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Slope instability, hazard and risk associated with a rainstorm event - a case study

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Abstract

Over the last few decades there has been an increasing awareness of landslide hazard and risk in many coastal regions of Australia. Urban communities in hilly areas are, from time to time, adversely affected by rainfall-induced landsliding. However, acute awareness of hazard may be absent during periods between significant rainstorm events. In general, the serious consequences of landslides to property and life have been underestimated in Australia. It is now known that at least 80 deaths can be attributed to a number of landslides (Leiba, 1998). Some of these events have focussed the attention of the public, the most important being the Thredbo tragedy associated with the loss of 18 lives at the Thredbo in the Snowy Mountains region of New South Wales on July 30, 1997. That landslide was, however, not the consequence of a rainstorm event unlike most of the slope instability that occurs in Australia. This paper is concerned primarily with landsliding associated with the August, 1998 rainstorm event which affected the hilly suburbs of Wollongong along the Illawarra escarpment south of Sydney (Fig.1). The importance of protecting the escarpment is highlighted by the report of a recent commission of enquiry ordered by the State Government of New South Wales in recognition of widespread and sustained public concern (Commission of Inquiry, 1999).

Keywords

event, instability, slope, associated, case, study, risk, rainstorm, hazard

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Slope Instability, Hazard and Risk Associated with a Rainstorm Event - A Case Study

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INTRODUCTION

Over the last few decades there has been an increasing awareness of landslide hazard and risk in many coastal regions of Australia. Urban communities in hilly areas are, from time to time, adversely affected by rainfall-induced landsliding. However, acute awareness of hazard may be absent during periods between significant rainstorm events. In general, the serious consequences of landslides to property and life have been underestimated in Australia. It is now known that at least 80 deaths can be attributed to a number of landslides (Leiba, 1998). Some of these events have focussed the attention of the public, the most important being the Thredbo tragedy associated with the loss of 18 lives at the Thredbo in the Snowy Mountains region of New South Wales on July 30, 1997. That landslide was, however, not the consequence of a rainstorm event unlike most of the slope instability that occurs in Australia. This paper is concerned primarily with landsliding associated with the August, 1998 rainstorm event which affected the hilly suburbs of Wollongong along the Illawarra escarpment south of Sydney (Fig.1). The importance of protecting the escarpment is highlighted by the report of a recent commission of enquiry ordered by the State Government of New South Wales in recognition of widespread and sustained public concern (Commission of Inquiry, 1999).

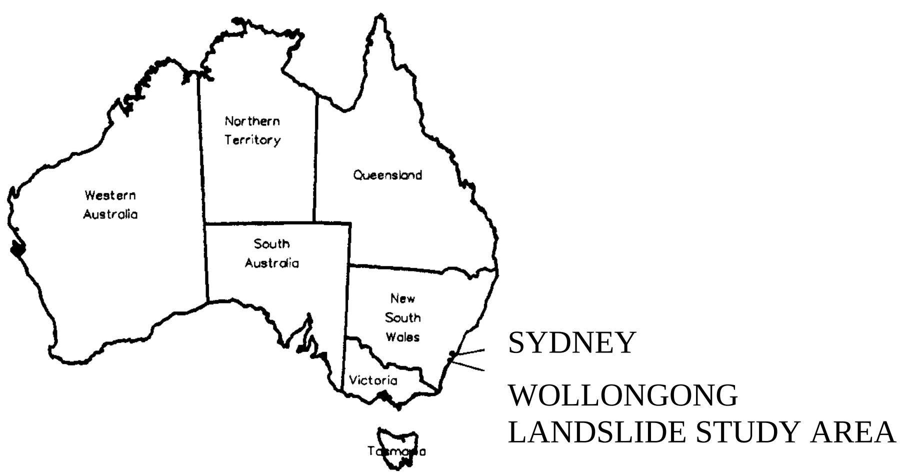

Figure 1. Location Plan

THE AUGUST 1998 RAINSTORM EVENT

The rainfall event extended from 6 p.m. Eastern Standard Time (EST) on Saturday 15 August to 6 p.m. EST on Wednesday 19 August 1998. The highest rainfall total was 745mm recorded at Mt Ousley. Extremely heavy rainfall occurred on 17 August 1998 between 5 p.m. and 8 p.m. causing flash flooding with extensive damage to property and the loss of one life. Before *5* p.m. on 17 August the rainfall total was 375mm over 47 hours. From 9 am Monday 17 August to 9 am Tuesday, 18 August the rainfall total was 445mm. The temporal pattern of the rainfall event and the accumulated rainfall from Mount Ousley rainfall station is shown in Fig. 2.

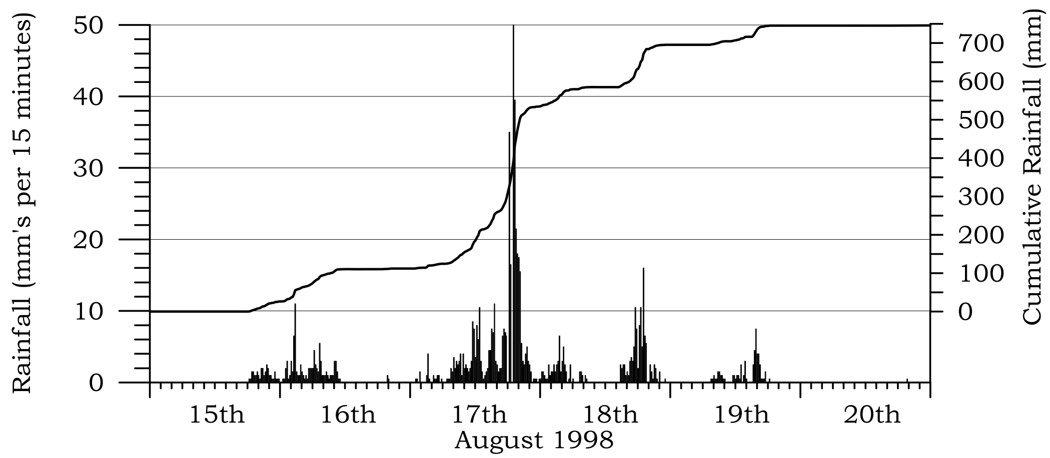

Figure 2. Temporal Pattern of 15 minute and Cumulative Rainfall at Mount Ousley

Return periods over 1 in 100 years were estimated for durations between 30 minutes and 6 hours along the top of the escarpment near Mount Ousley, Rixons Pass, Bulli Pass, Balgownie Reservoir and Beth Salem (Evans and Bewick, 1999). It is interesting to note that most of the above locations include areas of the urban Illawarra, which have historically had frequent landslide occurrences during major rainstorms such as the one of August 1998. Spatial distributions of total rainfall over different periods during the storm are considered important for landslide risk but are not included here due to space limitations.

LANDSLIDES TRIGGERED BY THE AUGUST 1998 STORM EVENT

The flash flood that occurred immediately after the peak of the rainstorm event on the evening of 17 August caused extensive damage to property and the loss of one life. Initially there was limited awareness of significant slope instability between 18 and 20 August although it was apparent later that many of the landslides and debris flows occurred during this period. A total of 191 geotechnical problem sites, including 148 sites of slope instability have now been identified and there may be several others which remain to be discovered. It is important to note that the local landslide database developed during recent research had only 328 landslide sites prior to this storm event. The precise time of occurrence of many of the identified landslides within the rainstorm period is not known or cannot be established. Some landslides were reported soon after they occurred while others were discovered during direct field inspections and inspections from the air by helicopter.

PREDICTION OF LANDSLIDING

During recent research at the University of Wollongong the concept of ARPET (Antecedent Rainfall Percentage Exceedance Time) has been proposed in attempts to develop relationships for a given region between the amount of rainfall, its frequency during a historical period and either (a) the occurrence of limited lateral slope movements or (b) the occurrence of disruptive lateral movements (or slope failure). Developing such quantitative measures requires a careful observational approach in addition to a comprehensive analysis of rainfall data.

Based on a consideration of the approximate ARPET values, very high likelihood of disruptive movements/landsliding was perceived and the University of Wollongong informed the media accordingly in a release on 19 August 1998. Daily rainfalls and two different periods of antecedent cumulative rainfall are shown in Fig. 3 along with the threshold magnitudes and associated ARPET values for (a) Rate Increase (initiation of movement) and (b) Failure. Note that the ARPET values are based on 20 year rainfall data on selected rainfall stations and that threshold values are based on observations of inclinometers at selected sites. It is of interest to examine whether the threshold values required for (a) initiation of lateral movement (rate increase) and (b) disruptive movement (failure) were exceeded considering the different antecedent periods.

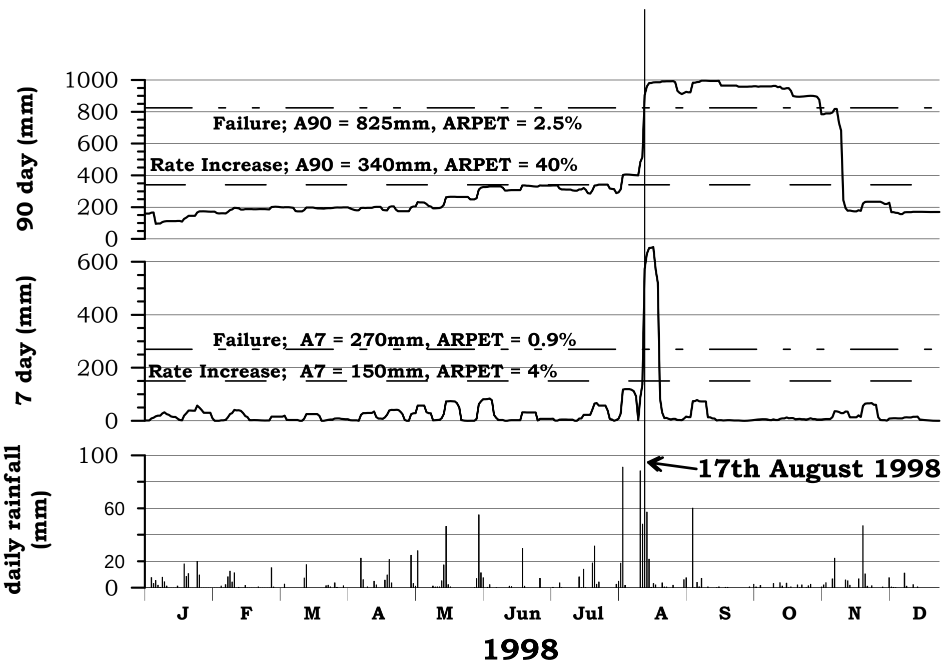

Figure 3. Rainfall pattern during 1998 including August rainstorm (Woonona rainfall station) showing cumulative rainfall, ARPET values and threshold rainfall amounts for (a) rate increase of movement and (b) for failure, considering 7 and 90 day antecedent rainfall periods (after Flentje, 1998).

Four antecedent rainfall periods, 7, 30, 60 and 90 days were considered. Only for the 90 day antecedent period were threshold values for initiation of movement (or rate increase) exceeded before the peak of the storm on 17 August. On the other hand the threshold values for 'failure' were exceeded during the peak of the storm for all the four periods. From experience the 7 day to 30 day range is significant for shallow slides and debris flows and a significant proportion of these failures did occur. However, the 30 day to 90 day range correlates with reactivation or 'failure' of deep seated landslides. While many of the existing deep seated landslides did reactivate, there was insignificant or limited disruption. This can be attributed to the fact that the bulk of the rainfall occurred in a very small period of time. Infiltration to the subsurface during the storm and a consequent sustained increase in pore water pressure would have been relatively small. Consequently, uncertainties are associated even with this comprehensive approach based on analysis of ARPET for different antecedent periods. The temporal distribution of rainfall needs to be considered very carefully to reduce the uncertainty.

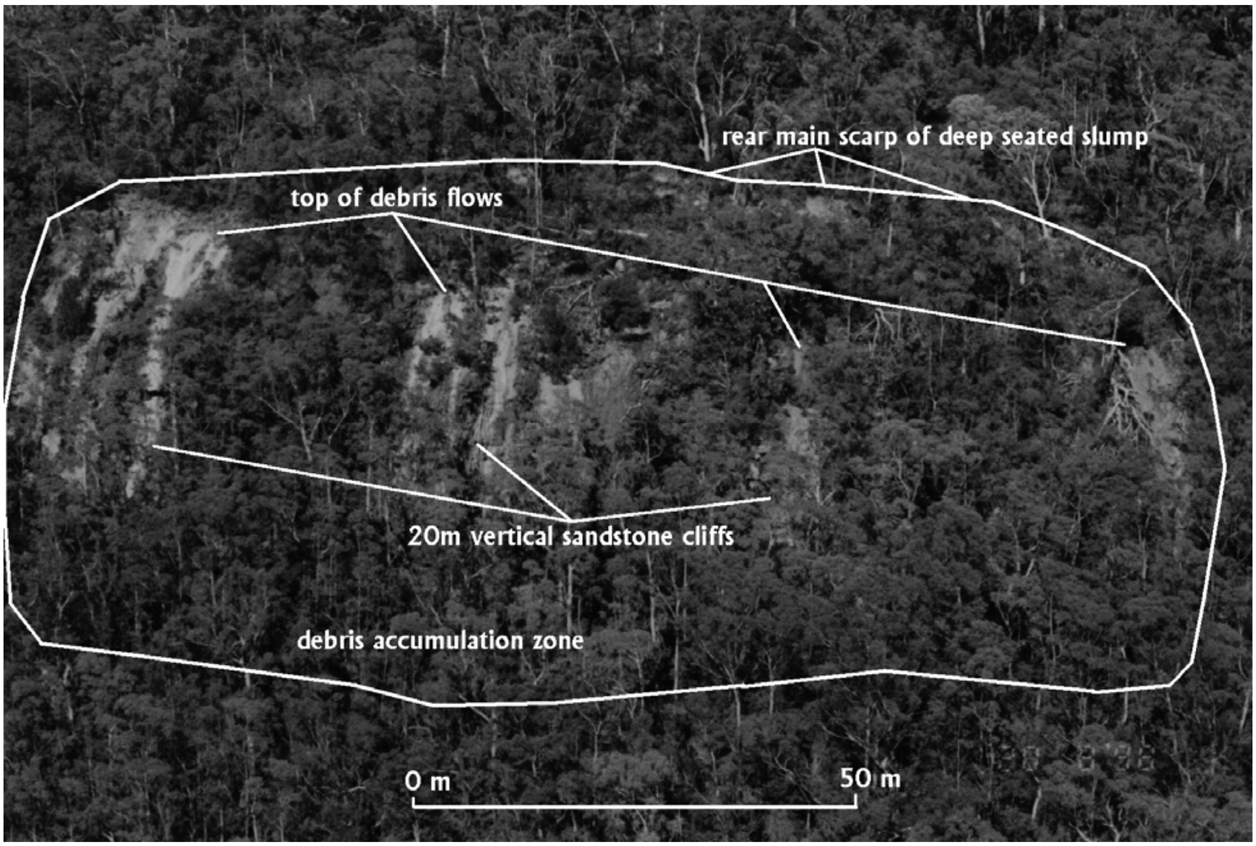

Figure 4. A view of a new deep seated landslide in Mount Kembla village which occurred as a consequence of the August 1999 rainstorm

Following the media release and several media interviews on 18 and 19 August the occurrence of a large scale landslide in the village of Mount Kembla became known as residents heard the nearby sounds of falling rocks and flowing water on the night of 19 August. In the early hours of 20th August (about 1 am) residents of Mount Kembla village were evacuated due to perceived risk of rocks or debris continuing to fall from the landslide. Most of the residents were allowed to return to their homes at approximately midday on the same day, after a geotechnical team flew over the site in a helicopter. Following careful ground inspections the geotechnical team concluded that the direction in which rocks could fall and debris may flow was away from the residential area. It also became clear that the rocks were falling from a large, deep-seated landslide (Fig 4) which might have occurred many hours (or even more than a day) earlier than the time at which the sound from falling rocks was heard and reported.

A comparison of the spatial distribution of the sites of slope instability with the spatial distribution of the rainfall magnitudes is considered to be very important for understanding the performance of the slopes in the escarpment. However, due to space limitation this is included in a separate paper.

PERFORMANCE OF EXISTING LANDSLIDE SITES

There are a number of relatively large, slow-moving, deep-seated landslides in the Northern Illawarra, the location of this intense rainstorm. Therefore, it was of considerable interest to review the performance of these sites. Several inclinometers were monitored after the rainstorm and only some revealed that some lateral movement had occurred. Disruptive movement or failure was restricted to a very few of these sites. A typical example is the Woonona Heights landslide (Site 134) and the rainfall and inclinometer data from several boreholes are shown in Fig. *5*. The last part of the graph for cumulative displacement shows that movement was not increasing continuously in all parts of the landslide. This is consistent with the previous finding that a higher cumulative rainfall over longer antecedent periods (1 to 3 months) is required to cause significant accelerated or sustained movements in these deep-seated, slow-moving landslides.

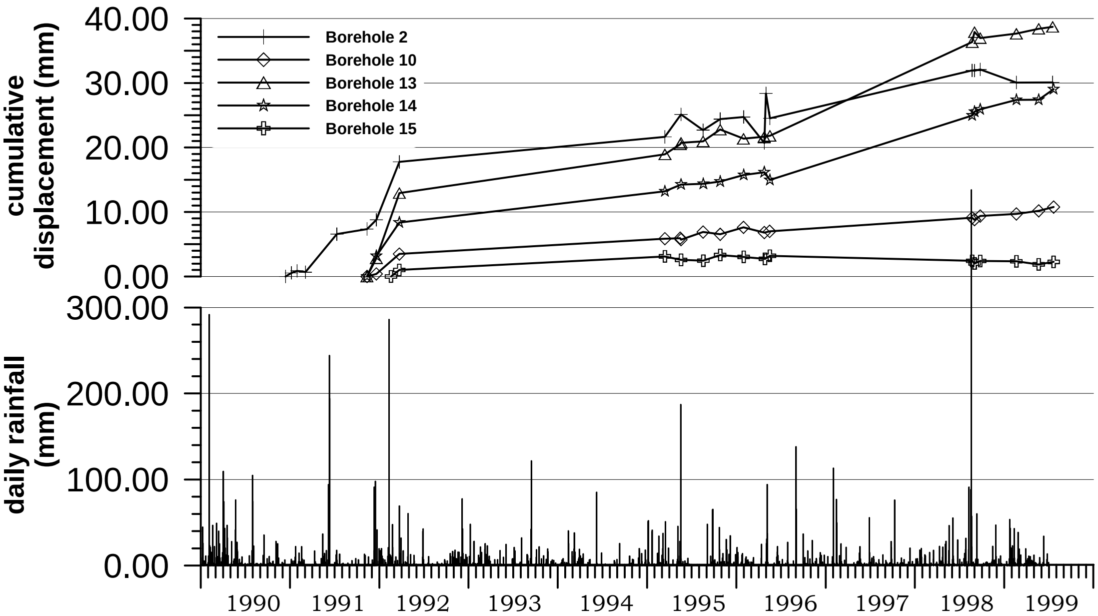

Figure *5*. Lateral movement records as a function of time (including 1998 August storms) and associated rainfall amounts - Woonona Heights (site 134)

ASSESSMENT OF HAZARD AND RISK

The assessment of future hazard and risk associated with the landslide sites was carried out by a three man geotechnical team during the weeks and months following the rainstorm emergency period. A hazard-consequence matrix method was used which broadly follows the generic approach recommended in the Risk Assessment Standard (AS/NZS 1995). Details of the generic approach and of the actual, modified approach adopted by the geotechnical team are not cited here due to space limitations. It is sufficient to state here that there are (a) five qualitative measures of the ‘probability of occurrence’ ranging from ‘rare’ to ‘almost certain’ (b) five measures of the ‘consequences of instability’ ranging from ‘insignificant’ to ‘catastrophic’ and (c) five descriptions of risk ranging from ‘very low’ to ‘very high’ each based on one or more combinations of ‘probability’ and ‘consequence’ categories mentioned in (a) and (b). Risk levels were considered separately for consideration of (a) impact on property and (b) impact on person (human life/safety).

Recently a more elaborate hazard-consequence approach has been developed in order to improve consistency, reproducibility and reliability of assessments by strengthening objective judgement (Chit Ko Ko et at, 1999).

The number of sites of instability, classified according to jurisdiction (authority responsible for site) are listed in Table 1. The number of sites perceived to involve (a) high to very high property risk and (b) high to very high personal risk are also shown in this table.

Jurisdiction*	Number of sites	Personal Risk High to Very High	Property Risk High to Very High	High to Very High Risk to both person and property
All Sites	191	17	64	15
Owner	72	9	37	6
Council	63	6	29	5
Rail Access Corporation	41	0	4	0
Roads and Traffic Authority	26	3	6	3
BHP	6	1	5	1
National Parks and Wildlife	6	0	3	0
Kembla Coal and Coke	1	0	1	0

*** not mutually exclusive**

Table 1. Number of Sites of Slope Instability with Different Jurisdiction and with High to Very High Risk Rating

The landslides were classified according to new sites and reactivations of existing sites and according to the types of instability. A summary of the number of sites in each category is given in Table 2. There are a large percentage of new sites of instability. Moreover, relatively large proportions of the new landslides are shallow movements and debris flows whereas relatively few of the new landslides are deep-seated movements.

CONCLUDING REMARKS

The August 1998 rainstorm caused extensive slope instability along the hilly suburbs of the Northern Illawarra area. A significant proportion of the new sites were shallow landslides and debris flows. Almost 50% were new sites of instability as distinct from reactivations of existing landslides. The total damage to property was relatively insignificant when compared to the widespread and catastrophic property damage caused by the flash flooding. It is noted that at several specific sites property damage due to landsliding was however significant.

Type of Instability		Total number of sites	Reactivation* of known sites	New Sites
All Sites		191	80	111
All Landslides		148	75	73
	a) Deep Seated failures	69	52	17
	b) Shallow failures	70	22	48
	c) Debris Flows**	14	4	10
Scour and or Flood		29	5	24
Other		14	-	14

* **Not all reactivations constituted a disruptive lateral movement or failure**

** **Several debris flows are associated with shallow failures**

Table 2. Number of sites of Slope Instability According to Different Types of Movement and Differentiating New Sites from Reactivations of Existing Sites.

The nature, extent and distribution of slope instability during a storm event is greatly influenced by the spatial variation in susceptibility of slopes to failure which depends on important site-specific factors such as geology, slope inclination, slope length and geomorphology. The intensity of a rainstorm and the magnitude of antecedent rainfall before the storm are extremely important for rainfall-induced landsliding. As stated earlier in this paper, an observational approach combined with the ARPET concept enabled the slope instability to be ‘predicted’ based on a significant rainstorm event such as that of August 1998. The ‘prediction’ of precise locations of instability is much more difficult not only because of uncertainty concerning the temporal distribution of a rainstorm but also because of its spatial distribution. Very little attention has been given to the latter in landslide research internationally. Due to limitations of space this aspect is not covered here in more detail.

The observational approach combined with ARPET must be area-specific before it can be applied with confidence. It is also important to consider the type of landslides on which it is based. In the present case, the estimated threshold values of cumulative rainfall required for (a) initiation of movement and (b) failure were based on observation of slow-moving and deep-seated landslides. However, significant proportions of the landslides resulting from the August 1998 storm event were new and significant proportions were shallow landslides. Consequently, there are uncertainties associated with the ‘prediction’ due to this factor in addition to those mentioned above such as the spatial variation of susceptibility and the temporal and spatial variation of the rainstorm.

There is future hazard and risk associated with each site of instability and it was stated earlier that quite a number of sites were found to be associated with ‘high’ to ‘very high’ risk. Management options must be considered to deal with such sites and this aspect is covered in more detail in another paper.

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