Landslides and debris flows caused by the 15-17 June 2013 rain storm in the Marahau-Motueka area, and the fatal landslide at Otuwhero Inlet

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M. J. Page, GNS Science, PO Box 30368, Lower Hutt 5040, New Zealand

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ABSTRACT

A rain storm in the Tasman District on the 15-17 June 2013 caused numerous landslides and debris flows in the Motueka area. One of these landslides struck a house at Otuwhero Inlet, killing the woman occupant. Another landslide in the Marahau Valley destroyed part of a dwelling, fortunately just missing a father and daughter who were sleeping in another room. Landsliding was particularly severe in a logged area of Shaggery Forest west of Motueka. Many roads were blocked by landslides and debris flows between Marahau and Kaiteriteri, in the Riwaka and Brooklyn Valleys, and along the west bank of the Motueka River as far south as Rocky River. A salmon farm at Anatoki west of Takaka was badly damaged by a debris flow.

A site inspection was made of the fatal landslide site at Otuwhero Inlet. The landslide occurred at ~1 pm on Sunday 16 June after ~180 mm of rain fell in the preceding 24 hours and ~80 mm fell in the preceding 4 hours. The house was pushed several meters off its piles and collapsed, and the woman's body was subsequently recovered from the landslide debris outside the house. The landslide occurred in an area of convergent drainage on the slope directly above the house. The head scarp of the landslide is level with an access track that cuts across the slope. The house had been built on material deposited by an earlier (paleo-) landslide.

Factors contributing to the landslide were: the high intensity rainfall, the deeply-weathered Separation Point Granite lithology, steep convergent slopes, and probably the side castings deposited along the outer edge of the track during construction and maintenance. The death of the occupant was the result of the house being located at the base of slopes susceptible to landsliding, and the light-weight materials with which the house was constructed.

The landslide that severely damaged the dwelling in the Marahau Valley occurred after ~290 mm rainfall in the preceding 24 hours, ~140 mm in the preceding 12 hours and ~30 mm in the preceding hour. Again the dwelling had been built at the base of steep convergent slopes underlain by Separation Point Granite, and on material deposited by an older landslide. In this case the natural toe of the slope had been excavated to increase the area for building. This steepening of the lower part of the slope reduced support for the area above and facilitated the landslide.

Elsewhere landslides occurred on both natural and modified slopes, and a number of other properties had "near misses". This storm is the fourth in the last three years that has caused landslides and debris flows in the Golden Bay-Nelson district. Given the number of rural life style properties in the Tasman District, more consideration should be given to identifying at-risk existing houses and at-risk sites prior to planning consent and house construction.

KEYWORDS

Landslide fatality, rainfall-triggered landslides, debris flows, Separation Point Granite, forestry, Motueka, Marahau

1.0 INTRODUCTION

1.1 15-17 JUNE STORM

The Meteorological Service issued a severe weather warning for the Tasman and Nelson areas for the weekend of 15-16 June 2013. A large complex low in the Tasman Sea delivered a strong moist northeast air flow with heavy rain. Over a 48-hour period, beginning about 2 pm on Saturday afternoon, between ~100 and ~400 mm of rain was recorded around the district. This led to flooding, many landslides and debris flows. The worst affected areas were between Marahau Valley, Kaiteriteri and Riwaka Valley where 48-hour rainfalls as high as 200-250 mm occurred, and at Anatoki in Golden Bay where 380 mm of rain was recorded over 48 hours (Figure 1 and Figure 2).

At Otuwhero Inlet, a landslide demolished a house, killing the occupant. At Marahau Valley, a private rain gauge located approximately 2.5 km from the landslide site recorded 336 mm in 48 hours, with 290 mm in 24 hours. Rainfall intensities of around 20 mm/hour occurred for a 3 hour period around midday on 16 June. Intensities peaked briefly again around 21:00 that day and around 02:00 on 17 June. These data provide estimates as this rainfall gauge has not been calibrated. The 48 hour rainfall at Marahau had a recurrence interval of ~50 years (based on NIWA's HIRDS (V3) software).

Rain gauges monitored by Tasman District Council (TDC) recorded 24-hour rainfall totals of 168 mm at Riwaka South, 192 mm at Motueka at Woodmans Bend, 118 mm at Motueka at Woodstock, and 335 mm at Anatoki at Happy Sams. These 24-hour rainfalls all had recurrence intervals of about 20 years, however the 2- to 3- hour rainfalls are likely to have had higher recurrence intervals (based on NIWA's HIRDS (V3) software).

1.2 SITE RECONNAISSANCE

Under the GeoNet[1] contract between GNS Science and the Earthquake Commission, a response is required to investigate and report on incidents where landslides or other land instability results in loss of life.

On the 19th June, two days after the storm, Mike Page (GNS Science), Glenn Stevens (TDC) and Paul Woperis (MWH) visited the site of the fatal landslide at Otuwhero Inlet. Mike Page and Glenn Stevens also visited the site of a landslide that damaged a home in the Marahau Valley. On the 20th June they inspected landslides and debris flows that occurred in the Shaggery Forest, accompanied by Craig McMiken (Manager, Tasman Forest Management Ltd.), and Warren Galbraith (TDC).

1.3 GEOLOGY

All three sites visited, at Otuwhero Inlet, Marahau Valley Rd, and Shaggery Rd Forest, (Figure 1) are underlain by Separation Point Granite (Rattenbury et al. 1998). These plutonic rocks are weathered and highly erodible. Landslides frequently occur in the upper 2-3 m of deeply-weathered rock and overlying soil (regolith), which readily becomes saturated during heavy or prolonged rainfall. Landslide-deposited sediments are typically coarse sands to fine gravels. At the Otuwhero landslide site numerous weathered clay veins, reddish in colour, were observed in rock exposures. Several of these were seen on the landslide scar surface above the house where the fatality occurred. It is likely that this clay influenced the formation of the slip plane.

1.4 Scope of Report

Landslides and associated debris flows were relatively common in the Motueka area affected by the 15-17 June 2013 storm. This report is confined to describing the conditions surrounding landslides at three sites, one where a fatality occurred and a house was destroyed, one where a house was severely damaged and the occupants were fortunate to avoid injury, and one where numerous landslides and debris flows occurred in an area of plantation forest. A Salmon Farm at Anatoki, west of Takaka was badly damaged by a debris flow, but this site was not visited due to road and weather conditions.

The circumstances surrounding these landslides are described and illustrated, and comments made on the factors contributing to the landslides and the resulting effects.

1.5 Recent Landslide/Debris Flow events

This is the fourth rainstorm to trigger landslides and debris flows in the Tasman District within the last three years. On 16 May 2010, landslides and debris flows occurred in the lower Wangapeka and Baton River catchments (Figure 1), on c. 8000 ha of hill country underlain by Separation Point Granite and planted in forest, much of which had been recently harvested (Basher 2010, Jelinek 2010). Storm rainfall was c. 200 mm, with peak intensities of 40–70 mm h^{-1}. Landslides were most common on recently clear-felled areas.

In December 2011 the Tasman District experienced an extreme rain storm which caused severe flooding and landsliding in Nelson and Golden Bay and resulted in the declaration of a civil defence emergency. In the Pohara-Ligar Bay area (Figure 1) debris flows inundated a number of homes and properties following c. 450 mm of rainfall in 24 hours (Page et al. 2012). As in 2010, the landslides and debris flows originated in steep hills underlain by Separation Point Granite, much of which were covered by mature pine forest.

On 21 April 2013, only two months before the rainstorm that triggered the fatal landslide at Otuwhero Inlet, a high-intensity rainstorm generated a debris flow in the Riwaka Valley (Figure 1). In this instance the debris flow originated in secondary indigenous scrub/forest and on Riwaka Complex Gabbro (undifferentiated gabbro diorite and ultramafic intrusive rocks). The preceding 2-hour rainfall was 127 mm, with an hourly maximum of 34.3 mm immediately preceding the debris flow.

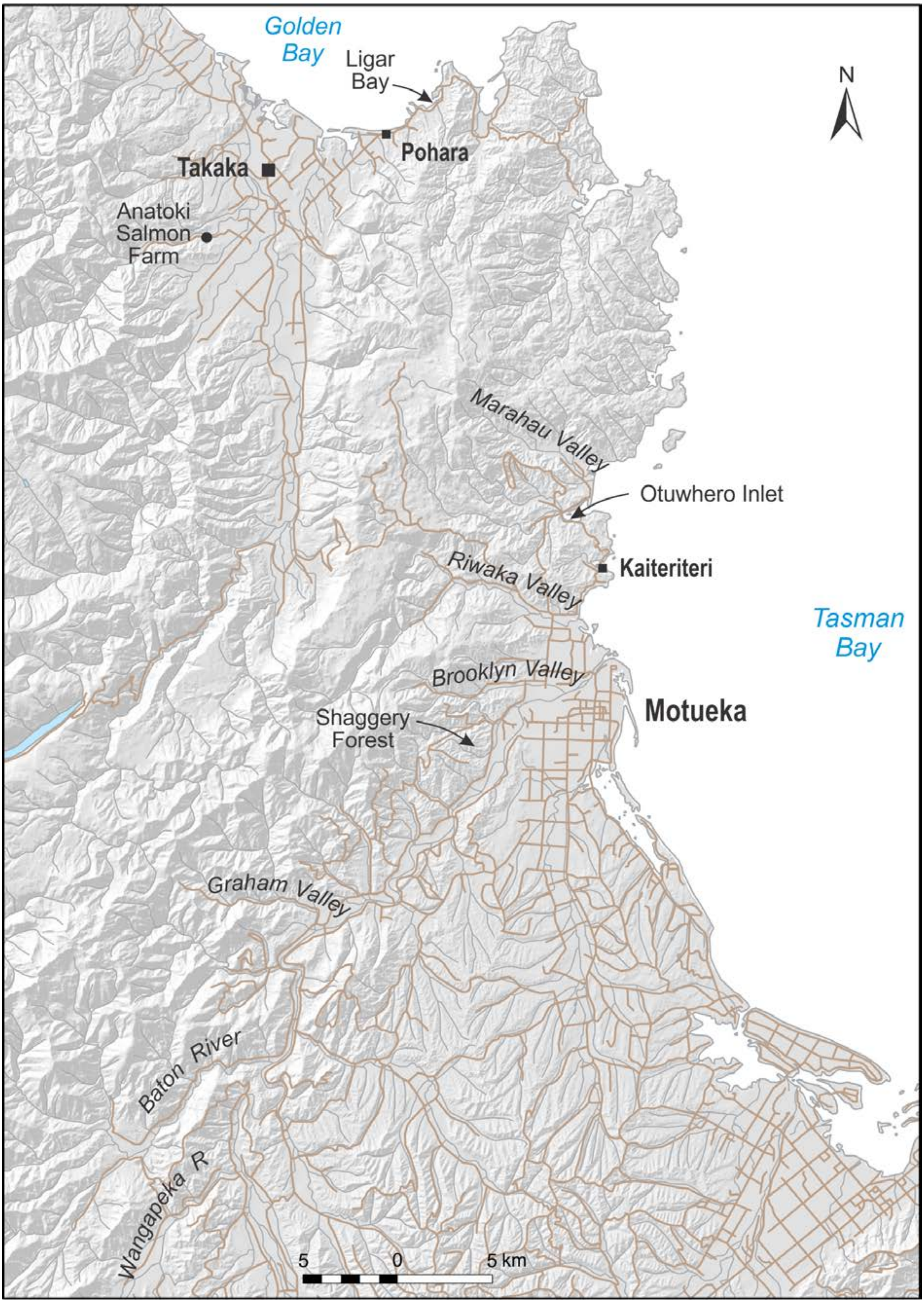


Figure 1 Map of Motueka-Takaka area with the locations referred to in the report.

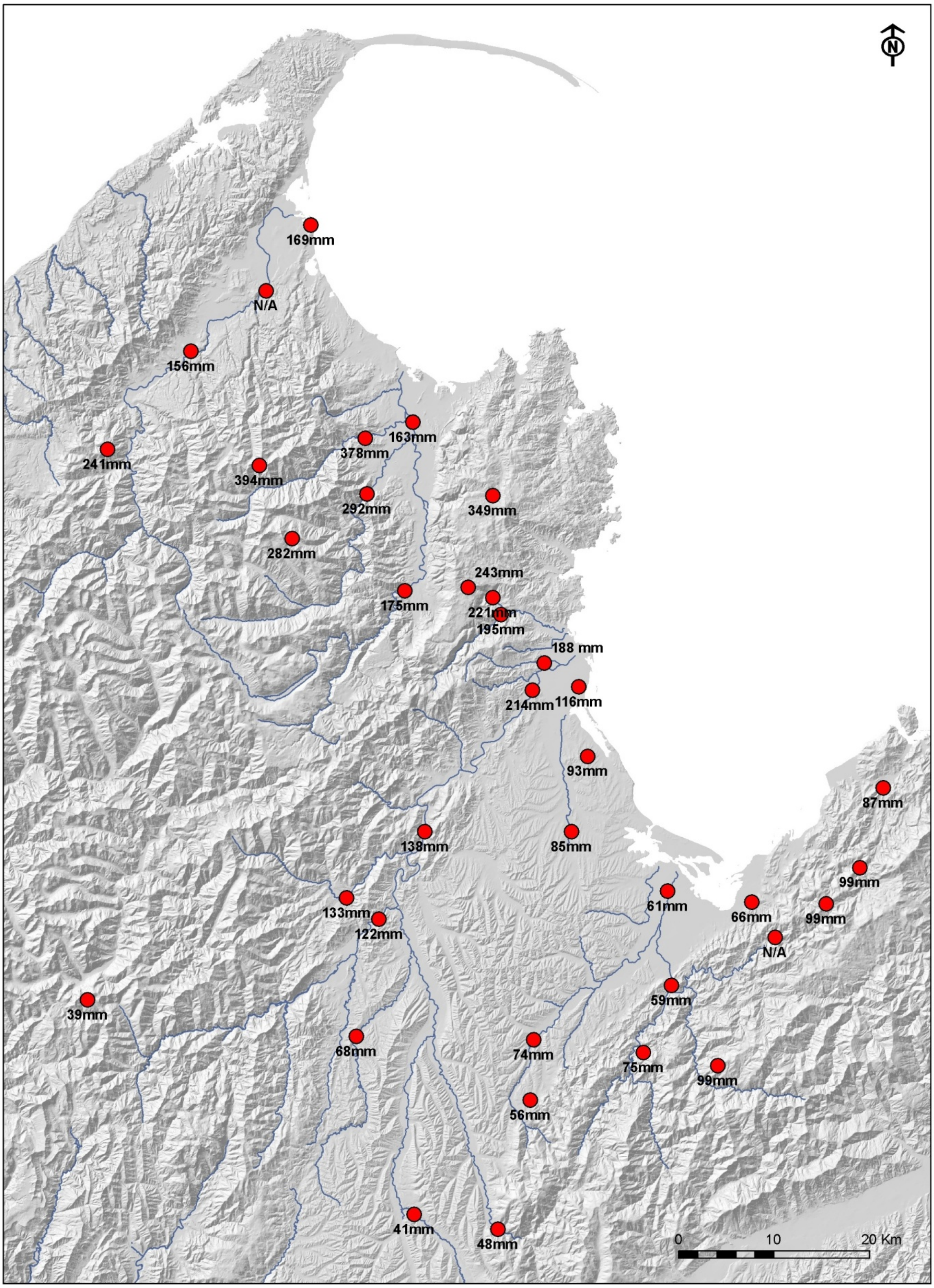


Figure 2 48 hour rainfall totals (15 to 17 June 2013) measured across the Nelson Tasman region (supplied by TDC).

2.0 OTUWHERO INLET FATAL LANDSLIDE

The house where the fatality occurred is located above the Otuwhero Inlet between Kaiteriteri and Marahau at 597 Kaiteriteri-Sandy Bay Road (Figure 3 and Figure 4). The landslide occurred at ~1 pm on Sunday 16 June, following ~180 mm rainfall in the preceding 24 hours and ~80 mm in the preceding 4 hours (Table 1, Figure 5 and Figure 6) (recorded at 49 Marahau Valley Rd, 2.5 km north of Otuwhero Inlet). The landslide debris destroyed the house (Figure 7), pushing it several metres off its piles (Figure 8). Three of the outer walls and the roof collapsed, and debris entered the house. A woman, 63 year old Jude Hivon was killed, and her body was subsequently dug out of debris outside the house by Police. (A Radio NZ report on 17th refers to Inspector Steve Greally who told morning report that "the slip occurred in the same place as a previous landslide during the 2011 flooding", however this was not the case).

Mike Page, Glenn Stevens and Paul Woperis spent about two hours on site, inspecting the landslide scar, an access track above the landslide, the landslide debris, and the house and site on which it was built. From available aerial photography, the access track was constructed sometime between 1952 and 1989. Another track, half-way upslope between the house and the access track is present on the 1989 photograph, but had become overgrown and disused by 2002. This track is below the landslide scar and was not instrumental in causing the landslide (Figure 5).

The landslide occurred in Separation Point Granite on a moderately steep hill slope covered with second growth scrub. The landslide scar is sited on a natural slope of 37°, in an area of convergent drainage (swale) (Figure 9 and Figure 10). A zone of red-weathered clay is exposed on parts of the landslide scar (Figure 11 and Figure 12). The head scarp of the landslide is level with the outer edge of the track. The scar (evacuation area) was estimated to have an average width of 12 m (15 m at the head scarp), a length of 28 m and an average depth of ~1.5 m. Together with an additional ~50 m^3 of spoil/side casting that had been deposited on the outer edge of the track during track construction and maintenance, this gives a volume of ~550 m^3 of material that was transported downslope. Much of this material was deposited on the slope below the landslide scar before the remainder of the debris tail impacted the house (Figure 13 and Figure 14).

The house was not a substantial structure. It was single storey with an area of only ~45 m^2 (~4 m wide x ~11 m long), and had a corrugated-iron roof and wall cladding of pressed metal. The house was built at the base of the hillslope on material deposited by an earlier (paleo-) landslide. The age of this landslide is unknown, but pre-dates the 1952 aerial photography and may relate to the period of forest clearance or earlier. The lobe of this earlier deposit is clearly visible from the road (Figure 15), and large boulders are present on its surface (Figure 16). Such old landslide deposits are attractive sites for houses in the district. As elevated sites they are often better drained than surrounding lower lying areas, and they afford better views.

Figure 3 Oblique Google Earth image (21/01/2013) showing house at 597 Kaiteriteri-Sandy Bay Road before the fatal landslide occurred on 16/06/2013. Note the side castings on the edge of the access track above the house. House is marked with an arrow.

Figure 4 Fatal landslide at 597 Kaiteriteri-Sandy Bay Road. Note access track at top of photo and old track in centre of photo. *(Nelson Mail photo 16/06/2013).*

Table 1 Maximum rainfalls recorded in vicinity of Otuwhero Inlet.

Site	Maximum Rainfalls 15 to 17 June 2013 (mm)				
	48 hour	24 hour	12 hour	6 hour	2 hour
Marahau at Simes[1]	336	290	160	100	55
Riwaka EWS[2] (Brooklyn Research Station)	188	163	109	79	45
Riwaka North at Littles[3]	221	189	119	61	27
Riwaka South at Moss Bush[3]	195	170	106	55	26
Motueka at Woodmans Bend[3]	214	193	142	109	66
Riwaka at Takaka Hill[3]	243	205	123	65	25
Takaka at Canaan[3]	349	295	175	108	45

[1]. Private rain gauge that has not been calibrated. Measured totals indicative only.

[2]. NIWA operated rain gauge.

[3]. TDC operated rain gauge.

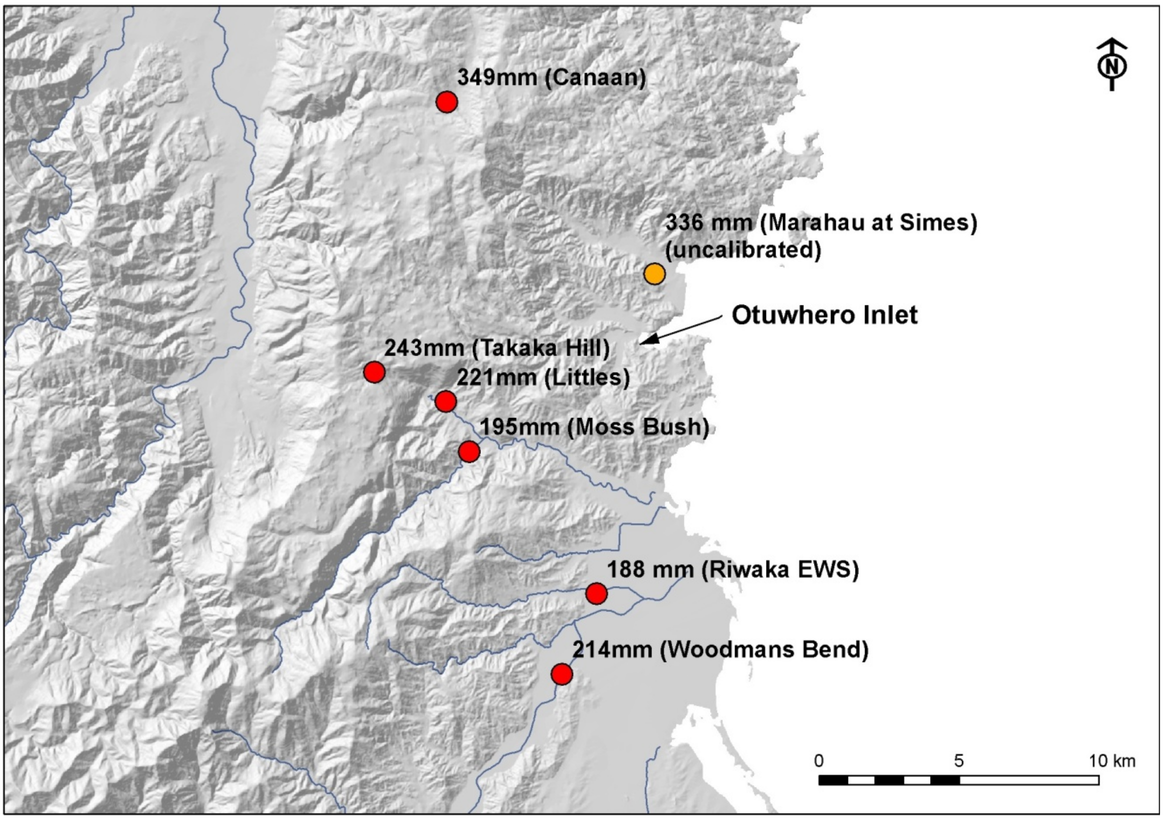
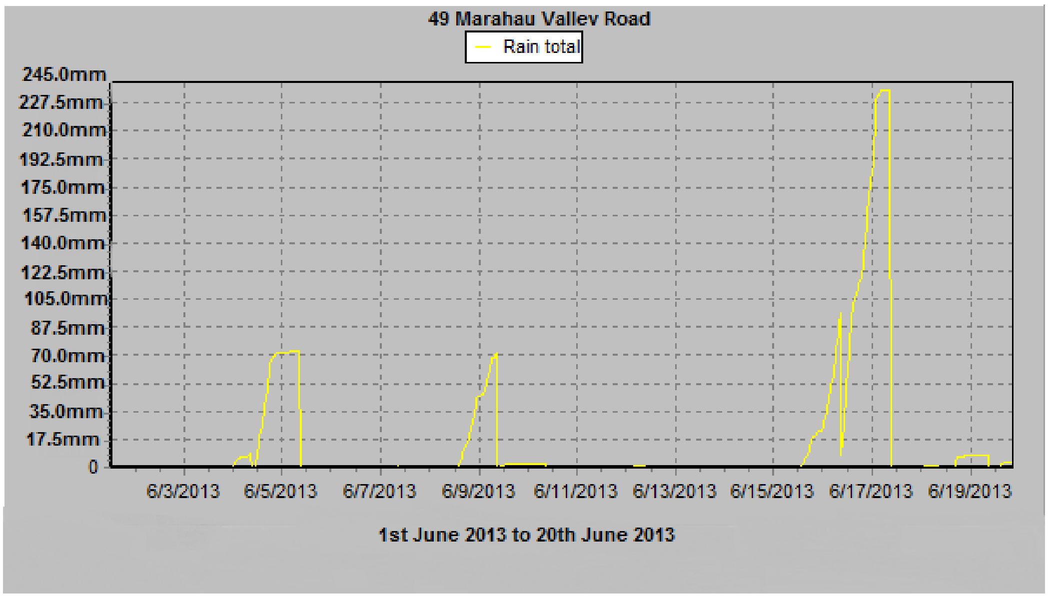


Figure 5 48 hour rainfall totals 15 to 17 June 2013 in the vicinity of Otuwhero Inlet.

A)



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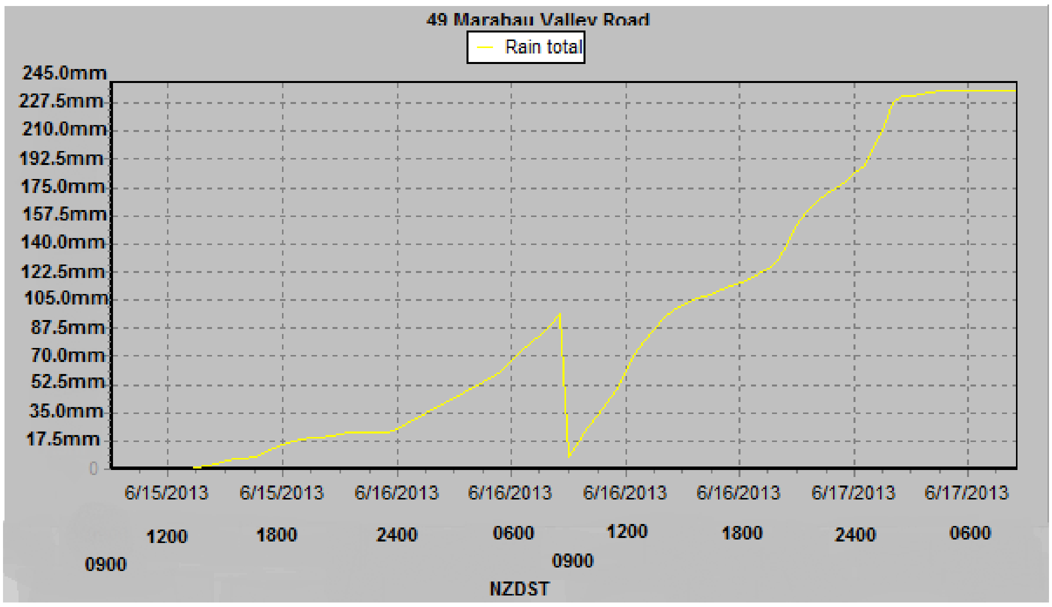

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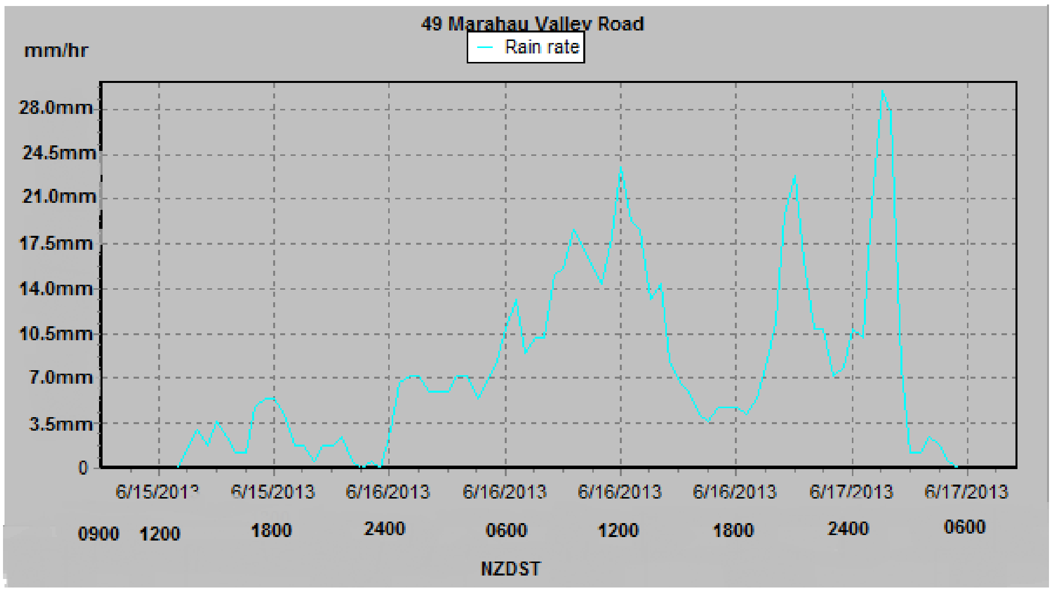

Figure 6 Graphs of un-calibrated rainfall recorded at 49 Marahau Valley Road. **a)** rainfall totals for 1 June to 20 June. **b)** cumulative rainfall from noon 15 June to 6 am 17 June (resets at 9:00am). **c)** rainfall rate (mm/hr) from noon 15 June to 6 am 17 June.

Figure 7 House at 597 Kaiteriteri-Sandy Bay Road (looking north). The house has collapsed with the impact of debris originating from the landslide scar in the upper left corner of the photo. The house is sited on an old landslide deposit. *(GNS Science photo).*

Figure 8 Remains of house (looking south) showing where landslide debris impacted the house, moving it several meters off its piles. Note how the landslide debris has “ridden up” against the wall. *(GNS Science photo).*

Figure 9 View of landslide looking up slope from Kaiteriteri-Sandy Bay Road. *(TDC photo).*

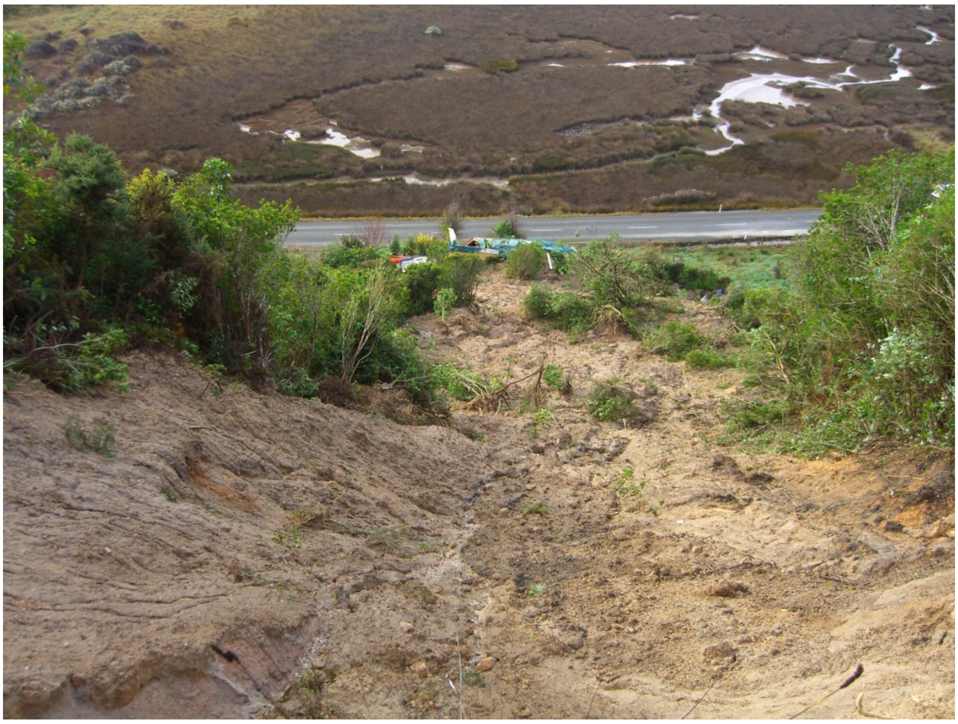

Figure 10 View of landslide looking down slope from access road towards Otuwhero Inlet. *(GNS Science photo).*

Figure 11 View of landslide looking across slope to the north. Note zone of red-weathered clay exposed below the slip plane in centre of photo. *(TDC photo).*

Figure 12 Close up of red-weathered clay. (GNS Science photo).

Figure 13 Landslide debris in the area between the landslide scar (upper right), and the house (lower left). Note debris has ridden over, and been deposited on top of the grass surface. *(GNS Science photo)*.

Figure 14 Lateral edge of landslide debris. *(GNS Science photo).*

Figure 15 Lobe of an earlier landslide deposit on which the house was built (outlined in white). *(GNS Science photo).*

Figure 16 Part of an earlier landslide deposit above the house. Note the large boulders on the surface. *(GNS Science photo).*

The access track is adequately constructed and well maintained. The surface is inclined away from the down slope side of the track toward the cut batter so that water is directed down track and not over the down slope edge of the track (Figure 17). There was no evidence of water running over the edge of the track where the landslide is located (e.g. flattened grass, flow lines, sediment deposition). About 60 m up the track from the landslide there is a hairpin bend in the track (Figure 18). Water running down the track above this point is directed into several culverts that lead under the track and discharge down slope (Figure 19 and Figure 20). It would appear then that overland flow of water down the track is unlikely to have been a contributory factor to causing the landslide.

At the head of the landslide, on the outer edge of the track, spoil associated with track construction and maintenance had been deposited. Tension cracks were present in these side castings, indicating that the unsupported outer edge had moved (Figure 21 and Figure 22). This cracking is likely to have increased saturation of the spoil and possibly allowed increased access of water to the natural slope beneath. The exposed head scarp of the landslide shows two separate side casting deposits at the site, an 80–100 cm deposit overlying a buried top soil, which is the side casting from the original track construction, and 40-60 cm of side casting which overlies the top soil developed on the earlier side casting (Figure 23). This second side casting probably was deposited during track maintenance between 2006 and 2010. As previously mentioned, these side castings had a volume of ~50 m^3 and they accounted for about 9% of the total eroded volume of the landslide. Aerial photos taken in 2002 and 2007, and Google Earth images from 2003, 2006, 2010 and 2011 show side castings along much of the track's length (Figure 24). Between ~2001 and 2006 four other landslides occurred on the track, and they were also sited at the edge of the track, in areas of convergent drainage and associated with side casting (Figure 25).

Based on the above observations, and in addition to the high-intensity rainfall and the deeply weathered Separation Point Granite lithology, the site factors contributing to the death of Jude Hivon were:

- the location of the house at the base of an area of steep slopes with convergent drainage where landslides have occurred before
- the light construction of the building
- the side castings deposited on the outer edge of the track above the house

The side castings from the track increased the debris volume, and therefore the runout distance and force with which the debris impacted the house. The side castings may also have lowered the landslide-triggering threshold. These effects are unlikely to have been large individually, but they may have been critical. It is recommended that side castings are not deposited along the outer edges of tracks above steep slopes and especially in areas of convergent drainage (swales).

Landslides also occurred above several nearby houses, although fortunately the debris runout distances or directions meant that the houses were not significantly affected. Numerous landslides also occurred in the Kaiteriteri-Marahau area on natural slopes and slopes associated with roads, some of which were blocked. These landslides occurred in areas of second growth scrub, indigenous forest and pine plantations.

Figure 17 Head scarp of the landslide at the edge of the access track. The track surface is inclined away from the downslope edge and towards the cut batter to direct water down the track and away from the slope below the track. The head scarp has exposed two buried soils overlain by two side casting deposits. *(GNS Science photo)*.

Figure 18 Hairpin bend 60 m up the track from the landslide (marked with an arrow). Water running down the track above this point is carried under the track by a series of culverts and discharged down slope. *(GNS Science photo).*

Figure 19 Hairpin bend showing culverts to discharge water from the track. *(GNS Science photo).*

Figure 20 Culvert under access track just above hairpin bend. *(GNS Science photo).*

Figure 21 Side castings on track edge adjacent to head scarp of landslide. The landslide has removed ~50 m^3 of side cast material. Note tension cracks in side cast deposit. *(GNS Science photo).*

Figure 22 Side castings partially eroded adjacent to head scarp of landslide. Note tension cracks. *(TDC photo).*

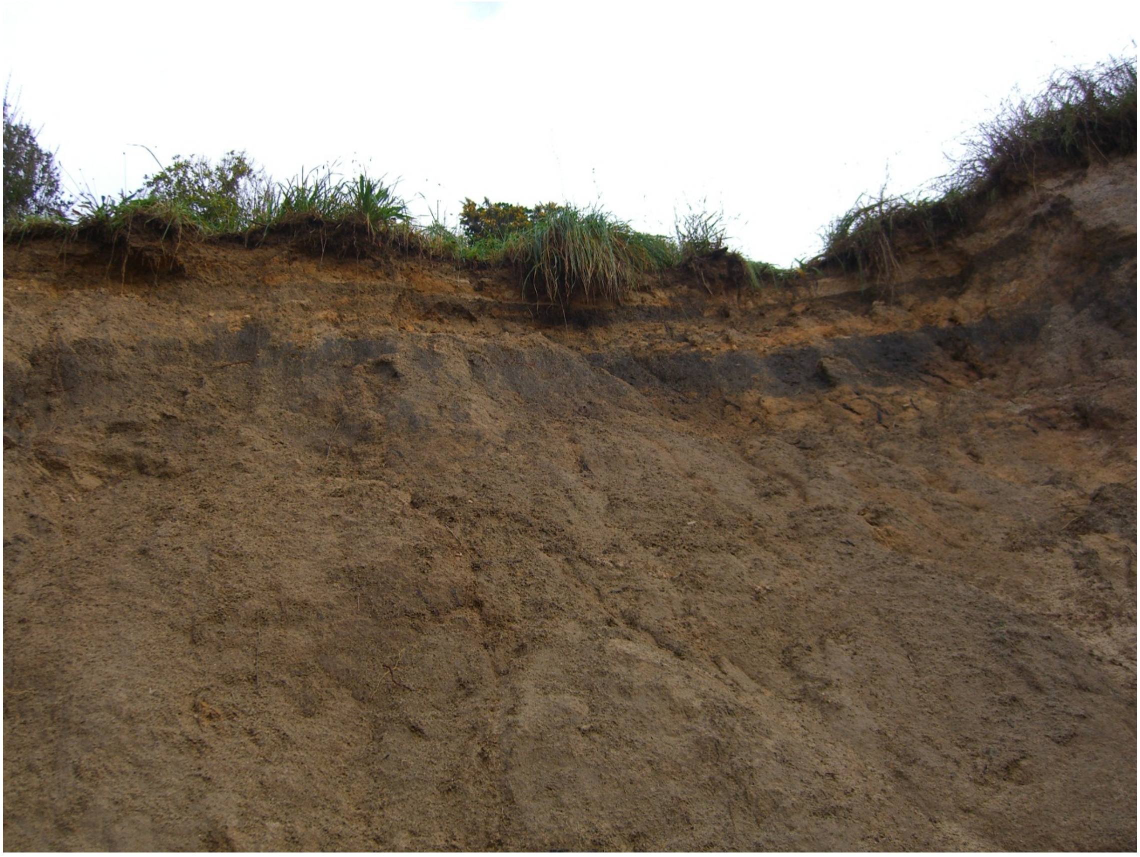

Figure 23 Head wall of landslide showing original buried soil overlain by side castings from original track construction. A soil formed on these side castings has in turn been buried by a second side casting deposited during track maintenance. Total side casting thickness is ~1.2-1.6 m. *(GNS Science photo).*

Figure 24 Google Earth image (28/11/2010) showing recent side castings (outlined in red) deposited between 2006 and 2010 (white and grey curved feature adjacent to the track above the house). Compare with 2006 Google Earth image in Figure 3. Grey areas elsewhere along the track represent earlier side castings.

Figure 25 Vertical Google Earth image (28/08/2006) showing house at 597 Kaiteriteri-Sandy Bay Road before the fatal landslide occurred on 16/06/2013. Note other landslides along access road above the house. House is marked with an arrow.

3.0 MARAHAU VALLEY LANDSLIDE

On the afternoon of the 19th June, Mike Page and Glenn Stevens visited the site of a landslide at 198 Marahau Valley Road that severely damaged the home (caravan and lean-to) of Lisa Humphreys and Bruce Anderson and their two children. This landslide occurred at ~2 am on Monday 17th June, after ~290 mm rainfall in the preceding 24 hours, ~140 mm in the preceding 12 hours and ~30 mm in the preceding hour (Table 1, Figure 5 and Figure 6) (recorded at 49 Marahau Valley Rd, 1.2 km down the valley towards the coast). The landslide occurred in deeply-weathered Separation Point Granite on a moderately steep hill slope with second growth scrub, and was located on the lower third of the 100 m slope (Figure 26, Figure 27 and Figure 28). The landslide was similar in dimensions to the one at Otuwhero Inlet, with a volume of ~500 m^3. The debris from the landslide destroyed the lean-to where the kitchen was located, part of which collapsed with the remainder partially filling with sediment (Figure 29, Figure 30 and Figure 31). Fortunately Bruce Anderson and his daughter were in the caravan that was largely unaffected, and his wife was in another nearby building.

As at the Otuwhero Inlet landslide, the dwelling was sited close to the base of the slope and on an old (paleo-) landslide deposit. A platform for the dwelling had been created by cutting into and levelling the surface of the old landslide deposit, and to increase the platform area the natural toe of the hillslope had been removed (Figure 27 and Figure 32). This has steepened the lower part of the slope and removed some support for the area above (Figure 33). The landslide occurred in an area of convergent drainage (swale) directly above this cut slope. Nearly all of the landslide debris was transported off the slope and deposited onto the levelled area of the old landslide deposit. While the lean-to was directly below the cut slope and was severely damaged, the caravan was located just beyond the edge of the cut slope and not directly in the landslide path.

Figure 26 Landslide that partially destroyed the dwelling at 165 Marahau Valley Road. Photo is taken from Harvey Road on north bank of the Marahau River. *(GNS Science photo).*

Figure 27 View of landslide looking upslope from levelled building site. *(GNS Science photo).*

Figure 28 View of landslide, caravan and damaged lean-to. *(TDC photo).*

Figure 29 Close up of landslide debris and damaged lean-to. *(GNS Science photo).*

Figure 30 Close up of landslide debris and damaged lean-to. Note toe of slope has been cut back and over-steepened. *(GNS Science photo)*.

Figure 31 Close up of landslide debris and damaged lean-to. *(GNS Science photo).*

Figure 32 View of cut back, over-steepened toe slope. *(GNS Science photo).*

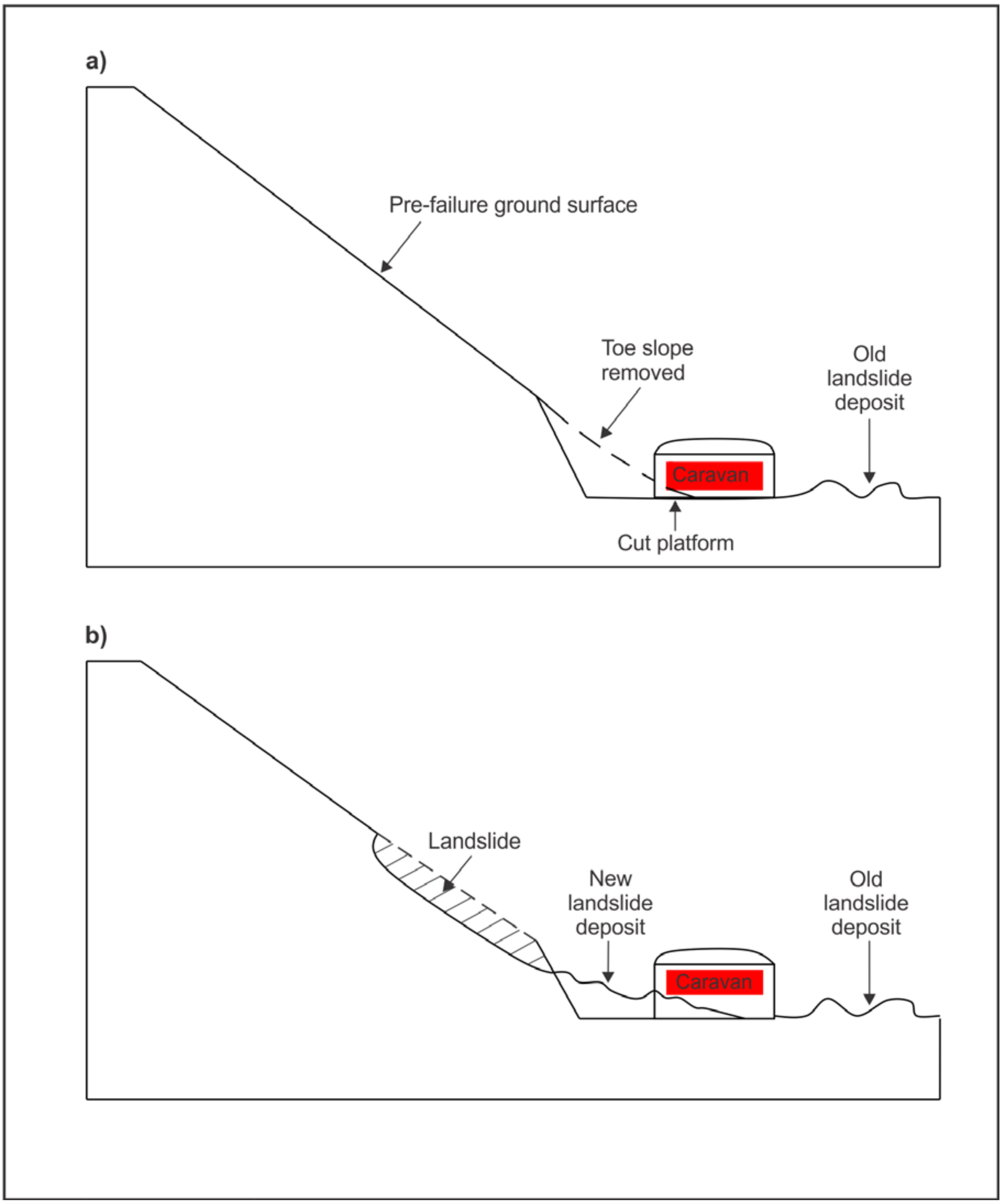

Figure 33 Cartoon showing **a)** profile of slope before landslide, with cut toe slope, levelled building platform and earlier landslide deposit **b)** profile of slope after landslide, with new landslide material deposited on cut platform and impacting on dwelling.

4.0 SHAGGERY RIVER LANDSLIDES AND DEBRIS FLOWS

On the 20th June, Mike Page and Glenn Stevens inspected the landslides and debris flows that occurred in the Shaggery Forest. They were accompanied by Craig McMiken (Manager, Tasman Forest Management Ltd.), and Warren Galbraith (TDC). The Shaggery Forest is owned by CNBM Forest Products New Zealand Limited, and is largely planted in *Pinus radiata.* The area is underlain by Separation Point Granite. Rainfall of 214 mm was recorded for the storm at the Woodmans Bend rain gauge (~2 km to the east). The maximum hourly rainfall was 36 mm with 66 mm (2-hour), 109 mm (6-hour) and 142 mm (12-hour) being recorded (Table 1, Figure 5). These rainfalls had recurrence intervals in the order of 30 years with the 2-hour rainfall having a recurrence interval of ~50 years (based on NIWA's HIRDS (V3) software).

While some landslides occurred within the established forest (Figure 34), the most severely affected area were steep slopes that had been logged during the summer of 2012/2013 (Figure 35). Here, landslides occurred on both natural slopes, and where slopes were associated with a mid-slope access road (Figure 36) and landings. The landslides delivered material into stream channels (Figure 37) where, as more landslides contributed, debris flows formed (Figure 38), scouring the channel and transporting sediment and debris to the Shaggery River (Figure 39, Figure 40, Figure 41, Figure 42 and Figure 43). Woody debris and sediment were deposited on the valley floor beyond the forest (Figure 44) and there were instances of channel avulsion (Figure 45). Debris backed up at the bridge across the Shaggery River from Motueka River West Bank Road to Peach Island, leading to scouring and loss of the bridge approaches. Residents were cut-off for three days until the bridge was repaired. Old (paleo-) debris flow deposits (Figure 46), and buried soils beneath flood deposits were observed in stream banks along the Shaggery River (Figure 47 and Figure 48), indicating that such events have occurred before, and prior to the establishment of the plantation forest.

Despite the highly erodible underlying Separation Point Granite, areas of established forest had relatively few landslides. The distribution of landslides in the logged area in Figure 35, suggest that ~53% of landslides occurred on natural slopes and ~47% were associated with the access road or landings. While this is only based on preliminary observations, a more thorough assessment of road-related mass movements was made by Coker and Fahey (1993) in Motueka and Golden Downs Forests underlain by Separation Point Granite following four rainstorms in July and August 1990. At Riwaka, rainfalls of between 87-350 mm were recorded in over 4-7 day periods. Along 209 km of roads 366,700 t of sediment was eroded, representing 2820 t km^{-2}. Of this total, half was estimated to have entered streams. Fifty seven percent of the failures were cutback failures and 43% were sidecast failures. The area of the Shaggery Forest (then referred to as the West Bank Block of the Motueka Forest) had the greatest number of failures per kilometre of road.

While forest management and road and landing construction have improved since 1990, the study of Coker and Fahey (1993) together with the recent landsliding in harvested areas of Shaggery Forest highlight the landslide hazard associated with road construction, and the "window of vulnerability to erosion" that exists between forest harvesting and canopy closure following replanting. The coincidence of a high-magnitude, low-frequency rainstorm occurring in an area of erodible hill country which has been recently logged will inevitably result in increased landsliding. In areas of high risk, management strategies can include: retirement, a mix of species with different rotation lengths which has the effect of reducing the area at risk at any one time, and effective buffer zones around streams where vegetation is retained to prevent material entering the streams (Phillips et al. 2012).

Figure 34 Landslide in established plantation in Shaggery Forest. *(TDC photo).*

Figure 35 Landslides in area of Shaggery Forest logged over summer 2012/2013. In addition to the mid-slope forestry road, there is another road along the skyline ridge. Landslides occurred on both natural slopes and associated with the forestry roads. *(GNS Science photo).*

Figure 36 Landslides associated with the forestry road, where the sediment was delivered directly to a stream channel. *(GNS Science photo).*

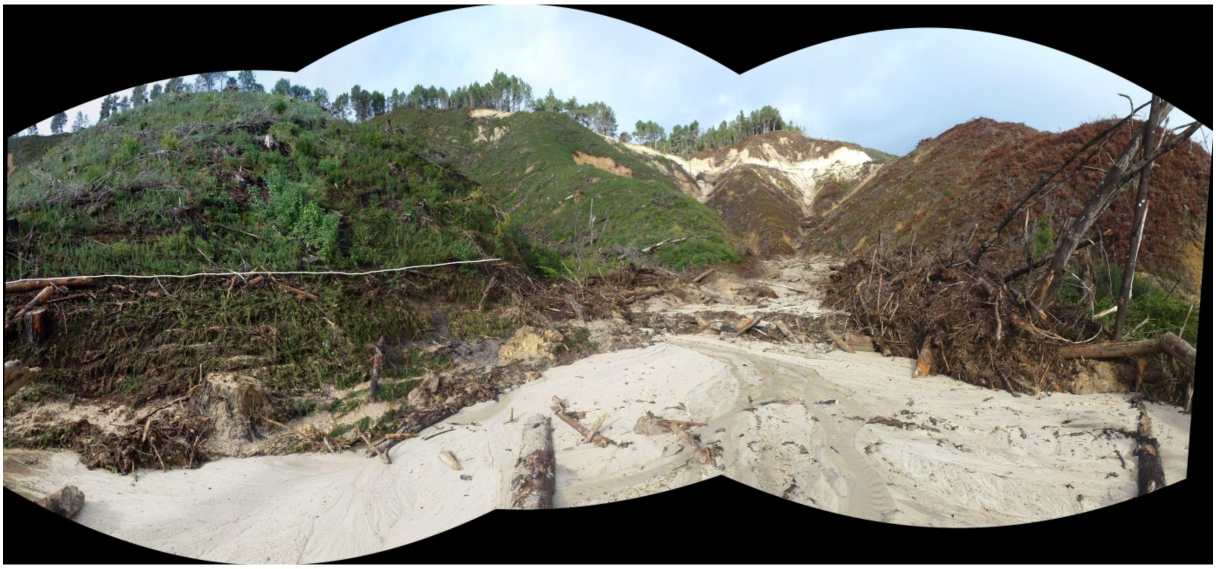

Figure 37 Landslide sediment and woody debris deposited in stream channel above forestry road. Note trim line in vegetation mid-way up hillslope on left (marked with white line), denoting height of debris flow/flood. *(TDC photo).*

Figure 38 Debris flow deposit on forestry road/landing just downstream of Figure 36. *(GNS Science photo).*

Figure 39 Stream channel scoured by sediment and woody debris-laden debris flow. *(GNS Science photo).*

Figure 40 Close up of scoured stream channel. Note exposed bedrock along channel bed. *(TDC photo).*

Figure 41 Tributary stream channel at the confluence with the Shaggery River. *(GNS Science photo).*

Figure 42 Debris flow deposit from tributary stream at the confluence with the Shaggery River. *(TDC photo).*

Figure 43 Shaggery River showing sediment and woody debris deposited by tributary stream. *(TDC photo).*

Figure 44 Woody debris deposited in and adjacent to the Shaggery River, ~1 km downstream from the area of logged forest. *(GNS Science photo).*

Figure 45 Shaggery River with main (original) channel to the left, and a post-storm (avulsed) channel to the right. *(TDC photo).*

Figure 46 Paleo-debris flow deposit exposed in a bank of the Shaggery River, next to the ford shown in Figure 43. *(TDC photo).*

Figure 47 Sediment deposition on the valley floor ~300 m downstream from the area of logged forest. Earlier flood deposits and a buried soil are exposed in stream bank. *(GNS Science photo).*

Figure 48 Flood deposits overlying a buried soil in a bank of the Shaggery River directly downstream from Figure 47. *(GNS Science photo).*

5.0 CONCLUSIONS

There are common circumstances surrounding the Otuwhero landslide that killed Jude Hivon and destroyed her home, and the landslide in the Marahau Valley that partially destroyed the home of Lisa Humphreys and Bruce Anderson.

- Saturated ground conditions were created by rainfall in the preceding 24 hours of between ~200–300 mm, and rainfall intensities immediately prior to the landslides occurring of ~20–30 mm/hr
- The landslides occurred on weathered Separation Point Granite, a highly erodible lithology
- The dwellings were sited at the base of steep slopes (35-40°) and directly below hillslope swales (areas of convergent drainage)
- The dwellings were sited on old/previous landslide deposits
- Slope drainage and support were modified by earthworks (the deposition of side castings along the outer edge of a track across the slope at Otuwhero, and the excavation and resultant steepening of the toe slope at Marahau)
- The dwellings were built of light-weight materials, providing limited resistance to the forces of moving landslide debris

There were a number of other instances around the district where landslide debris narrowly missed houses in similar locations.

The landslides and debris flows that occurred in this rainstorm, together with those associated with rainstorms in the Tapawera area in May 2010, Golden Bay and Nelson in December 2011, and the Riwaka catchment in April 2013, have highlighted the vulnerability of houses built at the base of steep hillslopes where there is evidence of previous landslides, and on fans subject to debris flows/debris floods. Given the large number of rural life-style properties in the Tasman District, more consideration should be given to identifying at-risk existing houses and at-risk sites prior to planning consent and house construction.

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www.gns.cri.nz

Principal Location

1 Fairway Drive
Avalon
PO Box 30368
Lower Hutt
New Zealand
T +64-4-570 1444
F +64-4-570 4600

Other Locations

Dunedin Research Centre
764 Cumberland Street
Private Bag 1930
Dunedin
New Zealand
T +64-3-477 4050
F +64-3-477 5232

Wairakei Research Centre
114 Karetoto Road
Wairakei
Private Bag 2000, Taupo
New Zealand
T +64-7-374 8211
F +64-7-374 8199

National Isotope Centre
30 Gracefield Road
PO Box 31312
Lower Hutt
New Zealand
T +64-4-570 1444
F +64-4-570 4657