# CHAPTER 5: LANDSLIDE RISKS

## The Landslide Threat

A landslide is the movement of a mass of rock, debris or earth down a slope. Whilst the causes of slope movement can be quite complex, all landslides have two things in common - they are the result of failure of part of the soil and rock materials that make up the hill slope and they are driven by gravity. They can vary in size from a single boulder in a rock fall or topple to tens of millions of cubic metres of material in a debris avalanche.

Landslides can be caused in a number of ways. These include saturation of slope material from rainfall or seepage; vibrations caused by earthquakes; undercutting of cliffs by waves; or by human activity. Almost half the landslides causing injury or death in Australia were the results of human activity including:

- removal of vegetation;
- interference with or changes to the natural drainage;
- leaking water mains;
- modification of slopes by the construction of roads, railways or buildings on steep terrain;
- mining activities;
- vibrations from heavy traffic or blasting; or
- accidental displacement of rocks.

Certainly the most common trigger for landslides is an episode of intense rainfall. The rainfall threshold values for slope failure are in the range 8 - 20 mm over one hour, or 50 - 120 mm over a day, depending on geology and slope conditions. In Cairns, rainfall intensities of such magnitude have an average recurrence interval (ARI) of considerably less than one year, and landslides are not rare events.

The landscape around Cairns is dominated by a series of escarpments that are developing by scarp retreat. Weathering, erosion and removal of debris cause scarp retreat from the slope by two main processes (Michael-Leiba and others, 1999, in preparation):

- on steeper bedrock slopes, and bedrock slopes masked with a relatively thin mantle of broken rock and finer material, weathering and erosion leads to landslides (rock falls, rock slides, debris slides, and small debris flows confined to the slope). By this process rock and soil move down slope under the influence of tropical rainstorms and gravity; and,

- during the more extreme rainfall events, the combined effect of multiple landslides in the upper parts of gully catchments, and the remobilisation of accumulated debris in the major gully systems, periodically results in large debris flows. These can extend onto the depositional plains at the base of the bedrock slopes (**Photo 5-1**). Debris flows are a type of landslide triggered by the action of torrential rain on loose material on a mountainside or escarpment. The boulders and finer material, mixed with water, flow down the slope as a torrent. The coarser material (the proximal part of the debris flow) is deposited near the base of the slope, while the finer material ( the distal part of the debris flow) travels further as a flash flood across the floodplain. Debris flows can be highly destructive.

These processes are illustrated in **Figure 5.1**.

Based on existing geological mapping, the model of slope processes, field inspection and interpretation of aerial photographs, a geomorphic classification (**Table 5.1** and **Figure 5.1**) and landslide data map (**Figure 5.2**) have been created (Michael-Leiba and others, 1999, in preparation). A catalogue of landslides in the Cairns area (extracted from AGSO's *Australian Landslide Database*) is included as **Appendix I**. This catalogue was compiled from field observations in February and April 1997; from discussions with Cairns residents; from examining contemporary newspapers; and from literature searches in the Cairns Historical Society Library and the Cairns Public Library.

Table 5.1. Geomorphological units and potential hazards

| Unit | Hazard |
|---|---|
| b0 - upper interfluves, creep slopes and convex creep slopes - remnants of Mesozoic peneplain | Landslide? |
| b1 - fall faces or steep slopes with cliff lines, developed in bedrock | Rockfall |
| b2 - transportational midslopes developed as ridges and gullies in bedrock | Rockfall, small landslides confined to slope |
| b3 - bedrock footslopes, concave or planar deeply weathered bedrock sometimes locally covered with varying thickness of clayey colluvium from one to several metres thick | Rockfall, small landslides confined to slope |
| fc - massive core debris flow deposit with irregular lobate surface, numerous boulders greater than one metre | Proximal part of debris flow |
| fp - proximal debris flow fan/outwash with gentle undulating convex slope forms | Proximal part of debris flow |
| fd - distal outwash fan with uniform low angle slopes | Distal part of debris flow |
| a2 - distal outwash fan with uniform low angle slopes and no obvious major debris flow source (note that fd can grade into a2 or a2 alone can occur at the base of b3) | Distal part of debris flow |
| a3 - seasonal floodway incised into surface, possible transport corridor for debris flow | Distal part of debris flow grading into flood |
| as - Recent sands and gravels, flooded regularly | Not considered |
| af - possible floodway for extreme events in the Redlynch area | Distal part of debris flow grading into flood |

## The Cairns Landslide Experience

One definite, and two probable, large debris flow events are known to have occurred in the Cairns region since European settlement.

On 12 January 1951, a torrential deluge of about 700 mm of rain in just under five hours, triggered debris flows that affected 10 km of the Captain Cook Highway between Buchan and Simpson's Points (Ellis Beach). Huge quantities of debris were swept from the mountainside onto the road and over the precipice into the sea. Boulders up to three metres long were hurled into the Pacific "like marbles". Large slabs of bitumen were tilted up from the road and landslide debris was piled up as high as three metres. All culverts and inverts in this area were either damaged considerably or washed away entirely. The highway was not expected to carry normal traffic for at least two weeks (*Cairns Post*, 15 January 1951). The debris (**Photo 5-2**) is visible to this day on the landward side of the highway behind Ellis Beach, and large boulders (**Photo 5-3**), as well as pieces of concrete entrained in these debris flows, can still be seen on the beach.

The probable debris flow events happened in 1878 and 1911 on the eastern side of Trinity Inlet. Deposits from numerous debris flows have been identified in this area. On 8 March 1878, a "flood" followed by a severe cyclone triggered many landslides across the Inlet. They could be heard distinctly in Cairns (Jones, 1976). On 1 April 1911, a big landslide occurred in the Nisbet Range, also across the Inlet from Cairns. The scar could be seen in photos for several years afterwards (A. Broughton, Cairns Historical Society, personal communication, 1997). This landslide brought away trees, rocks and everything else from a considerable distance up the mountain side (*Cairns Post*, 3 April 1911).

On 31 May 1900, the landslide with the fourth largest number of Australian landslide fatalities happened in Cairns. Five men were killed and one buried alive for ninety minutes when an 8 m deep tramway cutting they were constructing at Riverstone for the mill at Gordonvale caved in. The location was at "Dead Man's Gully" or "Dead Man's Cutting" (A. Broughton, Cairns Historical Society, written communication, 1999), in a river terrace in Gordonvale, 3 km WNW of Walsh's Pyramid. The cutting was partly bulldozed in the 1980s, but the overgrown upper part of one side is still visible (**Photo 5-4**).

Landslides on hill slopes periodically block roads, particularly Lake Morris Road (**Photo 5-5**) and Kuranda Range Road (**Photo 5-6**). For example, detailed records of landslides along Lake Morris Road both before and after Tropical Cyclone *Justin* (22-23 March 1997) were made. Analysis of this information indicates that 21 batter failures and two fill failures occurred along this road during the 1997-1998 wet season prior to *Justin*, compared with 52 new batter failures <u>after</u> *Justin*. Forty-six new batter failures (**Photo 5-7**) and one new fill failure were logged along Kuranda Range Road after the 1997 cyclone.

The Cairns-Kuranda railway has an even more spectacular history of dislocation by landslides, the earliest of which was recorded during its construction in 1891. The most disruptive incident started on 15 December 1910, when a landslide at the Kuranda end of No. 10 tunnel partly closed the tunnel for more than two months. Several episodes of sliding occurred during this time (Broughton, 1984). The line was cleared for goods traffic on 25 February 1911 and for all traffic on 6 March 1911 (*Cairns Post*, 27 February and 7 March 1911). Another disruptive episode started on 5 March 1954 when a large landslide in the Red Bluff area, with its head well above the railway, and toe well below it, blocked the railway until 22 April 1954 (A. Broughton, Cairns Historical Society, personal communication, 1997).

In 1927 and again in 1984 or 1985, boulders smashed the water main at the No. 1 and No. 3 crossings respectively of Freshwater Creek. During the latter incident, the water supply pipeline slipped with a mudflow which took out the anchor blocks (Cairns City Council, 1927 and D. Gallop, Cairns City Council, personal communication, 1997).

Instances of landsliding have been recorded in the established suburbs (**Photo 5-8**), either on cuts behind houses or road cuts or fills. Two houses have been destroyed and several building blocks written off as a result. The following observations are relevant (Michael-Leiba and others, 1999, in preparation):

- most of the landslides appear to be associated with disturbances of the natural surface in the process of development;

- virtually all of the small landslides observed appear to be related to weak structures in bedrock or very steep cuts in colluvium; and,

- most of the landslides are less than 100 cubic metres in volume.

## Landslide hazard and risk analysis

Using a detailed catalogue of events based on field observations in Cairns and extensive historical research, the recurrence relation (ARI) for landslides per 10 km of escarpment on fully developed slopes has been tentatively established.

The extent to which future debris flows might extend from gullies has been estimated using an approach based on ‘shadow angles’ that geometrically define run-out distances. The shadow angle is the angle between the horizontal and a line drawn from the limit of the proximal or distal part (defined below) of the debris flow to the top of the escarpment. It is measured in the field using a clinometer.

The proximal portion is that part of the debris flow closest to the source of the landslide. It has a lumpy or convex surface and contains large boulders up to several metres in length. The distal portion of a debris flow is the more gently sloping and contains the finer grained, thinner sediments that are deposited further from the landslide source. Individual debris flows large enough to run out on to the plain may vary in size from tens of cubic metres to tens of thousands of cubic metres in the Cairns area. The large debris flow fans in the Redlynch area have volumes of millions of cubic metres, but these are built up over probably tens of thousands of years. The 1951 Ellis Beach debris flows had a total volume of over 300 000 $m^3$.

If the top of the escarpment is represented by a line in a GIS, and representative shadow angles are chosen to define the runout distances of the proximal and distal parts of a debris flow, then the GIS can be used to produce a map highlighting the areas below the escarpment which may be impacted by debris flow runout. The shadow angles were chosen initially from a variety of field observations (Michael-Leiba and others, 1999, in preparation), then refined by doing a series of trial runs using the GIS on a map of the South Redlynch debris flow fan (**Figure 5.8**). Maps were plotted with shadow angles being incremented or decremented one degree at a time from the values measured in the field. The shadow angles were selected which best matched the mapped proximal and distal debris flow runout, erring so as to slightly underestimate the runout, because South Redlynch is a large fan. These shadow angles were then checked by doing a GIS plot of predicted debris flow runout superimposed on the Cairns landslide data map (**Figure 5.2**). The overall fit appeared visually as good as could be expected when only one set of shadow angles was being used for the entire Cairns escarpment.

GIS polygons have been used to delineate and characterise the areas that could be affected by landslides.
Three main categories were chosen (Michael-Leiba and others, 1999, in preparation):

- the escarpment;
- areas which could be affected by the proximal portions of debris flows; and,
- areas which could be affected by the distal portions of debris flows.

In the following text and in **Table 5.3**, the average recurrence intervals (ARI) and hazard and risk probabilities per annum have been rounded to one significant figure. This is because of the large uncertainties in the estimates – the error bars on the ARI graphs are up to two orders of magnitude in length.

For each polygon, information on the ARI has been used (Michael-Leiba and others, 1999, in preparation) to estimate the landslide hazard (probability, *H*, per annum of a point being impacted by a landslide), and a GIS landslide hazard map has been prepared for the Cairns area. For points on the escarpment, the hazard occurrence probability is estimated to be 0.02% (an ARI of 6 000 years), assuming that the slope is developed. Thus, for undeveloped parts of the escarpment, this figure predicts what the hazard would be *if* the slope were to be developed *without adequate mitigation measures being taken*. The hazard would be expected to be considerably less on slopes developed with geotechnical consultation. It would also probably be less on undisturbed slopes. The hazard probability in areas which may be impacted by the proximal parts of debris flows is calculated to be 0.01% (an ARI of 8 000 years), and for the distal parts of debris flows, 0.01% (an ARI of 9 000 years).

The GIS polygons have then been interrogated to assess the nature and number of elements at risk (*E*). The vulnerabilities (*V*) of people, buildings and roads to destruction by landslides and debris flows were assessed (Michael-Leiba and others, 1999, in preparation). The vulnerability was taken to be the probability of destruction given that the person, building or road was hit by a landslide. For people and buildings on hill slopes, the assessment was based on information in the *Australian Landslide Database*, and for roads on hill slopes, the vulnerability was estimated from information provided by the Cairns City Council. There was insufficient information in the Australian Landslide Database to calculate vulnerabilities to large debris flows, so volumes were assumed from knowledge of the type of event and from overseas experience. The value of *V* ranges between 0 (none destroyed) and 1 (all destroyed) with the type of landslide and element at risk, as shown in **Table 5.2**. We do not have estimates of the uncertainties in these values.

Specific annual risk of destruction is the probability per annum of a person, building or section of road at a given point in the Cairns area being destroyed by a landslide. The specific risks to individual people, buildings and roads in susceptible parts of Cairns, if the areas were to be developed, have been calculated (Michael-Leiba and others, 1999, in preparation) from the equation *specific risk* = $H \times V$ and mapped using the GIS. **Figure 5.3** shows the specific risk to buildings. The values obtained are shown in **Table 5.3**, along with the annual probability of a road being blocked by debris at a locality.

Table 5.2. Assessed vulnerabilities of people, buildings and roads to destruction

| **Unit** | **Vulnerability of people** | **Vulnerability of buildings** | **Vulnerability of roads** |
|---|---|---|---|
| Hill slopes | 0.05 | 0.25 | 0.3 |
| Units susceptible to proximal debris flow | 0.9 | 1.0 | 1.0 |
| Units susceptible to distal debris flow | 0.05 | 0.1 | 0.3 |

A risk map depicting the estimated annual probability of a total road blockage somewhere in a 10 km length of road parallel to the escarpment was also prepared. For this risk map, 10 m wide roads were assumed. For the hill slopes, the estimated annual probability is 63% (an ARI of one to two years). For roads in potential proximal debris flow runout regions it is 1.0% (an ARI of 100 years), and in potential distal debris flow runout regions it is 0.4% (an ARI of 200 years).

Table 5.3: Specific annual risk of destruction of individuals, buildings and roads, and of road blockage

| **Unit** | **Specific annual risk of death - people** | **Specific annual risk of building destruction** | **Specific annual risk of road destruction** | **Specific annual risk of road blockage** |
|---|---|---|---|---|
| Hill slopes | 0.0008% (ARI of 100 000+ years) | 0.004% (ARI of 20 000 years) | 0.005% (ARI of 20 000) | 0.02% (ARI of 6 000 years) |
| Units susceptible to proximal debris flow | 0.01% (ARI of 9 000 years) | 0.01% (ARI of 8 000 years) | 0.01% (ARI of 8 000 years) | 0.01% (ARI of 10 000+ years) |
| Units susceptible to distal debris flow | 0.0005% (ARI of 200 000 years) | 0.001% (ARI of 90 000 years) | 0.003% (ARI of 30 000 years) | 0.007% (ARI of 10 000+ years) |

**The paucity of the data from which the landslide magnitude-recurrence relations (ARI) were derived must be emphasised. As the error bars for the data points are, in some cases, more than two orders of magnitude long, errors in all the hazard and risk estimates may be large.**

Because the Captain Cook Highway, Kuranda Range Road and Cairns-Kuranda Railway, which provide access to Cairns from the north and the Tableland, each pass through country with steep slopes, they may be blocked by landslides in the event of intense precipitation such as that associated with tropical cyclones. Outside the study area, the Bruce Highway and particularly the Gillies Highway (which links Gordonvale to the Atherton Tableland), may also be blocked by landslide. This makes the Cairns community particularly vulnerable to isolation.

Total risk is the number of elements at risk expected to be destroyed by a landslide in a given GIS polygon in a given period of time. Maps (**Figure 5.4** and **Figure 5.5**), which quantitatively depict the total risks per $km^2$ per 100 years for residential people and buildings in each GIS polygon in the currently developed parts of Cairns, were constructed (Michael-Leiba and others, 1999, in preparation) from the data for each polygon. These were based on the equation *total risk = H x E x V*, where *E* is the number of houses and flats, or people living in houses and flats, in a polygon. The greatest total risk for buildings (houses and flats) is on the hill slopes, where it is estimated that a total of 13 buildings throughout the map area could be destroyed in 100 years, *if no mitigation measures were taken*. The highest total risk for people living in houses and flats is in the proximal parts of debris flows. It is estimated that a total of 16 people in the map area could die over 100 years in these areas.

The values for all types of buildings, by suburb in alphabetical order, are listed in **Table 5.4**. These values do not compensate for the differing areas of the suburbs, because the data are used in the multi-hazard risk assessment, which is carried out on a suburb by suburb basis in **Chapter 8**. The suburbs are ranked from greatest to least total risk for buildings. The spatial distribution is shown in **Figure 5.6**.

The parts of these suburbs that are at greatest risk of landslide are in the Freshwater Valley, the lower slopes of the coastal escarpment, or near the base of Mount Whitfield. Note that with good engineering practice, such as adequate drainage and retaining walls, commonly used in developing the hill slopes in Cairns, the actual number of buildings destroyed per 100 years would be expected to be considerably less that that shown in the **Table 5.4**.

## Landslide risk scenarios

Most of the areas susceptible to debris flow in Cairns have only become closely settled in recent years, so it has not been possible to use data gained from historic debris flows in suburban Cairns for planning, mitigation or emergency management purposes. By choosing a realistic torrential rainfall scenario, and assessing its effects on a vulnerable part of Cairns, we can acquire valuable information *before* the event.

Table 5.4: Total risk of destruction of buildings by landslide

| Suburb | Risk Rank | Total risk | Suburb | Risk Rank | Total risk |
|---|---|---|---|---|---|
| Aeroglen | 13 | 0.6 | Mooroobool | 2 | 2.6 |
| Bayview Heights | 3 | 2.5 | Mount Peter | 26 | 0.01 |
| Bentley Park | 25 | 0.1 | Mount Sheridan | 12 | 0.7 |
| Brinsmead | 6 | 1.2 | Palm Cove | 16 | 0.4 |
| Caravonica | 20 | 0.3 | Redlynch | 1 | 5.5 |
| Clifton Beach | 22 | 0.2 | Smithfield | 6 | 1.2 |
| Earlville | 9 | 0.9 | Stratford | 8 | 1.0 |
| Edge Hill | 10 | 0.8 | Trinity Beach | 14 | 0.5 |
| Edmonton | 16 | 0.4 | Trinity East | 11 | 0.8 |
| Freshwater | 4 | 1.6 | White Rock | 24 | 0.1 |
| Gordonvale | 26 | 0.01 | Whitfield | 5 | 1.4 |
| Kamerunga | 19 | 0.4 | Woree | 22 | 0.2 |
| Kanimbla | 18 | 0.4 | Wrights Creek | 29 | 0.004 |
| Kewarra Beach | 26 | 0.02 | Yarrabah | 14 | 0.6 |
| Manoora | 21 | 0.2 | | | |

NOTE: In this table Total Risk relates to the estimated number of buildings that would be destroyed in the suburb in any 100 year period.

Let us suppose that 450 mm of rain falls in one day on the escarpment on the west side of Freshwater Valley. This is a rainfall event with an ARI of approximately 20 years (5% annual probability) on the escarpment in the Cairns area, and is approximately the rainfall intensity and duration involved in the January 1998 Townsville floods and the August 1998 Wollongong floods.

***Redlynch fan:*** The southern part of this debris flow fan includes Redlynch shopping centre and the suburban area to its west. This fan has been examined using aerial photography, and briefly in the field. The southern part of the fan is bounded by an ENE-trending erosional gully in the north and an ESE-trending creek to the south. Both could serve as conduits for debris flows and flash floods. These features are shown in **Figure 5.7**.

Up to five houses, the most likely number being two, may be susceptible to destruction by the proximal part of debris flows. Because these landslides are highly destructive, the probability of a person being killed in a house in the proximal part of a debris flow is about 90%. If the debris flows occurred at night, with an average occupancy rate of about three persons per house, the estimated number of fatalities would be six. During the day, when residents are at work or school, there may be about two fatalities caused by the proximal part of debris flows.

Because of the rapidly flowing, mud laden water, the distal parts of debris flows and flash floods could damage a further 60 houses. Of these, perhaps 20 are regarded as being particularly vulnerable, and one or two people could be killed.

As the roads out of the fan would almost certainly become flooded, evacuation from the area would need to take place before flooding commenced. Relief efforts into the area would also be hindered. Unless flooding was all encompassing, however, residents could take refuge on the higher part of the fan if sufficient warning and suitable shelter were available.

***South Redlynch fan:*** This debris flow fan is south of Redlynch shopping centre. It contains many relatively new houses and the Redlynch State School and Pre-school. This fan has also been mapped using both aerial photography and field observation (Michael-Leiba and others, 1999, in preparation). **Figure 5.8** is a map of the debris flow fan and in it, the geomorphological units are as described in **Table 5.1**, except that **as** is alluvium of Freshwater Creek subject to regular flooding.

Debris flows and flash floods in channels tend to block culverts, and when they encounter a sharp change in direction in their channels, part of the material may continue to flow in the original direction. Taking this behaviour into account, the map has been used to assess the possible consequences of torrential rain in the catchment.

Between zero and six houses may be destroyed by the proximal parts of debris flows, the most likely number of houses being two. If the debris flows occurred at night, the estimated number of fatalities would be six. During the day when many residents are at work or school, there may be about two fatalities caused by the proximal part of debris flows.

Because of the rapidly flowing, mud laden water, around 30 houses would be expected to be damaged by the distal part of debris flows and flash flooding, and one or two residents could be killed.

Water and/or debris in several places would likely block Redlynch Intake Road, Harvey Road and Robb Road. In some of these places, scouring may destroy the roads. The Cairns-Kuranda Railway would probably be rendered impassable by debris flows, other landslides and wash-outs. Because of these blockages, the South Redlynch area would be isolated. For many residents, evacuation to centres either in the area or elsewhere would need to take place before the onset of flooding. Freshwater Creek would probably be in flood, causing inundation to low lying adjacent areas. It is possible that the road or creek flooding may also claim one or two people.

***Southern, upper, part of Freshwater Valley:*** About 50 houses may be damaged by river flooding, flash flooding and minor debris flows. This could lead to one or two deaths. The Cairns water mains could also be damaged or destroyed by boulders where they cross Freshwater Creek.

## Interpretation

Until the Thredbo landslide tragedy in 1997 there had been little public recognition that landslides were a significant threat in Australia. Where landslides occur, their physical impact is typically confined to a few properties or a short length of road or railway, but the effect can be disturbing or disruptive. Insurance policies in Australia do not normally cover landslide, and this can cause anguish to property owners. One landslide blocking a road or railway can cause inconvenience and economic loss. The evidence is clear that in Cairns landslide has been, and remains, a significant risk. Whilst the risk of significant debris flows impacting on suburban development is relatively small in terms of probability, the impact of such an event would be considerable. Flash flooding in Freshwater Creek, or debris flows, have the potential to disrupt the Cairns water supply by blocking the intake or destroying sections of the pipeline.

## Limitations and Uncertainties

There are some specific technical limitations that may be recognised but cannot be dealt with in this reconnaissance report. The most important of these are:

- the regional nature of this study, and

- the paucity of the data from which the landslide magnitude-recurrence relations were derived. As the error bars for the data points are, in some cases, more than two orders of magnitude long, errors in the risk estimates may be large.

The chief simplifying assumptions of the risk assessment are as follows:

- a uniform process rate across, and from top to bottom of, the entire escarpment, irrespective of local geomorphology, rock type, soil cover or position on the escarpment, and

- a uniform shadow angle for debris flows. The assumption implicit in this is that the runout distance of debris flows is greater for higher escarpments, and depends only on the height of the escarpment, not on the volume of source material available to be incorporated in the landslide, nor the height on the escarpment at which the landslide originates.

The uniform process rate assumption will have a smoothing effect on the results. Hazard and risk will be overestimated in some areas and underestimated in others. However, because the magnitude-recurrence relation for landslides on hill slopes was weighted heavily by observations of landslides along the Kuranda Range Road, the Cairns-Kuranda Railway and Lake Morris Road, the hazard and risk will tend to be grossly overestimated in suburban areas where mitigation measures have been put in place.

The uniform shadow angle assumption may overestimate the area susceptible to debris flow runout in some cases. This is because the shadow angles assumed in the risk analysis were mainly derived from the large south Redlynch debris flow complex which has accumulated in a part of the escarpment which has had favourable conditions for debris flow production for tens of thousands of years.

Also, while very large debris flows can bury an entire settlement, smaller debris flows can be slowed when they encounter buildings, causing the landslide to deposit most of its load of boulders and thus lose much of its destructive potential – a possibility not taken into account in our analysis. This happened with the debris flow that hit the Magnetic Island International Resort in January 1998. Only units in the row furthest uphill were damaged or destroyed by boulders. These buildings reduced the rate of flow and all but a few boulders were dumped there. Buildings further down the slope were affected only by water and the finer sediments that remained.

**Finally, the reconnaissance nature of the field mapping must be emphasised. Polygon boundaries are approximate only and some details on the landslide data map may change with further and more detailed field work. For detailed site-specific assessments, our broad findings should be checked by geotechnical specialists.**