LANDSLIDE FAILURE PERSPECTIVES IN PRACTICE
IN SOUTH EAST QUEENSLAND

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ABSTRACT
Quantitative Risk Analysis (QRA) is one of the tools used in Landslide Risk management. Ideally its matrix approach should provide similar conclusions when used by different geotechnical professionals. However in practice some differences in interpretation and application occur. This assessment tool is examined for various case studies in south east Queensland.

By examining landslide events that have occurred with the benefit of hindsight in order to calibrate the approach, one finds that the interpretation of consequences has scope for variation in the application of this QRA tool if it is applied as is. The perception of risk governs landslide risk management in practice in Queensland. Other consequential variables also have a significant effect and may govern the result of the risk assessment process. The QRA is a decision tool with risk analysis at its core, but users must also not overemphasise the analysis in a risk assessment approach.

1 INTRODUCTION
The Landslide Risk Management (LRM) approach in AGS (2000) and expanded in AGS (2007a, 2007b, 2007c and 2007d) has Guidelines and Practice Notes with commentary. AGS (2007a) introduces descriptors for risk zoning property loss criteria with the associated probabilities of occurrence for both the hazard and risk to life. This is discussed further as a quantitative risk analysis (QRA) matrix in the practice note (AGS, 2007c) with the corresponding risk level. A risk level has an associated numerical annual probability, yet such a number can be subjective to the user, as its “test” cannot realistically be verified in a forward prediction. This theoretically sound approach to LRM can translate to a subjective assessment and leaves many users uncertain on its application.

This paper examines probability inferences for various case studies in Queensland via

- Walking trails where minor landslide failures have occurred. A probability of failure can be derived from its areal extent. This represents a physical interpretation of an acceptable failure criterion for people traffic with no effect on property.
- River bank failures in Brisbane in terms of probability of failures rather than factors of safety. A calculated unacceptable probability of failure (and where failure has occurred) is compared to the probabilities of failure at surrounding areas which have not failed to date. The consequence for this site has a potential effect on property.
- The above event is compared with the lineal probabilities of failure along the river from historical data. Such failures affect both river traffic, and property along the river.
- A landslide prone stretch of a major road which is being realigned due to its high maintenance costs. This road represents an unacceptable probability of failure for vehicular traffic.
- A landslide prone stretch of a local road which has a high maintenance cost due to recent high rainfalls. Yet such failures represented an acceptable probability of failure for vehicular traffic on this road.

All of these represent actual slope failures in south east Queensland. These cases are used to examine (with the clarity of hindsight) the application of the QRA method.

Risk perception is initially discussed, as risk assessment is not only based on probabilities and consequences, but societal and political acceptance and perceptions and also the number of stakeholders involved.

It is also important to put landslide hazards in perspective compared to other natural hazards events, as landslides are often not stand alone events but occur in tandem with other hazards e.g. landslides tend to occur with flood or cyclone events or the next rain events following major bushfires when the ground has lost its vegetative cover.
The significant rainfall events in the summer of 2010 / 2011 in Queensland, culminating with major floods in central and south east Queensland, provide a significant spike in the landslide inventory data. Over 150 landslides were recorded in the Sunshine Coast region alone, affecting both properties and road connections. Significant events near to the waterways in Brisbane also occurred during this extreme rainfall event. These are briefly discussed.

2 A HISTORICAL PERSPECTIVE OF THE LRM DOCUMENT

The landslide which occurred at Thredbo Village on 30 July 1997 was the subject of extensive investigation and inquiry through a Coroner’s inquest (Hand, 2000). Eighteen people in the two lodges died in the landslide - the worst landslide disaster in Australian history. Excluding epidemics and war, the worst natural disaster in Australia in terms of fatalities was the 1938 heatwave in Victoria in which 438 people died (EMA Database). The Coroner (Hand, 2000) found that the landslide was triggered when water from a leaking water main saturated the south-west corner of the fill embankment of the Alpine Way setting off the first stage of the landslide. The causes of the tragic deaths which occurred as a result of that landslide are complex and included (summarising from Hand, 2000):

- The failure of any government authority responsible for the care, control and management of the Kosciusko National Park and the maintenance of the Alpine Way to take any steps throughout that period to ensure that the Village was safe from exposure to that marginally stable embankment.
- The approval and construction of a water main which could not withstand the movement which was taking place in the marginally stable Alpine Way embankment into which it was laid.
- Leakage from the water main leading to the saturation of the marginally stable fill embankment.
- The Alpine Way fill embankment was in a marginally stable state because of the way in which it was originally constructed for the limited purpose of use in connection with the Snowy Mountains Hydro-Electric Scheme.
- Landslides occurred along the Alpine Way leading up to Thredbo and adjacent to the Village throughout the period from the construction of the Alpine Way until July 1997. The history was well known although not recorded in any systematic fashion.

The Coroner accepted that much was done by the responsible government authorities over the intervening years to try to keep the Alpine Way and other poorly constructed roads in the Park operational. They had to struggle with the problems occasioned by inheriting roads not designed for the purpose to which they were later put and were subject to funding constraints.

The Coroner stated “It also seems to me that the geotechnical community needs to evaluate the way it conducts its investigations to ensure that investigations whether of conditions of roads or the suitability of building sites, be undertaken having regard to the potential effect of instability on human life and the risk of loss of life or injury”.

This latter finding was one of the key initiators that led to the production of LRM type documents. Leventhal (2007) provides the historical framework which led to the development of the current AGS LRM documents. The RTA’s Guide to Slope Risk Assessment (2001) was also developed in the period following an initial AGS (2000) Guideline. The RTA document is considered by many practitioners as a more operational document, but which follows the philosophy of the AGS documents.

It is important to note that there was a series of events that led to this tragic event at Thredbo and not simply one cause. This highlights the need to heed historical data, document observations, proper design and maintenance, and appreciate that “temporary” construction can often lead to permanent systems. This latter point suggests possible deconstruction to avoid such temporary systems being used beyond their purpose.

Given the Thredbo tragedy, a forum serves to remind the profession of the consequences of non vigilance. However risk can have different meanings to the profession, to legislators and to the public at large. It is therefore useful to have an initial background on both landslides as compared with other hazards as well as risk perception, before embarking into these Queensland cases of landslide risk management.
3 LANDSLIDES AS COMPARED WITH OTHER HAZARD EVENTS

Bryant (2005) ranks natural world hazards (Table 1). The ranking differs for individual countries and latitudes, e.g. drought would not be the number 1 ranked economic loss for the United States or the United Kingdom, although droughts can occur locally within those countries from time to time.

Table 1: Ranking of hazard characteristics and impacts Bryant (2005)

<table>
<thead>
<tr>
<th>Rank</th>
<th>Event</th>
<th>Degree of severity</th>
<th>Length of event</th>
<th>Total Area extent</th>
<th>Total loss of life</th>
<th>Total economic loss</th>
<th>Social Effect</th>
<th>Long Term Impact</th>
<th>Suddenness</th>
<th>Number of associated hazards</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Drought</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>4</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>2</td>
<td>Tropical Cyclone</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>5</td>
<td>1</td>
<td>5</td>
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<tr>
<td>3</td>
<td>Regional Flood</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>4</td>
<td>3</td>
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<tr>
<td>4</td>
<td>Earthquake</td>
<td>1</td>
<td>5</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>3</td>
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</tr>
<tr>
<td>8</td>
<td>Bushfire</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>9</td>
<td>Expansive soils</td>
<td>5</td>
<td>1</td>
<td>1</td>
<td>5</td>
<td>4</td>
<td>5</td>
<td>3</td>
<td>1</td>
<td>5</td>
</tr>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>Landslides</td>
<td>4</td>
<td>2</td>
<td>2</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>5</td>
<td>2</td>
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<td></td>
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<td></td>
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<tr>
<td>20</td>
<td>Flash Flood</td>
<td>3</td>
<td>5</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>5</td>
<td>1</td>
<td>5</td>
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<td></td>
</tr>
<tr>
<td>28</td>
<td>Subsidence</td>
<td>4</td>
<td>3</td>
<td>5</td>
<td>5</td>
<td>4</td>
<td>4</td>
<td>5</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>29</td>
<td>Mud and Debris Flow</td>
<td>4</td>
<td>4</td>
<td>5</td>
<td>4</td>
<td>5</td>
<td>5</td>
<td>4</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>31</td>
<td>Rockfalls</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>1</td>
<td>5</td>
<td></td>
</tr>
</tbody>
</table>

1 = Largest or most significant; 5 – smallest or least significant

Table 1 show that landslides are ranked differently from debris avalanches, creep and solifluction, mud and debris flows or rock-falls. Yet all of these are sub – categories of “landslides” for geotechnical classification purposes. Landslide hazards are considered middle order events within that assessment system. Often the landslide is an associated event so its effect may well be a subset of another event e.g. landslides occurring during earthquakes or storm events.

The table also includes the other land movements of expansive clays and subsidence which are also of interest to the geotechnical profession.

Bryant (2005) refers to the World Health Organisation data which shows the number of people killed or displaced due to natural hazards during the twentieth century. Some key numbers are:

- Total deaths are approximately 10,052,401 for 11 such highly ranked hazards of which 60,501 was associated with landslides, avalanches and mud flows i.e. 0.6% of deaths.
- The total homeless associated of 183, 533, 065 had landslide events having 3,759,329 i.e. 2.0% of homeless.
- The top 8 natural hazards (earthquake, flood, tropical storm, etc) had $631.25 billion damage associated with them, with landslides not being listed.

Based on the above world statistics one would expect Australia to have a lower landslide fatality and cost proportion as compared to other hazards, since the Australian continent is one of the flattest. Figure 1 shows the annual landslide cost in Australia represents less than 1% (Middelmann, 2007). Similarly, Figure 2 shows landslide events account for 2% to 3% of fatalities which is a surprisingly high figure as compared to world statistics.

The total socioeconomic cost of landslides was estimated at $500 million from 1900 to 1999, in 1998 dollars (quoted here from Middelmann, 2007). He also quotes the following infrastructure related costs.
• the construction cost of diverting the Lawrence Hargrave Drive coastal route around a cliff face subject to rockfalls was $49 million in 2006
• railway infrastructure in Wollongong amounted to $175 million from 1989 to 1996
• the cost of repairs to Reconstruction of the Alpine Way after the Thredbo landslide was $24 million.

All of these quoted significant cost examples are in New South Wales. This therefore begs the question, whether other States are experiencing similar but unreported costs. This is discussed further below.

4 ADDITIONAL DATA ON LANDSLIDE FATALITIES
In considering available data on fatalities from landslide, Wikipedia (Anon, 2011) has compiled the fatalities from major disasters in Australia since the late 1700's, using 215 reference sources. Events resulting in 10 or more fatalities are fully listed, with only significant events causing 1 to 10 fatalities included. This data shows 42 fatalities attributed to significant landslides.

The Australian Government data on landslide fatalities indicates a total of between 75 and 95 are attributable to landslides, the numbers varying by author. In some publications fatalities from children becoming buried while
digging holes at the beach or in sand cliffs is included as attributable to landslides, which would not seem to be the conventional understanding of a landslide. Accepting, however, that the number of fatalities is about 95, the highest estimate, Table 2 shows probabilities of loss of life in Australia for various natural disasters. This data was not expected to match exactly the Middelmann (2007) data but similar trends are observed i.e. Bushfire, floods, storms and cyclones present significantly more risk than landslides or earthquakes within the Australian context. “Heatwaves” is a disaster not covered in the “Natural Disasters” discussed in the previous sections and Figures.

Table 2: Fatalities and probabilities of loss of life from natural disasters

<table>
<thead>
<tr>
<th>Disaster</th>
<th>Qld</th>
<th>Rest of Australia</th>
<th>Total Australia</th>
<th>Qld</th>
<th>Rest of Australia</th>
<th>Total Australia</th>
<th>Ratio Qld to Rest of Australia</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cyclone</td>
<td>930</td>
<td>792</td>
<td>1722</td>
<td>3 x 10⁻⁸</td>
<td>4 x 10⁻⁹</td>
<td>6 x 10⁻⁹</td>
<td>7.6</td>
</tr>
<tr>
<td>Bushfires</td>
<td>0</td>
<td>623</td>
<td>623</td>
<td>0</td>
<td>3 x 10⁻⁹</td>
<td>2 x 10⁻⁹</td>
<td>0</td>
</tr>
<tr>
<td>Heatwaves</td>
<td>5</td>
<td>2542</td>
<td>2547</td>
<td>1 x 10⁻¹⁰</td>
<td>1 x 10⁻⁸</td>
<td>1 x 10⁻⁸</td>
<td>0.01</td>
</tr>
<tr>
<td>Flood</td>
<td>87</td>
<td>218</td>
<td>305</td>
<td>3 x 10⁻⁹</td>
<td>1 x 10⁻⁹</td>
<td>1 x 10⁻⁹</td>
<td>2.6</td>
</tr>
<tr>
<td>Landslides</td>
<td>5</td>
<td>37</td>
<td>42</td>
<td>1 x 10⁻¹⁰</td>
<td>2 x 10⁻¹⁰</td>
<td>2 x 10⁻¹⁰</td>
<td>0.9</td>
</tr>
<tr>
<td>Earthquake</td>
<td>0</td>
<td>13</td>
<td>13</td>
<td>0</td>
<td>6 x 10⁻¹¹</td>
<td>5 x 10⁻¹¹</td>
<td>0</td>
</tr>
</tbody>
</table>

+ Fatalities listed are those that only include more than one death per event. For landslides a further 40 could be included in individual events but these would not have a major effect on overall comparative risk levels.

Population statistics from 1788 have been obtained from Australian Government websites to relate the numbers of fatalities to the average population present over the years of the record.

For landslides it is interesting to note that the risk level in Queensland is similar to that of the rest of Australia. This is explained by the fact that while Queensland has had fewer fatalities, the population is proportionally lower. Table 2 also highlights that for Queensland, the natural disasters of cyclones and floods present a 300 times and 30 times greater risk, respectively, than that from landslides.

Regional landslide susceptibility assessment often requires a different approach from that at the micro level where limit equilibrium (factor of safety) slope stability analysis, or monitoring by geotechnical instrumentation is used to assess stability. A Geographic Information Systems (GIS) based approach may be appropriate as was shown for a regional case study in south East Queensland (Look, 2005). This case study was based on limited case study data, which used slope heights, orientation, geology, aspect, land usage, etc to assess the landslide susceptibility for a local shire. However susceptibility is not the same as risk.

5 THE PERCEPTION OF RISK

Slovic (2000) describes risk perceptions, in judging frequency of death occurring. Diabetes, lighting, strokes and stomach cancer were most underestimated while all accidents, tornadoes and floods were over estimated. Figure 3 shows this relationship of (mis)judgement. While landslides are not tabulated, it would be likely to be overestimated by a lay person, as the greater misjudgement seems to occur with natural events and/or those with less regular occurrence.
Figure 3: Relationship between judged frequency and the actual number of deaths per year (Slovic, 2000).

The technical concept of risks focuses narrowly on the probability of an event and the magnitude of specific consequences. However other aspects of risk such as voluntariness, personal ability to influence risk, familiarity with the hazards and the catastrophic potential also shape public response. Technological assessment of risk is therefore essential, but risk perception must also be considered. Social amplification of risk involving two major stages (or amplifiers) is also described in Slovic (2000) as (1) the transfer of information about the risk or event and (2) the response mechanisms of society.

Figure 4 shows the comparative fatality statistics of $10^{-6}$ to $10^{-7}$ for the natural hazards. Landslides are expected to be less based on the above considerations.

Societal risk for risk to life is captured in the GEO (1988) concept of “As Low as Reasonably Practical” – Refer Figure 5 for ALARP. This is also used in the LRM documents (AGS 2007d) and discussed in Ho et al. (2000) and Fell et al. (2005).
Figure 4: Comparative fatality statistics (Steffen et al. (2006), here from Read and Stacey (2009)).

Figure 5: Societal Risk Criteria (Geotechnical Engineering Office, 1988)
6 CASE STUDIES IN SOUTH EAST QUEENSLAND

The following case studies examine past and recent landslide events in south east Queensland. Some of these more recent landslides within the Brisbane region following the extreme 2010/2011 summer rainfalls are discussed further in Section 7 with respect to risk to property. All the case studies are then collectively summarised in Section 8 to compare the judgemental risk assessments made with the QRA risk assessment tool.

6.1 VERY LOW CONSEQUENCE - WALKING TRAIL AT MOUNT COOTTHA

This is a very low consequence scenario both in terms of economic loss or loss to life. This is a bush walking track (Honeyeater Track – Figure 6) used by the principal author for the past 15 years, where some minor slides have been observed with no known fatalities. No large scale issues are currently known to exist at this area. Within the risk zoning descriptors of the AGS (2007a), this would be expected to be classed as a very low risk zone, based on the observed history and use of the site. This case study therefore acts as a benchmark to see how the AGS (2007c) guideline matches this probability of failure.

The first 490 m from Greenford Street is generally sloping upwards from RL 60 m up to RL 100 m. From that point to the top, the track traverses a sidelong part of the hill, and the width narrows from approximately 2.0 m to 1.5 m at the sidelong areas to RL 240 m. The Google contour map does not show this clearly due to the scale of the map and contour interpolation.

Two landslides were noted over a total lateral visual distance of 25 m i.e. approximately 12 m either side of the track but this varies along the way. One area with distinctive change of vegetation with nearby lean of trees has been noted 6 m down slope of the track and can be classed as a potential slide area, but has not yet slipped. The overall sidelong gradient is 40 m in 100 m or 1 Vertical: 2.5 Horizontal, but was 1V: 1.5H at the slide areas and locally at other areas.

The surface geology is Bunya Phyllites which are exposed near to the surface with an extremely weathered to highly weathered profile. The sidelong route of the Honeyeater Trail is 1495 m

- Slide 1 occurs at the upside edge of track and is about 4 m long X 6.5 m wide X 0.8 m deep, an area of 26 m²
- Slide 2 occurs 5 m upside of track and is about 5.5 m long X 6.5 m wide X 0.8 m deep, an area of about 36 m²

The potential slide at 6 m downside of track is about 6 m long X 12 m wide, an area of about 72 m². Based on the above the total slide area is 62 m² over a total visual sloping area of 1495 m X 25 m = 37,375 m². The percentage slide area is 62 / 37,375 X 100 = 0.17% for this walking trail. This increases to 0.36% if the potential slide is included.

Using this information as a reference a What if self questionnaire is now used
• **What if** twice those size slides occurred → This is still considered low risk.

• **What if** twice those number and same size slides → This number is still considered low risk as this is a walking track with no consequences to property. Based on approximately 30 to 40 “G’days” typically over the 1 hour walk during the weekend the principal author estimates less than 1,000 users over the weekend, with significantly less during the week. The low number of users and when factored for its temporal distribution indicates a very low risk to life.

Therefore while 0.17% to 0.36% currently exists, an increased factor of 4 (based on above *what ifs*) with a resulting probability if 0.7% to 1.4% (~10^{-2}) would still be considered acceptable for this walking trail / parkland. How would this number translate into an annual probability of failure is uncertain. Given, these observations have been there for at least 15 years with no further occurrences, an inference is here made. A design life would typically be 50 years or less, resulting in an annual probability of failure in the range 10^{-3} to 10^{-4} per annum.

Using the AGS 2007c, Appendix C this indicative annual probability is “possible to unlikely” and given the insignificant consequence to property would be zoned as a very low risk.

This matches favourably with the original assessment prior to the detailed risk matrix classification. The conclusion from this case study is that at this consequence level the AGS 2007 descriptors are a reasonable fit to this case study.

Part way through the preparation of this paper significant summer rainfall events occurred culminating in the Brisbane floods in early 2011. No observed failures occurred along the above track during this period. However, an adjacent side-track (the Reservoir Trail – 425 m length which leads to the top of Fleming road) had 2 minor failures during that period. This is a mainly paved private road with a locked gate. The paved side drains were blocked (and still are at the time of writing this paper), with no consequences to any (infrequent) road user or the performance of the road (Figure 7). In this case the total square area of the two slides is 15 square metres over a visible square area slope of 425 m x 8 m, an area of 3400 sq m, or an occurrence of 0.44% which is within the range of the nearby track previously discussed.

The summer rainfall 2010/2011 for Brisbane was 953 mm compared to 415 mm average i.e. 230% of the summer average.

![Figure 7: Private road – blocked drain – very low consequence.](image)

### 6.2 VERY HIGH CONSEQUENCE: BRUCE HIGHWAY AT BLACK MOUNTAIN - MAJOR ROAD

In 2001, a study of the above roadway was carried out for Queensland Main Roads. The Black Mountain area is located between Cooroy (Elm Street) on the eastern side of Figure 8 and Pomona Connection Road along the Bruce Highway of the Sunshine Coast Region. The study was over approximately 4 km with cuttings up to 12 m and several embankments over most of the length. The Pomona (Tertiary age) and Kin Kin (Triassic age) Beds are the dominant geology although there are also alluvium intrusions.
There are rock-falls occurring along this constrained area, as well as various embankment slides that had to be repaired at various times, including the use of a sheet piled wall and toe berm. Look et al. (2007) discussed a creep failure at this area where a dilatometer and inclinometer was used to assess the movement.

Over the 8 km total length of slopes at this area, there was over 225 metres with a record of failure or assessed as a potentially unstable i.e. a 2.8% occurrence of failure along this length. As this was over a 7 year data time frame, the probability is 0.4% annually using an average occurrence rate. However these failures did not affect the travelled lanes as there was a rock trap fence in the rock fall area and at the embankment slide areas occurred in areas with a suitable shoulder area with suitable barriers.

The cost of damage to this infrastructure is minor, and based on the Quantitative risk assessment (QRA) provided in the AGS (2007c) document, the risk could be assessed as moderate. The AGS (2007c) document provides guidance in Appendix C on risk calculations when fatalities could occur. This case study predates that document, but irrespective of that approach advocated, the road user risk was considered high at the time as well as the potential for accidents in an area where the road regularly changed from 2 lanes to one lane. The vulnerability of the risk user therefore governed during any “minor” cost maintenance at this area.

This case study provides a benchmark on what was considered a (societal) unacceptable risk to the road user at that time by the various parties, client and consulting engineer. The average annual daily traffic (AADT) was 12,000 vehicles in 1999, but was predicted (at that time) to be approximately 17,000 and 23,000 vehicles per day for the 10 year and 20 year prediction respectively. A procedure for estimating temporal and spatial variability is shown in Roberds (2005). The AGS (2007d) example uses a vulnerability of a person in the vehicle to be 0.3 and 0.15 for the different lanes, and also illustrates an approach on temporal spatial probability. No attempt is used herein to check using such an approach as the changing number of lanes at various sections would need to be considered, coupled with this case study having no known historical record of the slides / rockfalls directly affecting the travelled lanes.

AGS (2007c), in the Practice Note Guidelines for LRM Studies, suggest a tolerable risk of loss of life for the person most at risk to be $10^{-4}$/annum for an existing slope. Using the ALARP approach the resulting evaluation would show an unacceptable risk level.

6.3 LOW CONSEQUENCE: LOCAL COUNCIL ROADS AT SUNSHINE COAST - MINOR ROADS

Following the significant rainfall events in 2010/2011, there were several road closures due to the number of landslides across the State. Detours are often required and the demands of the travelling public require an emergency response to open the road as soon as possible or keep access where possible with suitable temporary traffic control measures such as barriers, road signs, traffic lights, etc. Despite these controls, one has to reduce the vulnerability of the travelling public as soon as possible by stabilisation of the landslide area followed by the road repair.

Yet in these emergency response situations, there is little time for detailed geotechnical investigations, surveys and subsequent analysis, as often this requires several weeks before a confident solution can be tabled. Only then can mobilisation of suitable plant begin for the landslide rectification, which may also take several weeks. Combined with the quantum of landslides (over 125 in the Sunshine Coast region alone), such an approach to a confident and cost effective solution is not always possible. The travelling public is exposed to significant risk during the initial time period after the failure, as well as the increasing public angst from a perceived delayed response.
response. The time requirements associated with a confident solution must therefore be weighed against the risk of doing nothing and a delayed response. An emergency response adopting a less confident solution may be required in some instances to minimise the immediate risk to the travelling public.

A local road is now examined as there is a high maintenance cost to repair this road. This site is a local road in Montville, Sunshine Coast. The road has experienced several slides from 9.3 km to 12.1 km. A cumulative slide length of 425 metres over this 2.8 km length equates to 15% of the road length. However if one considers the total length of 5.6 km (2 sides) and using the corresponding lengths on either side results in 450 m length on either side affected and now equates to 8% of length. Most of these recent slides observed on this road occurred in the past 12 months and none in the previous 20 years, although historically a 100 m section of road was known to have been built over a historical area of movement, and a 20 m Gabion wall was built at another area along this road (Modolo, 2011). Using this 20 year time frame, the relative length may be considered to give 0.4% annual probability of occurrence, although the events have been concentrated to the 2010/2011 summer rainfall events and not distributed over the whole period.

This is overall a low consequence situation as there was negligible effect on property or on life, despite the social effects of the thru road traffic having to use alternative routes and the imposition of load limitations. There were some moderate risks at some areas where services (electrical & communications) could be affected. With this current quantum of slides, some practitioners may well argue that this is “high” risk road. However this is without regard to the negligible slides on this road for the previous 20+ years, or the low traffic volume affected.

This road is near the Maleny area, where the summer rainfall 2010/2011 was 1849 mm compared to 796 mm average i.e. 232% above average summer average (Bureau of Meteorology). The summer rainfall 2010/2011 for the nearby Kenilworth areas was 1232 mm compared to 532 mm average i.e. 231% of average summer rainfall. This shows a similar proportion variation although a different magnitude rainfall. At this stage no analysis has been carried out to assess the relationships between antecedent rainfalls to landslides.

![Figure 9: Local Road – Low consequence - high maintenance cost following recent rainfall.](image)

An emergency risk matrix approach was adopted for this and similar affected roads where the risk to the public was greater than could be accepted if the do nothing and wait for a confident geotechnical solution was adopted. The matrix shown in Figure 10 illustrates the relative ranking approach and varied solutions used for this emergency situation for some of these slides and will not be discussed further here.
6.4 HIGH ECONOMIC CONSEQUENCE: BRISBANE RIVER – BANK FAILURES

This case study examines the probability of river bank failures in a major flood event.

In January 1974 Brisbane experienced a major flood event following weeks of heavy rainfall and the passage of Cyclone Wanda. Generally this event was considered to have about a 1 in 100 year return period in terms of river flows. Immediately after the flood, falling river levels led to the initiation of numerous slides in the predominantly alluvial soils of the river banks. The then Department of Harbours and Marine subsequently commissioned mapping of these slides, a copy of which was provided to Brisbane City Council (Coffey & Hollingsworth, 1975). The mapping identified seven modes of failure consisting of straightforward erosion of banks plus six landslides with rotational modes. The results, in terms of probability of failure per unit length of river bank, are summarised in Table 3.

Excluding the erosional failures, 9.8% of the total bank length was affected by slide failures, the majority occurring during the week after the flood peak as the river fell to normal levels. This could be considered as an annual probability of failure of $2.7 \times 10^{-3}$ although obviously data is scarce on the occurrence of failures prior to 1974. Similar size floods of 4.5 m or above at the City Gauge has occurred seven times since the first recorded flood in 1840, giving an average occurrence period of about 30 years, which indicates the adopted recurrence in Table 3 as reasonable. As these floods were all of a significant level and submerged a large proportion of the alluvial banks, the occurrence of drawdown failures would be expected to be of similar order of magnitude during each event.

Table 3: Probability of Flood induced River bank Failures

<table>
<thead>
<tr>
<th>Failure Mode</th>
<th>Erosion</th>
<th>Translational slide of soil over rock and deeper joint dominated slides</th>
<th>Low level small rotational slide</th>
<th>Higher level large rotational slide</th>
<th>Scour induced block failures</th>
<th>Major rotational slides</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Approximate Failure length (m)</td>
<td>2605</td>
<td>955</td>
<td>820</td>
<td>2870</td>
<td>400</td>
<td>660</td>
</tr>
<tr>
<td>-------------------------------------</td>
<td>------</td>
<td>-----</td>
<td>-----</td>
<td>------</td>
<td>-----</td>
<td>-----</td>
</tr>
<tr>
<td>Failure length per m of bank +</td>
<td>0.045</td>
<td>0.016</td>
<td>0.014</td>
<td>0.049</td>
<td>0.007</td>
<td>0.011</td>
</tr>
<tr>
<td>Failure length per m of bank +</td>
<td>4.5</td>
<td>1.6</td>
<td>1.4</td>
<td>5</td>
<td>0.7</td>
<td>1.1</td>
</tr>
<tr>
<td>Annual probability of failure ++</td>
<td>1.25 x 10^-3</td>
<td>4.58 x 10^-4</td>
<td>3.93 x 10^-4</td>
<td>1.38 x 10^-3</td>
<td>1.92 x 10^-4</td>
<td>3.17 x 10^-4</td>
</tr>
<tr>
<td>Annual probability of failure ++</td>
<td>1.25 x 10^-3</td>
<td>Slides excluding erosion 2.74 x 10^-3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

+ total length of bank considered was 57.9 km.
++ A 36 year period was assumed based on a similar scale recurrence of this event in 2011.

As a comparison Look (1999) examined a river bank failure along the St Lucia stretch and combined soil variation and tidal variation (a time factor to model ground water variations) to show the annual probability of failure was 10^-3 adjacent to that failed area for the operational water level but the “stable area” adjacent to the slide could be as high as 0.075 for a significant MHWS to MLWS variation. These probabilities were derived from back-analysis of a failed slope. The cost of the repair was 2.5 times the cost of the structure.

In terms or human risk, it is understood there was no direct loss of life associated with these river bank failures. In the 2011 event no injuries or fatalities were recorded from riverbank failures. It is also thought that no fatalities in 1974 have been attributed to landslides along the banks associated with the flooding in that year. Specific data on rate of movement was not available.

The risk to property is more problematic. The data from the 1974 event has not been able to be sourced in terms of actual property losses from landslides. For the 2011 event the assessment will take several months and to date no data are yet available.

From personal observations, the actual cost of property damage from riverbank landslides only, is not considered to be significant. A handful of houses were partially damaged, mainly the outside pool and deck areas, and in numerous cases there was the loss of fences and garden walls and beds. Several roads and footpaths were also partially damaged. The significant factor in property damage and risk is not the cost of the damage per se, but the cost of remediation. This is discussed further in later sections.

### 7 RISK TO PROPERTY

In early 2011 Brisbane experienced numerous landslides following weeks of heavy rainfall. The landslides that occurred during this event, within the Brisbane Council area, involved generally smaller rock falls from urban road cuttings, fill slope failures generally associated with creek banks and also extensive riverbank slides along the Brisbane River.

Property damage, as defined by the value of property damaged or lost in the landslide, would not appear to be significant. No data is yet available on the assessed costs of damage by insurers; however observations during inspections of many of the landslides suggest the monetary value of property damaged to be generally low. An example of several of the landslides where property damage was incurred is given in Table 4.

These examples are typical of the numerous landslides that occurred in January 2011 and represent many of the worst slides where damage occurred. Many other smaller and similar slides occurred that involved negligible or no damage to property. What is apparent is the significant discrepancy between the value of the property damage incurred, and the cost to reinstate or remediate the failures, and the need to do so.

<table>
<thead>
<tr>
<th>Case</th>
<th>Landslide Extent</th>
<th>Description of Property Damage</th>
<th>Severity of Damage to Asset affected</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Fill slope on creek bank failed affecting house immediately above the bank</td>
<td>Undermining of house foundations and loss of rear fence and paved area. House structure undamaged on pile foundations</td>
<td>External areas damaged, house intact</td>
</tr>
<tr>
<td>2</td>
<td>Fill slope on creek bank failed affecting house immediately above the bank</td>
<td>Loss of rear fence and vegetable garden. House unaffected</td>
<td>Minor external (fence) damage</td>
</tr>
<tr>
<td>3</td>
<td>Large rotational slide on riverbank</td>
<td>Pool and deck severely damaged and house verandah poles moved. Public sewer main broken.</td>
<td>Major external damage to pool and decks and likely structural damage to house. Public</td>
</tr>
</tbody>
</table>

Table 4: Typical indicative direct loss of property due to landslide.
<table>
<thead>
<tr>
<th>Case</th>
<th>Landslide Extent</th>
<th>Description of Property Damage</th>
<th>Severity of Damage to Asset affected</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>Medium size rotational slide on fill slope above creek</td>
<td>Retaining wall collapsed and potential undermining of edge of house foundations</td>
<td>Medium external damage and possible structural distress to house</td>
</tr>
<tr>
<td>5</td>
<td>Medium size rotational failure on riverbank</td>
<td>Low usage roadway damaged</td>
<td>Road damage required closure</td>
</tr>
<tr>
<td>6</td>
<td>Medium failure on fill slope above creek</td>
<td>Road undamaged but closed for safety</td>
<td>Minimal damage to road</td>
</tr>
<tr>
<td>7</td>
<td>Rock slope failure</td>
<td>Footpath above collapsed</td>
<td>Footpath above requires reconstruction, plus footpath below buried by debris</td>
</tr>
<tr>
<td>8</td>
<td>Rotational / drawdown failure of riverbank</td>
<td>Loss of gardens and landscape retaining walls</td>
<td>Only garden areas damaged</td>
</tr>
<tr>
<td>9</td>
<td>Translational failure on fill slope</td>
<td>Footpath destroyed at base, retaining walls, fences and gardens damaged at crest</td>
<td>Footpath and retaining walls damaged. No house or road damage.</td>
</tr>
<tr>
<td>10</td>
<td>Liquefaction failure of edge of fill slope after inundation from creek</td>
<td>Sewer main broken.</td>
<td>No property or house damage, sewer main requires relocation.</td>
</tr>
<tr>
<td>11</td>
<td>Several minor rockfalls from urban road cuttings</td>
<td>None to property, footpaths require clean up.</td>
<td>Negligible damage to footpaths</td>
</tr>
<tr>
<td>12</td>
<td>Rotational slide on riverbank</td>
<td>Concrete bikeway destroyed in slide area</td>
<td>Bikeway requires reconstruction</td>
</tr>
</tbody>
</table>

Under the LRM approach, the risk to property is considered as the risk to a structure, but includes a reference to the stabilisation works required (AGS, 2007c). In the actual landslides that occurred, it became apparent that the relationship between the property damage incurred and the stabilisation works required are different to that assumed in the LRM guidelines. Appendix C of the AGS Practice Note Guidelines (AGS, 2007c) identifies the Qualitative Measures of Consequence to Property as ranging from Catastrophic to Insignificant. Catastrophic is described as complete destruction of a structure and major engineering works for stabilisation, while minor for example is described as limited damage and requiring some stabilisation.

The qualitative risk assessment (QRA) is used to define the risk level. Examples of the risk level implication are then provided.

The experience of the recent Brisbane events is that examples of minor or limited damage require sometimes major stabilisation works of equal magnitude to those assumed necessary where significant structural damage occurred. This apparent contradiction would have a significant effect on the risk determined for an assumed event if remedial measures were to be ignored.

As an example, Case 2 involves notionally a $0.5 M house. The slide that occurred destroyed the rear fence and a 1 m wide section of the yard. No distress or damage occurred to the building itself. A hypothetical risk assessment that could have been undertaken prior to the flood and slide would probably identify the likelihood of the slide, and its extent, and due to the slope geometry would also have identified in the majority of cases that a slide would probably not affect the house.

Using Appendix C of the Practice Note Guidelines it would be reasonable to assume that the consequence to property might be Level 4 – minor with 5% as the notional value of damage if remedial works were ignored. Therefore if the Likelihood of the event was determined as Level C - Possible the risk would be determined as Moderate. If the event was determined as Level A - Almost Certain, the risk would be high, but with still only a 5% notional value of damage. In fact the slide directly only caused about 2% damage, the cost of a fence, but the remedial works is almost $1 M, or 200% of the property value. The reason is that the landslide resulted in a high steep failure scarp within the property yard, which posed a serious threat of ongoing collapse and further damage, plus a real threat to safety of the occupants. While this regression (in hindsight) should form part of the danger and the risk analysis, it is unlikely to have been predicted without the hindsight benefit. Continued slides would also eventually endanger adjoining properties although these properties were not directly impacted in the initial failure.

The majority of the cases above are in the same category, where the cost of reinstating the failures far outweighs the notional value of damage to fences, walls or footpaths. It could be argued that the failures need not be
reinstated if the value of infrastructure affected is minor, but in all cases the damaged sections are an integral part of a road or footpath system within an established developed area. There is therefore a social responsibility on the part of the local authority to reinstate even slightly damaged areas, and a public expectation that this will occur (Thorley and Weingarth, 2007).

Diversion around a slide for example would not be feasible in most cases. Similarly in private properties it is not reasonable to ignore for example a large rotational failure that has damaged, or removed in some cases, a proportion of a property and garden. Obviously for falling boulders from a cliff the current approach would be reasonable, but for larger rotational slides which remove the actual land itself the approach could be reconsidered. Qualitative measures of consequence to property could be redefined to take account of the actual costs of reinstating the land for these types of large rotational landslides, and not be based solely on the cost of damage to property, especially if the likely property damaged is not the house itself.

8 DISCUSSION

Table 5 below provides a summary of the case studies discussed in this paper. In most cases the probability of failure for actual landslides assessed in South East Queensland was $10^{-2}$ to $10^{-3}$ - however the consequential loss was different in each case. Using the LRM risk matrix (AGS 2007c), the risk could range from very low to very high for this probability of failure. The local road case (Sunshine Coast Region) and Brisbane River compared favourably with the LRM risk level implication which could reasonably be assessed before the event.

In the other cases, the actual risk level implication also considered the ALARP principles, but was factored for the high cost of repair, risk to the travelling public, alternative routes and /or the current practice of acceptable risks, as compared to other natural hazards.

If one used the risk level implication (in hindsight) in most cases this was not coincident with the forward risk level advocated in a forward prediction QRA approach, although the trending was approximately comparable. Table 6 considers the effect on the travelling public, and also what seems to be an acceptable societal risk to date.

In risk assessment the consequences may not be limited to property damage and loss of life/injury (Fell et al., 2005). Other consequences may include loss of reputation, consequential costs (e.g. a road is closed for some time affecting business along the road), political repercussions, and adverse social and environmental effects. These factors need to be considered, although often not directly, in the QRA process.

Table 5: Summary of case studies examined in this paper.

<table>
<thead>
<tr>
<th>Facility</th>
<th>Evaluation Method</th>
<th>Existing Annual probability of failure</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mt Cootha Walking Track</td>
<td>Area method</td>
<td>0.2% to 0.5% (2011)</td>
<td>1.0% could be acceptable for this very low consequential loss</td>
</tr>
<tr>
<td>St Lucia boat shed river bank failure</td>
<td>Back analysis</td>
<td>7.5% for “stable” area for a significant tide event (1996) 0.1% operational condition</td>
<td>0.1% operational seemed acceptable, but 7.5% even for an extreme event was considered unacceptable and some stabilisation works occurred</td>
</tr>
<tr>
<td>Brisbane River</td>
<td>Lineal method</td>
<td>0.27% occurred (prior to 2010)</td>
<td>0.3% currently although significant rectification cost for relatively “low” economic value</td>
</tr>
<tr>
<td>Main Road at Black Mountain</td>
<td>Lineal method</td>
<td>0.4% occurring (2005)</td>
<td>0.4% is not acceptable for a major road due to vulnerability of travelling public. Considerations on risk to life governs</td>
</tr>
<tr>
<td>Local Road at Sunshine Coast Region</td>
<td>Lineal method</td>
<td>0.4% (2011)</td>
<td>0.4% is acceptable as a local road, although high maintenance cost for this extreme event</td>
</tr>
</tbody>
</table>

Table 6: Comparison of Predicted Risk and the previously adopted Risk Level

<table>
<thead>
<tr>
<th>Facility</th>
<th>Annual</th>
<th>LRM – QRA approach</th>
<th>Previously</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mt Cootha Walking Track</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>St Lucia boat shed river bank failure</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brisbane River</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Main Road at Black Mountain</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Local Road at Sunshine Coast Region</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Location</td>
<td>Probability of Failure</td>
<td>Likelihood Level</td>
<td>Consequences to Property</td>
</tr>
<tr>
<td>--------------------------------</td>
<td>------------------------</td>
<td>------------------</td>
<td>---------------------------</td>
</tr>
<tr>
<td>Mt Cootha Walking Track</td>
<td>1.0%</td>
<td>B</td>
<td>Insignificant</td>
</tr>
<tr>
<td>St Lucia boat shed river bank</td>
<td>0.1%</td>
<td>B</td>
<td>Catastrophic</td>
</tr>
<tr>
<td>Brisbane River</td>
<td>0.3%</td>
<td>B/C</td>
<td>Medium</td>
</tr>
<tr>
<td>Main Road at Black Mountain</td>
<td>0.4%</td>
<td>B/C</td>
<td>Medium</td>
</tr>
<tr>
<td>Local Road at Sunshine Coast</td>
<td>0.4%</td>
<td>B/C</td>
<td>Minor</td>
</tr>
</tbody>
</table>

The above should not be considered as criticism of the QRA technique. The alternative of hiding behind “professional opinions” lacks accountability for decision making which the LRM approach provides. However as the LRM has QRA at its core, one must also be clear that this tool is not overemphasised and becomes the only basis for a decision. Other consequenatial losses also need to be considered that are not formally part of the QRA matrix in AGS 2007c.

### 9 CONCLUSION

Case studies in South East Queensland are used to compare the intent of the LRM document and what is occurring in practice locally. The bigger picture of Natural Hazards risk was also discussed to show that the consequences of floods and cyclones far outweigh that of landslides in Queensland. That said both authors (at the time of writing this paper) have been recently spending a significant amount of time assessing landslides in South East Queensland and are aware of over 150 such incidents following the rains associated with the Brisbane floods.

The consequential risks do not seem to align always with the LRM intent, with other considerations affecting the risk decision beyond cost of property. A few of these that include:

- the cost of rectification in many cases far outweigh the property value
- societal impacts
- available funding with due consideration to the pecking order as compared to other hazards
- public perceptions

The qualitative risk assessment leads to an initial assessment which may not necessarily be coincident with the reality of the final risk decision. Thus the hindsight view herein is different in some cases from the foresight assessment using the LRM.

The AGS (2007) approach is theoretically sound, yet the risk perception as outlined herein seems to govern in the Queensland practice. This should not be seen as not advocating this LRM approach, but understanding that risk perception and an engineering output may not be fully coincident. The QRA approach is a useful framework and a tool for ranking and decision making, but still requires judgement on other consequences which go beyond property value and risk to life to be applied in practice.

### 10 ACKNOWLEDGEMENTS

These case studies were based on the author’s experiences on various landslide studies. These are the opinions of the authors and do not reflect those of the organisations associated with these studies. The paper benefited from the critical review of Bruce Walker.

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