAL HAZARDS

(1) Information sources

Meteorological hazard information for this section is drawn from several sources. Thompson (1982) published a comprehensive summary of meteorological data from sites around the Wairarapa. The National Institute of Water and Atmospheric Research (NIWA) was commissioned by WELA to update and analyse the data with specific respect to hazards to the Wairarapa's engineering lifelines (NIWA, 1999-2000). Additional detail on the effects of events has been gathered from print media and other publications.

Further reading:

1. *Meteorological Hazards Relevant to Wairarapa Engineering Lifelines* (includes supplementary reports completed in 2000 on *Wairarapa Windstorms and High Intensity Rainfalls*), National Institute of Water and Atmospheric Research, Wellington, 1999-2000.
2. *Floods in New Zealand 1920-53*, Soil Conservation and Rivers Control Council, Wellington, 1957.
3. Thompson, C S, *The Weather and Climate of the Wairarapa Region*, New Zealand Meteorological Service, Wellington, 1982.

(2) Heavy rain/severe storms

HAZARD DEFINITION

Heavy rain in itself is not generally regarded as a hazard, but its associated effects are. The hazards associated with heavy rain include river and surface flooding, and rainfall-triggered landslides. These hazards are discussed in more detail in the following section. Heavy rain includes both high-intensity rainfalls and large-volume rains. High-intensity rainfalls affect river and surface flooding hazards, while large-volume rainfalls can trigger landslides.

WAIRARAPA CONTEXT

Heavy rainfalls can occur in both westerly and easterly airstreams. Annual rainfall varies widely across the Wairarapa (**Figure 2.22**). The highest rainfall is in the Tararua Ranges. The Wairarapa Valley is drier, with medium rainfall in the eastern hills. However, it is unlikely the effects of a single storm or series of storms will have a rainfall pattern similar to the annual rainfall. This is because high-intensity rainfall during storms only affect specific areas on a single occasion.

To address this issue, NIWA studied the rainfall in the Wairarapa (NIWA, 1999-2000). The main findings of the report are summarised below. More detail on the different weather systems that lead to high rainfall in the Wairarapa and a summary of flood-producing rainfall events can be found in the report.

The report details two major scenarios: an easterly storm and a northwesterly storm (NIWA, 1999-2000). Although no two storms are exactly the same, these two storm scenarios are considered typical of past major rain events. The 24-hour rainfall for each scenario was determined for both the one in 142 year (10 percent chance of exceedence in any 15-year period) and one in 475 year (10 percent chance of exceedence in any 50-year period) return periods. (These recurrence intervals match those used for the analysis of seismic hazards).

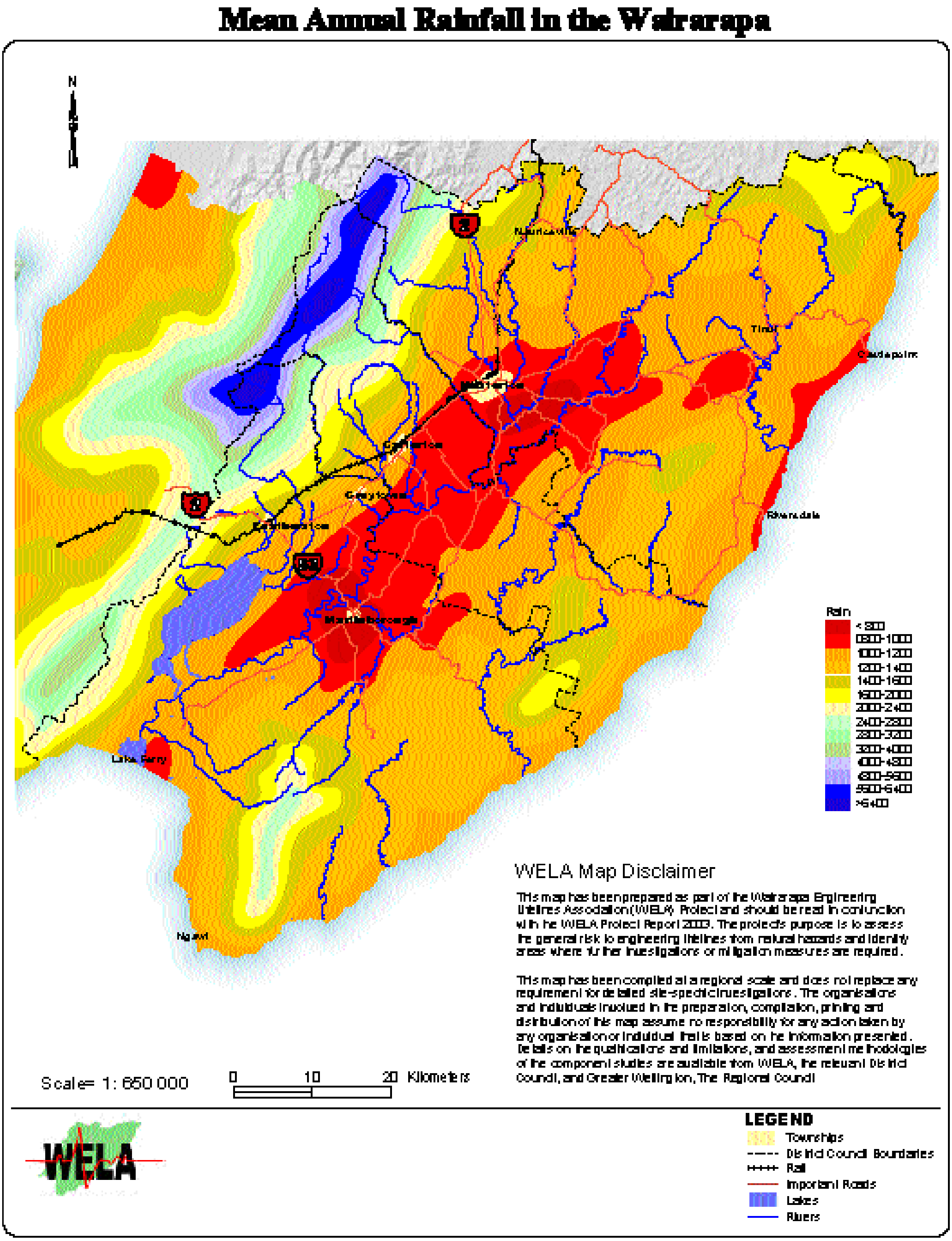

Figure 2.22. Mean annual rainfall (mm) in the Wairarapa. *Source*: NIWA (1999-2000).

These scenarios are useful for thinking about ways to respond to severe rainfall events. However, unacceptable errors would be encountered if they were used to estimate flood flows using WRC flood prediction models. Standard hydrological procedures would be more appropriate (NIWA 1999-2000; Morgan, 2000).

7-8 November 1994

The storm on 7-8 November 1994 was chosen as the scenario northwesterly storm. The highest reported rainfall for that day was 309 millimetres, at Angle Knob. With a return period of approximately 10 years, this was not a particularly significant rainfall event for the site at Angle Knob.

The importance of this event was the unusually high spillover rain in the Tararua foothills and the Wairarapa Valley. Large volumes of rain were recorded at many rainfall sites in the Wairarapa Valley: Phelps (230 millimetres), Mikimiki (189 millimetres), and Woodside (205 millimetres). The rainfall at Woodside exceeded the theoretical one in 142 year event of 190 millimetres (measured from a Gumbel distribution for the site).

Figure 2.23 and **Figure 2.24** show the predicted rainfall patterns from one in 142 year and one in 475 year return period events from a scenario northwesterly storm.

8-10 April 1991

The Tinui storm on 8-10 April 1991 was chosen as the scenario easterly storm. A cold front, which passed over the Wairarapa during the morning of April 9, stalled over the Gisborne area. Thunderstorms developed over the warm waters just east of the Wairarapa, and drifted southeast onto land. The low remained almost stationary until after midnight on April 10.

The wettest day was April 10. A number of rainfall sites measured over 200 millimetres of rain. The highest observation of 244 millimetres exceeded the theoretical one in 142 year event of 234 millimetres (measured from a Gumbel distribution for the site). In addition to widespread river and surface flooding, extensive landsliding was recorded (see the 'Landslides' section below).

Figure 2.25 and **Figure 2.26** show the predicted rainfall patterns from one in 142 year and one in 475 year return period events from a 'scenario' easterly storm.

FURTHER READING

1. *Meteorological Hazards Relevant to Wairarapa Engineering Lifelines*, (includes supplementary reports completed in 2000 on *Wairarapa Windstorms and High Intensity Rainfalls*), National Institute of Water and Atmospheric Research, Wellington, 1999-2000.
2. *Floods in New Zealand 1920-53*, Soil Conservation and Rivers Control Council, Wellington, 1957.
3. Thompson, C S, *The Weather and Climate of the Wairarapa Region*, New Zealand Meteorological Service, Wellington, 1982.

(3) Windstorms

HAZARD DEFINITION

High winds often occur when deep cyclonic depressions move over the country. Most wind statistics give average wind speed, although the maximum speed (three-second gust speed) is a better indication of the damage potential of a windstorm.

Mountain ranges and hills can cause acceleration of winds that pass over them. High winds also occur on the lee (downwind) side of these features, as the winds accelerate downhill. For large topographic features, these effects can be modelled using standard weather models. Local escarpments, river gorges, hills, and shelterbelts can also lead to localised wind effects. These need to be determined separately by site-specific assessment. The hill shape and escarpment multipliers given in NZS 4203 vary from 1.04 to 1.54, and the channelling multiplier from 1 to 1.2.

Winds may cause structural failure to buildings, trees, and power and communication lines. Winds around120 kilometres per hour frequently damage conventional structures, such as homes and farm buildings, while wind speeds of 50-120 kilometres per hour can damage trees. High winds can also cause electrical faults, and possibly fires when power lines clash together or are brought down by fallen trees. Existing fires may be fanned by high winds, causing them to spread more quickly and create more damage.

WAIRARAPA CONTEXT

High winds are common in the western ranges, Haurangi Ranges (in the southeast) and the eastern coastal hills *(Thompson, 1982)*. Strong winds can occur at any time of the year.

Low-level winds are typically channelled through Cook Strait and to a lesser extent through the Manawatu Gorge in the north. This results in parts of the Wairarapa Valley being relatively sheltered. In contrast, the Wairarapa coast, e.g. Castlepoint and Cape Palliser, have remarkably high wind speeds. The Featherston area is also renowned for its windiness, the result of winds gusting over the Tararuas and the town's location near a river gorge (NIWA, 1999-2000).

Rainfall in the Wairarapa for a scenario 1 in 142-year Northwesterly

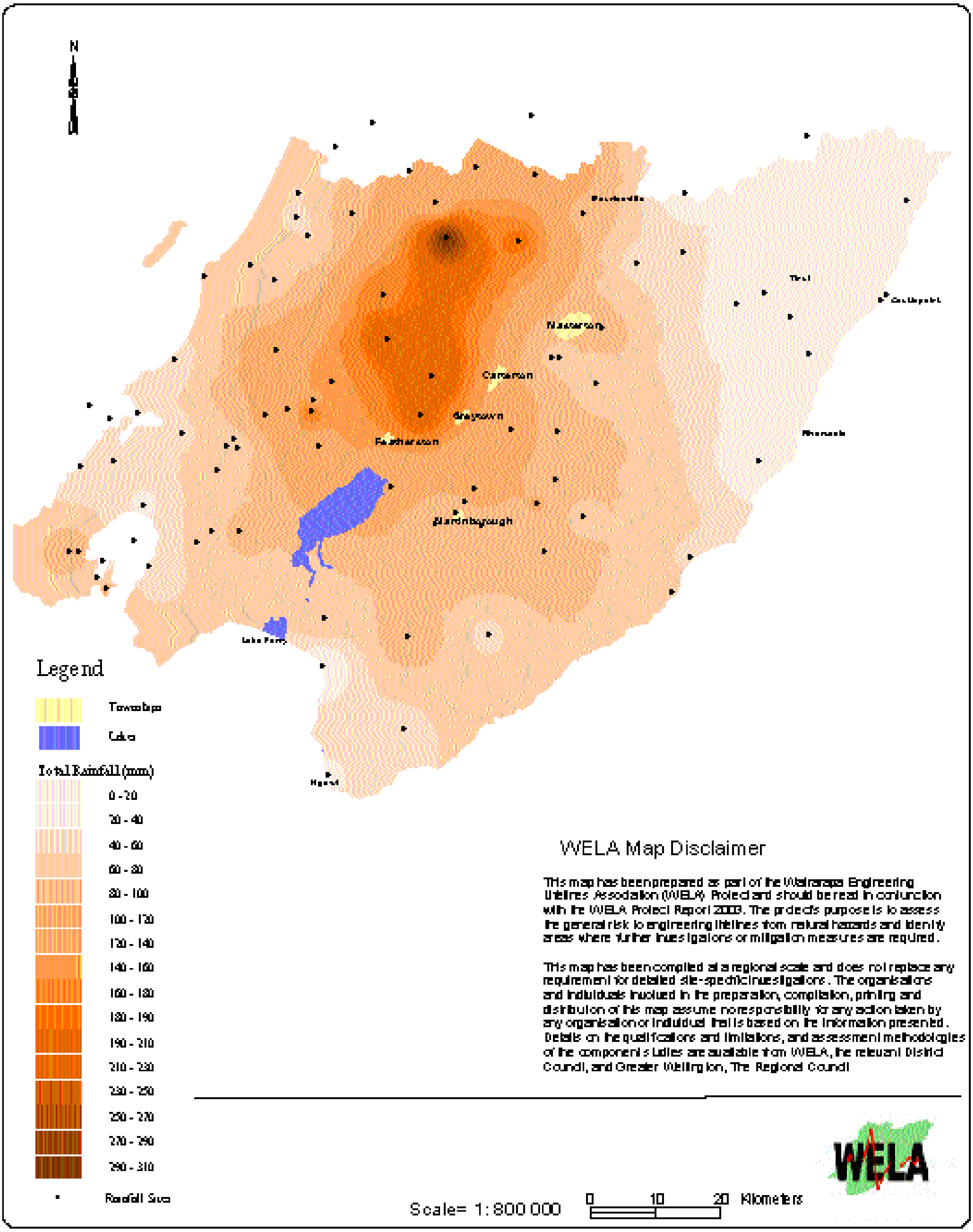

Figure 2.23. 24 hour rainfall for a 1 in 142 yr scenario northwesterly Wairarapa storm, based on the rainfall from the 7-8 November 1994 storm. *Source*: NIWA 1999-2000.

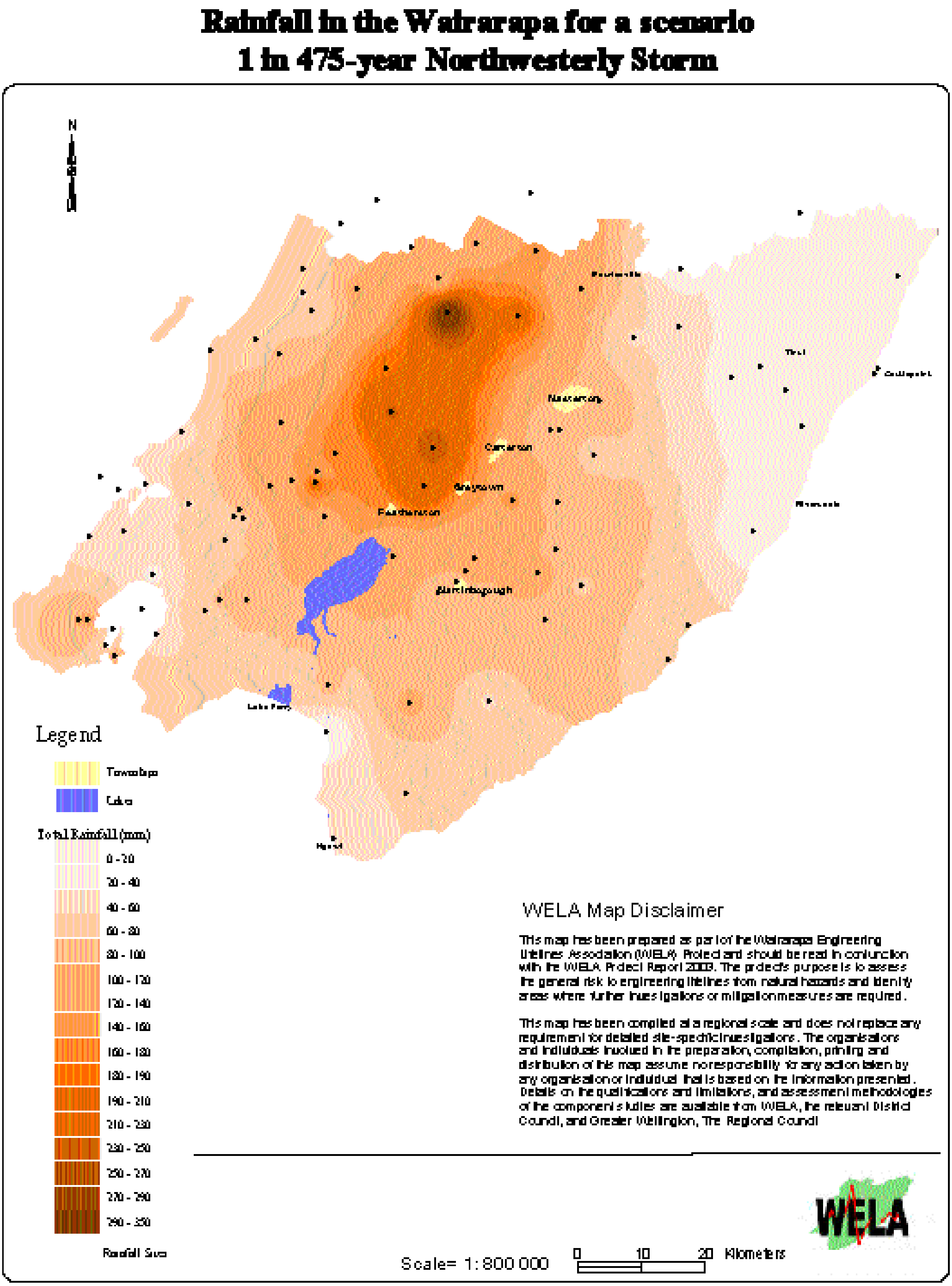

Figure 2.24. 24 hour rainfall for a one in 475 year scenario northwesterly Wairarapa storm, based on the rainfall from the 7-8 November 1994 storm. Source: NIWA 1999-2000.

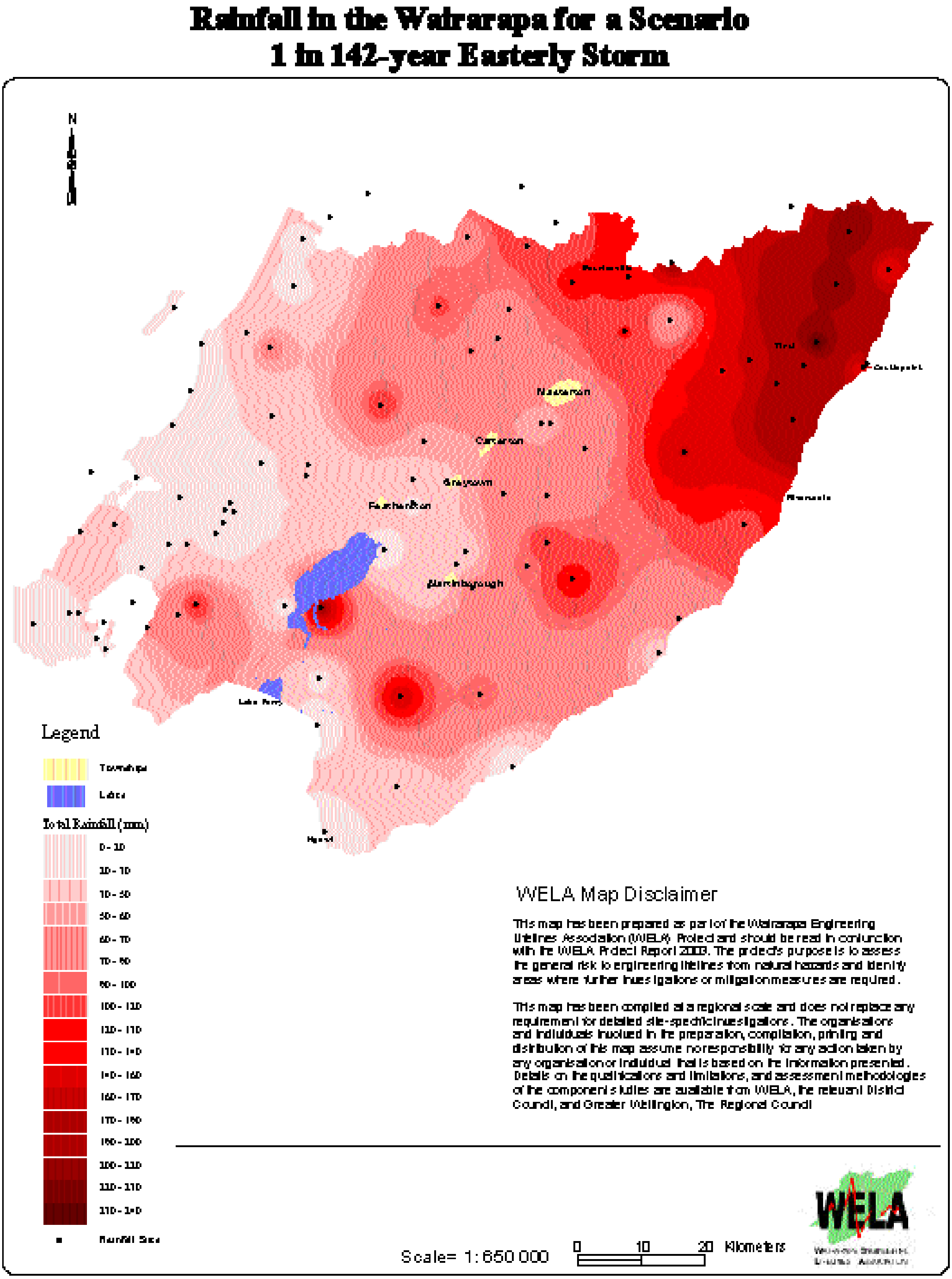

Figure 2.25. 24 hour rainfall for a one in 142 year scenario easterly Wairarapa storm, based on the rainfall from the 8-10 April 1991 storm. *Source*: NIWA 1999-2000.

Rainfall in the Wairarapa for a Scenario 1 in 475-year Easterly Storm

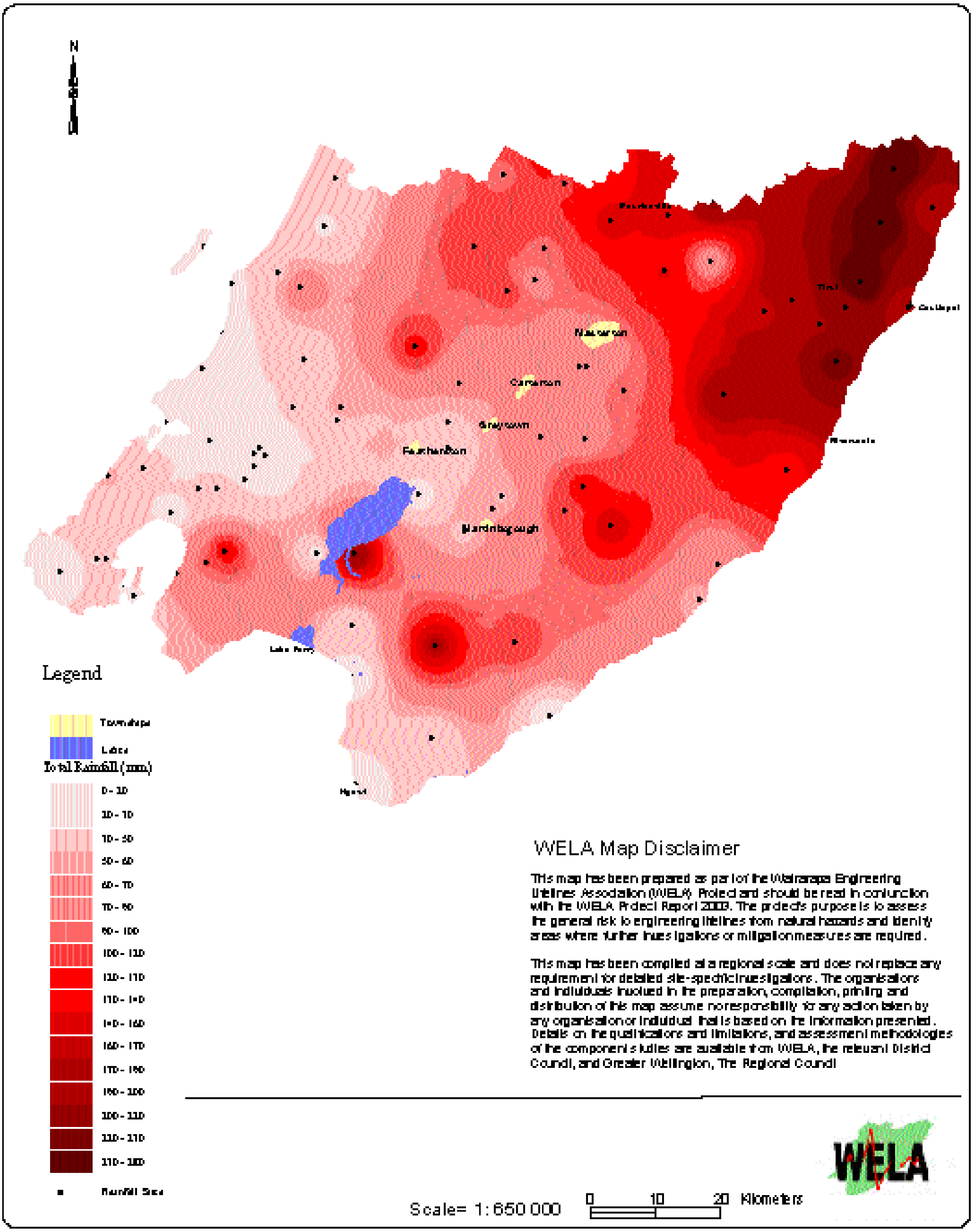

Figure 2.26. 24 hour rainfall for a one in 475 year scenario easterly Wairarapa storm, based on the rainfall from the 8-10 April 1991 storm. *Source*: NIWA 1999-2000.

Mean wind speed and direction are important for general meteorological assessments. However, the speed of extreme wind gusts is of importance in lifelines studies, since they have potential to cause much damage. While the strongest wind gusts in the Wairarapa are from the northwest, strong winds also occur from the south (NIWA 1999-2000).

Northwesterly wind stom

Northwesterly windstorms tend to be associated with frontal passages. They are a common occurrence in the Tararua ranges and its foothills, in the Haurangi Mountains, and in the coastal hills of eastern Wairarapa.

On October 19 1998, an extensive northwesterly airstream covered the Tasman Sea and New Zealand. It was associated with an approaching trough of low pressures in the mid-Tasman Sea and a very deep depression south of New Zealand.

At Castlepoint the maximum wind gust recorded was 183 kilometres per hour. A 124 kilometres per hour wind gust was recorded at the same time, at East Taratahi (near Masterton). Gales throughout the Wairarapa brought down trees, branches, power lines, roofing iron, farm buildings, sheds, and television aerials.

Southerly wind stom

Between 8-12 April 1968, ex-tropical cyclone Giselle (also known as the Wahine Storm) passed to the east of the Wairarapa. Wind gusts of up to 213 kilometres per hour were reported at Cape Palliser. Wind speeds along the Wairarapa's east coast were less severe, with gusts to 59 kilometres per hour recorded at Castlepoint. However, strong winds on the Masterton-Castlepoint Road at Te Ore Ore, snapped several telephone poles (**Figure 2.27**).

The following damage in the Wairarapa was reported in the regional press *(Press Association, Wellington)*:

> *Schools were closed, homes damaged, roads cut and power and telegraph lines brought down. High seas at Castlepoint reached almost to the lighthouse which perches more than 100 ft (~30 m) above the normal high tide mark. At 10 am almost the entire Wairarapa was without electricity and engineering staff said they could only guess at the extent of the damage.*
>
> *Hundreds of trees crashed over roadways, bringing down power and telegraph lines. Telephone communication was subject to indefinite delay and teleprinter links between the Chief Post Office and other main New Zealand centres were cut.*

Figure 2.27. On the Masterton-Castlepoint Road at Te Ore Ore, telephone poles snapped during the Wahine Storm, April 1968.

Predictions of extreme wind storms

Wind speeds in the Wairarapa have been predicted for one in 142 year and one in 475 year return periods (see **Figure 2.28** and **Figure 2.29**). The predictions are based on modelling of winds over the lower North Island.

The wind gust speeds shown in Figures 23 and 24 are a broad assessment of the variation of the wind hazard in the Wairarapa area. It should be noted that the data is the value at 10 metres above the ground. N.B. this data should not be relied on for detailed design of structures, for which the provisions of NZS4203 should still be followed. For important structures, site specific wind-engineering advice should be sought.

The basic wind speed values in NZS 4203 are for a risk of exceedance of about five percent in 50 years (return period of about 900 years) also at a height above ground of 10 metres. The wind speeds in the code are normally modified by terrain/height and 'limit state' multipliers. The affect of the limit state multiplier of 0.93 is to reduce the return period to about 475 years.

The speeds are further modified by the hill-shape and escarpment multipliers given in NZS 4203 which vary from 1.04 to 1.54; and the channeling multiplier, which varies from 1 to 1.2.

To allow some sort of comparison with the values given in **Figures 2.28** and **2.29**, the basic wind speeds in NZS 4203 applying to the open terrain of the Wairarapa Valley floor (Terrain category 2), when modified as above, give values which vary from about 45 metres per second for wind from the north-west and westerly directions to 40 metres per second from the east. In the eastern hill country and for site specific topography elsewhere, wind speeds are increased by the hill-shape and channeling multipliers mentioned earlier. Higher basic wind speeds apply to the areas around Palliser Bay.

The wind gust speeds given in the study do not take account of possible trends which may occur in the climate over the next 50-100 years. Recent climate change assessments suggest an increase in westerly winds across New Zealand, but no scenarios have yet been developed on how this may affect wind extremes.

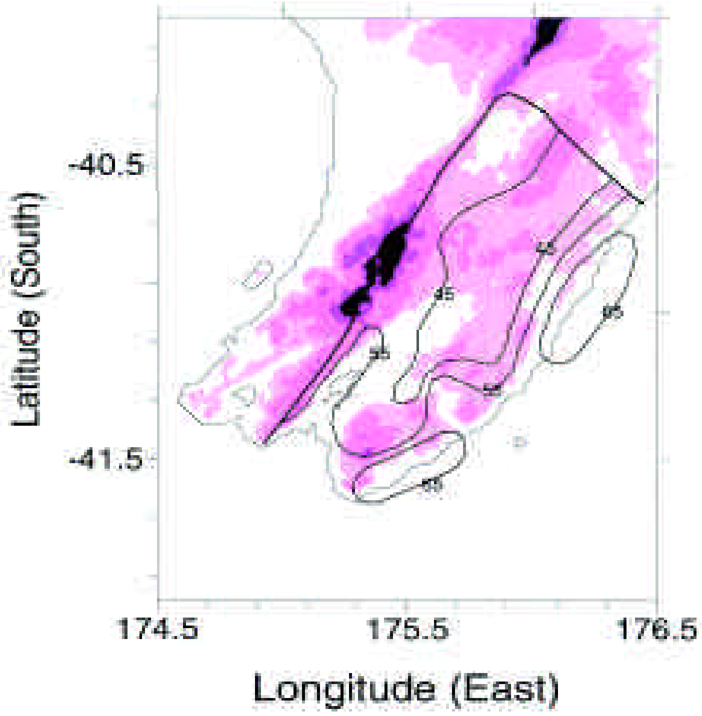

Figure 2.28. Contours of maximum wind gust speeds (metres per second) expected to be equalled or exceeded at average intervals of 142 years in the Wairarapa.
Source: NIWA 1999-2000.

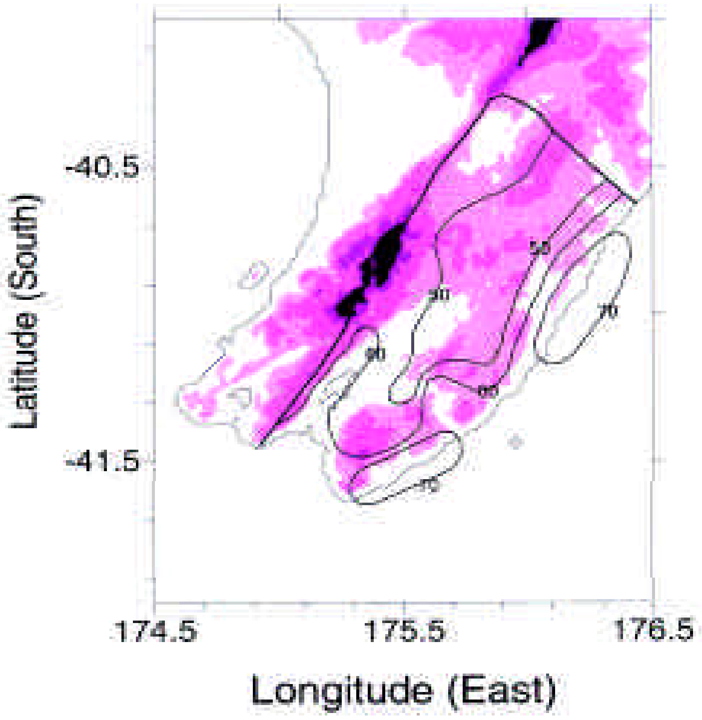

Figure 2.29. Contours of maximum wind gust speeds (metres per second) expected to be equalled or exceeded at average intervals of 475 years in the Wairarapa.
Source: NIWA 1999-2000.

Comparison with observed gusts

The modelled wind gust speeds compare well to observed gust speeds (**Table 2.7**). The modelled one in 142 year gust speeds are higher than the maximum gusts observed at Masterton and Castlepoint, but lower at Cape Palliser. The one in 475 year modelled speed for the Wairarapa Coast is only marginally higher than the maximum measured gust at Cape Palliser (observed during the Wahine Storm in 1968).

Station	Max observed gusts (km/hr)	One in 142 model (km/hr)	One in 475 model (km/hr)
Masterton	148	162	180
Castlepoint	183	198	216
Cape Palliser	213	198	216

Table 2.7. Comparison between observed and modelled Wairarapa wind gusts. *Source*: NIWA (1999-2000).

Local wind effect

Local wind effects are higher than expected local wind speeds resulting from the acceleration of the wind caused by topographic features such as mountain ranges, hills, escarpments and valleys. These local wind effects are well known to people living in the area who are in a position to observe the end results of the hazard and take precautions accordingly.

There are several points on the Rimutaka Hill section of State Highway 2 where experience has shown that higher than expected local wind speeds are generated in high winds. Traffic on these portions of the road is protected to some extent by the special high slatted fences or by warning signs. In other areas such as south of Mt Bruce, local wind effects are experienced due to channelling by the topographic features of the Ruamahunga Valley in the foothills of the Tararua Ranges. Experience has shown that this affects traffic on State Highway 2 and the Transpower transmission lines in the area.

FURTHER READING:

1. *Meteorological Hazards Relevant to Wairarapa Engineering Lifelines* (includes supplementary reports completed in 2000 on *Wairarapa Windstorms* and *High Intensity Rainfalls*), National Institute of Water and Atmospheric Research (NIWA), Wellington, 1999-2000.
2. Thompson, C S, *The Weather and Climate of the Wairarapa Region*, New Zealand Meteorological Service, Wellington, 1982.

OCTOBER 13-27, 1998 WINDSTORMS AND DAMAGE TO ELECTRICITY SUPPLY IN THE WAIRARAPA

This was a particularly windy period, with severe gale northwesterlies throughout the lower North Island on 13,19, 20 and 27 October.

On 19 October, Wellington Airport recorded a maximum gust of 65 knots (120 kilometres per hour) in the hour ending 7pm, while Beacon Hill recorded a maximum of 88 knots (166 kilometres per hour) in its 6pm synoptic report. In Cook Strait, Brothers Island reached 69 knots (127 kilometres per hour) in the hours ending 7pm and 8pm. In the Wairarapa, where the strongest wind gusts were recorded, Castlepoint reached 99 knots (183 kilometres per hour) in the hour ending midnight (highest there since records began in 1972), while Hau Nui wind-farm, south of Martinborough, recorded gusts to 112 knots (207 kilometres per hour).

Local electricity supplier, Powerco, recorded its greatest unplanned outage to the Wairarapa electricity supply during October – over 80 minutes of power outage for connected customers. The monthly average for the period 1995-1999 was approximately 10 minutes.

Outages were attributed to wind damage to poles and equipment. Almost 30 poles were lost on the 11kV line to the east of Tinui. The failures started just beyond the road bridge over the Whareama River. Powerco budgets on loosing 20 poles per year to various hazards including wind and in 1998 it lost a total of 40.

Included in the loss were two multi-pole structures each consisting of two pre-stressed concrete poles with wire rope guys and anchors. The galvanised steel bolts to the wire rope guys failed under the exceptionally high wind loads with yielding evident at the failure. There were also some signs of corrosion of bolts due to electrolysis caused by fault currents. (Current practice is to use insulators on wire rope guys on 11 and 33 kV lines).

(4) Cyclones of tropical origin

HAZARD DEFINITION

Cyclones, a distinctive feature of the Southwest Pacific climate, are large depressions accompanied by high winds and heavy rain. They are usually classified by their maximum wind speed. Tropical systems having wind speeds greater than 62 kilometres per hour are called tropical cyclones.

They usually form between November to April over the warm water of the tropics (between 5°S and 20°S). After formation and development, the majority of cyclones move southeastwards out of the tropics. On occasion they pass close to or over New Zealand. By the time they move into New Zealand's latitudes, many have lost much of their intensity. Although often downgraded to mid-latitude storms, some cyclones crossing near New Zealand can still be intense (e.g. Cyclone Bola).

Hazards arising from cyclones include the effects of heavy rain, high wind (see above), and storm surge. Heavy rain can cause localised flooding, widespread river flooding, and landslides. High winds may cause structural failure to buildings, trees, and power and communication lines. Storm surge is the temporary elevation of sea-level due to very low atmospheric pressure. Storm surge, coupled with high waves and strong onshore winds can cause extensive sea flooding of coastal areas.

WAIRARAPA CONTEXT

Between 1960 and 1989, 32 tropical cyclones passed close to New Zealand. Of these, 10 came within 300 kilo metres of the Wairarapa (**Figure 2.30**). Only one – cyclone Elsa in January 1976 – directly crossed the Wairarapa.

Current data indicate that, on average, a cyclone passes over or close to the Wairarapa once every three years (NIWA 1999-2000). Insufficient data exists for a full analysis of the recurrence interval of cyclones in the Wairarapa.

Past experiences of cyclones that have passed over or close to the Wairarapa indicate that they are generally no more significant than the typical mid-latitude storms that pass over the region (NIWA 1999-2000). Of the 10 cyclones to affect the Wairarapa to date, single-day maximum rainfalls varied from as little as 17 millimetres to only 136 millimetres. These amounts are much less than single-day rainfalls recorded around the Wairarapa during other weather patterns. Similarly, high winds in the Wairarapa are often formed in the Wairarapa from other weather patterns.

Since cyclones appear to be no more significant than other Wairarapa storms, it is probably more appropriate to study the associated hazards individually rather than specifically assessing the effects of tropical cyclones (see '*Heavy Rain*' and '*Windstorms*' sections above).

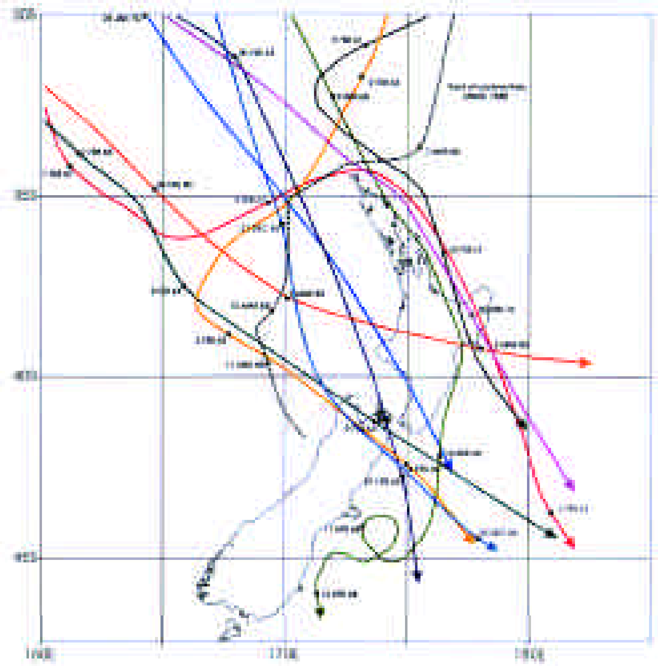

Figure 2.30. Tracks of cyclones which came within 300 km of the Wairarapa from 1960-1989. Their noon positions are labelled. *Source*: NIWA (1999-2000).

FURTHER READING

1. *Meteorological Hazards Relevant to Wairarapa Engineering Lifelines* (includes supplementary reports completed in 2000 on *Wairarapa Windstorms* and *High Intensity Rainfalls*), National Institute of Water and Atmospheric Research (NIWA), Wellington, 1999-2000.

(5) Lightening

HAZARD DEFINITION

Lightning is a visible electrical discharge from the sky during a thunderstorm. The most dangerous lightning is cloud-to-ground discharge. Large amounts of energy (billions of joules) are released in each lightning strike.

Hazards from lightning generally result from direct strikes on humans, animals or property. Humans may suffer electric shock and/or severe burns, sometimes resulting in death. The huge electrical discharge produced during a lightning strike can disrupt power lines, cause power surges that may damage unprotected electronic equipment, or start fires when electronic systems are short circuited. Lightning strikes may also spark bush and forest fires, especially if preceded by very dry conditions.

Lifelines that are particularly vulnerable include communication networks (cell phone sites, aerials, and overhead lines) electricity transmission lines and substations.

WAIRARAPA CONTEXT

Estimating the number of lightning ground strikes in the Wairarapa is difficult because until recently there has been no systematic way of measuring them (NIWA, 1999-2000).

Traditional meteorological observations record the number of *thunderdays*. Unfortunately, this tends to underestimate the actual number because it does not include missed observations, observations at night and areas of the Wairarapa where there were no observers.

Electronic lightning flash counters (LFCs) count both cloud to cloud and cloud to ground strikes. Hence LFCs tend to over-estimate the number of lightning ground strikes. They can be considered an 'upper limit'. A more detailed discussion on both *thunderday* observations and LFC counts is presented in NIWA's 1999-2000 report (see below).

The number of *thunderdays* in the Wairarapa (**Figure 2.31**) should be treated as the minimum. Based on estimates from both *thunderday* observations and LFC counts, it is estimated that, on average, lightning is likely somewhere between 10 and 20 days per year over much of the Wairarapa (NIWA, 1999-2000).

Transpower and the New Zealand MetService have recently installed a network of lightning counters that are able to determine the direction and location of lightning strike over long distances. The data from these counters should, over time, improve knowledge of lightning hazard in the Wairarapa.

FURTHER READING

1. *Meteorological Hazards Relevant to Wairarapa Engineering Lifelines* (includes supplementary reports completed in 2000 on *Wairarapa Windstorms* and *High Intensity Rainfalls*), National Institute of Water and Atmospheric Research (NIWA), Wellington, 1999-2000.

(6) Snow

HAZARD DEFINITION

Snowfalls typically occur between May and October when cold south to south-easterly precipitation-bearing weather systems pass over New Zealand. They are generally restricted to areas higher than 500 metres above sea level.

Snowfalls are a hazard mostly to farmers' stock, although in populated areas power and communication lines, communication nodes on high ground (cell phone repeaters), and transportation routes may be disrupted. Falls in late spring can be particularly hazardous to stock with recently born

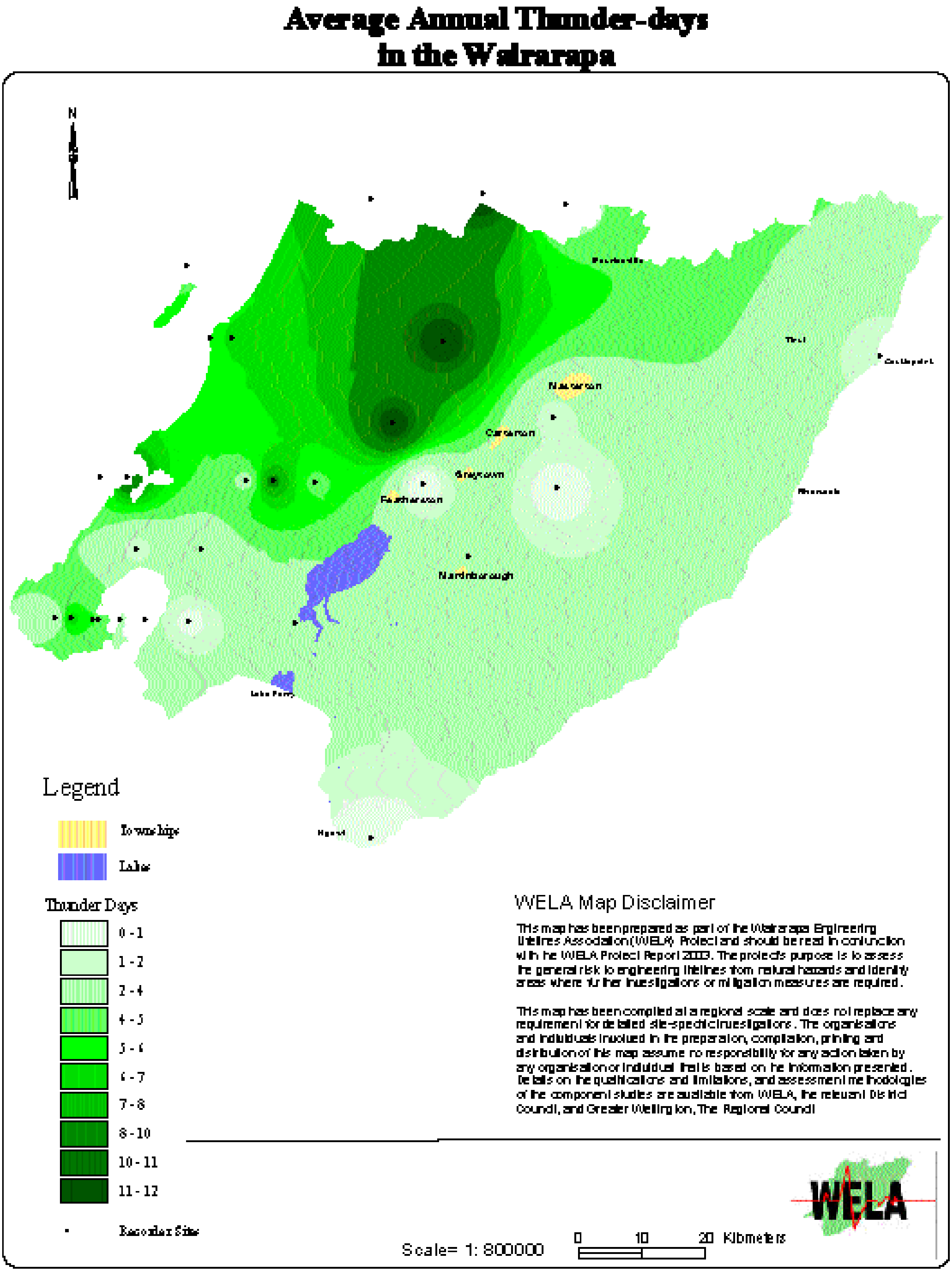

Figure 2.31. Average annual thunder-days over the Wairarapa. Derived from meteorological 'thunder-day' reports to 1994. *Source*: NIWA (1999-2000).

offspring or if stock have already been moved to higher ground.

Prediction of weather related events is improving, allowing accurate and reasonable (24-36 hours ahead) warnings. MetService issues severe weather warnings for the North Island when 10 cm or more of snow is expected in a six hour period over an area of 1000 square kilometres or more. The same warning is issued when 25 centimetres or more of snow is expected in a 24 hour period.

WAIRARAPA CONTEXT

Most snow in the Wairarapa is associated with deep lows or troughs over or just east of the North Island. It is accompanied by strong cold south to southwest winds over and east of the South Island *(Thompson, 1982)*.

Most snowfalls in the Wairarapa occur in the Tararua and Rimutaka Ranges and are more common during winter and early spring. However, most observation sites are located in the Wairarapa Valley, where snowfalls are relatively rare. Hence it is difficult to make a comprehensive assessment of snowfall hazard over most of the Wairarapa (NIWA, 1999-2000).

It is possible to estimate snowfall risk by plotting the relationship between the number of snowfall observations per year with the altitude of the observation site (**Figure 2.32**). The relationship suggests that below 200 metres, snow occurs about once every 2-5 years. **Figure 2.33**, combining data from the Wairarapa and Hawke's Bay, suggests that there are approximately five snowfalls per year around 600 metres. Above 800 metres, more than 20 snow days per year can be expected (NIWA, 1999-2000).

FURTHER READING

1. *Meteorological Hazards Relevant to Wairarapa Engineering Lifelines* (includes supplementary reports completed in 2000 on *Wairarapa Windstorms* and *High Intensity Rainfalls*), National Institute of Water and Atmospheric Research (NIWA), Wellington, 1999-2000.
2. Thompson, C S, *The Weather and Climate of the Wairarapa Region*, New Zealand Meteorological Service, Wellington, 1982.

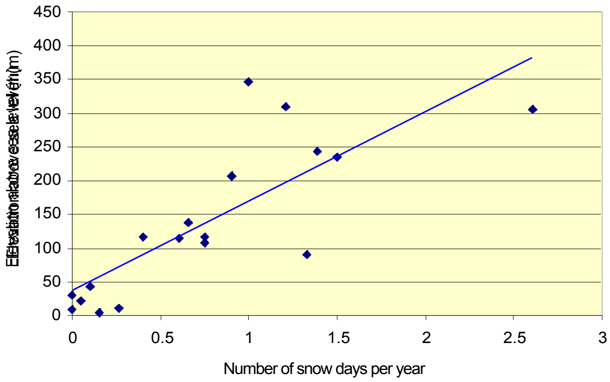

Figure 2.32. Number of snowfall days per year for a given altitude. *Source*: NIWA (1999).

2.5 FLOODING

Flooding poses a risk to human life, animals, engineering lifelines, the built environment, and the productive and natural landscape. Flooding has been a major hazard to human settlement for thousands of years. There are two types of flooding which are hazards. These are surface flooding and river flooding, as described below.

(1) Surface flooding

HAZARD DEFINITION

Surface flooding occurs under intense rainfall when surface drains and soil infiltration cannot cope with the rainfall intensities. It is most pronounced in the urban environment with its large areas of impermeable roofs and paved surfaces. Here flooding may be exacerbated by debris blockages at the entries to culverts and drains.

While unlikely to pose a direct threat to human life, surface flooding can be both disruptive and costly. When it enters sewage reticulation systems, overflows may pose a serious health hazard. Flooding of houses and commercial premises may occur, with resultant damage and disruption costs similar to those associated with river flooding.

WAIRARAPA CONTEXT

Surface flooding can affect any Wairarapa town in a particular storm event. Masterton has been particularly vulnerable in two locations. At upper Renall Street, surface water from Upper Plain would impound behind the railway and flood roads and footpaths and surround houses. The Queen Street, Lincoln Road area would experience heavy flooding from north-west Masterton and shops became flooded on a number of occasions. Storm water drainage systems have been installed to counteract flooding in these two areas.

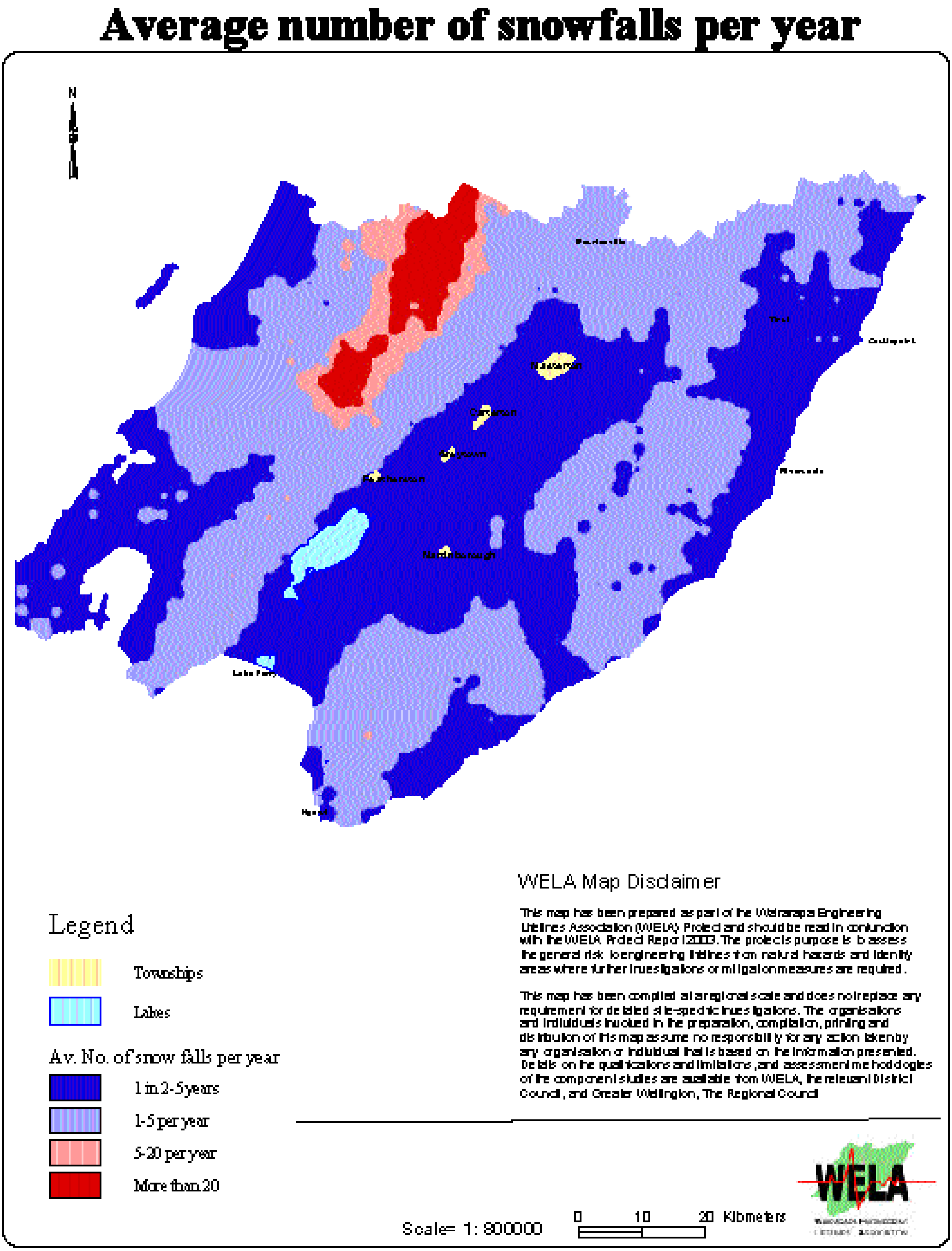

Figure 2.33. Number of snowfall days per year for a given altitude. Based on the relationship between snowfall reports and elevation above sea level. *Source*: NIWA (1999-2000).

Masterton flooding – Dec 1993/Jan94

A 'freak' cloudburst over Masterton on 31 December 1993 saw over 50 millimetres of rain falling within an hour. Surface water from western Masterton built up at the town centre, turning Lincoln Road and Church Street into a river. Several shops were flooded, especially in the Star Block where up to 400 millimetres of water accumulated. The fire brigade received many calls for assistance and requests to pump water. The cost of damage was subsequently estimated at $0.5 million.

An investigation showed that such floods could be expected every five to 10 years, with longer duration and more damaging events possible. The need for a significant increase in capacity of the storm water system in the town drain catchment was identified and an additional 1800 millimetres diameter drain installed along Chapel Street to the Queen Elizabeth Park Lake at a cost of $1.58 million.

Figure 2.34. Surface flooding in Queen Street, Masterton during the 1993-94 flood. *Source*: Wairarapa Times-Age.

(2) River flooding

HAZARD DEFINITION

In their natural state, rivers and streams would overflow their banks two or more times each year. They were a dynamic part of the natural landscape, frequently shifting and changing course over their floodplains and eroding and depositing silts, gravels, and debris.

Man has sought to fix the rivers in the landscape. Stopbanks have been used to contain floodwaters and allow farming and urban development on the valuable flood plain soils.

People's action in restricting rivers and reducing their flooding has created its own requirements and risks. Managing rivers and keeping them within a defined channel requires considerable ongoing, costly, maintenance and repair. Stopbanks can offer a false sense of security. Large floods can exceed their capacity, or breaches can heighten localised damage and risk to human life.

River flooding has several components that are often interrelated:

Inundation

This occurs when excess floodwaters overflow from the normal river channel and pass over property. Once river levels fall, flooding ceases, although in low-lying areas, ponds may remain for a number of days.

Resultant damage relates to several factors such as:

- Depth of floodwater
- Velocity of floodwater
- Duration of flooding and subsequent ponding
- Debris accumulation
- Scour
- Silt/gravel deposition

Flooding may be induced by landslides. Landslides can dam significant volumes of water within valleys. The release of this stored water can produce a 'flash flood', often occurring during floods and adding a sharp peak to flood levels.

Change of course

This occurs when river flows become routed down a new overland course, leaving the normal riverbed partly or completely abandoned. Damage is caused by the factors accompanying inundation. However without quick intervention, damage is considerably more severe as it arises from a continuing, and not a short term effect.

Bank erosion

Bank erosion results from the erosive force of floodwaters removing soil and gravel material from riverbanks, adding it to the bed load of the river. This frequently results from the accumulation of debris or gravel in the riverbed, which directs floodwaters to attack the river bank. Such erosion can be very rapid and destroy bank protection works and stopbanks. It may also lower natural ground contours, allowing floodwaters to spill over at far lower river levels than previously.

Bank erosion is invariably a precursor to increased flooding and changes of river course.

Scour

Scour occurs when floodwaters remove sufficient bed material to put an asset at risk of undermining, loss of support or damage. This is particularly relevant to bridge abutments and piers, water intakes, and pipelines and cables that pass under riverbeds. Scour can also result from the concentration of flow due to river bed obstructions, or a progressive lowering of the riverbed.

Aggradation

This is a progressive increase in river bed levels. This reduces channel capacity and subsequently increases flood risk and frequency. At the same time the river flow pattern may become unstable, increasing the risk of bank erosion. It is of particular concern when it reduces the waterway openings under bridges.

WAIRARAPA CONTEXT

Geographical setting

The geography of the Wairarapa has three distinct landscapes (**Figure 2.35**). The western Tararua and Rimutaka Ranges form part of the New Zealand axial mountain system and range in height from 350 metres above sea level in the foothills at Kaituna to a maximum height of 1571 metres above sea level at Mitre Peak. They comprise steeply tilted Triassic greywacke and argillite rocks, which are faulted in a south-west to north-east direction. The main headwaters of the Ruamahanga River and most of its tributaries – the Waingawa, Waipoua, Waiohine and Tauherenikau follow these fault valleys.

Beyond the grassed or scrub covered foothills, the ranges are largely forested. Mixed podocarp forest occupies the lower valleys, giving way to beech on the higher more exposed slopes. At 1200 metres above sea level a scrubby, leatherwood zone gives way to tussock grassland. The Tararuas provide water for all Wairarapa towns except Martinborough.

The Wairarapa Valley was formed by the infilling of a faulted depression with gravel material, eroded from the mountains in the west. The resultant plain has a general slope to the south with the course of the Ruamahanga River occupying the lowest parts of the plain, abutting the eastern hill country. The tributary rivers have historically criss-crossed the valley, which is characterised by numerous former channels and terrace systems. To the south, Lakes Wairarapa and Onoke represent the remaining part of the fault depression that is still being infilled with sediment. They are shallow lakes with an average depth of only one metre. Land in this vicinity is very flat and low-lying and depends on drainage pumps for protection and production.

The Eastern Hills comprise tertiary sedimentary rocks – limestone, mudstone, siltstone, sandstone, and argillite. Apart from limestone, these rocks are weakly structured and susceptible to soil erosion, which can be accentuated under pastoral use. Widespread earthquake faulting adds to this erosion susceptibility.

Deep, free-draining gravels underlie the plains. The gravels are coarsest close to the mountains and progressively reduce in size towards the south until, in the lower valley, deep silts predominate with restricted natural drainage. Along the rivers more recent fertile silts are found, derived from the deposition of silts and fine sands during floods.

The Wairarapa Valley does not contribute significantly to floods. No rivers arise on the plain, and natural watercourses are limited to small spring-fed streams often sourced at fault scarps. The plains have a predominant pasture cover with no significant areas of forest.

Approximately 35 percent of the eastern hill country lies within the catchment of the Ruamahanga River, with the Taueru being its largest tributary catchment (**Figure 2.36**). Other rivers are the Kopuaranga, Whangaehu, and Huangaroa. The balance of the hill country drains directly to the coast by way of the Mataikona, Whareama, Kaiwhata, Wainuioru/Pahaoa, Awhea, and Opouawe rivers. These rivers have high silt loads and are poor water sources. Their limited floodplains have heavy soils that are prone to flooding.

History

Rivers with their ongoing risk of flooding constitute the most frequent hazard to the Wairarapa. Maori history records events such as the Waingawa changing its course to join the Waipoua at Akura, and the damming and drying up of the Ruamahanga River by the Hidden Lakes landslide. This was followed by a huge spate when the dam later burst.

Early Wairarapa newspapers report the repeated flooding of Masterton and Greytown, while flooding in the Lower Wairarapa Valley was a significant issue until the flood protection scheme was completed in 1983. (See **Figure 2.37 and 2.38**) During the 1947 flood, 20,000 hectares were inundated for many days with severe stock and productive losses (**Figure 2.39 and 2.40**).

Flood conditions

Floods most frequently arise from heavy westerly rain in the mountain ranges. Lying across the prevailing westerly winds, the Tararua and Rimutaka Ranges cause warm moist laden air direct from the Tasman Sea to rise and cool. This adiabatic effect causes clouds to

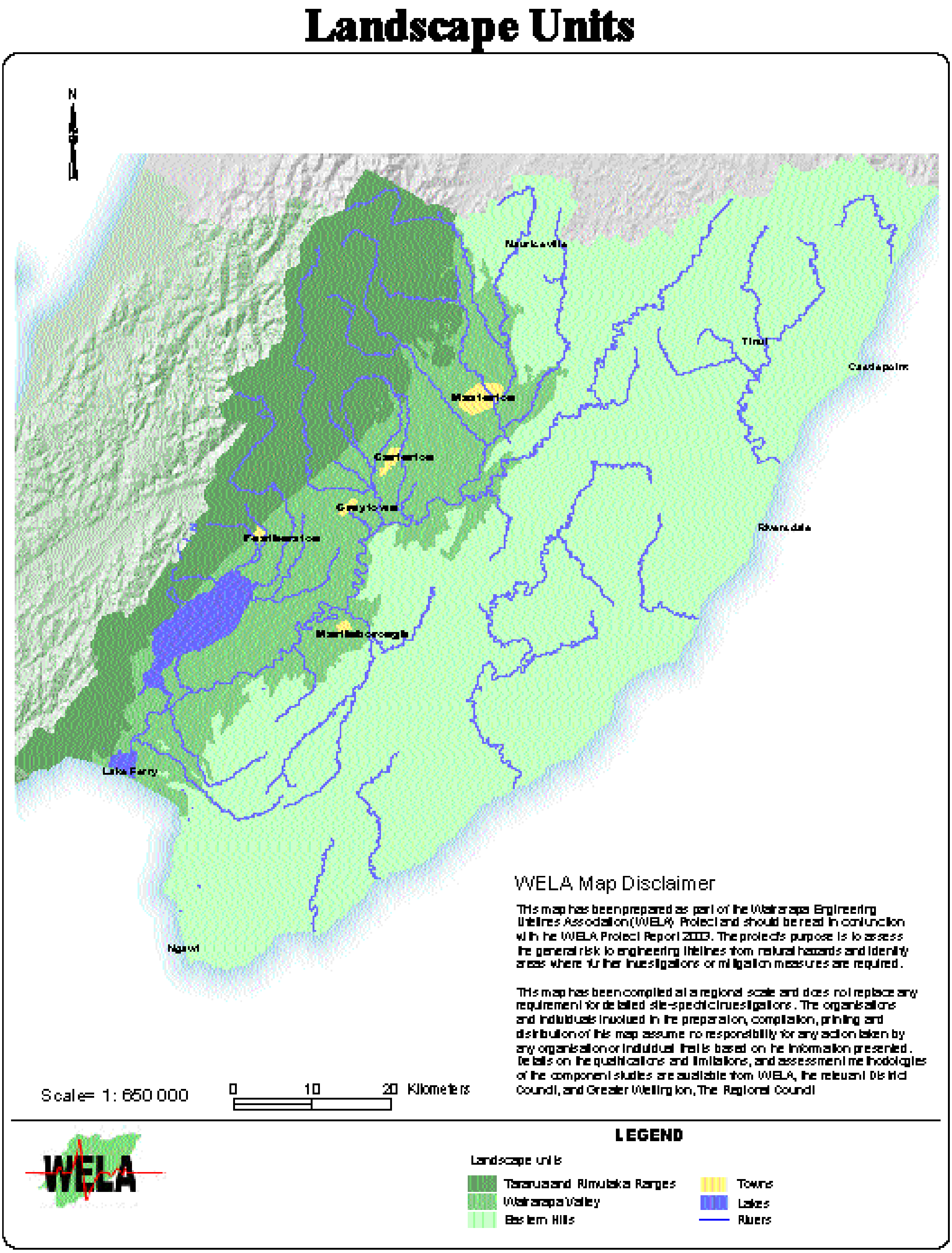

Figure 2.35. The three distinct units of the Wairarapa landscape; the Tararua and Rimutaka Ranges, the Wairarapa Valley and the Eastern Hills.

River Catchments

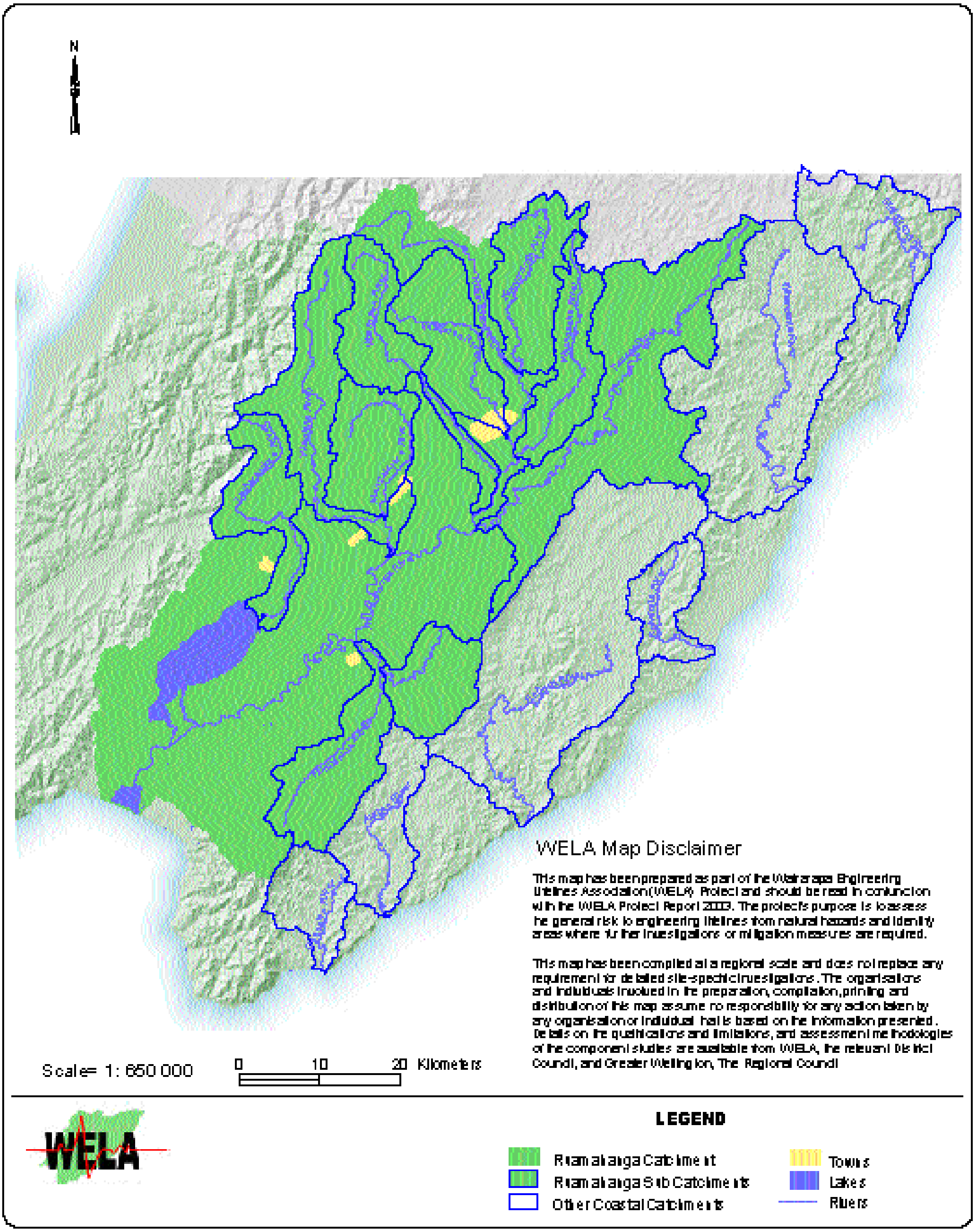

Figure 2.36. The main Wairarapa rivers and their catchments. The major Ruamahanga River Catchment is highlighted.

Flooding at Settlement - c1850

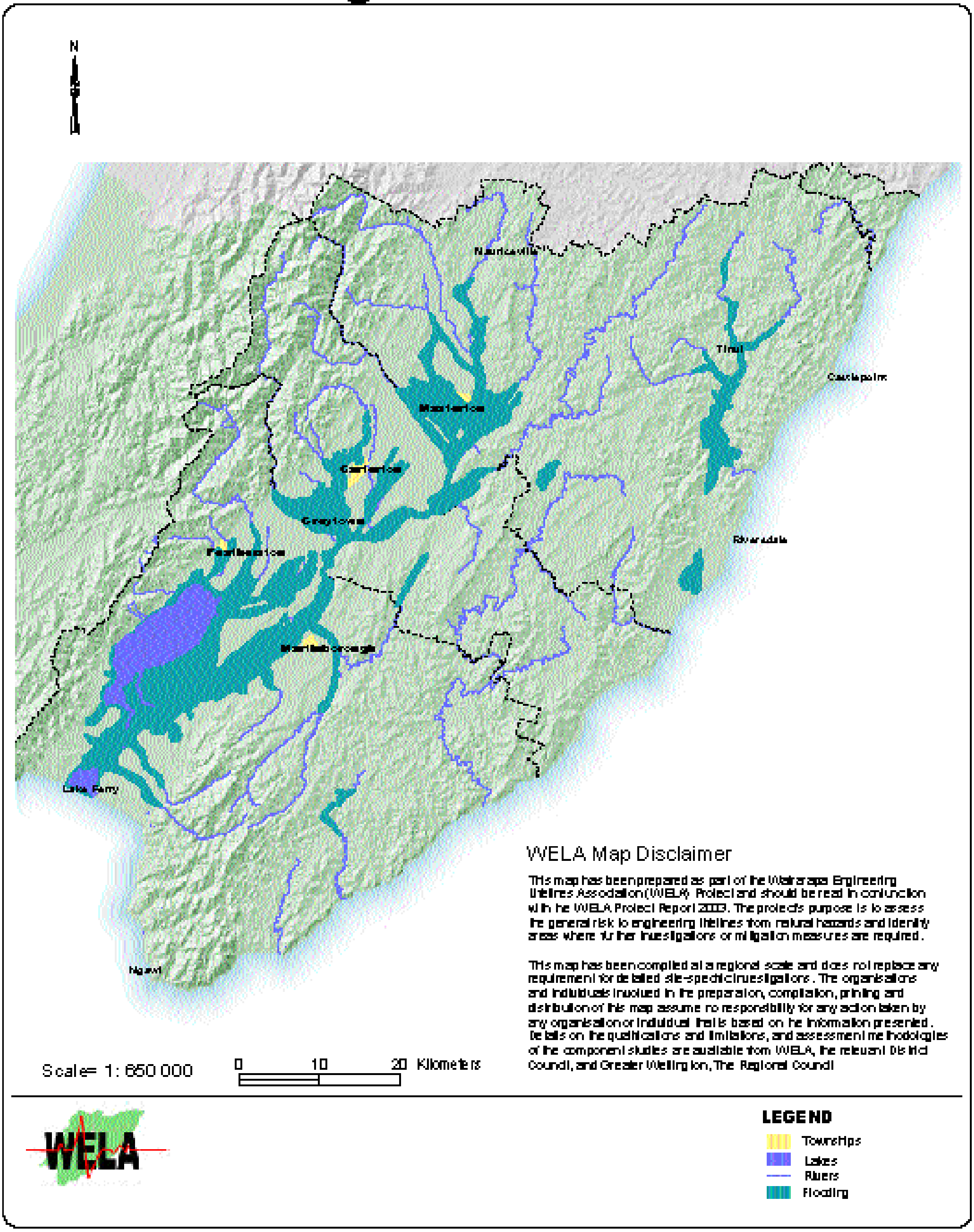

Figure 2.37. An indication of areas vulnerable to flooding at time of settlement, before the days of river boards, river management and flood protection works.

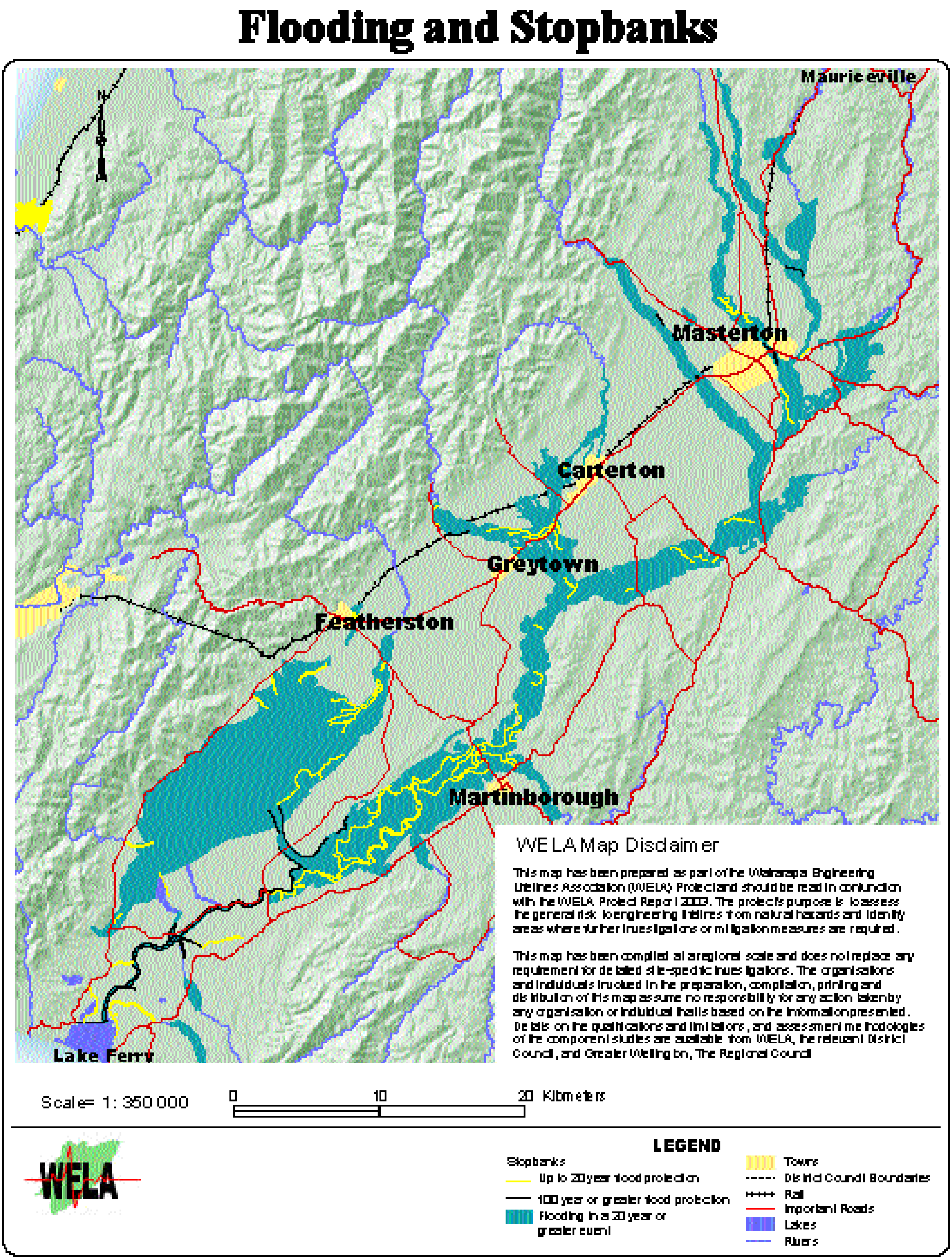

Figure 2.38. This figure shows the extent of flooding anticipated in a one in 20 and one in 50 year event. It provides for existing flood protection structures to function to their design standards during such events. Not all catchments would be expected to flood in any particular storm event.

Lower Wairarapa Valley flood, 1947

Report from Wairarapa Times Age

A disastrous flood has occurred in the South Wairarapa, described as the worst for 50 years....Every stopbank in the Upper Lake area was overwhelmed and a huge area in the Pukio Basin and Kahutara has been inundated. Many settlers had to be rescued from their homes which had been invaded by flood waters.

In the Pirinoa area, the property of Kumenga Ltd is almost entirely under water and on 1.5 acres of dry land 12 people are marooned....supplies are to be dropped in by plane.....The Lake level has reached a height of 11 foot 6 inches above normal.

Many residents of the Pukio and Kahutara districts were faced with grave danger to their lives when the Ruamahanga River, bursting over its stopbanks, poured into the Pukio Basin inundating 10,000 acres of farm land. It is reported in places that the water was ten feet deep.

The Martinborough-Featherston Road, and the Martinborough - Lake Ferry Roads are now open......others still impassable.

A preliminary estimate of stock losses of about 5000 sheep and 300 cattle is given by the Assistant Director General of Agriculture.......individual stock losses and damage to property were very serious for many of the farmers.....donations of cash and hay continue to come in to assist sufferers and an organisation has been set up to administer the flood relief fund.

(The 1947 flood recorded a peak flow of 2044 cubic metres per second at Waihenga Bridge and was calculated to have a 100 year return period. The second large flood of November 1994 flood had a peak flow of 1819 cumecs and a 50 year return period).

Figure 2.39. Waihenga (Martinborough) Bridge and Tawaha Settlement, looking downstream 18 hours after the flood peak on Sunday 29 June, 1947.

lose their moisture and can give rise to large volumes of rain falling within only a few hours.

In January 1990, 268 millimetres of rain fell within six hours at Angle Knob in the Tararuas. In this event, a peak rainfall intensity of 61.5 millimetres per hour was recorded. This is equivalent to approximately one third of Masterton's total annual rainfall of 860 millimetres, falling within six hours. The average annual rainfall for Angle Knob is 6814 millimetres and is eight times greater than Masterton, although the sites are only 24 kilometres apart.

Westerly rainfall events are generally associated with the passage of a warm westerly front, that eventually gives way to cold and wet southerly conditions. It is rare for flooding to be associated with the subsequent southerly conditions. The westerly floods affect the Wairarapa Valley but have no impact on the eastern hill country. Intense westerly rainfall and severe flooding has occurred on days when the Wairarapa Valley has been basking in warm sunshine.

The rivers that rise in the Tararuas are relatively short and have steep gradients. They are 'high energy rivers' and give little time to warn people of forthcoming floods. Floods in the headwaters of the Waiohine River take only three hours to reach the Waiohine Rail Bridge and pose a threat to Greytown. Floods in the Upper Ruamahanga headwaters take two hours to reach the State Highway 2 bridge at Mount Bruce, and a further four hours to reach Masterton.

The lower reaches of the Ruamahanga River by contrast are meandering and have a gentle gradient. Floodwaters from Mount Bruce take some ten hours to reach a peak at Waihenga Bridge near Martinborough. Some two days then elapse before downstream floodways cease flowing and roads can be reopened.

Easterly to south-easterly events can also produce floods, often related to a relatively stationary area of low pressure lying off the Wairarapa coast to the south-east. Alternatively, heavy easterly rain may arise from

Figure 2.40. Lower Wairarapa Valley looking west over the Tuhitarata (Lower Valley) Bridge during the June 1947 floods.

Figure 2.42. The Waimoana Bridge after the June 1981 flood. The bridge had a clearance of eight feet when built.

the passage of a sub tropical cyclone down the North Island. The duration of such events and their intensities are difficult to predict.

Under easterly conditions, both the eastern hill country and the Tararua foothills can become saturated. The flooding that accompanies any further rain is usually prolonged, with sluggish catchments, such as the Taueru, remaining in high flood for a number of days. Floods affect road access in both the Ruamahanga sub catchments (Kopuaranga, Taueru, Whangaehu, and Huangaroa) and the coastal catchments (Whareama, Kaiwhata and Awhea.) In the Tararua and Rimutaka foothills, smaller rivers such as the Waipoua, Mangaterere, Donald's Creek and Cross Creek may also flood extensively.

The high coastal ranges can have an adiabatic effect under such easterly conditions. Over the years a number of localised, severe flood events have occurred under such easterly conditions with extreme localised damage to roads and bridges. The Kaiawhata and Flat Point areas were devastated by such a storm in 1981 (**Figure 2.42**).

In the Tinui storm of 10 April 1991, many sites received a 24 hour rainfall greater than 200 millimetres and a rainfall intensity of 35 millimetres per hour occurred at Anerley. Rapid and devastating flooding resulted with widespread damage. Several people were lucky to escape with their lives.

Cost of damage estimates ranged between $2.08 and $2.84 million.

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2.6 LANDSLIDES

HAZARD DEFINITION

Landslides are the displacement and downslope movement of parts of a slope. They may be earthquake-triggered, rainfall-triggered or a combination of both. The two triggering mechanisms are treated together, because the effects on lifelines are similar, regardless of the triggering mechanism.

Landslides, like other forms of ground deformation, cause catastrophic failure of lifelines that lie in their path. They can affect all lifelines that are sited on or below steep slopes. Landslides that block rivers or streams can flood upstream assets and cause flash floods if they burst suddenly.

In New Zealand, rainfall is the most common, and earthquakes the second most common means of

River	Geographical zone	Catchment area in square km (Note 1)	Largest Recorded flood in cumecs (Note 2)	Year
Ruamahanga at Mt Bruce	Tararuas	78	467	1982
Kopuaranga	Eastern Hills	164	56	1998
Waipoua	Tararuas	149	326 (Note 4)	1994
Whangaehu	Eastern Hills	145	80	1991
Ruamahanga at Wardells	Combined	637	1024	1998
Waingawa	Tararuas	139	426	1980
Taueru	Eastern Hills	497	488	1992
Mangaterere	Tararuas	146	370 (Note 4)	1994
Waiohine	Tararuas	378 (Note 3)	1558	1982
Huangaroa	Eastern Hills	315	135	1997
Ruamahanga at Waihenga	Combined	2340	2044	1947
Tauherenikau	Tararuas	140	670	1994
Ruamahanga at Onoke Spit	Combined	3365	NA	-
Mataikona	Eastern Hills	191	NA	-
Whareama	Eastern Hills	531	1021	1991
Kaiwhata	Eastern Hills	99	351	1991
Pahaoa	Eastern Hills	639	1108	1992
Awhea	Eastern Hills	145	NA	-
Opouawe	Eastern Hills	104	NA	-

Note 1: Measured to river mouth or confluence. Note 2: Measured at gauging station not bottom of catchment. Note 3: Includes Mangaterere catchment. Note 4: Estimate

Table 2.8. Wairarapa rivers, their catchment sizes and largest recorded flood.

Tinui flood – 10 April 1991

Even with its long history of flooding, Tinui was completely taken by surprise by the savageness of this flood. The speed with which the village went under water and the depth of water inside houses and businesses shocked long-time residents. Floodwaters entered five houses, the school, two shops, a church and the hotel. Communications were lost for 12 hours, the electricity substation was flooded and failed, and there was widespread road damage.

Figure 2.41. Vehicle lifted onto hedge by the 1991 flood waters.

triggering landslides. Hancox *et al* (1997), have produced the most comprehensive study to date on the subject of earthquake-triggered landslides in New Zealand and relevant findings are summarised below. Earthquake-triggered landslides, although less frequent than rainfall-triggered landslides, tend to be bigger and capable of greatest impact.

Since 1840, 22 New Zealand earthquakes are known to have produced damaging landslides. Damage to buildings and other structures by earthquake-triggered landslides are second only to that caused by strong shaking *(Hancox et al, 1997)*. Many roads and buildings have been destroyed or closed by landslides and rock falls, and at least seventeen people are known to have been killed. Areas below steep natural slopes and man-made slopes are regarded as highly hazardous during earthquakes *(Hancox et al 1997)*.

In terms of earthquake magnitude, very small landslides may occur at Richter Magnitude 5 but significant landsliding only occurs at Richter Magnitude 6 or greater. Very large rock avalanches are caused by earthquakes greater than Richter Magnitude 6.5 on slopes steeper than 25-30 degrees and more than 100-200 metres high. The most common intensities for significant landsliding are MM VII and MM VIII. Very large landslides occur at MM IX and MM X (**Figure 2.43**).

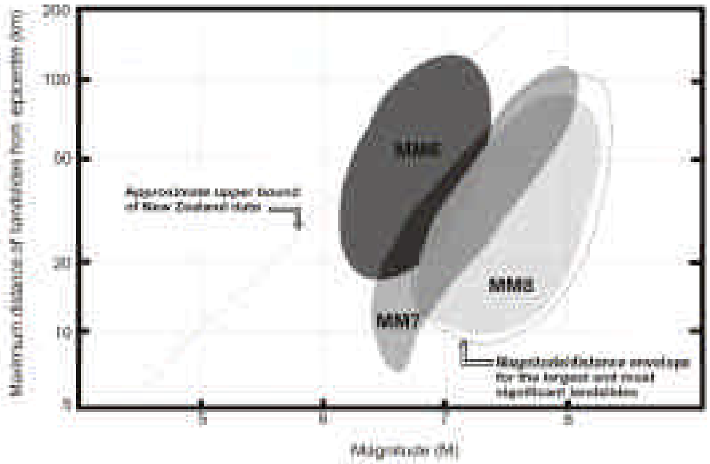

Figure 2.43. This figure highlights the shaking intensity that has triggered landslides in New Zealand. The shaded envelopes show the MM intensities (MM VI to MM IX or greater) at which landslides have occured in relation to earthquake magnitude and distance from source. *Source*: Hancox et al, 1995.

Most earthquake-triggered landslides occur on slopes of 20–50 degrees. They are commonly rock and soil falls on very steep cliffs, escarpments, gorges, gravel banks and high, unsupported artificial cuts.

Rainfall-triggered landslides are the displacement and downslope movement of parts of the slope caused by rainfall.

The susceptibility of an area to landsliding depends on soil/rock type, the degree of weathering, vegetation cover and the slope of land. Rainfall-triggered landslides depend both on the amount of rain that has fallen in the preceding 24 hours, and the soil moisture conditions (related to the amount of rain and evaporation of the preceding days). Therefore, the incidences of rainfall-triggered landslides are related to both large volumes of intense rainfalls and extended periods of rainfall with a lack of drying conditions. High soil moisture can weaken slopes and make them more susceptible to earthquake shaking-induced landslides.

LANDSLIDE TYPES

Different landslide types have been discussed from a hazard perspective by Crozier (1990). The most important of these are discussed briefly below.

Shallow regolith episodes

The most frequent and widespread landslide problem in New Zealand is represented by regional clusters of rainstorm-triggered 'regolith' landslides (generally involving just the surficial layers of soil, slope deposits, artificial fill slopes (e.g. road base) and weathered material above the bedrock). These events produce numerous 'earth slips' and 'soil slips' seldom greater than 2-3 metres in depth but which may flow out for several tens of metres. Slope movements of this sort are seldom found on slopes less than 20 degrees and most commonly on slopes between about 25-30 degrees.

On average, two or three of these major episodes occur somewhere in the country each year, affecting up to hundreds of square kilometres at a time and can occur in any region of the country. Hundreds of individual landslides may occur simultaneously.

Catastrophic debris flow

These flows are rapid and dangerous, short-lived and characteristically occur repetitively on the same track – usually some form of stream channel. Because they tend to re-occur in the same places, dangerous runout zones can often be recognised and mapped by examining the deposits of previous movements and the morphology of depositional fans. They are generated in alpine regions and steep terrain on slopes above 15 degrees but generally around 30-35 degrees. Once initiated they may continue to run out, until slopes of 4-8 degrees are reached.

Deep-seated slope failures

Deep-seated slope failures such as slumps and block slides are often attributed to inherent factors such as unfavourable geological structure, over-steepening, or weak rock. Poor drainage causing a build-up of water increases the risk of deep-seated failures. The most common triggering mechanism for first-time failures is earthquake-related shaking. In terms of rainfall-triggered deep-seated failures, a greater threat than new failures is the reactivation of old features. Areas displaying landslide morphology need to be treated carefully in high-risk areas and fully investigated in areas of proposed development.

Free-face slips

This group contains falls, topples and short-distance rock slides from short, steep, rock faces such as road cuts, construction platforms, sea cliffs and scarps. The depositional area is immediately downslope of the failure surface and usually constitutes an artificial platform or natural surface which arrests further movement. Free-face slips are a common form of failure during both earthquakes and rainfall.

WAIRARAPA CONTEXT

The Wairarapa is susceptible to both earthquake- and rainfall-induced landslides. The map shown in **Figure 2.44** shows the areas in the Wairarapa susceptible to landslides.

Earthquake-triggered landslides

Extensive, but mostly small landsliding has resulted from many of the large earthquakes centred in or near the Wairarapa, including the 1855 Wairarapa, the 1934 Pahiatua, and the 1942 Masterton earthquakes. Maps of the landslides triggered by those earthquakes are presented in **Figures 2.45 and 2.46**.

The main area of landslides triggered by the 1855 Wairarapa earthquake, extended over about 5000 square kilometres around the epicentre in southern Wairarapa. Small slides are known to have been triggered over 20,000 square kilometres.

The main landslide types included rock avalanches, deep-seated slope failures, disrupted rock and soil slides and rock and soil falls *(Hancox et al 1997)*. There were several very large landslides resulting from the 1855 earthquake, including one of 11 million cubic metres at Kopuranga (see *Side Bar* for more detail) and Mukumuka Stream (five million cubic metres) in the southern Rimutaka Range.

James Crawford described the area north of Masterton as "…severely fissured with numerous landslides on adjoining hills to the east." *(Grapes and Downes, 1997)* Extensive landsliding was reported in the Rimutaka ranges and along the coast to Cape Palliser *(Hancox et al, 1997)*. Mr R. Willray travelled from Wellington to the Wairarapa three days after the earthquake. He reported:

> *"On the ascent up the Rimutaka gorges, for upwards of seven miles [11 kilometres], the landslips and crevices are both numerous, dangerous and almost impassable, even on foot. Barricades of the largest trees, stumps and rocks, avalanches of earth, underwood, decayed trees, and boulders, bar your progress, and conceal your line, while loose logs and stones hang in threatening positions far above your head." (Grapes, 2000)*

There is probably extensive under-reporting of landslides in eastern Wairarapa due to the low population densities there at the time. The 1934 Pahiatua earthquake (Richter Magnitude 7.6) caused widespread minor landsliding over an area of about 6,500 square kilometres. The landslides were generally concentrated between Dannevirke and Masterton, east of the Tararua and Ruahine Ranges. The landslides were generally small (less than 10,000 cubic metres) and were predominately soil and soft rock slides. Small rock falls were widely distributed but these had only minor impact *(Hancox et al, 1997)*.

The June 1942 Masterton earthquake (Richter Magnitude 7.2) caused widespread minor landslides over an area of about 3,700 km2 centred near Masterton. Roads blocked by landslides were common in the MM VIII isoseismal near the earthquake epicentre. Other landslides in the Wairarapa occurred in the Waiohine River gorge and on the Rimutaka Incline; and the railway line north of Eketahuna. The August 1942 Masterton earthquake caused only moderate landslide damage and less ground damage than the earlier June earthquake.

Rainfall-triggered landslides

Glade (1998) analysed records of rainfall and landslides in the Wairarapa since 1880. He found that landslides always occurred when daily rainfall exceeded 120 millimetres. Rainfalls between 40 and 120 millimetres sometimes produced landslides if preceded by wet days. Those that did, were usually encompassed within three-day rainfall totals that exceeded 120 millimetres.

Table 2.9 shows an analysis of rainfall data for the Wairarapa and displays the recurrence interval of one and three-day rainfalls exceeding 120 millimetres *(Hicks, 2000)*. Such rainfall events occur more frequently in the eastern hills than in the main Wairarapa Valley. Numerous slips triggered by intense rainfall can be expected on a four to 12 year frequency in the hills. Sporadic slips can be expected on a one to three year frequency.

Figures showing the rainfall patterns for a one in 142 year and one in 475 year theoretical storm (e.g. figures 19-22) show that significant areas of hill country are likely to receive a 24-hour rainfall total of greater than 120 millimetres. During these storms considerable landsliding is likely to occur.

A study by Crozier *et al*, (1982) identified 18 rainfall-triggered landslide events that have probably affected the Wairarapa since 1880. There was a concentration of eight events in the late 1930s and 1940s. Based on the Crozier *et al,* (1982) identification, they estimate a recurrence interval of five to six years. This agrees well with Hicks' (2000) analysis, presented in Table 2.7.

Extensive rainfall triggered landsliding occurred in the Wairarapa in 1924, 1932, 1941, 1947, 1953, 1961, 1977 and 1991. **Table 2.10** details some of the effects of those storms. Pre-existing deep-seated, slow-moving failures can be re-activated following heavy rain events, and several such examples can be found in the Wairarapa. **Figure 2.47** shows a large deep-seated landslide on the Masterton-Castlepoint Road which threatened to close the road after the heavy rain experienced in 1977.

Scarps cliffs and soil slips

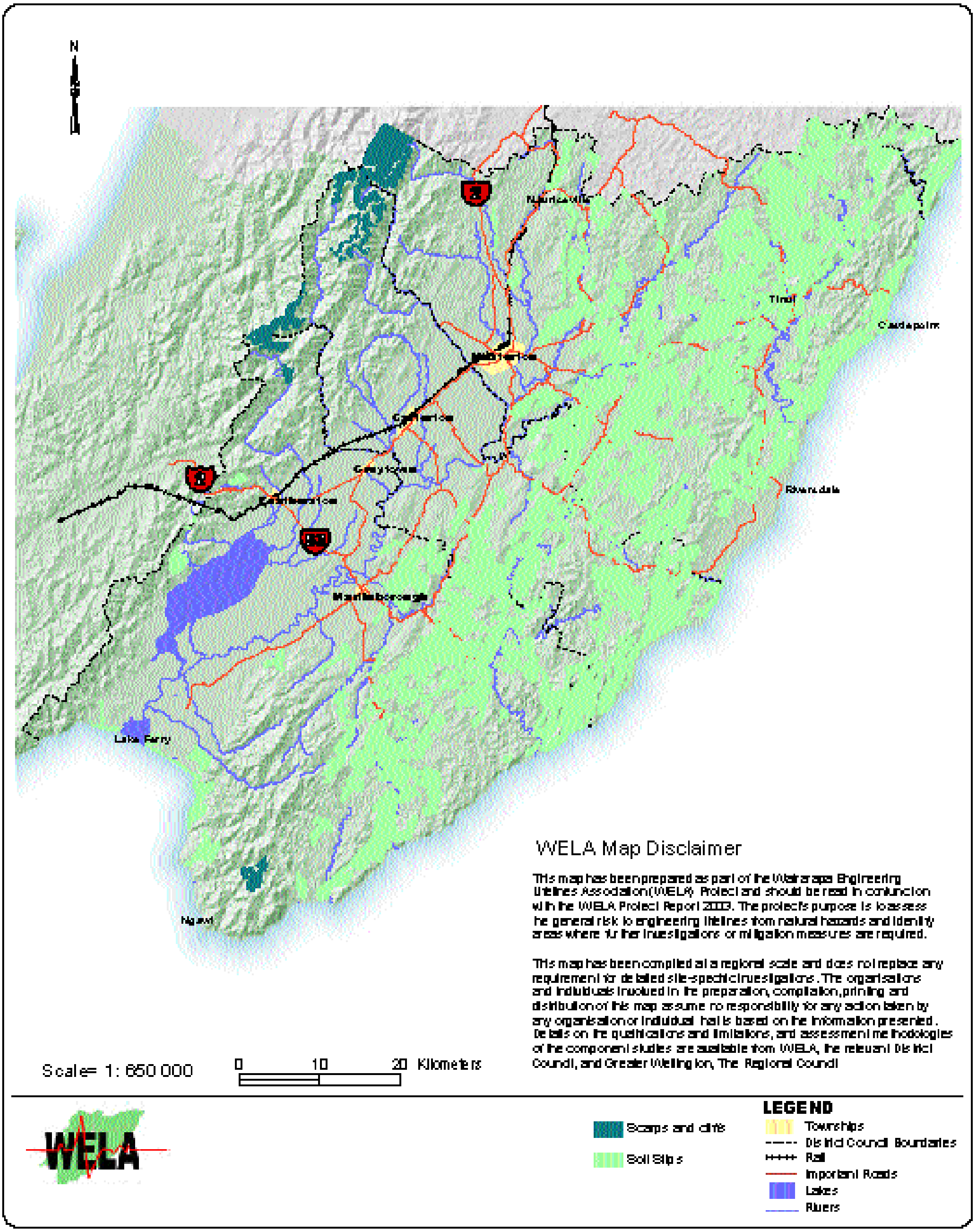

Figure 2.44. Map showing the susceptibility of the Wairarapa to landslides (Hicks, 2000).

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	Return period of rainfalls exceeding 120 mm	
Rain gauge	**In 24 hrs**	**In 72 hrs**
Riverside (northern valley)	76.0 years	15.2 years
Purunui (northeast hill country)	11.6 years	2.8 years
Featherston (southern valley)	31.3 years	3.8 years
Lagoon Hill (southeast hill country)	4.0 years	1.4 years

Table 2.9. Frequency of 24 and 72 hour rainfalls in the Wairarapa exceeding 120 mm.

Date Rainfall	Comments	
18 Dec 1924	Many roads were blocked by landslides in the country around Masterton	179 mm in 24 hrs near Masterton
20 Aug 1932	Widespread in the Wairarapa, roads everywhere were impassable. Damage to Masterton District roads cost £1,600	76 mm in 24 hrs recorded at Pahiatua
4 May 1941	Large landslides and washouts blocked many roads. High intensity rainfall also caused much slipping and scarring of hillsides.	254 mm in 30 hrs estimated in the coastal ranges
27-29 Jun 1947	Many landslides observed in the region	182 mm in 24 hrs near Martinborough
10 Jun 1953	Landslides blocked many roads and several areas were completely isolated	133 mm in 24 hrs at Masterton
5-8 Aug 1961	Landslides observed in the region	140 mm in 72 hrs measured at Ngaumu
Sep 1977	Disastrous landsliding, approximately 1,350 km^2 of hill country affected	High monthly totals, but no intense rainfall, lack of drying conditions
8-10 Apr 1991	Range of hill face erosion, landslides closed or partially blocked many roads in the Tinui and Maurceville areas	>200 mm in 24 hrs recorded on 10 Apr, 3-day totals up to 350 mm

Table 2.10. Summary of some storms that have triggered landslides in the Wairarapa. Data compiled from SCRCC (1957), Crozier *et al*, (1982), and WRC records.

Figure 2.47. The Te Maire slump, Masterton-Castlepoint Road is typical of many deep-seated landslides in the Wairarapa. This vast landslide recommenced movement following the very wet 1977 winter, threatening to close the road, destroy houses and create a large lake. Extensive earthworks, drainage, planting and stream control were necessary to eventually stabilise the movement.

Landslides attributed to the 1855 Wairarapa Earthquake

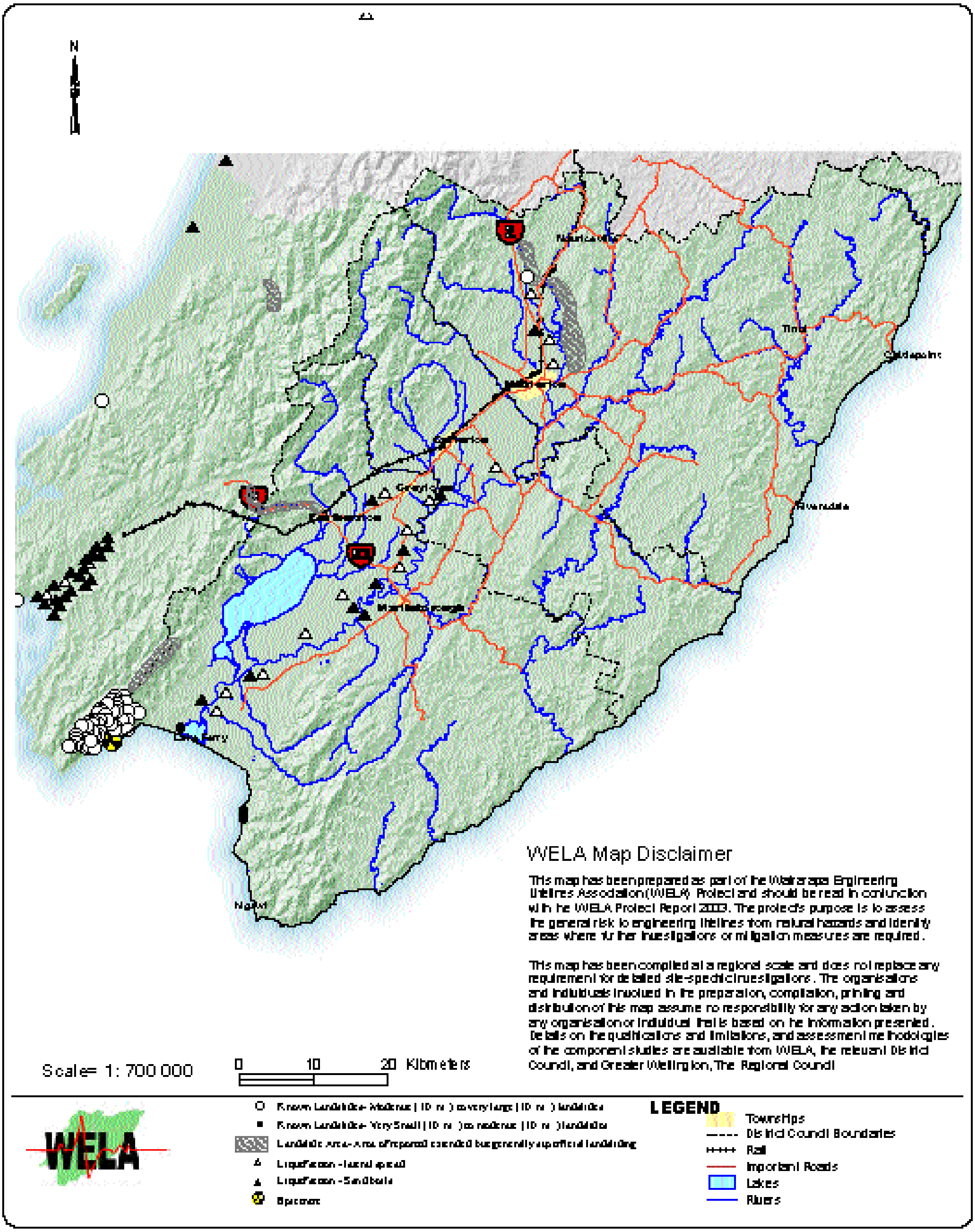

Figure 2.45. Landslides attributed to the 1855 Wairarapa earthquake. *Source*: Hancox et al, 1997.

Landslides attributed to the 1934 Pahiatua earthquake, and June and August 1942 Masterton Earthquakes

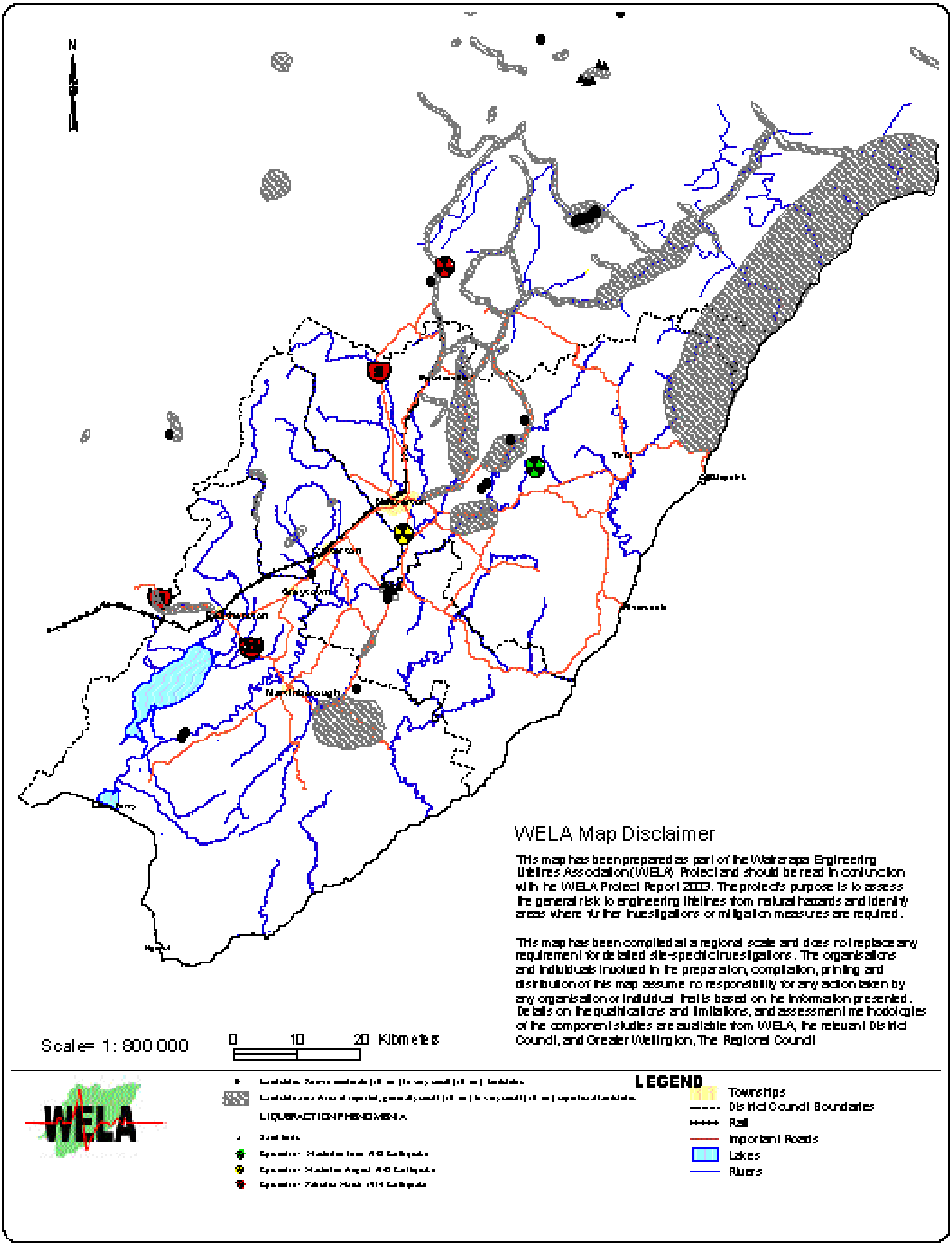

Figure 2.46. Landslides attributed to the 1934 Pahiatua earthquake and 1942 Masterton earthquakes. *Source*: Hancox et al, 1997.

Hidden Lakes landslide, Kopuaranga

Near Kopuaranga, north of Masterton, ground-shaking during the 1855 earthquake caused a landslide of almost 11 million cubic metres in volume (see Figs 2.48 a and b). Vennell (1891) (in *Grapes and Downes, 1997*) records that a "mountain [Bruce's Hill] near Masterton was literally rent in twain."

The slide blocked the Ruamahanga River and caused a large lake to form upstream. Later a group of eel collectors not far downstream heard a rumbling noise and saw a wave of water surging down the almost dry riverbed *(Grapes, 2000)*. This surging wave was a large flood caused when the river broke through the landslide.

The landslide is still very evident today. It is roughly circular in plan with an area of about half a square kilometre. The failure plane forms a curved scarp, 100 metres high. Several lakes, known as the Hidden Lakes, have formed on the rotated blocks of landslide debris.

This example illustrates two potential hazards from earthquake-triggered landslides. First, the landslide would be catastrophic to lifelines and settlement located on or below the slope. Second, where the landslide dams a river or stream, a dam may form, creating the potential for a flash flood if the dam breaks. This can be a hazard soon after the earthquake or for some considerable period after the earthquake.

2.48 (a)

2.48 (b)

Figure 2.48. The 1855 landslide at Kopuaranga, which temporarily blocked the Ruamahanga River. The 'Hidden Lakes' (Bruce Lake) has formed at the base of the slip and behind the landslide. **(a)** The Ruamahanga River has progressively eroded the toe of the landslide to form a large unstable cliff that may lead to future movement. **(b)** the pronounced scarp at the head of the movement and the lakes occupying the disrupted surface.

2.7 COASTAL EROSION

HAZARD DEFINITION

Coastal erosion is the removal of material at the shoreline leading to a loss of land as the shoreline retreats landwards, primarily as a result of wave action. Other processes can also cause or heighten coastal erosion such as shifting river mouths, tectonics, landslides, wind, and reductions in sediment supply.

Much of the Wairarapa coast is in a state erosion and there are several locations where erosion is significant and affecting engineering lifelines. These areas include Palliser Bay (**Figure 2.49**), Riversdale, Castlepoint and Mataikona. The lifelines at risk include the roads and any infrastructure that follows the road line.

WAIRARAPA CONTEXT

Palliser Bay

At Palliser Bay, between Lake Ferry and Cape Palliser, the coastline comprises a narrow strip of land sandwiched between soft, easily eroded mudstone cliffs and the sea. The road along this shore is the only vehicle access to the settlements further along the coast of, Whatarangi, Ngawi and Mangatoetoe.

King (1930) measured erosion rates at Whatarangi of 1270 millimetres per year. Beca Carter Hollings and Ferner (1994) noted that this erosion rate appears to have decreased in the 40s, 50s and 60s, and then rapidly increased in the periods 1976-1977 and 1992-1994. Many houses have been removed or fallen into the sea and erosion now threatens the road in a number of places.

Riversdale

The properties and infrastructure situated along the beachfront at Riversdale are located on unconsolidated sand dunes and are at risk from coastal erosion. Short-term episodic storm induced erosion up to 30 metres has occurred since 1902 and long-term coastal erosion rates of 0.3 to 3.0 metres per year predominate along the stretch of coast from Flat Point to Whareama

(*Gibb, 1986*). However, dune conservation measures along the beachfront at Riversdale have managed to reverse this trend of erosion in recent years in the areas where dunes have been developed.

Castlepoint Beach

The coastal processes operating on Castlepoint Beach, in relation to episodic trends of removal of sand from the beach, are less well defined than those on Riversdale Beach. Erosion is more likely to be in the form of inshore/offshore sand movement rather than more permanent longshore movement, as at Riversdale. However, erosion of the roadside in front of the houses along the beachfront is continuing and new protective measures are proposed to counter this trend.

Mataikona Road

The coastal road to the north of Castlepoint leading to Mataikona provides another example of the long term erosion trends along the Wairarapa Coast. As at Whatarangi in Palliser Bay, the road is being increasingly threatened by coastal erosion in several places.

Figure 2.49. Whatarangi, Cape Palliser. Erosion of the mudstone material by the sea is forcing the road landward with each new phase of erosion. There is no longer anywhere for the road to be relocated and coastal protection works are being put in place to reduce the rate of recession.

FURTHER READING

1. Purves, A and Hastie, W, *Assessment of Coastal Processes and Coastal Hazards at Riversdale Beach, Wairarapa*, Wellington Regional Council, Wellington, 1992.
2. Beca Carter Hollings and Ferner, Study Report – *Palliser Bay Erosion*, report prepared for the Wellington Regional Council and South Wairarapa District Council,1994
3. Gibb, J G, *Preliminary Assessment of Coastal Processes and Coastal Hazards at Riversdale Beach, Wairarapa East Coast, North Island, New Zealand*, Masterton, 1986.
4. Saunders, W, *Coastal Hazards in the Wairarapa*, Technical Report No. 00/19, Wellington Regional Council, 2000.

2.8 WILDFIRES

HAZARD DEFINITION

A wildfire is an unplanned fire that starts in open grassland or forested areas.

Fire can be caused by lightning strike (the most common natural cause), spontaneous combustion of sawdust piles, volcanic activity or by people. Fires are most dangerous in dry conditions or when flames fanned by high winds. Under these circumstances they can spread quickly.

Lifelines potentially at risk include roads, rail, electricity transmission lines and communication equipment. If the fire spreads from scrub towards populated areas it can also threaten farms, communities, and buildings.

WAIRARAPA CONTEXT

In 1998, the Wellington Regional Council commissioned a report to study the wildfire hazard over the entire Wellington region, including the Wairarapa *(Forme, 1998)*. The fire hazard model developed was based on vegetation type, degree of curing, slope, rainfall, and ignition sources *(WRC, 1998)*. The risk is divided into five hazard categories ranging from 'low' to 'extreme'.

Approximately 10 percent of the entire region is classified as having a significant ('high' or 'extreme') fire hazard (see **Figure 2.50**). The areas at significant risk from wildfire are generally characterised by gorse and scrub vegetation, steep slopes (**Figure 2.51**), relatively low rainfall, and proximity to areas frequented by people *(WRC, 1999)*. In the Wairarapa, the significant areas at risk include the eastern foothills of the Tararua and Rimutaka ranges, the Cape Palliser coast and significant portions of the inland hills in the eastern Wairarapa. The route of State Highway 2 over the Rimutaka range is particularly vulnerable to wildfire which can result in road closures and subsequent debris movement *(WRC, 1999)*.

FURTHER READING:

1. *Rural Fire Hazard in the Wellington Region, prepared for the Wellington Regional Council WRC/RP-G-98/12*, Forme Consulting Group Ltd, Wellington, 1998.
2. *Annual Environment Report 1998*, Wellington Regional Council, Wellington, 1998.
3. *Measuring Up: The State of the Environment Report for the Wellington Region 1999*, Wellington Regional Council, Wellington, 1999.

2.9 VOLCANIC ASHFALL

HAZARD DEFINITION

Volcanic ashfall is the deposition of fine particles (less than two millimetres in diameter) that have been ejected from a volcano (Neall et al 1999).

Volcanism is a measure of the activity and effects of volcanic activity.

Water supplies, traffic, sewerage systems, electricity aerial transmission and distribution networks and substations may be affected by ash fall (see **Table 2.10**). Ash itself is not toxic. Turbidity and acidity of water supply sources caused by ash fall usually return to normal within a few hours of a fall.

WAIRARAPA CONTEXT

There has been no comprehensive study of the hazard that volcanic ashfall poses to the Wairarapa. A brief 'desktop' study was carried out by the Wellington Regional Council to assess the threat of volcanic ashfall to the Wairarapa *(Paterson, 2001)*. The report drew information mostly from a comprehensive study of volcanic impacts in the Hawke's Bay region *(Scott et al, 1998)*. Since there are no *active volcanoes* in or around the immediate vicinity of the Wairarapa, 'ashfall' is the only volcanic hazard of relevance to the Wairarapa. The nearest active volcanoes capable of eruptions of sufficient size to produce ashfalls in the Wairarapa are listed in **Table 2.11**. Also shown in the Table are the potential eruption sizes, frequency of occurrence, and the distance of each volcano from Masterton. For a volcanic ash event to affect the Wairarapa, there needs to be both a significant eruption and wind coming from the appropriate direction. The predominant winds in the Wairarapa are from the west and northwest (ashfall direction for Mt Taranaki). Northerly winds are less frequent (ashfall direction for the other volcanoes). Paterson (2001) summarised the volcanic ashfall hazard for the Wairarapa as:

- 1-5 millimetres of ashfall in the Wairarapa might be expected once every 1300-1600 years from Mt Taranaki. There is a reasonable likelihood of a coincidence between an eruption of Mt Taranaki and appropriate wind direction;
- Small amounts of ashfall (less than two millimetres) from an eruption of Ruapehu might be expected only if the wind direction is appropriate. This will occur no more than 10 percent of the time, probably less if the direction of high altitude winds is accounted for. The return period for this is estimated to be greater than 2000 years;

Figure 2.51. Wairarapa Tunnel portal, Western Lake. Destruction of vegetation by wildfire would likely result in instability of the steep slopes above the portal.

- Ashfall in the Wairarapa is possible from a large prolonged eruption of Taupo and Okataina, but would be of low frequency (2,000-10,000 years). The thickness of ashfall related to those eruptions is difficult to predict.

FURTHER READING:

1. Neall, V E and Alloway, B V, . *Volcanic Hazards at Egmont Volcano*, Ministry of Civil Defence Volcanic Hazards Information Series No. 1, Wellington, 1991.
2. Neall, V E, Houghton, B F, Cronin, S J, Donoghue S L, Hodgson, K A, Johnston D M, Lecointre, J A, and Mitchell, A R, *Volcanic Hazards at Ruapehu Volcano*, Ministry of Civil Defence, Volcanic Hazards Information Series No. 8, Wellington, 1999.
3. Paterson, M C H, *Wairarapa Volcanic Hazard Assessment*, Wellington Regional Council Internal Report, Wellington, 2001.
4. Scott, B J, Johnston, D M, and Manville, V, *Volcanic impacts in the Hawke's Bay region*, Institute of Geological and Nuclear Sciences Client Report 71754D.10, Taupo, 1998.

Wildfire Hazard in the Wairarapa

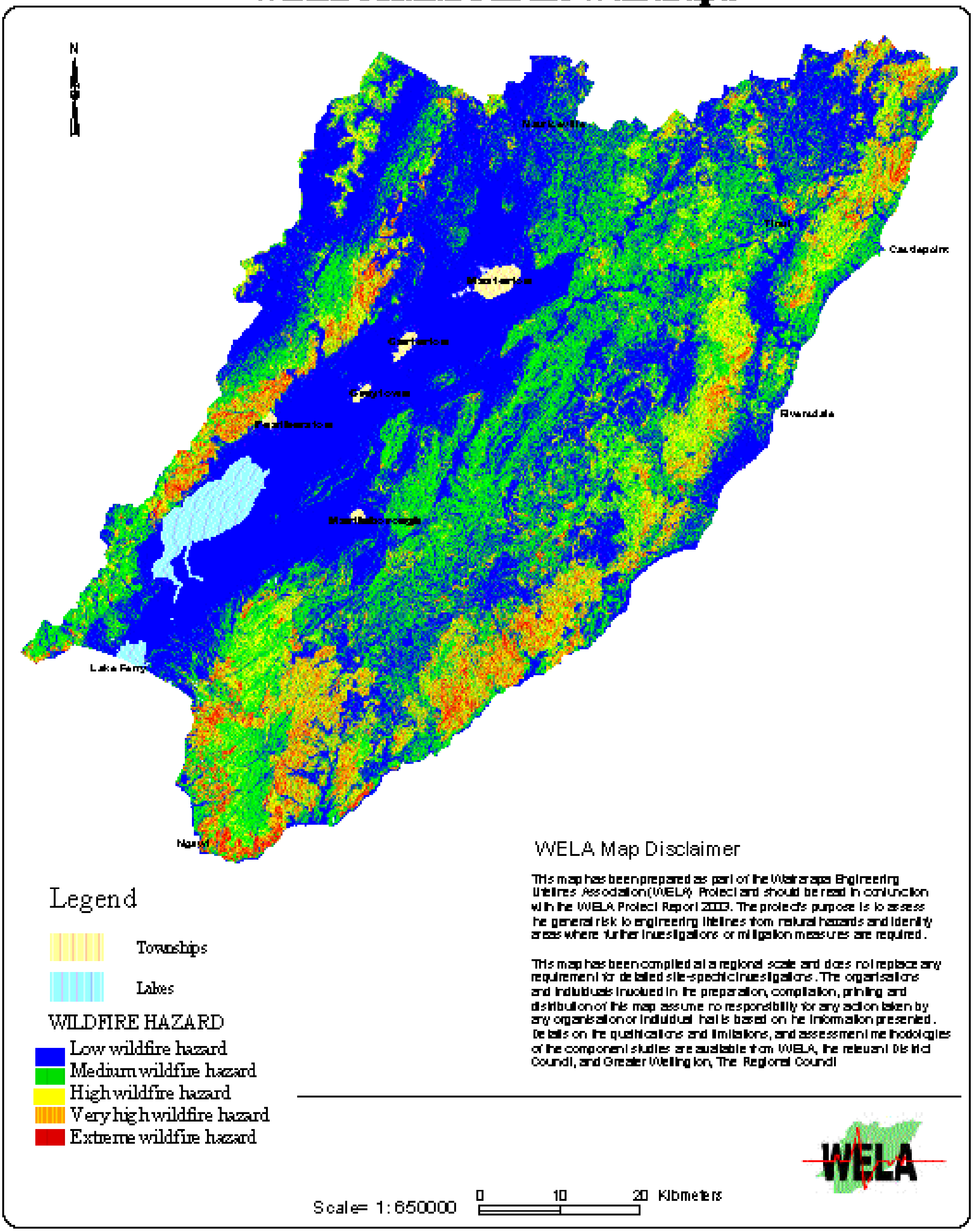

Figure 2.50. Wildfire hazard in the Wairarapa.

Impact of ash falls
Less than one millimetre ash thickness • Will act as an irritant to lungs and eyes • Airports will close due to potential damage to aircraft • Possible minor damage to vehicles, houses, and equipment caused by fine abrasive ash • Possible contamination of water supplies, particularly roof-fed tanks • Dust (or mud) affects road visibility and traction for an extended period
1-5 millimetre ash thickness Effects that occur with less than one millimetre ash will be amplified; plus • Possible crop damage • Some livestock may be affected; most will not be unduly stressed, but many suffer from lack of feed, wear on teeth, and possible contamination of water supplies • Minor damage to buildings will occur if fine ash enters, soiling interiors, blocking air-conditioning filters etc • Electricity may be cut; short-circuiting occurs at substations and line insulators if ash becomes wet and therefore conductive. Low voltage systems more vulnerable than high • Water supplies may be cut or limited due to failure of electrical supply to pumps • Contamination of water supplies by chemical leachates may occur • High water-usage will result from ash clean-up operations • Roads may need to be cleared to reduce the dust nuisance and prevent stormwater systems becoming blocked • Sewerage systems may be blocked by ash, or disrupted by loss of electrical supplies • Damage to electrical equipment and machinery may occur

Table 2.11. Impact of ash falls. The impact of ash falls greater than five millimetres are not included here because they are considered highly unlikely for the Wairarapa. Detail on the impacts of deeper ashfalls can be found in Neall et al, (1999). *Source*: Neall et al, (1999).

Volcano	**Potential eruption size (km3)**	**Frequency of occurrence**	**Distance from Masterton**
Ruapehu	Small (0.01-0.1) Medium (0.1-1.0 Large (<1)	20 years 100-500 years 10,000 years	~180 km
Ngauruhoe	Small (<0.01) Medium (0.01-0.1)	10-20 years 100-200 years	~190 km
Tongariro	Small (<0.01) Medium (0.01-0.1) Large (0.1-1.0)	100 years 1000 years 10,000 years	~190 km
Taranaki (Egmont)	Small (<0.01) Medium (0.01-0.1) Large (<1)	300-500 years 1300-1600 years 10,000 years	~220 km
Taupo	Small (0.1-0.9) Medium (1-10) Large (10-100)	1300-1600 years 2500-5000 years 5-10,000 years	~240 km
Okataina (near Rotorua)	Medium (1-10) Large (10-20)	1500-2000 years 2000-5000 years	~320 km

Table 2.12. Volcanic sources of relevance to the Wairarapa.