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Landslides caused by the February 2004 rainstorms and floods in southern North Island, New Zealand

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G.T. Hancox and K. Wright

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ABSTRACT

Heavy and prolonged rainfall during the February 2004 storm caused widespread landsliding over about 16,000 km^2 of southern North Island, extending across the Wanganui–Manawatu area to southern Hawke's Bay, Wairarapa, and the greater Wellington areas. Landslide damage was more extensive, with a wider and more diverse area affected, than occurred during Cyclone Bola in 1988. The most severely damaged areas were in the Mangawhero, Whangaehu, Turakina, and Pohangina valleys. Many thousands of small to medium (<100–1000 m^3) shallow (1–2 m deep) soil and debris slides and flows occurred. There were also some larger (~1000-200,000 m^3) deep-seated landslides in Tertiary mudstone. Some landslides dammed streams to form lakes.

Most landslides occurred on steeper (~20-35°) grass-covered hill slopes, gullies and steep terrace edges. In some areas, numerous shallow landslides produced extensive areas of coalescing soil slides affecting many hectares. Debris from many landslides did not reach stream channels, but remains on the slopes. Gully and river-bank failures, however, contributed considerable sediment and trees to flooded rivers, with the latter causing some bridge failures. Soil and debris flows exhibit scar length to debris runout length ratios of 1:3 to more than 1:10 in some of the more mobile soil flows.

Landslide distribution was clearly related to land use and vegetation. Hill slopes covered with native bush and exotic forest were much less affected by landslides than were grassland slopes, with only a few isolated landslides observed in forested areas. Forest cover provided good protection against landsliding during the February 2004 storm. Recently-milled areas with tree stumps in the ground were severely landslide-damaged, suggesting that rainfall interception by forest canopy decreases runoff rates, and is more important in reducing landsliding than strengthening of soils by tree roots. Some trees planted close to river banks collapsed into flooded rivers, contributing to the debris that caused bridges to collapse.

Damage to farmland was extensive across the region, and many roads were severely damaged and closed by slips. State Highway 3 through the Manawatu Gorge was closed for almost 3 months by several large landslides. Some slips came close to houses and buildings causing minor damage, but few were significantly affected. Only one house (at Karaka Bay, Wellington) was destroyed. One large landslide (~200,000–300,000 m^3) dammed the Hutt River at Te Marua near Upper Hutt and diverted it through the golf course, causing extensive erosion.

None of the many pre-existing, deep-seated very large bedrock slides in Tertiary hill country – such as the Otoko Lakes (~100 million m^3) and Ohorea (~175 million m^3) landslides in the upper Mangawhero Valley – appear to have been affected by the storm, and no new landslides of this type and size were formed. These very old (prehistoric) landslides were probably initiated by other factors such as river incision or large earthquakes several thousand years ago, and appear to be unaffected by the high-intensity rainfall that causes superficial but often severe landslide damage to steep hill country.

KEYWORDS

February 2004 storm, rainfall-induced landsliding, high-intensity rainfall landslide-triggering events, soil and debris slides and flows, southern North Island, New Zealand.

1. INTRODUCTION

1.1 February 2004 storms

The storms that lashed the lower North Island in February 2004 were the worst in several decades. They caused the most devastating floods in 100 years in some areas, leaving many families homeless, and farms and roads severely damaged by flooding and landslides. By the end of February 2004 the damage cost was estimated to be close to $300m (roads $65 million, farms $159-189 million, private claims ~$100 million - *Dominion Post 2/3/04*). The NZ Metrological Service reported that the storm that peaked on 15 and 16 February 2004 was the biggest of the 2003/04 summer, and would have to be rated one of the most severe and expensive storms in New Zealand's recent history, certainly on a par with Cyclone Bola in 1988 (Grey and Hancox, 2004; NZ Metrological Service, 2004). It began on the morning of 14 February when a small low moved quickly from the central Tasman Sea east-southeast across central New Zealand. On 15 February the low situated to the east of the country deepened (Figure 1), and a very strong southeast to southwest air flow developed across southern North Island, bringing heavy rainfall and gales, and causing damage in many areas.

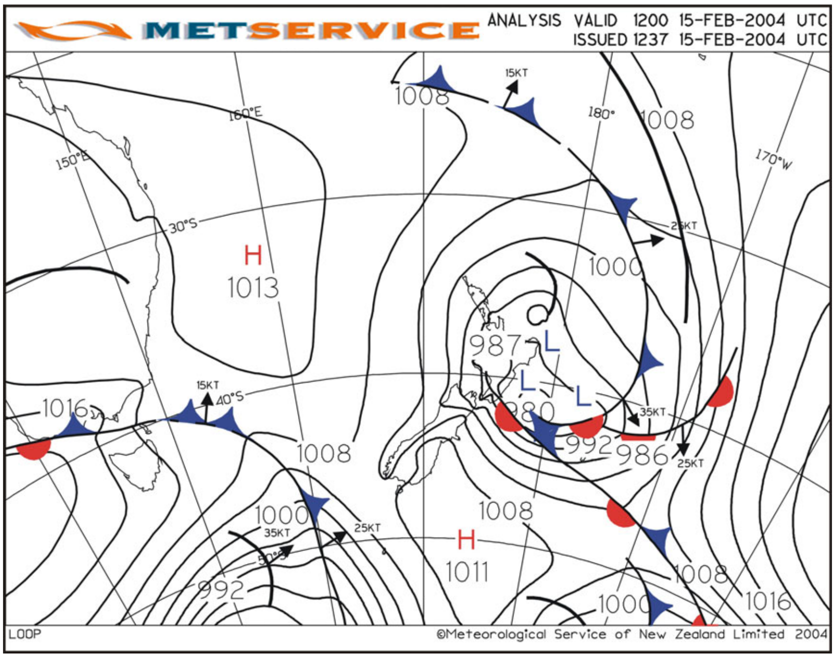

Figure 1: A deep and complex low developed east of the Wairarapa (midnight 15th February), feeding moisture-laden air at gale force onto the lower North Island. *(Courtesy of MetService (NZ) Ltd.)*

The front associated with the low intensified as it crossed the North Island, producing thunderstorms and heavy rain in some northern districts. The low became almost stationary and intensified overnight 15-16 February when injected with moisture from a tropical depression joining the weather system to the northeast of the country. Persistent heavy rain fell over much of the southern half of the North Island, with falls in the ranges exceeding 200mm in 24 hours (NZ Metrological Service, 2004). Figure 2 shows the rainfall pattern caused by the low over central New Zealand on 15 February 2004, with estimated 24-hour rainfall totals up until 9 am on 16 February 2004.

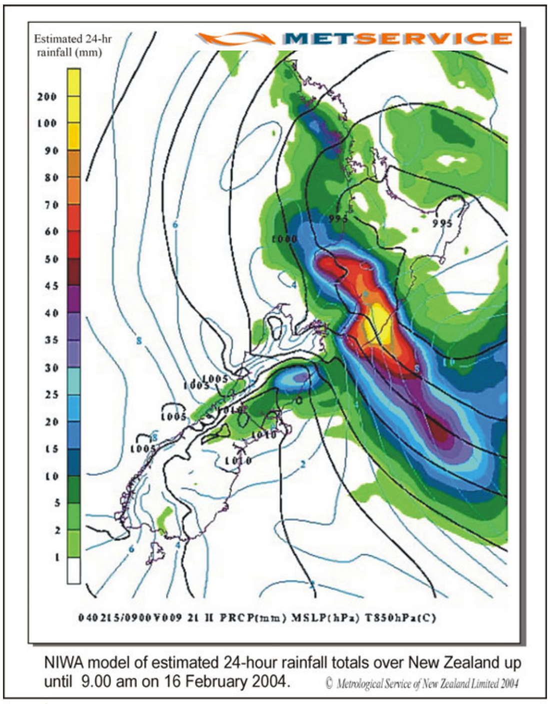

Figure 2. Map showing the modelled rainfall pattern associated with the low that affected central New Zealand on 15 February 2004. This map shows estimated 24-hour rainfall totals up until 9 am on 16 February 2004 *(map provided by courtesy of the N Z Metrological Service Limited).*

Rainfall totals from MetService stations (in the 24 hours to 9am on 16 February) included: 134.0mm at Waiouru, 62.6mm at Palmerston North, 64.8mm at Paraparaumu, 64.2mm at Normanby (South Taranaki), 51.0mm at Wanganui, 75.4mm at Masterton, 123.4mm at Castlepoint, 57.2mm at Ngawi, 64.4mm at Kelburn (Wellington) and 56.8mm at Wellington Airport. Unofficial readings from Wellington suburbs (over the same time period as above) included: 200mm at Wainuiomata, 170mm at Lower Hutt, 136mm at Silverstream (Upper Hutt), 130mm at Stokes Valley, 101mm at Whitby, 75mm at Johnsonville, and 78mm at Karori (Grey and Hancox, 2004). During the afternoon of 16 February, the low east of Hawke's Bay finally moved away and conditions eased over the North Island, allowing a start to the cleanup in places. However, the respite was short-lived with another low moving east over central New Zealand on 17 February. This brought thunderstorms and heavy downpours to northern and central districts.

NIWA report that about 4–6 times the usual rainfall was recorded in February 2004 (mainly during the 15–17 February storm) in areas extending from Wanganui *(239 mm cf. 40 mm normal)* to Feilding *(334 cf. 57 mm)*, Palmerston North *(299 cf. 60 mm)*, Paraparaumu *(361 cf. 60 mm)*, Upper Hutt *(403 cf. 64 mm)*, Lower Hutt *(482 cf. 68 mm)*, and Wellington *(364 cf. 62 mm)*. Much higher rainfall was recorded in the Taraura *(1288 cf. 300 mm)* and Ruahine *(621 cf. 217 mm)* ranges. Judging by the severe flooding seen in the lower Wanganui, Whangaehu, Turakina, and Rangitikei valleys, similar high rainfall fell in the steep hill country north east of Wanganui as far as Raetihi and Taihape (NZ Metrological Service, 2004).

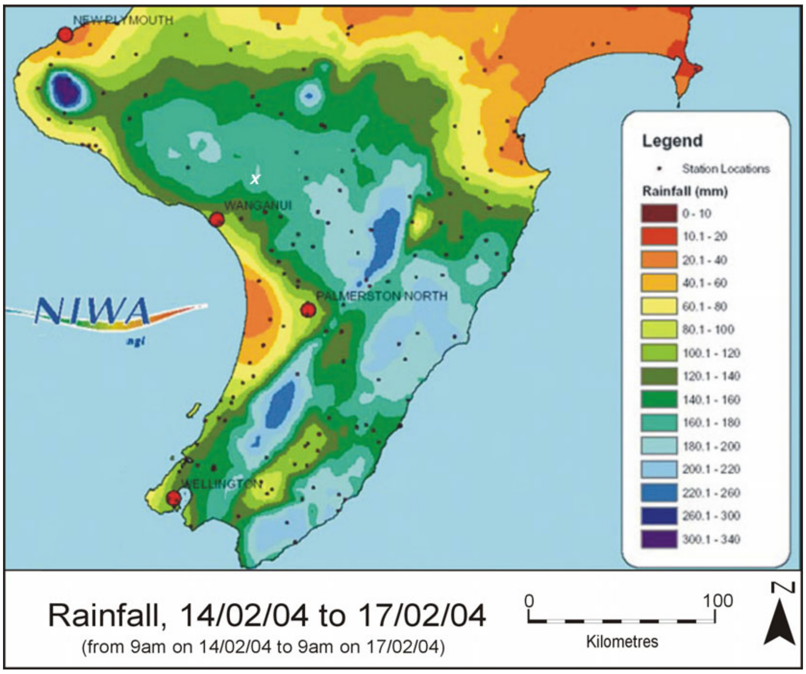

Figure 3. Map showing rainfall recorded over the southern North Island over a 72-hour period from 9 am 14/02/04 to 9 am on 17/02/04 *(map provided by NIWA).*

Figure 3 shows the rainfall recorded over the southern North Island over the 72-hour period from 9 am 14/02/04 to 9 am on 17/02/04. Landslide damage in the hill country north of Wanganui suggests that rainfall in that area was somewhat higher in some areas than others. There are few metrological stations in the area, but rainfall recorded by farmers indicates that in some areas about 200 mm could have fallen in the 72-hour period shown. Rainfall recorded at one farm in the Mangawhero valley (x, Figure 3) indicates that 193 mm rain fell over that 72-hour period, with most of that (140 mm) falling over the 24-hours to 9am on 16 February (15/2 – 25 mm; 16/2 – 140 mm; 17/2 -28 mm, pers. comm., J. Medlicott, 2004). The largest landslide caused by the storm in this area (and other hill country areas) occurred at about 9 am on 16 February 2004 at the end of the period of heaviest rainfall (pers. comm., J. Medlicott 2004). Very high local rainfall readings by farmers on 15 and 16 February are supported by rainfall recorded by Horizons (Manawatu–Wanganui) Regional Council, who report that over this period heavy rainfall in excess of 100 mm in 24 hours was recorded at 22 sites, with 3 of those sites recording in excess of 200 mm (Horizons Regional Council, 2004).

Heavy rain on both sides of the Tararua and Ruahine ranges led to the Manawatu River overtopping its banks at several locations, with the peak flow recorded being the second highest on record (the highest was in 1902). The peak flow of the Rangitikei River was the third highest on record since 1897 (Source: MCDEM). In the Wanganui/Manawatu area, four bridges were destroyed, and 21 bridges were seriously damaged, several showing signs that masses of trees and other debris, mainly from river-bank collapses, lodged against piers contributed to their failure. Many highways were blocked by slips, and SH 2 through the Manawatu Gorge Rd was closed for about three months due to several large landslides. Damage costs resulting from the storm were estimated at close to $300 million, and around 2500 people were displaced, mainly by the floods. Along with the damage caused by heavy rain and high river flows, significant damage was done by strong wind during the 15-17 February event. Wind gusts of up to 230 km/h were recorded in the Tararua Ranges.

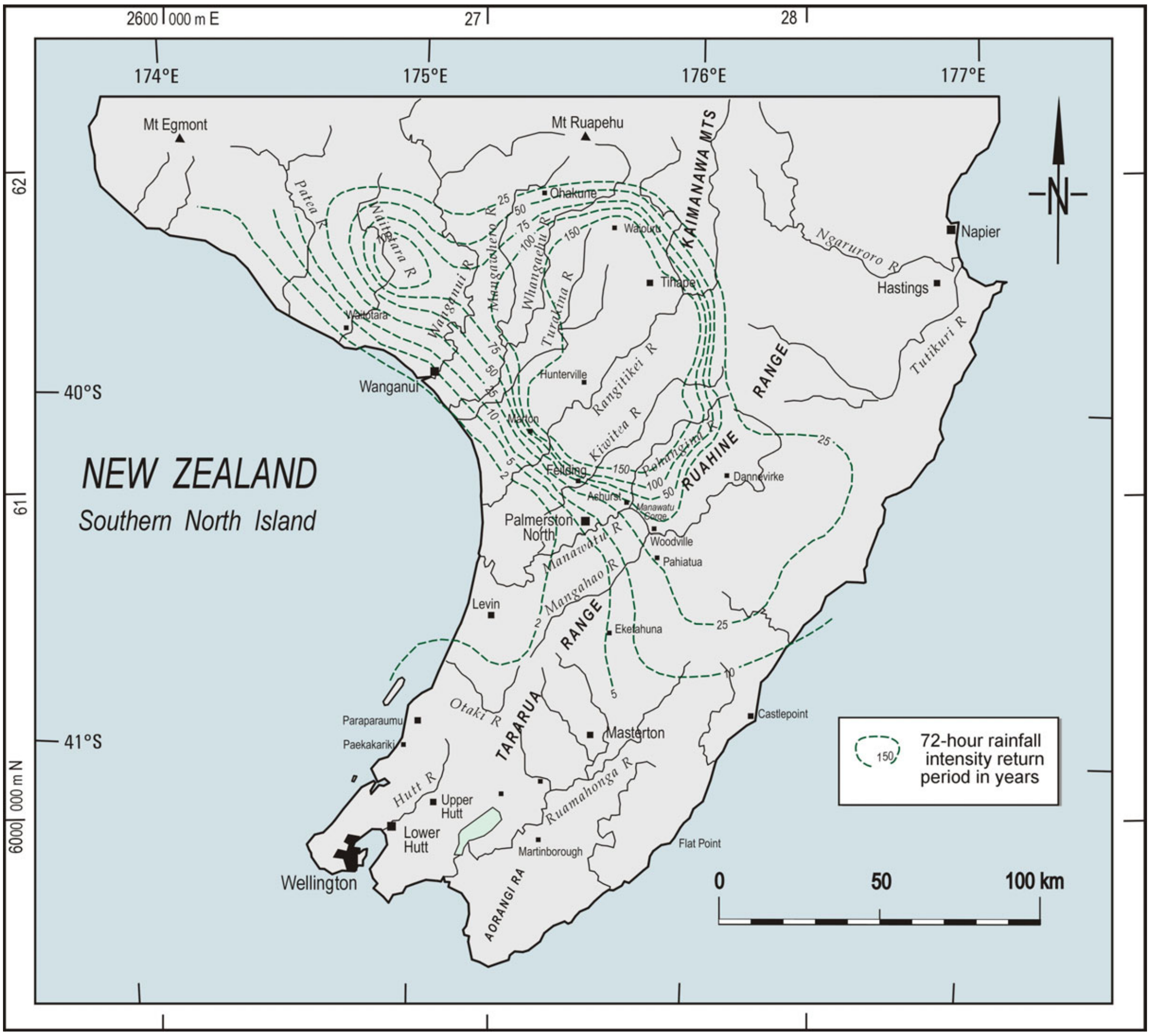

Figure 4. Map showing estimated return periods of the 72-hour rainfall over the area of heaviest rainfall recorded from 9 am 14/02/04 to 9 am on 17/02/04 *(New Zealand Metrological Service Limited).*

One of the notable impacts of the 15–17 February storm was the large number of landslides affecting hill country in the Wellington, Wairarapa, Manawatu, Wanganui, and southern Hawke's Bay hill country. Landslide damage seen in hill country north of Palmerston North was most striking, with extensive areas of coalescing shallow soil slides and flows occurring in some areas. Rainfall data presented in Figure 4 suggests that the 72-hour rainfall recorded in the Wanganui-Manawatu hill-country from 15-17 February 2004 has a return period of about 100–150 years (Horizons Regional Council, 2004). This illustrates the extreme nature of the storm.

1.2 Landslide response

A *'Landslide Rapid Response'* was initiated by *GeoNet** on 17 February 2004, with the objective of carrying out a ground and aerial reconnaissance to map and photograph landslides caused by the storm that battered the southern North Island on 15 and 16 February. The storm was initially thought to be a 40-year recurrence interval event, but it was later upgraded to a 100 years or greater return period storm, as rain continued to fall over a 72-hour period. Bad weather prevented flying for several days so Graham Hancox and Nick Perrin (GNS Lower Hutt), and Kim Wright (a student at Victoria University Wellington) examined landslide damage in the greater Wellington region on the ground, including Wellington City, Miramar Peninsula, Eastbourne, Paekakariki, Haywards Hill, Stokes Valley, and Upper Hutt–Te Marua areas.

When weather suitable for flying arrived on 25 February 2004, Graham Hancox and Kim Wright undertook a reconnaissance flight to map and photograph landslides in the Wellington, Hutt valley, Manawatu Gorge, the Pohangina valley and Hunterville areas. Following this reconnaissance, preliminary data and impressions of the nature and extent of landsliding caused by the storm were reported by GNS in an Immediate Report (Hancox, 2004), which was distributed to local authorities, MCDEM, and other interested parties. The initial flight only partly covered the very large area of landslide damage. To complete the aerial landslide reconnaissance, areas north of Hunterville to Taihape, Raetihi, Wanganui, Mangawhero, Whangaehu, Turakina and Waitotara valleys were surveyed in three further flights on 27 February, 12 and 22 March 2004. This was followed on 19–21 May 2004 by ground checking in the Pohangina, Mangawhero and Whangaehu valleys.

Further information on the extent of landsliding caused by the February 2004 storm in southeast Wairarapa was gathered in aerial and ground inspections by G. Hancox in November 2004. In addition, more detailed information on storm-induced landsliding in a small catchment in the Mangawhero valley was obtained for an MSc thesis by Kim Wright.

1.3 Scope of report

This report outlines the overall extent and location of landsliding caused by the 15–17 February 2004 storm (Figure 5). It also describes and illustrates the nature and types of landslides in the main areas affected, and the resulting damage to farms and roads. The significance and implications of the landsliding for land use practices and prevention of landslide erosion in hill country terrain and other affected areas are also briefly discussed. More detailed analysis of factors that controlled the distribution of landslides, sediment delivery into streams and rivers, landslide damage, and mitigation measures and failures is presented in a companion report (Hancox and Wright, 2005).

* *GeoNet Project is a collaboration between the Earthquake Commission, the Institute of Geological & Nuclear Sciences, and the Foundation for Research, Science & Technology for the monitoring, data collection and rapid response to earthquake, volcano, landslide and tsunami hazards in New Zealand. It is managed by the Hazards Monitoring Section of GNS.*

2. LANDSLIDE MAPPING

The extent of landsliding caused by the 15-17 February storm in southern North Island was initially determined from GNS oblique aerial photography taken on several reconnaissance flights over the vast area affected by intense and prolonged rainfall. More than 1000 aerial oblique digital photos of landslides, flooding and infrastructure damage were taken during the reconnaissance flights, plus several hundred more on later ground surveys. The aerial photos allowed the approximate extent and relative intensity of landslide damage in the Manawatu–Wanganui hill country to be mapped (Hancox and Wright, 2004).

Following the floods, landslides, and wind damage caused by the February storms, the Ministry of Civil Defence and Emergency Management (MCDEM), together with Land Information New Zealand and the Ministry of Agriculture and Forests, arranged for six SPOT5 satellite images of the most affected areas of the Manawatu –Wanganui and northern Wairarapa hill country to be obtained (taken over period 16/3/04–21/4/04). However, no SPOT images were obtained of the Wellington and southeast Wairarapa areas, and the only remote-sensing information available was from the initial GNS reconnaissance flight on 25 February and subsequent GNS fights in October and November 2004.

In addition, GNS, MCDEM, Landcare Research, and Horizons Manawatu paid for a number of vertical aerial photo runs to be taken over the worst affected parts of the Wanganui–Manawatu hill country. These medium format (52 x 52 mm) photos were taken between 26/3/04 and 14/4/04 at an altitude of ~3350 m, giving a photo (negative) scale of 1:67,000. Full details of the flight lines, locations, and numbers of the oblique and vertical aerial photos relating to the February storm are held in GNS files at Lower Hutt.

Figure 5 shows the extent and areas affected by landsliding caused by the storm of 15–17 February 2004. This map was compiled mainly from studies of oblique and vertical aerial photos and ground checking by GNS, and computer analysis of landslide distribution on SPOT5 images by Landcare Research (Dymond *et. al.*, in prep). Aerial photo flight lines and SPOT image coverage are shown in Figure 6. About 16,000 km^2 of the southern North Island was severely affected by landslides, mainly in the Manawatu, Wanganui, Wairarapa, and Wellington hill country. The initial landslide mapping based on reconnaissance flight photos (Figure 7) proved to be reasonably accurate compared to later more detailed mapping by Landcare using SPOT5 images (Figure 8), although a few areas of landslide damage in the Wairarapa and southern Hawke’s Bay were missed. However, both aerial photography and SPOT imagery missed the landslide damage in southeast Wairarapa.

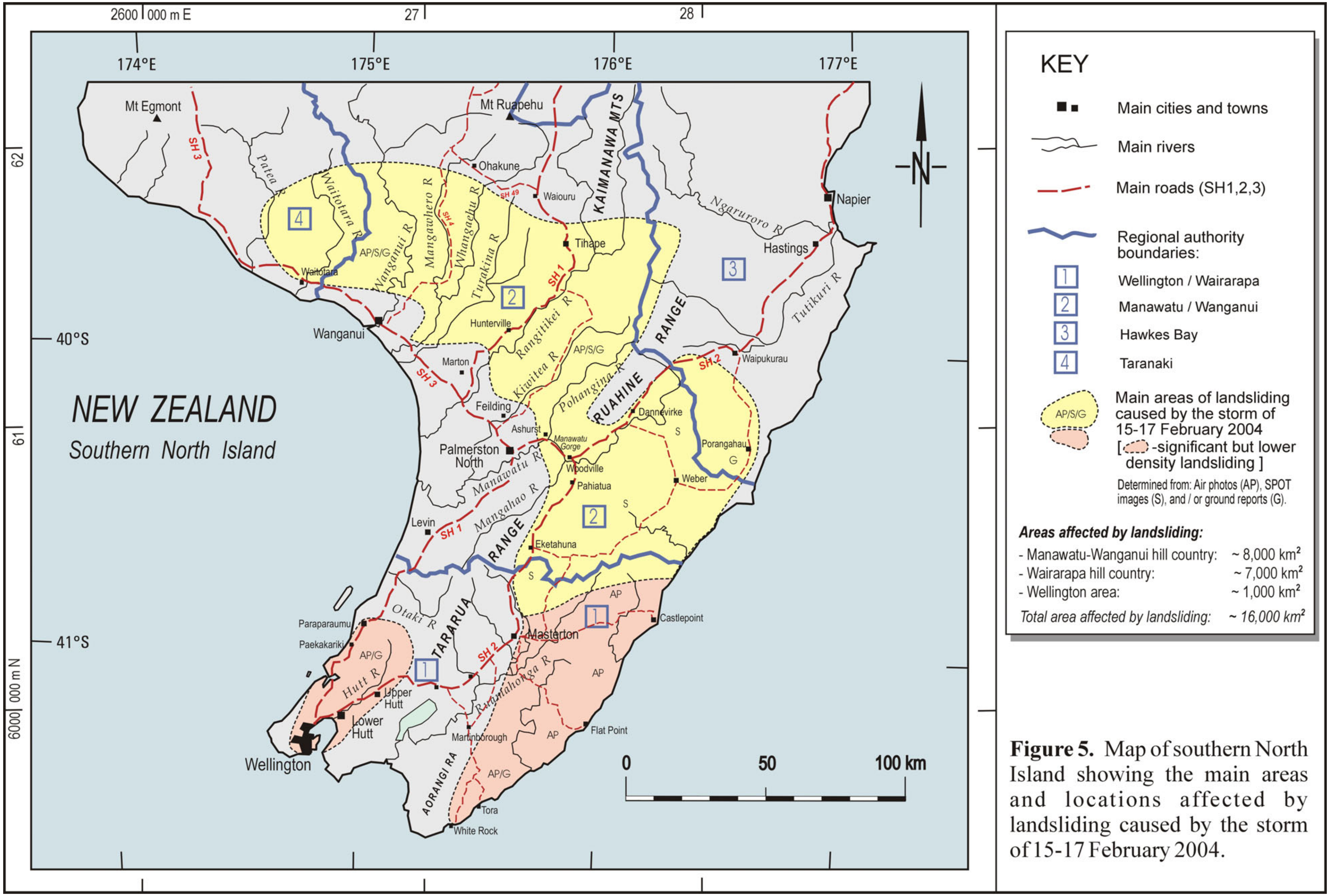

Figure 5. Map of southern North Island showing the main areas and locations affected by landsliding caused by the storm of 15-17 February 2004.

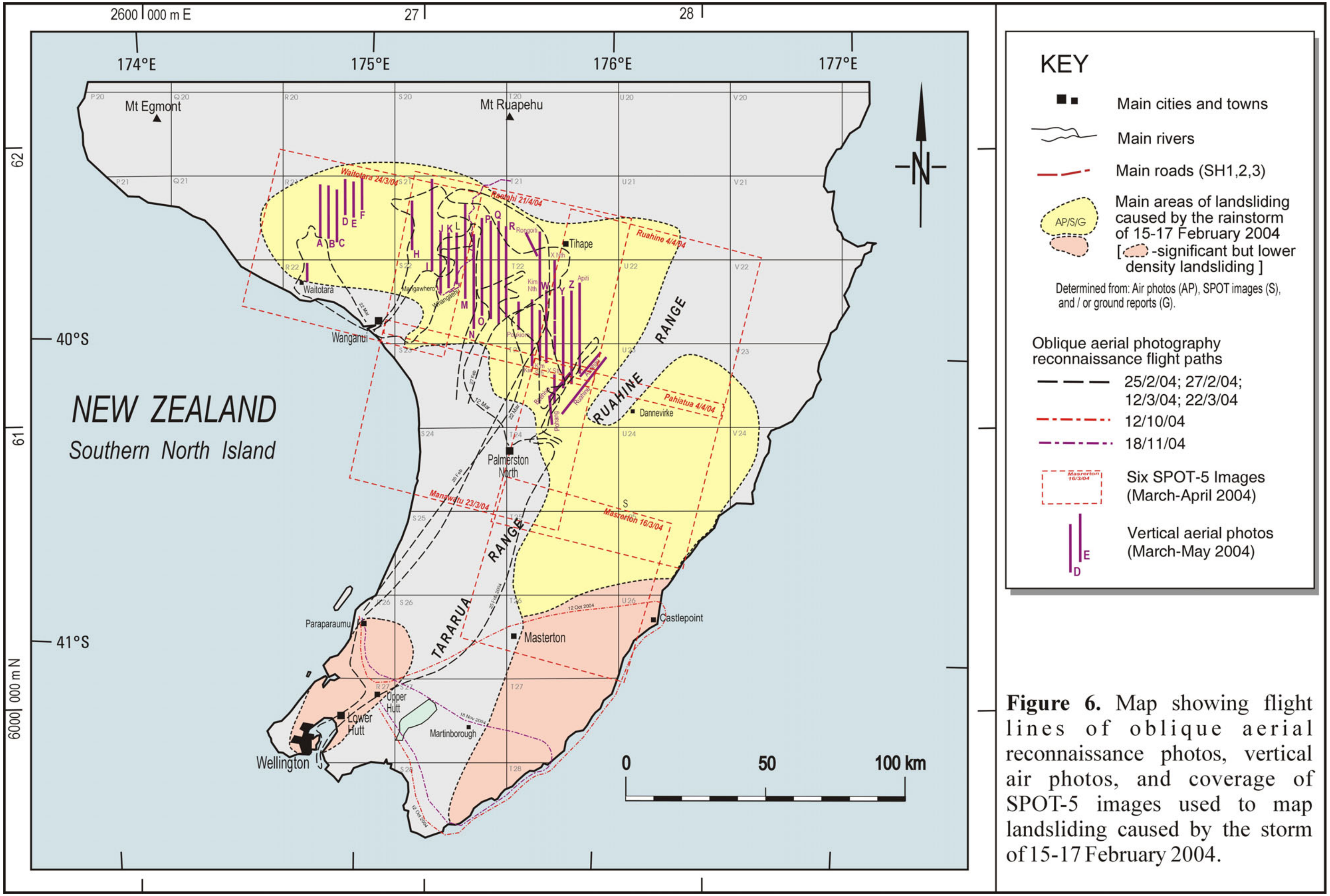

Figure 6. Map showing flight lines of oblique aerial reconnaissance photos, vertical air photos, and coverage of SPOT-5 images used to map landsliding caused by the storm of 15-17 February 2004.

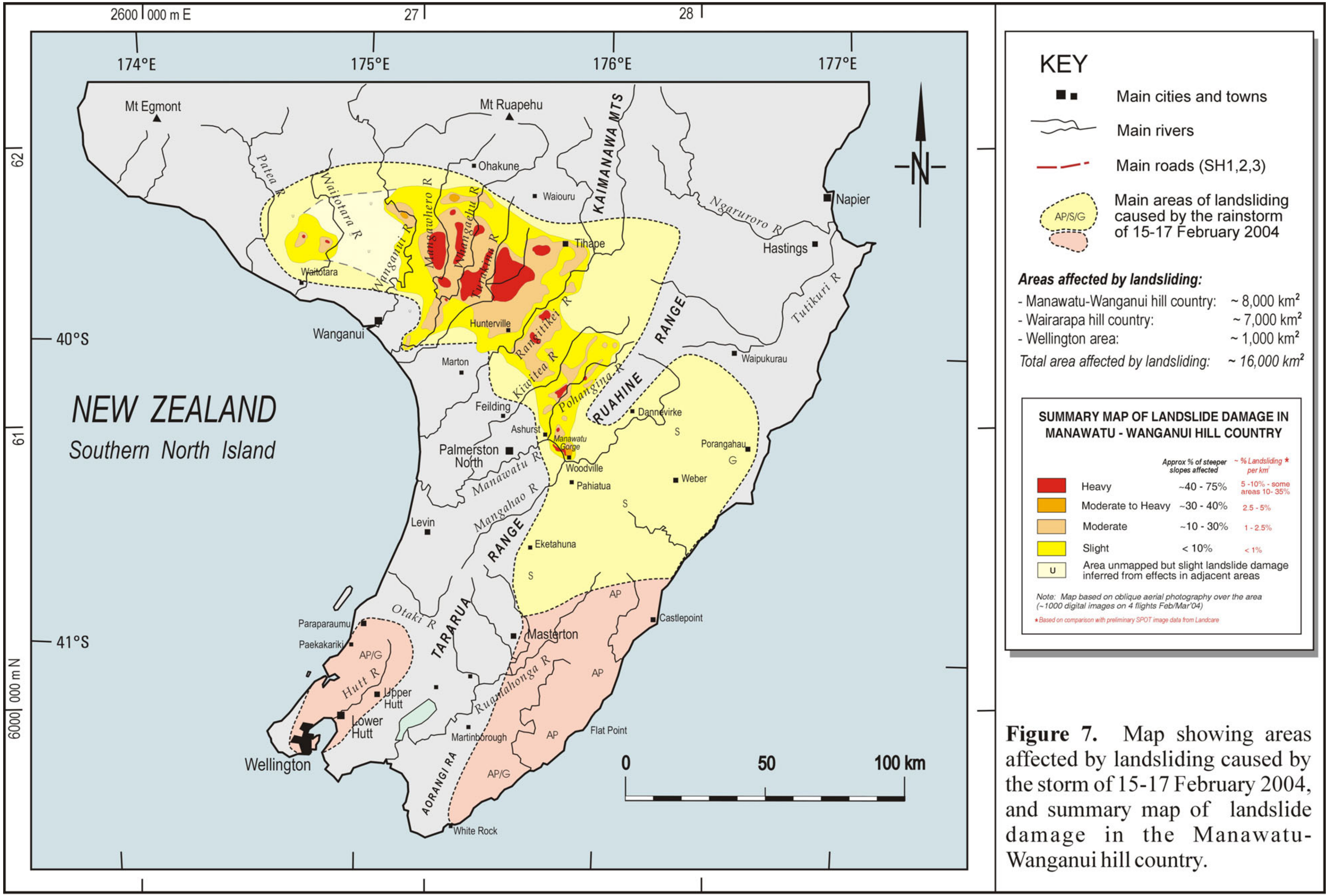

Figure 7. Map showing areas affected by landsliding caused by the storm of 15-17 February 2004, and summary map of landslide damage in the Manawatu-Wanganui hill country.

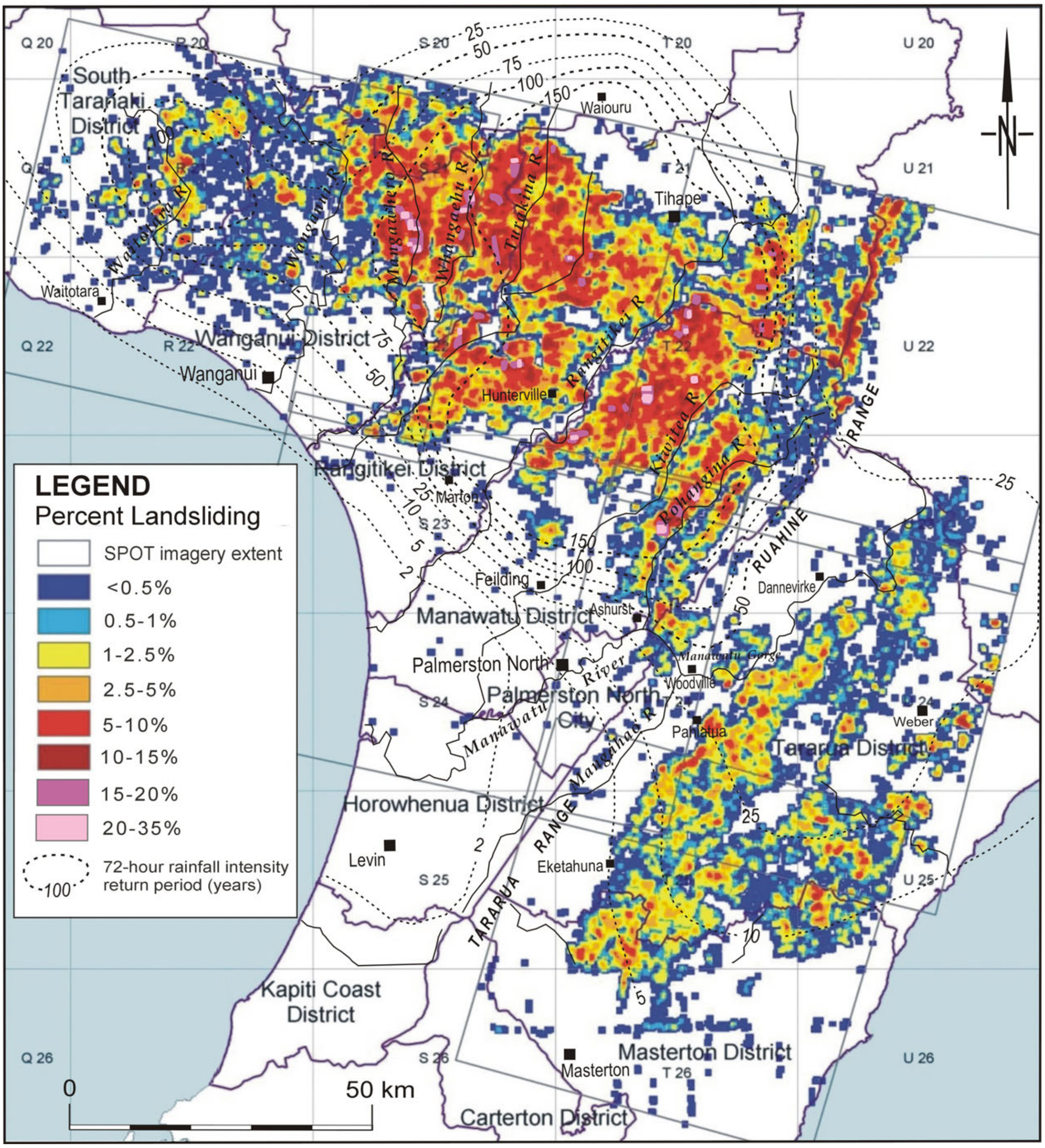

Figure 8. Summary map of landslide density resulting from the 15-17 February 2004 storm, as mapped from SPOT images *(by Landcare Research).* Colours show the percentage of land in one square km covered by landslides (source-area scars and debris are undifferentiated). 72-hour rainfall return period contours are also shown *(from NIWA). [Map modified after Landcare Research[3], [6]*

3. REGIONAL GEOLOGY AND TOPOGRAPHY

The regional geology of the area affected by landsliding during the February 2004 rainstorms is shown in Figure 9 (based on GNS 1:2,000,000 Geological Map). Bedrock in the bush-clad and less landslide-affected Tararua and Ruahine ranges and greater Wellington area is mainly hard greywacke and argillite of Triassic/Jurassic age (~150–200 million years). The more landslide-affected steep hill country north of Wanganui and Palmerston North is underlain by younger (Pliocene–early Quaternary, ~5–2 million years) soft mudstone, sandstone, and conglomerate. Widely-affected areas of northern and southern Wairarapa are also underlain by similar weak sedimentary rocks (sandstone, siltstone, claystone) of Cretaceous to Miocene age (~100–15 million years), with less landslide damage apparent in bush-covered hills and ranges of harder Jurassic–Cretaceous sandstone (Figure 9).

The distribution of landslide damage shows that topography, geology (rock and soil types), and vegetation cover all had a strong influence on landslide occurrence during the February 2004 storms. Although very high rainfall was recorded during February 2004 in the Taraura *(1288 mm)* and Ruahine *(621 mm)* ranges, mainly during the 15–17 February storm, the incidence of landslides in those native bush and tussock-covered ranges was low (Hancox, 2004; Dymond et. al., in prep). Comparison of these mountain areas with grass and forest-covered hill country suggest this was not due to the higher strength of the greywacke rock mass or rocky regolith, but was more probably related to the greater protection provided by forest cover, possibly by reducing the rate of runoff on slopes. Severe landsliding in areas of milled exotic forest showed that stumps and tree roots offered little protection against landsliding. This suggests that rainfall interception by the forest canopy decreases runoff rates, which is more important in reducing landsliding and erosion than strengthening of soils by tree roots. These issues and the nature and extent of landsliding related to terrain, geology, vegetation, and damage in different areas are discussed more fully in the next section.

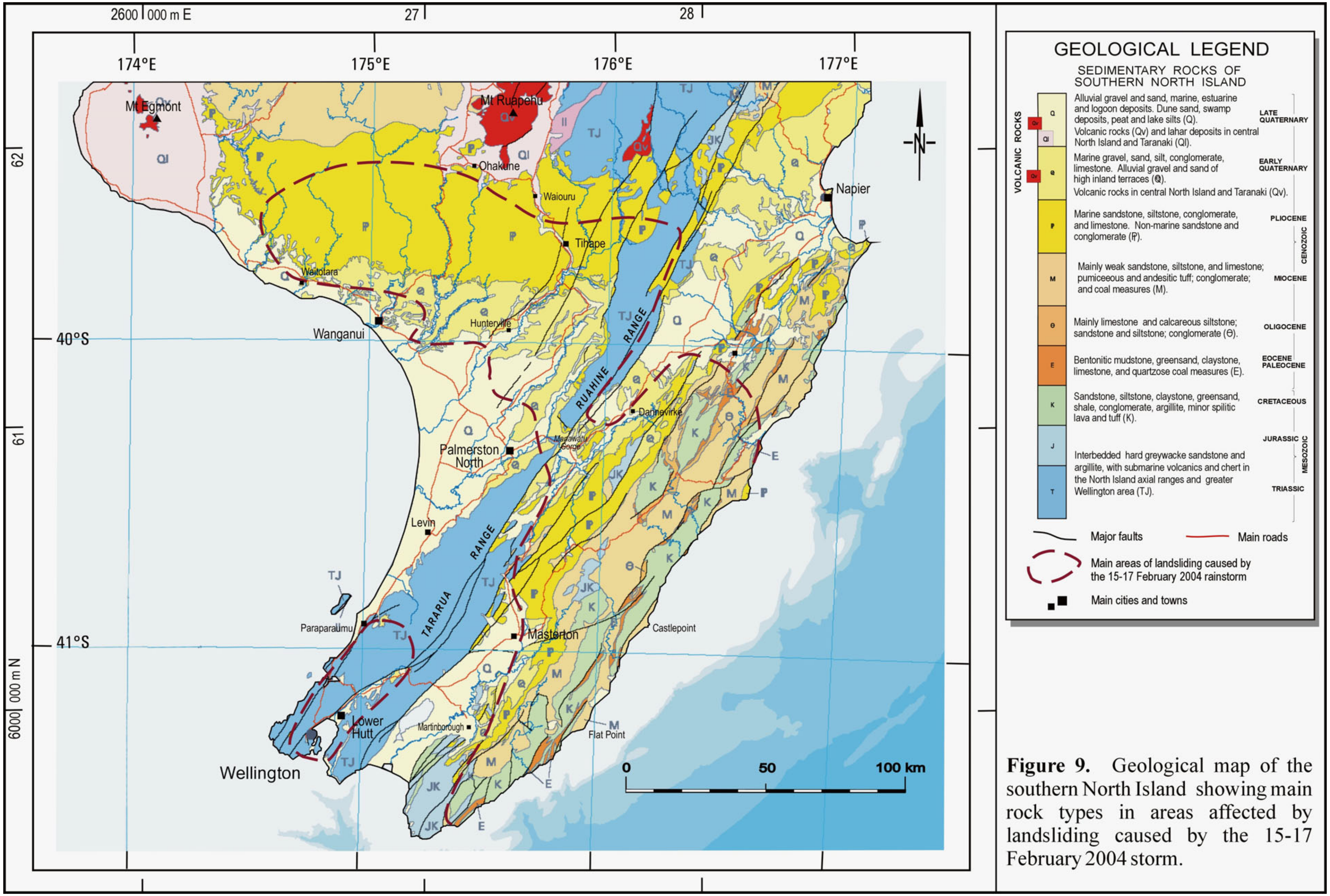

Figure 9. Geological map of the southern North Island showing main rock types in areas affected by landsliding caused by the 15-17 February 2004 storm.

4. DESCRIPTION OF LANDSLIDING

4.1 Definitions of landslides

Many technical and non-technical names are used to describe landslides. Definitions of terms used in this report for landslides and associated phenomena are as follows:

Landslide is a general term for gravitational movements of *'rock'* or *'soil'* down a slope' (Hutchinson, 1988; Cruden and Varnes, 1996). In this context *'soil'* includes both *'earth'* (material smaller than 2 mm) and *'debris'* (material larger than 2 mm), while *'rock'* is a hard or firm intact mass, and in its natural place before movement. Landslides are usually classified or described in terms of: (a) the type of material involved (rock, earth, debris, or sometimes sand, mud etc.), and (b) the type of movement - fall, topple, slide, flow, spread, which are kinematically distinct modes of movement. Combining these two terms gives a range of landslide types such as: rock fall, rock slide, rock topple, debris fall, debris slide, and with increasing water content soil and earth flows. Slope failures or landslides involving both surficial soils and bedrock are often called *'landslips'*, *'slips'* or *'slides'*, while smaller failures in soils with semi-rotational failure surfaces are generally referred to as *'slumps'*.

Debris flows and ***debris floods*** are both hydrological mass-movement/transport phenomena, but they have different hazard and risk implications. *Debris floods* are very rapid hyper-concentrated flows of water charged with sediment in stream channels. *Debris flows* have much higher sediment concentrations with a consistency rather like wet concrete, and are therefore potentially much more hazardous and destructive (Hungr *et al.*, 2001). Strictly speaking, a *debris flood* is not a landslide, but is a mass-transport phenomenon with destructiveness similar to that of water, but less than that of debris flows. Objects inundated by debris floods are surrounded or buried by flood debris but are often little damaged. These characteristics were clearly demonstrated at Paekakariki during the October 2003 and February 2004 floods, as discussed below.

4.2 Wellington region

Although the February 2004 became most widely known for the flooding and landslide damage in the Manawatu–Wanganui area, there was also flooding and damaging landslides in the Wellington region extending over about 1000 km^2 (Figure 5). While landslide density in the greater Wellington area was shown by GNS aerial reconnaissance to be relatively low (up to ~1–5/km^2), the landslides that occurred were significant as they were mainly on cut slopes, and blocked roads and damaged houses. Landslides disrupted traffic flow in several areas and damaged property in Wellington City, Miramar Peninsula, Eastbourne, Paekakariki, Haywards Hill, Stokes Valley, and Upper Hutt–Te Marua area (Hancox, 2004). Most of the failures were small regolith (soils and weathered bedrock) slides, but there were also a few deeper-seated debris and rock fall/slides in moderately to highly weathered bedrock. Some of these failures blocked or undermined roads, caused minor damage to houses and drive ways, and also destroyed a house at Karaka Bay (Figure 10). Although landslide damage to private homes was generally minor, the overall cost was significant, resulting in about 250 claims to EQC. Road closures due to landslides stopped traffic for several hours at Eastbourne (Figure 11), Haywards Hill, and SH 1 at Paekakariki (Figure 12).

Figure 10. This large rock slide at Karaka Bay in Wellington destroyed a house at the bottom of an unprotected cut excavated at the toe of the slope behind the house. Slope failure was caused by storm water channelled down a path above the house. *[GNS Photo: GH1709]*

Figure 11. This moderate sized (~100-200 m^3) rockfall in weathered greywacke closed the road to Eastbourne for several hours. It was typical of slope failures in the Wellington area during the February 2004 storm. *[GNS Photo: GH1726]*

Figure 12. About 10,000 m^3 of debris flood gravel from the Fly-by-Wire gully (left) was deposited around the Belvedere Motel at the bottom of the Paekakariki Hill Road during the October 2003 storm. Similar gravel deposition and flooding problems occurred at this site during the February 2004 storm, and again in January 2005, causing long delays for motorists on SH 1. *[GNS Photo: GH1228]*

State Highway 1 was closed by flood water at Paekakariki because culverts under the highway were blocked by debris-flood gravel deposits from the Fly-by-Wire Gully (Figure 12). This was a repeat of the problem that first occurred in the October 2003 storm (Hancox, 2003). Gravel from the Fly-by-wire Gully was mobilised after ~60 mm rain fell in one hour on 20/2/04, blocking the culvert under SH 1. This led to extensive flooding at Paekakariki and closed SH 1 overnight, despite the efforts of 4 diggers to remove gravel from the steam channel. The combined cost to Transit NZ of clearing gravel from the culvert entrance during the 2003 and 2004 floods was about $700,000, which made previously recommended debris dams in the Fly-by-wire gully (Hancox 2003) a cost-effective option. Such measures are now planned by Kapiti Coast District Council, and design, access and consents issues are now being worked through. Further gravel blockage and flooding at the same location occurred in January 2005, providing another reminder of the gravel deposition problem that has developed at this site since deep erosion gullies were opened up in the streams above Paekakariki during the 2003 storm.

Similar debris flood gravel problems also closed the Paekakariki Hill Road at the 'hair-pin' gully in 2003, and again in 2004, but construction of a recommended debris fence at the gully mouth above the road prevented further problems in January 2005 (Figure 13).

Figure 13. During the February 2004 storm, gully erosion and debris flood gravel closed Paekakariki Hill Road at the 'hair-pin' gully. A steel and tyre *catch fence* constructed after the storm (right) prevented a recurrence of such damage during the January 2005 storm. *[GNS Photos: GH1574(L) / GH2261(R)]*

The largest and most spectacular landslide in the greater Wellington area occurred during heavy rain on Tuesday (pm) 17 February 2004. A large (200,000–300,000 m^3) deep-seated rock and debris slide in regolith and bedrock occurred on the eroded old Wellington fault-line scarp north of Upper Hutt. The landslide dammed the Hutt River and diverted it through the Te Marua golf course, causing extensive erosion damage and creating a new 'water hazard' through the fairway (Figure 14a). This was the largest bedrock landslide that has occurred in the Wellington area in several decades. It may have formed on a pre-existing failure area. Remedial earthworks have since been completed at the site to clear landslide debris from the river channel, construct a stop bank to reposition the river in its former channel, and repair damage to the golf course (Figure 14b). The top of the landslide scar is now significantly over-steepened and remains vulnerable to further slope failures, which could be initiated by river erosion of the debris cone, by heavy rainfall, or by strong earthquake shaking. However, no new failures were noted during rain storms in August 2004 and March 2005, or several moderately strong (MM 5-6) earthquakes in January 2005.

Figure 14a. Aerial photo of the large rock/debris slide (~200,000 – 300,000 m^3) which dammed the Hutt River at Te Marua near Upper Hutt and diverted it through the golf course causing significant erosion damage.
[GNS Photo: GH1745]

Figure 14b. View of the landslide at Te Marua in November 2004, after earth works had been completed to clear slide debris from the river channel, construct a stop bank to control river flow, and repair damage to the golf course. The slope remains vulnerable to further slope failures, which could be initiated by river erosion, heavy rainfall, or strong earthquake shaking.
[GNS Photo: GH2499]

4.3 Tararua Ranges and Wairarapa hill country

Further north in the Wellington region a few small landslides occurred on road cuts along SH 2 across the Rimutakas, but as with other areas the slide debris had been cleared when this area was inspected from the air on 25 February. Only minor fresh landslides were observed on slopes in the Rimutaka and Tararua ranges south of the Manawatu gorge. These slopes are mostly well protected by native bush and tussock, and were not visibly affected by the very high rainfall that occurred. However, recent moderately large river-bank collapses and gully-head failures were seen in a few places along the flight route taken across the Taraura Range.

In November 2004, extensive landslide damage caused by the February 2004 storm was seen in steep country southeast of Martinborough (South Wairarapa District) and in the coastal hills from Castepoint to White Rock (Figure 5). The extensive shallow soil slides and flows in the hills southeast of Martinborough (Figure 15) were of a similar nature and density to those seen in the Manawatu–Wanganui hill country and northern Wairarapa (Figure 8). Although this landsliding was not seen by GNS for several months, it was not unexpected as the terrain is similar to that further north, and rainfall there was high enough for landslides to occur.

Figure 15. Extensive shallow soil slides and flows formed by the February 2004 storms in hills country southeast of Martinborough. More damage occurred in August 2004. *[GNS Photo: GH2576, Nov 2004]*

The distribution of landslides in southeast Wairarapa was not uniform in that region, but as also seen in the Manawatu area, was generally restricted to grassland hill country. A high level of landslide damage occurred in some areas, and was low in other areas of similar terrain (as shown in Figure 15). This probably reflects spatial variations in rainfall intensity rather than differences in the terrain. There were very few landslides in areas of native bush, scrub, or exotic forest. Although the steep coastal cliffs from Castlepoint to White Rock were not badly affected, there were a number of moderate to large debris slides and flows with runout across the coastal platform. Some of these failures crossed the coastal road, as illustrated by Figure 16, which shows a typical debris flow on a debris fan ~5 km north of Tora. Although these failures did little damage during the February 2004 storm, they illustrated the potential hazards that exist on debris fans. Similar but more extensive and damaging soil slides and flows occurred in this area during a rainstorm on 31 March 2005 (pers. comm. Doug Harris, 2005). These landslides were subsequently photographed and mapped by G Hancox in April 2005.

Figure 16. Large debris slide and flow on steep cliff and debris fan on the southeast Wairarapa coast a few km northeast of Tora. The end of the debris flow debris crossed the coastal road but did little obvious damage in this area. *[GNS Photo: GH2588]*

4.4 Manawatu and Wanganui hill country

Landsliding was most widespread in the Manawatu–Wanganui area, where about 8000 km^2 of steep hill country was affected. Notable examples of landslides in this area are discussed below.

Manawatu Gorge

Several large debris and rock falls occurred along SH 3 on the south side of the Manawatu Gorge, with one very large landslide at the eastern end of the gorge taking about three months to clear (Figure 17). Almost all of the landslides were road cutting failures in colluvium, regolith, and weathered bedrock, some of which extended ~50–100 m above the road. No significant landslides were seen on the northern or railway side of the gorge. Cuts along the railway line are much smaller and older than those along SH 3. The road through the Manawatu Gorge remains susceptible to further slope failures and closures, but the existence of alternative routes across the Pahiatua Track and Saddle road apparently make a permanent solution to reduce landslide hazard in the gorge uneconomic (pers. comm. Transit NZ).

Figure 17. Large rock and debris slide (80–100,000m^3, right) in the Manawatu Gorge which blocked SH 3 for about 3 months after initial failure during the February 2004 storm. A series of ~6 further failures delayed road clearing at this site. *[GNS Photo: GH2287, 12/3/04]*

Hill country areas

The most extensive and the largest number of landslides occurred in the Tertiary hill country northeast and northwest of Palmerston North and Feilding, with the worst affected areas located in the middle reaches of the Mangawhero, Whangaehu, Turakina, and Pohangina valleys (Figures 7 and 8). Most of the landslides were typically superficial soil and debris slides and flows about ~1–2 m deep, and of small to moderate size (~10–500 m^3). However, there were also a number of larger bedrock failures (possibly 200,000–300,000 m^3), with some larger slides forming small landslide-dams in the Mangawhero and Whangaehu valleys. Details of landslide densities, size, scar to debris runout length ratios, and terrain characteristics in these four valleys are presented in a companion report (Hancox and Wright, 2005). The style of landsliding and some typical examples of significant landslides in the worst affected areas are presented below.

Pohangina valley

Some of the most spectacular landsliding was seen in the lower Pohangina valley about 20 km northeast of Feilding. In some areas the landslides were so numerous that they produced large areas of coalescing shallow erosion scars 0.5–1 m deep affecting the steep grass-covered hills on the west side of the Pohangina valley (Figure 18). As in other areas, there were few landslides on slopes covered by native scrub or exotic forest (Figure 19).

Figure 18. Multiple shallow (~0.5–1 m deep) soil/debris slides and flows scarring steep grass-covered hills on the west side of the Pohangina valley.
[GNS Photo: GH1848]

Figure 19. Although shallow soil slides and flows were widespread on steep grass-covered hill slopes of the lower Pohangina valley, there were few failures in areas of scrub and exotic forest (left).
[GNS Photo: GH2400]

Although exotic forest provided good protection against landsliding on hill slopes, trees planted close to river banks collapsed into the river channel when undercut by rivers in flood. Collapse of pine trees into the Pohangina River (Figure 20) contributed to the vegetation and tree debris that caused the collapse of the road bridge at Ashhurst (Figure 21, about 25 km downstream from the site shown in Figure 20). Pine trees planted close to the river channel do little to prevent river bank erosion, and in this situation the trees are a potential (man-made) hazard.

Figure 20. Area of pine trees planted close to the river bank in the upper Pohangina valley. Some trees collapsed into the river during the February 2004 flood. Debris from the fallen trees contributed to the collapse of the road bridge across the Pohangina River at Ashhurst ~25 km downstream (left).
[GNS Photo: GH2376]

Figure 21. Pine and poplar tree debris contributed to collapse of the Saddle Road bridge across the Pohangina River at Ashhurst.
[GNS Photo: GH1817]

Effects on buildings – Rangitikei and Mangawhero valleys

Despite the density of landslides in the Manawatu–Wanganui hill country, no houses or buildings are known to have been significantly damaged by landslides in this area, although there were a few near misses. For example, a farmhouse in the Rangitikei valley 12 km southeast of Hunterville narrowly escaped damage from large shallow soil slides/flows on a nearby steep slope. In this case trees protected the house from the soil debris, but sediment-charged water appears to have reached it (Figure 22). In another location further to the west in the Mangawhero valley, large soils slides and flows caused extensive damage to farmland and farm tracks, but did not reach SH 4 or an adjacent farmhouse (Figure 23).

Figure 22. Large shallow soil slides and flows which came close to damaging a farmhouse in the hills above the Rangitikei valley. Trees stopped most of the debris but the soil-charged watery part of the flow reached the house. *[GNS Photo: GH2425]*

Mangawhero valley

Figure 23. Large (~2000 – 5000 m^3) soils slides and flows which damaged farmland and tracks close to SH 4 in the Mangawhero valley. The bedrock failure (left) was typical of many larger slides in the area.

[GNS Photo: GH2728]

The aerial reconnaissance photography and mapping (Figure 7) and analysis of SPOT imagery (Figure 8) showed that the middle and lower reaches of the Mangawhero valley were the most landslide-affected areas in the Wanganui hill country. The highest density of small (<100m^3) and medium (100–1000 m^3) landslides and many of the largest landslides were found in the lower Mangawhero valley, including a large (~200,000 m^3) rotational slide (the largest observed) in mudstone bedrock with associated soil flow lobes almost ~1 km long near Lakes Hill and Otoko Pa (Figures 24 and 25).

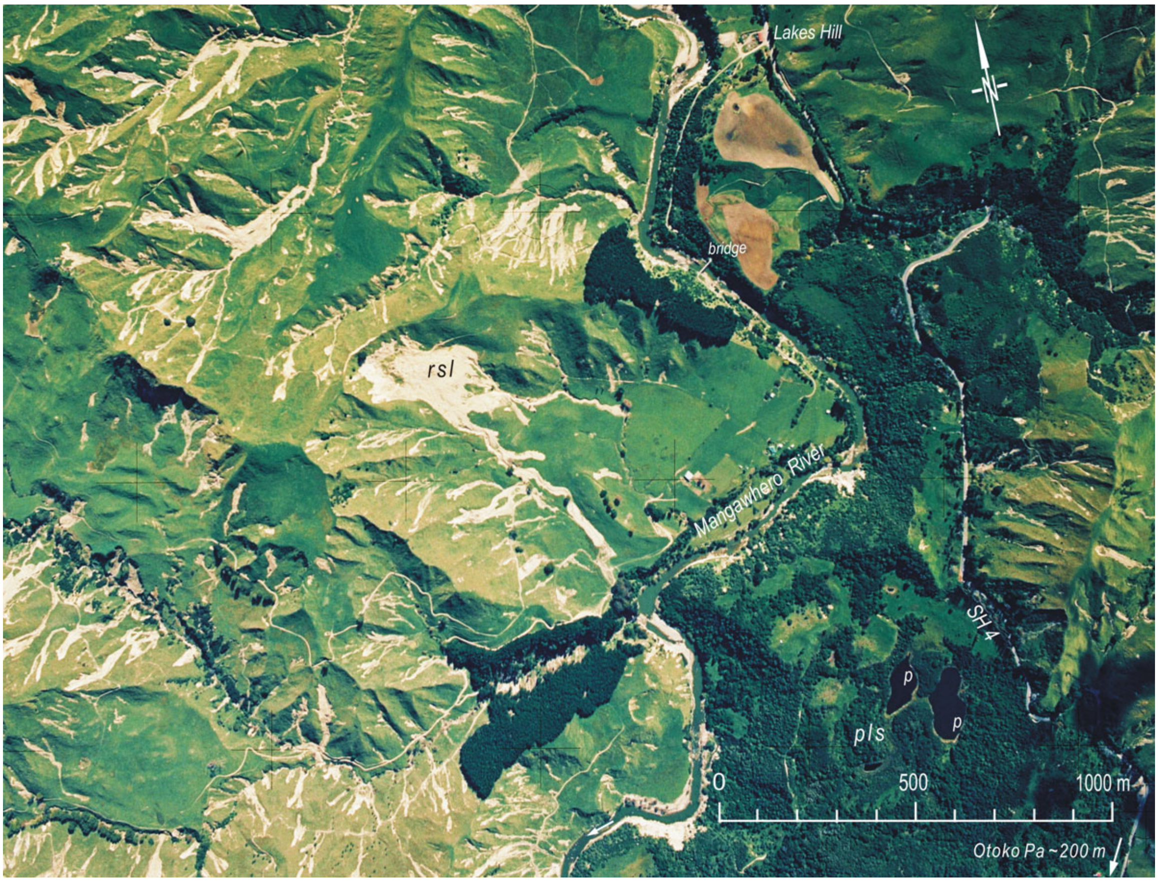

Figure 24. Vertical aerial photo showing multiple small soils slides and a large (~200,000 m^3) rotational slide and soil flow *(rsl)* in mudstone bedrock in the Mangawhero valley to the west of SH 4. A very large (>10^8 m^3) prehistoric landslide *(pls)* was unaffected by the storm. *[Lawrie Cairns Photo: K6]*

Figure 25. Closer view of the ~200,000 m^3 rotational slide in the Mangawhero valley. The scale of the slide can be seen here by the head scarp, which is about 50 m high and cuts deeply into mudstone bedrock. Soil and debris flows associated with this failure extended almost 1 km to the Mangawhero River. Slide debris caused significant damage to fences. *[GNS Photo: GH2159]*

The protection against landsliding provided by pine forest was further demonstrated in the Mangawhero valley by small areas of pine trees in the Lakes Hill area (Figure 24). This effect was even more apparent in larger forested areas about 10 km to the south on hills along the east side of the Mangawhero River. In this area steep recently-milled and grass-covered hill slopes were severely scarred by landslides (Figures 26 and 27). Old tree stumps left in the ground did little to prevent shallow landsliding in recently-milled areas. Similar effects were seen in other areas of milled or replanted forest after the February 2004 storm, which suggests that rainfall interception by the forest canopy, leading to reduced rates of soil saturation and runoff is more important in preventing landslides on steep hill country than root binding of the soils. It was notable that many large areas of mature un-milled forest were almost untouched by landslides, although in some forest areas a few small slides were seen in steep gullies.

Figure 26. Oblique aerial photo of numerous small shallow slides and flows on recently-milled hills in the Mangawhero valley, but no obvious slides in mature un-milled forest in this area.
[GNS Photo: GH2130]

Figure 27. Aerial photo showing numerous shallow soil slides and flows on grass-covered hills in the Mangawhero valley, with few obvious landslides in areas of mature forest. Lower intensity rainfall is inferred in grass-covered areas little affected by landslides (top right) *[GNS Photo: GH2667]*

Landslide dams – Whangaehu and Turakina valleys

A number of landslide dams and lakes were formed in the Wanganui hill country. The examples shown here are located in small side streams of the middle Whangaehu valley (Figures 28 and 31), and at the head of the Mangapapa River in the upper Turakina valley (Figure 29). All of these lakes are impounded by large (~10,000–30,000 m^3) rotational slides in mudstone, which formed large landslide dams in small streams. In all cases where landslide-dammed lakes were seen, the streams were not large enough to breach the dams that were formed. Because of the small water volumes involved, the risk of a future dam-break flood from these features is thought to be low. Older landslide-dammed lakes in the Wanganui–Manawatu hill country may provide data on when similar high intensity landslide events have occurred in the past in that area.

Figure 28. Small landslide dammed lake formed by a large rotational landslide in a small side stream of the Whangaehu River.
[GNS Photo: GH2193]

Figure 29. Landslide-dammed lake impounded by a large rotational landslide in mudstone. This example is located at the head of the Mangapapa River in the upper Turakina valley.
[GNS Photo: GH2458]

Damage caused by landsliding

The many landslides caused by the February 2004 storm resulted in considerable damage in some areas due to loss of pasture and grazing on hill country farms (Figures 18 and Figure 24), damage to fences (Figure 25) and some buildings (Figure 22). Landslide damage to farm tracks caused loss of access (Figure 23). Roads in the Wanganui–Manawatu area were severely affected by landslides, either by collapse of road edges or blockage by slide debris. Landslides in the Manawatu gorge (Figure 17) caused the most significant and longest road closure in the area – for about three months. Many rural roads in the area were closed by soil and debris flows for a few days to weeks, but in most cases the damage was minor and the slide debris was quickly cleared away. However, in some more isolated rural areas, such as the middle Whangaehu valley, roads remained closed or under repair for several months. In many cases landslides affecting roads were small rock and soil falls from steep road cuts, but failures on natural slopes also affected roads. For example, the upper Pohangina valley road was closed by extensive soil and debris flows from a steep terrace riser on the east side of the road (Figure 30). Large long-runout debris flows and small rock falls also cut the road in the middle Whangaehu and Wanganui valleys (Figures 31, 32, and 33).

Figure 30. Extensive debris and soil flows from this steep terrace riser temporarily blocked the road in the upper Pohangina valley but did little serious damage. The slide debris had been cleared away and the road reopened when this photo was taken on 12 March 2004. *[GNS Photo: GH2339]*

Figure 31. This debris flow briefly cut the Whangaehu valley road but did no serious damage. The spread and form of the distal lobes indicate the high fluidity of the flow. A small landslide-dammed lake can be seen in a side valley (top right).
[GNS Photo: GH2183]

Figure 32. Debris flows and small rock falls (in cutting left) still blocked the Whangaehu valley road when this photo was taken (27 February 2004). *[GNS Photo: GH2205]*

Figure 33. Debris flows from steep natural slope briefly blocked the Wanganui valley road, but the debris had been cleared when the photo was taken on 27 February 2004. *[GNS Photo: GH2097]*

5. DISCUSSION

The floods of 15-20 February 2004 were amongst the most severe recorded in New Zealand, with recurrence intervals of 100–150 years in some places (Horizons Regional Council, 2004). Record rainfall for February fell over much of the lower North Island, with recorded 72-hour rainfall averaging 100–200 mm over much of the region, and up to ~1000 mm in some mountain areas (New Zealand Metrological Service, 2004). The prolonged heavy rainfall caused widespread landsliding over about 16,000 km^2 of the southern North Island, extending across Wanganui–Manawatu to southern Hawke's Bay, Wairarapa, and the greater Wellington areas. The Manawatu and Wanganui hill country was by far the worst landslide-affected area, with thousands of shallow soil and regolith slides, and some large deep-seated landslides formed on steep grass-covered hill slopes underlain by weak Tertiary mudstone. The Wairarapa and Wellington regions were affected by landsliding to a lesser extent, but the Ruahine, Taraura, and Rimutaka greywacke ranges generally suffered little damage, mainly because of the protection against erosion provided by native bush and sub-alpine tussock.

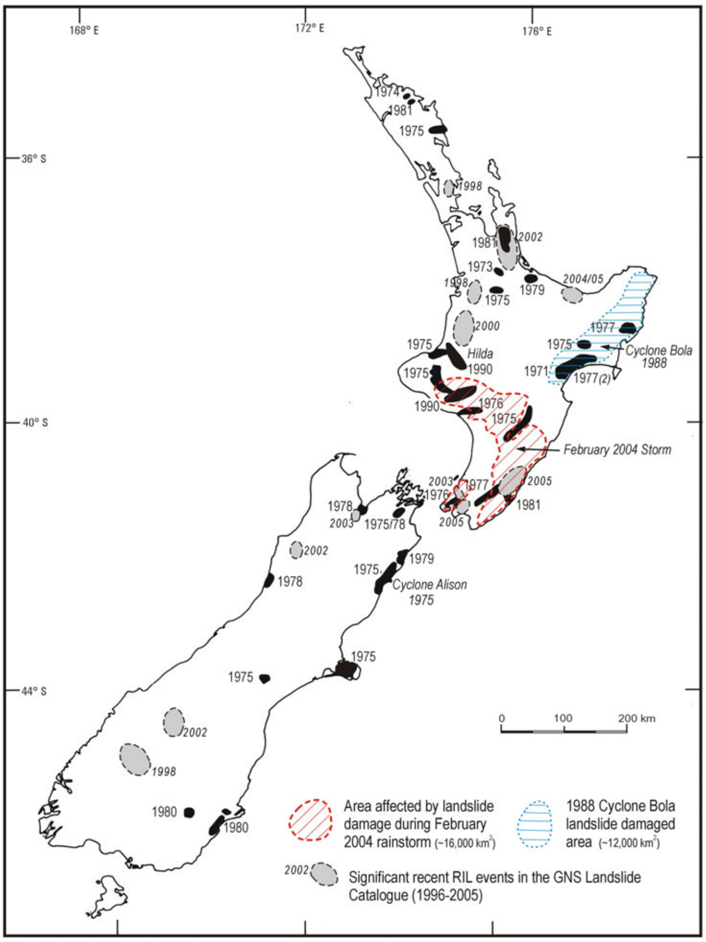

Figure 34. Extent of the area affected by landsliding during the February 2004 storm in relation to areas affected by Cyclone Bola (1988) and other significant rainfall-induced landslide (RIL) episodes since 1970 *(modified from Eyles and Eyles, 1982. Includes data from Crozier et al. 1992; GNS Landslide Catalogue 1996–2005).*

Landslides triggered by rainstorms are a well recognised problem in New Zealand, with on average two or three economically-significant episodes in the country each year (Crozier, et al. 1992; and GNS Landslide Catalogue 1996–2005), especially along the east coast of the North Island and northern South Island (Figure 34). Such extreme events often cause widespread damage to roads, buildings, and structures, but more often the greatest long-term cost results from severe erosion of farmland and in loss of pasture productivity (Glade, 1998).

These effects were shown by the February 2004 storm, which is possibly the most widespread rainfall-induced landslide episode to have occurred in New Zealand in the last 35 years. Landslide damage in the Wanganui–Manawatu hill country during the February 2004 storms was probably as severe as damage in the Gisborne and Hawke's Bay areas during Cyclone Bola in March 1988, but was probably more widespread (Figure 34).

Cyclone Bola caused severe landslide damage over a 12,000 km^2 area of the east coast of the North Island (Trotter, 1988; Trotter *et. al.*, 1989; Page *et. al.*, 1994). However, the landslide damage that occurred during the February 2004 storms was more extensive than what occurred during Cyclone Bola in 1988, with a wider and more diverse area affected. The full extent of this damage, especially in the southeast Wairarapa, did not become apparent until late 2004 because the initial aerial reconnaissance photography and SPOT imagery concentrated on the more severely damaged Wanganui–Manawatu hill country areas. Initial assessments of the extent of landslide damage in the southern North Island were therefore somewhat lower than the 16,000 km^2 area determined in this study.

Probably close to 80,000 new landslides formed during the February 2004 storm. At least 62,000 landslides covering 190 km^2 were identified from SPOT imagery over ~12,000 km^2 in the Wanganui–Manawatu and northern Wairarapa regions (Dymond *et al*., in prep). This suggests an average landslide density of ~5.2 landslides per km^2, with landslides occurring on grassed slopes steeper than ~20°, but especially on slopes steeper than 35°. Based on computer analysis of SPOT images, Dymond *et al.* (in prep) suggest that forest and scrub cover reduces landsliding probability by 90% and 80% respectively. Similar observations were made after Cyclone Bola, during which areas of young pine trees 3–5 years old suffered badly from landslide damage but stands older than about 8 years were virtually undamaged (Trotter, 1988). These observations are consistent with impressions gained from the initial aerial photography and reconnaissance mapping, and data presented in this report.

The SPOT images had sufficient resolution to allow new landslides and the extent of landsliding produced during high intensity rainstorms to be quickly and accurately identified. Acquisition of two more images covering the Wellington and southeast Wairarapa areas would have allowed the full extent of the landslide damage to be appreciated earlier and assessed more accurately. However, SPOT images are expensive and aerial photography in a fixed-wing aircraft provides a cheaper and reasonably accurate means of assessing the extent of the landslide damage and obtaining good images of specific landslides. The resolution of the SPOT images was, however, too low for identification of landslide scars and debris runout areas, with oblique and especially vertical aerial photographs being preferable for such studies. Aerial photos clearly show many landslides (soil and debris flows) with scar to debris runout length ratios of about 1:3 to 1:10. These ratios are considerably higher than the scar to debris tail area ratios (~1:1.2 to 1:1.6) reported by Dymond *et al.* (in prep), or the ~1:2 to 1:3 ratios reported for Cyclone Bola using SPOT images (Trotter et. al., 1989). These aspects and other issues such as vegetation, land use, and other terrain characteristics are analysed and discussed in more detail by Hancox and Wright (2005).

It was notable that none of the many pre-existing, deep-seated very large bedrock slides in the area – like the Otoko Lakes Landslide (~100 million m^3, Figure 24) and the Ohorea landslide (~175 million m^3) in the upper Mangawhero Valley – was obviously affected or reactivated by the storm, and no new landslides of this type and size were formed. These very old prehistoric landslides were probably initiated by other factors, such as river down cutting and large earthquakes over the last several thousand years, as suggested by Crozier et al. (1995) for over 100 similar old landslides in southeast Taranaki. Although it seems likely that their origin is not directly related to high-intensity rainfall, they may exhibit accelerated creep movements in response to very high rainfall. Further mapping, dating, and monitoring studies of these giant landslides is required to better understand their current activity, nature, and origin.

6. CONCLUSIONS

(1) Heavy and prolonged rainfall during the February 2004 storm caused widespread landsliding over about 16,000 km^2 of the southern North Island, extending across the Wanganui–Manawatu, southern Hawke's Bay, Wairarapa, and greater Wellington areas. Landslide damage was greater than what occurred during Cyclone Bola in 1988, with a wider and more diverse area affected. The most severely damaged areas were in the Mangawhero, Whangaehu, Turakina, and Pohangina valleys, where tens of thousands of small to medium (<100–1000 m^3) shallow (1–2 m deep) soil and debris slides and flows in regolith occurred, along with some larger (~1000-200,000 m^3) deep-seated landslides in Tertiary mudstone bedrock. Some landslide-dammed lakes formed in small streams.

(2) Most of the landslides occurred on steep (~20-35°) grass-covered hill slopes, gullies and steep terrace edges. Some of the shallow landslides were so numerous and extensive that they produced areas of coalescing soil slides and flows affecting many hectares. The debris from many landslides did not reach permanent stream channels, but remains on the slopes. Gully and river bank failures contributed considerable sediment and trees to flooded rivers, with the latter causing bridge failures. Soil and debris flows exhibit scar-to-debris length ratios of 1:3 to more than 1:10 in some more mobile flows.

(3) Landslide occurrence was clearly related to land use. Hill slopes covered with native bush and exotic forest were much less affected by landsliding than grassland areas, with only a few isolated landslides observed in forested areas. Forest cover provided good protection against landsliding during the February 2004 storm. Recently-milled areas with tree stumps in the ground were severely landslide-damaged, suggesting that forest canopy is more important in reducing landsliding than strengthening of soils by tree roots. However, trees planted close to river banks collapsed into flooded rivers, contributing to the debris that caused bridges to collapse.

(4) Damage to farmland was extensive across the region, and many roads were severely damaged and closed by slips. State Highway 3 through the Manawatu Gorge was closed for almost 3 months by several large landslides. Some slips came close to houses and buildings causing minor damage, but as far as we are aware few were significantly damaged and only one house was destroyed (in Karaka Bay, Wellington). One large landslide (~200,000–300,000 m^3) dammed the Hutt River at Te Marua near Upper Hutt and diverted it through the golf course, causing significant erosion damage.

(5) None of the many pre-existing, deep-seated very large bedrock slides in the area - like the Otoko Lakes (~100 million m^3) and Ohorea landslide (~175 million m^3) in the Mangawhero Valley - was observably affected or reactivated by the floods, and no new landslide of this type and size was formed. These very old (prehistoric) landslides were probably initiated by other factors such as river incision and large earthquakes several thousand years ago, and appear to be unaffected by the high intensity rainfall that causes superficial but often severe landslide damage to steep hill country.

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