LANDSLIDES CAUSED BY THE JUNE–AUGUST 2008 RAINFALL IN AUCKLAND AND WELLINGTON, NEW ZEALAND

GT Hancox, S Nelis

GNS Science Report 2009/04
31 March 2009

GNS SCIENCE
TE PŪ AO

BIBLIOGRAPHIC REFERENCE

Hancox, G.T., Nelis, S., 2009. Landslides caused by the June–August 2008 rainfall in Auckland and Wellington, New Zealand. *GNS Science Report* 2009/04. 30pp.

G. T. Hancox, GNS Science, PO Box 30368, Lower Hutt.

S. Nelis, GNS Science, PO Box 30368, Lower Hutt.

GeoNet Landslide Response Report (Project No. 430W6000)

ISSN 1177-2425
ISBN 978-0-478-19661-0

CONTENTS

FIGURES

ABSTRACT

The winter of 2008 was stormy and wet, with floods in many parts of New Zealand. Rainfall of 150% above normal in Auckland, and 135% higher in Wellington triggered many landslides in those areas, closing roads and damaging or destroying several houses. The rain was only moderately intense but prolonged. Most of the landslides occurred towards the end of several episodes of wet weather from June to August 2008, during which c. 50-120 mm rain fell over periods of 5 to 10 days.

Major landsides occurred at Torbay, Glenfield, and Huia in Auckland, damaging several houses. These slides were initiated by rainfall, but the underlying causes resulted from building on old landslides, or previously unstable land where there had been major alterations to the ground profile, without due allowance for the underlying instability.

The prolonged rainfall also triggered numerous landsides on coastal cliffs, but other factors, such as wave undercutting of cliffs and houses built along the cliff-edge, provided the underlying pre-conditions for the failures. A common problem is that many houses are built too close to the edge of unstable cliffs that are prone to erosion and periodic slope failures. Most of the houses affected by coastal cliff failures appear to have been built close to, or in some cases within the *'Foreshore Yard'*, a 15-25 m wide buffer zone from which cliff-top residential development in Auckland is set back from the coast.

Most landslides on Auckland's east coast cliffs were small falls of soil, regolith, and vegetation at the tops of cliffs and did little or no damage to houses. Major landslides at Achilles Point and Buckland's Beach, which caused substantial damage, involved both regolith falls and failures on joints and faults within the underlying interbedded sandstone and siltstone bedrock. Rainfall also reactivated an old large coastal landslide at Kawakawa Bay. The failure closed the northern access road to the settlement for one month, and necessitated demolition of a house, extensive earthworks, and drainage works to stabilise the slope and make the road safe. This landslide illustrates the danger of constructing an unsupported road cut across the toe of an old landslide, and the role of prolonged rainfall in its reactivation.

The 2008 landslides are a reminder that much of Auckland is at high or moderate risk from landslides. New houses or modifications to homes on coastal cliffs and other high-risk areas may need geotechnical assessments and stabilising measures to proceed. Building too close to the cliff-edge is inadvisable, and a set-back distance of at least the height of the cliff may be required. Buyers of existing homes would be wise to obtain pre-purchase geotechnical assessments to determine if there are any slope stability issues or hazards that could affect the property.

Prolonged and higher than normal rainfall in Wellington triggered landslides in many places, causing substantial damage to roads and houses. However, other factors appear to have provided the preconditions for the slope failures. All of the observed landslides occurred on modified (cut) slopes which had not been stabilised or designed for long-term stability.

The houses affected by landslides in Wellington in 2008 were not substantially damaged. Post-failure response mainly involved temporary evacuation of occupants, restoration of damaged services, and clearance of debris from roads. Although the affected properties have been reoccupied the failed slopes have not been permanently stabilised. All of the houses that were undermined by landslides were built too close to the tops of unsupported cuts, and they are at significant risk of further collapses in the future. Such slope failures are typical of those that occur in Wellington during heavy and prolonged rainfall. All houses in Wellington that are built too close to the tops or bottoms of steep (>~60), high cuts are at risk from landslides, not only during future rainstorms, but also during strong (MM 8 to MM10) earthquake shaking.

KEYWORDS

Rainfall-induced landslides, winter 2008, Auckland, coastal cliff failures, foreshore yard, Wellington, house damage, earthquake-triggered landslides.

1.0 INTRODUCTION

1.1 Background and Weather Conditions

The authors carried out a limited GeoNet response to inspect and document some of the rainfall-induced landslides that occurred in the Auckland and Wellington areas during the 2008 winter. This report presents the results of those responses.

Winter weather in 2008 was very stormy and wet with floods and snow to low levels. Of the four main centres, winter rainfall (from June-August) was 150% of normal (long-term mean) in Auckland, and 135% in Wellington (Table 1), which caused numerous landslides in those areas, closing many roads and damaging or destroying a number of houses.

The New Zealand MetService reported that not only were the rainfall totals far above normal in Auckland and Wellington, but the number of days with rain was also much higher than average, particularly during July (22 in Auckland and 20 in Wellington). The 2008 winter climate pattern was dominated by depressions ('lows') crossing central New Zealand and often centred to the east, producing westerlies over the North Island, with south easterly flows over the South Island. Overall, winter temperatures were slightly warmer than usual, with the national average temperature (8.5 °C) 0.2 °C above the winter average.

The 2008 winter produced several high rainfall flood-producing events in the Auckland and Wellington areas (Table 1). Significant high rainfall events that occurred were:

- 29 June: 40 to 50 mm of rain in Wellington and the Hutt Valley up to 5 pm on the 29th produced some local flooding of roads, with slips closing Paekakariki Hill road.
- 9 July: Lower Hutt received 26mm of rain between 4am and 6am on the 9th.
- 26 July: A river burst its banks on the 26th near the township of Panguru, on the northern side of Hokianga Harbour, and up to 35 people had been evacuated and roads throughout Northland were closed by flooding.
- 29-30 July: About 63 mm of rain fell over two days in Torbay, Auckland. A slow moving landslide caused the destruction of one North Shore home and placed another 14 homes risk.
- 2–3 August: Wellington City had more than 20 slips, causing road closures and property damage.

The heavy rainfall event on 29 July 2008 caused flooding, slips and damage in the Auckland area was widely reported in the News Media after a North Shore home in Lingham Crescent, Torbay, was destroyed by a slip and another 14 homes were at risk in the same area. Serious landslides also occurred on the coastal cliff at Bucklands Beach in late August 2008, causing several families to evacuate their homes, and at Kawakawa Bay, where a large landslide caused closure of the access road to Kawakawa Bay for several weeks. The Bucklands Beach landslide is one of several failures on the steep cliffs on Auckland's east coast that are discussed in the report.

Days of Month	Daily Rainfall (mm) Auckland Airport				Daily Rainfall (mm) Wellington (Kelburn)			
	June	July	August	Sept	June	July	August	Sept
1	2.8	0.6	2.4	0.6	1.2	0.0	1.4	0.0
2	1.6	2. 4	4.8	0.0	8.2	6.0	10.2	0.0
3	0.0	4.2	11.8	0.6	0.0	5.2	26.2	0.0
4	2.2	12.8	6.2	0.0	3.0	11.0	2.6	10.4
5	0.0	9.0	1.4	0.0	0.0	4.8	7.2	2.0
6	0.0	10.8	0.2	0.0	0.0	0.0	0.0	15.0
7	2.8	6.0	0.0	0.0	6.2	0.4	0.0	0.0
8	6.0	0.0	4.6	6.0	1.2	0.0	25.8	6.6
9	0.0	0.0	12.0	0.0	0.0	0.0	5.2	8.8
10	0.0	0.6	0.0	4.4	0.0	0.0	0.0	0.8
11	0.0	2.0	0.0	4.4	0.0	6.0	0.6	8.0
12	0.0	3.8	8.6	1.6	0.0	24.0	11.4	0.4
13	0.0	0.2	3.8	0.8	0.0	0.0	7.2	0.0
14	0.0	0.2	16.2	0.0	0.0	0.0	7.4	0.0
15	0.2	0.0	15.8	0.0	0.0	0.0	5.6	0.0
16	24.4	5.6	17.6	0.0	0.0	15.4	3.0	0.0
17	2.6	0.2	9.2	6.2	0.0	15.2	3.2	0.0
18	0.0	1.4	5.0	1.4	0.0	7.0	1.0	7.0
19	0.0	7.8	5.4	4.2	0.0	0.0	0.0	0.8
20	0.0	9.8	1.4	0.0	0.0	0.4	0.0	0.0
21	0.0	1.6	3.2	0.0	0.0	0.0	0.0	0.0
22	46.2	18.4	0.0	0.0	3.6	15.4	0.0	0.0
23	3.4	3.0	7.0	0.0	14.6	15.2	0.4	0.0
24	12.6	3.2	33.0	0.0	6.4	7.0	17.6	0.0
25	13.4	0.0	0.2	1.0	1.4	0.0	2.4	0.0
26	5.6	25.8	0.2	0.0	0.0	12.0	16.0	0.0
27	18.6	7.6	0.0	0.0	6.4	15.0	4.4	9.6
28	10.0	1.6	0.0	1.0	2.6	0.4	0.0	0.0
29	4.0	21.2	0.0	4.2	29.8	2.6	0.4	3.4
30	1.6	42.2	0.0	0.4	0.6	14.6	0.0	4.4
31	-	12.2	0.0	-	-	29.0	0.0	-
Totals	158	214	170	36.8	85.2	191.4	159.2	77.2
LT mean	115.5	131.3	112.6	96.6	113	110.9	100.7	83.1
% LT mean	137	163	151	38	75	173	158	93
LT max	220	304	218	208.4	190	261	234	177
Winter Rain (Av % mean)	150 %				135 %			

(grey)	Rain Day >=0.1mm
(light cyan)	Wet Day >=1.0mm
(cyan)	Very Wet Day >=5.0mm

Table 1. Daily Rainfall Totals at Auckland and Wellington – June to September 2008 *(Data from NZ Met Service MetConnect Web Site, Climate Summary, 2008).*

Following continued high rainfall and further landsliding in the Auckland area through August, the NZ Herald reported on 14 Sep 2008 that half of Auckland was at "high risk" of being affected by landslides, and it could cost homeowners up to $500,000 in engineering earthworks to make their houses safe, based on an Auckland Regional Council map showing widespread susceptibility to landslides throughout the region. More than half the area is labelled as "high" or "moderate risk", meaning slopes are unstable or may become unstable depending on rain or erosion.

The 2008 winter is considered by local engineers to be noteworthy because of the number of larger slips that occurred due to the continuous rain that fell throughout the winter. The NZ Herald reported (14 September 2008) that the slips that occurred were considered by some local engineers (e.g. John Leeves, Tonkin and Taylor) to be the worst in terms of size and depth in the last 40 years. This report discusses and illustrates some of these landslides.

1.2 GNS GeoNet Landslide Response

General information on the 2008 winter weather were widely reported in the news media (TV, radio, newspapers), while specific rainfall and weather-related data (Section 1.1, Table 1) was obtained from the MetService website (*http://www.metconnect.co.nz*). Because of widespread news media reports of the damage to houses caused by landslides during the July-August rainstorms, GNS undertook a response under the GNS/GeoNet contract with the Earthquake Commission to record and gather information on landslides in the most affected urban areas in Auckland and Wellington.

The various GeoNet landslide responses included:

(a) *Ground reconnaissance inspections:* Ground inspections were carried out during August 2008 to evaluate landslides in Wellington (G Hancox, N Perrin), and Auckland in early September (G. Hancox, S Nelis, S McColl)

(b) *Aerial inspection and photography:* An aerial inspection and photographic flight was carried out in Auckland on 4 September 2008, during which about 300 high resolution (12.3 Mp) digital photos were taken. The flight line, landslide locations, and the numbers of selected photos of the main landslides are shown in Figure 1. Digital copies of the full set of these photos are housed in, and are available through the GNS Photo Library.

1.3 Scope of report

This report documents the locations and discusses some of the significant landslides that occurred in Auckland and Wellington regions during the winter of 2008, especially those that damaged houses or closed roads. A summary of the main landslide events that occurred in those regions from June-August 2008 is presented in Table 2 (data based on GeoNet Landslide Catalogue, 2008). The landslides are then briefly discussed and illustrated by photos taken during ground inspections and the reconnaissance flight (Figures 2-30).

The landslides are not described in great detail as that is beyond the scope of a GeoNet Response report. General comments are made on the factors that contributed to some slope failures, and the resulting damage, but a detailed analysis of the landslides has not been carried out. However, the overall significance of the landslides in terms of the assessed hazard and risk and damage to houses and roads, causative factors, preventative measures, and future landslide susceptibility and risk are briefly discussed.

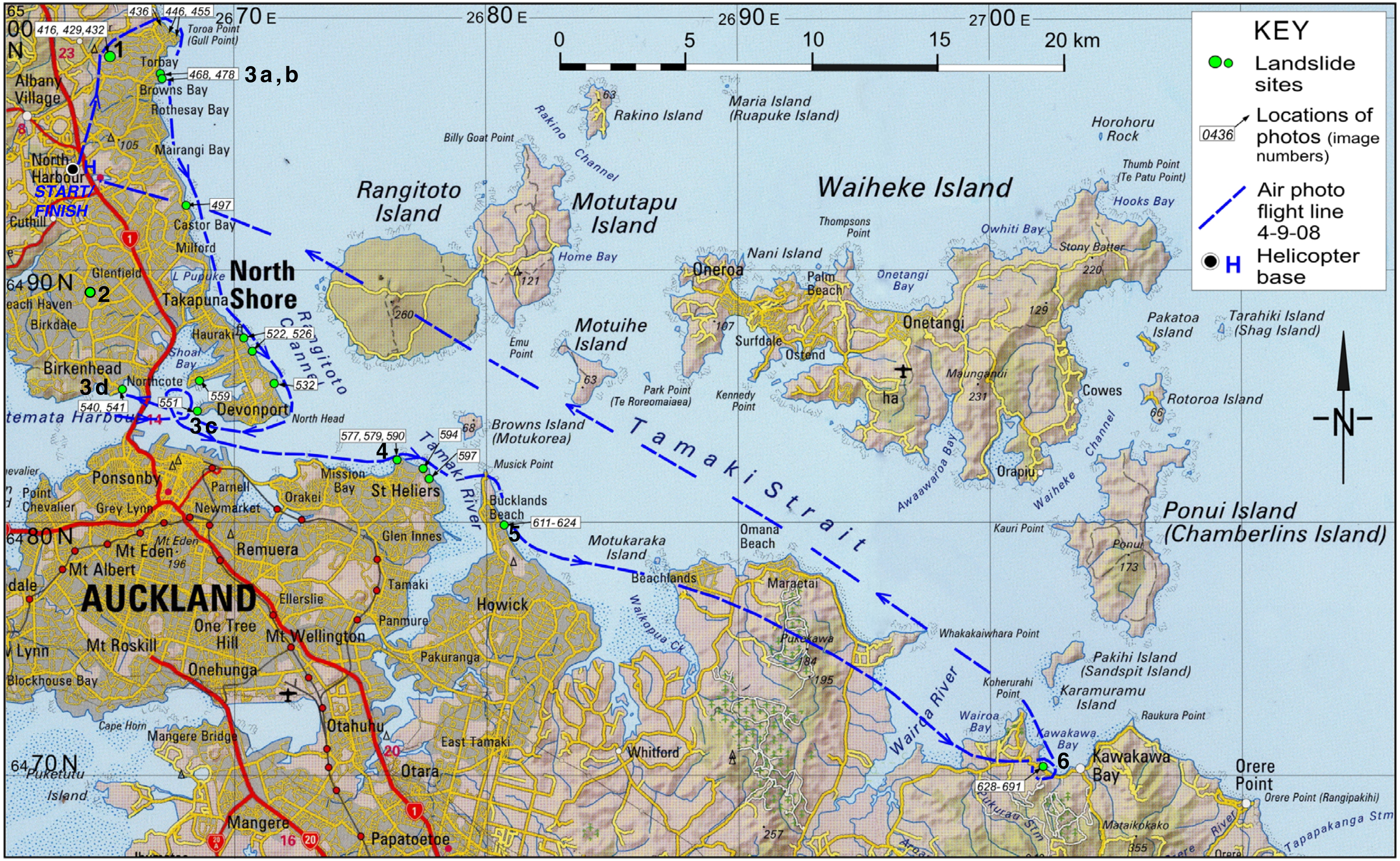

Figure 1. Map showing the flight line for the Auckland aerial reconnaissance on 4 September 2008, locations of the main landslides that occurred during the winter 2008, and image numbers of selected landslide photos presented in the report. *Main landslide locations: 1 – Torbay landslide; 2 – Glenfield Landslide; 3a,b,c,d – Smaller cliff failures; 4 – Cliff Road, St Heliers; 5 – Buckland's Beach landslide; 6 – Kawakawa Bay landslide).*

Month	Landslides in the Auckland Region	Landslides in the Wellington Region
June 2008	<u>Monday 22nd</u>: Slip on SH 1 Dome Valley, North of Warkworth. Road reduced to one lane *(Police Comm. Ctr. Updates, 22/06/08)*.	<u>Tuesday 3rd</u>: Slip reported on SH 2 - Rimutaka Hill *(Morning Report Radio NZ National)*.
July 2008	<u>Tuesday 29th</u>: Heavy rain on 29-30th caused large slow moving landslide in Torbay, damaging at least two houses and threatening several others. <u>Wednesday 30th</u>: SH 1 north of Warkworth closed by slip in Dome Valley. SH 1 Pohuehue Viaduct partially blocked by slip south of Warkworth. SH 11 Lemons Hill, Kawakawa Bay, briefly blocked by slip. <u>Thursday 31st</u>: - One house in Lingham Cres. Torbay was demolished because of slip, and other 14 homes had to be evacuated. because of slips. - Two houses in Mulberry Place, Glenfield, were evacuated after being threatened by a large landslide. The houses were still unoccupied in February 2009 because of ongoing ground movements. - Four houses affected by deep-seated landslide, Birdwood Road, Swanson, Waitakere City. .	<u>Wednesday 2nd</u>: Small slip on Grant Road Wellington, near Harriett St corner (about 2-3 m^3) – probably many similar ones around the area *(N. Perrin, pers. observation).* <u>Saturday 12th</u>: Slip blocked both south bound lanes of SH 1 just south of Pukerua Bay near Whenua Tapu intersection. *(Police Comm. Ctr Update, AA Road Watch)*. <u>Wednesday 23rd</u>: Train derailed by slip on Johnsonville line about 7:30 pm near Ngaio station. Train services resumed in afternoon of 24 July. (Radio NZ National). Slip affected private footpath in Brooklyn, Wellington – council disputes responsibility. Slip on SH 1 at Paekakariki and another between Whenua Tapu and Pukerua Bay; both cleared that day. Manawatu Gorge down to one lane after large slip caused by torrential rain. *(stuff.co.nz, 24 July)*. <u>Thursday 24th</u>: SH 2, Rimutaka Hill road affected by several small slips reducing road to one lane in places. *(Radio NZ National)* <u>Thursday 31st</u>: SH 2 Rimutaka Hill partially blocked by two slip near summit. A number of Wellington city streets reported to be partly blocked by slips.
August 2008 September 2008	<u>Wednesday 13th</u>: SH 1 affected by slip at Bombay. <u>Friday 15th</u>: Slip destroyed 100 m of a water supply pipeline at Redoubt Rd, cutting off water for 3000 Manukau houses. - First signs of instability noted on coast road at Kawakawa Bay. <u>Monday 18th</u>: Slip closed one lane of Hunua Road, Papakura. <u>Wednesday 20th</u>: Northbound lane of SH 1 closed by slip at Waiwera, north of Auckland. <u>Sunday 24th</u>: Fall of 500 m^3 from landslip on Kawakawa Bay Road (Turei Hill) closes road (for c. month); three properties are declared unsafe because of the developing, slow moving large landslide on Turei Hill. <u>Monday 25th</u>: Four houses evacuated in Unsworth Heights, Auckland North Shore. Properties at 141 and 143 Albany Highway were said to be most at risk. Albany Highway and Condor Place cordoned off. A house in St Mary's Bay was also affected by a fallen tree on a slip (a large pohutukawa) on the cliff below Ring Terrace. <u>Tuesday 26th</u>: Parnell baths closed by slip – carpark and walkway to Point Resolution closed. Slip behind the swimming complex left cracks at the top of the cliff through paved viewing area. <u>Saturday 30th and Sunday 31st</u>: A major subsidence at 114–120 Clovelly Road, Buckland's Beach, causes 5 residences to be evacuated. Kawakawa Bay road still closed by major landslide on Turei Hill. *<u>Note:</u> Kawakawa Bay road reopened on 25 September 2008 after landslide movement stopped.*	<u>Sunday 3rd</u>: House in Devon St, Aro Valley, Wellington evacuated after landslide beneath it. Slips also reported from Miramar, Kilbirnie, Mt Cook, Kelburn, Houghton Bay, Northland, Karori and Khandallah. <u>Monday 4th</u>: Large slip below house in Palliser Road, Roseneath; road closed to remove debris. <u>Tuesday 5th</u>: Small landslides in Tinakori Road near Thorndon Quay intersection blocked one lane; A slip in Ohiro Rd, Brooklyn, blocked north-bound lane near Penthouse cinema. <u>Wednesday 6th</u>: Road to Eastbourne blocked by a slip at Point Howard about 9 pm. Open for one lane by midnight *(Radio NZ National midnight news, DomPost 7 August)*. A house above the slip was evacuated. <u>Monday 25th</u>: Petone Overbridge, SH 2 blocked by slip during the evening. <u>Tuesday 26th</u>: SH2, Rimutaka Hill – one lane blocked by slip halfway between summit and Featherston. <u>Wednesday 27th</u>: Heavy rain caused 15 slips in Wellington large enough to block road lanes. Oban St (Wadestown), Seatoun Tunnel, Upland Road and Ngaio Gorge had highest rainfall (32 mm at Kelburn). <u>Friday 29th</u>: Near Eastbourne, a house was damaged by a rock fall from the cliff just south of Sunshine Bay (boulder fell through roof and demolished the kitchen). Boulders and debris blocked one lane of the road, causing morning traffic chaos, and Eastbourne residents were advised to stay home. Note - no rain had fallen in previous 24 hours.

Table 2. Summary of landslide events in the Auckland and Wellington regions June-August 2008.

2.0 DESCRIPTION OF LANDLIDES

2.1 Landslides in Auckland

The monthly rainfall totals in Auckland from June to August were far greater than normal (137%, 163% and 151%), and the number of days with rain was also much higher than usual (Table 1). The increased rainfall caused numerous landslides in Auckland, closing roads, destroying several houses, and causing damage worth several millions of dollars. Some of the more significant landslides are discussed and illustrated below.

2.1.1 Torbay Landslide

On 29-30 July 65 mm rain in Auckland caused flooding and numerous damaging landslides. A house in Torbay on Auckland's North Shore was evacuated and later demolished because of damage by slow movements of a deep-seated landslide (Figures 1 and 2). Several other houses in the area were also affected and evacuated temporarily.

Figure 2. House site in Lingham Crescent, Torbay where a home damaged by slow movement (700 mm on 30 July 2008) of a creeping landslide was evacuated and later demolished. Site evidence suggests the landslide is an old feature that was active before the site was developed, and reactivated by the prolonged rainfall in July 2008. *[GNS Photo: GTH-0429].*

The landslide that occurred in Lingham Crescent in Torbay was a deep-seated earth slide. Significant slide movements occurred on 30th July 2008 following a sustained period of heavy rainfall over two weeks. GNS Science staff (S Nelis and S McColl) inspected the site on 1st September 2008, after the most severely damaged house had been demolished and removed (Figure 2). The landslide is thought to be a reactivation of an older feature that was most likely active before the site was developed. Geomorphic evidence for this being a reactivated old landslide includes existing scarps 200-500 mm in height running through the back of the property (Figure 3).

Figure 3. View of property, above the demolished house showing relict landslide scarps *[Photo S Nelis].*

The landslide scarps above the demolished house have clearly been modified during development of the site, but are continuous across property boundaries, suggesting that they are instability features that extend across part of the housing area, rather than being caused by landscaping of any one property. The scarps may be pre-existing natural failures, but they could have been initiated by earthworks during development of the subdivision.

The main effect of the slide was to displace the building foundations downslope, resulting in structural damage to the property, which later had to be demolished (Figure 4). Monitoring data collected by North Shore City Council suggested that maximum vertical movements within the slide body were 700 mm over a 24 hour period. In an attempt to reduce the rates of movement in the landslide a number of sub-horizontal drainage holes were drilled into the slope, in addition to storm water drainage from adjacent properties being taken offsite. In addition, two piezometers were constructed to monitor water levels within the slope. The house eventually had to be demolished because engineers were unable to stop the landslide movement quickly enough to prevent significant damage to the house from occurring.

Figure 4. View of house foundations (left) after the most severely damaged house in Lingham Crescent (above) was demolished. The concrete driveway seen here has slid 100 mm towards the road as a result of the landslide movement. *[Photo S Nelis]*

2.1.2 Huia Landslide

At Huia in Waitakere City in west Auckland, c.10 km west of Mt Albert, a large deep-seated earth slide began moving episodically during August 2008, and continued moving through September. Movement episodes were driven mainly by two periods of prolonged rainfall (43 mm from 1-9 August, and 126 mm from 12-24 August, see Table 1).

The landslide affected a subdivision at Huia. The slip plane has formed along the contact between intact, unweathered voclaniclastic sandstones and completely weathered overlying material. At the contact between the two materials, spring seepage was noted (Figure 5) indicating the permeability boundary created by the underlying volcaniclastic sandstone.

Figure 5. Completely weathered sandstone/residual soil *(Cws)* overlying intact, unweathered voclaniclastic sandstone *(Ivs)*. The slip has formed at the boundary of the two material types with heavy seepage along the boundary. Damage includes structural damage to the house on the main slide, and damage to the vehicle access for the adjacent properties where the headscarp follows the driveway. *[Photo S Nelis]*

The Huia failure is an old reactivated landslide. This is indicated by numerous older scarps within the slide mass, including a 2-3 m headscarp about 10 m up slope of the main scarp of the present failure. Historical information suggests that there was a smaller failure within the landslide in 1968. The activity during August and September 2008 involved tension cracking and formation of other minor scarps up to 1 m high within the landslide body (Figures 6, 7, and 8).

In an attempt to prevent further water from entering the slide, plastic sheeting had been placed at the head of the active area (Figure 9). At the time of the landslide site inspection by GNS Science there were plans to install sub-horizontal drains to help relieve pore water pressures at the slip plane. The Huia landslide did considerable damage to one property in August 2008, and also damaged a stormwater and sewer line in September.

Figure 6. Old scarp visible at the rear of the property indicating the landslide to be a reactivation of a much older feature. *[Photo S Nelis]*

Figure 7. Fresh scarp showing recent landslide movement at Huia. *[Photo S Nelis]*

Figure 8. Tension cracking through the property garage, resulting in structural damage to the property. *[Photo S Nelis]*

Figure 9. View of the main head ward scarp of the recent landslide movement showing the plastic sheeting used to reduce water entry to the slide plane. The bank on right of the photo is the main headscarp of the old landslide. *[Photo S Nelis]*

2.1.3 Glenfield Landslide

On Auckland's North Shore two houses in Mulberry Place in Glenfield were evacuated on 1 August 1 due to a landslip, which had crept slowly towards the homes over several days. Geotechnical engineers acting on behalf of the North Shore Council monitored the situation. Bored drains were installed and storm water lines diverted away from the area to help stabilise the area, and a large retaining wall was planned to secure the edge of Mulberry Place. The landslide completely lifted the footpath, and part of the road slumped by about half a metre. The landslide continued to move slowly over the next six months. By February 2009 the houses were still evacuated and stability problems had still not been resolved by the council.

2.1.4 Small coastal cliff failures

The steep cliffs on Auckland's east coast were significantly affected by numerous landslides triggered by the prolonged rainfall, particularly during August. Most slope failures were small soil and regolith falls from the tops of 15-20 m high cliffs cut in weak, interbedded Tertiary sandstone and siltstone (Waitemata Group); and did little or no damage to houses. They did, however, threaten some valuable properties, and in several places cliff-top gardens, decks and swimming pools were undermined and placed in danger of collapse, as shown in Figures 10 and 11. In both of those cases building too close to the cliff and inappropriate tree planting along the unstable cliff edge seems to have provided the basic preconditions for slope failure. Although the landslide on the coastal cliff at Torbay (Figure 10) was triggered by rainfall, building a deck too close (almost directly on top of) to the cliff edge will have contributed significantly to the landslide by locally overloading the slope. Slope failure occurred despite ineffective shotcrete along the cliff edge aimed at keeping water out of the unstable slope.

Figure 10. This landslide on the coastal cliff at Torbay was triggered by rainfall. However, building too close to the edge of the cliff will have contributed to the failure by locally overloading the slope. This landslide (soil and regolith debris fall) occurred despite ineffective shotcrete along the cliff edge aimed at keeping water out of the unstable slope.
[GNS Photo: GTH-0468]

Figure 11 shows a landslide at Devonport where Pohutakawa trees planted along the cliff edge of have collapsed into the sea. This was one of several such failures that occurred. Figures 12 and 13 show other coastal cliff failures where trees appear to have decreased stability of the overlying soil and regolith layer. Trees make a good wind break in places, but on the edge of cliffs trees can reduce slope stability and cause failures by locally overloading the weak cliff edge, root wedging in joints, and tree movements due to wind. Although the landslide shown in Figure 11 was triggered by rainfall, all of these factors, as well the decks and swimming pool built very close to the edge of the cliff (in this case within the 9-30 m 'foreshore yard') seem to have contributed to the slope failure at this location.

Figure 11. Pohutakawa trees planted along the edge of this coastal cliff in Devonport make a good wind break. In this situation, however, trees can reduce slope stability by locally overloading the slope, root wedging in cracks, and tree movements due to the wind. Although the landslide seen here was triggered by rainfall, all of these factors, as well the decks and swimming pool built very close to the edge of the cliff seem to have contributed to the slope failure at this location. *[GNS Photo: GTH-0551]*

Figure 12. Small soil and regolith debris fall on the cliff face 1 km north of Castor Bay, where trees have contributed to the collapse instead of preventing it. *[GNS Photo: GTH-0497]*

Figure 13. Cliff collapse at Birkenhead, showing trees that have fallen into the sea under their own weight overloading the cliff edge. The retaining wall being built along the cliff edge (right) must be founded on stable sandstone bedrock to be effective. *[GNS Photo: GTH-0540]*

2.1.5 Slope failure at Achilles Point, St Heliers

In June 2008 emergency engineering works with an estimated cost of possibly $4 million were initiated to stabilise part of Cliff Road at Achilles Point, St Heliers (Figure 1), which was in danger of subsiding during heavy rain, after movements and cracks were discovered in the ground in April and May. A geotechnical investigation confirmed that cracking and ground movements were occurring over a 200 m length of the footpath, possibly because of natural erosion of the adjacent sea cliff. The situation was potentially serious as the movements threatened 5 houses. Slumping of only 300 mm could have damaged underground services such as water supply, stormwater, power, telephone and gas, and affect property access. Heavy rainfall would increase the risk of slope failure. The proposed stabilisation works included extending a 100 m retaining wall to increase stability, and improve drainage. Figures 14 and 15 show the works in progress in early September 2008.

Figure 14. Aerial view showing engineering stabilisation works in progress at Cliff Road above Achilles Point *(lower left)* St Heliers, 4 September 2008. Rainfall during August caused small shallow slope failures (left) but did not adversely affect the area being stabilised.
[GNS Photo: GTH-0579]

Figure 15. Closer view of the drainage system, tie-backs, and retaining wall, which was under construction in September 2008. The main failure here is deep-seated within the sandstone and siltstone bedrock, but there have also been small, shallow failures in the overlying soil and regolith (fresh scars lower right), which have typically resulted in the loss of cliff-edge vegetation.
[GNS Photo: GTH-0581]

The Auckland City Council reported on 18 December that engineering works to stabilise the cliff at Achilles Point were completed and Cliff Road would be reopened on 24 December 2008. A geological survey is planned by Auckland City Council along the full length of Cliff Road in early 2009 to review the stability and safety of the section of the coastal cliff.

2.1.6 Buckland's Beach Landslide

At Buckland's Beach in southeast Auckland, episodic movements of a slow-moving landslide on the coastal cliff adjacent to resulted in serious damage to one house causing that house and four other nearby houses in Covelly Road to be evacuated at the end of August 2008 (Figures 16 and 17). Slope movements continued after more rain fell in December 2008, and in February 2009 three houses were still unoccupied. The house at 116 Covelly Road (yellow house in Figure 16) has been most affected by the ground subsidence, with 100 mm wide cracks through the lower story, and up to 1 m subsidence of the lawn area (Figure 17).

Figure 16. This apparently innocuous landslide (lower left) severely damaged the yellow house (top centre) and the two houses on either side. These houses were still unoccupied in February 2009 as slope movements continued. Although rainfall seems to have triggered the landslide movements, excavation and building too close to the unstable cliff edge, especially the yellow house, and the large house to the north (right), were important underlying reasons for the failure. *[GNS Photo: GTH-0611]*

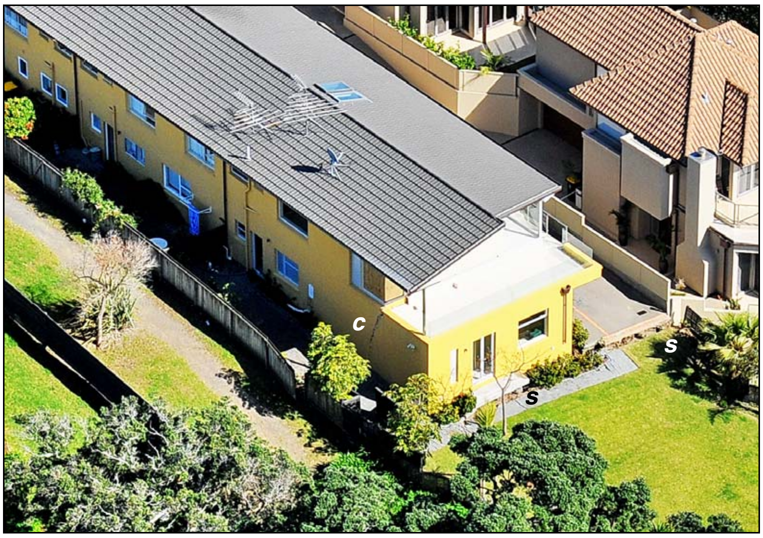

Figure 17. The yellow house at 116 Covelly Road was most damaged by the slow ground movements, which caused significant cracking *(c)* and structural damage to the front part of the house, and up to 1 m subsidence *(s)* of the lawn. *[GNS Photo: GTH-0617]*

The timing of the initial movements of the landslide can be linked to 116 mm rainfall over two weeks from mid-late August (Table 1). However, excavation and building too close to the unstable cliff edge most probably provided the basic preconditions for slope failure at this site, as it has at several other locations on Auckland's east coast cliffs (see Figures 10-13). Figure 16 clearly shows that the two houses that were most damaged by the ground movements have been built noticeably closer to the cliff edge. Siting the houses so close to the cliff is likely to have overloaded the top of the steep slope making it more susceptible to slope failure, especially during periods of intense or prolonged rainfall.

2.1.7 Kawakawa Bay Landslide

On Sunday 24 August, the prolonged rainfall over the preceding two weeks triggered a c. 500 m^3 landslide at Turei Hill, closing the northern access road to the coastal settlement of Kawakawa Bay, 40 km southeast of Auckland (Figure 1). Three properties were found to be at risk because of a developing, slow moving large landslide mass above the road near the coast. This landslide, located only 200 m from Kawakawa Bay settlement, was found to be a newly-active lobe of a much larger old landslide which extended about 65 m above the coast road, almost to the top of Turei Hill (Figures 18 to 22).

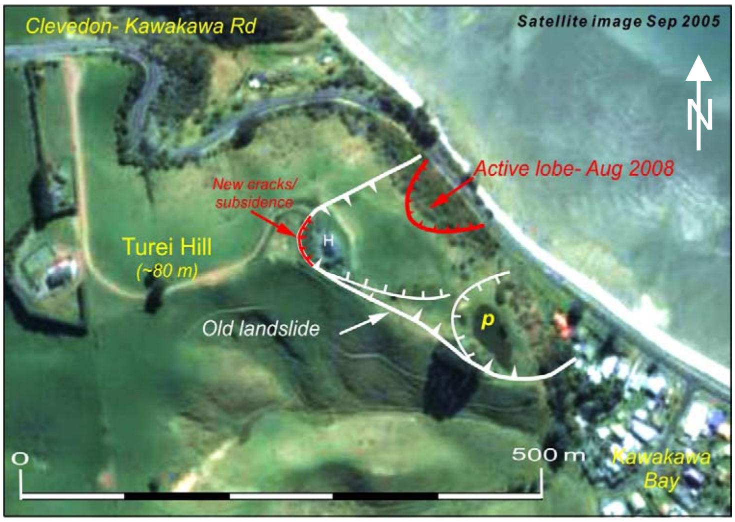

Figure 18. Satellite image (Sep 2005) showing the newly-activated lobe *(red)* of a much larger old landslide at Kawakawa Bay *(white)*. New cracking and subsidence extended to the head of the old slide, behind a recently-built house *(H)*. The old landslide comprises two main lobes: a main (northern) lobe which was reactivated by rainfall; and a smaller southern lobe (lower right), which has a large landslide pond *(p)* at the back of the slumped block.

Figure 19. Oblique aerial photo of the Kawakawa Bay landslide showing the debris slide *(dsl)* reactivation at the slide toe, which recently closed the coast road. Cracks *(c)* and incipient slumping are clearly evident at the top of the new failure area. Tension cracks and subsidence of up to 1 m also occurred behind the house *(H)* on the head scarp *(hs)* of the old landslide, but the smaller slumped block *(sb)* and landslide pond *(p)* to southeast were not affected. *[GNS Photo: GTH-0667]*

Figure 20. Closer aerial view of the large debris slide which blocked the road at Kawakawa Bay. Cracking and incipient slumping are obvious at the top of the new failure, but the reactivated area extends to the headscarp of the old landslide behind the house at the top of the slope (top right). The black polythene strips seen here were used to keep water out of cracks. *[GNS Photo: GTH-0661]*

Figure 21. Remedial works to stabilise the landslide at Kawakawa Bay were well advanced in early February 2009. The measures used have included horizontal drains drilled into the lower slope, and extensive earthworks at the top of the landslide to unload the head of the slide, part of which required removal of a house built just below the headscarp. *[Photo 9 Feb 2009, Manukau City Council.]*

The road to Kawakawa Bay was closed for a month while drainage and ineffective sluicing was carried out to dislodge partly failed material poised above the road (Figures 19 and 20). Slope movements slowed and stopped once the rain ceased, allowing the road to be reopened on 25 September, and easing the burden on Kawakawa Bay residents of having to make a 100 km detour, or a long walk over Turei Hill, just to go to work.

Earthworks at the top of the slope and horizontal drainage holes in the lower slope have now been carried out to permanently stabilise the landslide (Figures 21 and 22). Unfortunately these works have necessitated the removal of the house built at the top of the hill near the old headscarp. This landslide illustrates the danger of constructing an unsupported road cut across the toe of an old landslide, and the role of prolonged rainfall in its reactivation.

Figure 22. Earthworks on Turei Hill to stabilise the Kawakawa Bay landslide, February 2009. The remains of the demolished house on the head scarp are visible in the foreground. *[Manukau CC Photo]*

2.1.8 Observations and conclusions about landslides in Auckland

(1) Rainfall in Auckland during the winter of 2008 triggered many landslides across a wide area, causing damage worth several million dollars. Although the rainfall was only of moderate intensity, it was prolonged and rainfall totals were much higher than normal (137% June, 163% July, 151% August). The landslides mainly occurred towards the end of wet periods when around 50-120 mm of rain fell over 5-10 days.

(2) Although the recent landsides at Torbay, Glenfield, and Huia were clearly related to greater-than-normal rainfall, in these cases, however the underlying cause appears to have resulted from, or be associated with, development and building on old landslides (as at Torbay) or on previously unstable land that has undergone major alterations to the ground surface profiles, without due recognition or allowance for the underlying instability.

(3) Landsides on coastal cliffs occur when lateral support is removed and slopes are oversteepened by wave erosion. Although the prolonged rainfall triggered the landslides, other factors have also provided pre-conditions for the slope failures. Foremost amongst these is the desire to build houses in positions that have grand views, but invariably are sited too close to the edge of unstable cliffs that are prone to slope failure and erosion. Most of the houses affected by landslides appear to have been built very close to, or even within the '*Foreshore Yard'*, a 15-25 m wide buffer zone from which cliff-top residential development in Auckland is set back from the coast (Jongens et al. 2007).

(4) Most of the landslides on Auckland's east coast cliffs were small falls of soil, regolith, and cliff-edge vegetation, which did little or no damage to houses. However, the landslides at Achilles Point and Buckland's Beach, which caused significant damage, also involved the underlying bedrock (interbedded sandstone and siltstone), where slope failure was probably controlled by joints and faults, as is typical of sea-cliff failures in Auckland's east coast bays (Moon and Healy, 1994; Jongens et al. 2007).

(5) Mapping by GNS Science and the Auckland Regional Council suggests that much of Auckland is at high or moderate risk of being affected by landslides, and it could cost homeowners tens to hundred of thousands of dollars for engineering works to safeguard their properties. Any new housing developments or modifications to existing homes in high-risk areas, such as those along Auckland's coastal cliffs, are likely to need engineering geological and geotechnical assessments, and possibly stabilising measures, to proceed safely. Because of potential landslide problems on the cliff edge, building close to or within the *'Foreshore Yard'* is inadvisable. As a rough guide, a set-back distance for buildings of at least the height of the cliff may be required.

(6) Buyers of existing properties are also urged to be vigilant and to look beyond the views that cliff-top properties offer. GNS Science and consulting engineers can carry out pre-purchase engineering geological assessments of properties to determine any potential slope stability issues and hazards that people should be aware of before buying a home.

2.2 Landslides in Wellington

Rainfall-induced landsliding started to cause problems in the Wellington area during July 2008, when rainfall was 173% of the monthly mean, and the number of days with rain was also very high (Table 1). The increased rainfall caused numerous landslides in the Wellington area, closing roads and damaging houses. A summary of the landslide events that occurred from June-August 2008 is presented in Table 2. Locations of some of the more significant landslides are shown in Figure 23, and these are discussed below.

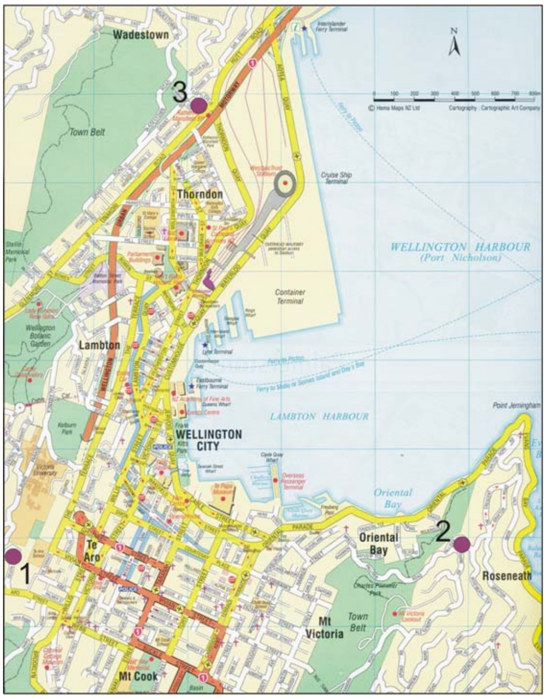

Figure 23. Map of Wellington City area showing locations of significant landslides in Devon Street (1), Palliser Road (2), and Tinakori Road (3).

Rain fell almost continuously from 22-31 July 2008 (Table 1). On 23 July the persistent rain caused a slip that derailed a train on the Johnsonville railway line near Ngaio station (about 2 km NW of slide (3) in Figure 23), disrupting train services for 20 hours.

The same storm caused slips on SH 1 at Paekakariki and (as usual) between Pukerua Bay and Whenua Tapu Cemetery, blocking the south-bound lane for several hours (Figure 24). The vulnerable Rimutaka Hill and Manawatu Gorge roads were also reduced to one lane by slips brought down by the torrential rain.

Figure 24. Shallow earth slide on a relatively new road cut (constructed on the last 5 years), which blocked the south-bound lane of SH 1 between Pukerua Bay and Whenua Tapu Cemetery on 23 July 2008. Smaller similar failures occurred in several other locations. This landslide is formed in weak, sandy loess and weathered greywacke, and is typical of batter failures that occur frequently on this section of SH 1 during heavy rainfall.

2.2.1 Devon Street Landslide

The heaviest rain in Wellington City fell between 30 July and 3 August, when 80 mm fell over four days. On Sunday 3 August a house in Devon St was evacuated after a large landslide occurred on the road cut beneath it, leaving the undermined house poised precariously above a 15 m drop to the road below (Figure 25). Similar slips also occurred in Mt Cook, Kelburn, Northland, Karori, Khandallah, Kilbirnie, and Miramar.

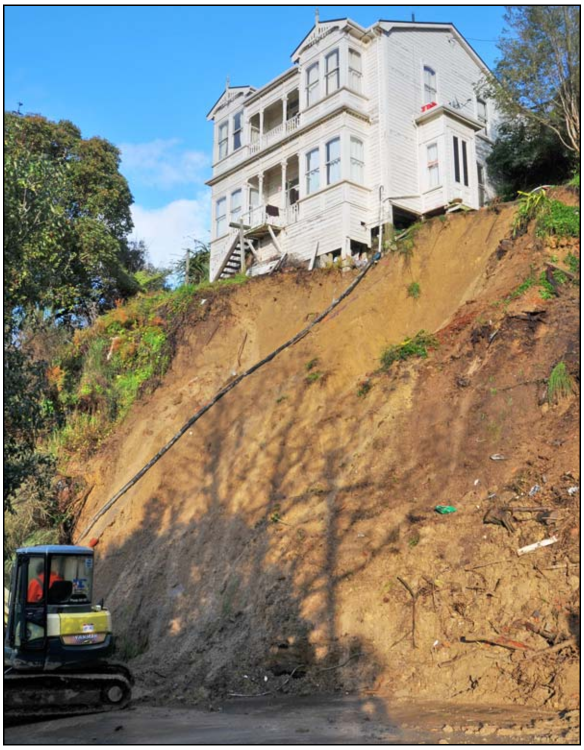

Figure 25. This house in Devon Street in the Aro Valley, Wellington, was undermined by collapse of a steep, unsupported road cut in weathered greywacke. This slope failure on 3 August during heavy rainfall caused the house to be evacuated. *Photo 5 August 2008: GTH-0178]*

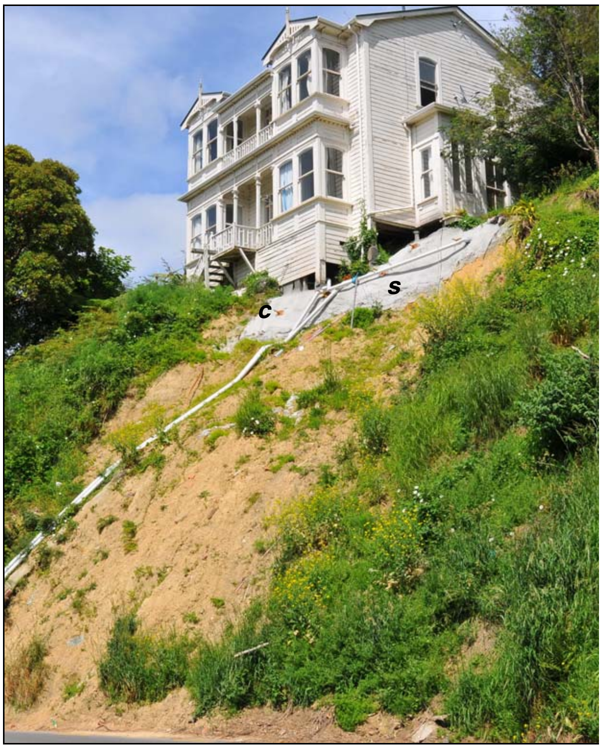

Figure 26. Photo of the batter failure below the house in Devon Street taken in December 2008. It shows that the slope was eventually stabilised using long grouted cables *(c)*, shotcrete *(s)*, and drainage, allowing the house to be reoccupied. *[Photo 12 December2008: GTH-1369]*

The landslide in Devon Street closed the road for several days while debris and unstable slope debris was cleared away. The failure partly undermined the house foundations, and destroyed a foot access path to dwelling. The slope below the house was eventually stabilised using grouted rock cables, shotcrete, and drainage works (Figure 26), allowing the house to be reoccupied.

This type of cut slope failure is typical of those that frequently occur in Wellington during prolonged periods of wet weather, particularly in the older hill suburbs, where many high road cuts are unsupported. Not only was the batter unsupported, but the Devon Street house was built too close to the top of the road cut, as is the case in most failures of this type. Other failures of this type that occurred in August 2008 are discussed below.

2.2.2 Palliser Road Landslide

A similar landslide occurred in Palliser Road on 4 August, when a road cut failure endangered a house which was temporarily evacuated, and closing the road for two days while debris was removed (Figure 27). This earth and debris fall in soil and weathered greywacke (regolith) undermined part of the house foundations above the landslide scar, leaving it poised precariously above the road.

Figure 27. House in Palliser Road undermined by road cut failure in weathered greywacke on 4 August, after 26 mm rain the previous day. The house was evacuated and the road closed while the debris was cleared away. *[Photo 5 August 2008: GTH-0196]*

Figure 28. Photo of the batter failure in Palliser Road, December 2008, by which time no further failures had occurred, and the house had been reoccupied. Stabilisation measures here are still to be decided. *[Photo 12 December2008: GTH-1373]*

Figure 28 shows this landslide in December 2008. After four months no further failures had occurred, and the house had apparently been reoccupied. Permanent stabilisation works still need to be carried out at this site, as the house is still highly vulnerable to foundation collapse, especially if a strong earthquake occurs.

2.2.3 Tinakori Road Landslides

After more rain two similar landslides occurred in Tinakori Road on the morning of 5 August, closing one lane of the road near the Thorndon Quay intersection (Figures 29 and 30). The failure at the northern site undermined a house at the top of the batter, leaving it vulnerable to collapse (Figure 30). Permanent stabilisation measures have yet to be implemented at that site. Failure of this unsupported road cut is typical of those that occur in Wellington during prolonged rainfall. Where houses have been built too close to the tops or bottoms of steep, unsupported cut slopes that are susceptible to such failures, there is substantial risk to property and life during heavy rain, and also strong earthquake shaking (Figure 31).

Figure 29. This small (~20 m^3) debris fall from an unsupported road cut blocked one lane of Tinakori Road near the Thorndon Quay intersection on 5 August. To the left an older failure area (where the Wellington Fault was formerly exposed) has been treated with shotcrete. *[Photo 5 August 2008: GTH-0163]*

Figure 30. Another debris fall on 5 August from the same road cut (but 20 m north of Figure 29) also partially blocked Tinakori Road, and significantly undermined the house at the top of the batter. Permanent stabilisations measures at this site are still to be implemented. In the meantime the house remains vulnerable to collapse, especially during a strong earthquake. *[Photo 12 December2008: GTH-0158]*

2.2.4 Observations and conclusions about landslides in Wellington

(1) Prolonged and higher than normal rainfall in Wellington in July and August 2008 triggered landslides in many places causing substantial damage to reads and houses. However, other factors appear to have provided the preconditions for the slope failures. All of the observed landslides occurred on modified (cut) slopes which had not been stabilised or designed for long-term stability during heavy rainfall or earthquakes.

(2) The landslides in the winter of 2008 were initiated by moderate and prolonged, higher than normal rainfall (173% July, 158% August – Table 1), which occurred in several events producing c. 50-100 mm rain over 4-5 days. The pattern of rainfall was similar to, but slightly less intense than the rainfall which caused more widespread landsliding in Wellington in the winter of 2006 (Hancox et al., 2007).

(3) The houses affected by landslides in Wellington were not substantially damaged by the 2008 slope failures. Post-failure actions mainly involved, temporary evacuation of occupants, restoration of damaged services, and clearance of debris from roads so they could be reopened. Although the affected properties have apparently been reoccupied, most of the failed slopes have not been permanently stabilised. All of the houses that were undermined by landslides appear to have been built too close to the tops of cuts to be safe, and they are at significant risk of further collapses in the future.

(4) Failures of unsupported road cuts and excavations for houses are typical of those that occur in Wellington during prolonged rainfall. All houses in suburban Wellington that have been built too close to the tops or bottoms of steep, unsupported cuts are likely to be affected by landslides in the future. These failures will present considerable risk to both property and life during future rainstorms, but especially during strong earthquakes.

(5) Larger and more rapid landslides are expected in the Wellington area during a typical M 7.5 earthquake on the Wellington Fault (Brabhaharan et al. 1994, Hancox et al. 2002; Hancox, 2005). During such an event houses with undermined foundations on the edge of steep high slopes (as shown in Figures 25-30) are likely to be at greater risk of sudden collapse because of amplified shaking effects on exposed buildings on steep slopes.

In the early 1990s the Wellington Regional Council commissioned a series of studies to assess seismic hazards in the Wellington region, including earthquake-induced slope failure (Brabhaharan et al. 1994). Figure 31 shows the modelled earthquake-induced landslide (EIL) susceptibility zones in the northern Wellington City area *(based on factors such as slope angle, geology, slope modification, and existing landslides),* and the predicted severity of landslide effects under strong earthquake shaking (MM8 to MM10). Such shaking is expected during a Wellington Fault earthquake, which is regarded as having a relatively 'high' probability of occurring in the next 50 years [(1)].

[(1)] A magnitude 7.5 earthquake on the Wellington Fault occurs on average about once every 500 years. This probability equates to about a 10% chance of a Wellington Fault Earthquake in 50 years.

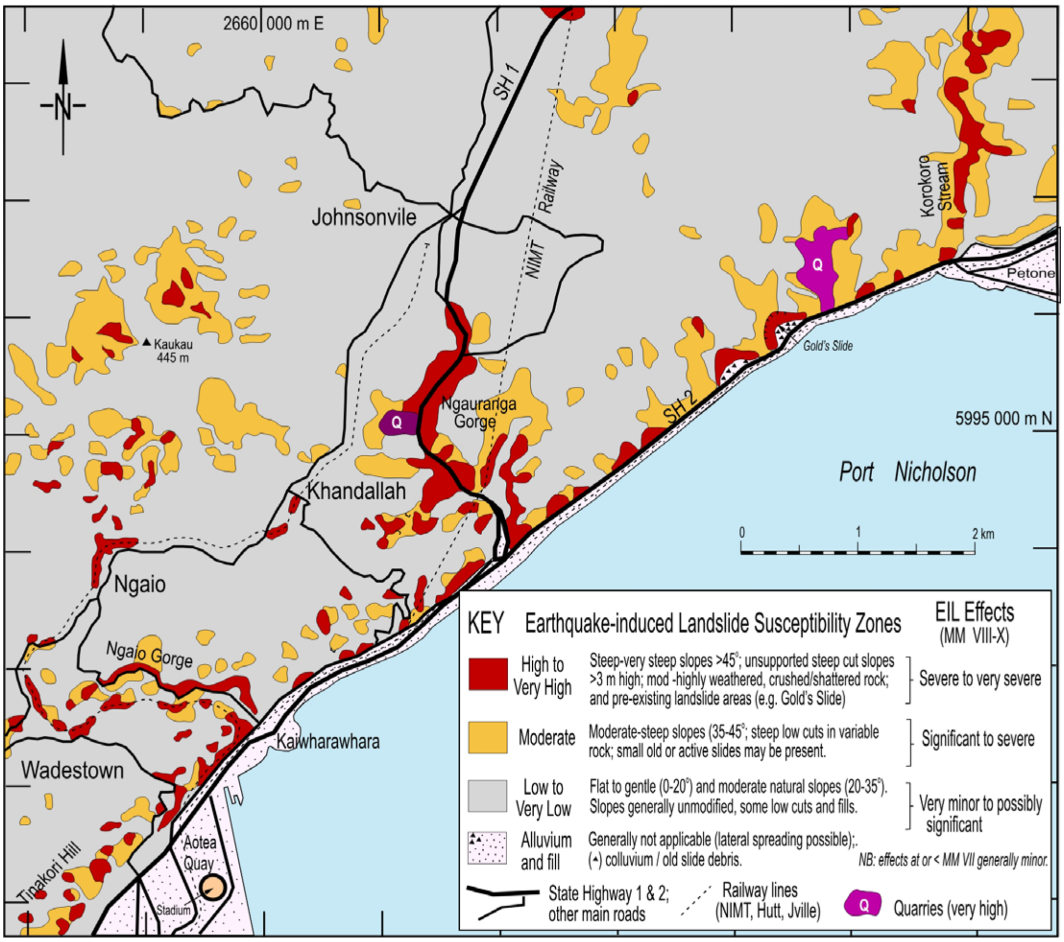

Figure 31. Earthquake-induced landslide susceptibility hazard map of the northern Wellington City area *(after Brabhaharan et al. 1994)*.

The landsliding effects predicted by Brabhaharan et al. (1994) for different susceptibility classes (Figure 31) for MM8–MM10 shaking during a Wellington Fault earthquake were:

High-Very High: *Severe to Very Severe* - widespread large landslides (10^4–10^6 m^3 or >), particularly on unsupported high (>5–10 m), steep cuts (>60°).

Moderate: *Significant* - small to moderate failures (10^3–10^4 m^3) on steeper (>35°) natural slopes and unsupported 35– 60° cuts 3 to 5 m high.

Low-Very Low: *Minor and Very Minor* – Very small falls (10^2 m^3 or <) and boulders.

On most natural hill slopes in the Wellington area EIL susceptibility is low to very low. However, on steeper slopes (>35°) in gorges or on coastal cliffs along the Wellington Fault scarp bordering Port Nicholson, landslide susceptibility is high to very high.

Slopes that have been modified by steep, unsupported cuts for roads, railway lines, and the main highways north of Wellington (SH 1 Ngauranga Gorge, and SH 2 Hutt Motorway) have moderate to very high EIL susceptibility and are vulnerable to severe earthquake damage. Steep cuts for buildings >2–3 m high are also vulnerable to failure unless supported. Most of these cuts are marginally stable and they frequently fail during heavy rainfall, but they have never experienced earthquake shaking greater than MM6-7. This occurred in June 1942, causing minor rock falls and liquefaction (sand boils) in Wellington City (Downes et al. 2001). The landslides that are likely to occur in Wellington City on both natural and cut slopes due to MM 9–10 shaking during the next Wellington Fault earthquake are likely to be larger and more widespread than any that have occurred in the area over the last 150 years.

3.0 SUMMARY AND CONCLUSIONS

The winter of 2008 was stormy and wet, with floods in many parts of New Zealand. Rainfall of 150% above normal in Auckland, and 135% higher in Wellington triggered many landslides in those areas, closing roads and damaging or destroying several houses. The rain was only moderately intense but prolonged. Most of the landslides occurred towards the end of several wet periods from June to August 2008, during which c. 50-120 mm rain fell over 5 to 10 days.

Landslides in Auckland: Major landsides at Torbay, Glenfield, and Huia in Auckland damaged several houses. These slides were initiated by rainfall, but the underlying causes resulted from building on old landslides, or previously unstable land where there had been major alterations to the ground profile, without due allowance for the underlying instability.

The rain also triggered numerous landsides on coastal cliffs, but other factors, such as wave undercutting of the cliffs and residential development along the cliff-edge, provided the underlying pre-conditions for these failures. A common problem is that many houses are built too close to the edge of unstable cliffs that are prone to slope failure and erosion. Most of the houses affected by coastal cliff failures appear to have been built close to or within the '*Foreshore Yard*', a 15-25 m wide buffer zone from which cliff-top residential development in Auckland is set back from the coast.

Most landslides on Auckland's east coast cliffs were small falls of soil, regolith, and cliff-edge vegetation, which did little or no damage to houses. However, major landslides at Achilles Point and Buckland's Beach, which caused substantial damage, involved failure on joints and faults within the underlying interbedded sandstone and siltstone bedrock. Rainfall also reactivated an old large landslide on the coast at Kawakawa Bay. The failure closed the coast road for a month, and necessitated demolition of a house, extensive earthworks, and drainage works to stabilise the slope and make the road safe. This landslide illustrates the danger of constructing an unsupported road cut across the toe of an old landslide, and the role of prolonged rainfall in its reactivation.

The 2008 landslides are a reminder that much of Auckland is at high or moderate risk from landslides. New houses or modifications to homes along coastal cliffs and other high-risk areas are likely to need geotechnical assessments and possibly stabilising measures before they proceed. Building too close to the cliff-edge is inadvisable, and a set-back distance for buildings of at least the height of the cliff may be required. Buyers of existing homes would be wise to obtain pre-purchase geotechnical assessments to determine if there are any slope stability issues or hazards that could affect the property.

Landslides in Wellington: Prolonged and higher than normal rainfall in Wellington in July and August 2008 triggered landslides in many places causing substantial damage to roads and houses. However, other factors appear to have provided the preconditions for the slope failures. All of the observed landslides occurred on modified (cut) slopes which had not been stabilised or designed for long-term stability.

Houses affected by landslides in Wellington in 2008 were not substantially damaged. Post-failure response mainly involved temporary evacuation of occupants, restoration of damaged services, and clearance of debris from roads. Although the affected properties have been reoccupied the failed slopes have not been permanently stabilised. All of the houses that were undermined by landslides were built too close to the tops of unsupported cuts, and they are at significant risk of further collapses in the future. Such slope failures are typical of those that occur in Wellington during heavy and prolonged rainfall. All houses in Wellington that are built too close to the tops or bottoms of steep, high cuts are at risk from landslides, not only during future rainstorms, but also during strong earthquake shaking.

4.0 REFERENCES

Brabhaharan P, Hancox GT, Perrin ND, Dellow GD 1994. Earthquake-induced slope failure hazard study, Wellington Region. *Works Consultancy Services Reports and Maps covering six study areas. Prepared for Wellington Regional Council by Works Consultancy Services Ltd and Institute of Geological & Nuclear Sciences.*

Downes, G.L., Dowrick, D.J., Van Dissen, R.J., Taber, J.J., Hancox, G.T., and Smith, E.G.C., 2001. The 1942 Wairarapa, New Zealand Earthquakes: Analysis pf Observational and Instrumental Data. *Bulletin of the New Zealand Society for Earthquake Engineering,* 34(2) 125-157.

Hancox, G.T., Perrin, N.D., Dellow, G.D., 2002. Recent studies of historical earthquake-induced landsliding, ground damage, and MM intensity in New Zealand. *Bulletin of the New Zealand Society for Earthquake Engineering,* 35(2) 59-95.

Hancox, G.T., 2005. Landslides and liquefaction effects caused by the 1855 Wairarapa earthquake: Then and now. *Proceedings of 1855 Wairarapa Earthquake Symposium September 2005, pp 84–94 (Greater Wellington Regional Council: GW/RINV-T05/205)*.

Hancox, G.T., Dellow, G.D., Massey, C., Perrin, N.D. 2007. Reconnaissance studies of landslides caused by the July-August 2006 rainstorms in southern North Island, New Zealand. *GNS Science Report 2006/26. 46 pp.*

Jongens, R., Gibb, J., Alloway, B.V., 2007: A new hazard zonation methodology applied to residentially developed sea-cliffs with very low erosion rates, East Coast Bays, Auckland, New Zealand. *Natural Hazards (2007) 40:233–244.*

Moon, V.G., Healy, T.R., 1994: Mechanisms of coastal cliff retreat and hazard zone delineation in soft flysch deposits. *Journal of Coastal Research 10:663–680.*

5.0 ACKNOWLEDGEMENTS

The authors wish to thank GNS colleagues Grant Dellow and Nick Perrin for reviews of this report. This reconnaissance study and report was initiated through the GeoNet Project, funded by the Earthquake Commission and the Foundation for Research Science and Technology.