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Preliminary Report on Landslides, Gully Erosion, and Debris Flood Effects in the Paekakariki Area as a Result of the 3 October 2003 Flood

by G.T. Hancox

20 October 2003

Institute of Geological & Nuclear Sciences Limited

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Preliminary report on landslides, gully erosion, and debris flood effects in the Paekakariki area as a result of the 3 October 2003 flood

Prepared for

Duffill Watts & Tse Ltd
on behalf of the Kapiti Coast District Council

by G.T. Hancox

Institute of Geological & Nuclear Sciences client report 2003/120
Project Number: 430W1094

The data presented in this Report are available to GNS for other use from
November 2003

20 October 2003

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SUMMARY

The rainstorm that hit Paekakariki on Friday 3 October 2003 affected many parts of the Wellington region causing flooding and slips that closed roads, with the Kapiti Coast being one of the worst affected areas. Rainfall appears to have been much heavier in the Paekakariki area, where it was probably well in excess of 100 mm in 24 hours, causing severe flooding and extensive landsliding, gully erosion and debris flood damage on the steep coastal hills. The area of greatest ground damage coincides with the area of maximum rainfall accumulation indicated by radar imagery. This shows that the heaviest rainfall occurred in a narrow band about 10 km wide and extending from just south of Kapiti Island and directly across Paekakariki towards Upper Hutt. The areas most affected by landslides and debris floods were around the junction of the Paekakariki Hill road with State Highway 1, and across the hills ~2 km south of Paekakariki, especially in the Fly-by-Wire gully above the BP Service Station and Belvedere Motel, and the Hill Road gully ~700 m to the south. The average return interval of rainfall in this area during the flood (>82 mm in 4 hours) is estimated from nearby rain gauges to be greater than 125 years. In other areas where there was less rainfall the landsliding and flood damage was generally minor.

About 3000 m^3 of gravel from the flooded Fly-by-Wire gully was deposited around the Belvedere Motel buildings and across SH 1 at the bottom of the Paekakariki Hill Road. All of the flood water and gravel was passed through the culvert under the hill road, which was not affected at this site. Based on the lack of damage to buildings the gravel was deposited gradually as a debris flood over several hours, not as a single debris flow. The buildings on the east side of SH 1 at the bottom of the Paekakariki Hill Road are built on an old debris fan formed at the gully exit. This makes it potentially a dangerous site for future flooding, debris floods, and possibly debris flows which can cause much more damage.

The upper part of the Fly-by-Wire gully was severely damaged by numerous shallow slumps and deep erosion gullies. Geomorphic evidence suggests that locally the flood was a very rare event with a return period of more than 100 years, possibly several hundred years. A large amount of soil and gravel from steep slopes and gullies was transported down the stream and deposited on the debris fan around the motel buildings and across SH 1. However, much of the gravel was also deposited in the stream channel and will continue to be transported downstream during future floods. This problem could be minimised by erecting steel catch fences in the upper reaches of the stream, and/or by constructing a stream bypass with a debris fence and accumulation area at the culvert entrance just above the motel site.

Damage to the northern end of the Paekakariki Hill Road was the result of flood water and gravel deposition as a debris flood, rather than debris flow. Damage to road cuts on the hill road was generally minor, with only a few small rock and soil falls observed north of the summit. Gravel trapped behind fences and gates above the road suggests that this material accumulated slowly. Most of the silt and sand was carried away in flood water, which flowed over the road and washed out road edge fills and severely undermined the road in several places. This mechanism suggests that steel catch fences above the road and culvert entrances could be used to trap gravel during floods, while allowing water to pass through culverts. The control of debris in the head of gullies would potentially reduce gravel inundation problems for the Paekakariki Hill Road, and for SH 1 and the NIMT railway line.

1.0 INTRODUCTION

On Friday 3 October 2003 the Wellington area was hit by a rainstorm which isolated the region and caused severe flooding in many places. One of the worst hit areas was the Kapiti Coast, and particularly the Paekakariki area which was largely cut off by flood waters from early on Friday evening until mid day Saturday. Besides flooding the storm caused severe landslide and debris flood (a hyper-concentrated flow of water laden with gravel, sand, and silt – Hutchinson, 1988; Hungr *et al*., 2001) damage in the surrounding hills and along the northern lower section of the Paekakariki Hill Road. Gravel carried by the flood was deposited around and partly buried a motel and another building at the bottom of the Paekakariki Hill Road, and spilled across SH 1 and the NIMT Railway line.

As the Landslides Response Duty Officer (for GeoNet Project of the Institute of Geological and Nuclear Sciences Ltd) at time of the flood, the author inspected and photographed the flooding and landslide damage at the bottom of the Paekakariki Hill Road early on Saturday afternoon and Sunday morning, and on Monday inspected the source of the debris floods deposits in the Fly-by-Wire gully above the motels. As a result of media comments about the landsliding and debris flood damage, the author was invited to brief Duffill Watts & Tse Ltd. and representatives of the Kapiti Coast District Council and Transit NZ on his observations. As a result of this briefing, Duffill Watts & Tse Ltd engaged the author through the Institute of Geological and Nuclear Sciences Ltd. (GNS) to provide technical assistance with:

- Assessing the background causes of the slips in the hills behind Paekakariki that occurred during the 3 October 2003 flood, and the consequent damage to Paekakariki township, State Highway 1, Paekakariki Hill Road, and North Island Main Trunk railway.
- Describing the mechanism of the debris floods, so that mitigation measures against future floods could be developed.
- Determining the risk and hazard of similar events in the future.
- Taking a series of oblique aerial photos of the landslide and debris flood damage to facilitate this assessment, and providing digital copies to KCDC.

This report describes the initial assessment of the extent and causes of the slips, and the mechanism by which 'soil' and water has moved down the hillsides and across the roads. It includes a landslide map, which has been prepared from the aerial photos taken by the author on Wednesday 8 October, and his ground observations and photos taken 1–3 days after the event. Brief comments are also included on the nature and frequency of the flood event, the risk of further movement of material down slopes and stream channels in the future, and some possible hazard mitigation measures that could be considered. A number of photos are included illustrating the damage and effects at the most affected sites.

2.0 THE FLOOD EVENT

The rainstorm that hit Paekakariki on Friday 3 October 2003 affected many parts of the country, with recorded rainfall of more than 300 mm in a 24-hour period in some areas. In the Tararua Ranges 345 mm fell between 6 am Friday and 6 am Saturday. Roads were closed by flooding in several places across the region, including Paekakariki and Plimmerton, and the Paekakariki, Akatarawa, and Rimutaka hill roads were closed by slips and wash-outs, severely disrupting traffic for several hours overnight.

It is uncertain exactly how much rain fell at Paekakariki during the flood as it lies between weather Stations. From 6am Friday to 6 am Saturday approximately 60 mm was recorded at Paraparaumu airport (33 mm fell between 4–10 pm on Friday during the height of the flood), while about 150 mm fell at Wellington. The Met Service reports that rainfall appears to have been much heavier in some places (such as Paekakariki) than others, with the heaviest rain restricted to a narrow band that went across the country. This was caused by a slow-moving convergence line (where air from the northeast was meeting air from the west) crossing the region (pers. comm. John Crouch). On a wider scale, however, this convergence was only a small feature embedded in a vigorous broad trough of low pressure, which produced heavy rainfall in many parts of the country (pers. comm. Ross Marsden, NZ MetService).

Variations in rainfall over the Wellington Region for the period 6:45 am to 10:00 pm on Friday 3 October 2003 are shown by a radar-derived rainfall accumulation image supplied by the Met Service (Figure 1). This shows that the heaviest rain occurred in a narrow band about 10 km wide that extended southeast from the southern end of Kapiti Island and across Paekakariki towards Upper Hutt. This suggests that that rainfall at Paekakariki was considerably greater than at Paraparaumu or Wellington.

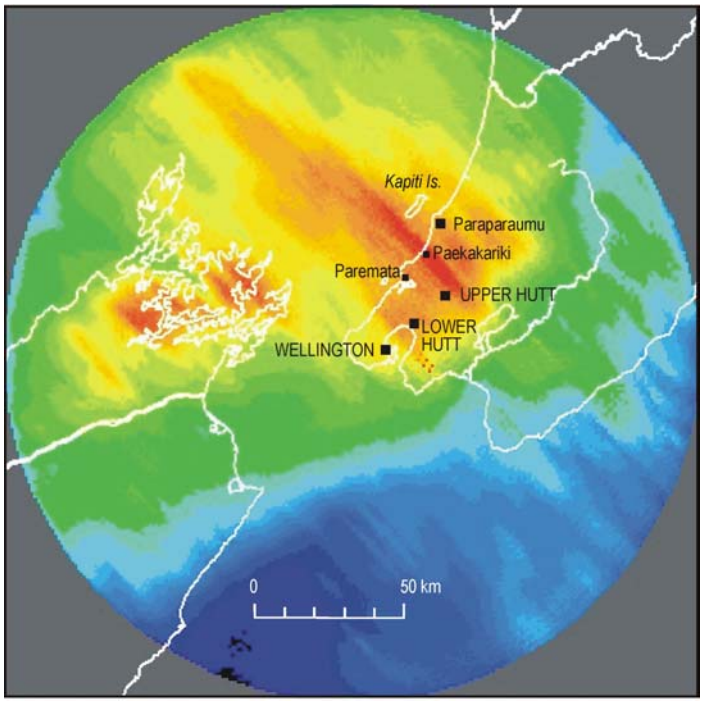

Figure 1. Radar-derived rainfall accumulation image for Friday 3 October 2003, showing total rainfall over the Wellington region for the period 6:45 am to 10:00 pm. Red is the heaviest rain and blue is the lightest. The band of heaviest rainfall coincides with the severe landsliding and flood damage observed in the Paekakariki area *(Image supplied by John Crouch, MetService)*

Some indication of what the rainfall might have been in the worst hill country south of Paekakariki is provided by rainfall data compiled by NIWA. At the Paekakariki Hill rain gauge station (~3.5 km south-southwest of Paekakariki, at elevation ~230 m) 119 mm of rain was recorded from 9 am Friday 3 October to 9 am Saturday, with 82 mm recorded in 4 hours between 6–10 pm on Friday night during the height of the storm (pers comm. Bob Guyton, NIWA rainfall observer). Similar rainfall was recorded by a private observer ~900 m to the northeast where 71 mm fell between 7–11 pm on Friday night, although the rain had eased noticeably after 10 pm (pers. comm. Mike Crosland).

Extrapolating from unpublished rainfall data provided by NIWA (pers. comm. Stuart Burgess) the observed 82 mm rainfall in 4 hours equates to an average return interval of about 125 years. Therefore, based on the distribution of landsliding and flood damage in the area it is inferred that rainfall in the areas most affected by flooding (2–3 km to the northeast) was much heavier, probably with a return period of considerably more than 125 years. More definitive information on the causes of the heavy rainfall at Paekakariki during the 3 October 2003 flood, and possibly rainfall intensities and the return period, will be given in a report being prepared by the MetService (John Crouch) for the Kapiti Coast District Council.

3.0 LANDSLIDING AND FLOODING EFFECTS

3.1 Extent and nature of the affected area

Ground and aerial inspections in the week following the 3 October 2003 flood have allowed the nature of the landsliding and debris flood damage and its extent to be determined. The worst affected area was in the steep coastal hills within about 2 km of Paekakariki, especially in the two gullies at the northern end of the Paekakariki Hill Road. Figure 2 shows the location and extent of this area, and the main landslides, gully erosion features, and debris flood deposits that were observed, and relationships to affected buildings, SH 1 and the NIMT railway line, and the Paekakariki Hill Road. Although other areas to the north east and south were affected by flooding in streams, the landslide and debris flood damage in these areas was generally minor. Landslide damage in these areas, and also the wider Wellington area, will be described in a GeoNet report at a later date.

The areas most affected by landsliding and flood damage were the Fly-by Wire gully directly behind (east of) the motels and BP Service Station on SH 1, and the 'Hill Road gully' with the hair-pin bend at the northern (lower) end of the Paekakariki Hill Road (Figure 2). Flood debris from the latter spilled across the railway line at the exit of the gully. Some minor slipping and gully erosion damage also occurred in the hills to the north and east of these worst affected areas. Local farmer John Perkins reports that flooding damage and gravel deposition was quite extensive in Transmission Gully (Te Puke Stream) and also Smith Creek (Wainui Stream, ~500 m to the east - not shown on Figure 2). Flood water from both these streams and the smaller stream to the west affected SH 1 locally, while water from the latter also flowed south towards the Paekakariki railway station.

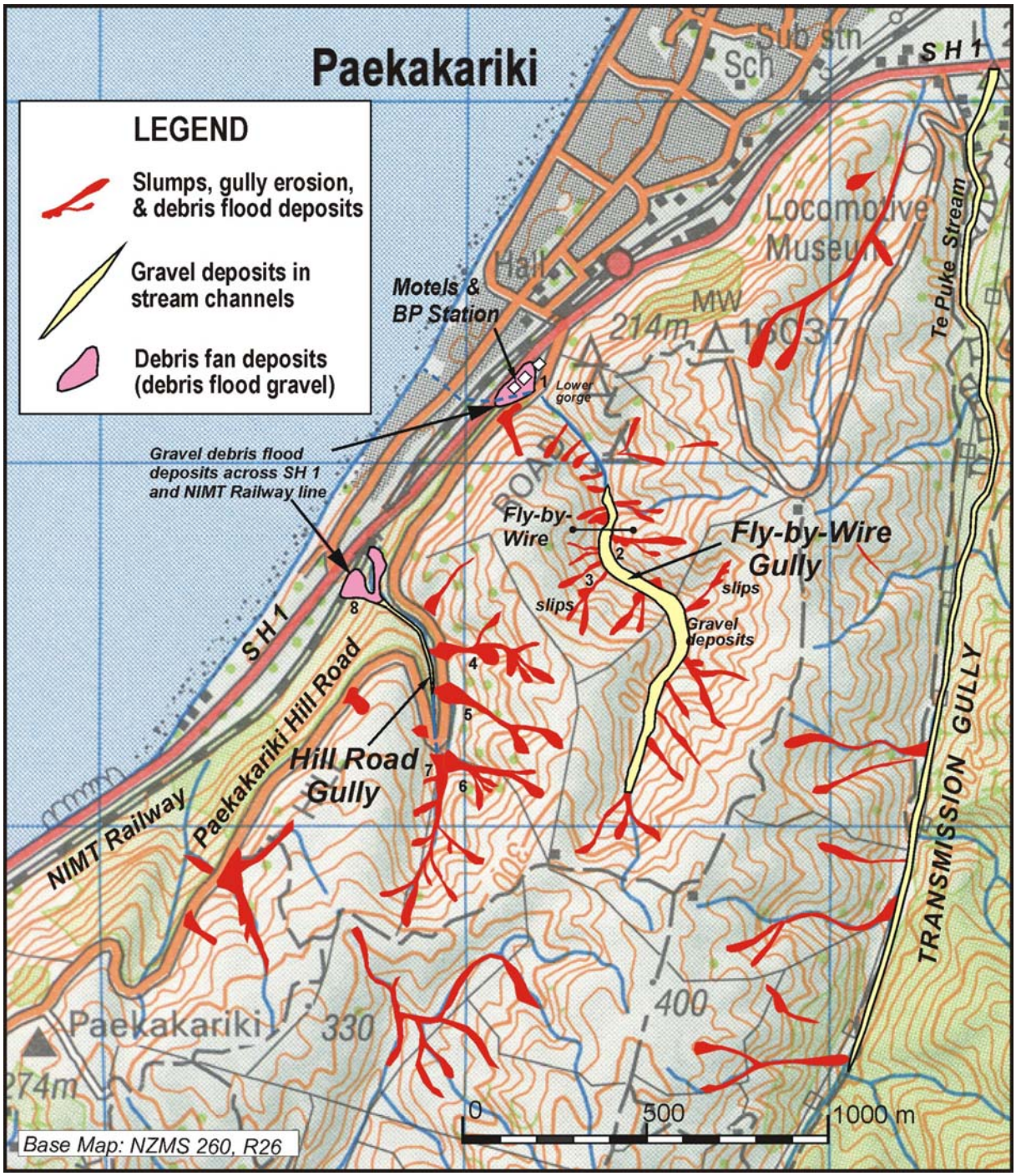

Figure 2. Map of the Paekakariki area showing the main landslides, gully erosion features and debris flood deposits resulting from the flood of 3 October 2003. Some of the main features and sites (numbered 1-8) are illustrated by photos and are discussed more fully in the report.

The terrain in the worst affected areas is hilly and very steep. The main gullies (Fly-by-Wire and Hill Road) extend 1 km or more southwards into the steep Paekakariki escarpment, falling from 300–400 m to the narrow coastal strip with an average gradient of about 1 in 4 (25%). This is steep for stream channels, giving them considerable erosive and transporting potential. The bedrock in the area is relatively strong jointed greywacke sandstone and mudstone. The near surface rock mass is weathered to a depth of 10 m or more, and is considerably weaker. In addition, most slopes are covered with a mantle of top soil, colluvium, and solifluction deposits – a ~1–5 m thick layer of clayey-silty wind blow loess and angular frost-shattered rock fragments (gravel) in a silty matrix – which accumulated during the last ice age, 10,000–25,000 years ago. These surficial deposits tend to be somewhat thicker in gullies, where they are prone to shallow slumping, gully erosion, and debris flows during exceptional rainstorms (as seen during the December 1976 storm that devastated parts of Wellington) - a situation which may recur at intervals of only hundreds of years (Eyles and McConchie, 1992).

3.2 Main areas affected

The areas that were most affected by landsliding, gully erosion, and debris flood damage are described briefly below, and the main features and sites are illustrated by a number of photos taken during the ground and aerial inspections in the week following the flood (Figures 3–18).

3.2.1 Motel area and State Highway 1

The Belvedere Motel and the building to the south (Havana Cigars Showroom) were flooded and inundated by a debris flood of silty gravel from the Fly-by-Wire stream (Site 1, Figure 2), which flows though a ~1.3 m diameter culvert under the lower Paekakariki Hill road and exits about 35 m southeast of the buildings (Figure 3 and 4).

Figure 3. View of Belvedere Motel the day after being buried by debris flood gravel from the *Fly-by-Wire gully* (in distance behind motel buildings) during the 3 October 2003 flood.

Figure 4. Aerial photo taken on Wednesday 8 October 2003 showing the gravel *(g)* from the Fly-by-Wire gully *(fg)* deposited around the Belvedere Motel *(M)* and Showroom *(S,* formerly the 1906 Restaurant) at the bottom of the Paekakariki Hill Road *(HR),* and across SH 1. A new stream channel *(sc)* was dug the day after the flood. The hill road and vegetation at the gully exit was unaffected by the flood, showing that all the debris passed through the culvert *(c)* below the road. The BP Service Station *(BP)* was flooded but was largely unaffected by gravel inundation. A small shallow soil flow slide *(sf)* spilled debris on to the hill road ~70 m south of the gully exit.

About 3000 m^3 of flood debris comprising coarse (~50-100 mm) gravel, sand and silt was deposited up to roof height (~2.5 m) around the motel and showroom buildings, and burying a swimming pool and several cars (Figures 3–6). Based on the lack of damage or deformation to the buildings and cars that were buried (Figure 5), this material was deposited gradually as a *debris flood* over several hours between 7-11 pm on Friday night. Television footage taken by TV3 during the flood clearly demonstrates the debris flood mechanism at this site. The BP Service Station on the northern side of the motel was slightly flooded, but was not inundated by gravel as it was protected by the motel. However, all the buildings on the east side of SH 1 at the bottom of the Paekakariki Hill Road are built on a debris fan built by the Fly-by-Wire stream and are therefore at risk from similar flood events in the future. Debris fans are potentially hazardous places because of the risk of both flooding and sediment deposition.

Ground observations show that the flood water and gravel did not flow over the Paekakariki Hill Road at this site, but was passed through the culvert under the hill road (Figure 6). Wood debris from damaged walk-ways and bridges in the Fly-by-Wire gully were seen to be lodged in the culvert entrance on Saturday afternoon, but it appears that this debris did not prevent the flood water and gravel from flowing through the culvert.

Figure 5. View of the debris flood gravel deposited around the Belvedere Motel and buried cars from the gully exit on the Paekakariki Hill Road. SH 1 is visible in the distance (top right).

Figure 6. Culvert discharge area behind the Belvedere Motel the day after the flood. This view shows that vegetation above the culvert on the side of the hill road was unaffected by the flood, indicating that all the gravel and flood water passed through the culvert and not over the road.

3.2.2 Fly-by-Wire Gully

Numerous shallow slumps occurred in the higher slopes of the upper section of the Fly-by-Wire Gully, with many transforming into deep erosion gullies lower down (Figure 2). Elevated gravel levees along the sides of some steep, deeply incised erosion gullies (such as that illustrated in Figure 7) show that debris flows carried large amounts of gravel, sand and silt into the main stream channel. Some of this gravel was transported down the gully and deposited on the debris fan around the motel buildings and across SH 1, but a considerably greater volume was deposited in the channel. Upstream of the Fly-by Wire Site gravel deposits raised the stream bed about 1–2 m and infilled the channel over a distance of ~800 m (Figure 8). Other features in this gully are illustrated in Figures 9 and 10.

Figure 7. Typical shallow soil 'slump' (top right) and a deep erosion gully (centre) formed high on the northern side of the Fly-by-Wire (FBW) gully. The gully is about 2–3 m deep at the bottom where it joins the main channel just upstream of the FBW shed (Site 2, Fig. 2). The absence of similar but older geomorphic features in the area suggests that locally the flood was a very rare event, possibly with a return period of more than 100 years.

Figure 8. Thick gravel deposits infilling the bed of the upper Fly-by-Wire gully (upstream of Site 2, Fig. 2). Erosional terraces formed as the flood level decreased, but continued to transport gravel downstream. A considerable volume of gravel has been deposited in the upper parts of this gully. This material will gradually be eroded and carried downstream in future floods, even during smaller more frequent events, and deposited on the fan at the gully exit causing ongoing problems in that area.

Figure 9. View looking down the lower Fly-by-Wire gully showing the extensive gravel deposits in the stream channel above the lower gorge (in the distance around the bend to the left).

Figure 10. Aerial view of the lower section of the Fly-by-Wire gully looking south. The FBW hut is in the centre of the picture, with extensive gravel deposits in the stream channel both upstream and downstream. Large debris slides and flows can be seen on the upper slopes (top left, Site 3, Fig. 2), while smaller soil slumps and slides scar the sides of the lower gorge (bottom right). Most of the wooden walkways and bridges up the valley to the FBW site were destroyed by the flood.

Overall the Fly-by-Wire gully was severely damaged by the 3 October flood event. The shallow (1–2 m deep) soil slumps and flow slides seen in the catchment were typical of the slope failures seen elsewhere on the Kapiti Coast north of Waikanae during a similar flood in 1998. However the transition of some slumps into debris flows in very deep erosion gullies carrying large volumes of gravel into the main stream channel is far less common. There are no known old ('fossil') gullies of a similar nature in the immediate area. From family records the local farmer reports that flood damage to his farm, which includes the Fly-by-Wire gully, was the worst in the last 150 years (pers. comm. John Perkins). The absence of similar but older geomorphic features supports this report, and suggests that locally the flood was indeed a very rare event with a return period of more than 100 years, possibly several hundred years.

3.2.3 Paekakariki Hill Road

The northern end of the Paekakariki Hill Road was extensively damaged by debris flood deposits and collapses of saturated road edge fills, especially around the hair-pin bend section of the 'Hill Road Gully', about 1–1.5 km south of Paekakariki (Figure 2). Ground observations two days after the flood showed that many of the culverts carrying very small side streams were unable to cope with the very high flood flows partly because of the large volume of water, but mainly because they were blocked with gravel. As a result the water flowed across the road (or in some places down it) and washed out the road edge fills. The worst affected sites were in the Hill Road Gully (Sites 4–7 in Figure 2). Although some of the debris flood gravels was carried all the way down this gully, where it spilled across the NIMT railway line (Site 8, Figure 2), much of the gravel was trapped by fences above the road, or deposited across the road. The main sites of this damage are discussed and illustrated in Figures 11 to 17 below.

Figure 11. Aerial view of Sites 4 (left) and Site 5 (right) on the Paekakariki Hill Road (see Figure 2) showing the slips, gully erosion, and debris flood gravel deposits across the road, and undermining of the road due to fill wash-outs and collapses.

Figure 12. Ground view of damage Site 4 on the lower Paekakariki Hill Road, showing the soil slump and gravel debris deposited in the gully just above the road, where it has been trapped behind a farm fence. Some gravel was also washed across and down the road. Fill collapse has undermined the road edge here over a distance of about 10 m (the area in shadow bottom right).

Figure 13. Damage Site 5 on the lower Paekakariki Hill road (see Figure 2), showing debris flood gravel from a small gully spilled across and down the road. The road edge fill has also collapsed and undermined the road.

Figure 14. Damage Site 7 on the Paekakariki Hill Road (Site 6 is a debris lobe from the steep gully out of picture to the left – see Figure 16). At this site a large volume of gravel has been carried down from the head of the Hill Road Gully as a debris flood. However, here all of the gravel was trapped behind the fence and gate above the road (see Figure 15 also). Only flood water appears to have crossed the road at this location, washing out the road edge fill and undermining the road. No gravel debris has been carried across the road. The low volume of water flowing from the broken culvert pipe here is seeping through the gravel, which has completely blocked the culvert intake above the road.

Figure 15. A closer view of Site 7 showing gravel trapped behind the fence and gate above the road. There was, however, little damage to the fence and gate, which suggests that the gravel accumulated slowly, from a hyper-concentrated debris flood of water laden with silt, sand, and gravel. Most of the finer sediment was carried away in the flood water. This type of mechanism shows that steel catch fences above the road could be used effectively to control future debris floods.

Figure 16. View of Site 7 on the Paekakariki Hill Road showing the deep erosion gully and large lobe of gravel debris formed at the bottom of a steep but normally dry gully. The lack of damage to trees inundated by gravel (lower left) suggests that this too was a debris flood event - not a debris flow. Note that the gravel debris lobe overlies material in the valley bottom, suggesting it was still forming after the flood in the main gully at the bottom had declined. This very deep erosion gully and large debris lobe is another example of the type of ground damage that suggests that the flood was a very rare event, as no old or 'fossil' features of a similar nature are visible in the present landscape in the area.

The distribution of ground damage affecting the lower Paekakariki Hill Road was mainly related to very high flood flows in small streams which normally carry small flows or are dry. For these streams the 3 October flood was certainly an extreme event. Culverts which have been large enough to manage most floods in the past were unable to cope with the large amount of gravel that was mobilised, blocking culverts and spilling across the road. The deep erosion gullies formed in the Hill Road Gully (Figure 16) and also the Fly-by-Wire gully (Figure 7) are examples of the type of ground damage that suggest the flood of 3 October was almost certainly a very rare event for this area. There are no known 'fossil' features of a similar nature in the present landscape of the affected areas.

Gravel trapped behind little damaged fences and gates above the road (Figures 12, 14, and 15) suggests that it was deposited slowly from a flow of water laden with silt, sand and gravel. Most of the finer material was carried away in the flood water, which flowed over the road and washed out the road edge fills, severely undermining the road in several places (see Figures 12-14). This type of flooding and deposition mechanism suggests that catch-fences erected well above the road and culvert entrances could be used to mitigate the effects of similar floods in the future. Steel catch-fences or similar structures could effectively retain much of the gravel debris carried by a similar event in the future, but allow flood water to pass through culverts if they were big enough to carry larger flood flows. Figure 17 shows two gullies on the lower hill road where such measures could be used to minimise flooding and debris transportation problems. Control of debris in the head of these gullies would lessen problems for the lower Paekakariki Hill Road, and for SH 1 and the NIMT railway lime at the bottom of the Hill Road gully (Site 8, Figure 2, and shown in Figure 18).

Figure 17. Aerial view of damage Sites 5 (left) and 6/7 (top) on the lower Paekakariki Hill Road on Wednesday 8 October after remedial work had begun. It shows two gullies where debris control fences could be effective in preventing, or at least reducing such damage in the future.

Figure 18. Aerial view of damage at Sites 8 at the bottom of the 'Hill Road Gully' on Wednesday 8 October showing the large volume of gravel, sand and silt that spilled across the NIMT railway line during the 3 October flood. Control of debris higher up this gully would minimise problems at this site. Some form of debris passing structure may also be necessary at the culvert entrance to prevent blockages and allow flood water to be safely passed under the railway and SH 1.

3.2.4 Other areas

Damage in other areas of the Kapiti Coast was generally minimal compared to what occurred in the Paekakariki area. Damage to road cuts on the Paekakariki Hill Road was generally minor, with only a few small rock and soil falls observed north of the summit. Small rock falls may also have occurred to the south of the summit, but that area was not inspected. Some small slips were also noted in the hills just north of McKays crossing, and two large debris slides occurred in the gully draining north from the MW tower (Figure 2). Some small landslides were seen in bush on the western side of Mt Wainui, but these were minor features compared to those already described. As already mentioned flood damage was quite extensive in the stream bed of Te Puke Stream (the northern part Transmission Gully).

4.0 CAUSES AND IMPLICATIONS OF DEBRIS FLOOD DAMAGE

Many of the causes and mechanisms that contributed to the landsliding and debris flood damage that occurred during the flood of 3 October have already been mentioned in the site descriptions given above. The debris accumulations that affected the lower part of the hill road and the motel site on SH 1 were clearly the result of a *debris flood*, rather than *debris flow*, which are like wet concrete and are potentially much more destructive and harder to deal with. *Debris flood* is a very rapid hyper-concentrated flow in stream channels of water charged with sediment (Hutchinson, 1988; Hungr *et al*., 2001).

Strictly speaking, a *debris flood* is not a landslide, but is a *mass transport* phenomenon with destructiveness similar to that of water, but less than that of *debris flows*. Objects impacted by debris floods are surrounded or buried by flood debris but are often largely undamaged (Hungr *et al.,* 2001). These characteristics of the 3 October 2003 flood are clearly demonstrated at the motel site on SH 1 (Figure 5) and along the lower Paekakariki Hill Road (Figure 15). The main factors that contributed to the damage caused by the Paekakariki flood and some implications for the main damage sites are summarised below.

Motel site and SH 1

The flooding and debris flood gravel that accumulated around the Belvedere Motel buildings and across SH 1 originated in the Fly-by-Wire gully. The flood clearly did not flow over the Paekakariki Hill Road, but was passed through the culvert under the hill road. Based on the lack of significant damage to the buildings that were buried, the gravel was deposited gradually as a *debris flood* over several hours, not as a single *debris flow*. The latter is potentially a much more hazardous and damaging type of event, which could occur in the future given the large volume of gravel now stored in the upper reaches of the gully, especially if initiated by slides on the steeper slopes upstream of the lower gorge (Figure 10). All of the buildings on the east side of SH 1 at the bottom of the Paekakariki Hill Road are built on an old debris fan formed at the gully exit. It is therefore considered to be a potentially dangerous site which is at risk from future flooding, debris floods, and possibly debris flows. The marked change in grade on the debris fan causes sediment to be deposited at the culvert entrance during floods and this will be an ongoing problem at this site in the future.

Fly-by-Wire Gully

The numerous shallow slumps and deep erosion gullies that occurred in the upper reaches of the Fly-by-Wire gully were caused by very high flood flows eroding near surface soils and gravely colluvium on steep slopes and heads of gullies. Some of this material was transported down the gully and deposited on the debris fan around the motel buildings and across SH 1, but a very large volume was deposited in the stream channel above the lower gorge. The absence of old deep erosion gullies in the area suggests that the 3 October flood was a very rare event with a return period of more than 100 years, possibly several hundred years. Nevertheless, the gravel now present in the stream channel will continue to be transported downstream, even by smaller but more frequent flood events than that of 3 October. This problem could be minimised, however, by erecting steel catch fences in the upper reaches of the steam to reduce gravel transportation downstream. A debris fence and accumulation area with a stream bypass could also be built at the culvert entrance just above the motel site.

Paekakariki Hill Road

The gravel accumulations that affected the lower part of the Paekakariki Hill Road were the result of a *debris flood.* Debris trapped behind little damaged fences and gates above the road suggests that that steel catch fences could be erected above the road and culvert entrances to trap gravel carried down gullies during floods, while allowing water to pass through culverts. The control of debris in the head of gullies would potentially reduce gravel inundation problems for the Paekakariki Hill Road, and for SH 1 and the NIMT railway line.

5.0 CONCLUSIONS

The main conclusions arising from this preliminary study are as follows:

(1) The rainstorm that hit Paekakariki on Friday 3 October 2003 affected many parts of the Wellington region causing flooding and slips that closed roads, with the Kapiti Coast being one of the worst affected areas. Rainfall appears to have been much heavier in the Paekakariki area, where it was probably well in excess of 100 mm in 24 hours, causing severe flooding and extensive landsliding, gully erosion and debris flood damage on the steep coastal hills. The area of greatest ground damage coincides with the area of maximum rainfall accumulation indicated by radar imagery. This shows that the heaviest rainfall occurred in a narrow band about 10 km wide and extending from just south of Kapiti Island and directly across Paekakariki towards Upper Hutt.

(2) The areas most affected by landslides and debris floods were around the junction of the Paekakariki Hill road with State Highway 1, and across the hills ~2 km south of Paekakariki, especially in the Fly-by-Wire gully above the BP Service Station and Belvedere Motel, and the Hill Road gully ~700 m to the south. The average return interval of rainfall in this area during the flood (>82 mm in 4 hours) is estimated from nearby rain gauges to be greater than 125 years. In other areas where there was less rainfall the landsliding and flood damage was generally minor.

(3) About 3000 m^3 of gravel from the flooded Fly-by-Wire gully was deposited around the Belvedere Motel buildings and across SH 1 at the bottom of the Paekakariki Hill Road. All of the flood water and gravel was passed through the culvert under the hill road, which was not affected at this site. Based on the lack of damage to buildings the gravel was deposited gradually as a debris flood over several hours, not as a single debris flow. The buildings on the east side of SH 1 at the bottom of the Paekakariki Hill Road are built on an old debris fan formed at the gully exit. This makes it potentially a dangerous site for future flooding, debris floods, and possibly debris flows which can cause much more damage.

(4) The upper part of the Fly-by-Wire gully was severely damaged by numerous shallow slumps and deep erosion gullies. Geomorphic evidence suggests that locally the flood was a very rare event with a return period of more than 100 years, possibly several hundred years. A large amount of soil and gravel from steep slopes and gullies was transported down the stream and deposited on the debris fan around the motel buildings and across SH 1. However, much of the gravel was also deposited in the stream channel and will continue to be transported downstream during future floods. This problem could be minimised by erecting steel catch fences in the upper reaches of the stream, and/or by constructing a stream bypass with a debris fence and accumulation area at the culvert entrance just above the motel site.

(5) Damage to the northern end of the Paekakariki Hill Road was the result of flood water and gravel deposition as a debris flood, rather than debris flow. Damage to road cuts on the hill road was generally minor, with only a few small rock and soil falls observed north of the summit. Gravel trapped behind fences and gates above the road suggests that this material accumulated slowly. Most of the silt and sand was carried away in flood water, which flowed over the road and washed out road edge fills and severely undermined the road in several places. This mechanism suggests that steel catch fences above the road and culvert entrances could be used to trap gravel during floods, while allowing water to pass through culverts. The control of debris in the head of gullies would potentially reduce gravel inundation problems for the Paekakariki Hill Road, and for SH 1 and the NIMT railway line.

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Acknowledgements:

The author wishes to acknowledge the various individuals who contributed information for this report, including John Crouch and Ross Marsden of the NZ MetService, Stuart Burgess of NIWA, rainfall observers Bob Guyton and Mike Crosland, and John Perkins the local farmer whose property was most affected by the flood. Thanks are also due to the author's GNS colleagues Grant Dellow and Nick Perrin who viewed the damage and reviewed this report, and Mauri McSaveney for discussions about the work.

Institute of Geological & Nuclear Sciences Limited

www.geonet.org.nz

LOWER HUTT

41a Bell Road South
PO Box 30 368
Lower Hutt
New Zealand

Phone + 64 4 570 1444
Fax + 64 4 570 4676
Email info@geonet.org.nz

WAIRAKEI

Wairakei Research Centre
State Highway 1
Wairakei
Private Bag 2000
Taupo
New Zealand

Phone + 64 7 374 8211
Fax + 64 7 374 8199

DUNEDIN

Dunedin Research Centre
764 Cumberland Street
Private Bag 1930
Dunedin
New Zealand

Phone + 64 3 477 4050
Fax + 64 3 477 52 32