

CHAPTER 7: LANDSLIDE RISKS

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The landslide threat

A landslide is the movement of a mass of rock, debris or earth down slope. Whilst the causes of slope movement can be quite complex, all slides 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. Landslides can vary in size from a single boulder in a rock fall to tens of millions of cubic metres of material in a debris avalanche. While not as well recognised as many other hazards such as cyclones, storm surge, floods and earthquakes, in Australia landslides cause more economic loss as well as injury and loss of life than is generally recognised.

Whilst the Thredbo, New South Wales, landslide which killed 18 people in July 1997, or the Gracetown, Western Australia, cliff collapse which caused nine fatalities in September 1996, made the world news, many smaller events kill one or two people at a time, and do not receive such extensive media coverage. In Australia, a total of 88 people are known to have been killed by 38 landslides since 1842. An additional 115 people are known to have been injured. It is almost certain that these statistics are incomplete and that the number of fatal events is much higher than presently reported. Globally landslides are one of the most common geohazards accounting for about 25% of the annual death toll from natural hazards (Hansen, 1984).

Data are too incomplete to give accurate costs incurred from landslides but are estimated to total about 500 million dollars since 1900. This may equate to hundreds of millions, or perhaps billions, of present-day dollars. Landslides have caused many instances of damage and disruption to buildings, roads, railways, and pipelines. An example is the Wollongong-Sydney-Brisbane railway, where costs associated with landslide damage are estimated to average \$25 million per year during the period 1989-1996. The costs prior to 1989 are not available. More than 200 buildings throughout Australia have been damaged by landslide. Many of these were destroyed, the total cost is estimated to be of the order of \$30 million in present-day dollars.

By developing and applying reliable and accurate methods for assessing landslide hazard and risk it is possible to enhance forward planning strategies leading to disaster mitigation, reduce economic losses and build safer communities and environments.

The landslide phenomenon

Landslide causes can be divided into internal and external. External causes include the steepening or heightening of a slope by river erosion or excavation, the deposition of material along the upper edge of slopes and earthquake shocks. If an external cause leads to a landslide the shearing stresses along the potential surface of sliding must have increased to the point of failure. Internal causes are those which lead to a slide without any change in surface conditions. These include increased pore-water pressure and decrease in sediment cohesion. If a slope fails in spite of the absence of external causes, then it must be assumed that the shearing resistance of the material has decreased (Terzaghi, 1950).

Certainly the most common trigger for landslides is an episode of intense rainfall. The rainfall threshold values for slope failure in various parts of the world are in the range 8 - 20 mm over one hour, or 50 - 120 mm over a day depending on geology and slope conditions (John Braybrooke, Douglas Partners Pty. Ltd., written communication, 1998). In much of the south

east Queensland study area, rainfall intensities of such magnitude have an average recurrence interval (ARI) of about one year.

It is important to note that many slope movements/landslides occur after much longer periods of rainfall. Thus, the antecedent rainfall magnitude over a period (before the day of landslide occurrence) of one week or a month, or even more, may be of critical importance (Robin Chowdhury and Phil Flentje, University of Wollongong - Personal Communication, February 2001). In particular, Flentje (1998) has developed an interesting approach for rainfall analysis which includes the concept of Antecedent Rainfall Percentage Exceedance time (ARPET). Regarding the rainfall thresholds in the Wollongong area of New South Wales, Chowdhury and Flentje have concluded that threshold magnitudes for relatively long antecedent periods of rainfall (1 to 3 months) are relevant to most of the deep-seated, slow moving landslides (Robin Chowdhury and Phil Flentje, University of Wollongong - Personal Communication, February 2001).

On the other hand relatively short antecedent periods (1 day to one week) are relevant to most shallow slips and shallow debris flows. However, one must emphasise that these periods are specific to one region. Periods of antecedent rainfall for which threshold magnitudes are relevant would differ markedly from one region to another, depending on geology, climate, geomorphology, etc (Robin Chowdhury and Phil Flentje, University of Wollongong - Personal Communication, February 2001).

Landslides common to the study area include:

Rotational slides: In the Canungra-Beechmont, Numinbah, Tamborine, Springbrook Plateau, upper Tallebudgera and Currumbin valley areas develop on moderate to steep slopes (15°-25°), where colluvial material has accumulated around concave slopes adjacent to gullies and below the base of the basalt. These slides move quickly. They exhibit a semi-circular, back tilted upper section and a disrupted toe section. This type of failure is very difficult to predict and areas where they may occur must be treated cautiously (the geology of the South-East Queensland area is described in Chapter 2. Landsliding in areas underlain by the older Neranleigh Fernvale Beds (essentially to the east of the basalts) occur as translational and rotational slides on the flanking slopes of the quartzite ridges. In the Brisbane and Ipswich areas, rotational slides have also been noted on shallower slopes in soil or colluvium, and on slopes as low as 7° on unlaterised Tertiary sediments. Many alluvial river bank failures in South-East Queensland are probably rotational slides.

Complex multiple rotational slides: in the Canungra-Beechmont, Numinbah, Tamborine, Springbrook Plateau, upper Tallebudgera, and Currumbin valley areas are characterised by broad, relatively deep, slow moving slides that occur on the outer edges of benches and on colluvial fans where gentle slopes occur above a drop-off. Virtually all benches and colluvial aprons show examples of these failures, which in places are very numerous. The slopes of their upper sections are low but steepen over the lip of the drop-off to between 13° and 25°. They almost always occur around gully mouths where the gully drops over the scarp of a bench. Some of the largest slides cover almost the entire width of a bench or apron being up to several hundred metres across. They are of great significance for planning of future settlement, as they occur on relatively flat land seemingly suitable for building.

Debris flows: in the Canungra-Beechmont, Numinbah, Tamborine, Springbrook Plateau, upper Tallebudgera, Currumbin valley, the western part of Pine Rivers and Caboolture areas are triggered by the action of torrential rain on loose material (rocks and finer material) on mountainsides or escarpments, adjacent to gullies or concave slopes where colluvial debris is thicker. The boulders and finer material, mixed with water, flow down the slope as a torrent. The coarser material is deposited near the base of the slope, while the finer material travels further as a flash flood. Debris flows can be highly destructive. Within the study area debris

flows occur mainly on the steeper slopes (>25°). Due to the difficulty of building in these areas they therefore impact settlement only rarely. Roads in these areas are however subject to the effects of debris flows and undercutting adds to instability.

Debris flows are common on slopes that formally supported rainforest. The flows are possibly aided by a greater thickness of colluvial material as well as on the basalt scarps. Small flows also occur on cleared steep slopes adjacent to gullies underlain by the Marburg Formation and to a lesser extent the Neranleigh-Fernvale beds and the Woogaroo Sub-Group.

Rock falls: in the Canungra-Beechmont, Numinbah, Tamborine, Springbrook Plateau, upper Tallebudgera and Currumbin valley areas occur sporadically from exposed rock faces on the scarp line. Due to the steep nature of the terrain towards the scarp line there is little potential for settlement impact.

Rock falls have also been recorded along the South-East Queensland coastline, especially the sea cliffs in the Point danger area of Coolangatta and Redcliffe. These rock falls are largely the result of the under-cutting of the cliff by wave action over time. At Burleigh Heads, rocks fall from a columnar outcrop at the top of the headland. They can roll down to sea level crossing two footpaths that round the headland. Rock falls can also occur on steep river banks such as the Tertiary sediments along the Brisbane River.

Landslide hazard and risk methodology

Hazard: Quantitative estimates of landslide hazard have been made based on a 100 year ARI rainfall event. The hazard probability estimate is calculated in the following manner:

$$\boxed{\begin{array}{l} \text{PROBABILITY OF BEING} \\ \text{IMPACTED AT A POINT WITHIN} \\ \text{A GEOLOGICAL / SLOPE UNIT} \\ \text{GIVEN A 1 IN 100 YEAR} \\ \text{LANDSLIDE EVENT} \end{array}} = \boxed{\begin{array}{l} \text{TOTAL AREA OF} \\ \text{MAPPED} \\ \text{LANDSLIDES PER} \\ \text{GEOLOGICAL/} \\ \text{SLOPE UNIT} \end{array}} \bigg/ \boxed{\begin{array}{l} \text{AREA OF} \\ \text{GEOLOGICAL /} \\ \text{SLOPE UNIT} \end{array}}$$

Equation 7.1. Calculation for a 100 year ARI landslide hazard probability.

Vulnerability: Risk estimates have only been determined for three principal elements, namely, people (p), buildings (s) and roads (r).

Vulnerability (V) is the potential degree of loss of elements within the area affected by the landslide. In this report, we have considered only vulnerability to destruction. For example, if a particular instance of landsliding has a 50% chance of destroying a property impacted by it, then V=0.5. If it is judged that landsliding will have a one in ten chance of causing a fatality in a building impacted by it, then V=0.1. If a building is destroyed, V=1 it is taken to mean that the building is damaged to a degree that it is regarded as unfit for habitation.

The Australian Geomechanics Institute (2000) and the International Union of Geological Sciences (1997) provide summaries of vulnerability. The latter make the apt observation:

“Although the state of the art for identifying the elements at risk and their characteristics is relatively well developed, the state of the art for assessment of vulnerability is in general relatively primitive”.

Very few quantitative assessments of vulnerability have been made and those that do are usually semi-quantitative in nature. Application of vulnerability values derived from other studies is difficult as vulnerability is affected by many factors, the more obvious of these include:

- nature of the element at risk
- position of the element at risk
- velocity of landslide movement
- magnitude of landslide displacement
- volume of landslide and
- prior warning

A number of general observations concerning the nature of the landslide and the vulnerability have been made, these include:

- higher velocities usually result in greater vulnerability; this is qualified however, by the fact that rate of movement is less important for structures than it is for loss of life (Fell and Hartford, 1997)
- landslides with greater displacement such as debris slides, flows and rock falls will produce greater vulnerabilities
- the greater the depth of slide material the greater the vulnerability for structures and persons (International Union of Geological Sciences, 1997) and,
- landslides that provide little warning result in greater vulnerability; this will especially be true of debris slides, flows and rock falls.

The velocity, magnitude of displacement, volume and prior warning are closely associated with landslide type. With the above factors and observations in mind, it becomes necessary to assess vulnerability as a function of landslide type.

Previous Estimates of Vulnerability: Vulnerability estimates for rotational slides and slumps derived from the Cairns area, and used in the South-East Queensland study region, were made by Michael-Leiba *et al.* (1999). By using the Australian Landslide Database the vulnerability of persons (V_p) was estimated at $V_p=0.1$. This was revised to $V_p=0.05$ to reflect a more realistic value based on the probability that landslides causing death are more likely to be reported in the media (and therefore included in the database statistics) than those that do not. This estimate is in good agreement with Wong *et al.* (1997), for the vulnerability of a person in a building if debris strikes the building. Building vulnerability (V_s) in Cairns was estimated at $V_s=0.5$. This assessment was altered to $V_s=0.25$ in order to reflect the conservative nature of the estimate given that many slightly damaged buildings would go unreported. Vulnerability of roads (V_r) in the Cairns region were estimated from council records and a mean value of $V_r=0.3$ was adopted.

Michael-Leiba *et al.* (2000) also derived qualitative vulnerability estimates for elements subject to debris flows in the Cairns region. These areas are analogous to slopes $>25^\circ$ in the South-East Queensland study region. Leiba *et al.* analyse debris flow by dividing it into proximal (bouldery, $>19^\circ$) and distal (flash flood, $14^\circ-19^\circ$) portions and estimate the associated vulnerability. Providing that the occupants are within a structure then $V_p=0.9$. Buildings have been estimated at $V_s=1$ and roads at $V_r=1$.

Vulnerability estimates for people, buildings and roads in the South-East Queensland field area are presented in Table 7.1. Vulnerability estimates for elements on slopes $<25^\circ$ are derived from subjective approximation and the work of various authors. Vulnerability estimates for debris flows occurring on slopes $>25^\circ$ are more sound, with agreement between Michael-Leiba *et al.*, Fell and Hartford and others. This agreement may simply be a result of

the extreme values, however they do seem logical and are adopted here. The vulnerability for roads was estimated following discussion with the Cairns City Council about the incidence of road blockage and repairs due to landslides in Cairns. We do not know the magnitude of the uncertainty in these figures.

Table 7.1. Vulnerability of elements.

	Vulnerability (V)		
	Persons (p)	Structures (s)	Roads (r)
Debris slides, flows and rock falls, >25° slope in Canungra-Beechmont, Numinbah, Tamborine, Springbrook Plateau, upper Tallebudgera and Currumbin valley areas	0.9	1	1
Rotational slides and slumps, <25° slope in Canungra-Beechmont, Numinbah, Tamborine, Springbrook Plateau, upper Tallebudgera and Currumbin valley areas	0.05	0.25	0.3
Small debris slides, flows, slumps and rock falls in Caboolture, Pine Rivers, Redcliffe, Brisbane, Ipswich, Redland and Logan areas	0.05	0.25	0.3

Specific risk: In this report, we have taken specific risk as being the probability that an individual will be killed, property lost or road destroyed or blocked by landslide given a 100 year ARI rainfall event.

The specific risk (R_s) for both buildings and roads is the product of the hazard (H) and vulnerability (V) (Equation 7.2).

Equation 7.2. Specific risk.

$$R_s = H \times V$$

The specific risk of an individual being killed by a landslide is taken to be the probability of the *occupant of a building* being killed by a landslide given a 100 year ARI event. This is the probability of the building being impacted by a landslide (H) multiplied by the vulnerability (V_p) of an individual.

Equation 7.3. Specific risk for people.

$$R_p = H \times V_p$$

Total risk: Total risk is a measure of the expected number of lives lost, or buildings or km of roads destroyed from a 100 year ARI rainfall event scenario given the present level of development.

Total risk (R_t) is calculated by multiplying the specific risk (R_s) by the number of each of the elements at risk (E). It must be remembered however, that estimates are only based on the present state of development, future changes such as vegetation clearing will alter the exposure to risk (the total risk for undeveloped areas is considered zero).

Equation 7.4. Total risk.

$$R_t = H \times V \times E$$

Landslide in the Gold Coast Hinterland Region

The region of South-East Queensland covered in this landslide hazard and risk assessment (Figure 7.1) is approximately 654 km². This region has been chosen firstly, as it is recognised as having significant landslide potential and secondly, because it has been the focus of detailed studies in the past (Willmott 1981 and 1983; and Willmott and Hayne, 2001) on which this analysis will build.

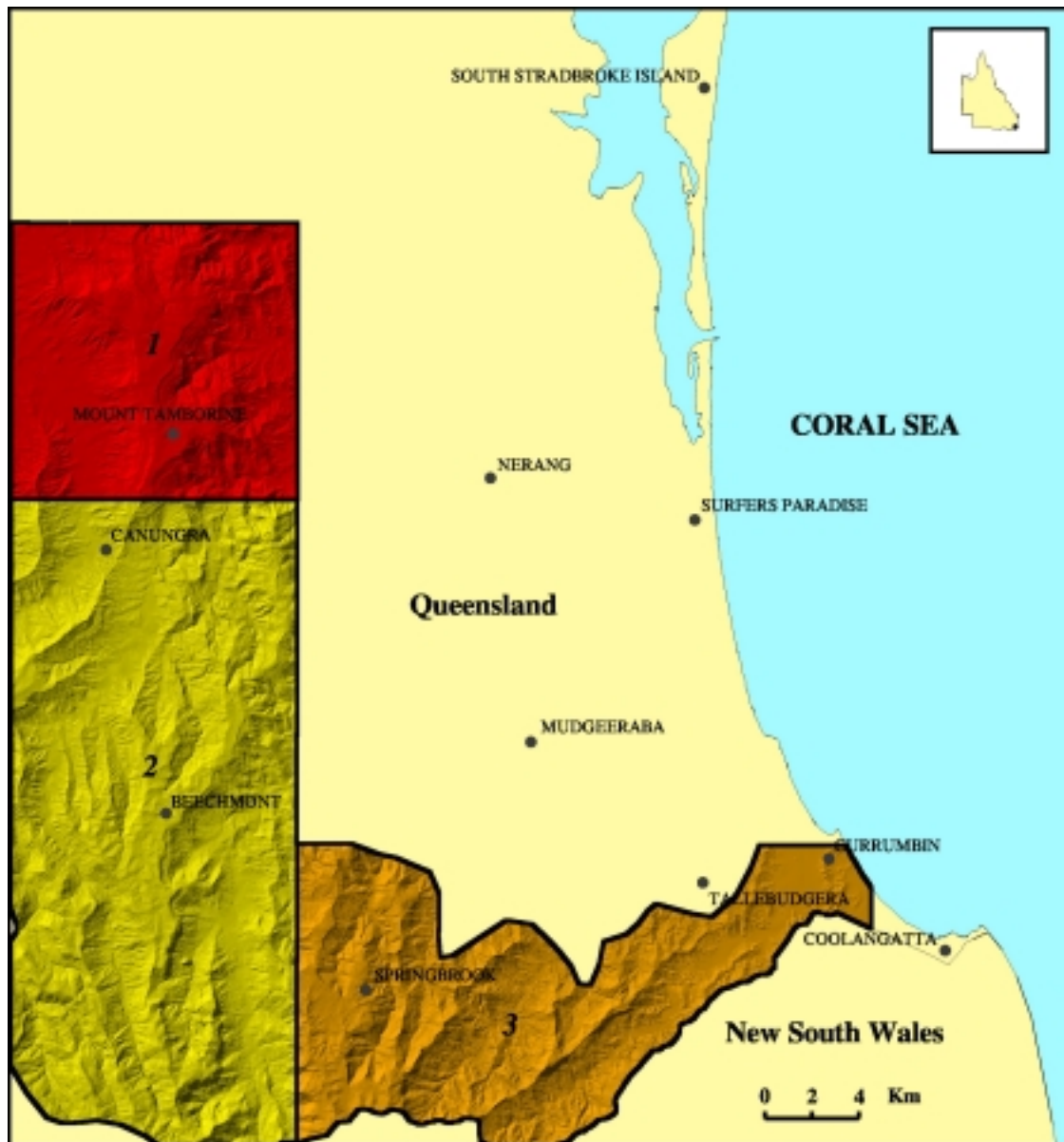


Figure 7.1. Gold Coast regional landslide investigation area.

The region is characterised by deep valleys that have been eroded back forming ranges capped by a plateau. The valleys cutting into the plateaux have steep sides with intermittent benches that have developed large deposits of colluvial material that are prone to landsliding. The valleys act as catchments for a number of rivers and creeks that trend in a northeasterly direction. These streams continue to erode the valley heads and future problematic development of urban, rural and semi-rural areas intensifies already burgeoning slope stability problems.

Willmott (1981 and 1983) and Willmott and Hayne (2001) documented a detailed and comprehensive mapping survey of the landslides and geology of the Canungra-Beechmont, Numinbah, Tamborine, Springbrook Plateau, upper Tallebudgera and Currumbin valley areas. Landslides resulting from the 25-28th January 1974 rainfall event were mapped from aerial photos and ground surveying. On the basis of combinations of topographic, geological and groundwater conditions the region was divided into stability zones.

The Snowy Mountains Engineering Corporation (SMEC) (1999) carried out a broad landslide risk assessment of the administrative area of the Gold Coast City. This included the basalt areas, for which risk was extrapolated from the earlier 1983 study of areas to the west. Using a Digital Terrain Model (DTM), a lattice grid based on 50 metre squares was developed. Based on slope angle and geology overlaid on this grid, stability classifications were developed. Stability assessments have also been made by consultants for various building blocks but no attempt has been made to collate this material.

Areas of potential landslide have also been investigated using a machine-learning approach (Hayne and Gordon, 2001). The high resolution achieved in this study is generated from a 5m DEM. Environmental variables of aspect, slope, geology, morphology, curvature and vegetation were measured from landslides resulting from the 1974 rainfall event and used to identify further areas of landslide potential.

Willmott (1984) has documented observations of the causes of landsliding on the basalt plateaux of South-East Queensland. A comparison of forests cleared and uncleared on slopes surrounding Mt. Tambourine has highlighted the development of permanent springs after clearing. Close inspection of the uncleared slopes revealed little evidence of sliding whereas, on cleared slopes large areas of land have failed dramatically. Vegetation plays a crucial role in landslide occurrence. The geological nature of the area enables groundwater to be fed laterally outward onto the hillsides. Following the loss of tree canopy on the steeper scarps and slopes rapid saturation of the soil occurs and there is a reduction in soil strength caused by the loss of tree root systems.

Identification of individual aquifers is not generally possible due to colluvial cover, although some particularly active layers can be inferred by lines of springs on some benches. The Chinghee Conglomerate (Th), consisting of interbedded coarse sandstone and conglomerate, has been identified by Willmott as a unit which can act as an aquifer giving rise to hill side springs. The junction between the basalt and the underlying rocks can also act as an aquifer, possibly due to a weathered, impermeable clayey zone at the junction, or simply because the underlying rocks are less permeable. Apart from the major aquifers, however, the close stratification of the lavas suggests that many local permeable zones would be present, and it must be assumed that virtually all the basalt flanks of the plateau and ranges are influenced to some extent by seepage.

In summary, a number of unique geological features within the volcanic terrain of the Gold Coast hinterland combine to produce an area prone to landslip. These include:

- horizontal strata that directs ground water movement between porous and nonporous layers;

- accumulations of colluvial debris;
- the presence of clays; and
- the presence of beds of soft sediments.

As previously alluded to, the role of vegetation in landslide occurrence is complex due to the fact that vegetation influences the majority of factors involved in landslide development. These include climatic, hydrological, erosion and weathering factors. Most importantly deforestation of areas can produce elevations in the water table and increased pore-water pressures due mainly to the reduction in evapotranspiration. Clearing of vegetation may also reduce the overall internal strength due to the loss of tree root support. The effects upon a geologically sensitive location have been exacerbated by forest clearing through:

- a rise in groundwater levels and pressures caused by reduced transpiration, resulting in a reduction in strength of soil and colluvial debris, especially on benched slopes;
- increased rate of absorption of rainfall by the soil, reducing the time taken to reach high groundwater pressures;
- decreased release of groundwater pressures on lower slopes because of changes in soil texture and compaction; and
- a direct reduction in strength of surface material through the loss of the binding support of roots, especially on scarps and steep slopes.

Hazard and risk: The spatial distribution of potential sliding may alter in relation to rainfall intensity. Willmott (1981, 1983) and Willmott and Hayne (2001) undertook detailed mapping of the landslides associated with the major rainfall event of 25-28 January 1974 associated with TC *Wanda*. Mapping from both field observations and stereoscopic aerial photographs was used. Rainfall distribution across the study area from this event ranged from 1000 mm in the north to 1100 mm in the south, however by far the majority of the area received about 1000 mm of rain over a three day period. Intensity-Frequency Duration curves for a number of stations throughout the study area indicate that the 1974 rainfall event was in fact a 100 year ARI event.

As this is the only detailed recording of landsliding associated with a rainfall event a full suite of return period scenarios has not been developed. A landslide hazard map and hazard and risk estimates for this particular event will be presented.

In order to quantify hazard and risk for large regions such as the Canungra-Beechmont, Numinbah, Tamborine, Springbrook Plateau, upper Tallebudgera and Currumbin valley areas it is necessary to subdivide the region into similar physical characteristics, in this instance geology and slope have been chosen. The importance of geology as a controlling influence on landslide distribution and frequency in the study area has been noted by Hayne and Gordon (2001); Willmott (1981 and 1983) and SMEC (1999). Field observations and research by Hayne and Gordon (2001), Michael-Leiba et al. (1999), Fell and Hartford (1997) and Willmott (1981 and 1983) indicate different hazard and risk values between debris slides, flows and rock falls, and rotational slides and slumps and complex multiple rotational slides. In the study region debris slides, flows and rock falls occur predominantly on very steep slopes and scarps $>25^\circ$, while rotational slides and slumps and complex multiple rotational slides occur predominantly on slopes $<25^\circ$ (Willmott, 1981, 1983 and Willmott and Hayne, 2001).

The geological history of the South-East Queensland region is outlined in Chapter 2, however, in order that the geological boundaries and hazard and risk estimates can be compared the geology of the Canungra-Beechmont, Numinbah, Tamborine, Springbrook Plateau, upper Tallebudgera and Currumbin valley areas is presented below (Figure 7.2). Calculations of hazard and risk are presented in Table 7.2.

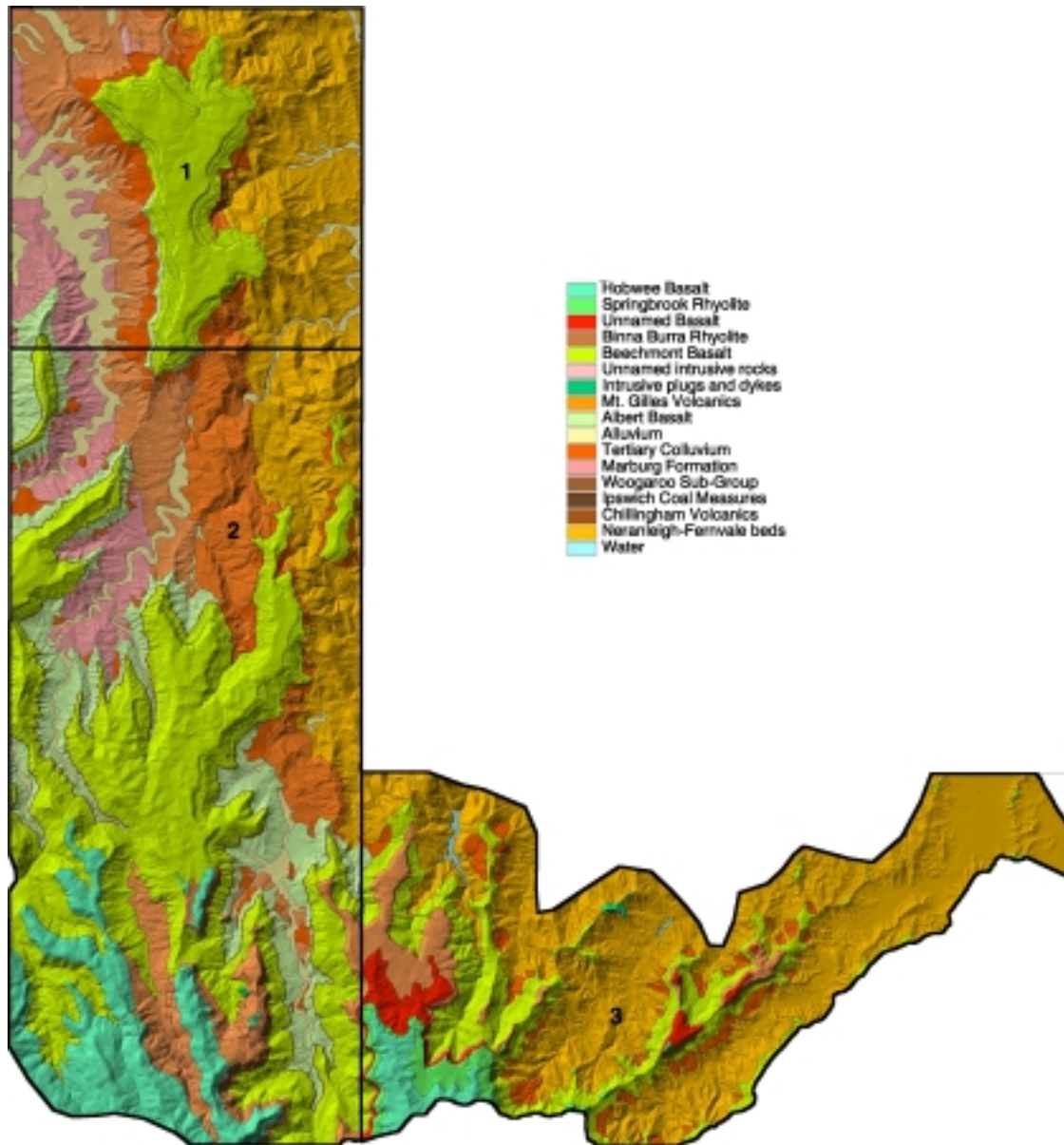


Figure 7.2. Geology of the Gold Coast hinterland region

	Geological Unit/Symbol	Geological Unit Area (m ²)	Area of Mapped Landslides (m ²)	Probability of Impact	Specific risk (Rs)			Number of dwellings	Persons in Dwellings	Dwellings destroyed given a 1 in 100 year event	Fatalities given a 1 in 100 year event	Road length (km)	No. of slides blocking roads	Expected road closures/km	Expected road destruction/km
					Persons (p)	Buildings (b)	Roads (r)								
Debris slides, flows and rock falls, >25° slope	Hobwee basalt /Tlh	11,833,605	0	0.00000	0.00000	0.00000	0.00000	5	14	N/L	N/L	0.6	0	0.0	0.0
	Springbrook Rhyolite /Tls	1,511,044	0	0.00000	0.00000	0.00000	0.00000	6	17	N/L	N/L	0.4	0	0.0	0.0
	Unnamed Basalt /Tl	1,495,873	0	0.00000	0.00000	0.00000	0.00000	7	20	N/L	N/L	0.1	0	0.0	0.0
	Binna Burra Rhyolite /Tlr	12,085,786	0	0.00000	0.00000	0.00000	0.00000	8	22	N/L	N/L	0.7	0	0.0	0.0
	Beechmont Basalt /Tlb	54,766,891	881,101	0.01609	0.01448	0.01609	0.01609	80	224	1.28705644	3.24338224	13.3	3	0.2	0.2
	Unnamed intrusive rocks /Ti	10,902	0	0.00000	0.00000	0.00000	0.00000			N/D; N/L	N/D; N/L	0.0	0	0.0	0.0
	Intrusive plugs and dykes /Tir	238,260	0	0.00000	0.00000	0.00000	0.00000			N/D; N/L	N/D; N/L	0.0	0	0.0	0.0
	Mt. Gilles Volcanics /Th	1,275,702	61,316	0.04806	0.04326	0.04806	0.04806	1	3	0.04806452	0.12112258	0.3	0	0.0	0.0
	Albert Basalt /Ta	6,261,465	195,002	0.03114	0.02803	0.03114	0.03114	3	8	0.09342957	0.23544252	0.9	0	0.0	0.0
	Alluvium /Qa	146,547	0	0.00000	0.00000	0.00000	0.00000	2	6	N/L	N/L	0.1	0	0.0	0.0
	Tertiary Colluvium /TQc	4,221,210	35,977	0.00852	0.00767	0.00852	0.00852	18	50	0.15341241	0.38659927	0.1	0	0.0	0.0
	Marburg Formation /Jbm	2,262,885	31,730	0.01402	0.01262	0.01402	0.01402			N/D	N/D	0.4	0	0.0	0.0
	Woogaroo Sub-Group /RJbw	2,937,798	10,700	0.00364	0.00328	0.00364	0.00364			N/D	N/D	0.5	0	0.0	0.0
	Ipswich Coal Measures /Ri	80,369	0	0.00000	0.00000	0.00000	0.00000			N/D; N/L	N/D; N/L	0.0	0	0.0	0.0
	Chillingham Volcanics /Rc	6,371,640	12,663	0.00199	0.00179	0.00199	0.00199	2	6	0.00397480	0.01001650	0.9	0	0.0	0.0
	Neranleigh-Fernvale beds /DCf	47,959,386	40,940	0.00085	0.00077	0.00085	0.00085	299	837	0.25523805	0.64319988	19.0	0	0.0	0.0
Rotational slides and slumps, <25° slope	Hobwee basalt /Tlh	26,754,288	0	0.00000	0.00000	0.00000	0.00000	78	218	N/L	N/L	14.5	0	0.0	0.0
	Springbrook Rhyolite /Tls	3,891,199	0	0.00000	0.00000	0.00000	0.00000	157	440	N/L	N/L	7.5	0	0.0	0.0
	Unnamed Basalt /Tl	4,249,677	0	0.00000	0.00000	0.00000	0.00000	44	123	N/L	N/L	5.9	0	0.0	0.0
	Binna Burra Rhyolite /Tlr	14,025,717	0	0.00000	0.00000	0.00000	0.00000	383	1072	N/L	N/L	19.8	0	0.0	0.0
	Beechmont Basalt /Tlb	133,779,457	2,629,538	0.01966	0.00025	0.00491	0.00590	545	1526	2.67809842	0.37493378	187.6	13	0.1	0.0
	Unnamed intrusive rocks /Ti	328,081	0	0.00000	0.00000	0.00000	0.00000			N/D; N/L	N/D; N/L	1.6	0	0.0	0.0
	Intrusive plugs and dykes /Tir	86,786	0	0.00000	0.00000	0.00000	0.00000			N/D; N/L	N/D; N/L	0.0	0	0.0	0.0
	Mt. Gilles Volcanics /Th	2,748,577	178,234	0.06485	0.00081	0.01621	0.01945	3	8	0.01621148	0.00081057	1.5	1	0.7	0.2
	Albert Basalt /Ta	34,617,841	1,074,525	0.03104	0.00039	0.00776	0.00931	56	157	0.00775991	0.00038800	24.3	14	0.6	0.2
	Alluvium /Qa	26,632,325	11,022	0.00041	0.00001	0.00010	0.00012	73	204	0.00010346	0.00000517	45.6	4	0.1	0.0
	Tertiary Colluvium /TQc	20,885,697	304,024	0.01456	0.00018	0.00364	0.00437	59	165	0.00363914	0.00018196	6.4	4	0.6	0.2
	Marburg Formation /Jbm	27,477,271	94,661	0.00345	0.00004	0.00086	0.00103			N/D	N/D	32.0	0	0.0	0.0
	Woogaroo Sub-Group /RJbw	35,430,000	94,081	0.00266	0.00003	0.00066	0.00080	3	8	0.00066385	0.00003319	52.4	0	0.0	0.0
	Ipswich Coal Measures /Ri	1,828,942	0	0.00000	0.00000	0.00000	0.00000			N/D; N/L	N/D; N/L	3.0	0	0.0	0.0
	Chillingham Volcanics /Rc	24,803,509	62,383	0.00252	0.00003	0.00063	0.00075	33	92	0.00062877	0.00003144	15.5	0	0.0	0.0
	Neranleigh-Fernvale beds /DCf	141,743,377	77,834	0.00055	0.00001	0.00014	0.00016	9520	26656	0.00013728	0.00000686	277.7	0	0.0	0.0

Table 7.2. Specific risk and total risk for people, buildings and roads.

Hazard based on geology and landslide type (slope angle $<25^\circ$ or $>25^\circ$) in the Canungra-Beechmont, Numinbah, Tamborine, Springbrook Plateau, upper Tallebudgera and Currumbin valley areas is presented below (Figure 7.3). This estimate is based on a 100 year ARI rainfall event.

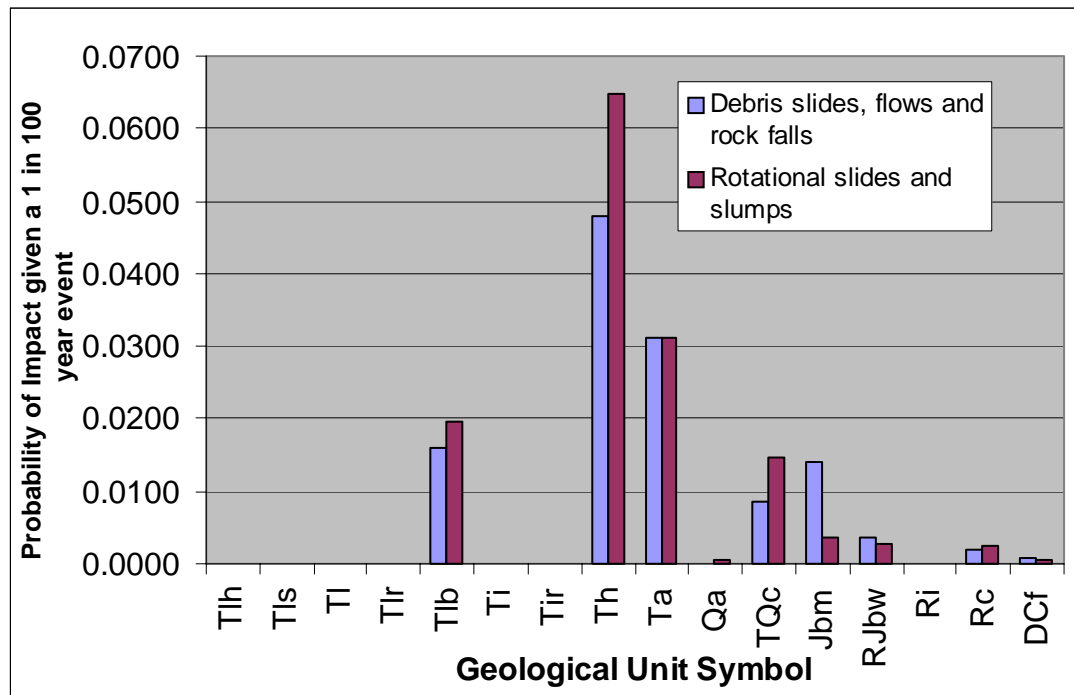


Figure 7.3. Landslide hazard probability for geology and slope units given a 100 year ARI rainfall event.

The specific risk: people, buildings and roads – the assessment of specific risk from both debris slides, flows and rock falls; and rotational slides and slumps given a 100 year ARI rainfall event is presented in Figure 7.4 and Figure 7.5, respectively. Calculations for these figures are given in Table 7.2.

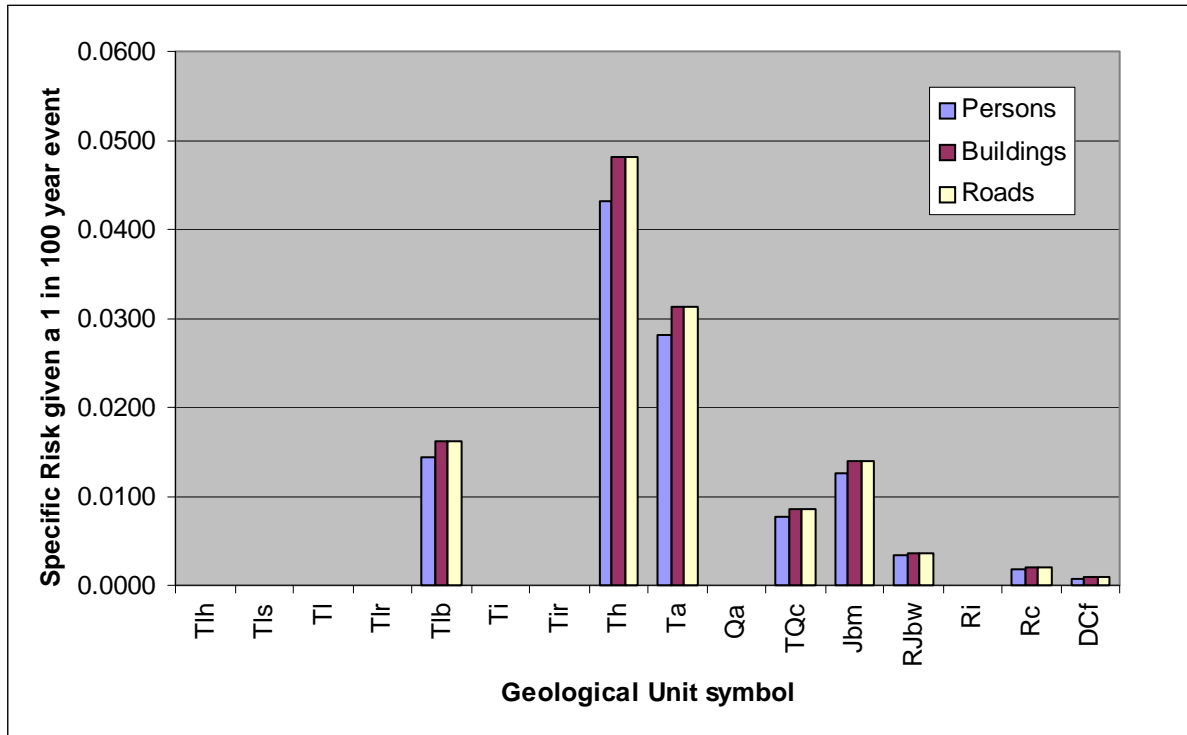


Figure 7.4. Specific risk from debris slides, flows and rock falls given a 100 year ARI rainfall event.

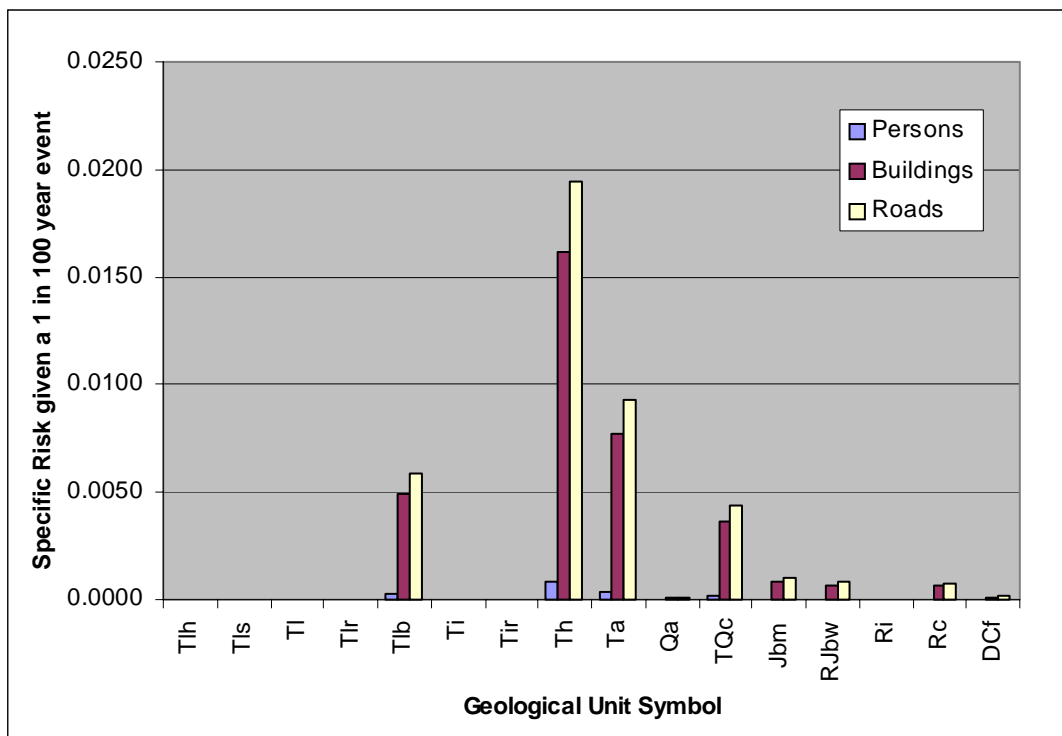


Figure 7.5. Specific risk from rotational slides and slumps given a 100 year ARI rainfall event.

The following specific risk maps (Figure 7.6 and Figure 7.7) include each of the elements at risk: persons, buildings and roads. These figures have been developed from the specific risk estimates (Table 7.2). Probability has been divided into five increments from lowest to highest.

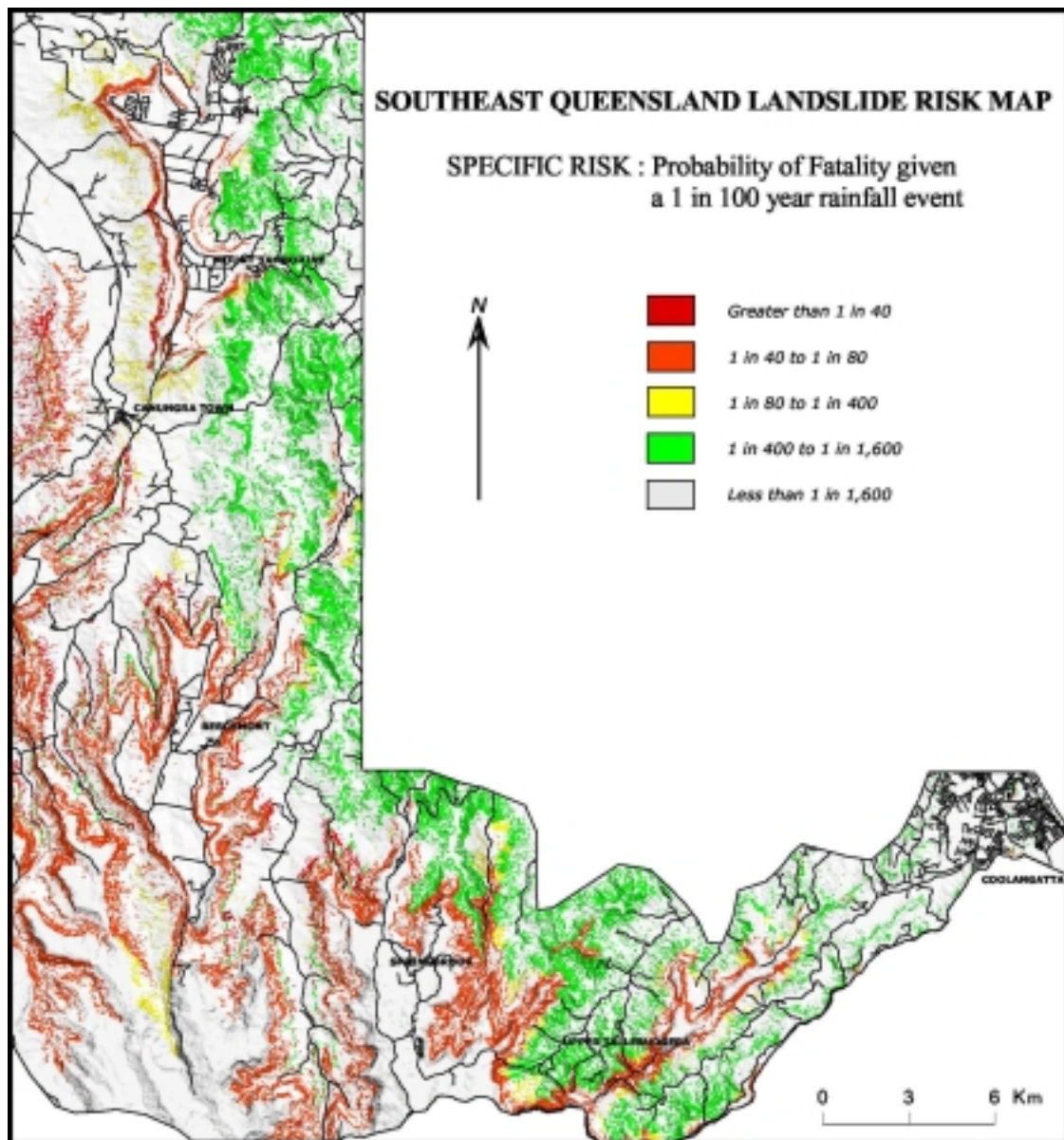


Figure 7.6. Specific risk of fatality given a 100 year ARI rainfall event.

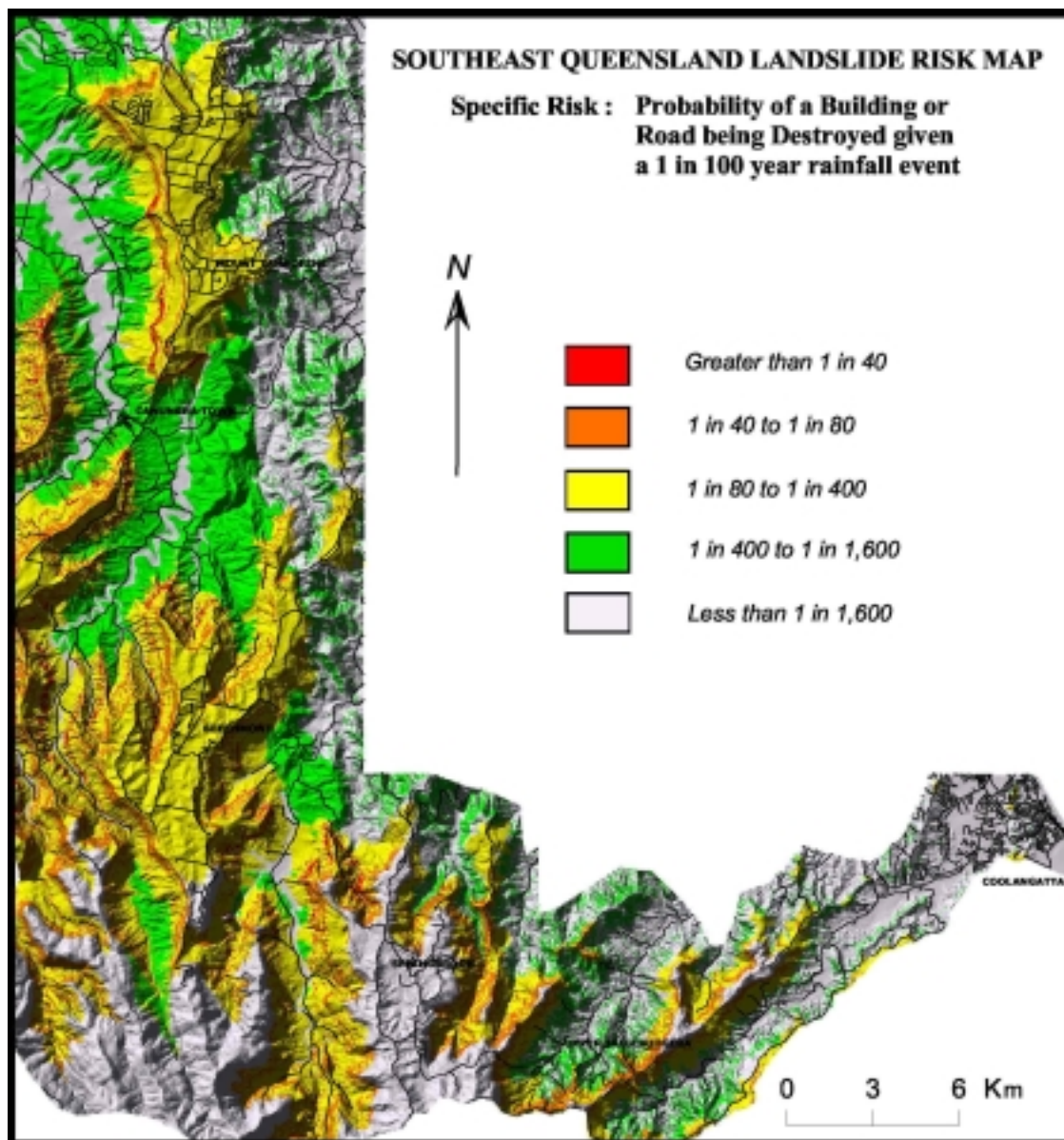


Figure 7.7. Specific risk of destruction of a building or a section of road given a 100 year ARI rainfall event.

Total risk: People - to assess the total risk for people, the probability of impact (H) is multiplied by the vulnerability of persons (V_p) and then by the number people (E_p). The mean number of people per dwelling within the study area is 2.8 (Australian Bureau of Statistics, 1996). Building data was not available for the Beaudesert Local Government Area (LGA) and total risk for this region has therefore not been assessed. The total risk of fatalities given a 100 year ARI rainfall event is divided into six categories, shown in Figure 7.8.

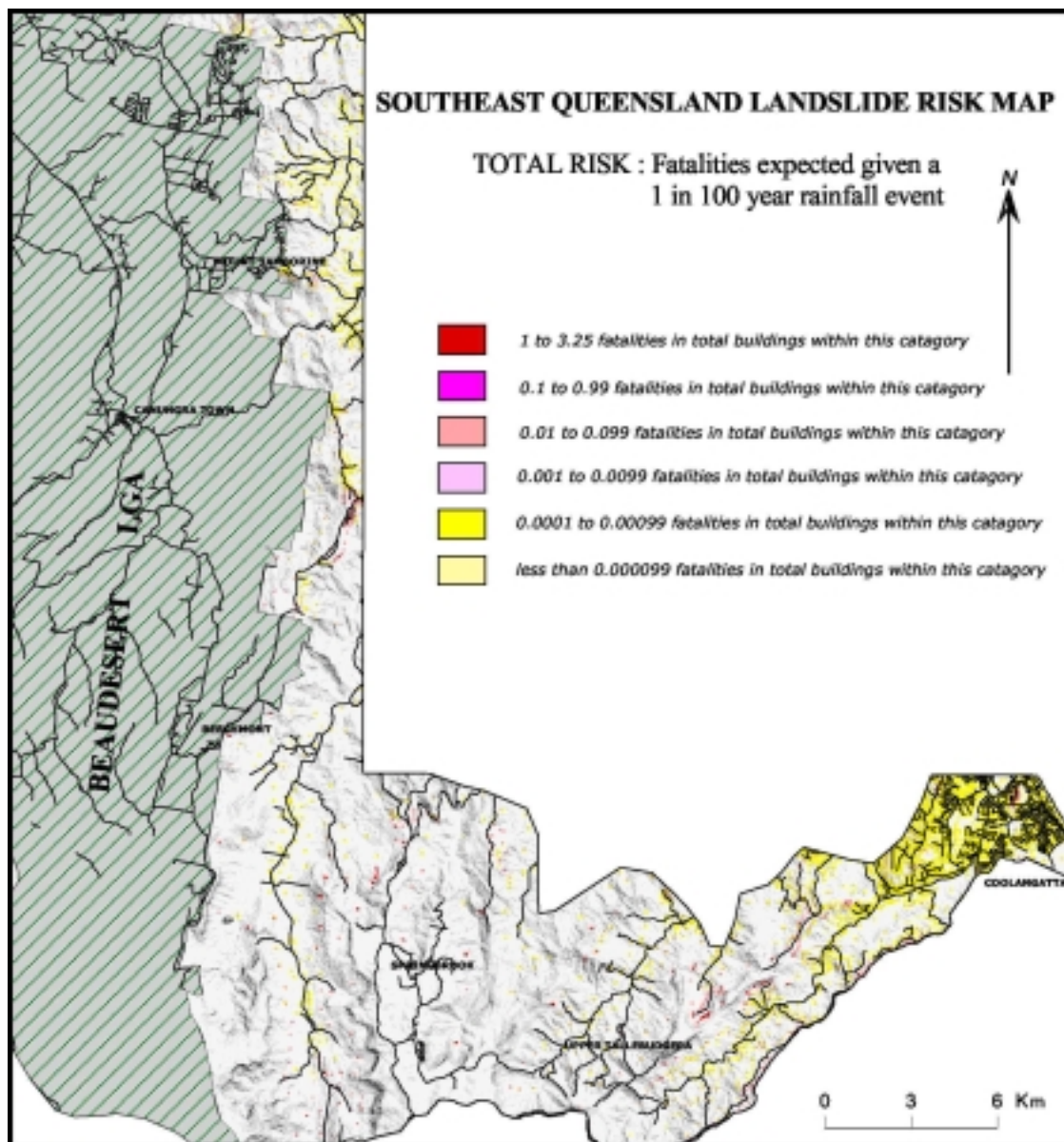


Figure 7.8. Total risk of fatalities given a 100 year ARI rainfall event.

Buildings: the buildings considered in the total risk calculations were houses and blocks of flats as these were the only structures for which mean numbers of occupants could be calculated from the GIS data. To calculate the total risk for buildings the probability of impact (H) is multiplied by the vulnerability of structures (Vs) which is multiplied by the number of buildings (Es). The number of dwellings in the study region is 11,385. The total risk of building destruction from a 100 year ARI rainfall event is shown in Figure 7.9. Each dwelling is displayed with a 50 m buffer to aid visual interpretation.

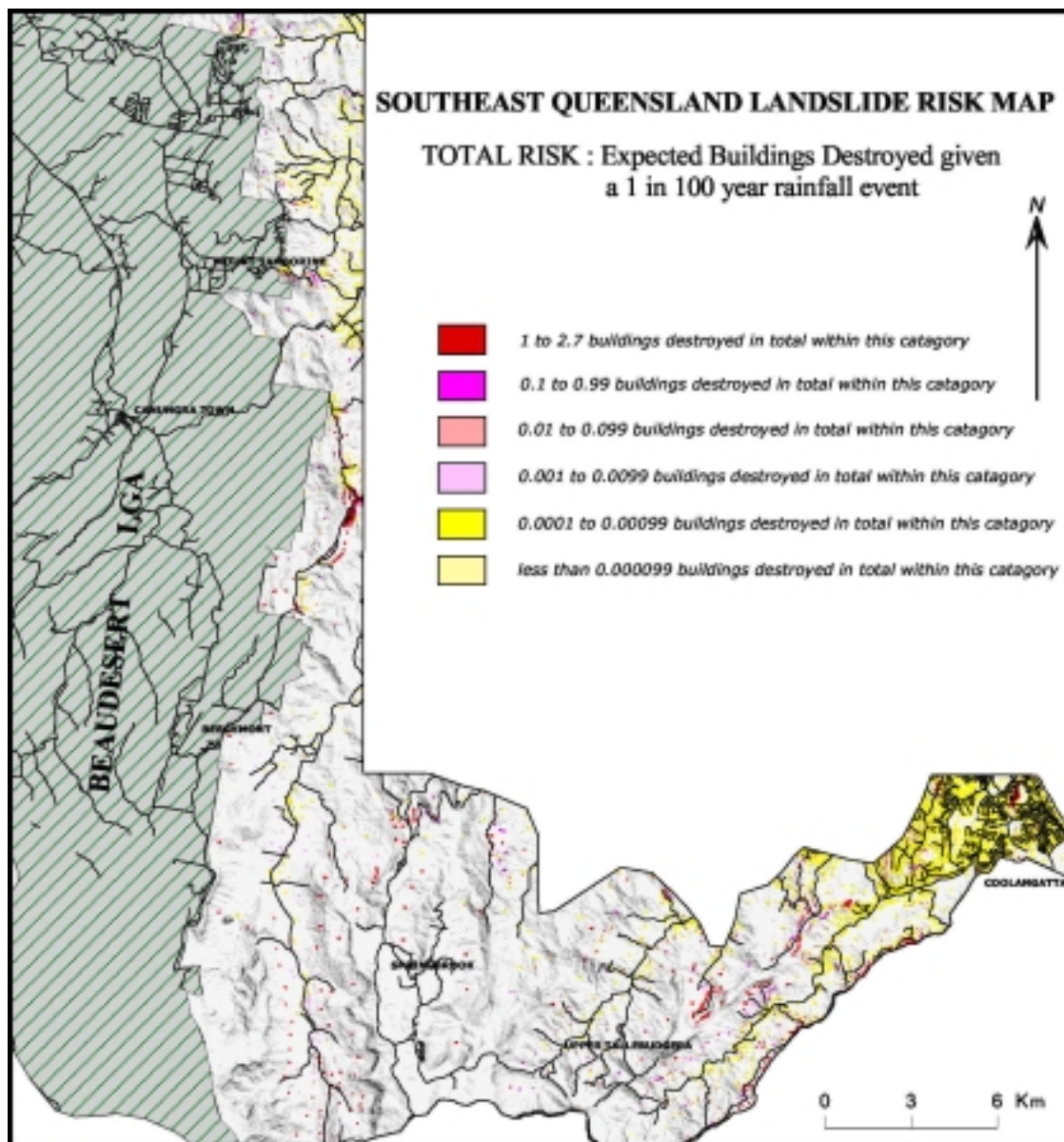


Figure 7.9. Total risk of building destruction given a 100 year ARI rainfall event.

Roads: finding a suitable unit of measure for the calculation of road closures from road area per unit area is difficult therefore, an approach has been adopted here which does not incorporate the use of specific risk. In the case of road closure due to either blockage or destruction, total risk estimates are calculated using landslides mapped from the 1974 rainfall event and the present day road distribution network.

The expected road closures per kilometre per geologic/slope unit given a 100 year ARI rainfall event are calculated below (Equation 7.5). This estimate (Figure 7.10) is based on slide material blocking the road and/or destruction of a section of road (it should be noted that this estimate does not assess the volume of material that could be expected to block a road) within geological/slope units. Calculations are presented in Table 7.2. Not all roads have been captured digitally resulting in an incomplete analysis.

Equation 7.5. Total risk of road closures.

$$\frac{\text{Expected number of road closures/km due to blockage or destruction given a 1 in 100 year rainfall event.}}{\text{Total number of slides cutting roads resulting from the January 1974 event.}} \times \text{Total distance (km) of present day roads per geologic/slope unit.}$$

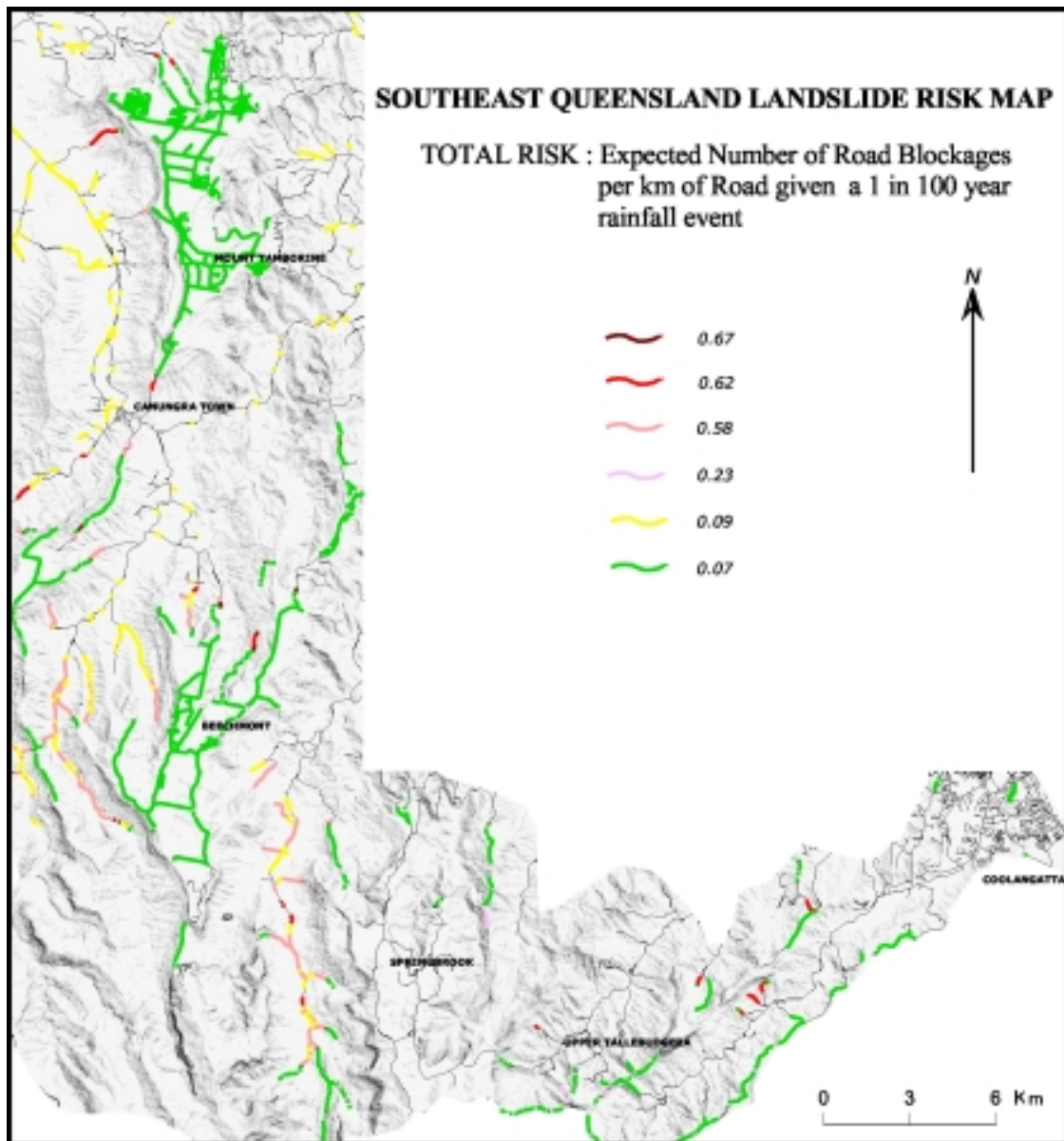


Figure 7.10. Total risk for roads: expected number of road blockages per km of road given a 100 year ARI rainfall event.

Secondly, if the above calculation is multiplied by the vulnerability of roads to destruction (Table 7.2) an estimate of expected number of road closures/km due to destruction by landslide can be provided (Figure 7.11). Calculations are presented in Equation 7.6.

Equation 7.6. Total risk of roads to destruction.

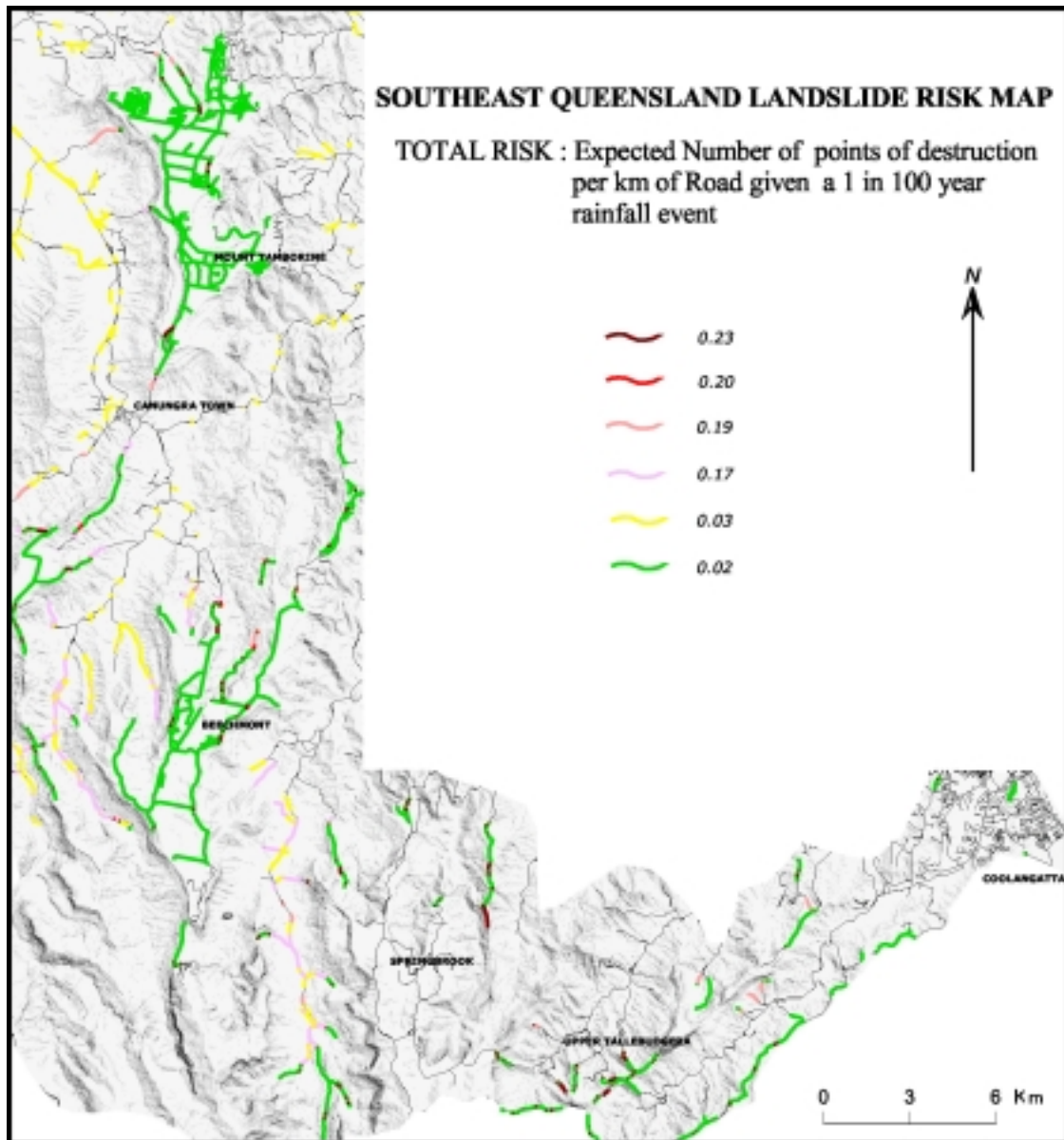
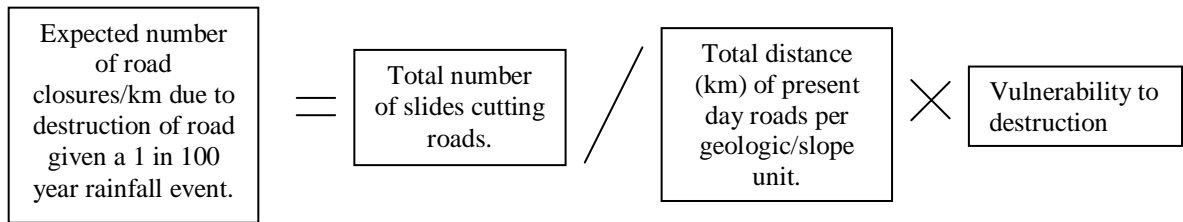


Figure 7.11. Total risk roads: expected number of points of destruction per km of road given a 100 year ARI rainfall event.

Landslide in Caboolture, Pine Rivers, Redcliffe, Brisbane, Ipswich, Redland and Logan.

Caboolture: There has not been a landslide assessment of the Caboolture local government area.

Debris flows may occur during periods of heavy rainfall on cleared steep slopes adjacent to gullies in the old rocks in the western and southwestern parts of the Caboolture study area, like they do in the Mapleton-Maleny area.

The Neranleigh-Fernvale beds do not occur in the Caboolture local government area but, in the western and southwestern parts of the study area, the Kurwongbah beds and Rocksberg Greenstone are metamorphosed rocks of the same age, which may be subject to landslides under similar circumstances to the Neranleigh-Fernvale beds.

In Caboolture Shire there are two areas of basalt that would be susceptible to landslides: the tail end of the Maleny Plateau in the far northwest; and Mount Mee (Warwick Willmott, Geological Survey of Queensland, email communication, March 2001). Both are outside our study area.

The alluvial banks of rivers in the Caboolture area are probably landslide-prone, like those in Brisbane.

Pine Rivers: There has not been a landslide assessment of the Pine Rivers local government area, but landslides would probably occur in alluvium along the banks of rivers and creeks under circumstances similar to those in Brisbane.

The Tertiary sediments in the Pine Rivers area are 65 to 45 million years old and consist predominantly of mudstone, siltstone, sandstone, oil shale, brown coal and limestone of the Petrie Formation. Hofmann and Willmott (1984) stated that, on the bank of the South Pine River, small slides have occurred in soil and weathered Tertiary sediments. They noted landsliding on a hill in Brisbane with slopes of the order of only 7-11° on unlateritised Tertiary sediments. Similar problems may occur on slopes in the Petrie Formation in the Pine Rivers study area.

Small exposures of Tertiary basalt occur in the far western part of the Pine Rivers study area, at Mount Glorious. Failures, like those in the Rosewood-Marburg area, may be associated with the basalts at Mount Glorious.

As in Brisbane, if the Enoggera Granite in Pine Rivers Shire is decomposed, then slumping may occur, and landsliding could happen in the Neranleigh-Fernvale beds in the Pine Rivers area under similar conditions to those in the Brisbane area.

In the Bunya Phyllite, rock slides have been reported in the bank of the Brisbane River (Hofmann and Willmott, 1984). There are extensive exposures of this rock in the Pine Rivers study area, so rock slides may happen on steep slopes. It is also possible that debris flows could occur during periods of heavy rainfall in the older rocks that cover much of the western and central parts of the Pine Rivers area.

Redcliffe: There appears to have never been a landslide assessment of Redcliffe ever carried out. During a brief reconnaissance field examination in April 2001, there was evidence of landsliding in cliffs of poorly consolidated material opposite Phillip Street in Scarborough. Debris slides, a small one of which was very recent, and rock falls with volumes up to 4 m³ were observed in cliffs of deeply weathered basalt opposite Warde Street in Scarborough. A section of the cliff was overhanging and appeared ready to fall in the near future. At Scotts

Point, Woody Point, numerous rock falls have occurred from a 7 m high cliff. The fallen boulders are up to 6 m³ in volume.

Brisbane: Hofmann and Willmott (1984) conducted a landslide susceptibility study of natural slopes in the City of Brisbane. They noted that ‘on natural slopes, landslides have affected mainly Tertiary claystone of the Corinda Formation and the Quaternary alluvium along the Brisbane River.’ The following is a summary of their observations of situations in which landslides may occur.

Along the Brisbane River, large slumps in alluvium can be triggered by lowering of the river level after prolonged or large floods, and minor erosion or slumps can be caused by tidal effects or heavy rainfall. Along creeks, alluvial bank failure can be caused by undercutting. Removal of trees has increased the incidence of landslides. In AGSO’s Australian Landslide Database, the most spectacular report of river bank failure in Brisbane is of a landslide near North Quay on 7 February 1890. The *Sydney Morning Herald* of 8 February 1890 states that the Old Queens Wharf, a morgue, a jetty and a new sanitary wharf and shed were partly or wholly wrecked. Gangs of men were employed to save what could be saved. Gas and water pipes were also seriously interfered with. Hofmann and Willmott (1984) noted that there were widespread instances of alluvial bank failures along the Brisbane River following the 1974 flood. In Newlands Street, Fig Tree Pocket, a major landslide affected 10 residential blocks and a street, destroying part of a serviced subdivision.

The Tertiary sediments in the Brisbane area are 65 to 45 million years old and consist predominantly of claystone, mudstone, sandstone and siltstone with minor amounts of basalt, limestone, conglomerate and oil shale. They occur largely in the far northern, eastern and southern parts of the area. Fortunately, they are mostly in flat terrain, because problems can arise on slopes. Hofmann and Willmott (1984) noted that landsliding on a hill at Oxley had occurred in the 1970s as a result of clearing and excessive pore water pressure following heavy rain. Several houses were demolished because remedial measures were considered uneconomic. The slopes are of the order of only 7-11° on unlateritised Tertiary sediments. On a steep bank of the Brisbane River, rock falls have occurred in Tertiary sandstone.

Hofmann and Willmott (1984) observed that, in the Tivoli Formation (part of the Ipswich Coal Measures), landslides have been noted, usually at gully heads, in completely weathered fine-grained sandstone associated with seepage, and in residual soil and colluvium in shales and siltstones. Shallow slumps and creep have occurred in soil on cleared slopes.

They also noted that, in deep soil of decomposed Enoggera Granite, there had been a few shallow slumps. We have estimated an angle of 15 degrees from their map as the threshold slope on which these took place.

Hofmann and Willmott (1984) also noted small rotational slides in soil and colluvium, chiefly on concave slopes around gully heads, on deforested slopes on the Neranleigh-Fernvale beds in the Brisbane area. Whilst these slumps happen on slopes as low as 11 degrees in association with seepage zones, they usually occur on slopes steeper than 17 degrees. They also noted soil slumps on a grassed slope of 11 to 17 degrees in a greenstone zone with seepage. They remarked on the apparent increased landslide susceptibility of greenstone-derived soils and of red colluvial soils derived from banded chert.

In the Bunya Phyllite, rock slides have been reported in the bank of the Brisbane River. Hofmann and Willmott (1984) also noted a large multiple rotational slide in weathered rock and colluvium overlying the phyllite north of the ferry landing at Dutton Park. This may have been triggered by a stormwater leakage and by seepage.

Ipswich: There has not been a landslide assessment of the entire Ipswich local government area, but Willmott (1987) investigated slope stability and its constraints on building in the Rosewood-Marburg area. He found few areas prone to slope instability, but noted some small landslides in the following situations:

- on the sides of gullies with slopes of the order of 10 to 15 degrees in the Walloon Coal Measures and the Marburg Formation, small to moderate-sized rotational slumps grading into mudflows can occur. These may be caused by groundwater seepage into the gullies, particularly when the slope has been cleared. From his map, we measured 8 degrees as the threshold for landslides on the Walloon Coal Measures, and 15 degrees on the Marburg Formation;
- on the steeper basalt slopes and scarps, small debris slides and steep rotational slumps can occur in deep soils and small pockets of colluvium, probably more commonly when the area has been cleared;
- on the gentler, intermediate to lower basalt slopes, small rotational slumps, adjacent to gullies and on the sides of local knobs, can occur in soils and local pockets of colluvium. They are probably caused by seepage. From his map we measured 11 degrees as the threshold for landslides in basalt;

Landslides have been noted on the banks of the Bremer River after floods, and on hills after clearing (David Kay, Ipswich City Council, personal communication, 1999).

Willmott (1983) noted debris flows on basalt scarps with slopes greater than 25 degrees, and also on cleared steep slopes adjacent to gullies in older rocks, in the Mapleton-Maleny area. It is thus possible that debris flows could occur during periods of heavy rainfall in hilly country in the older rocks of the far north east of the Ipswich area, and in the basalts of the Little Liverpool Range and The Bluff.

The Neranleigh-Fernvale beds have been mapped in the north-eastern part of the Ipswich local government area, and may be susceptible to small rotational slides and slumps under circumstances similar to those observed in Brisbane by Hofman and Willmott (1984).

AGSO's Australian landslide database records a major landslide at Tallegalla Hill, Minden. The locality was just west of our study area, and about 11 km from Rosewood and 10 km from Marburg. It was reported in the *Sydney Morning Herald* of 18 March 1890 as follows:

“A large hill...slipped bodily into a creek, by which it was surrounded with a roaring noise like that of an earthquake. Now where the hill stood is a sheet of water and five or six farms are not recognisable, the high land being now low and vice versa.”

The *Sydney Morning Herald* of 19 March 1890 had noted that at least 323 700 m² had bodily shifted, sometimes to a depth of 12 m, and that entire farms were ruined and houses destroyed. If a mean depth of 6 m is assumed, then the volume of this landslide is estimated to be almost 2 million cubic metres. It was probably triggered by the tropical cyclone that crossed the south Queensland coast on 11 March 1890. This cyclone caused flooding in the Brisbane River. The landslide may have been a debris flow.

Mine subsidence is a well recognised problem in Ipswich, but it is not addressed in this report, which deals only with landslides on natural and cut slopes.

Redland: There appears not to have been a landslide hazard assessment of Redland carried out. In AGSO's Australian landslide database, there are records of two landslides on North

Stradbroke Island. The first happened at Amity Point in September 1936. A 6-7 m high sea cliff collapsed, burying two children under several tonnes of sand. One child died. The second was in 1998 when a 400 m long landslide happened near a sand mine.

Landslides occur in the canal estates in fissured clays developed on weathered Tertiary basalt of the Petrie Formation, apparently on slopes generally less than 10 degrees. Cuts of these slopes were generally in excess of 25 degrees (Len Cranfield, Geological Survey of Queensland, email communication, 12 April 2001).

Much of the mainland part of the Shire is underlain by Neranleigh-Fernvale beds, with some hilly terrain (Warwick Willmott, Geological Survey of Queensland, email communication, March 2001). Slumps were observed on slopes steeper than about 11 degrees in red colluvial soils, derived from banded chert in the Neranleigh-Fernvale beds, at Mount Cotton, just south-east of Brisbane (Hofmann and Willmott, 1984).

Logan: We have been able to find no records of landslides in Logan City, nor does there appear to have ever been a landslide assessment of Logan carried out.

There is an area of possible pediment slope wash, about 1 km long, situated near the boundaries of Loganholme, Shailer Park and Cornubia, that may be deposits from one or a number of flash floods and/or small debris flows built up during periods of intense rainfall.

The most common form of landsliding in Logan is likely to be small failures in cut slopes on some of the higher hills of the Neranleigh-Fernvale beds.

Landslide hazard on uncut slopes

Based on observations outlined in the preceding section and by Hofmann and Willmott (1984), the slopes shown in Table 7.3 may be susceptible to landslide during periods of heavy rainfall, or when seepage occurs.

Because colluvium, pediment slope wash, and anthropogenic deposits consist of unconsolidated material, they could be prone to landslide, and have been included in Table 7.3. A landslide in dolerite colluvium in Tasmania was active on a slope of only 7 degrees (Lloyd Matthews, Mineral Resources Tasmania, personal communication, 1996) so this was chosen as the threshold for potential slope instability in unconsolidated materials. However, as the only significant mapped colluvium is that shed from quartzites of the Neranleigh-Fernvale beds (Warwick Willmott, Geological Survey of Queensland, email communication, March 2001), a threshold of 11 degrees was chosen for the colluvium. Landslide susceptibility maps for uncut slopes in Caboolture, Brisbane and Ipswich are shown in Figure 7.12, Figure 7.13 and

Figure 7.14. We do not have detailed contour information for Pine Rivers, so a map could not be produced.

Table 7.3. Uncut slopes susceptible to landslide.

Slope and geological formation	Type of landslide
Greater than 25 degrees	Small debris slides, rotational slumps, or debris flows, in deep pockets of soil or colluvium
17-25 degrees – Neranleigh-Fernvale beds, Bunya Phyllite	Rotational slumps in soil and colluvium, chiefly on concave slopes around gully heads. (NOTE: Slumps may occur on slopes as low as 11 degrees on greenstone-derived or red colluvial soils)
20-25 degrees – Rocksberg Greenstone	Small debris slides, rotational slumps, or debris flows, in deep pockets of soil or colluvium
15-25 degrees – Enoggera Granite	Shallow rotational slumps in deep soil of decomposed granite
15-25 degrees - Marburg Subgroup (Koukandowie Member), Tivoli Formation, Darra Formation, Hector Tuff	Small to moderate-sized rotational slumps, grading into mudflows, on the sides of gullies
11-25 degrees - Brassal Subgroup - Tingalpa Formation and Tivoli Formation; Archerfield Basalt Member of Oxley Group; Petrie Formation - basalt	Small slides near gully heads
11-25 degrees - basalt	Small rotational slumps, adjacent to gullies and on the sides of local knobs, in soils and local pockets of colluvium
11-25 degrees - colluvium (sand, soil, clay, rock debris). Some residual (non-transported) material may inadvertently be included.	Small rotational slides
11 degrees or greater - lowest river terrace, estuarine channels and banks; active stream channel	Slumps in river banks
8-25 degrees – Walloon Coal Measures, Blackstone Formation, Redbank Plains Formation	Small to moderate-sized rotational slumps, grading into mudflows, on the sides of gullies
7 degrees or greater – unlateritised Tertiary sediments (Corinda, Darra and Petrie Formations)	Rotational slides and slumps on hill slopes; rock falls and rotational slides and slumps on river banks
7-25 degrees – pediment slope wash (clay, scree, soil), anthropogenic deposits	Slumps or earthflows

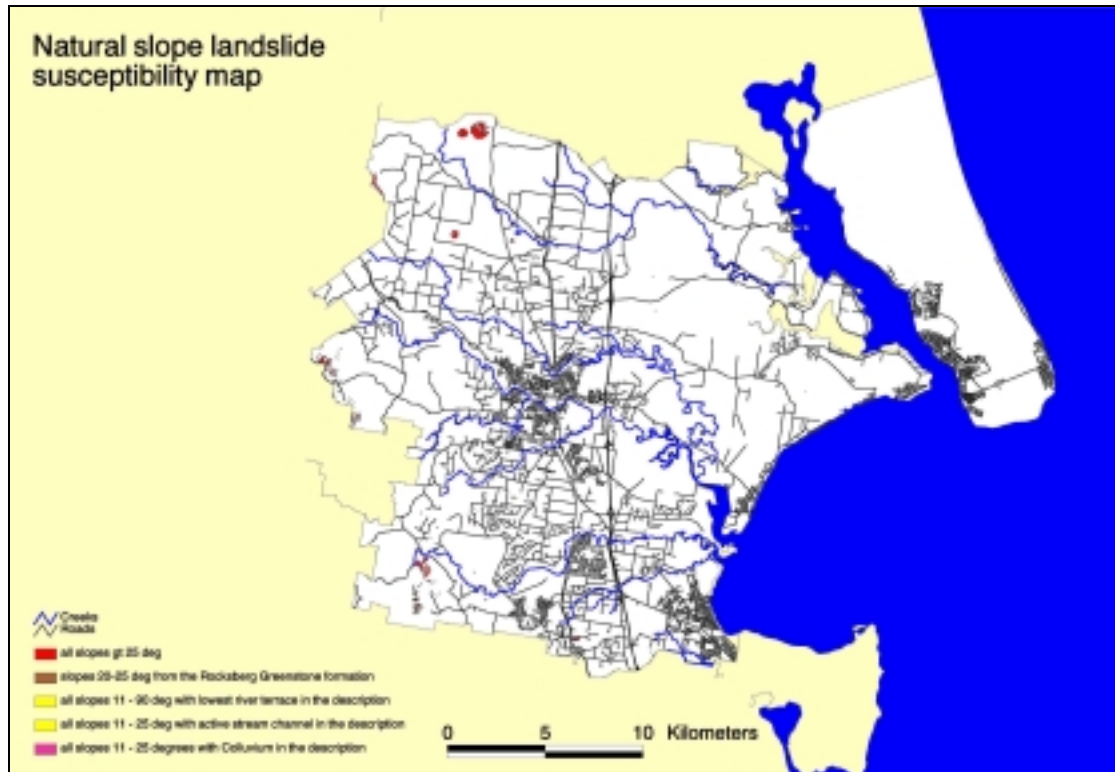


Figure 7.12. Caboolture natural slope landslide susceptibility map.

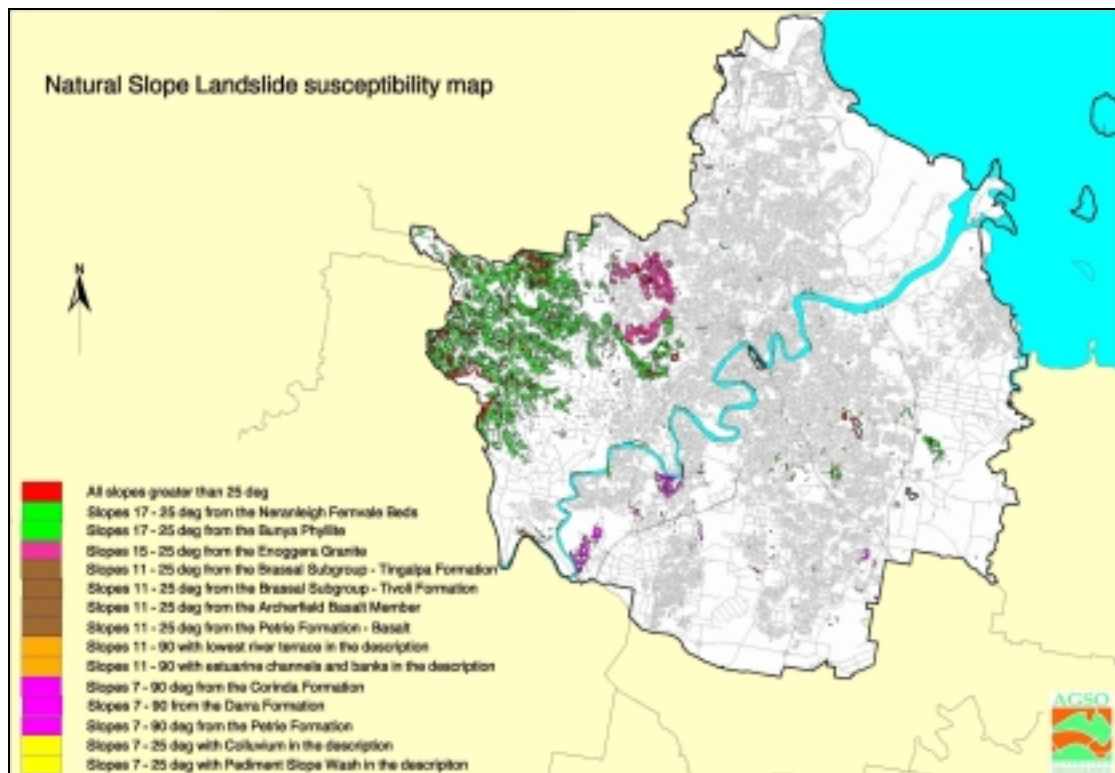


Figure 7.13. Brisbane natural slopes landslide susceptibility map.

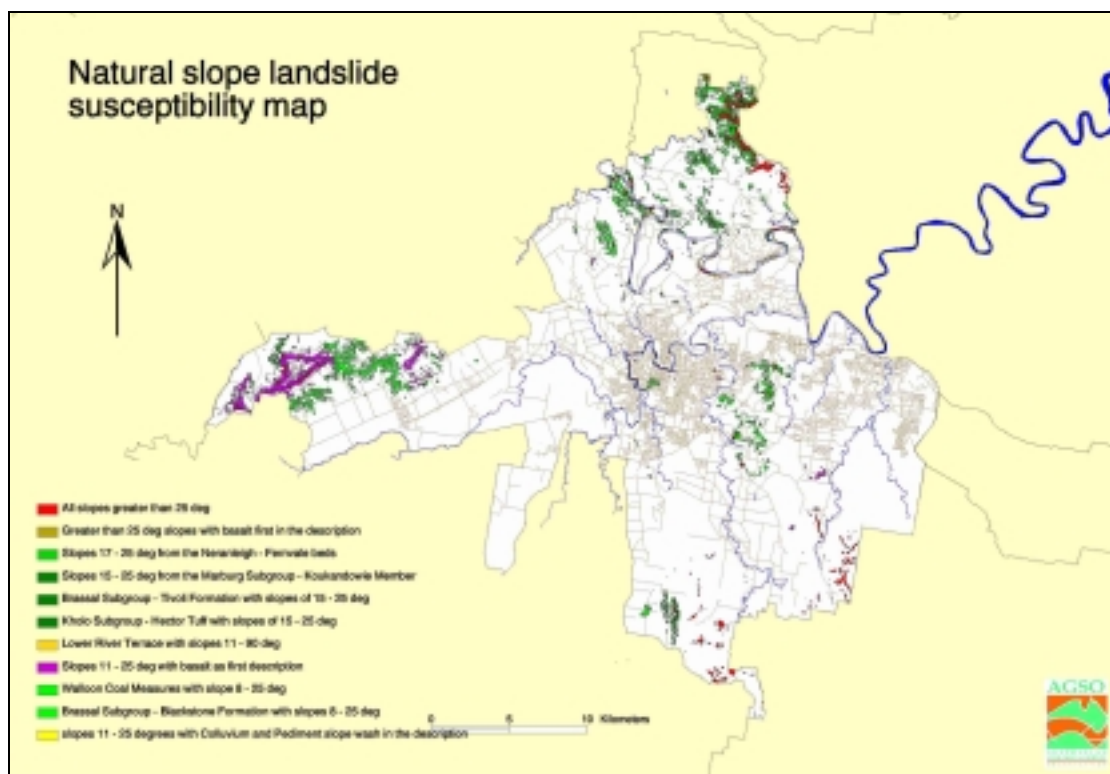


Figure 7.14. Ipswich natural slopes landslide susceptibility map.

Debris flows are a type of landslide triggered by the action of torrential rain on loose material (rocks and finer material) on a mountain side or escarpment. The boulders and finer material, mixed with water, flow as a torrent, scouring out a path down the slope. The boulders and some of the finer material are deposited first, while the remainder of the mud travels further as a flash flood. The landslide susceptibility areas in Figure 7.12 (Caboolture) Figure 7.13 (Brisbane) and

Figure 7.14 (Ipswich) do not take into account the fact that material from debris flows and flash floods runs out down-slope from the area of slippage.

The high country in the western part of Caboolture and Pine Rivers is a potential source of debris flows. These very fluid landslides frequently, but not always, follow stream channels. Those that are channelled can deviate, and continue to flow in the original direction, if the channel makes a sharp bend.

Because we have insufficient information about the frequency of landslide occurrence in south-east Queensland, apart from the Gold Coast, it is not possible to quantitatively assess the landslide hazard on uncut slopes.

Landslide hazard on cut slopes

Cut slopes tend to be more susceptible to landslide than uncut slopes because of:

- artificially steepening the slope with batters;
- potentially weakening the site with fill;
- loading the upper part of the slope;
- removing support from the base of the slope;

- clearing vegetation during development; and,
- watering developed land.

However, the risks can be, and frequently are, mitigated by carrying out the development with appropriate geotechnical advice.

As the assessment of landslide susceptibility and risk was carried out using a GIS, it was necessary to select cut slope landslide susceptibility polygons for which to estimate landslide risk for various scenarios, assuming the entire area is developed without appropriate mitigation measures.

The landslide susceptibility polygons were selected as follows:

- rock slopes that would have at least a 3 m high, 60 degree batter if a 10 m wide section of slope were cut and levelled. This would require a natural slope of at least 13 degrees; and,
- slopes in unconsolidated material (soil or colluvium) that would have at least a 3 m high, 45 degree batter if a 10 m wide section of slope were cut and levelled. This would require a natural slope of at least 10 degrees.

It was assumed that collapse of at least a 3 m high batter would normally be necessary to destroy a house and possibly cause the death of a resident.

The landslide susceptibility maps for cut slopes in Caboolture, Brisbane and Ipswich are shown in Figures 7.16, 7.17 and 7.18. A map could not be produced for Pine Rivers because of lack of DEM data.

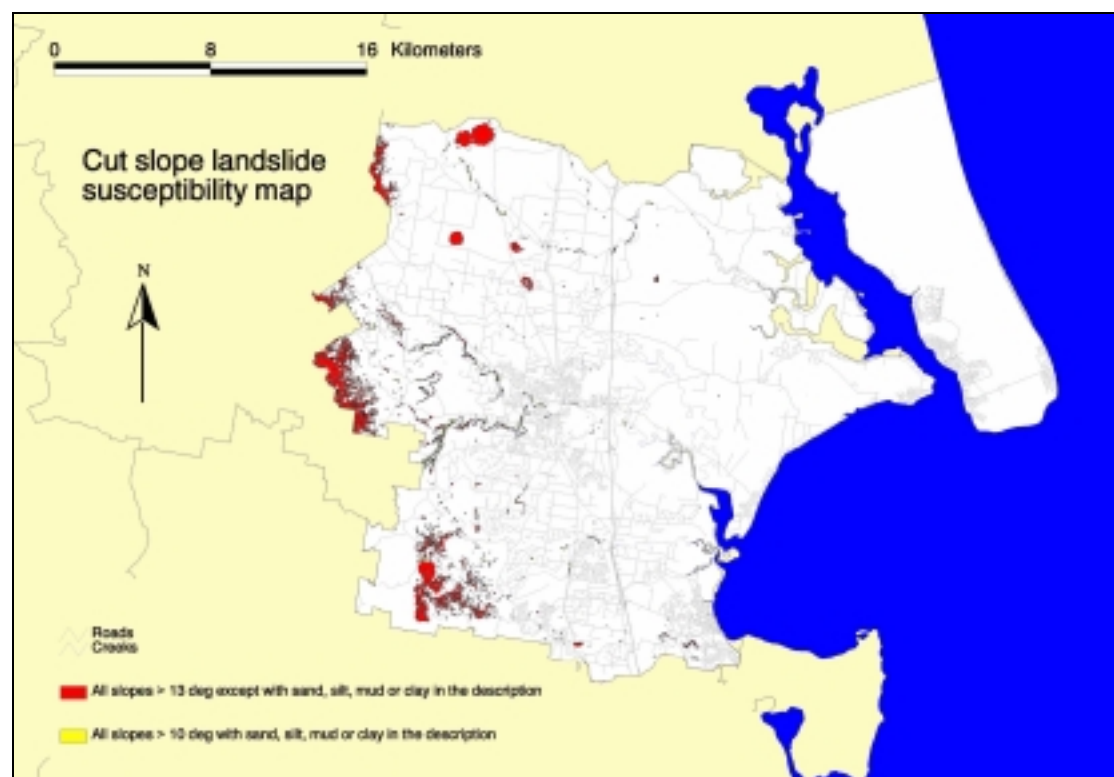


Figure 7.15. Caboolture cut slope landslide susceptibility map.

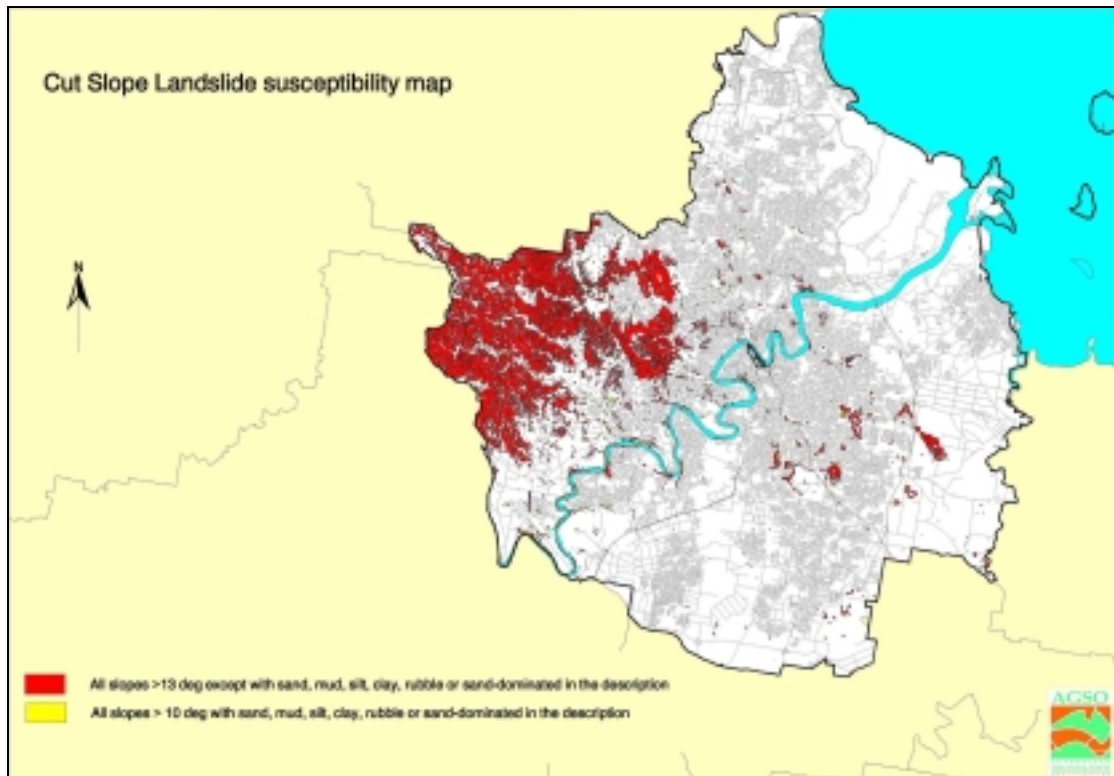


Figure 7.16. Brisbane cut slope landslide susceptibility map.

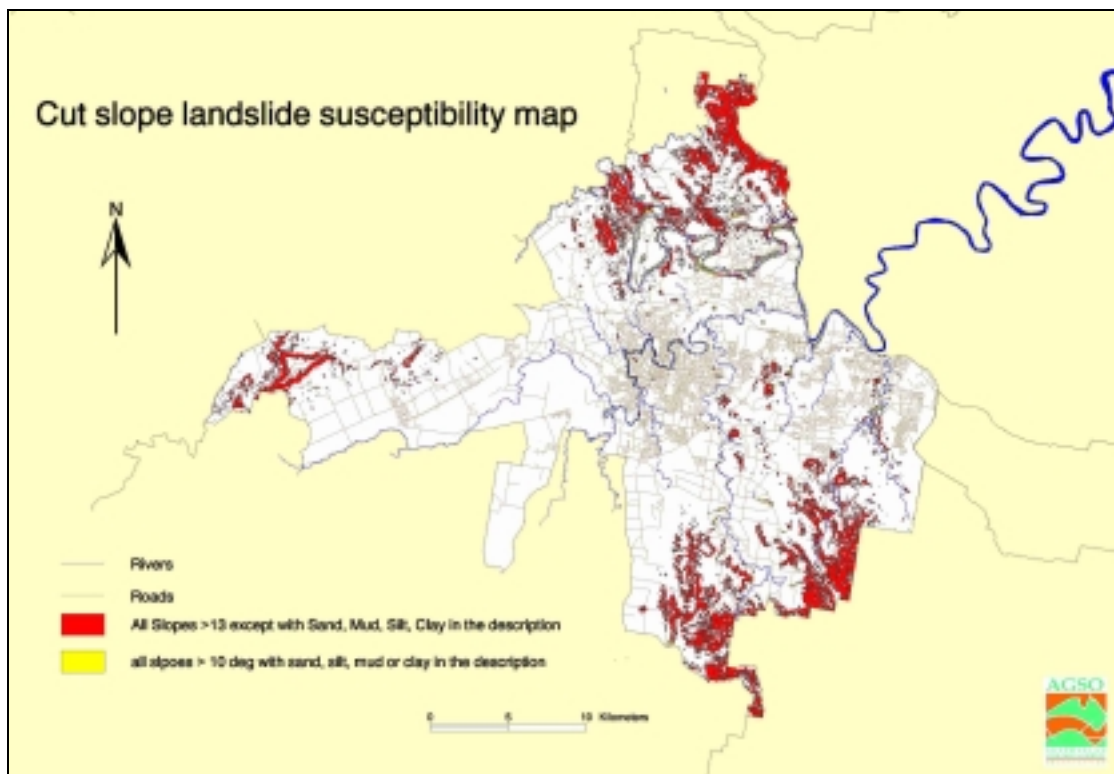


Figure 7.17. Ipswich cut slope landslide susceptibility map.

Landslide recurrence intervals

There are no detailed landslide logs, following rainfall events in south east Queensland, from which to estimate average recurrence intervals (ARI) of landslides on cut slopes. However, this has been done for developed slopes in Cairns (Michael-Leiba and others, 1999). To get an order of magnitude estimate for Caboolture, Pine Rivers, Brisbane and Ipswich, the cut slope failure rates observed following various rainfall intensities in Cairns were assumed to hold good for cut slopes in these areas also. However, the recurrence intervals of these rainfall intensities in south east Queensland would be considerably longer than in Cairns, because the rainfall is much lower.

The Bureau of Meteorology IFD (Intensity-Frequency-Duration) data for rainfall stations close to, or within the study areas were used to estimate the recurrence intervals at Caboolture, Pine Rivers, Brisbane and Ipswich by linear interpolation of data tabulated for average recurrence intervals of 1, 2, 5, 10, 20, 50 and 100 years, and in some cases by extrapolation of a log-linear graph plotted from these data. The results are shown in Table 7.4.

Table 7.4. Cut slope failure rate recurrence intervals for Cairns, Brisbane, Ipswich, Pine Rivers and Caboolture.

24 hour rainfall intensity (mm/h)	ARI Cairns (years)	ARI Caboolture (years)	ARI Pine Rivers (years)	ARI Brisbane (years)	ARI Ipswich (years)	Cut slope failure rate in Cairns (m ³ /sq km)
7.86	1	3.7	3.7	8.5	22	33
10.5	2.3	12	12	33	100	108 (max) 0.98 (min)
12.3	3.9	27	27	72	230	180 (max) 1.39 (min)

These data are plotted in landslide recurrence graphs for Caboolture, Pine Rivers, Brisbane and Ipswich in Figure 7.18. Because of the scarcity and scatter of data, the line is drawn to pass through the same relative level on the error bars as in the corresponding graph for Cairns in Michael-Leiba and others (1999). This is because the graph for Cairns was better constrained because it had two additional points for higher rainfall intensities. The vertical bars on the graphs were derived from maximum and minimum failure rates logged after two tropical cyclones in Cairns. The maximum failure rates (tops of the vertical bars) were for landslides (mainly batter failures) logged along roads up the escarpment. The minimum failure rates (bottoms of the vertical bars) were for batter failures in residential areas.

Because most of the batter failures in Cairns occur in rocks much more deeply weathered than those in south east Queensland, the incidence of failures on unengineered batters in Cairns would be expected to be higher than in south east Queensland for corresponding rainfall intensities. Consequently, the hazard and risk in Caboolture, Pine Rivers, Brisbane and Ipswich would tend to be overestimated by this methodology for cut slopes for which no mitigation measures had been taken, and would be grossly overestimated for slopes developed with competent geotechnical advice.

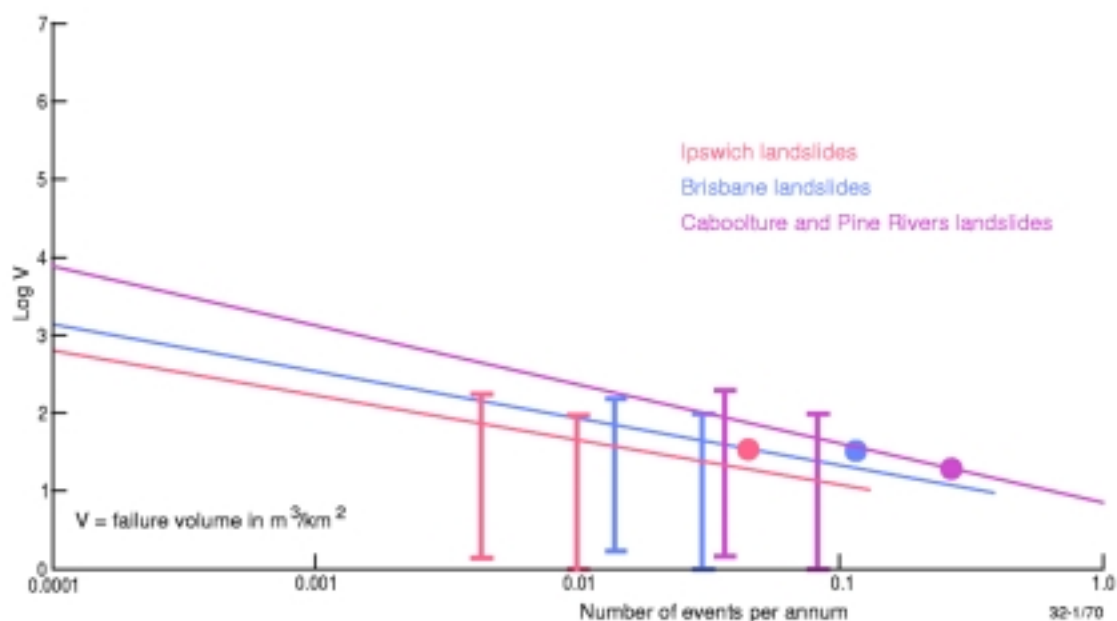


Figure 7.18. Recurrence relation for fully developed slopes.

From the landslide recurrence graphs, the failure volumes were read for an average recurrence interval of 100 years. If the mean thickness of the landslides is assumed to be 1.5 metres, the mean area, A (square metres) can be calculated by dividing the failure volume by 1.5. This is the landslide area per square km, that is per 1 million square metres, so the hazard for the scenario (the probability of a point in the susceptible area being impacted by a landslide, given that the scenario happens) is A divided by 1 million. The results for the 100 year rainfall event scenario are given in Table 7.5. These would apply to the landslide susceptibility areas for cut slopes in Figures 7.16 (Caboolture), 7.17 (Brisbane) and 7.18 (Ipswich).

Because of the very broad assumptions and uncertainties in the methodology used to derive these results, they should be considered to be a “back of an envelope” type of estimate only, usually giving an upper bound to the hazard values.

Table 7.5. Landslide hazard for the 100 year ARI rainfall scenario.

	Caboolture	Pine Rivers	Brisbane	Ipswich
Landslide volume ($\text{m}^3/\text{sq km}$)	229	229	91	46
Landslide area ($\text{m}^2/\text{sq km}$)	153	153	61	31
Landslide hazard (probability of impact at a point in a susceptible area)	0.0002 (1 in 7000)	0.0002 (1 in 7 000)	0.00006 (1 in 16 000)	0.00003 (1 in 30 000)

Landslide Risk Scenarios

Hazard is taken to be the probability of impact of a landslide at a point (Table 7.5), given that the scenario takes place, and vulnerability to be the probability of a building, person living in a building, or a section of road being destroyed if hit by a landslide. Both range in value from 0 (impossible) to 1 (certain).

The vulnerabilities for elements at risk from small debris slides, flows, slumps and rock falls on hill slopes in the Cairns study (Michael-Leiba and others, 1999) were assumed to be applicable also to Caboolture, Pine Rivers, Brisbane and Ipswich. The values are given in Table 7.1.

By multiplying the hazard values in Table 7.5 by the appropriate vulnerability in Table 7.1, the specific risk of destruction of resident people, buildings and roads in the 100 year ARI rainfall scenario can be calculated. The results are given in Table 7.6. These apply to the landslide susceptibility areas for cut slopes in Figures 7.16, 7.17 and 7.18. It must be remembered that these are rough estimates only; the uncertainty in them is not known, and they will tend to overestimate the risk.

Table 7.6. Specific annual risk of destruction on cut slopes in the 100 year ARI rainfall scenario.

	Caboolture	Pine Rivers	Brisbane	Ipswich
Specific risk – Resident people	0.000008 (1 in 100 000)	0.000008 (1 in 100 000)	0.000003 (1 in 300 000)	0.000002 (1 in 600 000)
Specific risk – Buildings	0.00004 (1 in 30 000)	0.00004 (1 in 30 000)	0.00002 (1 in 70 000)	0.000008 (1 in 100 000)
Specific risk – roads	0.00005 (1 in 20 000)	0.00005 (1 in 20 000)	0.00002 (1 in 50 000)	0.000009 (1 in 100 000)

Total risk on cut slopes: The landslide susceptibility polygons in Figures 7.16, 7.17 and 7.18 were interrogated using the GIS to determine the number of buildings and resident people they contain. There are 111 buildings and an estimated 322 people in Caboolture; 4699 buildings and an estimated 15 056 people in Brisbane; and 576 buildings and an estimated 1700 people in Ipswich. This was used to calculate the total risk of destruction figures in Table 7.8.

Again, it must be emphasised that these are “back of an envelope” type of estimates only; the uncertainty in the figures is unknown, but they are probably an overestimate.

Because we do not have detailed contour information, it is not possible at this stage to derive landslide susceptibility polygons that can be interrogated to ascertain the number of elements at risk, and hence to assess total landslide risk in the Pine Rivers area.

Table 7.7. Total risk of destruction in the 100 year ARI rainfall scenario.

	Caboolture	Brisbane	Ipswich
Number of resident people killed	0.002	0.05	0.003
Number of Buildings destroyed	0.004	0.07	0.004

Interpretation

Gold Coast Hinterland Region

Total Risk to People (Figure 7.8): There are about 1200 people living in the Canungra-Beechmont, Numinbah, Tamborine, Springbrook Plateau, upper Tallebudgera and Currumbin valley areas that are subject to debris slides, flows and rock falls (slopes $>25^\circ$), this is only about 4% of the population that is at risk from land instability. The remainder of the “at risk” population live in areas subject to rotational slides and slumps (slopes $<25^\circ$). In areas with slopes $>25^\circ$ there is a maximum total risk of about 4.6 fatalities given a 100 year ARI rainfall event (Figure 7.8). By far the greatest total risk to people living in these areas from such an event is in the Beechmont Basalt Unit where about 224 people reside and it is estimated that about 3.2 fatalities could occur. The next greatest total risk occurs in the Neranleigh-Fernvale beds with slopes $>25^\circ$, where an average of 0.64 of a fatality could occur. In areas with slopes $<25^\circ$ the population is about 30670, the total risk of a fatality is 0.4. The greatest total risk of fatality from landslides resulting within this geological/slope unit is in the Beechmont Basalt where about 0.38 fatalities could occur.

Overall the total expected risk from landslides for the Gold Coast Region given a 100 year ARI rainfall event is 5 fatalities. The expected number of fatalities in areas subject to debris slides, flows and rock falls is 4.6, substantially greater than for areas subject to rotational slides and slumps at 0.4.

Total risk to Buildings (Figure 7.9): There are about 431 dwellings in regions subject to debris slides, flows and rock falls (slopes $>25^\circ$), this is only about 4% of the total number of at risk dwellings. The remaining buildings are in areas subject to rotational slides and slumps (slopes $<25^\circ$). The greatest total risk by far to dwellings from landslides occurs in the Beechmont Basalt Unit on slopes $<25^\circ$, here the expected number of buildings destroyed given a 100 year ARI rainfall event is about 2.7. The next greatest total risk of dwelling destruction occurs again in the Beechmont Basalt Unit on slopes $>25^\circ$, here the number of buildings destroyed given a 100 year ARI rainfall event is about 1.3. The combination of the total risk of the Beechmont Basalt slope units accounts for 90% of the total risk for dwellings within the study area.

The total risk for the study area is about 4.5 buildings destroyed given a 100 year ARI rainfall event. In areas subject to debris slides, flows and falls, 1.8 buildings could be expected to be destroyed. This is less than half that for areas subject to slides and slumps where 2.7 could be destroyed. This estimate is based only on the present level and distribution of development and should not be transferred to proposed areas of development without reinterpretation.

Total Risk of Road Blockage and Destruction (Figure 7.10 and Figure 7.11): The total road length in areas subject to debris slides, flows and rock falls is 37 km. This is substantially less than the almost 700 km of road in areas subject to rotational slides and slumps (it must be noted that not all roads have been captured digitally). The only unit where roads are affected by debris slides is the Beechmont Basalt, which is transected by 13 km of roads that are impacted a total of three times from slides associated with the 1974 rainfall event. This suggests that on average within the Beechmont Basalt, a road blockage or destruction of an section of road caused by debris slides, flows and rock falls will occur every 5 km.

On slopes subject to rotational slides and slumps, roads impacted by landslides include those in the Beechmont Basalt, alluvium, Albert Basalt, Tertiary colluvium and the Mt. Gilles Volcanic units. Of these, the Mt. Gilles Volcanics, Tertiary colluvium and the Albert Basalt could given a 100 year ARI rainfall event be blocked or partially blocked every 1 to 2 km. These same roads could also be expected on average to have a section destroyed by landslide

about once every 5 km. The Beechmont Basalt and alluvium are less at risk, on average they could be expected to be blocked once every 10 to 15 km and sections destroyed by landslide about every 50 km.

Caboolture, Pine Rivers, Redcliffe, Brisbane, Ipswich, Redland and Logan areas

Fortunately, the low values of specific and total risk in Table 7.6 and Table 7.7 suggest that it is unlikely that existing buildings would be destroyed or people killed by landslides on cut slopes in Caboolture, Brisbane and Ipswich given a 100 year ARI rainfall event. However, this situation could change if more use is made of susceptible areas such as river banks or slopes requiring cut and fill. For debris flows, the 100 year ARI rainfall scenario may be sufficient to trigger a few flows from the escarpment in the far western part of Caboolture and Pine Rivers. These could cover, scour or flood roads in their path, and possibly cause flash flood or landslide damage to isolated buildings near the escarpment.

Redcliffe: Given the low lying terrain of the city, landslides are expected to be a minor problem and confined to rock falls and possible landslides along the low sea cliffs of Margate, Scarborough and Woody Point.

Brisbane: The maximum daily rainfall in Brisbane during the January 1974 floods was approximately equivalent to a 100 year ARI rainfall event. This triggered widespread failures in alluvial banks of the Brisbane River. Alluvial river bank failures would be expected to happen given a future similar scenario, along with possible landslides on hill slopes and river banks in unlateritised Tertiary sediments, and isolated landslides in pockets of colluvium or soil overlying older rocks, particularly near gully heads. Isolated small landslides may occur in road batters and cuts adjacent to buildings on hills.

Redland: Given the generally low lying terrain of the area, landslides are expected to be a minor problem confined to the Neranleigh-Fernvale beds, particularly on Mt Cotton; the low sea cliffs of North Stradbroke Island, Redland Bay and Wellington Point; the fissured clays developed on weathered basalt in the canal estates; and on the sand dunes of North Stradbroke Island. Landslide risk is considered to be very low, but the fatality at Amity Point should not be forgotten. The most likely cause of landslides in the mainland part of Redland will be from man-made cuts in hillsides underlain by the Neranleigh-Fernvale beds, where small wedge failures occur after rain, especially where prominent joints dip outwards into the excavation (Warwick Willmott, Geological Survey of Queensland, email communication, March 2001).

Logan: Given the terrain of the city, landslides are expected to be a relatively minor problem and confined, if they occur at all, to areas of steeper land on the slopes of Mount Cotton and Daisy Hill. The most common form of landsliding in Logan is likely to be small failures in cut slopes on some of the higher hills of the Neranleigh-Fernvale beds (Warwick Willmott, Geological Survey of Queensland, email communication, March 2001).

Limitations and uncertainties

Gold Coast Region

It is assumed that both landslide distribution and the distribution of development within geologic/slope units are random. This may in fact not be the case and may result in errors in hazard and risk calculations.

Research in these areas does not take into account failure on cut slopes and results should be related to natural slope failure only.

By dividing the risk analysis on the basis of slide type, ie. debris slides and rock falls on slopes $>25^\circ$ and rotational slides and slumps on slopes $<25^\circ$, and calculating appropriate hazard values, the assumption is that all slides in either zone conform only to that slide type. This is not necessarily the case and may result in the overestimation of risk on slopes $>25^\circ$ and underestimation of risk on slopes $<25^\circ$.

The assumption is that landslide intensity is uniform across a landslide.

Areas identified as having no landslide hazard may in fact be subject to minimal levels of residual hazard.

The calculations of vulnerability are based on the data derived from the Australian Landslide Database, the Australian Geomechanics Society (AGS, 2000) as well as the Cairns study (Leiba *et al.*, 2000). The estimates do not represent an assessment of vulnerability specifically for the study site.

The assumption exists that hazard and risk are independent of landslide magnitude.

Hazard and risk are based on landslide occurrence rather than area or volume.

A significant number of roads have not been captured digitally. The distribution of these roads appears to be random throughout the study area thus eliminating possible bias between one geological/slope unit and another.

Caboolture, Pine Rivers, Redcliffe, Brisbane, Ipswich, Redland and Logan areas

Nothing appears to have been published on landslides in the Caboolture, Pine Rivers, Redcliffe, Redland and Logan local government areas.

Landslides on cut slopes: Landslides have not been logged systematically after significant rainfall events to enable a local landslide recurrence relationship to be established so that a quantitative landslide risk assessment can be carried out. Data from Cairns were modified to take into account the lower rainfall in Caboolture, Pine Rivers, Brisbane and Ipswich. However, the landsliding mechanisms in Caboolture, Pine Rivers and part of Ipswich are undocumented, and the geology is different from Cairns. This may affect the applicability of the data. *The uncertainty in the Cairns specific risk estimates are of the order of one order of magnitude.*

The Cairns data assumed that the hazard is uniform over the entire hillslope. This oversimplification will underestimate the hazard in the parts of the slope immediately adjacent to cuts and fills, and will overestimate the hazard on parts of the slope distant from cuts and fills.

Because most of the batter failures in Cairns occur in rocks much more deeply weathered than those in Caboolture, Pine Rivers, Brisbane and Ipswich (Warwick Willmott, Geological Survey of Queensland, email communication, March 2001), the incidence of failures on unengineered batters in Cairns would be expected to be higher than in these areas for corresponding rainfall intensities. Consequently, the hazard and risk in these areas would tend to be overestimated by this methodology for cut slopes for which no mitigation measures had been taken, and would be grossly overestimated for slopes developed with competent geotechnical advice.

Errors in the average recurrence intervals will have been introduced by the method of interpolation of the Bureau of Meteorology IFD data, but these are probably small in

comparison with those introduced by importing Cairns observations into south east Queensland.

Debris flows: Debris flows and their deposits have not been specifically mapped in the Caboolture and Pine Rivers areas, and the extent of runout of debris flows during extreme rainfall events is unknown.

It is also not known what rainfall intensity or duration is necessary to trigger debris flows in the Caboolture and Pine Rivers areas.

Forecasting and warnings

The Bureau of Meteorology routinely includes a generic caution regarding the possibility of landslides during periods of heavy rain, such as those associated with cyclones. Given the very low probability and non-specific nature of the landslide threat, such warnings are probably adequate. There does not appear to be any justification for the establishment of an automated landslide monitoring system.

When slopes are developed using cut and fill, mitigation can usually be effected through proper geotechnical design. Mitigation of risk from debris flows, and flash floods from gullies, may be possible by engineering constructions such as levees and channels.

If it has not been done already, warning signs should be erected at cliffs when there is a potential for sand or rock to fall, causing injury or death. In the past four years, four children in Queensland have been temporarily buried as a result of two separate instances of their tunnelling into sand cliffs. If people had not been present to rescue them quickly, both incidents could have resulted in fatalities. Also, it should be noted that, for the whole of Australia, during the period January 1996 – June 1999, six out of the 12 landslides causing injury or death involved the fall or topple of a single rock!