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Australian Geomechanics

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Landslide Risk Management

ENGINEERS
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AUSTRALASIAN INSTITUTE OF MINING & METALLURGY

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Australian Geomechanics Society

Internet Web Site

www.australiangeomechanics.org

M. B. Jaksa (Webmaster, email: mark.jaksa@adelaide.edu.au)

The Australian Geomechanics Society actively maintains an internet web site that can be found at www.australiangeomechanics.org. The web site contains the information about the Society, its constitution, the National Committee, supporting members, membership details and forms, prizes and awards, upcoming conferences, useful geotechnical links and information related to *Australian Geomechanics*, such as advertising rates, recent tables of contents and author instructions. Most importantly, the web site contains links to the web pages of the various AGS Chapters. In this way, members can easily see what is going on in their chapter, as well as others around Australia. It is a good idea, before attending a meeting in your Chapter, to check the relevant web site for the latest information. Any suggestions for improving or updating the web pages, will be warmly received.

Front Cover: Cliff-top residential developments at North Bondi

The coastal cliff line that approximates the eastern boundary of the residential properties shown is 22 metres high. The cliff is composed of massive facies and sheet facies strata of Hawkesbury Sandstone that are characterised by sub-horizontal bedding planes, inclined cross-beds and sub-vertical intersecting joint sets. As less resistant strata are weathered and eroded by exposure to the elements, overlying strata are undercut. As undercutting advances, the overlying strata eventually collapse due to brittle failures occurring along the abovementioned rockmass defects. This is the dominant process in the natural cliff line regression that occurs in Hawkesbury Sandstone. The process is evidenced by the rock debris that litters the tidal rock platforms and it is also evidenced by the open rock fractures and the extent of the undercutting that can be seen in the cliff face.

The above described natural regression processes have encroached across the eastern boundary of the properties in the cover photograph by over 4 metres.

Photo and description courtesy of Greg Kotze.

AUSTRALIAN GEOMECHANICS

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LANDSLIDE RISK ASSESSMENT AND MANAGEMENT

[All papers have been refereed in accordance with the full DETYA review process, unless stated otherwise.]

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CHAIRMAN'S COLUMN

We enjoyed another glorious summer in WA with some very mixed reactions to the trial introduction of daylight saving. I am temporarily working in the UK and the winter temperatures in Manchester are a very good advertisement for the Perth climate.

LANDSLIDE RISK MANAGEMENT

This issue of *Australian Geomechanics* is dedicated to the results of the LRM project which has been carried out over the last three years with funding support from the 2004-2005 National Disaster Mitigation Program. The project has involved AGS and representatives from Local Government in the development of three guidelines including a Hazard Zoning Guideline and Commentary, LRM Practice Notes and Commentary and GeoGuides for Slope Management and Maintenance. These documents were reviewed by an AGS sub-committee, co-ordinated by **Mark Drechsler**, during December and January.

The finalised versions of the documents have been provided to the relevant client bodies and are published in this issue of *Australian Geomechanics*. Downloadable versions of the documents will be available from the AGS web page in the near future.

AGS and the LRM team wish to acknowledge and thank the following people for volunteering their time over the Xmas and New Year period to review the draft documents. **Bill Bamford** (University of Melbourne), **Bruce Bulley** (GHD), **Tom Bowling** (Hydro Tas), **Mark Delaney, Graham Scholey** (Golder Associates), **Bram Knoop** (Hydro Tas), **Greg Hawkins** (Douglas Partners), **Colin Mazengarb** (Mineral Resources Tasmania), **Chris Haberfield** (Golder Associates) and **Tony Meyers** (Rocktest). I would particularly like to acknowledge and thank Mark Drechsler who assisted with the review process and volunteered to coordinate and administer the communication and document collection with the review panel.

AGS NATIONAL COMMITTEE

Our first national committee meeting for 2007 is scheduled for 30 March and will be held in Melbourne. We thank **Beng Cheah, Doug Stewart, John St George** and **Fred Baynes** for their earlier contributions. We now look forward to active engagement and contributions from **David Williams (QLD)** and **Barry Lehane (WA)**. **Alan Moon** and **Tony Meyers** will be assuming their new roles as the Australasian VP's for IAEG and ISRM respectively.

Patrick MacGregor has included details of the current members of the National Committee in this edition of AG to assist with communications between all AGS members and the committee.

It is pleasing to note that our membership numbers continue to grow. Please pass on details of the significant technical and professional development advantages of joining and supporting AGS, to all new entrants into the Australian geotechnical – geological industry. In particular, recent graduates and skilled migrants that are new to Australia, all of whom will obtain maximum benefits from the CPD delivery and networking opportunities to be found within AGS, should be encouraged to join wherever possible.

In early February I represented AGS at a meeting with Engineers Australia (EA) in relation to national and international issues. Of particular note was an increased level of involvement by EA on the international engineering arena, including the September 2010 CECAR conference that Civil College will host in Sydney. Additionally, the soon to be introduced revised arrangements for measuring and recording of CPD will be very relevant to all members of EA. Details of these interesting and important initiatives can be found at the EA web site www.engineersaustralia.org.au.

COMING EVENTS

Burt Look and the committee members in QLD are finalising the conference arrangements for the **10th ANZ Conference "Common Ground"** in Brisbane from 21 to 24 October 2007 (www.anzgeo2007.com). The conference web page is up and running and online registration facilities are expected in the very near future.

As immediate past chair, **Mark Jaksa** continues to co-ordinate our national and international distinguished speaker programme. Arrangements are in place for **Allan McConnell** to deliver his talk, entitled ***Two Geotechnical Mess-ups at the Gold Coast – What really happened?,*** to the different state chapters between 10 and 18 April 2007.

On 19 February **John Carter** delivered his **2005 E H Davis lecture** to a large and appreciative WA Chapter audience and he is expected to complete his tour in the near future.

It is also hoped that **Professor Robert Mair** will be returning to Australia in 2007 and that he will find the time to visit more of our regional Chapters to present his 2006 Rankine Lecture. Details of these, and other national initiatives, are available from your local Chapter Chair or by contacting **Mark Jaksa** (mark.jaksa@adelaide.edu.au).

As previously advised, the very successful, bi-annual, Geology for Engineers course, run in Adelaide by **Alan Moon** and **Fred Baynes**, is to be organised again for April 2008. This course is always fully booked well in advance so make an early note in your 2007 diary if you are interested in attending in 2008.

AGS WEB PAGE (WWW.AUSTRALIANGEOMECHANICS.ORG)

Following discussions at the 2006 National Committee meetings, review of commercial proposals for the provision of web page services and a recent meeting with Engineers Australia, we are about to decide on the optimum arrangements to ensure that the AGS webpage (www.australiangeomechanics.org) is updated and enhanced on a regular basis. Based on both potential arrangements we are comfortable that an enhanced and fully functional web page will be available by around the middle of 2007.

Any comments in relation to the AGS web page are welcomed and can be sent to Peter Robinson (pbmr@optusnet.com.au), myself (marc_woodward@coffey.com.au) or Mark Jaksa (mark.jaksa@adelaide.edu.au).

AGS AWARDS

We are very pleased to confirm that **Professor Robin Fell** of the University of New South Wales is the recipient of the **2007 John Jaeger Award**. As detailed in the awards page on our web site, this award is made ***to recognise contributions of the highest magnitude over a lifetime of commitment to the geotechnical profession in Australia***. Robin will be presenting his John Jaeger award paper, provisionally entitled *Internal Erosion and Piping of Embankment Dams and their Foundations* at the Brisbane ANZ conference in October.

We are also very pleased to confirm that the 2007 **E H Davis Memorial Lecture** will be presented by **Professor Chris Haberfield** of Golder Associates in Melbourne. I am sure that all AGS members will join us in congratulating Chris on this prestigious award in recognition of his ***distinguished recent contribution to the theory and practice of Geomechanics in Australia*** and look forward to his lecture tour later in 2007.

The AGS Joint Societies Award will be decided and announced at the Brisbane ANZ Conference, to recognise ***the most valuable conference paper***, as judged by an executive committee formed from AGS, NZGS and the international societies VP's.

ISSMGE, ISRM AND IAEG NEWS

As previously advised, **Fred Baynes** is now the **International President of IAEG** and we look forward to enhanced Australasian involvement with IAEG resulting from his new international role.

Fred Baynes has now handed over the role of **Australasian Vice President (VP)** for **IAEG** to **Alan Moon** and we look forward to Alan's contributions in 2007. Alan will be attending the 2007 IAEG Council meeting in the USA in June 2007 to represent Australasia.

Professor John Carter continues to actively represent Australasia as our **International VP** for **ISSMGE**. The next ISSMGE board and Council meetings will be held in Brisbane to coincide with the opening of the ANZ conference. John continues to report on progress with the formation of FIGS from an ISSMGE perspective to help us assess the implications of these proposed international changes for Australasia.

AGS has been asked to provide nominations of suitable people to join the ISSMGE TC37 ***Interactive Geotechnical Design***. Please check out the ISSMGE web page (www.issmge.org) or contact John Carter (john.carter@newcastle.edu.au) if you require any additional details and/or would like to make a nomination.

As previously advised **Tony Meyers,** of Rocktest in Adelaide, is the **Australasian VP** for **ISRM** for 2007 to 2011. We look forward to continuing active involvement from Tony and note that he submitted a paper on the AGS role and industry activity to the January 2007 Mining Bulletin. Tony has also played a positive and proactive role in explaining AGS activity in relation to the proposed AusIMM Geoscience Society that is expect to be formed later in 2007. It is anticipated that there will be some technical common ground and close interaction between AGS and the AusIMM Geoscience Society. We will provide additional details of these developments in future editions of AG as they become available.

Tony has previously reported the excellent news that Professor Edwin (Ted) Brown was awarded the prestigious 5th Muller Award and that Ted will present the Muller lecture at the 11th ISRM Congress in Lisbon in July 2007.

SECRETARIAT AND FINANCIAL ISSUES

The successful and efficient provision of secretariat services by **Peter Robinson,** of Money Tree Associates, continues with our accounting, auditing and reporting up to date and transparent. We are very pleased to confirm that Peter has extended his contract with AGS for a second year and we can look forward to his active and efficient support up to and beyond late 2007.

With ongoing assistance from Engineers Australia, and particularly Lois Wurzer, Peter has made significant progress with our membership records and contact details. Please make sure that you let Engineers Australia (lwurzer@engineersaustralia.org.au) and the AGS Secretariat (pbmr@optusnet.com.au) know if you change your address or contact details so that we can keep the membership database up to date.

Our treasurer Neil Benson and Peter Robinson continue to actively monitor and report our financial affairs and we are pleased to note that AGS is in a healthy financial position.

SPECIALIST GEOTECHNICAL CONTRACTORS

I would like to recognise and thank the contributors from **Austress Menard, Broons Hire, Keller, Rock Engineering** and **Vibropile** for their interesting and valuable contributions to the December 2006 "Specialist Geotechnical Contractors" issue of AG. I hope these papers have given other members of AGS a useful insight into the activities of these Australian specialist geotechnical contractors and hope that we will continue to have enhanced engagement between the consulting, academic and contracting areas of our profession.

LIAISON WITH NZGS

Kevin McManus, the current Chair of NZGS, is expected to attend the next national committee meeting in Brisbane that will coincide with the opening of the 10th ANZ Conference. The opportunity for face to face contact significantly enhances the ongoing communications between AGS and NZGS. We thank Kevin for finding the time to join us and look forward to continuing fruitful liaison between our two societies

Mark Eggers, Alan Moon and **Fred Baynes** will maintain direct contact with **Ann Williams** and the NZGS team organising 2010 IAEG Congress to ensure effective support from AGS.

The NZGS committee now have confirmed that liaison personnel will be appointed for each international society VP, to ensure appropriate levels of communication are maintained between AGS and NZGS in relation to IAEG, ISSMGE and ISRM activity. We have been advised that **Ann Williams** will fill the role of NZGS liaison for IAEG, the other positions will be finalised after the next NZGS committee meeting.

ACKNOWLEDGEMENTS

In closing my fifth Chair's letter it is appropriate again to acknowledge the continuing assistance and support that I have received from **Peter Robinson, Mark Ja**ksa and **Neil Benson** and the other members of the national committee.

Patrick MacGregor and **Sarah Lanesman** again deserve our special thanks and appreciation for their excellent ongoing work on the editorial, production and management of advertising with AG which continues to grow in quality and industry support with each edition.

Please feel free to contact me if there are any issues that you feel can be better addressed by AGS in the interests of our members and the wider geotechnical profession.

Regards

Marc Woodward
September 2006
Tel: (08) 9347 0000
marc_woodward@coffey.com.au

Geoscience Australia has been coordinating the development of a collaborative landslide inventory framework as part of a larger project that will demonstrate a way of bringing diverse landslide databases together. The inventory structure adopts agreed standards, terminology and classification systems as outlined within this edition of the AGS Journal and provides guidance in the fields required for reporting. Fields chosen have been selected with consideration of data requirements for landslide risk assessment and aim to highlight where current gaps in knowledge are. The framework is being developed in conjunction with project partners, members of the AGS LRM taskforce, review committees and local government. It is anticipated the framework will be provided to the AGS for official technical review in 06/07. Further information on Geoscience Australia's initiative is outlined in AGS Volume 41, No 3 September 2006. p177, as a Letter to the Editor.

Australian Geomechanics Society Corporate Members

The Australian Geomechanics Society gratefully acknowledges the contribution made by its Corporate Members who are listed below. Please contact either the National Secretariat or your local state secretary for further information on becoming a Corporate Member of AGS.

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AGS NATIONAL COMMITTEE

Chair - Marc Woodward

Marc is the Western Regional Manager for Coffey Geosciences. Educated in Britain he has more than 24 years experience in civil and geotechnical engineering construction, design and project management. Marc has experience in geotechnical grouting projects, ground anchor projects, piling projects, slope stabilisation and retaining walls, forensic engineering and geotechnical remediation projects, site investigation and other geotechnical projects.

Mark Jaksa - Immediate Past Chair

Mark is a Senior Lecturer in the School of Civil and Environmental Engineering at the University of Adelaide. Before that, Mark worked for Coffey's and B. C. Tonkin and Associates, both in Adelaide, for a total of 4 years. Mark's research and consulting interests focus on the spatial variability of soils, the application of statistics and probability to geotechnical engineering, geostatistics, artificial neural networks, expansive soils, *in situ* testing, environmental geotechnics and enhancing student learning. Mark has been a member of the AGS since 1984 and a member of the National Committee since 1999. He is married with four children.

Neil Benson Vice-Chair and Treasurer

Neil is a Chartered Geologist, with over twenty years experience in mining and engineering geology, geotechnical engineering, and project management with experience in the UK, South Africa and Australia. His career has include a range of projects in civil and environmental engineering including large complex investigations, assessment of ground conditions and construction problems, tunnelling in the urban environment and construction of environmental remediation solutions.

Kevin McManus – Chair NZGS

Kevin has been Chair of the New Zealand Geotechnical Society since 1994. Kevin is a geotechnical engineer and is a director of McManus & Grocott Ltd, a firm specialising in geotechnical engineering and engineering geology based in Christchurch, New Zealand. His main (professional) interests include earthquake resistance foundation design, soil liquefaction, use of ground anchors in geotechnical engineering, and earthquake resistant design of retaining systems. His career includes stints at the University of New South Wales and the University of Canterbury as well as time with construction firms and in construction management.

AGS NATIONAL COMMITTEE

Stephen Fityus – Newcastle Representative

Stephen is currently a senior lecturer and a member of the Geotechnical Research Group in the School of Engineering at the University of Newcastle. After completing his undergraduate degrees, he worked in the public service and the geotechnical consulting industry before returning to University to complete his PhD and take up an academic appointment. He is active in a wide range of research areas, with a primary focus on foundations in residual soils. He has been an active member of the AGS for more than 10 years.

David Williams
Queensland Representative

David Williams graduated in Civil Engineering with First Class Honours from Monash University and obtained a PhD in Soil Mechanics from Cambridge University, before returning briefly to the then Country Roads Board of Victoria. He joined Golder Associates, working first in Melbourne before transferring to Brisbane. In mid-1983, he joined the Department of Civil Engineering at The University of Queensland, where he is now Associate Professor of Geomechanics. David's main research, teaching and consulting interests concern the application of soil mechanics principles to the disposal, management and rehabilitation of mine wastes, an area in which he enjoys an international reputation.

Graham Scholey – New South Wales Representative

Graham graduated as an engineering geologist in the UK and later obtained a Master's degree in geotechnical engineering in the US. He has been in Australia for about 6 years, with Golder Associates in Sydney. His main professional interests are in geotechnical risk management and most of his work is for major transport infrastructure projects. Graham has served on the committee of the AGS Sydney Chapter since 2001. In that time he has endeavoured to encourage new initiatives that promote the advancement of geomechanics in our region.

Mark Drechsler
South Australia Representative

Mark has over twenty years experience in geotechnical consulting and the construction materials industry. His major area of expertise is in geotechnical investigations and resource management for civil and mining projects, as well as construction materials and quarry management. His project experience includes: wind farms, transmission lines and substations; slope stability analysis; open pit design; tailings dam design; quarry development geopolymer and waste materials technology; environmental management and auditing; waste management; marine and harbour developments; and residential and commercial developments. He has worked throughout Australia and Papua New Guinea.

AGS NATIONAL COMMITTEE

Fraser White – Tasmania Representative

Fraser is a civil engineer with over 18 years experience. For most of his career he has worked on projects associated with renewable energy: hydro power and wind developments. He has had a number of roles over the years but he has been mainly involved in design, investigation and construction supervision of dams, tunnels, underground structures, power stations and the civil aspects of small and large scale wind farms. He is presently working for Hydro Tasmania Consulting (HTC) and is currently the managing the civil team from its Hydropower and Major Projects Group.

Barry Lehane
West Australia Representative

Barry has nearly 25 years experience as a practitioner and academic in geotechnical engineering. He is a Professor in the School of Civil & Resource Engineering and a consultant to Arup Australia. His research interests include deep and shallow foundations, soil-structure interaction, numerical modelling and geotechnical investigation.

Chris Boyd – Victorian Representative

Chris is a Principal Geotechnical Engineer with Maunsell Australia and has over 10 years experience in the geotechnical site investigation, geotechnical design and project management of infrastructure, building and water projects.

Tony Meyers – ISRM AusIMM Liason

Tony Meyers is the Australian Nominee for the International Society for Rock Mechanics. In this role he assists the regional Vice President (Australasia) with his duties in Australia. In July of this year he takes over the VP role. He also acts as the liaison between the AusIMM and the National Committee of the AGS. From a family with a long history in mining, he finally completed a drawn out Mining Engineering degree in 1987, a PhD in Rock Mechanics in 1993 and a diploma in Finance in 1999. His business, Rocktest Consulting, based in Adelaide carries out rock mechanics design and assessment for the surface and underground Mining and Civil industries throughout Australia. His specialisation and research interests include probabilistic risk assessment and discontinuity characterisation.

AGS NATIONAL COMMITTEE

John Carter – Vice-President ISSMGE

John has 30 years experience in teaching, research and consulting in civil, geotechnical and offshore engineering. His research interests include analytical and numerical modelling, soil-structure interaction, rock mechanics, the behaviour of cemented and uncemented carbonate soils, soft soil engineering, tunnelling and offshore foundations. He is the former Challis Professor in Civil Engineering at Sydney University and in February 2006 he took up an appointment as the Pro-Vice-Chancellor, Faculty of Engineering and Built Environment at the University of Newcastle.

Peter Godfrey
Engineers Australia Representative

Peter is a civil engineer with management qualifications. Peter has over 20 years experience in contracting, construction materials, equipment supply and consulting industries. He is Southern Regional Manager of Coffey Geosciences, specialising in geotechnical, mining, environmental, water resource consulting services and construction material testing. In Engineers Australia Peter is currently National Vice President for Engineering Practice, a member of the AGS National Committee and is a past President of Tasmania Division and past Chairman of the Civil College Board.

Alan Moon - Vice-President IAEG

Alan Moon is an engineering geologist with 35 years experience on a wide variety of projects in Australia, New Zealand and South East Asia. He is a Senior Principal with Coffey Geotechnics based in their Adelaide office. Alan has served on AGS state committees in South Australia, Queensland and Tasmania. Every two years, Alan, Fred Baynes and Isabelle Lamb prepare and present a two week field based course on geology for engineers on behalf of the AGS.

Burt Look – ANZ Conference Representative

Dr Burt Look is the Chair of the organising committee for the upcoming ANZ Conference on Geomechanics, to be held in Brisbane, October 2007. He obtained his first degree in Civil Engineeering from The University of The West Indies, Masters degree from Imperial College, London, in Soils Mechanics and Engineering Seismology and his Phd from The University of Queensland. He also has completed a Graduate Certificate In Philosophy (Critical Thinking). Burt is the Connell Wagner Geotechnical Group Leader for Queensland, based in Brisbane. He is the past Chairman of the Queensland Chapter of the Australian Geomechanics Society.

AGS NATIONAL COMMITTEE

Sara Lanesman

Advertising in Australian Geomechanics

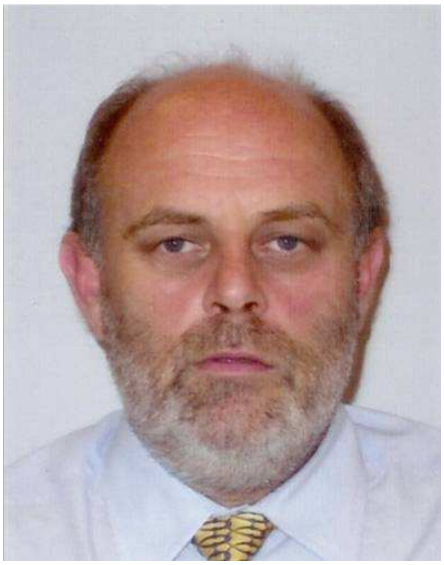
Sara took on the role of advertising in Australian Geomechanics just over two years ago, after her second child was born. She has a postgraduate diploma in Human Resources Management and in Marketing (from the University of Cape Town). In addition to her role with Australian Geomechanics Sara works part time as Personal Assistant for the directors of a Business Consulting Firm.

Patrick MacGregor –Editor Australian Geomechanics

Patrick is an engineering geologist with almost 50 years experience working on projects in more than 20 countries.

He was formerly with SMEC and Coffeys and now is a consultant on major projects when it does not conflict with his yacht racing, golf and bridge.

Peter Robinson – AGS Secretary



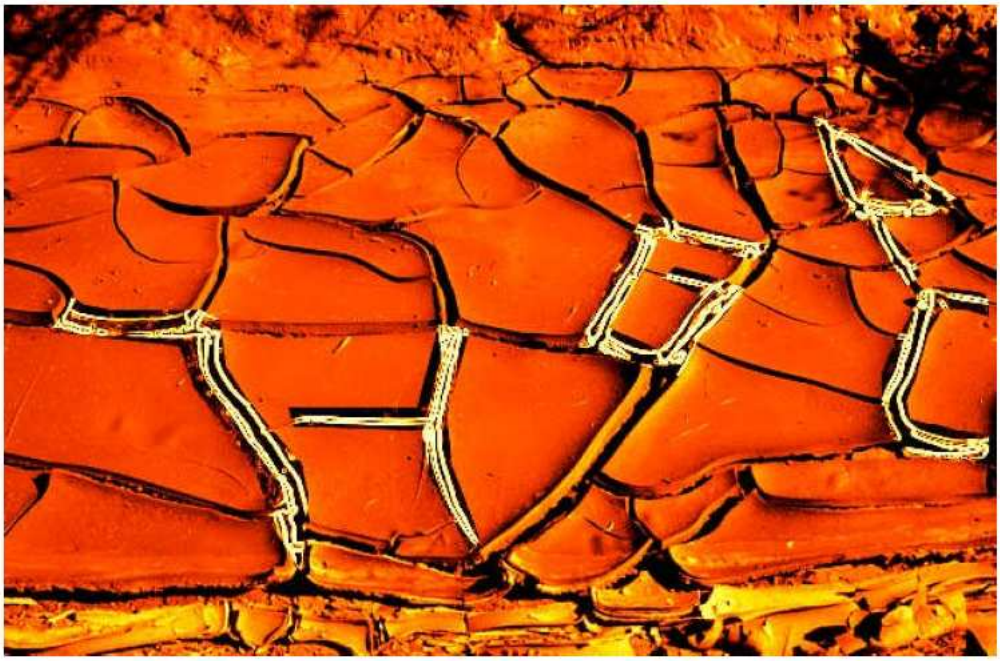
Peter is an Accountant and Chartered Secretary and currently runs his own company Money Tree & Associates, which recovers unclaimed money for clients from Federal and State government departments. His previous positions included Harris Technology as the GM Finance & Administration and Longmac Associates as the CFO and Company Secretary. Peter has been married to Anita for 25 years with two daughters Jenna and Sara.

7YGPC

7th Young Geotechnical Professionals Conference

ADELAIDE, 2006

Conference Proceedings



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Australian Geomechanics Society

Sydney Chapter

2007 Symposium

Engineering Advances in Earthworks

Wednesday 10 October 2007

First Announcement and Call For Papers

OVERVIEW OF THE SYMPOSIUM

Infrastructure, residential, commercial and industrial projects have typically involved earthworks design and construction as a matter of course. Recently, the issue of civil earthworks has become more prevalent in areas such as mining and marine. In addition, there have been advances in the design methodologies and construction methods related to earthworks. An understanding of these advances is an important tool for owners, contractors, civil and geotechnical consultants.

The Sydney Chapter of the Australian Geomechanics Society (AGS) is proud to present our eleventh annual Symposium to be held in October 2007 on Engineering Advances in Earthworks. The Symposium is an annual event and forms part of the continuing program of events by the Sydney Chapter of the AGS, designed to keep the engineering profession aware of recent developments in particular aspects of geotechnical practice. The goal of this symposium is to provide engineering geologists, geotechnical engineers and civil engineers from consulting, contracting and government organisations the opportunity to meet and exchange information on their experiences in earthworks and the innovative engineering application of earthwork practices.

The papers may be published in Australian Geomechanics, providing a national focus for the event, and we are therefore seeking contributions nationally in support of this initiative.

POSSIBLE TOPICS

The focus of the symposium will be engineering advances and innovation in the application of earthworks to projects, investigation of earthworks materials, modelling and monitoring of earth structure performance, and construction. The following are some suggested topics for the Symposium:

- Innovations in earthworks applications;
- Ground Remediation
- Advances in investigation of earthworks materials;
- Advances in modelling earthworks performance
- Innovation in embankment and earth dam design and construction;
- Advances in earth containment barrier design and construction;
- Advances in earthworks monitoring, testing and control;
- Innovations in remediation of fill materials;
- Use of recycled materials in earthworks, including overburden, slag and bottom ash

SYDNEY 2007 SYMPOSIUM

Abstracts are to be received by **20 April 2007**, with final papers to be completed by **27 July 2007**. All papers should be submitted in AGS format, the details of which will be forwarded at an appropriate stage.

STUDENT PAPER CONTEST

As part of the Symposium, The Australian Geomechanics Society will be holding a contest for the best student paper, with a $500 prize being awarded. Students must be the lead author of the paper. The papers will be judged by the AGS Committee, Sydney Chapter, and the best paper will be presented at the Symposium by the author.

Please indicate on your abstract submission whether you will be entering the student paper contest.

EARTHWORKS PHOTO CONTEST

For this years Symposium, the Australian Geomechanics Society will be holding a Photo Contest for the most interesting earthworks photograph.

The photographs must be related to Engineering Advances in Earthworks and include a brief description (less than 25 words) of the photograph. Only one photograph per entrant is permitted.

Photographs will be judged by the AGS Symposium Committee with the winner receiving a cash prize of $100, which will be presented on the day. The winning photograph and 2 runners-up will be included in the Symposium proceedings. In addition, a selection of the photographs will be displayed at the venue.

Please email your photograph entries to richard_moyle@coffey.com.au in jpg format by 1 September 2007. Emailed photographs must be less than 250Kb, and the original photograph can be up to 5Mb.

ADDITIONAL INFORMATION

For submission of abstracts or if you would like any additional information or would like to discuss a possible topic, please contact any of the following:

AGS Symposium Organising Committee

Roberta Lindbeck	Hana Liu	Richard Moyle
GHD Geotechnics	PB	Coffey Geotechnics
57 Herbert Street	680 George Street	Unit 8/ 12 Mars Road
Artarmon NSW 2064	Sydney, NSW 2000	Lane Cove West, 2066
Phone: 9462 4835	Phone: 9272 5170	Phone: 9911 1000
Email: Roberta.lindbeck@ghd.com.au	Email: HLiu@pb.com.au	Email: richard_moyle@coffey.com.au

Australian Geomechanics Society

Sydney Chapter

2007 Symposium

Engineering Advances in Earthworks

Wednesday 10 October 2007

Sponsorship Opportunities

The Sydney Chapter of the Australian Geomechanics Society (AGS) is holding a Symposium on Engineering Advances in Earthworks. The Symposium will be a high profile, all day event that is expected to attract over 100 attendees. Selected papers will be published in Symposium proceedings that will be dedicated to Engineering Advances in Earthworks.

The Symposium will be the eleventh of the Sydney Chapter's annual symposiums designed to keep the engineering profession aware of recent developments in particular aspects of geotechnical and construction practices. Topics will include advances and innovation in earthworks applications; investigation of earthworks materials; modelling of earthworks performance; embankment and earth dam design and construction; earth containment barrier design and construction; earthworks monitoring, testing and control; remediation of fill; use of recycled materials in earthworks and case histories.

The symposium will offer owners, suppliers, contractors, civil and geotechnical consultants a unique opportunity to promote their products and services to a wide cross-section of the industry, through sponsoring the symposium.

Sponsorship… An Introduction

What is sponsorship?

Sponsorship is a strategic marketing vehicle that provides companies the opportunity to align themselves with organisations that have an existing relationship with that company's target customers.

What sponsorship will do for you

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- Promote your organisation to hundreds of senior-level decision-makers in the industry, and nearly 1000 readers of *Australian Geomechanics* spread throughout Australia
- Establish name and product recognition
- Demonstrate to colleagues and clients that you support the industry.

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- Sponsorship is a direct line to customers who may never come to you
- AGS sponsorship is a targeted, cost effective marketing opportunity.

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Benefits of Sponsorship

- Acknowledgement of sponsorship in 2007 AGS Symposium materials
- Recognition of your sponsorship at the Symposium and to readers of *Australian Geomechanics*
- Sponsorship recognition signs at venue.

There will be three levels of sponsorship - Platinum, Gold and Silver.

1. Platinum Sponsor (one only) - Minimum $3,000 (incl. GST) exclusive

The Platinum Sponsor will be entitled to acknowledgement on the presenter's podium and in the Symposium proceedings, and to have their brochure included in the proceedings. The sponsors will also have their company name on the badge of every symposium attendee and receive a full page advertisement in the Symposium proceedings that will be dedicated to Engineering Advances in Earthworks. Promotional benefits include recognition of company name on signage, acknowledgement in program and sponsorship of the bar.

The Platinum Sponsor will be able to set up a booth at the symposium to distribute promotional material to attendees.

Three of the Platinum Sponsor's employees will be entitled to free admission to the Symposium. The first written and paid offer of platinum sponsorship received will be nominated for this level of sponsorship.

2. Gold (Major) Sponsors – Minimum $1,500

Gold Sponsors will be entitled to acknowledgement as a Gold Sponsor in the symposium's proceedings, to have their brochure included in the proceedings, and will receive a half-page advertisement in the Symposium proceedings.

Two of the Gold Sponsor's employees will be entitled to free admission to the Symposium.

3. Silver Sponsors – Minimum $750

Silver Sponsors will be entitled to acknowledgement as a Silver Sponsor in the symposium's proceedings, to have their brochure included in the proceedings, and receive a half-page advertisement in the Symposium proceedings.

Please register your interest by returning the registration form to Hana Liu, AGS Committee Member:

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Company _____ Contact _____

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☐ Enclosed is a cheque payable to *Australian Geomechanics Society* for $_____

☐ Please send me a tax invoice for my sponsorship payment

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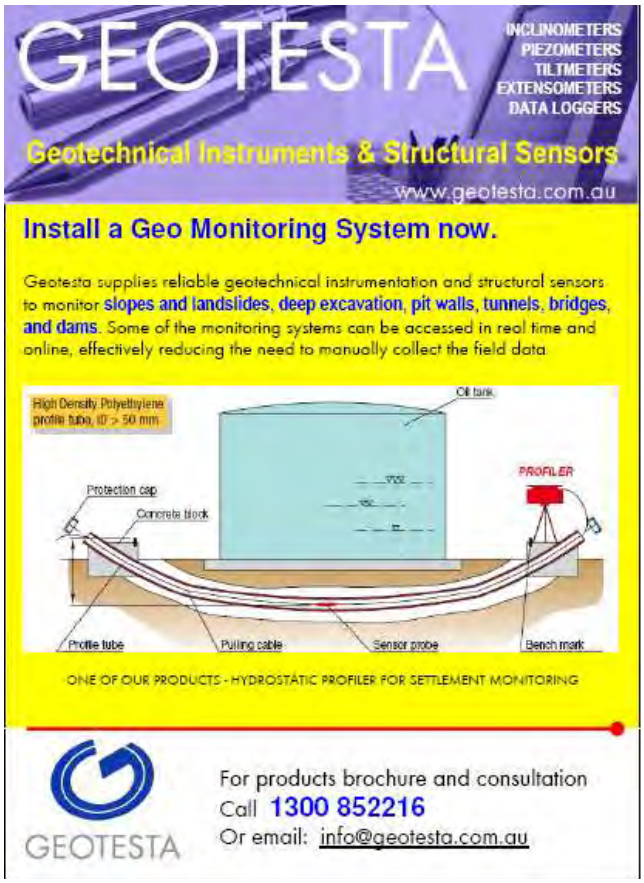
Hana Liu
PB
GPO Box 5394
Sydney, NSW 2001

Phone: 61 2 9272 5170
Fax: 61 2 9272 5101
Email: HLiu@pb.com.au



INSERT GEOTEXTILE SUPPLIES AD (SUITABLY SIZED QUARTER PAGE) AS IN VOL 41 NO 4 PAGE XXIII

INSERT AUSTRALIAN SOIL TESTING AD AS IN VOL 41. NO 4 PAGE XXIII (SUITABLY SIZED QUARTER PAGE).

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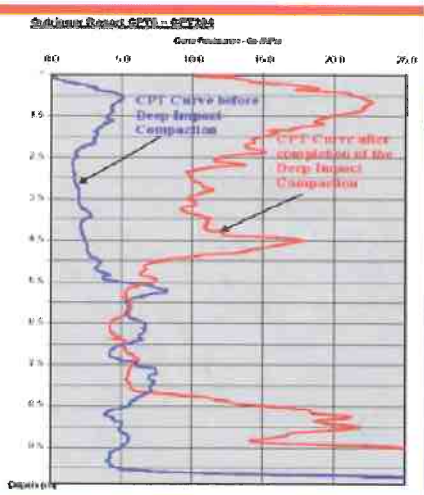
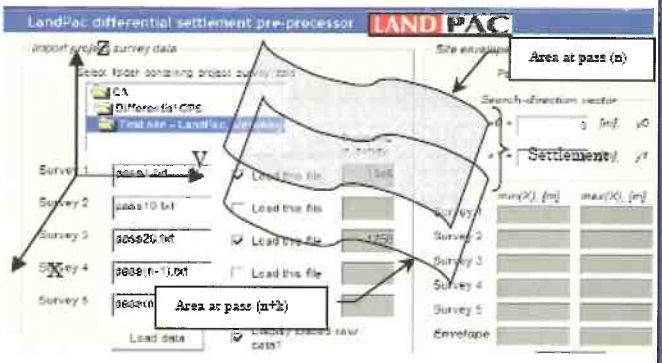
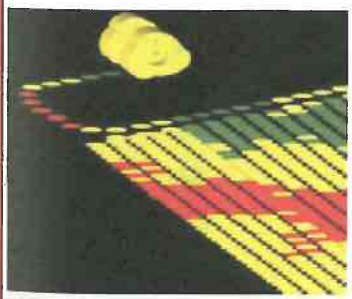
Landpac has developed monitoring and quality control systems to assist in the assessment of compaction levels and sub-grade strength during the ground treatment . Engineers can thus provide soil design parameters for the whole site area with higher confidence levels.



Landpac's *"DiffSett" system*, is a differential GPS and software tool that assists in the measurement of incremental induced settlements that are indicative of the compaction levels over the site.





Landpac's "CIR" system measures the soil response over the whole site to the high dynamic loads induced by the impact drums. It identifies localized soft areas and weak sub-grades that could have adverse effects on foundation performance.

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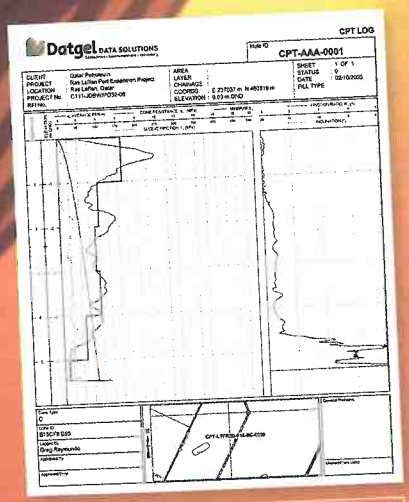

gINT CPT LOG

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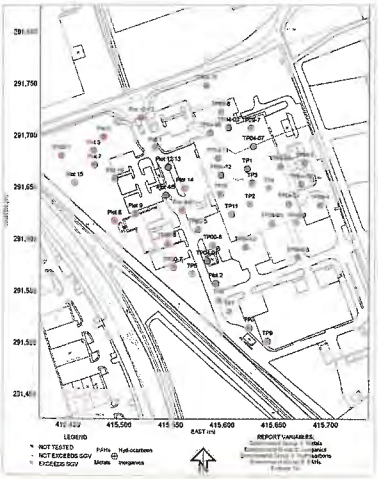
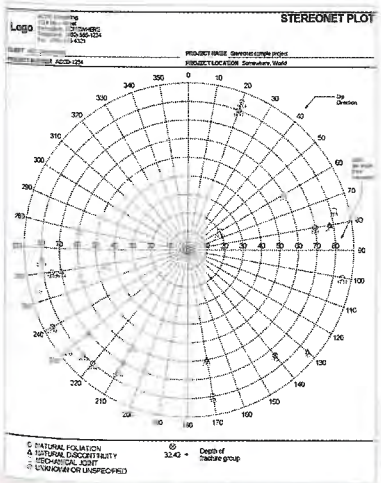


gINT CONTAMINATION SITE MAP



gINT STEREONET PLOT

Key Benefits

- Not just a logging program, gINT is a relational database – store all data for a project in one database, enter data once and use it in many ways
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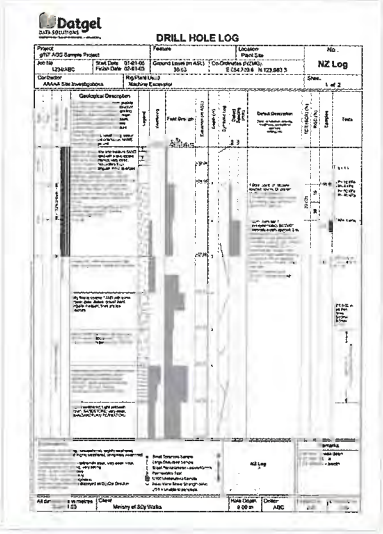
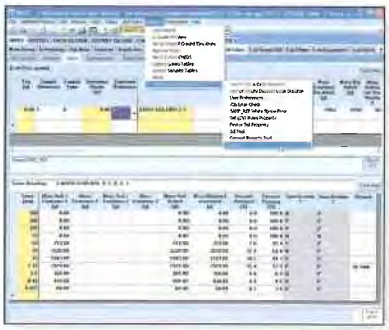


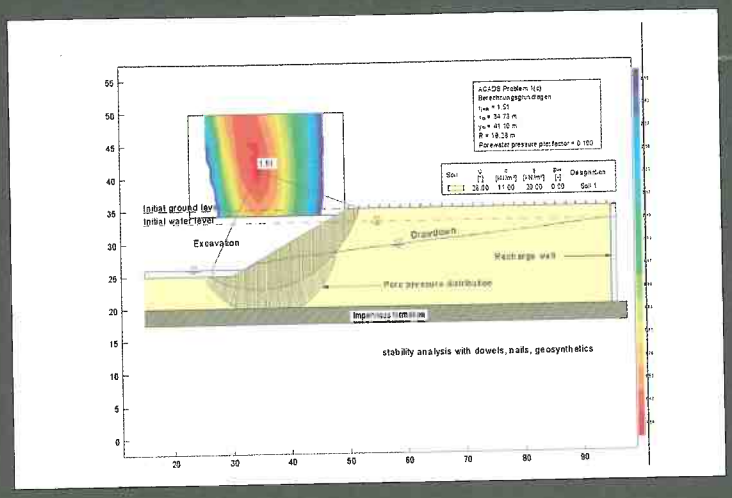
gINT BOREHOLE LOG

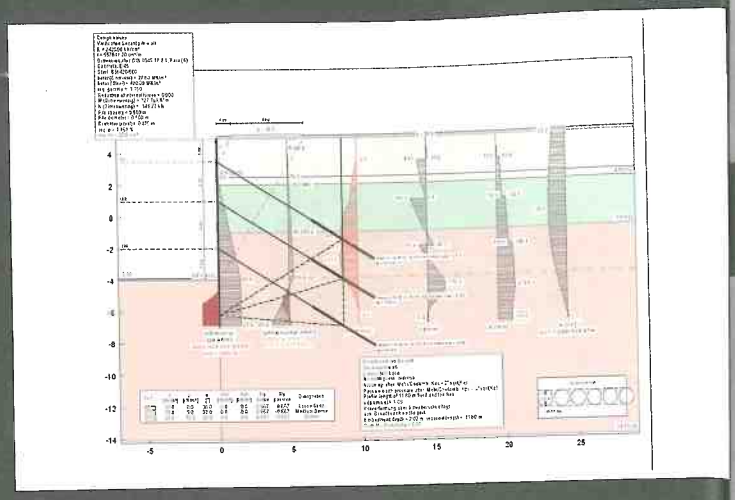
gINT FOR ARCGIS

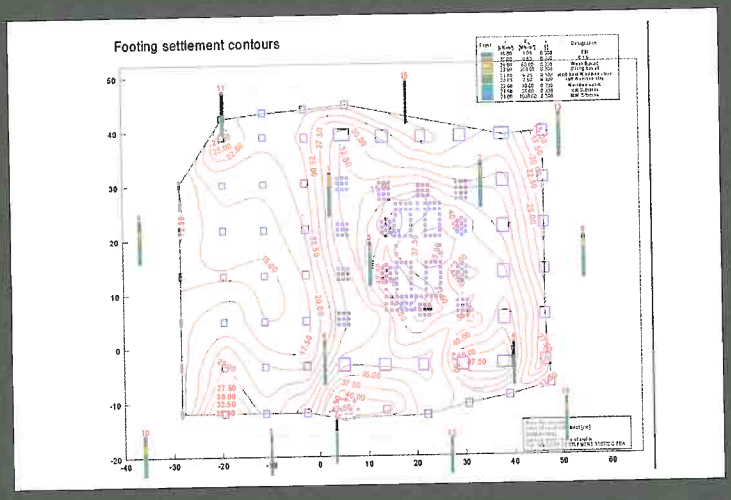
gINT GRAPHICAL DATA INPUT

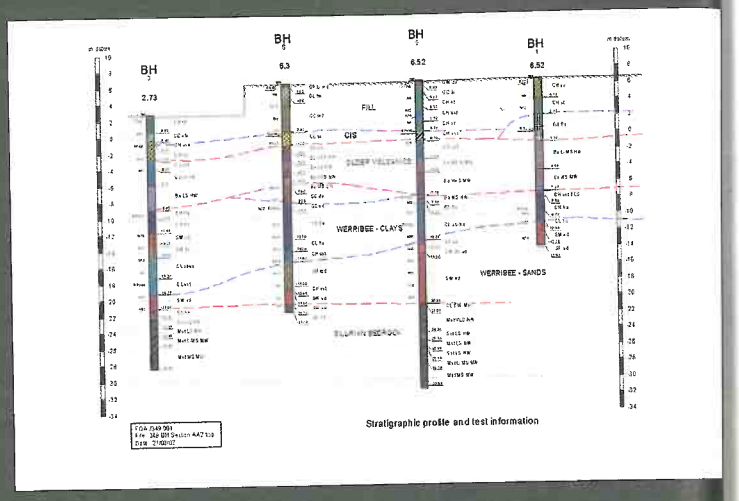


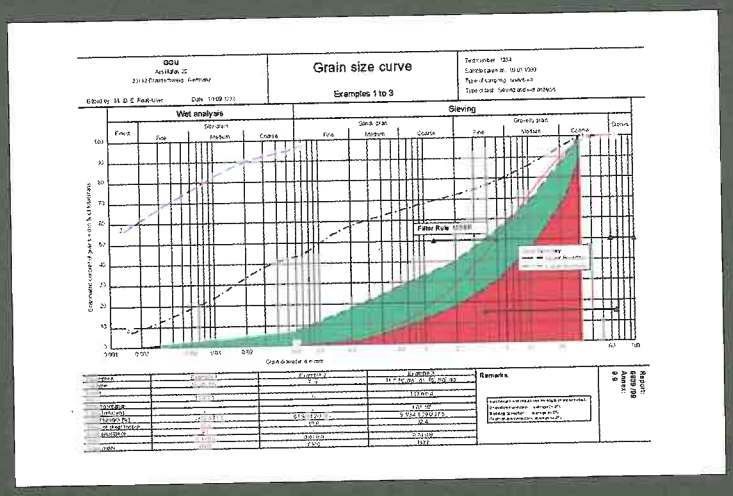
gINT RULES

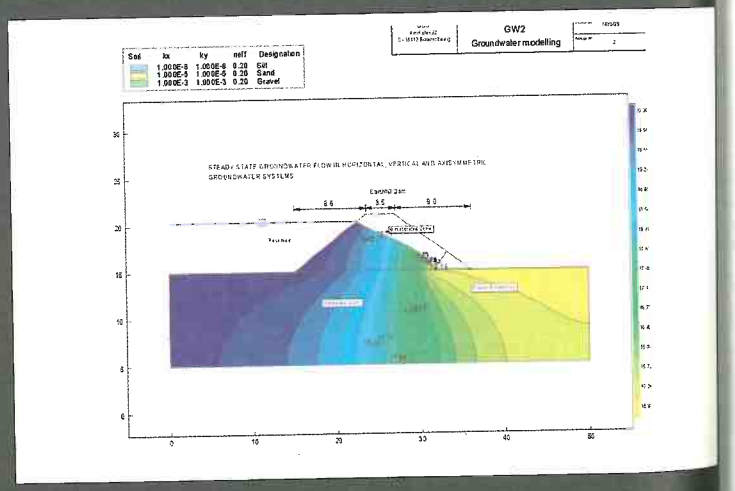


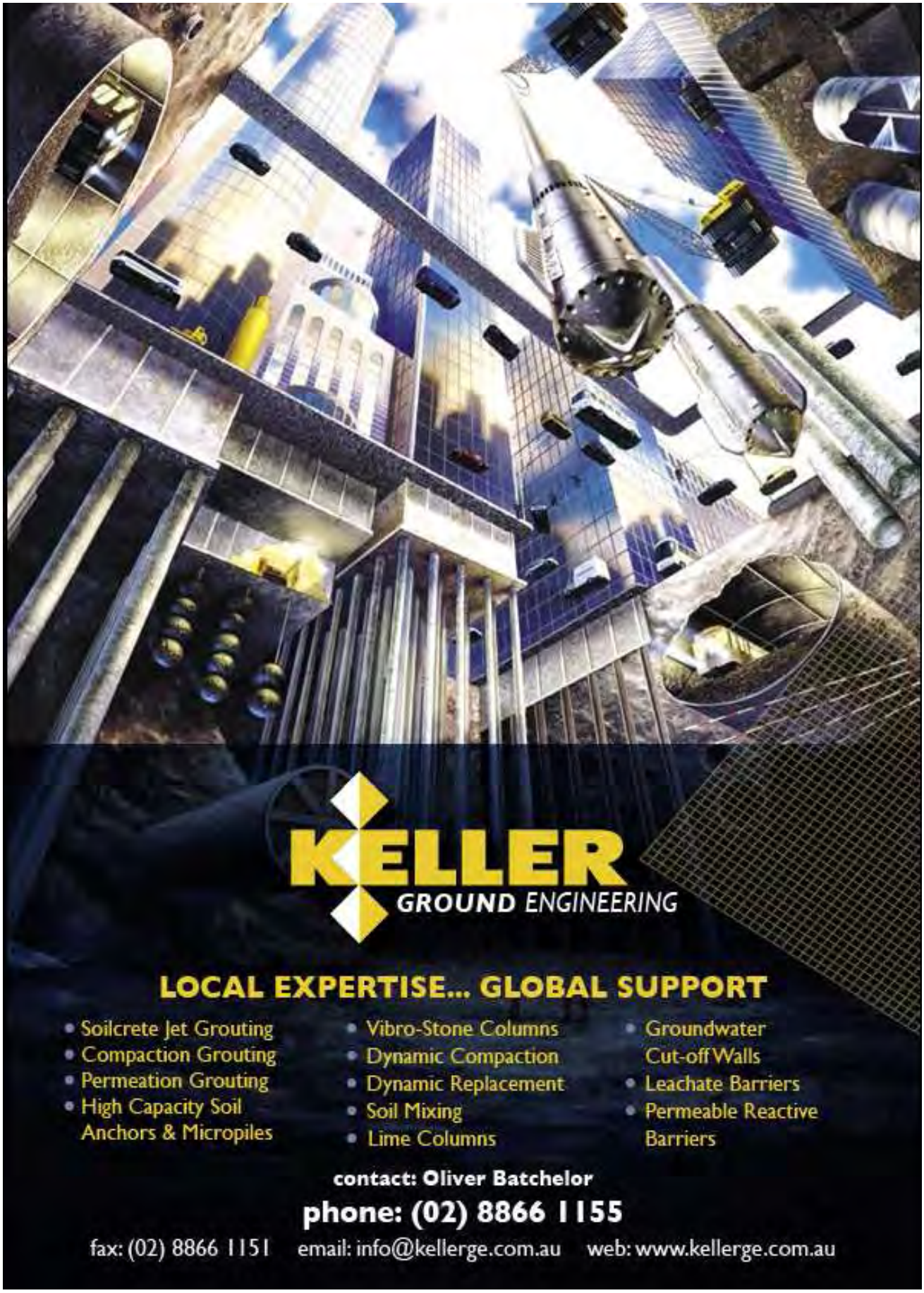








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web: www.kellerge.com.au

The **Australian Geomechanics Society** records its deep appreciation for the support of the Australian Commonwealth Government, the New South Wales Government, the Sydney Coastal Councils Group and Pittwater Council through their assistance in the development of the suite of Landslide Risk Management Guidelines and papers presented herein.

The projects were developed with the assistance of the

NATIONAL DISASTER MITIGATION PROGRAM
which is aimed at identifying and addressing natural disaster risk priorities across the nation.

Australian Government
Department of Transport and Regional Services

New South Wales Government

emergencyNSW

Pittwater Council

Sydney Coastal Councils

Botany Bay · Hornsby · Warringah Council

A NATIONAL LANDSLIDE RISK MANAGEMENT FRAMEWORK FOR AUSTRALIA

Andrew R Leventhal
Principal Geotechnical Engineer, GHD Geotechnics, Sydney, Australia
National Chairman (2002 & 2003), Australian Geomechanics Society
Chair, Steering Committee, NDMP Landslide Taskforce, Australian Geomechanics Society
Chair, Steering Committee, NDMP PWC Landslide Likelihood Research Project, Australian Geomechanics Society

SYNOPSIS

The Australian Geomechanics Society (AGS) is publishing a series of benchmark guidelines on Landslide Risk Management (LRM) and slope management and maintenance. This is a continued recognition by AGS of the benefits of risk based systems in managing landslide hazards. This paper provides an introduction to the LRM guidelines that have been developed under the National Disaster Funding Program (NDMP) - with the aim of managing the risk to occupants and property from landslide hazards. These guidelines are tools that can be introduced into the legislative framework of Australian governments at National, State and Local levels and to thereby promote appropriate use of land in recognition that it is a valuable resource which should be developed on its merit.

1 INTRODUCTION

There have been a number of technical developments and legislation changes in Australia which have presented the opportunity for the development of a national landslide risk management strategy, as discussed by Leventhal & Walker (2005, 2005a).

The continuing need for residential development in all major cities and coastal areas means that increasingly such development will occur in areas previously considered too hazardous for development. Hence, there is an increased likelihood for damage to property and loss of life from landslide. Given the nature of State legislation on planning and development, there is a requirement for Councils to consider a range of planning and development issues for each Development Application and one such issue is whether the area of a proposed development is subject to instability. This is in the context that: (i) slope instability occurs in many parts of urban and rural Australia and (ii) it has been estimated that virtually every Local Government Area (LGA) in Australia has landslide hazards of one form or another.

2 NATIONAL DISASTER MITIGATION PROGRAM

In 2003, the Australian Government introduced the National Disaster Mitigation Program (NDMP) to fund disaster mitigation, addressing hazards such as flooding, bushfire and landslides. Governments throughout Australia recognised the risks posed to property and life from landslides.

AGS has recognised these risks for over 30 years and has developed guidelines for landslide risk management - as it is now known – in 1985, 2000 and 2002. However, it was recognised that there were limitations to these guidelines, that there was a need to develop them further and to complement them with additional advice.

In view of this, AGS and representatives from Local Governments sought funding assistance for the development of three guidelines under the 2004-2005 National Disaster Mitigation Program. Funding assistance for landslide likelihood research was also sought from NDMP under the 2003-2004 funding round.

AGS successfully obtained assistance under the NDMP for three projects dealing with landslide risk management:

i) landslide likelihood research;
ii) development of two guidelines – one for landslide zoning, and another for slope management and maintenance (the latter now known as the Australian GeoGuides) and
iii) development of a practice note.

In addition to the guidelines, two commentaries have been developed to provide further explanation to the Landslide Zoning guideline and the Practice Note. The guidelines, their accompanying commentaries, Australian GeoGuides and technical papes are listed in Table 1. They have been cited consistently in this manner throughout this issue of *Australian Geomechanics*.

The activities have been conducted under the authority of the AGS National Committee and have been subjected to extensive peer review.

Table 1: NDMP LRM guidelines, commentaries and papers.

Guideline Title	Abbreviated Title	Reference	Intended Users
"Guideline for landslide susceptibility, hazard and risk zoning for land use planning", *Australian Geomechanics*, Vol 42 No 1, March 2007.	Landslide Zoning Guideline	AGS (2007a)	Regulators, Geotechnical Practitioners
"Commentary on guideline for landslide susceptibility, hazard and risk zoning for land use planning", *Australian Geomechanics*, Vol 42 No 1, March 2007.	Commentary on Landslide Zoning Guideline	AGS (2007b)	As above
"Practice Note guidelines for landslide risk management", *Australian Geomechanics*, Vol 42 No 1, March 2007.	Practice Note 2007	AGS (2007c)	Geotechnical Practitioners, Regulators
"Commentary on Practice Note guidelines for landslide risk management', *Australian Geomechanics*, Vol 42 No 1, March 2007.	Practice Note Commentary	AGS (2007d)	As above
"Australian GeoGuides for slope management and maintenance", *Australian Geomechanics*, Vol 42 No 1, March 2007.	Australian GeoGuides	AGS (2007e).	General Public, Regulators, Geotechnical Practitioners
"Landslide likelihood in the Pittwater Local Government Area", *Australian Geomechanics*, Vol 42 No 1, March 2007.	PWC Landslide Likelihood Research	MacGregor *et al.*, 2007	Geotechnical Practitioners
"Rainfall Data Analysis and Relation to the Incidence of Landsliding at Newport ", *Australian Geomechanics*, Vol 42 No 1, March 2007.	PWC Rainfall Statistics	Walker (2007)	Geotechnical Practitioners
"An assessment of rockfall frequency for the coastal cliff-lines of Pittwater local government area, Sydney", *Australian Geomechanics*, Vol 42 No 1, March 2007.	PWC Coastline Rockfall Likelihood	Kotze (2007).	Geotechnical Practitioners

3 DETAILS OF THE PROCESS OF DEVELOPMENT

Landslide Likelihood Research

Under the 2003-2004 NDMP funding round, research was undertaken into landslide likelihood in the Pittwater Council local government area. The objective of the research was to ascertain historic frequencies of landsliding which could be used to assist in estimating landslide hazard and risks within the study area.

Pittwater Council was the sponsoring agency as it is situated within a geotechnical setting prone to landsliding and the Council area has experienced several significant house-block-sized landslides which have demolished and damaged houses. Records held by Pittwater Council (which are public documents) were used as base data for the study. The outcomes from this study are presented by MacGregor *et al.* (2007), Walker (2007) and Kotze (2007).

Landslide Taskforce Guidelines and Australian GeoGuides

The development of three guidelines was funded under the 2004-2005 NDMP funding round. This application was sponsored by the Sydney Coastal Councils Group (SCCG) with Mosman Council, a northern Sydney Council, as the lead agency representing the SCCG in this project. For convenience use has been made of the name "Landslide Taskforce".

The Landslide Zoning Guideline provides guidance in the methods of Landslide Zoning to government regulators (officers of local government and state government instrumentalities) and geotechnical practitioners. Such characterisation will provide input to the planning process in areas of landslide hazard.

The Practice Note Guideline provides guidance both to practitioners in the performance of project specific landslide risk assessment and management, and also to government officers in interpretation of the reports they receive. The Practice Note can be used an external reference document for legislative requirements and supersedes the recognised industry "standard" on LRM in Australia – AGS (2000). AGS (2000) remains as a complementary commentary and reference document. The Practice Note will provide uniformity in the quality of assessment and reporting and so will promote confidence in the planning and risk management process in regard to landslide hazards.

The Practice Note provides: (i) a revised risk to property matrix to address shortcomings identified in usage; (ii) recommendation for the adoption of tolerable risk criteria for risk to life; (iii) the introduction of Importance Levels and linked tolerable risk criteria for risk to propoerty; (iv) the introduction of a suite of model sign-off forms, linked to recommendations from risk assessments, to improve the linkages between assessment, design and construction; (v)

further explanation of the risk equation and method of calculation, together with further eamples and references and (vi) guidance on the contents of a LRM report.x

The Australian GeoGuides for slope management and maintenance provide owners, occupiers and therefore the public in the broader sense with guidance on management and maintenance of properties subject to landslide hazard.

The guidelines and Australian GeoGuides benefit the general community and Local Government regulators through achieving safer, more sustainable communities in relation to their exposure to landslide risk and reduce risk to the community through improved planning and slope management practices – key requisites of the NDMP funding. These guidelines will link with the risk management practices presented in AGS (2000) – enhanced by the Practice Note - and the BCA Guideline (2006) and will provide long-term natural disaster mitigation benefits to housing and infrastructure.

Development and Review Process

A Working Group was established for development of each of the guidelines as well as for development of the Practice Note. All Working Groups report to a Steering Committee which consists of a representative of AGS, the SCCG as the sponsoring agency and the convenors of each of the Working Groups. The convenor of each working group is the principal author of that group's guideline. Review was provided by the members of the Steering Committee, the Landslide Taskforce - which consists of 16 practitioners (engineering geologists and geotechnical engineers) and regulators from across the nation. Membership of the Landslide Taskforce did not preclude membership of a working group.

NDMP Landslide Taskforce at their Workshop held in Sydney on 21 September 2005:

(L to R) Andrew Leventhal (chair), Angus Gordon, Arthur Love, Robin Fell (Hazard Zoning working group convenor), Grahame Wilson, Fiona MacGregor, Ralph Rallings, Max Ervin, John Braybrooke, Grant Murray, Warwick Davies, Peter Tobin, Alex Litwinowicz, Ian Stewart, Mark Eggers, Greg Kotze, Garry Mostyn, Garth Powell, Tony Phillips (Slope Management working group convenor), Bruce Walker (Practice Note convenor), Tony Miner, Graham Whitt, Geoff Withycombe (Sydney Coastal Councils Group), Henk Buys.

The SCCG established an External Observer Group to provide nationwide perspective for the SCCG Expert Group. The members of the External Observer Group include managers of federal and state government departments and local government areas responsible for coastal processes throughout the nation.

A peer review process for the guidelines was implemented by the AGS National Committee. Additionally, specific independent technical external review was also established by the Steering Committee. The Expert Panel of the SCCG and the nationwide External Observer Group established by the SCCG each also conducted reviews in regard to planning issues.

The output from the studies are nationally endorsed by AGS as guidelines.

An international Landslide Zoning guideline is being developed under the auspices of JTC-1, the Joint Technical Committee on Landslides and Engineered Slopes established by the ISSMGE, the ISRM and the IAEG. This included an international workshop held in Barcelona in 2006 which was attended by two members of the projects' Steering Committee. The Australian draft of the guideline at that time was used as the initial draft for the international version. Both versions have benefited from review by each group and are similar in their final forms. The international guideline will be published later this year in the international journal, *Engineering Geology*.

4 HOW DOES THIS ALL FIT TOGETHER?

Figure 1 shows the flowchart for LRM as promoted in AGS (2000), which includes brief descriptions of the tasks involved. An abbreviated version is provided in Figure 2 – see also the Landslide Zoning Guideline (AGS, 2007a) and the Practice Note (AGS, 2007c) which also present this flow diagram. Figure 3 demonstrates how the Landslide Zoning (AGS, 2007a), the Practice Note (AGS, 2007c) and the Australian GeoGuides (AGS, 2007e) fit into the framework.

Figure 3 demonstrates how:

1) The technical basis is provided by AGS (2000), and that AGS (2000) is now complemented by AGS (2007c).
2) The Building Code of Australia guideline (2006) provides an overarching legislative requirement. Note that the current version of this document requires revision to agree with the outcomes from these NDMP projects.
3) Implementation of policies at state and local government levels that are universal and uniform will be beneficial to all participants.
4) Landslide zoning guidelines are provided by the Landslide Susceptibility, Hazard and Risk guideline and its commentary (AGS, 2007a and 2007b).
5) Landslide likelihood research provides some fundamental data as an example of a starting point for semi-quantitative or quantitative assessments (MacGregor *et al* 2007, Walker 2007 and Kotze, 2007).
6) The Practice Note and its commentary (AGS, 2007c and 2007d) provide guidance on the process and minimum requirements for conducting a landslide risk assessment and supersede AGS (2000).
7) Slope management principles are provided for the owner and occupier through the Australian GeoGuides (AGS, 2007e).
8) Technical competence of practitioners can be demonstrated through the specific area of practice within NPER.

The framework diagram in Figure 3 shows the inter-relationship between each of those elements and the benefits of them in their entirety to complete a systematic and defensible risk management process throughout Australia.

Figure 4 provides an indication of the manner in which the investigation phases of the LRM process could interact and Figure 5 similarly indicates the design and verification stages of a LRM project.

5 WHAT ARE THE NATIONAL BENEFITS?

The Australian Geomechanics Society has established a framework for conducting LRM within a defensible and rigorous set of guidelines and legislative requirements. There is now clear guidance both to the regulator and the practitioner and a consistent approach can be adopted notwithstanding that there will be different drivers and various planning schemes throughout the nation.

The Steering Committee of the Landslide Taskforce believes AGS has made a contribution to the wellbeing of the Australian people, and perhaps to the broader international community.

6 ACKNOWLEDGEMENT

The projects have been conducted with the assistance of NDMP funding. The contribution from the Commonwealth Government, NSW State Government and our sponsors at local government level is recognised.

The support of our sponsors – Pittwater Council and the Sydney Coastal Councils Group – has benefited the development of the projects through their awareness of the needs for the project outcomes and enthusiasm and cooperation to achieve them.

The members of the AGS National Committee are acknowledged for their support during the projects and the peer review of the Landslide Taskforce guidelines that they conducted. Independent peer reviews of those guidelines were conducted by Chris Haberfield, Paul Hardie and Colin Mazengarb and this is gratefully acknowledged.

The developments that have been achieved thus far are the result of the endeavours of many. Without the input of various steering and working groups development of the current status of the guidelines and framework would not have been possible. A list of the contributors to these NDMP projects is presented in the Appendix and their contribution is gratefully acknowledged by the Steering Committee.

It should be appreciated that many of those listed in the Appendix have contributed to this endeavour for a period of over 20 years. That contribution is respectfully noted. The list of employers who have provided support over those years is equally lengthy and their support in these endeavours is also gratefully acknowledged.

Amongst the many, it is important to recognise the particular contribution of the convenors of the Working Groups in this current task, who were responsible as principle authors for the Guideline documents developed under the NDMP Landslide Taskforce:

Robin Fell (Landslide Zoning);
Bruce Walker (Practice Note) and
Tony Phillips (GeoGuides).

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Kotze, G.P. (2007) "An Assessment of Rockfall Frequency for the Coastal Cliff Lines of Pittwater Local Government Area, Sydney" *Australian Geomechanics*, Vol 42 (1), March 2007.

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Leventhal, A.R. and Walker, B.F. (2005a) "Risky Business – the development and implementation of a national landslide risk management system for Australia, the state of play, September 2005", *Australian Geomechanics*, Vol 40 No 4, Dec 2005.

MacGregor, J.P., Walker, B.F., Fell, R. and Leventhal, A.R. (2007). "Landslide Likelihood in the Pittwater Local Government Area", *Australian Geomechanics*, Vol 42 No 1, March 2007.

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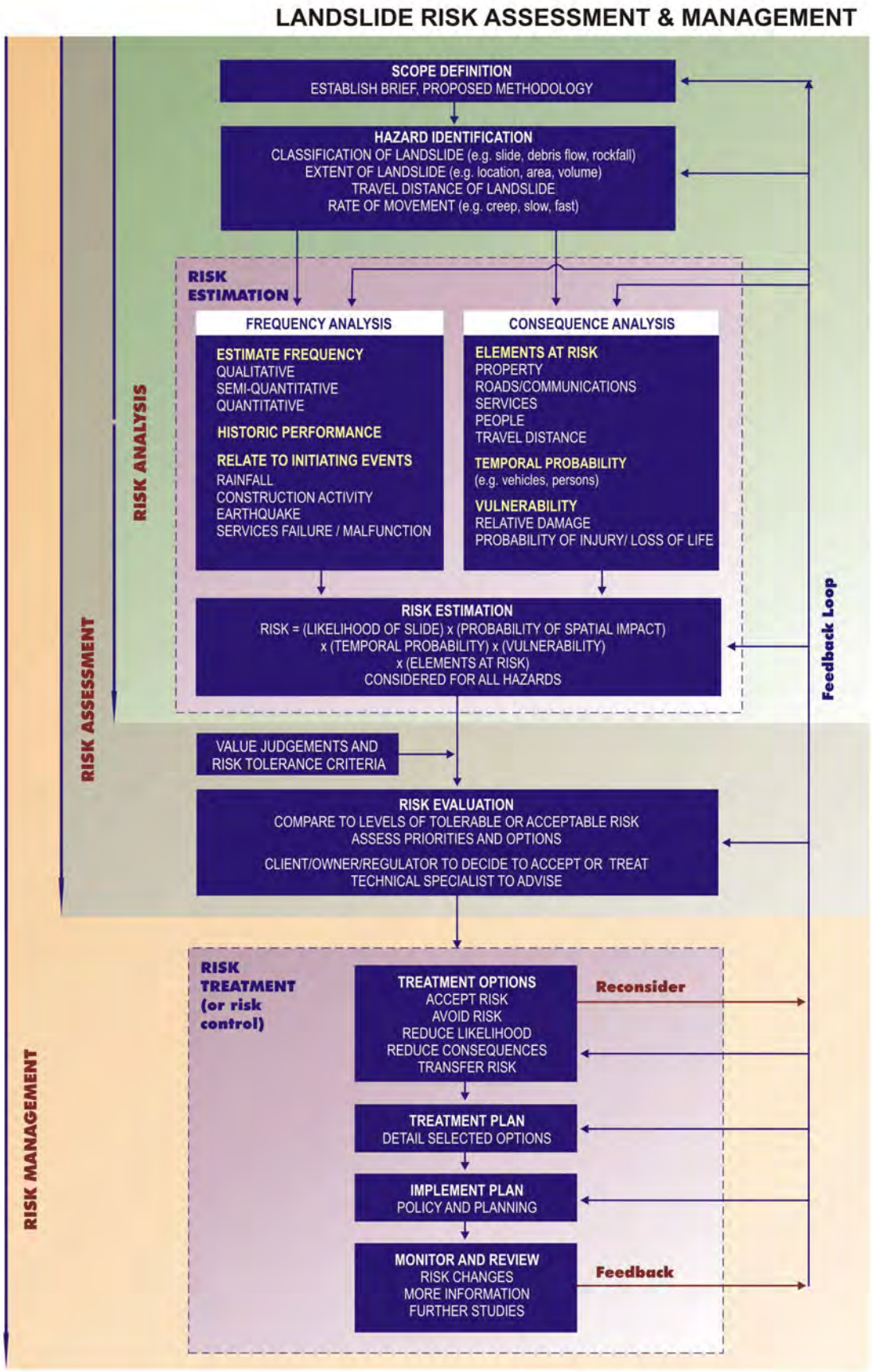

Figure 1: Flowchart for Landslide Risk Management
(after AGS 2000).

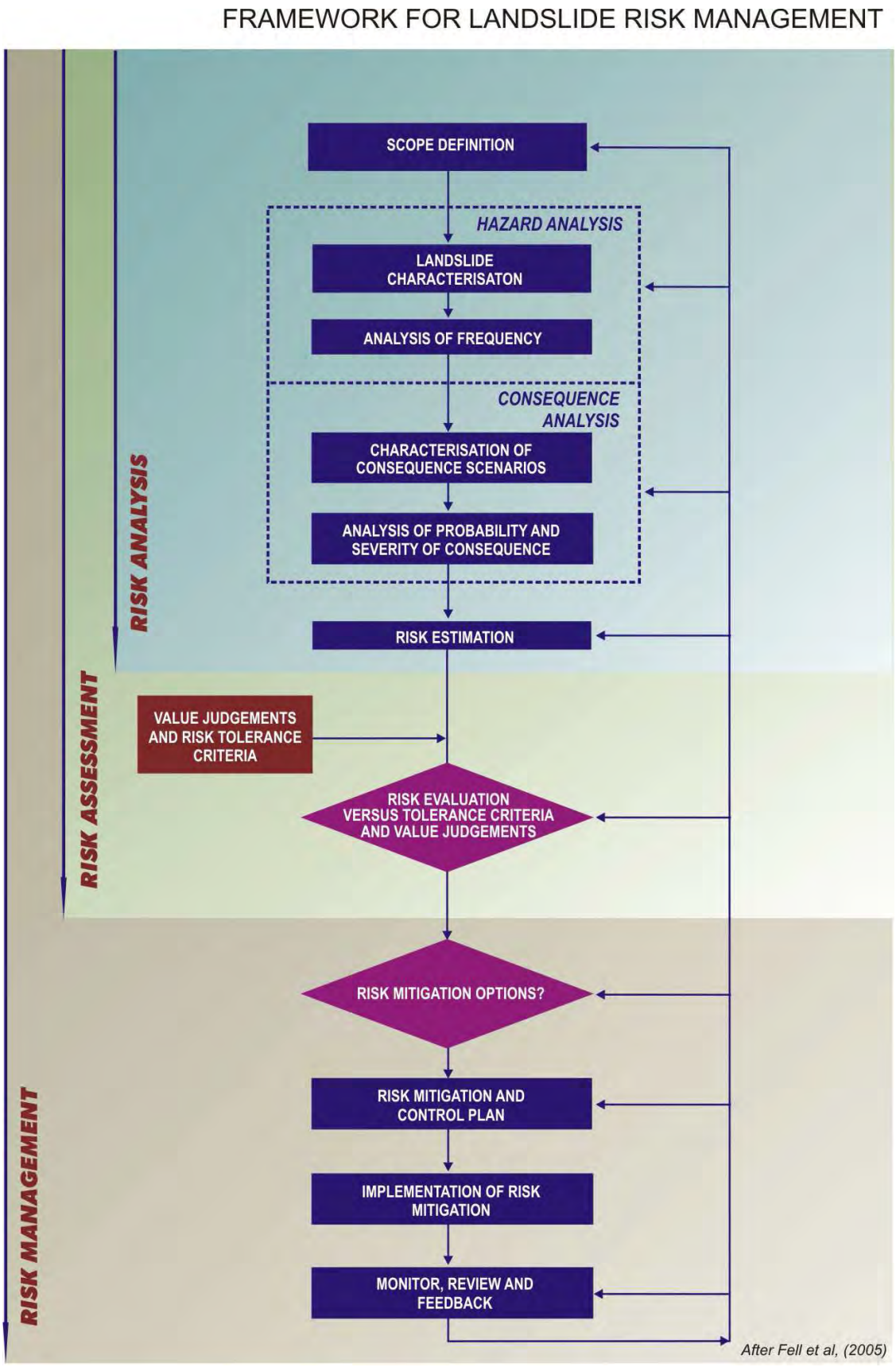

Figure 2: Abbreviated flowchart for Landslide Risk Management.
Ref: AGS (2007a, 2007c)

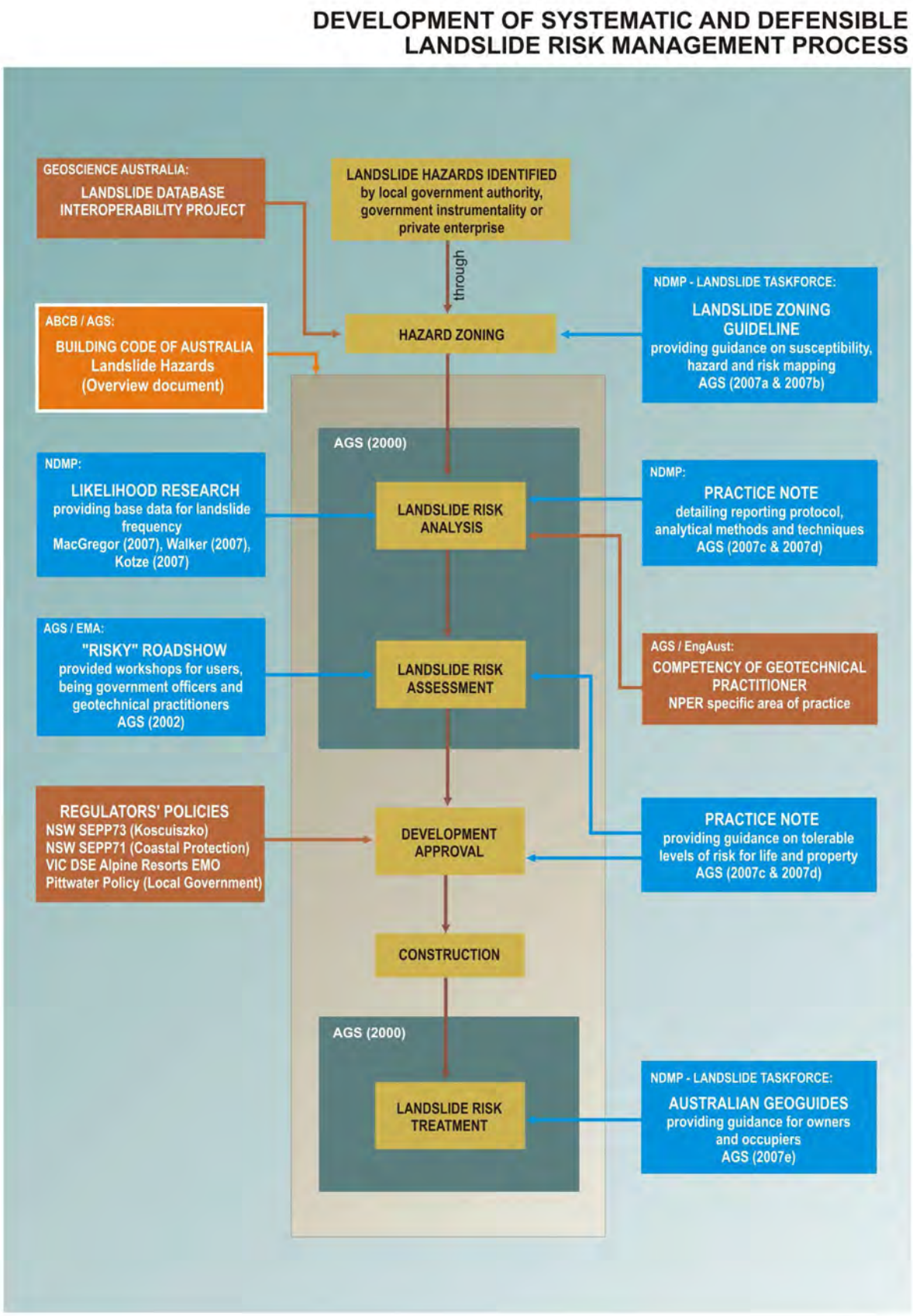

Figure 3: Systematic and defensible Landslide Risk Management framework.

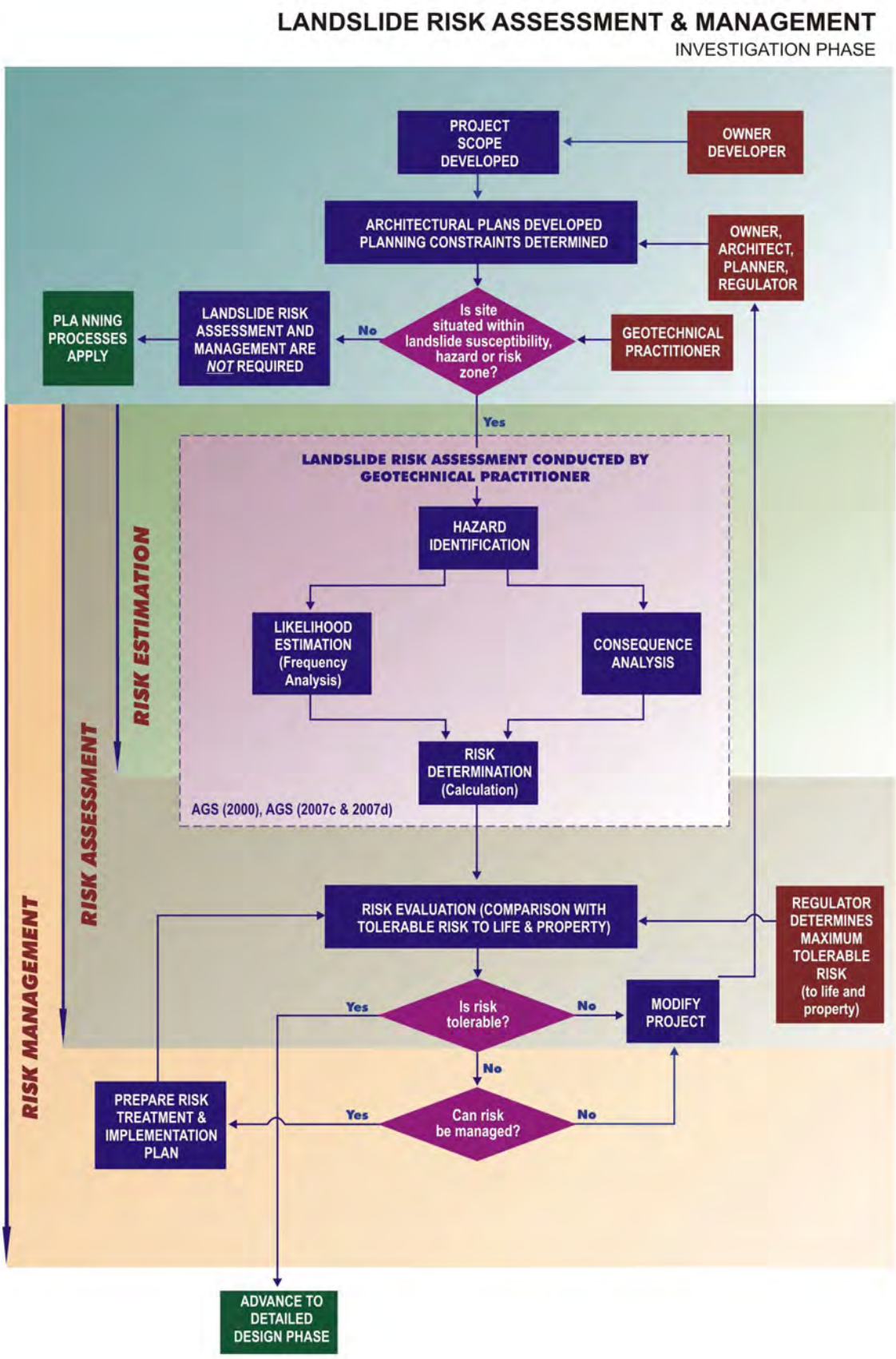

Figure 4: Investigation phase of a project incorporating LRM.

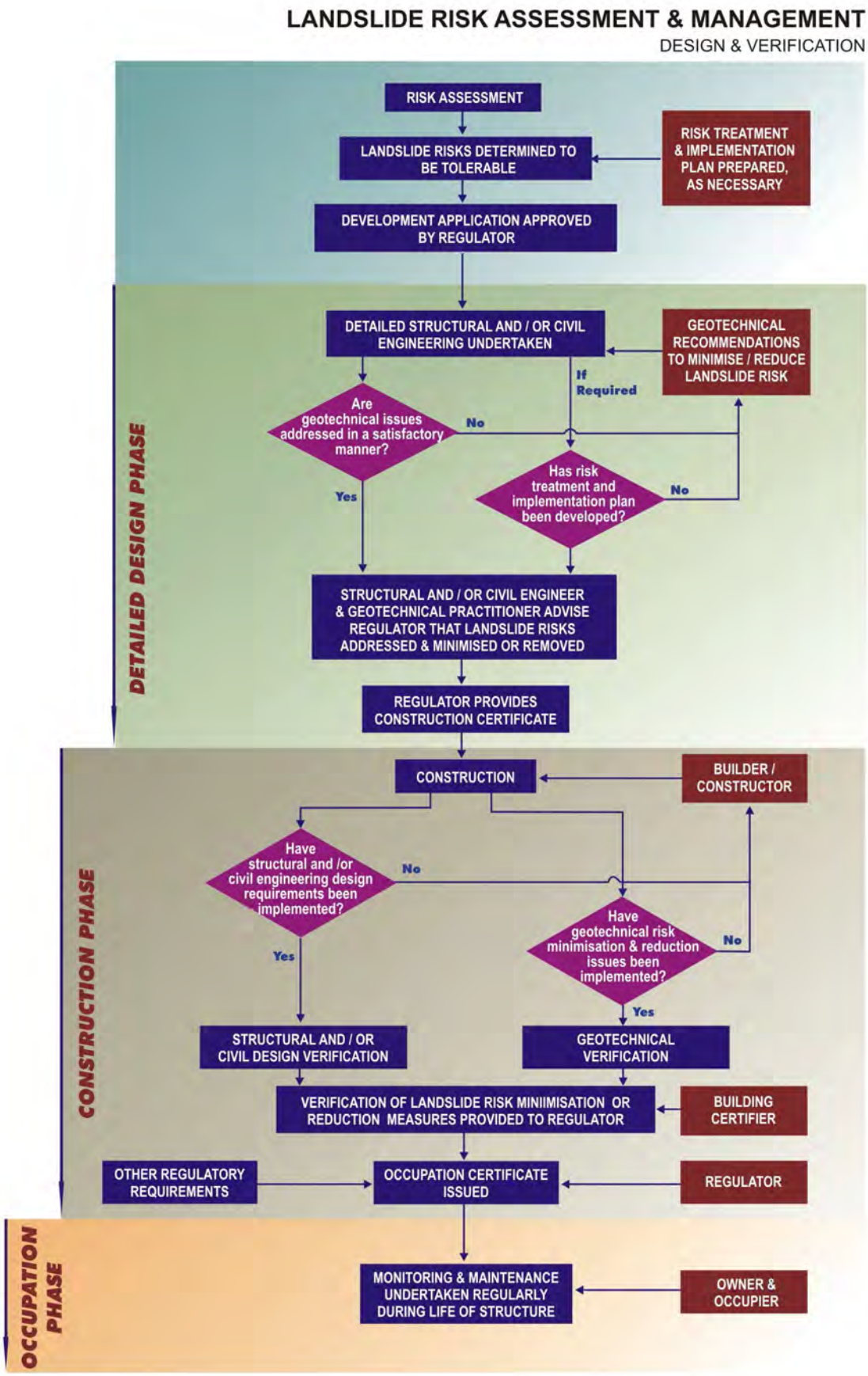

Figure 5: Design and verification phases of a LRM project.

APPENDIX

NDMP LANDSLIDE TASKFORCE GUIDELINES PROJECTS

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GUIDELINE FOR LANDSLIDE SUSCEPTIBILITY, HAZARD AND RISK ZONING FOR LAND USE PLANNING

Australian Geomechanics Society Landslide Zoning Working Group

TABLE OF CONTENTS

1 INTRODUCTION

There are a number of natural hazards which are relevant to urban, residential, rural and undeveloped property throughout Australia. These include flooding, bush fire, coastal processes and landslides. This guideline addresses landslide susceptibility, hazard and risk zoning for land use planning.

In 1998, following the Thredbo landslide in which 18 persons were killed, the Institution of Engineers Australia and the Australian Geomechanics Society (AGS) formed a Taskforce on the Review of Landslides and Hillside Construction Standards. The Taskforce after reviewing the Australian Standards and relevant codes on landslides and hillside construction concluded that they were inadequate and recommended the production of four guidelines:

- Landslide hazard zoning for urban areas, roads and railways
- Slope management
- Site investigations, design, construction and maintenance
- Landslide risk assessment

The Australian Geomechanics Society "*Landslide Risk Management Concepts and Guidelines*", already under preparation at the time of the Thredbo landslide, was published in 2000 (AGS 2000, 2002). This document touched on all four areas but mainly addressed the fourth. It is used extensively throughout Australia.

In 2005 the Australian Geomechanics Society in collaboration with the Sydney Coastal Councils Group, was successful in obtaining funding under the Australian governments' National Disaster Mitigation Program (NDMP) to further the development of the guidelines which had been recommended by the Taskforce. Work to prepare these guidelines has

progressed in 2005 and 2006 and has involved extensive consultation with those involved in landslide mapping for land use planning and the application of such mapping for planning in local government.

This Guideline for Landslide Susceptibility, Hazard and Risk Zoning for Land Use Planning provides:

- Definitions and terminology.
- Description of the types and levels of landslide zoning.
- Guidance on where landslide zoning and land use planning is necessary to account for landslides.
- Definitions of levels of zoning and suggested scales for zoning maps taking into account the needs and objectives of land-use planners and regulators and the purpose of the zoning.
- Guidance on the information required for different levels of zoning taking account the types of landslides.
- Guidance on the reliability, validity and limitations of the investigation methods.
- Advice on the required qualifications of the persons carrying out landslide zoning and advice on the preparation of a brief for consultants to conduct landslide zoning for land use planning.

The guideline considers landslides occurring in natural slopes and from failure of constructed slopes including cuts, fills and retaining walls and the impact of the landslides on the area to be zoned. It is intended for use by local, state and national government officials, geotechnical professionals, land use planners and project managers.

This guideline has been developed at the same time as similar guidelines prepared by the JTC-1 *The Joint International Committee on Landslides and Engineered Slopes* and there has been an interchange of concepts and detailed inputs between the two guidelines.

Through the NDMP, Australian governments (at Commonwealth, State and Local Government levels) are also funding the development of a Practice Note Guideline (AGS 2007c) to supersede the Landslide Risk Management Guideline (AGS 2000, AGS 2002), and a series of GeoGuides on Slope Management and Maintenance (AGS 2007e).

2 DEFINITIONS AND TERMINOLOGY

2.1 DEFINITIONS

Definitions for terms used in landslide zoning and risk management are given in Appendix A. These definitions are based on IUGS (1997), with some amendments in matters of detail based on internationally adopted definitions prepared by The International Society of Soil Mechanics and Geotechnical Engineering (ISSMGE) Technical Committee 32. These definitions should be used for all zoning, reports and land use planning documents. It is recommended that the definitions are attached to these documents so there is no misunderstanding of the terms.

Definitions of the main terms are:

- **Landslide.** The movement of a mass of rock, debris, or earth (soil) down a slope**.**
- **Landslide Inventory.** An inventory of the location, classification, volume, activity and date of occurrence of individual landslides in an area.
- **Landslide Susceptibility.** A quantitative or qualitative assessment of the classification, volume (or area) and spatial distribution of landslides which exist or potentially may occur in an area. Susceptibility may also include a description of the velocity and intensity of the existing or potential landsliding.
- **Hazard.** A condition with the potential for causing an undesirable consequence. The description of landslide hazard should include the location, volume (or area), classification and velocity of the potential landslides and any resultant detached material and the probability of their occurrence within a given period of time.
  Landslide hazard includes landslides which have their source in the area or may have their source outside the area but may travel on to or regress into the area.
- **Risk**. A measure of the probability and severity of an adverse effect to health, property or the environment. Risk is often estimated by the product of probability and consequences. However, a more general interpretation of risk involves a comparison of the probability and consequences in a non-product form.
  For these guidelines risk is further defined as:
  (a) *For life loss*, the annual probability that the person most at risk will lose his or her life taking account of the landslide hazard and the temporal spatial probability and vulnerability of the person.
  (b) *For property loss*, the annual probability of the consequence or the annualised loss taking account of the elements at risk, their temporal spatial probability and vulnerability.
- **Elements at Risk.** The population, buildings and engineering works, economic activities, public services utilities, infrastructure and environmental features in the area potentially affected by the landslide hazard.

- **Vulnerability.** The degree of loss to a given element or set of elements within the area affected by the landslide hazard. It is expressed on a scale of 0 (no loss) to 1 (total loss). For property, the loss will be the value of the damage relative to the value of the property; for persons, it will be the probability that a particular life (the element at risk) will be lost, given the person(s) is (are) affected by the landslide.
- **Zoning.** The division of land into homogeneous areas or domains and their ranking according to degrees of actual or potential landslide susceptibility, hazard or risk.

In this guideline use of the word 'landslide' implies both existing (or known landslides) and potential landslides which a practitioner might reasonably predict based on the relevant geology, geometry and slope forming processes. Such potential landslides may be of varying likelihood of occurrence.

The term landslip is sometimes used to describe landslides but is not the recommended term.

It is noted that the term "zoning" has particular application by planners in Australia. This document uses the term as it best describes the process and is used internationally. To avoid confusion, those preparing landslide zoning using this document should always refer to " landslide susceptibility zoning", "landslide hazard zoning" and "landslide risk zoning".

2.2 LANDSLIDE CLASSIFICATION AND TERMINOLOGY

It is important that those carrying out landslide mapping use consistent terminology to classify and describe the landslides. It is recommended that the classifications of Cruden and Varnes (1996), Varnes (1978) or Hutchinson (1988) and terminology described in IAEG (1990) be used. These are reproduced in AGS (2007c).

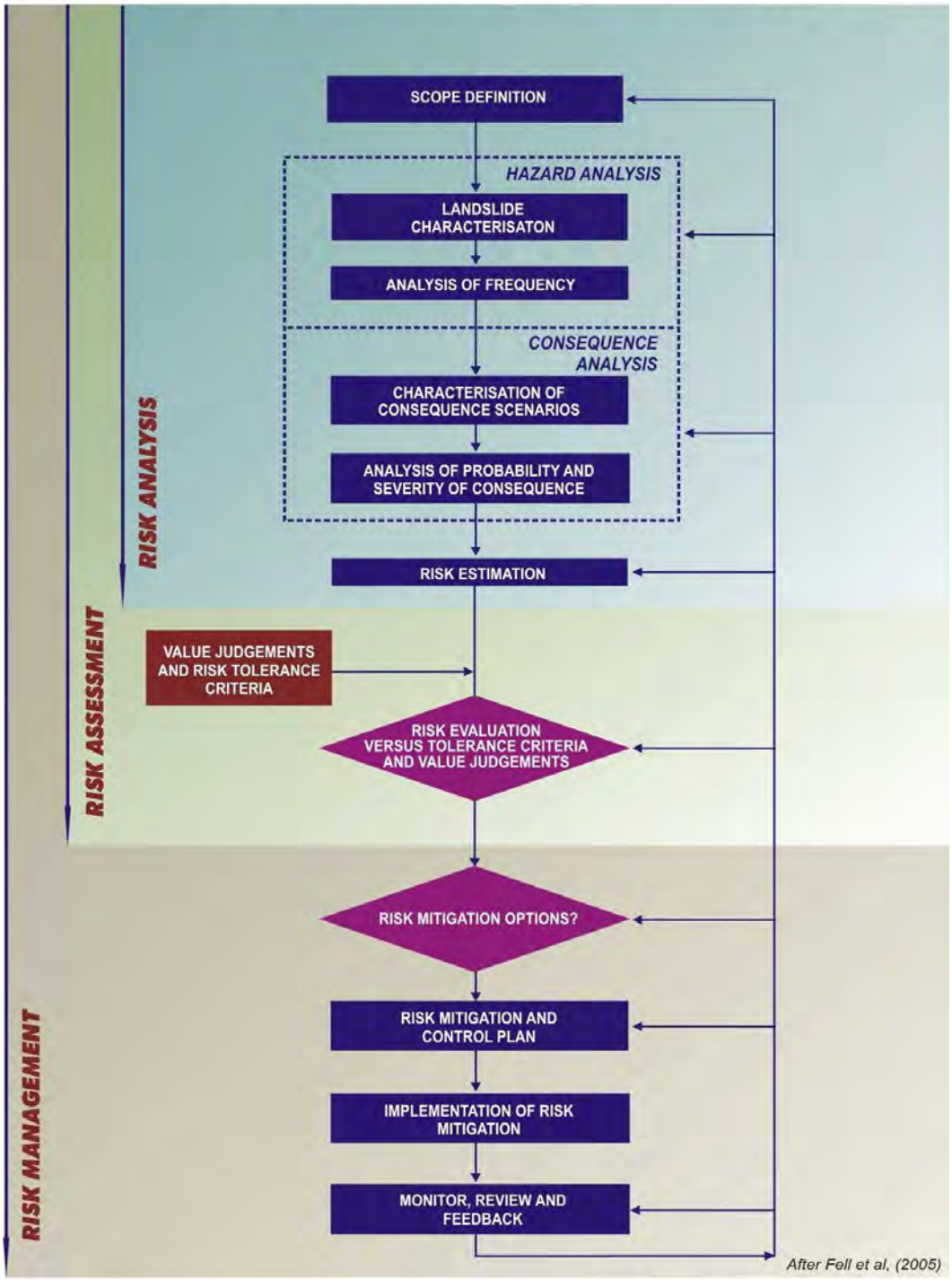
3 LANDSLIDE RISK MANAGEMENT FRAMEWORK

Since the publication of AGS (2000), many local government authorities have required a quantitative risk assessment approach for assessment of life loss risk for individual building developments. They have generally accepted qualitative or semi-quantitative assessment of property risk. These assessments are carried out using the risk based framework described in AGS (2000) and AGS (2002).

Figure 1 summarizes the framework for landslide risk management. This is taken from Fell *et al.* (2005) and represents a framework widely used internationally. It was the basis for the State of the Art papers and invited papers at the International Conference on Landslide Risk Management held on Vancouver in May 2005 and is consistent with AGS (2000), AGS (2002)and AGS (2007c).

It is recommended that this general framework be used for landslide susceptibility, hazard and risk zoning whether a quantitative or qualitative approach is being taken.

Figure 1. FRAMEWORK FOR LANDSLIDE RISK MANAGEMENT



4 DESCRIPTION OF LANDSLIDE SUSCEPTIBILITY, HAZARD AND RISK ZONING FOR LAND USE PLANNING

4.1 TYPES OF LANDSLIDE ZONING

Landslide Susceptibility Zoning involves the classification, volume (or area) and spatial distribution of existing and potential landslides in the study area. It may also include a description of the travel distance, velocity and intensity of the existing or potential landsliding. Landslide susceptibility zoning usually involves developing an inventory of landslides which have occurred in the past together with an assessment of the areas with a

potential to experience landsliding in the future, but with no assessment of the frequency (annual probability) of the occurrence of landslides. In some situations susceptibility zoning will need to be extended outside the study area being zoned for hazard and risk to cover areas from which landslides may travel on to or regress into the area being zoned. It will generally be necessary to prepare separate susceptibility zoning maps to show landslide sources and areas onto which landslides from the source landslides may travel or regress.

Landslide Hazard Zoning takes the outcomes of landslide susceptibility mapping, and assigns an estimated frequency (annual probability) to the potential landslides. It should consider all landsliding which can affect the study area including landslides which are above the study area but may travel onto it and landslides below the study area which may retrogressively fail up-slope into it. The hazard may be expressed as the frequency of a particular type of landslide of a certain volume or landslides of a particular type, volume and velocity (which may vary with distance from the landslide source) or, in some cases, as the frequency of landslides with a particular intensity where intensity may be measures in kinetic energy terms. Intensity measures are most useful for rock falls.

Landslide Risk Zoning takes the outcomes of hazard mapping and assesses the potential damage to persons (annual probability the person most at risk loses his or her life) and to property (annual value of property loss) for the elements at risk, accounting for temporal and spatial probability and vulnerability.

It will often be necessary to produce separate susceptibility, hazard and risk zoning maps for the different types of landslides affecting the area; e.g. for rock falls, small shallow landslides and deep-seated larger landslides. It may be necessary to produce separate maps for landslides from natural slopes and constructed slopes. If these are combined on to one map the boundaries may be confusing.

Appendix A in the Commentary has examples of landslide susceptibility, hazard and risk zoning for slopes which may experience rock falls, small landslides and large landslides.

5 GUIDANCE ON WHERE LANDSLIDE ZONING IS USEFUL FOR LAND USE PLANNING

5.1 GENERAL PRINCIPLES

Landslide zoning for land use planning is most commonly required at the local government level for planning urban development, but may be required by state or federal governments for regional land use planning or disaster management planning. It may also be required by land developers, those managing recreational areas or those developing major infrastructure such as highways and railways. The following are some examples of situations that are more susceptible to landslide occurrence. Their identification through landslide zoning would facilitate development planning and landslide risk management. It is the combination of having an area which is potentially subject to landsliding and the scale and type of development of the area that will determine whether landslide zoning is needed for land use planning. The type of zoning required is discussed in Section 6.

5.2 TOPOGRAPHICAL, GEOLOGICAL AND DEVELOPMENT SITUATIONS WHERE LANDSLIDING IS POTENTIALLY AN ISSUE

The following are examples where landsliding is potentially an issue in land use planning:

(a) Where there is a history of landsliding e.g:
- Deep-seated sliding on natural slopes.
- Widespread shallow slides on steep natural slopes.
- Rock falls from steep slopes and cliffs.
- Rock falls from coastal cliffs.
- Landslides in cuts, fills and retaining walls on roads, railways and associated with urban development.
- Large currently inactive landslides subject to undercutting by active erosion of the toe or subject to reactivation by development.
- Debris flows and earth slides from previously failed slopes.
- Widespread shallow creep type landslides in slopes of any inclination.

(b) Where there is no history of sliding but the topography dictates sliding may occur. e.g:
- Cliffs (coastal and inland).
- Natural slopes steeper than 35° (landslide travel is likely to be rapid).
- Natural slopes between 20° and 35° (rapid landslide travel is possible).
- Steep, high road or rail cuttings.
- Steep slopes degraded by recent forest logging, forest fires and/or construction of roads.

- Large currently inactive landslides subject to rising groundwater regimes; e.g. by forestry and agricultural operations.

(c) When there is no history of sliding but geological and geomorphologic conditions are such that sliding is possible e.g:

- Weathered basalt overlying other more competent rocks (sliding often occurs on the boundaries).
- Weathered granitic and volcanic rocks.
- Weathered interbedded rocks (such as claystone, shale and siltstone) and sandstone or limestone.
- Sand dunes.
- River banks in soil subject to floods and/or active erosion.
- Steep natural slopes in regions affected by large earthquakes.
- Slopes in highly sensitive weak clays (e.g. quick clays).
- Where there is active undercutting of slopes by rivers or the sea.
- In seismically active regions slopes in loose saturated soil which are susceptible to liquefaction.

(d) Where there are constructed features which, should they fail, may travel rapidly e.g:

- Loose silty sandy fills (residual/extremely weathered granite; ripped sandstone etc).
- Other side cast fills on steep slopes.
- Large retaining walls.
- Mine overburden spoil and mine waste dumps, particularly those sited on hillsides.
- Tailings dams constructed using upstream construction methods.

(e) Forestry works and agricultural land clearing where landsliding may lead to damage to the environment by degrading streams and other receiving water bodies.

It should be noted that rapid sliding is important because of the potential for life loss. However slow and very slow moving landslides are also of importance because they may also lead to property damage.

5.3 TYPES OF DEVELOPMENT WHERE LANDSLIDE ZONING FOR LAND USE PLANNING WILL BE BENEFICIAL

The following are examples of where landslide zoning for land use planning will be beneficial:

(a) Residential land development

- New urban areas.
- Subdivision of rural land.
- Subdivision of urban land where a number of allotments will be formed. It is envisaged that an area of at least 2 hectares or 20 house allotments would be involved. For smaller areas the procedures for individual risk assessments can be followed.
- Redevelopment of urban areas.

(b) Residential development controls in existing urban areas potentially affected by landsliding.

- Within part or all of a local government area.
- City wide.

(c) Development of important infrastructure.

- Hospitals, schools, fire brigades and other emergency services.
- Critical communications infrastructure.
- Major lifelines such as transport, water, gas pipelines and electricity power lines

(d) Recreational areas.

- Alpine resorts.
- Other resorts e.g. islands.
- State and national parks (coastal and others).
- Sports facilities.
- Coastal walkways.

(e) Development of new or redevelopment of existing highways, roads and railways.

- Rural.
- Urban main roads.
- Urban subdivision roads.

(f) Public land where landsliding may travel on to or retrogress into adjacent developments.

- State forests.
- State and National parks.
- Municipal parks.

(g) River valleys in which dams are to be constructed, including the slopes adjoining the reservoir and river valleys upstream where there is potential for blockage of rivers by landslides and breach of the landslide dam with subsequent outburst floods, and/or the creation of large waves which may overtop the dam if a large rapidly moving landslide travels into the reservoir.

It should be recognized that if the land under consideration for land use planning falls into any of the categories in Section 5.2, there will be potential land management benefits in carrying out landslide zoning.

The categories listed are not meant to be a complete list. Nether is it meant that if one or more of these categories are present that landslide zoning is essential. Those involved should assess whether zoning is necessary taking account of the factors detailed above, the development proposed and the applicable regulatory requirements.

6 SELECTION OF THE TYPE AND LEVEL OF LANDSLIDE ZONING

6.1 SOME GENERAL PRINCIPLES

Landslide zoning is carried out for regional, local and site specific planning. The outputs are usually in the form of one or more of the following: landslide inventory, susceptibility, hazard and risk zoning maps and associated reports.

The type and level of detail of the zoning and the scale of the maps depends on the purpose to which the landslide zoning is to be applied and a number of other factors:

- *The stage of development of the land use zoning plan or engineering project.* Susceptibility and hazard zoning are more likely to be used in preliminary stages of development with hazard and risk zoning for more detailed stages. However the choice depends mostly on the intended purpose of the zoning in land use management.
- *The type of development.* Risk zoning is more likely to be used for existing urban developments where the elements at risk are defined or for existing and planned road and railway developments where the elements at risk (the road or rail users) are readily predicted. However, the elements at risk often vary with time so risk zoning needs to be up-dated regularly.
- *The classification, activity, volume or intensity of landsliding*. Risk zoning is more likely to be required where the landslides are likely to travel rapidly and or have a high intensity as measured by the combination of volume and velocity (e.g. rock fall, debris flows, rock avalanches). For these situations life loss is more likely so it is useful to use risk zoning as this allows land use zoning to be determined using life loss risk criteria.
- *Funds available.* While the purpose should determine the level of zoning and the scale of the maps, the funding available may be a practical constraint. Landslide susceptibility zoning is lower cost than hazard zoning, and hazard zoning is somewhat lower cost than risk zoning, so land use planners may opt for a lesser type and level of mapping at least in a staged introduction of landslide land use planning.
- *The amount and quality of available information.* Only susceptibility zoning is performed where data on frequency of landslides either do not exist or are so uncertain as to not be relied on.
- *History of land use.* The history of the area being zoned and its evolution in terms of land use must be carefully taken into account as human activities may modify the slope instability environment and modify the susceptibility to and likelihood of landsliding and hence the hazard.
- *Degree of quantification.* Qualitative methods are often used for susceptibility zoning and sometimes for hazard zoning. It is better to use quantitative methods for both susceptibility and hazard zoning. Risk zoning should be quantified. More effort is required to quantify the hazard and risk but there is not necessarily a great increase in cost compared to qualitative zoning.
- *The required accuracy of the zoning boundaries.* Where statutory land use planning constraints are proposed large scale maps with appropriate levels of inputs should be used. In this regard it should be noted that State and Local governments may have different requirements. The largest scale required will determine the level and scale of landslide zoning.
- *Linkage to the proposed planning controls*. The use of complementary or linking processes such as planning schedules and development control plans whereby the landslide zoning initiates a more detailed assessment at site scale. In this case, the use of landslide susceptibility mapping which defines a planning control area may be sufficient to identify where a more detailed landslide risk assessment is needed.

Table 1: Recommended types and levels of zoning and zoning map scales related to landslide zoning purpose.

Purpose	Type of Zoning				Zoning Level			Applicable Zoning Map Scales
	Inventory	Susceptibility	Hazard	Risk	Preliminary	Intermediate	Advanced	
Regional Zoning								
Information	X	X			X			1:25,000 to 1:250,000
Advisory	X	X	(X)		X	(X)		
Statutory	NOT RECOMMENDED							
Local Zoning								
Information	X	X	X	(X)	X	(X)		1:5,000 to 1:25,000
Advisory	(X)	X	X	X	X	X	X	
Statutory		(X)	X	(X)		X	X	
Site Specific Zoning								
Information	NOT RECOMMENDED							>1:5000, typically 1:5,000 to 1:1,000
Advisory	NOT COMMONLY USED							
Statutory		(X)	X	X		X	X	
Design		(X)	(X)	X		(X)	X	

Notes: X= applicable; (X) = may be applicable

6.2 RECOMMENDED TYPES AND LEVELS OF ZONING AND MAP SCALES

Table 1 shows the recommended types of zoning, zoning levels and mapping scales that depend on the purpose of the zoning. The table is applicable to land use planning for urban development. The table is broadly applicable to other uses such as managing landslide hazard and risks for new and existing roads and railways.

It will usually be appropriate to carry out landslide susceptibility zoning as a first stage in the development of landslide hazard or risk zoning for planning purposes. Staging will allow better control of the process and may reduce the costs of the zoning by limiting the more detailed zoning only to areas where it is necessary.

It should be noted that it will seldom be necessary to carry out landslide zoning at an advanced level because the costs will potentially be so much larger than the costs for intermediate level zoning and this will potentially outweigh the benefits.

The levels of zoning and descriptors of susceptibility, hazard and risk are given in the following sections. It is recommended that these descriptors be used by all involved in landslide risk management.

6.3 DEFINITION OF THE LEVELS OF ZONING

Table 2 defines the levels of landslide inventory, susceptibility, hazard and risk zoning in terms of geotechnical and other input data. The definitions of the levels of the input data are given in Section 8. It is important to match the level of the zoning to the required usage, the scale of mapping and in turn match these to the level of the input data. It is not possible, for example, to produce a satisfactory advanced level hazard zoning without at least intermediate level assessment of frequency of landsliding. If only a basic level assessment of frequency can be made then the result will be no better than preliminary level and there is no point spending large resources getting the other inputs to a intermediate or, in particular, to a sophisticated level. On the other hand, if a preliminary level hazard zoning is required then the inputs may be at the basic level.

Table 2: Levels of activity required for susceptibility, hazard and risk zoning levels.

Type of Zoning	**Risk Zoning**						
	Hazard Zoning						
	Susceptibility Zoning						
	Inventory Mapping						
Zoning Level	**Inventory of existing landslides**	**Characteriz-ation of potential landslides**	**Travel distance and velocity**	**Frequency assessment**	**Temporal spatial probability**	**Elements at risk**	**Vulnerability**
Preliminary	Basic (1) (2)	Basic (1) (2)	Basic (1) Intermediate (2)	Basic (1,2)	Basic (1,2)	Basic (1,2)	Basic (1,2)
Intermediate	Intermediate	Intermediate	Intermediate	Intermediate	Intermediate	Intermediate	Intermediate to Basic
Advanced	Sophisticated	Sophisticated to Intermediate	Intermediate to Sophisticated	Intermediate to Sophisticated	Sophisticated	Sophisticated	Intermediate to Sophisticated

Notes:

(1) For qualitative zoning
(2) For quantitative zoning
(3) See Section 8 for description of the levels of input information. viz basic, intermediate, sophisticated.

6.4 LANDSLIDE ZONING REPORTS

Landslide zoning reports should include:

- A landslide inventory map and associated information on landslides in the inventory such as classification, location, time of sliding (if known), volume and a description of validation and limitations of the inventory.

- Susceptibility zoning map(s) with related information on how susceptibility was determined and a description of validation and limitations of the zoning.
- Where hazard zoning is required a hazard zoning map(s) at an appropriate scale with related information on how frequency of landsliding was assessed and a description of validation and limitations of the zoning. The report should also include the landslide inventory and susceptibility zoning.

Where risk zoning is required a risk zoning map(s) at an appropriate scale with related information on how frequency of landsliding was assessed and detail the assumed elements at risk, temporal spatial probabilities and vulnerabilities and how these were determined and a description of validation and limitations of the zoning. The report should also include the landslide inventory and susceptibility and hazard zoning.

7 LANDSLIDE ZONING MAP SCALES AND DESCRIPTORS FOR SUSCEPTIBILITY, HAZARD AND RISK ZONING

7.1 SCALES FOR LANDSLIDE ZONING MAPS AND THEIR APPLICATION

Table 3 summarizes map scales and the landslide inventory, susceptibility, hazard and risk mapping to which they are usually applied. Landslide zoning maps should be prepared at a scale appropriate for displaying the information needed at a particular zoning level.

Table 3: Landslide zoning mapping scales and their application.

Scale Description	Indicative Range of Scales	Examples of Zoning Application	Typical Area of Zoning
Small	< 1:100,000	Landslide inventory and susceptibility to inform policy makers and the general public	>10,000 square kilometres
Medium	1:100,000 to 1:25,000	Landslide inventory and susceptibility zoning for regional and local development or very large scale engineering projects. Preliminary level hazard mapping for local areas	1000 – 10,000 square kilometres
Large	1:25,000 to 1:5,000	Landslide inventory, susceptibility and hazard zoning for local areas Preliminary level risk zoning for local areas and the advanced stages of planning for large engineering structures, roads and railways	10-1000 square kilometres
Detailed	> 5,000	Intermediate and advanced level hazard and risk zoning for local and site specific areas and for the design phase of large engineering structures, roads and railways	Several hectares to tens of square kilometres

In practical terms the scale of mapping may be controlled by the scale of the available topographic maps.

7.2 DESCRIPTORS OF THE DEGREE OF SUSCEPTIBILITY, HAZARD AND RISK FOR USE IN LANDSLIDE ZONING

7.2.1 General

There will be considerable benefits if those carrying out landslide zoning use common descriptors to describe the degree of landslide susceptibility, hazard and risk. It will allow geotechnical professionals doing the zoning to relate to each other and allow legislators and those developing building controls to refer to these descriptors in the knowledge that they have a uniform meaning. This Section defines susceptibility, hazard and risk descriptors.

7.2.2 Examples of landslide susceptibility descriptors

It is difficult to standardise descriptions of landslide susceptibility because:

- Whether the geological, topographical, geotechnical and climatic conditions are judged to be conducive to landsliding is often subjective and not readily quantified.
- Different descriptors are required for the different types of landslides, e.g. the proportion of the area which may be affected by the landsliding for small scale landslides; the number of landslides/ square km for small landslides; the number of rock falls per kilometre length of cliff etc.

- The difficulty of assessing whether if landsliding occurs, it will travel on to slopes below or retrogress up-slope and the likelihood that a particular area will be affected by the landslide.
- The time frame in which landslides have occurred is not included (it is in hazard)

In some situations it may be sufficient to simply use two susceptibility descriptors; "susceptible" and "not susceptible". In general however there will be value in conveying to users of the maps the degrees of susceptibility either in quantified or relative terms.

Table 4 gives examples of landslide susceptibility mapping descriptors for some more common scenarios.

Table 4: Examples of landslide susceptibility mapping descriptors.

Susceptibility Descriptors	Rock Falls	Small Landslides on Natural Slopes	Large Landslides on Natural Slopes

(a) Quantified susceptibility descriptors

	Probability rock falls will reach the area given rock falls occur from a cliff (1)	Proportion of area in which small landslides may occur (2)	Proportion of area in which large landslides may occur (2) (3)
High susceptibility	>0.5	>0.5	>0.5
Moderate Susceptibility	>0.25 to 0.5	>0.25 to 0.5	>0.25 to 0.5
Low susceptibility	>0.01 to 0.25	>0.01 to 0.25	>0.01 to 0.25
Very low susceptibility	0 to 0.01	0 to 0.01	0 to 0.01

(b) Relative susceptibility descriptors

Susceptibility Descriptors	Rock Falls	Small Landslides on Natural Slopes	Large Landslides on Natural Slopes
	The proportion of the total landslide population in the study area.	The proportion of the total landslide population in the study area.	The proportion of the total landslide population in the study area.
High susceptibility	>0.5	>0.5	>0.5
Moderate Susceptibility	>0.1 to 0.5	>0.1 to 0.5	>0.1 to 0.5
Low susceptibility	>0.01 to 0.1	>0.01 to 0.1	>0.01 to 0.1
Very low susceptibility	0 to 0.01	0 to 0.01	0 to 0.01

Notes

(1) Spatial probability determined from historic, relative stability indexes, data or analysis taking consideration of the uncertainty in travel distance.
(2) Based on landslide inventory, geology, topography and geomorphology.
(3) Usually this is active, dormant and potentially reactivated slides, not first time slides.
(4) By "small" landslides is meant here landslides which are less than about 1000 m^3 volume.

Rock fall susceptibility may also be described in terms of the density of scars on a rock slope from which falls have occurred or the number of rocks which have fallen from a slope. For small shallow landslides the susceptibility may also be expressed as the number of slides per square kilometre.

There are advantages in using the quantified susceptibility descriptors in that the susceptibility of different areas being zoned can be compared. Relative susceptibility applies only within the study area and may represent quite different absolute susceptibilities in different areas being zoned.

For the relative susceptibility descriptors the objective usually is to include the largest number of landslides in the higher susceptibility classes whilst trying to achieve the minimum spatial area for these classes. So the higher susceptibility classes should have the greatest density of landslides, even though the density is not assessed.

It is important to note that landslide susceptibility mapping does not quantify the number of rock falls or small landslides which may occur in a given time period, nor for large landslides the annual probability that landsliding will occur. That is done in hazard mapping.

7.2.3 Recommended landslide hazard zoning descriptors

The manner in which landslide hazard is described depends on the type of landslide. For small slides and rock falls the hazard is described in terms of the number of slides per length of source area/annum, or the number of landslides per square kilometre of source area/annum. For large landslides hazard is described in terms of the annual probability of active sliding, or for active slides the annual probability movement will exceed a defined distance or the annual

probability that cracking within a slide exceeds a defined length. Table 5 presents recommended descriptors for the most common landslide and rock fall situations.

Table 5: Recommended descriptors for hazard zoning.

Hazard Descriptor	**Rock Falls from Natural Cliffs or Rock Cut Slope**	**Slides of Cuts and Fills on Roads or Railways**	**Small Landslides on Natural Slopes**	**Individual Landslides on Natural Slopes**
	Number/annum/km of cliff or rock cut slope	Number/annum/km of cut or fill	Number/square km/annum	Annual probability of active sliding
Very High	>10	>10	>10	10^{-1}
High	1 to 10	1 to 10	1 to 10	10^{-2}
Moderate	0.1 to 1	0.1 to 1	0.1 to 1	10^{-3} to 10^{-4}
Low	0.01 to 0.1	0.01 to 0.1	0.01 to 0.1	10^{-5}
Very Low	< 0.01	<0.01	< 0.01	$< 10^{-6}$

The description of the hazard should include the classification and volume (or area) of the landslides.

7.2.4 Recommended landslide risk zoning descriptors

Table 6 gives recommended descriptors for landslide risk zoning using life loss criteria. These are based on annual individual risk for the person most at risk.

If there is a potential for a large number of persons to be killed in one landslide event there should be an assessment of societal risk as described in AGS (2007c) and Leroi *et al.* (2005).

For property loss risks the risk matrix and terms in AGS (2007c) should be used. This is reproduced in Table 7.

It should be recognised that risk zones are dependent on the hazard, the elements at risk and risk control factors. If any of these alter the risk zoning will need to be revised.

Table 6: Recommended descriptors for risk zoning using life loss criteria.

Annual Probability of Death of the Person Most at Risk in the Zone	**Risk Zoning Descriptors**
$>10^{-3}$/annum	Very High
10^{-4} to 10^{-3}/annum	High
10^{-5} to 10^{-4}/annum	Moderate
10^{-6} to 10^{-5}/annum	Low
$< 10^{-6}$/annum	Very Low

Table 7: Recommended descriptors for risk zoning using property loss criteria (AGS 2007c).

Likelihood		**Consequences to property (With indicative approximate cost of damage)** (1)				
	Indicative Value of Approximate Annual Probability	**1: CATASTROPHIC 200%**	**2: MAJOR 60%**	**3: MEDIUM 20%**	**4: MINOR 5%**	**5: INSIGNIFICANT 0.5%**
A ALMOST CERTAIN	10^{-1}	VH	VH	VH	H	M or **L** (2)
B LIKELY	10^{-2}	VH	VH	H	M	**L**
C -POSSIBLE	10^{-3}	VH	H	M	M	**VL**
D UNLIKELY	10^{-4}	H	M	**L**	**L**	**VL**
E RARE	10^{-5}	M	**L**	**L**	**VL**	**VL**
F BARELY CREDIBLE	10^{-6}	**L**	**VL**	**VL**	**VL**	**VL**

Notes: (1) As a percentage of the value of the property.
(2) For Cell A5, may be subdivided such that a consequence of less than 0.1% is Low Risk.
(3) L low, M medium, H high, VL very low, VH very high.

7.2.5 Recommended approach

It is recommended that Table 6 be used universally for life loss risk zoning. It is suggested that Table 7 be used for property loss so far as is practicable but it is recognized that project specific terms may be developed.

It is suggested that so far as possible Tables 4 and 5 be used to describe susceptibility and hazard zoning, but it is recognised that there will be cases where site specific descriptors will be preferred. Whatever descriptors are used it is important that the definitions should be attached to the report and so far as practical shown on zoning maps. Landslide zoning will generally be done for conditions as they are at the time of the study. There may be situations where a second zoning may be presented to allow for hazard and risk management measures which may be proposed as part of a land development.

8 METHODS FOR LANDSLIDE ZONING FOR LAND USE PLANNING

8.1 THE PURPOSE OF THIS SECTION

This Section discusses the methods for landslide zoning for land use planning. It is based on Table 1 which lists the levels of susceptibility, hazard and risk zoning, how these are related to the methods used to assess the inputs to the zoning and whether the inputs are determined using basic, intermediate or sophisticated methods. The methods involve "activities" which are presented so there is a common understanding of what is involved in the zoning process.

8.2 THE IMPORTANCE OF UNDERSTANDING SLOPE PROCESSES AND THE GEOTECHNICAL CHARACTERISTICS OF THE LANDSLIDING

It is essential for all levels of landslide inventories and susceptibility, hazard and risk zoning that those carrying out the study have a detailed knowledge of slope processes which lead to landslides. This includes knowledge of geology, geomorphology, and hydrogeology and the soil and rock mechanics of landsliding. It is also essential that there is sufficient geotechnical information about the slopes to allow an understanding of the soil and rock mechanics of slope failure. Zoning done in the absence of this knowledge is almost certain to be misleading.

8.3 APPLICATION OF GIS-BASED TECHNIQUES TO LANDSLIDE ZONING

It is strongly recommended that landslide zoning be carried out in a GIS-based system so that the zoning can be readily be applied for land use planning and can be up-dated as more information becomes available.

A Geographic Information System (GIS) is a computer-based system which facilitates the acquisition, storage, management, analysis and display of geographic data. GIS typically includes relational database functionality incorporating spatial data attributes, but also includes the ability to spatially manipulate and present the data with elaborate mapping capabilities and powerful spatial analyses.

The essential feature of all GIS platforms is that they recognize the spatial attributes of the data presented allowing natural features to be treated as part of a spatial system, rather than an isolated object. This capability enables the spatial system, (i.e., the environment of any given region) to be built within the computer project environment using often disparate data sets. The data used in this process can come from a variety of sources, often the project itself (geological and engineering geological mapping, landslide mapping, traditional surveys, GPS surveys, drilling of boreholes, test pits etc) and other outside sources including government organizations and authorities, private companies and other spatial organizations (i.e., digital elevation models, cadastre, contours, aerial photography, land usage, vegetation etc).

One of the most important capabilities of GIS is the ability of the software to manage spatial data, from data collection and generation through to archiving and documentation of data. An important point is that once data is in the GIS, it remains available for editing and updating, for reproduction in the form of maps or on-screen review, manipulation and querying and for GIS-based development and modelling of susceptibility, hazard and risk.

8.4 LANDSLIDE INVENTORY

Preparation of a landslide inventory is an essential part of any landslide zoning. It involves the location, classification, volume, travel distance and state of activity and date of occurrence of landsliding in an area. Table 8 lists the activities which will typically be required at the basic, intermediate and sophisticated level.

Table 8: Activities required to preparing a landslide inventory.

Characterisation Method	Activities
Basic	Prepare an inventory of landslides in the area from aerial photographs and /or satellite imagery, and by mapping and from historic records. The inventory includes the location, classification, volume (or area) and so far as practicable the date of occurrence of landsliding.
	Identify the relationship to topography, geology and geomorphology.
	Show this information on inventory maps along with topographic information including contours, property boundaries, mapping grid, roads and other important features such as streams and water-courses.
Intermediate	**The same activities as Basic plus**
	Distinguish different parts of the landslides.
	Map landslide features and boundaries.
	Collect and assess historical information on the activity of landsliding.
	Analyse the past evolution of the land use to know whether human activities have had an influence on the incidence of landslides.
	Increased time and resources in the research phase of the inventory compilation resulting in more rigorous and extended coverage
Sophisticated	**The same activities as Intermediate plus**
	Prepare an inventory of geotechnical data.
	Implement investigations to better define geotechnical conditions.
	Geotechnical analysis to understand slope instability processes.
	Advanced temporal cataloguing of periodic reactivations of the same hazard and temporal windowing of specific triggering events to provide periodic inventory data sets which can then be used in advanced validation approaches.

8.5 LANDSLIDE SUSCEPTIBILITY ZONING

8.5.1 Landslide characterization and travel distance and velocity

Landslide susceptibility zoning involves the classification, volume (or area) and spatial distribution of existing and potential landslides in the study area. It may also include a description of the travel distance, velocity and intensity of the existing or potential landsliding.

Table 9: Landslide susceptibility zoning-activities required to characterise, determine the spatial distribution of potential landslides and their relationship to topography, geology and geomorphology.

Characterisation Method	Activities
Basic	Prepare a geomorphologic map. (1)
	Prepare a landslide inventory as described in Table 8, (1)
	Prepare calculations of the % of the total landslide count for each susceptibility class, the % of the area affected by landslides for each class and the % of each class in comparison to the total study area and classify according to Table 4.
	Correlate the incidence of landsliding with the geology and slope to delineate areas susceptible to landsliding.
	For regional zoning correlate the incidence of landsliding with annual rainfall or snowmelt, and/or seismic loading.
	Prepare the landslide susceptibility zoning map superimposed on the topography with a suitable legend.
	Implement the data and the maps in a GIS (recommended).
Intermediate	**The same activities as basic plus**
	Obtain basic soil classifications and depths in the study area.
	Classify more complex terrain units. Qualitative rating of the landslide susceptible areas based on overlapping techniques.
	Develop quantitative ratings (often relative rating) of landslide susceptible areas based on data treatment techniques.
	Implement the data and the maps in a GIS (recommended).
Sophisticated	**The same activities as Intermediate plus**
	Detailed mapping and geotechnical investigations to develop an understanding of the mechanics of landsliding, hydrogeology and stability analyses.
	Perform data treatment analysis (discriminate; neural networks; fuzzy logic; logistic regression; etc) and develop quantitative ratings to obtain susceptibility classes.
	Perform stability analyses.
	Implement the data and the maps in a GIS (recommended).

Note. (1) The landslide inventory and geomorphologic mapping should be carried out at intermediate and sophisticated levels for intermediate and sophisticated level susceptibility zoning.

Table 9 lists the activities required to characterise the potential landslides, their spatial distribution in the area to be zoned and their relationship to topography, geology and geomorphology. It should be noted that there is a direct relationship between the scale of zoning maps and the level of landslide characterisation, with larger scale zoning maps being required at the intermediate and sophisticated levels. Table 10 lists the activities required to assess the travel distance and velocity of potential landslides. This table is based on the assumption that the activities in Tables 8 and 9 have been carried out.

Table 10: Activities required for assessing the travel distance and velocity of potential landslides.

Travel Distance and Velocity Analysis method	Activities
Basic	Collect and assess historical information on travel distances and velocity.
	Assess limiting travel distances from geomorphologic data and old landslide deposits.
	Assess the likely travel distance and velocity from consideration of the classification of the potential landslides, geology and topography and empirical methods.
	Based on this information assess the limit (greatest) likely travel distance for each classification of potential landslide.
Intermediate	**The same activities as Basic plus**
	Assess likely landslide mechanisms and classification of soils in the landslides.
	Use empirical methods based on travel distance angle or shadow angle to assess travel distance accounting for the uncertainty in the empirical methods and data inputs.
	Assess velocity from potential energy and travel distance using simple sliding block models.
Sophisticated	**The same activities as Intermediate plus**
	Investigate geotechnical properties of the sliding materials as required by numerical models.
	Use numerical models to model travel distance and velocity.

8.5.2 Preparation of landslide susceptibility map

Preparation of a landslide susceptibility map is usually based on two assumptions:

- That the past is a guide to the future, so that areas which have experienced landsliding in the past are likely to experience landsliding in the future.
- Areas with similar topography, geology and geomorphology as the areas which have experienced landsliding in the past are also likely to experience landsliding in the future.

These assumptions are often reasonable but it should be noted there are exceptions such as when the source of the landslides is exhausted by earlier landsliding.

Landslide susceptibility zoning maps should include:

- A map or a series of maps showing the inventory of historic landslides, showing the location and area (or number of slides, e.g. for rock falls) of the source landslides; where appropriate the travel paths after sliding; or for larger slides the activity or velocity of sliding.
- Maps at the same scale showing the instability conditioning terrain factors: i.e. the topography and topographic units (slope, watershed areas), the geology (lithological units); superficial formations; vegetation cover; land use; etc.
- In areas having potential for shallow landslides and debris flows, it is highly recommended that a map is prepared of the superficial formations (colluvium, till, alluvium, residual soils, etc.) because these types of failures usually take place in these formations. However it must be taken into account that usually these formations are of limited extent so such a map can only be prepared at a large scale.
- Where appropriate prepare a map showing the travel distance limits either as a maximum value or quantified as suggested in Table 10.
- A map showing the interpreted susceptibility zoning classification areas. This map should show the topography and cadastral information as well as the susceptibility zoning classifications for the area being mapped.

In some cases these may be superimposed on the same zoning map to limit the number of maps but often this will be confusing and it will be necessary to produce separate maps at the same scale for each classification of landslides such as rock falls and small shallow landslides.

8.6 LANDSLIDE HAZARD ZONING

8.6.1 Frequency Assessment

Tables 11 and 12 list the activities required to assess the frequency of rock falls, slides from cuts, fills and retaining walls, small landslides; and large landslides.

Table 11: Activities required for assessing the frequency of rock falls, slides from cuts, fills and retaining walls and small landslides on natural slopes.

Frequency Assessment Method	Activities
Basic	Frequency established based on the relative freshness of the morphological features of the scars and landside deposits taking into account the presence of active geomorphic events (e.g. slope undermining by either river or sea erosion).
	Frequency established based on interpretation of numbers of landslides from aerial photographs taken at known time intervals.
	Assess the historic frequency of rock falls, slides from cuts, fills and retaining walls, or small landslides on natural slopes from basic landslide inventories.
	As above and relate to the basic level of frequency of triggering events such as daily rainfall or seismic events.
Intermediate	**The same activities as Basic plus**
	Relate to slope characteristics such as topography (slope angle, elevation, aspect), geology, geomorphology using multi-variate analyses.
	Assess the historic frequency of rock falls, slides from cuts, fills and retaining walls, or small landslides on natural slopes from landslide inventories. Where appropriate, develop and use frequency volume curves.
	Use proxy data such as silent witnesses (e.g. damage to trees and dendrochronology).
	More detailed analysis of rainfall including the effects of antecedent rainfall, rainfall intensity and duration on the incidence of individual landslides (the threshold) or large numbers of landslides.
	For seismically induced landsliding, relate the incidence of sliding to seismic loading including the peak ground acceleration and magnitude of the earthquake using empirical methods.
Sophisticated	**The same activities as Intermediate plus**
	Assess geotechnical parameters of the soils. Model slope factors of safety from geotechnical parameters and rainfall frequency or piezometric data.
	For seismically-induced landslides, analyse displacements using 'Newmark' type analyses and for liquefiable soils, the likelihood of liquefaction and flow sliding.

Table 12: Activities required for assessing the frequency of landsliding for large landslides on natural slopes.

Frequency Assessment Method	Activities
Basic	Assess the historic frequency of landsliding from the landslide inventoy including activity indicators such as cracked buildings, displaced fences, bent and tilted trees.
	Assess frequency from geomorphology evidence such as the freshness of slide scarps and other surface features associated with landslide movement using subjective assessment.
Intermediate	**The same activities as Basic plus**
	As above, and use of proxy data such as carbon 14 dating, lichenometry dating, of vegetation buried by sliding, or in raised alluvial terraces in valleys which may have been blocked by landsliding.
	Relate history of landsliding to rainfall intensity and duration and antecedent rainfall or to snow melt.
	Assess the likelihood of seismically-induced sliding from consideration of the mechanics of the landslide. Use empirical and simplified methods to assess likely displacements during earthquakes.
	As an alternative to estimating from historic data, assess frequency by subjective assessment, e.g. by assessing the probability of landsliding given a rainfall or seismic load.
Sophisticated	**The same activities as Intermediate plus**
	As above and relating the history of landsliding or factor of safety to rainfall, slope geometry, piezometric levels (where available), geotechnical properties and factors of safety.
	For seismically-induced landsliding analyse displacements using 'Newmark' type analyses and for liquefiable soils, the likelihood of liquefaction and flow sliding.

8.6.2 Intensity assessment

Landslide intensity may be assessed either as the spatial distribution of:

- The velocity of sliding coupled with slide volume or
- The kinetic energy of the landslide; e.g. rock falls, rock avalanches or
- Total displacement or
- Differential displacement or
- Peak discharge per unit width (m^3/m/second), e.g. for debris flows.

The assessment of velocity is discussed in Section 8.5.1. For basic and intermediate level assessments of intensity only velocity and volume might be assessed. For advanced assessments of rock fall and debris flow hazard the energy might be assessed. Whether landslide intensity is required as part of a hazard zoning should be determined on a case-by-case basis. It is likely to be required for rock fall hazard zoning.

8.6.3 Preparation of Landslide hazard zoning map

Landslide hazard zoning maps are developed from the susceptibility zoning maps with the areas classified according to the frequency (annual probability) of landsliding. The way the frequency is expressed will depend on the classification and volume of the potential landslides. For example:

- For rock falls the hazard may be expressed as the number of rock falls/annum which will reach the area being mapped per kilometre length along a cliff.
- For slides from cuts, fills and retaining walls the hazard may be expressed as the number of landslides of a certain volume and classification/annum per kilometre of road or per building allotment or per square kilometre.
- For small landslides on natural slopes the hazard may be expressed as the number of landslides of a certain volume, velocity and classification per square km/annum for the area being mapped
- For large landslides on natural slopes the hazard may be expressed as the annual probability that there will be landsliding in the area being mapped. To this should be added the likely velocity or total displacement of sliding should it occur.

The hazard zoning map should be at the same scale as the susceptibility zoning map and show the topography and cadastral information as well as the hazard zoning classifications for the area being mapped.

8.7 LANDSLIDE RISK ZONING

8.7.1 Elements at risk

For risk to be determined and hence for landslide risk zoning to be implemented the elements at risk have to be assessed. Table 13 lists the activities required to do this.

The elements at risk include the persons and property potentially affected by landsliding on, below and up-slope of the potential landslides. They may include indirect impacts such as reduced economic activity resulting from the landslide, e.g. due to loss of a road, and environmental impacts.

Table 13: Activities required for assessing the elements at risk.

Method for Assessing Elements at Risk	Activity
Basic	Make an assessment of the population who live, work and travel through the area; property such as houses, buildings, roads, railways and services which are permanently in the area and of property such as vehicles which travel through the area. For existing development base this on the current and proposed land use. For new development estimate from proposed land use and occupancy. Where applicable assess environmental values which may be affected by landsliding.
	Generic classifications based on the main land uses, namely urban, industrial, infrastructure, or agricultural.
Intermediate	As above in greater degree of detail. Economic consequences may be included.
Detailed	As above in detail. Economic consequences will be estimated such as the implications of loss of a road providing access to a town until repairs are carried out.

8.7.2 Temporal spatial probability and vulnerability

Table 14 lists the activities required to assess the temporal spatial probability of the elements at risk.

Table 14: Activities required for assessing the temporal spatial probability of the elements at risk.

Method for assessing Temporal Spatial Probability	Activity
Basic	*Life Loss Risks* For persons at risk in residential areas assume the temporal-spatial probability is 1.0. For other type of developments such as factories and schools, make an approximate assessment of temporal-spatial probability from the likely pattern of use of the buildings. For roads and railways and other situations with transient populations at risk; make an approximate assessment of temporal spatial probability from the traffic volumes and velocities. *Property loss risks* For buildings the temporal spatial probability is 1.0. For vehicles, make an approximate assessment of temporal-spatial probability from the traffic volumes and velocities.
Intermediate	*Life Loss Risks* For all situations estimate temporal-spatial probability taking account of the nature of development, living and work pattern, existence of protected places (e.g. reinforced shelters), traffic (where relevant) and the intensity of landsliding. *Property loss risks* As for basic assessment although in more detail (e.g. allowing for the variability of trajectories of rock falls).
Sophisticated	As above, with greater detail in the assessment, particularly the temporal/spatial distribution of the elements at risk.

Vulnerability is generally assessed empirically for persons and property using published information (e.g. AGS 2007a). More sophisticated methods are not as yet available.

8.7.3 Preparation of landslide risk zoning maps

Landslide risk zoning maps are prepared using the hazard zoning maps and allowing for the elements at risk, the spatial-temporal probability and vulnerability. Separate zoning maps will be required for life loss risk and property loss risk. The risk zoning maps should be at the same scale as the susceptibility and hazard zoning maps. They should also show the topography and cadastral information as well as the risk zoning classification of the area.

For life loss, the risk should be expressed as individual risk (annual probability of the person losing his/her life). For property loss, the map may show annualised loss ($/year) but the report should also list the pairs of loss value and annual probability of the loss (e.g. 0.001 annual probability of $10 million loss).

For new development there will have to be an assessment made regarding the proposed development and the elements at risk. The risk will be unique to this proposed development.

If there are several landslide hazards (e.g. rock fall and shallow landslides) the risks are summed to give the total risk. However, it may be useful to present maps showing the risk from each type of landslide, as well as the total risk.

8.8 THE NEED FOR DOCUMENTATION OF THE LANDSLIDE ZONING PROCESS

It is essential that the landslide zoning process be well documented in a report. The report should include

- Zoning maps and legends.
- The definitions of the susceptibility, hazard and risk zones.
- The basis upon which the zoning has been carried out including data sources, zoning methodology, the time period covered by the landslide inventory if one has been used to assess landslide frequency.
- A description of any limitations of the zoning including accuracy of zone boundaries.
- Other information to explain the use of the landslide zoning as required for the particular project.

This informs those who are using the landslide zoning and facilitates peer review.

9 RELIABILITY OF LANDSLIDE ZONING FOR LAND USE PLANNING

9.1 POTENTIAL SOURCES OF ERROR

9.1.1 Description

There are a number of potential sources of error in the zoning process. These include:

- Limitations in the landslide inventory upon which the susceptibility and hazard zoning maps are based.
- Limitations in the stability of temporal series. For example the relationship between the triggering factor (e.g. rainfall) and the frequency of landslides may change if the area is deforested.
- Limitations in the level of detail available of topography, geology, geomorphology, rainfall and other input data.
- Model uncertainty, meaning the limitations of the methods used to relate the inventory, topography, geology, geomorphology and triggering events such as rainfall to predicting landslide susceptibility, hazard and risk.
- Limitations in the skill of the persons carrying out the zoning.

It must be recognised that landslide zoning is not a precise science and the results are only a prediction of performance of the slopes based on the available data. In general, intermediate or advanced level zoning will be less subject to error than preliminary level zoning with each done at a suitable zoning map scale.

9.1.2 Landslide inventories

Cascini *et al.* (2005) conclude that the greatest source of error is limitations in the inventory. They give examples showing gross mismatch of inventory maps for landsliding from the same area of natural slopes prepared by two groups. They point out that the greatest errors occur when inventories rely on air photo interpretation, particularly of small scale photography. These errors are in part due to the subjective nature of aerial photo interpretation but also to vegetation covering the areas to be mapped. Aerial photographic mapping should be supported by surface mapping of selected areas to calibrate the mapping.

Inventories of landsliding of cuts, fills and retaining walls on roads, railways and urban development will seldom be complete. To get a reasonable estimate of the number of slides the zoning will have to make a judgement about the proportion of the slides which have been recorded.

9.1.3 Topographic maps

Good topographic maps are most important input to zoning at intermediate and advanced levels. Topographic maps facilitate the modelling and mapping of landslide zoning boundaries with an appropriate accuracy. For large scale zoning, contours at 2 metre or at most 5 metre intervals will be required. Even then, zoning boundaries should be checked on the ground because the implications for land owners of errors in boundaries can be significant.

9.1.4 Model uncertainty

Model uncertainty is a fact of landslide zoning and none of the methods are particularly accurate. In general terms hazard and risk zoning based on statistical analyses of the input data using intermediate level inputs will give the best accuracy.

Sophisticated methods for assessing the inputs rely on carrying out calculations (for example of the factor of safety of a slope) which have a theoretical attraction and the appearance of being able to produce better accuracy. In reality the parameter uncertainty is large due to limitations in the knowledge of the input data (such as shear strength and pore pressures) and these make it very difficult to achieve any greater accuracy than other modelling methods.

9.2 VALIDATION OF MAPPING

9.2.1 Peer review

For most zoning studies for land use planning there should be a peer reviewer appointed to provide independent assessment of the susceptibility, hazard and risk zoning. The peer reviewer should have a high level of the skills and experience listed in Section 11.2.The peer reviewer should meet with those carrying out the study at the beginning of the study and, depending on the scale of the projects, perhaps after initial mapping and then as the zoning is being

finalised. This process is a basic form of quality control and a form of validation if the peer reviewer has appropriate wide experience.

9.2.2 Formal validation

For more important advanced level mapping projects there can be a process of validation within the study. To do this the landslide inventory is randomly split in two groups: one for analysis and one for validation. The analysis is carried out in part of the study area (model) and tested in another part with different landslides. An alternative approach for advanced mapping projects is for an analysis to be carried out with landslides that have occurred in a certain period whilst validation is performed upon landslides that have occurred in a different period. Validation can also be carried out by this process after the mapping and land use planning scheme has been in place for some time. This is really only practical for high frequency landsliding because of the time frame required to gather performance data.

9.3 POTENTIAL EFFECTS OF CLIMATE CHANGE

There is a developing knowledge of climate change and the effects of this on rainfall and snowfall. It could be anticipated that for example a decreased frequency of high intensity rainfall might reduce the frequency of shallow landslides on steep hill slopes. However the science of prediction of the effects of climate change and the prediction of the frequency of landslides from rainfall is not sufficiently advanced at this time to warrant consideration of climate change when carrying out zoning studies.

Those involved in landslide zoning studies should keep informed of developments which might alter this conclusion.

10 APPLICATION OF LANDSLIDE ZONING FOR LAND USE PLANNING

10.1 GENERAL PRINCIPLES

These guidelines are for landslide susceptibility, hazard and risk zoning. Those who are considering the introduction of land use management controls for landsliding need to decide the type and level of zoning which they require based on the purpose of the zoning. This is detailed in Section 6. They may choose to stage the zoning and implementation of land use controls.

It should be recognised that it is not possible to delineate zoning boundaries accurately with regional and local zoning using small and medium scale zoning maps. This can only be done using local or site-specific zoning and large to detailed scale maps.

It is critical that the local governmental authority or other organization requiring the zoning, clearly and fully define the purpose and nature of any zoning study, understand the existing availability of potential input data, assess the implications for acquisition of new data and then define realistic goals for the zoning study taking into account, timeframes, budgets and resource limitations.

It should be noted that mapping will usually result in lines on a map delineating for example the landslide hazard zones based on contours and geomorphologic boundaries. However, for land use planning and zoning purposes the zone boundaries are often re-drawn to coincide with allotment boundaries for administrative reasons. This may lead to adoption of conservative boundaries and should be avoided where practical.

10.2 TYPICAL DEVELOPMENT CONTROLS APPLIED TO LANDSLIDE ZONING

Examples of the types of development controls which are applied to landslide zoning are:

- If zoning is by susceptibility the controls usually require geotechnical assessment of hazard and risk of the proposed development for zones determined as susceptible to landsliding whilst only minimal requirements (such as adherence to good hillside practice) in areas determined as very low susceptibility or not susceptible.
- If zoning is by hazard and the study has been done at an intermediate or advanced level it should be possible to delineate land use zones where: (a) Hazard is so low that no development controls are necessary; (b) Where some prescriptive controls such as limits to the heights of cuts and fills are necessary; (c) Where detailed geotechnical assessment of the hazard and risk is required before development can be approved and (d) Where the hazard is so high no development is possible.
- Where zoning is by life loss risk and the study has been done at an intermediate or advanced level, it should be possible to delineate land use zones where (a) Life loss risk is so low no development controls are necessary; (b) Where site specific assessment of the risk is required prior to approval of development and (c) Where the risk is so high that no development is possible.

In practice those considering landslide zoning for land use management would be well advised to seek advice from a Geotechnical Professional who is familiar with landslide zoning and risk management to provide advice in planning the landslide zoning study and applying the outcomes to land use planning.

10.3 NEED TO REVIEW AND UP-DATE LANDSLIDE ZONING

It should be recognised that there should be periodic reviews of landslide zoning because:

- The susceptibility, hazard and risk may be altered by development and land-use changes subsequent to the study.
- The state of knowledge of landsliding in the area will be improved with more detailed investigations carried out as part of the development.
- The elements at risk may change with time so landslide risk zoning should be reviewed to allow for this.
- Methods of landslide zoning are evolving so in combination with the factors listed above, improved zoning will be possible.

It is recommended that reviews be carried out at intervals no greater than about 10 years. In some cases more frequent reviews will be necessary.

11 HOW TO BRIEF AND SELECT A GEOTECHNICAL PROFESSIONAL TO UNDERTAKE A ZONING STUDY

11.1 PREPARING A BRIEF

The following are some matters which should be considered in preparing a brief for a landslide zoning study.

- Define the purpose of the zoning and how it will be used.
- Define the area to be zoned.
- Define what type of zoning is required: landslide susceptibility, hazard or risk.
- Define the level of zoning required and whether it will be staged.
- Identify the various stake holders and their interests.
- Describe what, if any, public consultation process will be required.
- State relevant legal and regulatory controls.
- Set out the documentation required for the results of the zoning, including details of what maps are required, map scales, and electronic formats and the supporting report describing the zoning processes, methods used, validation and limitations.
- Set a program for the study.
- Set a budget consistent with the scope and expectations of the study.
- Describe the peer review process which will apply.
- List the available data and the format it is in.
- Detail the expected method for the study.
- Define the terminology to be used to describe susceptibility, hazard and risk.

In so far as possible, this is best done in consultation with prospective consultants so there is a clear understanding of what is required.

11.2 SELECTING A CONSULTANT FOR THE ZONING

Landslide susceptibility, hazard and risk zoning is a science that should be done by well qualified geotechnical professionals who are experienced in mapping and who understand slope processes, risk assessment and geotechnical slope engineering. This will usually mean that a team of professionals will be needed including an engineering geologist, geomorphologist (for zoning of natural slopes where geomorphology mapping is required) and a geotechnical engineer. It should be noted that only a few engineering geologists and geotechnical engineers are experienced in geomorphologic mapping. It is essential that geotechnical engineers who understand the soil and rock mechanics of slope processes pre and post-failure are involved in the landslide susceptibility, hazard and risk assessments.

Consultants proposing to carry out landslide zoning should demonstrate they have personnel who will work on the project with the relevant skills and experience. It is not sufficient that a geotechnical company has done such studies because it is the personnel directly involved that are important.

One means of demonstrating competence is through registration upon the National Professional Engineering Register (NPER) under the specific area of practice for Landslide Risk Management (LRM).

11.3 PROVIDE ALL RELEVANT DATA

It is essential that the consultant is provided with all the available data regarding the incidence of landsliding in the study area. There should be a thorough search of records from files and works reporting repairs that have been carried out.

Where there is limited data on the incidence of landslides in the area those responsible will greatly benefit by establishing and maintaining a landslide inventory.

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The Australian Geomechanics Society established a Working Group within a Landslide Taskforce to develop the guidelines. The development of the guidelines was managed by a Steering Committee. Membership of the Working Group, Taskforce and Steering Committee is listed in Appendix B.

Concurrent with the development of the AGS guidelines, JTC-1, the Joint International Societies Technical Committee on Landslides and Engineered Slopes has been developing International Guidelines on Landslide Susceptibility, Hazard and Risk Zoning. Those guidelines have been prepared under the technical direction of a Scientific Committee. Membership of the JTC-1 Scientific Committee is attached in Appendix C.

Drafts of the AGS guideline have been subject to review by members of the AGS Landslide Taskforce, members of the geotechnical profession and local government.

Drafts of the International Guidelines have received extensive consideration and discussion and in a Workshop held in Barcelona from 18th to 20th September 2006. Later drafts of the guideline have been reviewed by attendees to the Barcelona Workshop and members of JTC-1. There has been an integrated approach between the groups developing the guidelines and they are similar except for details specific to AGS requirements.

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APPENDIX A - DEFINITION OF TERMS

Acceptable Risk – A risk which, for the purposes of life or work, society is prepared to accept as it is with no regard to its management. Society does not generally consider expenditure in further reducing such risks justifiable.

Annual Exceedance Probability (AEP) – The estimated probability that an event of specified magnitude will be exceeded in any year.

Consequence – The outcomes or potential outcomes arising from the occurrence of a landslide expressed qualitatively or quantitatively, in terms of loss, disadvantage or gain, damage, injury or loss of life.

Danger – The natural phenomenon that could lead to damage, described in terms of its geometry, mechanical and other characteristics. The danger can be an existing one (such as a creeping slope) or a potential one (such as a rock fall). The characterisation of a danger does not include any forecasting.

Elements at Risk – The population, buildings and engineering works, economic activities, public services utilities, infrastructure and environmental features in the area potentially affected by landslides.

Frequency – A measure of likelihood expressed as the number of occurrences of an event in a given time. See also Likelihood and Probability.

Hazard – A condition with the potential for causing an undesirable consequence.. The description of landslide hazard should include the location, volume (or area), classification and velocity of the potential landslides and any resultant detached material, and the probability of their occurrence within a given period of time.

Individual Risk to Life – The risk of fatality or injury to any identifiable (named) individual who lives within the zone impacted by the landslide or who follows a particular pattern of life that might subject him or her to the consequences of the landslide.

Landslide inventory –An inventory of the location, classification, volume, activity and date of occurrence of landsliding

Landslide activity –The stage of development of a landslide; *pre-failure* when the slope is strained throughout but is essentially intact; failure characterized by the formation of a continuous surface of rupture; *post-failure* which includes movement from just after failure to when it essentially stops and *reactivation* when the slope slides along one or several pre-existing surfaces of rupture. Reactivation may be occasional (e.g. seasonal) or continuous (in which case the slide is "active")

Landslide Intensity – A set of spatially distributed parameters related to the destructive power of a landslide. The parameters may be described quantitatively or qualitatively and may include maximum movement velocity, total displacement, differential displacement, depth of the moving mass, peak discharge per unit width, kinetic energy per unit area.

Landslide Susceptibility – A quantitative or qualitative assessment of the classification, volume (or area) and spatial distribution of landslides which exist or potentially may occur in an area. Susceptibility may also include a description of the velocity and intensity of the existing or potential landsliding.

Likelihood – Used as a qualitative description of probability or frequency.

Probability – A measure of the degree of certainty. This measure has a value between zero (impossibility) and 1.0 (certainty). It is an estimate of the likelihood of the magnitude of the uncertain quantity or the likelihood of the occurrence of the uncertain future event.

There are two main interpretations:

(i) Statistical – frequency or fraction – The outcome of a repetitive experiment of some kind like flipping coins. It includes also the idea of population variability. Such a number is called an "objective" or relative frequentist probability because it exists in the real world and is in principle measurable by doing the experiment.

(ii) Subjective probability (degree of belief) – Quantified measure of belief, judgement, or confidence in the likelihood of a outcome, obtained by considering all available information honestly, fairly and with a minimum of bias. Subjective probability is affected by the state of understanding of a process, judgement regarding an evaluation or the quality and quantity of information. It may change over time as the state of knowledge changes.

Qualitative Risk Analysis – An analysis which uses word form, descriptive or numeric rating scales to describe the magnitude of potential consequences and the likelihood that those consequences will occur.

Quantitative Risk Analysis – an analysis based on numerical values of the probability, vulnerability and consequences, and resulting in a numerical value of the risk.

Risk – A measure of the probability and severity of an adverse affect to health, property or the environment. Risk is often estimated by the product of probability x consequences. However, a more general interpretation of risk involves a comparison of the probability and consequences in a non-product form.

Risk Analysis – The use of available information to estimate the risk to individuals, population, property or the environment from hazards. Risk analyses generally contain the following steps: scope definition, hazard identification and risk estimation.

Risk Assessment – The process of risk analysis and risk evaluation.

Risk Control or Risk Treatment – The process of decision making for managing risk and the implementation or enforcement of risk mitigation measures and the re-evaluation of its effectiveness from time to time, using the results of risk assessment as one input.

Risk Estimation – The process used to produce a measure of the level of health, property or environmental risks being analysed. Risk estimation contains the following steps: frequency analysis, consequence analysis and their integration.

Risk Evaluation – The stage at which values and judgements enter the decision process, explicitly or implicitly, by including consideration of the importance of the estimated risks and the associated social, environmental and economic consequences, in order to identify a range of alternatives for managing the risks.

Risk Management – The complete process of risk assessment and risk control (*or risk treatment*).

Societal Risk – The risk of multiple fatalities or injuries in society as a whole: one where society would have to carry the burden of a landslide causing a number of deaths, injuries, financial, environmental and other losses.

Susceptibility – see Landslide Susceptibility

Temporal-Spatial Probability – The probability that the element at risk is in the affected area at the time of the landslide.

Tolerable Risk – A risk within a range that society can live with so as to secure certain net benefits. It is a range of risk regarded as non-negligible and needing to be kept under review and reduced further if possible.

Vulnerability – The degree of loss to a given element or set of elements within the area affected by the landslide hazard. It is expressed on a scale of 0 (no loss) to 1 (total loss). For property, the loss will be the value of the damage relative to the value of the property; for persons, it will be the probability that a particular life (the element at risk) will be lost, given the person(s) is affected by the landslide.

Zoning: The division of land into homogeneous areas or domains and their ranking according to degrees of actual or potential landslide susceptibility, hazard or risk.

APPENDIX B – TASKFORCE MEMBERS

AUSTRALIAN GEOMECHANICS SOCIETY

STEERING COMMITTEE

Andrew Leventhal, GHD Geotechnics, Sydney, Chair.
Robin Fell, School of Civil and Environmental Engineering, UNSW, Sydney, Convenor,Guidelines on Landslide Susceptibility, Hazard and Risk Working Group.
Tony Phillips, Consultant, Sydney, Convenor Slope Management and Maintenance Working Group.
Bruce Walker, Jeffery and Katauskas, Sydney, Convenor Practice Note Working Group.
Geoff Withycombe, Sydney Coastal Councils Group, Sydney

WORKING GROUP - Guidelines on Landslide Susceptibility, Hazard and Risk
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Graham Whitt, Shire of Yarra Ranges, Lillydale
Tony Miner, A.G. Miner Geotechnical, Geelong
Phil Flentje, University of Wollongong.

TASKFORCE

Laurie de Ambrosis, GHD Geotechnics, Sydney
Mark Eggers, Pells Sullivan Meynink, Sydney
Max Ervin, Golder Associates, Melbourne
Angus Gordon, retired, Sydney
Greg Kotze, GHD, Sydney
Arthur Love, Coffey Geotechnics, Newcastle
Alex Litwinowicz, GHD Geotechnics, Brisbane
Tony Miner, A.G. Miner Geotechnical, Geelong
Fiona MacGregor, Douglas Partners, Sydney
Garry Mostyn, Pells Sullivan Meynink, Sydney
Grant Murray, Sinclair Knight Merz, Auckland
Garth Powell, Coffey Geotechnics, Brisbane
Ralph Rallings, Pitt and Sherry, Hobart
Ian Stewart, NSW Roads and Traffic Authority, Sydney
Peter Tobin, Wollongong City Council, Wollongong
Graham Whitt, Shire of Yarra Ranges, Lillydale

APPENDIX C – JTC-1 MEMBERS

JTC-1 JOINT TECHNICAL COMMITTEE ON LANDSLIDES AND ENGINEERED SLOPES

SCIENTIFIC COMMITTEE

Robin Fell, University of New South Wales, Australia
Jordi Corominas, Technical University of Catalonia-UPC, Barcelona, Spain
Christophe Bonnard, École Polytechnique Féderale, Lausanne, Switzerland
Leonardo Cascini, University of Salerno, Italy
Eric Leroi, Urbater, France
Bill Savage, United States Geological Survey, Golden, Colorado, USA

COMMENTARY ON

GUIDELINE FOR LANDSLIDE SUSCEPTIBILITY, HAZARD AND RISK ZONING FOR LAND USE PLANNING

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PURPOSE OF THE COMMENTARY

The Commentary has been prepared to:

- Provide background notes to explain the reasons for adopting the provisions of the guideline.
- Elaborate on some parts of the guideline
- Provide references for additional reading.

The commentary is not meant to be a textbook on Landslide Susceptibility, Hazard and Risk Zoning.

C1 INTRODUCTION

There have been examples of landslide susceptibility and hazard zoning in use since the 1970's (e.g. Brabb *et al*., 1972; Nilsen, *et al*., 1979; Kienholz, 1978). The hazard and risk maps have usually incorporated the estimated frequency of landsliding in a qualitative sense rather than quantitatively. These examples of zoning have generally been used to manage landslide hazard in urban areas by excluding development in some higher hazard areas and requiring geotechnical engineering assessment of slope stability before development is approved in other areas. In some countries landslide susceptibility, hazard and risk maps are being introduced across the country. For example the PPR (Plans de Prevention des Riques Naturels Previsibles) in France and the Cartes de Dangers or Gefahrenkarten in Switzerland are carried out at the Canton level but with Federal funding support (Leroi *et al*., 2005).

C2 DEFINITIONS AND TERMINOLOGY

C2.1 DEFINITIONS

The definitions in the Guideline are consistent with International Landslides and Geotechnical Engineering practice.

Some practitioners in Australia have used the term "hazard" without including the frequency of landsliding in the definition. This is contrary to the AGS (2000, 2002) definition and to international practice.

C2.2 LANDSLIDE CLASSIFICATION AND TERMINOLOGY

There is no consensus within the international geotechnical community on which landslide classification system to use. All existing systems are seen to have shortcomings. In recognition of this JTC 1, the Joint Technical Committee on Landslides and Engineered Slopes has established a working committee to develop a new classification system on behalf of ISSMGE, IAEG and ISRM. This will not be completed until late in 2008.

In the meantime it is recommended that the classification and terminology described in Appendix B of AGS (2000, 2002) be used. These are based on Cruden and Varnes (1996), Varnes (1978) and IAEG (1990).

C3 LANDSLIDE RISK MANAGEMENT FRAMEWORK

More details on the use of risk management in landslides are given in the State of the Art papers in The International Conference on Landslide Risk Management, Vancouver, June 2005 (Fell *et al*., 2005; Picarelli *et al.*, 2005; Nadim *et al*., 2005; Hungr *et al*., 2005; Roberds, 2005; Leroi *et al*,. 2005; Cascini *et al.*, 2005 and Wong, 2005); in AGS (2000, 2002, 2007a) and Lee and Jones (2004).

For information on the historical development of landslide risk management, see Einstein (1988, 1997), Fell (1994), IUGS (1997) and Fell and Hartford (1997).

C4 DESCRIPTION OF LANDSLIDE SUSCEPTIBILITY, HAZARD AND RISK ZONING FOR LAND USE PLANNING

C4.1 TYPES OF LANDSLIDE ZONING

Landslide Inventory

Landslide inventories are essentially factual in nature. However in some cases there may be a degree of interpretation because they may be based on geomorphologic attributes seen on air photographs or mapped on the ground.

Landslide Susceptibility Zoning

Landslide susceptibility zoning involves a degree of interpretation. Susceptibility zoning involves the spatial distribution and rating of the terrain units according to their propensity to produce landslides. This is dependent on the topography, geology, geotechnical properties, climate, vegetation and anthropogenic factors such as development and clearing of vegetation. It should consider all landsliding which can affect the study area and include landslides which are uphill of the study area but may travel on to it, and landslides downhill of the study area which may retrogressively fail up-slope into it.

It should be recognized that the study area may be susceptible to more than one type of Landslide e.g. rock fall and debris flows, and may have a different degree of susceptibility (and in turn hazard) for each of these. In these cases it will often be best to prepare separate susceptibility and hazard zoning maps for each type of landslide.

Areas which may be affected by travel or regression of the landslides from the source will often be best shown on a separate map. The travel and regression of the landslides is dependent on different factors to those causing the landslides.

There are some differences of viewpoint amongst experts in landslide zoning as to whether susceptibility zoning should include an assessment of the potential travel or regression of landslides from their source. Some feel that this should be considered only in hazard zoning. However, in some situations it will be difficult to assess the frequency of landsliding and land use zoning may be carried out based on susceptibility zoning. In these cases the important matter of travel or regression would be lost. In view of this travel and regression should be considered in susceptibility zoning.

Landslide Hazard Zoning

Hazard zoning should be applied to the area in its condition at the time of the zoning study. It should allow for the effects of existing development (such as roads) on the likelihood of landsliding. In some situations the planned

development may increase or reduce the likelihood of landsliding. This can be assessed and a post-development hazard zoning map produced.

Hazard zoning may be quantitative or qualitative. It is generally preferable to determine the frequency of landsliding in quantitative terms so the hazard from different sites can be compared and the risk estimated also in quantitative terms. However in some situations it may not be practical to assess frequencies sufficiently accurately to use quantitative hazard zoning and a qualitative system of describing hazard classes may be adopted. Usually it will be possible to give some approximate guidance on the frequency of landslides in the zoning classes.

Landslide Risk Zoning

Risk zoning depends on the elements at risk, their temporal spatial probability and vulnerability. For new developments an assessment will have to be made of these factors. For areas with existing development it should be recognised that risks may change with additional development and thus risk maps should be updated on a regular basis. Several risk zoning maps may be developed for a single hazard zoning study to show the effects of different development plans on managing risk.

C4.2 EXAMPLES OF ZONING

Examples of landslide susceptibility, hazard and zoning maps are attached in Appendix CA. For other examples see Cascini *et al*. (2005) which references a number of zoning schemes. Note that the terms used in these examples are not necessarily consistent between each other or with this guideline.

C5 GUIDANCE ON WHERE LANDSLIDE MAPPING IS USEFUL FOR LAND USE PLANNING

C5.1 GENERAL PRINCIPLES

No comments or additional information.

C5.2 TOPOGRAPHICAL, GEOLOGICAL AND DEVELOPMENT SITUATIONS WHERE LANDSLIDING IS POTENTIALLY AN ISSUE

The examples given in the guideline are categorised into 5 classes based on:

(a) Where there is a history of landsliding. This is the most obvious class and the most common reason for deciding that landslide zoning should be carried out.

(b) Where there is no history of sliding but the topography dictates sliding may occur. If slopes are steep enough they may be susceptible to landsliding for a wide range of geological conditions. If sliding occurs, it is likely to be rapid and pose a hazard to lives of persons below the slopes.

(c) When there is no history of sliding but geological and geomorphologic conditions are such that sliding is possible.

The list of conditions is not meant to be complete, and other situations may be known locally to be susceptible to landsliding. It should be noted that in many of the cases listed the areas susceptible to landsliding may be in relatively flat terrain, with sliding occurring on low strength surfaces of rupture.

(d) Where there are constructed features which, should they fail, may travel rapidly.

Many of these cases relate to soils which lose a large amount of strength on sliding and thus will suffer a large drop in the factor of safety and travel rapidly after failure. The list is not meant to be complete but it is intended to give a reasonable range of examples.

(e) Forestry works and land clearing where landslides may lead to damage to the environment such as in degrading streams and other receiving water bodies. This is a separate class with the emphasis on environmental consequences.

C5.3 TYPES OF DEVELOPMENT WHERE LANDSLIDE ZONING FOR LAND USE PLANNING WILL BE BENEFICIAL

It should be noted that, unless specifically required by the organisation funding the zoning study or by the regulatory authorities, the impact of landsliding of the road or railway on road or railway users will not usually be considered in the landslide zoning. This is usually considered the responsibility of the road or railway owner, not those developing

adjacent land, unless the proposed development increases the landslide risk to the infrastructure and its users. The effect of landsliding of the road or railway on the adjacent areas which are being developed will usually be considered

C6 SELECTION OF THE TYPE AND LEVEL OF LANDSLIDE ZONING

C6.1 SOME GENERAL PRINCIPLES

Some landslide zoning management schemes rely only on susceptibility zoning to differentiate between areas where geotechnical assessment of landslide risk will be required for an individual development and areas where no geotechnical assessment is required. It should be recognised that:

(a) Such schemes are potentially expensive to implement in total cost terms because they do not differentiate areas for which some general development controls are required, such as limiting the height of cuts and fills, but no detailed geotechnical assessment of hazard or risk assessment is needed.

(b) They potentially categorize as equally susceptible areas which have different frequencies of landsliding and as a result different hazards.

The money saved by the planning authority in doing the lower cost susceptibility zoning study may be expended many times over by those in low hazard zones being required to fund unnecessary detailed hazard and risk assessments.

Only risk mapping allows assessment of the risks of life loss and comparison with tolerable life-loss criteria. Early experience is that many of those involved in landslide zonation were not sufficiently aware of the potential for loss of life from landslides and either did not considered life loss risk, or underestimated its importance.

C6.2 RECOMMENDED TYPES AND LEVELS OF ZONING AND MAP SCALES

Table 1 is intended for use by land-use planners in selecting the type, level and scale of landslide zoning that should be done. It is emphasised that this should be controlled by the proposed use of the landslide zoning. If statutory controls are to be imposed on development applications based on the landslide zoning then the zoning should be hazard or risk zoning and at an appropriate large or detailed scale. Zoning boundaries generally cannot be sufficiently accurately defined at the medium or small scale. It is also undesirable to base statutory zoning requirements which may for example impose restrictions on development based on susceptibility zoning that does not consider the frequency of the potential landsliding.

It is recognized that the funding available for landside zoning may be a constraint and this may force the use of smaller scale zoning of susceptibility or hazard. If this is done there should be a realistic understanding of the accuracy of zoning boundaries and of the susceptibility or hazard estimates. These types of zoning should only be used to act as a trigger for more detailed geotechnical assessment of landslide hazard and/or risk and not to impose statutory constraints on development.

C6.3 DEFINITION OF THE LEVELS OF ZONING

No comments or additional information

C7 LANDSLIDE ZONING MAP SCALES AND DESCRIPTORS FOR SUSCEPTIBILITY, HAZARD AND RISK ZONING

C7.1 SCALES FOR LANDSLIDE ZONING MAPS AND THEIR APPLICATION

Table 3 summarizes map scales and the landslide susceptibility, hazard and risk mapping to which they are usually applied. The table is based on Soeters and van Westen (1996), Cascini *et al.* (2005) and discussions at the JTC 1 Workshop on Landslide Susceptibility, Hazard and Risk Zoning held in Barcelona in September 2006. The following are some comments on the table:

(a) The input data used to produce landslide zoning maps must have the appropriate resolution and quality. Generally speaking, the inputs to the zoning should be at larger scales than the zoning map. Reliable zoning cannot be produced if, for instance, a landslide hazard zoning map prepared at a scale of 1:5,000 is based on a 1:25,000 geomorphologic or topographic maps because the accuracy of boundaries will be potentially misleading.

(b) The use of larger scale zoning maps must be accompanied by a greater detail of input data and understanding of the slope processes involved.

(c) In practice, only limited detail can be shown on small, medium and even large scale maps. Most examples of municipal (local government) landslide hazard or risk zoning maps which assign a hazard or risk classification on an individual property level should be prepared at the detailed level on large scale landslide zoning maps. There are some who believe that even at the detailed scale it is not technically or administratively defensible to make site specific decisions based on zoning maps, and that site specific assessment is necessary. Others believe it is possible, provided the zoning process includes ground inspection to define zoning boundaries, as was done by Moon *et al.* (1992) for debris flow hazard zoning.

(d) The usefulness and reliability of small scale landslide zoning mapping is considered by some to be questionable, even for regional developmental planning.

C7.2 DESCRIPTORS OF THE DEGREE OF SUSCEPTIBILITY, HAZARD AND RISK FOR USE IN LANDSLIDE ZONING

C7.2.1 General

The descriptors have been developed based on the experience of the scientific committee taking into account the opinions of the reviewers. There is not necessarily equivalence in risk for the different types of landslide having the same hazard descriptor.

C7.2.2 Examples of landslide susceptibility descriptors

Landslide susceptibility descriptors generally fall into the following categories:

- Likelihood that landsliding may occur in an area.
- The proportion or percentage of an area which may be susceptible to landsliding or on to which landslides may travel.
- The percentage (proportion) of the total events within the zoned area.
- The likelihood given landslides (e.g. rock falls) occur that they will reach an area being zoned.

Which of these is most appropriate should be determined on a study specific basis. The examples given in Table 4 should be used so far as practical to give some consistency between different zoning studies. It is emphasised that:

(a) Landslide susceptibility does not include a time frame or frequency of landsliding.

(b) The ability to recognize susceptibility to some types of landslide may depend on how long before the zoning study the landslides occurred. For example shallow landslides on steep natural slopes may not be evident a few years after they occur if the area revegetates.

(c) Some types of landslides may have occurred under different climatic conditions than now exist. Others may have exhausted the source material; e.g. shallow slides forming in drainage gullies on steep slopes may remove all the colluvial soil from the gully so that no further sliding will occur.

C7.2.3 Recommended landslide hazard zoning descriptors

Table 5 is meant to be used to assign verbal descriptors to the hazard zoning where the hazard has been quantified. It must not be used in reverse. If the assessed rock fall hazard is “high” by some qualitative method, this should not be interpreted to mean 1 to 10 rock falls/annum/km of cliff.

It should be noted that the “low” and “very low” descriptors for large landslides are most likely to be applied to slopes which have no geomorphic or other evidence of landsliding. It is difficult to assess such low frequencies to existing landslides.

In many cases there will be insufficient data to reliably quantify the hazard. In such cases the available data should be used to make a best estimate and the hazard which is then described as in Table 5 with a suitable qualification on the accuracy of the estimated hazard.

In some situations it may be possible to add to the description of the hazard the temporal occurrence within the year of the landsliding. For example, if the rainfall is monsoonal all landslides may occur within a 4 to 6 month period in the year. This can be useful additional knowledge for those managing the landslide hazard and should be done where practical.

C7.2.4 Recommended landslide risk zoning descriptors

Table C1 summarizes individual life loss risk criteria in use in a number of engineering related disciplines, including landsliding. It can be seen that there is a similarity between most of the criteria. Criteria in AGS (2000, 2002, 2007a) were determined taking many of these examples into account.

Table 6 has been developed taking as the starting point the individual life loss risk criteria of 10^{-6}/annum for acceptable risk and 10^{-5}/annum for tolerable risk, for the person most at risk for new cut and fill slopes suggested in AGS (2000, 2002, 2007a). It has been assumed that "acceptable risks" are "low" and tolerable risks are "moderate". Higher risks are often tolerated for existing slopes than for new slopes but it is considered impractical to adopt different figures for defining the descriptors for new and existing slopes in landslide zoning because of the common mix of existing and new development. Table 6 is meant to be used to assign verbal descriptors to the risk zoning where the risk has been quantified.. If the risk is assessed as "low" by some qualitative method it should not be interpreted to mean the annual probability of death of the person most at risk is assumed to be between 10^{-6}/annum and 10^{-5}/annum.

Whether risks within a zone are tolerable is a matter for the authority managing landslide hazards and regulators.There are no internationally accepted risk criteria for landsliding. It is necessary therefore to develop tolerable loss of life criteria for each situation, taking account of the legal framework of the country and regulatory controls in place. Criteria should be developed in consultation with all the affected parties, including the affected public. Those doing the risk analysis are likely to be most informed about precedents and understand the analyses and their limitations, so it is appropriate they are involved in this process. More information on tolerability of landslide risks is given in Leroi *et al.* (2005), ANCOLD (2003), Lee and Jones (2004), Bonnard *et al.* (2004) and Christian (2004).

Generally it should be possible to define risk zones in individual risk terms. However there may be some situations where a large number of deaths may result from a single landslide event. In these cases consideration of individual risks may not properly reflect societal aversion to such an event and societal risk criteria may require consideration. Leroi *et al.* (2005) present a discussion on societal risk and include examples of societal risk criteria.

Table C1: Individual life loss risk criteria. (Leroi *et al.*, 2005).

Organization	Industry	Description	Risk/annum	Reference
Health and Safety Executive, United Kingdom	Land use planning around industries	Broadly acceptable risk. Tolerable limit	10^{-6}/annum, public and workers 10^{-4}/annum public(1) 10^{-3}/annum workers	HSE (2001)
Netherlands Ministry of Housing	Land use planning for industries	Tolerable limit(2)	10^{-5}/annum, existing installation 10^{-6}/annum, proposed installation	Netherlands Ministry of housing (1989), Ale (2001), Vrijling *et al.* (1998)
Department of Urban Affairs and Planning, NSW, Australia	Land use planning for hazardous industries	"acceptable" (tolerable) limits (2)	$5x10^{-7}$/annum hospitals, schools, childcare facilities, old age housing 10^{-6}/annum residential, hotels, motels $5x10^{-6}$/annum commercial developments 10^{-5}/annum sporting complexes	
Australian National Committee on Large Dams	Dams	Tolerable limit	10^{-4}/annum existing dam, public most at risk subject to ALARP 10^{-5}/annum new dam or major augmentation, public most at risk, subject to ALARP.	ANCOLD (2003)
Australian Geomechanics Society guidelines for landslide risk management	Landslides (from engineered and natural slopes)	Suggested tolerable limit	10^{-4}/annum public most at risk, existing slope 10^{-5}/annum, public most at risk, new slope	AGS (2000)
Hong Kong Special Administrative Region Government	Landslides from natural slopes	Tolerable limit	10^{-4}/annum public most at risk, existing slope. 10^{-5}/annum public most at risk, new slope	Ho et al. (2000), ERM (1998), Reeves *et al*. (1999)
Iceland ministry for the environment hazard zoning	Avalanches and landslides	"acceptable" (tolerable) limit	$3x10^{-5}$/annum residential, schools, daycare centres, hospitals, community centres. 10^{-4}/annum commercial buildings $5x10^{-5}$ recreational homes(3)	Iceland Ministry for the environment (2000), Arnalds *et al*. (2002)
Roads and Traffic Authority, NSW Australia	Highway landslide risk	Implied tolerable risk	10^{-3}/annum(4)	Stewart *et al*. (2002), RTA (2001)

Notes: (1) But for new developments HSE (2001). advise against giving planning permission where individual risks are > 10^{-5}/annum. (2) Based on a temporal spatial probability of 1.0. (3) Assumes temporal spatial probability of 0.75 for residential, 0.4 commercial, 0.05 recreational. (4) Best estimate of societal risk for one person killed, top risk ranking. If slope ranks in this range action is taken to reduce risks within a short period. For the second ranking, societal risk is 10^{-4}/annum, and slope is put on priority remediation list.

The recommended descriptors for risk zoning for property loss criteria shown in Table 7 have been developed after considerable discussion and trialling of different versions. It has been developed mostly for use with residential dwellings. The "Likelihood" is the annual probability of the event which causes the property loss. It includes the annual probability of the landslide with allowance for whether it will reach the property. The damages include the cost of stabilization of the site to allow reconstruction of the residence so they can exceed the value of the property. For guidance on the use of this table refer to AGS (2007c).

C7.2.5 Recommended approach

No comments or additional information

C8 METHODS FOR LANDSLIDE ZONING FOR LAND USE PLANNING

C8.1 THE PURPOSE OF THIS SECTION

No comments or additional information.

C8.2 THE IMPORTANCE OF UNDERSTANDING SLOPE PROCESSES AND THE GEOTECHNICAL CHARACTERISTICS OF THE LANDSLIDING

It should be recognized that landslide zoning is a multidisciplinary exercise. Zoning carried out by persons who do not have the required knowledge and experience, or without sufficient detail of geotechnical investigations, is likely to be inaccurate and may be totally misleading.

C8.3 APPLICATION OF GIS-BASED TECHNIQUES TO LANDSLIDE ZONING

(a) GIS based landslide inventories

GIS-based landslide inventories can be quite simple or they can include extensive and detailed information compiled over longer periods of time in related tables and associated spatial data, typically in vector format.

Table C2 gives a generic example of the fields which may be included in an inventory.

The compilation and use of standard parameters for storage and reporting fields in landslide inventories has been the subject of an ongoing project initiated by Geoscience Australia. This work is addressing landslide inventory structure and includes generic categories whilst employing complex relational database structure. The project aims to establish a nationally consistent system of data collection to ensure a sound knowledge base for natural disasters such as landslides and facilitate better disaster mitigation. It is recommended that the future outcomes from this project to be published in Oschuwoski *et al*. be considered as a new guide for the development of landslide inventories.

Table C2: Generic Primary Landslide Inventory Fields. (courtesy of A Miner and P Flentje).

Field ID	Field Name	Data Type	Number Format	General Description of Field Contents
1	Inventory Number	Number	Single	Unique landslide site reference code
2	Landslide Type	Text	n/a	Cruden and Varnes (1996) basic landslide type (i.e, slide, flow, fall or as described elsewhere in this guideline Falls, shallow landslides, large landslides and small built environment failures)
3	Detailed Landslide Classification	Text	n/a	Cruden and Varnes (1996) full landslide classification
4	Reported By	Text	n/a	Name of person reporting landslide
5	Contact Details	Text	n/a	Contact details of reporter
6	Date Reported	Text	n/a	Date landslide reported
7	Date and Time of Landslide	Date/ Time	n/a	Date and time of landslide. Perhaps in related table with one to many relationship
8	Magnitude of displacement (m)	Number	Single	Distance travelled by landslide
9	Street Number	Text	n/a	Physical Street Number
10	Street Name	Text	n/a	Physical Street Name
11	Suburb	Text	n/a	Local Government suburb

12	City	Text	n/a	City or Country region
13	State	Text	n/a	State
14	Post Code	Number	Integer	Australian Post Code
15	Jurisdiction	Text	n/a	Organisation or individual responsible for land management of site
16	GDA1994 Easting	Number	Long Integer	GDA1994 Easting grid position to centre of landslide
17	GDA 1994 Northing	Number	Long Integer	GDA 1994 Northing grid position to centre of landslide
18	Method of Spatial Data Capture	Text	n/a	Field mapping, surveying, old reports, API etc
19	Positional Accuracy	Text	n/a	An estimate of positional accuracy such as +/- 20m or similar
20	Landslide Width across the slope (m)	Number	Single	Maximum width across the slope in metres
21	Landslide Length up/down the slope (m)	Number	Single	Maximum length up/down slope in metres
22	Landslide Depth (m)	Number	Single	Maximum thickness of landslide profile perpendicular to surface of rupture in metres
23	Volume	Number	Single	WP/WLI (1990) landslide volume calculation
24	Location	Text	n/a	Describe physical location of landslide to aid geographic positioning
25	Site Description	Text	n/a	Physical description of site to aid visualisation and detail positioning
26	Landslide Trigger	Text	n/a	Describe trigger if known (i.e rainfall intensity/duration; seismic Magnitude and location etc)
27	References	Text	n/a	Reference listing of Investigation Reports and other material pertaining to this landslide
28	Current Site	Number	Byte	Is this site still a current site or has it been superseded, see comments
29	Comments	Text	n/a	Addendum to any of the above and or additional comments
30	Ground slope	Number	Byte	Local area average ground slope
31	Geological Setting	Text	n/a	Geological Province
32	Bedrock Geology	Text	n/a	Geological formation - name of underlying bedrock units
33	Slide Geometry	Text	n/a	Generalised description of slide profile, if known.
34	Slide Material	Text	n/a	Description of bulk of material being displaced
35	Depth to Bedrock	Number	Single	Depth to bedrock (m)
36	Depth to Basal Failure Plane	Number	Single	Depth to basal failure plane (m)
37	What is the Relationship to Rainfall?	Text	n/a	What is the relationship between movement and rainfall if known?
38	Strength Parameters	Text	n/a	Reference to or list any geotechnical parameters either tested or back analysed
39	Houses Damaged	Number	Double	Number of houses damaged
40	Houses Destroyed	Number	Double	Number of houses destroyed
41	Person Injured	Number	Double	Number of persons injured
42	Person Killed	Number	Double	Number of persons killed
43	Infrastructure Damaged	Text	n/a	Description of infrastructure damaged
44	Infrastructure Destroyed	Text	n/a	Description of infrastructure destroyed
45	Environmental impact	Text	n/a	Description of environmental impact
46	Economic Loss	Text	n/a	Description of economic loss caused by landslide and date with references
47	Geotechnical Investigation Type	Number	List select	Type/Level of Geotechnical Investigation with references
48	Cost of Geotechnical Investigation	Number	Double	Cost of Geotechnical Investigation with references

(b) GIS based modelling of landslide susceptibility and hazard

With the available data in place various methods can be applied to establish inter-relationships and ultimately to establish levels of susceptibility and hazard. Key vector data sets typically used in landslide zoning studies include landslide polygons, geology, geomorphologic and or terrain units, cadastre, road, rail and utilities, land use and vegetation. Other data that can be imported given the required spatial data elements may include borehole information, soil strength parameters, pore water pressures, rainfall etc. The key grid or raster data is the digital elevation model (DEM). GIS software can derive numerous data sets useful in landslide zoning from the DEM such as slope, aspect, flow accumulation, soil moisture indices, distance to streams and curvature to name only a few.

A GIS model can be used to combine a set of input maps or factors using a function to produce an output map. The function can take many forms including linear regression, multiple regression, condition analysis and discriminate analysis etc.

These indirect methods involve qualitative or quantitative modeling and analysis techniques of various types (Soeters and Van Westen, 1996):

(i)Heuristic Analysis.
In heuristic methods the expert opinion of the person carrying out the zoning is used to assess the susceptibility and hazard. These methods combine the mapping of the landslides and their geomorphologic setting as the main input factors for assessing the hazard. Two main types of heuristic analysis can be distinguished: geomorphic analysis and qualitative map combination.

In *geomorphic analysis* the susceptibility and hazard is determined directly by the person carrying out the study based on individual experience and the use of reasoning by analogy. The decision rules are therefore difficult to formulate because they vary from place to place.

In *qualitative map combination* the person carrying out the study uses expert knowledge to assign weighting values to a series of input parameters. These are summed according to these weights, leading to susceptibility and hazard classes. These methods are common, but it is difficult to determine the weighting of the input parameters.

(ii) Knowledge based analysis.
Knowledge based analysis is the science of computer modeling of a learning process (Quinlan, 1993). The data mining learning process extracts patterns from the databases of landslides (Flentje *et al.* 2007). Pixels with attributed characteristics (from the input data layers) matching those for known landslides are used to define classes of landslide zoning. The percentage distributions of landslides within the zones are then used to help define the zones.

(iii) Statistical analysis.
The statistical approach is based on the observed relationships between each factor and the past distribution of landslides. Hence susceptibility and hazard zoning is conducted in a largely objective manner whereby factors and their interrelationships are evaluated on a statistical basis. Various methods exist for the development of the rules for and relationships between variables and these include bivariate analysis, multivariate analysis, Boolean approaches using logistic regression, Bayesian methods using weights of evidence and neural networks (Soeters and van Westen, 1996). Limitations with such methods result from data quality such as errors in mapping, incomplete inventory and poor resolution of some data sets as the models are essentially data trained. In addition, the results of such models are not readily transferable from region to region.

(iv) Deterministic Analysis.
Deterministic methods apply classical slope stability theory and principles such as infinite slope, limit equilibrium (e.g. Bishop, Sarma etc) and less commonly finite element and 3-D techniques. These models require standard soil parameter inputs such as soil thickness, soil strength, groundwater pressures, slope geometry etc. The resultant map details the average factor of safety and boundaries while susceptibility and hazard classes can be set according to factor of safety ranges (i.e. unstable <1.0, meta-stable 1.0 to 1.1 etc). See for example, Savage *et al*. (2004) and Baum *et al*. (2005). The variability of input data can be further used to calculate probability of failure in conjunction with return periods of triggers (Soeters and van Western, 1996).The main problem with these methods is the oversimplification of the geological and geotechnical model and difficulties in predicting groundwater pore pressures and their relationship to rainfall and/or snow melt.

These methods of data analysis are applicable to non-GIS based systems but the use of GIS greatly assists the process.

(c) Spatial data and scale in GIS

Scale in GIS is considered in relation to the subsequent use of the data. Landslide inventory maps, susceptibility and hazard zoning maps will be used by Local Governments and Government Authorities etc to make important land management decisions at a large scale, often down to the cadastral land parcel scale. Data queries and decisions based on data mandate the integrity of the data to be rigorous at that scale. Hence the scale at which input data is collected should relate to the required scale of the output.

(d) The need for calibration of GIS modelling.

The need to field check iterations of the GIS modelling output is critical in producing a quality zoning map that reflects, as best one can, the reality in the field. Calibration of this model is essential in any project. The significance of compiling the best possible input data to any GIS application cannot be overstated. Time and resources devoted to the assembly of comprehensive, accurate, high quality data which is captured at an appropriate scale and resolution is considered to be possibly the most significant task undertaken in any GIS-based inventory compilation and modelling project. The use of GIS is not a substitute for the involvement of geotechnical professionals with the skills required to carry out landslide zoning. GIS is a tool to assist them to do the zoning efficiently.

C8.4 LANDSLIDE INVENTORY

It should be noted that the landslide inventory is often the basis for all the zoning and it is important that this activity is done thoroughly. For rock falls, slides from cuts, fills and retaining walls the data will usually need to cover 10, 20 or more years so a number of significant rainfall events can be sampled in the inventory if it is to be used as the basis for frequency assessment. In many cases it will not be possible to create a good inventory from past records, so the inventory has limitations. These can be overcome with time if those responsible establish a system for gathering data which can then be incorporated in later zoning studies.

For small landslides in natural slopes, the quality of the inventory will be enhanced by carrying out surface as well as aerial photograph-based interpretation. Even experienced aerial photo interpreters may not be able to see slides which have been hidden by vegetation. Basic small or medium scale landslide inventory mapping at regional or local level may be followed by intermediate or sophisticated mapping of higher susceptibility areas. The inventory should be mapped at a larger scale than the susceptibility, hazard or risk zoning maps. Different information can be mapped depending on the scale. For example:

(a) Inventory scale 1:50,000 to 1:100,000 for regional zoning.
The minimum area covered by an inventoried landslide is 4 ha. Smaller landslides may be represented by a dot (or equivalent in GIS terms). It is unnecessary and impossible to distinguish between landslide scarp features and resulting mass or deposit. Landslides are only classified. Data about activity are simplified to active, dormant. Data about damages are simplified.

(b) Landslide inventory at scale 1:10,000 to 1:25,000 for local zoning.
The minimum area covered by an inventoried and mapped landslide is 1600 m^2. Smaller landslides are represented by a dot. Minor and lateral scarps may be distinguished as well as upslope deformations such as tension cracks or minor landslides. Landslides are classified. Original mass, volume and averaged velocity is recorded from direct information or expert assessment. Activity should be described using WP/WLI (1993). Data about damages if they are available are simplified to: no data, minor and major.

(c) Landslide inventory at scale 1: larger than 1:5,000 for site specific or local zoning.
The minimum area covered by an inventoried mapped landslide is 100 m^2. Smaller landslides are represented by dots. Mapped landslides may be divided into its components: scarp, rupture surface and mass or deposit. Rupture surface is digitized as a polygon comprising visible (scarps) and hidden sides covered by the mass. Landslides are classified. Mass volume and average velocity is estimated and recorded. GIS analysis may be used to obtain the total area of each landslide type in each lithological unit of the mapped zone so the distribution of landslide rupture surface by lithology units is obtained. Activity should be described using WP/WLI (1993). Data about damages are recorded if available with mention of economic losses or qualitative description of losses, number of days, weeks or months of interrupted services or catastrophic losses. Human losses are also detailed with number of injured and dead persons. Historical data or record of temporal distribution of landslides, triggering rainfall and earthquake magnitudes may also be added to the inventory. The inventory may also record landslide features relating to slope deformations associated to early stage of landslide development such as inclined trees, inclined fences and deformed structures, tension cracks on element at risk such as roads, walls, houses, pavements, etc. and tension cracks on slopes.

For landslides from cuts and fills and from rock fall even the most basic inventory of landslides can be valuable in estimating landslide frequency. This can be set up in GIS or simply as a spreadsheet with such data as the location, classification, volume, travel distance and state of activity and date of occurrence.

Those responsible for landslide risk management are strongly encouraged to develop a landslide inventory if one does not yet exist for their area.

C8.5 LANDSLIDE SUSCEPTIBILITY ZONING

C8.5.1 Landslide characterization and travel distance and velocity

Table C3 (a) to (d) provides more detail on the activities required to characterise the landslides for the four main classes of landslides and lists suggested useful references. In most cases where intermediate methods are being used basic methods will also be used. For advanced methods, intermediate and basic mehods will also be used. Note that much of these activities will be carried out in GIS and the terms used here are generic. It should be noted that the more advanced the characterization method the larger scale of the mapping and level of detail of information and understanding of slope processes is required. Some general references on mapping procedures include Van Westen (1994, 2004), and Guzzetti *et al.* (1999).

It should be recognized that even at the intermediate and sophisticated levels it is difficult to accurately define landslide susceptibility from terrain and geotechnical characteristics. This uncertainty should be borne in mind when carrying the information forward into preparing hazard and risk zoning.

Some useful references for assessing travel distance include:

- Empirical methods for assessing travel distance of soil and rock slides which become debris flows and debris slides: Evans and Hungr (1993), Hungr *et al*. (2005), Corominas (1996), Hunter and Fell (2003).
- Numerical methods for assessing travel distance: Hungr (1995), McDougall and Hungr (2004), Hungr *et al.* (2005).
- GIS based methods: Dorren and Seijmonsbergen (2003).

The landslide velocity can be estimated from the potential energy and assumed friction losses using the sliding block model as described in Hungr *et al*. (2005).

Care should be exercised when defining travel distance based on the location of ancient landslide deposits. The source of pre-historic landslides cannot always be properly located and travel distance estimation may be subjected to significant error. It should be noted that there is not yet available a commercial computer program with sufficient documentation or guidance on selection of input parameters to reliably model travel distance and velocities. The DAN Program (Hungr, 1995, McDougall and Hungr, 2005) is available for use commercially but requires calibration on failed slopes in the study area before being used in a forecasting mode. Because of this, empirical methods are the most widely used. These have a significant model uncertainty which should be allowed for in developing the susceptibility maps for landslides which will travel beyond the source landslide.

Table C3: Details of some activities which may be used to characterise, and evaluate the spatial distribution of potential landslides and their relationship to topography, geology and geomorphology.

(a) Rock Falls

Characterisation method	Activity	References
Basic	Map historic rock fall scars and record the number, spatial distribution, volume of fallen rocks below the source of the rock falls.	
	Relate rock fall occurrence to presence of fallen blocks and talus deposits.	
Intermediate	**The same activities as Basic plus**	Romana (1988) Selby (1980) Rouiller *et al*. (1998) Hungr, *et al*. (1999) Picarelli, *et al*. (2005) Moon, *et al*. (2005)
	Map geomorphic indicators (cracks, partially detached blocks).	
	Develop frequency-magnitude relationships from the historic data.	
	Relate rock fall activity to Slope Mass Rating, Rock Mass Strength or use techniques such as Matterock Use magnitude-frequency relationship techniques.	
Sophisticated	**The same activities as Intermediate plus**	Hoek and Bray (1981) Goodman and Shi (1985)
	Detailed mapping of geological structure and relate field performance to analysis of stability using planar, wedge and toppling analyses.	

(b) Small Landslides

Basic	Map historic landslides from air photography, preferably photographs taken at different times some years apart and using some surface mapping.	Nilsen *et al*. (1979) Brabb (1984) Evans and King (1998) Dai and Lee (2002)
	Relate landslide occurrence to topography (e.g. slope, elevation, aspect) and lithology using simple correlation of single variables and judgement.	
Intermediate	**The same activities as Basic plus**	Van Westen (1994) Carrara *et al*. (1995) Baynes and Lee (1998)
	Carry out more detailed surface mapping of the incidence of landslides and geomorphology mapping using air photographs and/or by surface mapping.	
	Relate landslide occurrence to topography, geology, type and depth of soils and geomorphology using statistical analysis techniques..	
Sophisticated	**The same activities as Intermediate plus**	Baum *et al.* (2005)
	Detailed surface mapping and aerial photo interpretation, geotechnical and hydrological investigations. Relate landsliding with coupled slope stability models implemented in a GIS.	

(c) Large Landslides

Basic	Map landslides from aerial photography and/or surface mapping. Prepare an inventory of landsliding.	Crandell *et al*. (1979) Cascini *et al.* (2005) Hungr *et al.* (2005)
	Relate landslide occurrence to topography (e.g. slope, elevation, aspect) and lithology using simple correlation of single variables and judgement.	
Intermediate	**The same activities as Basic plus**	Dikau, *et al*. (1996)
	Carry out more detailed geological and geomorphology mapping using air photographs and/or by surface mapping, distinguishing the activity of landsliding qualitatively.	
	Relate landslide occurrence to topography, geology, type and depth and geotechnical characteristics of soil and geomorphology using statistical analysis techniques.	
Sophisticated	**The same activities as Intermediate plus**	Wu and Abdel-Latif, 2000 Corominas and Satacana, 2003
	Detailed surface and air photo mapping, geotechnical and hydrological investigations. Some analyses of stability may be carried out. Analysis of historic and survey data to assess activity.	

(d) Cuts, fills and retaining walls in roads and railways and in urban development

Basic	Make an inventory of the classification, volume, location and date of occurrence of landslides from local government records, newspaper articles and consultants files.	
	Collect data on the population of slopes including the number, height, geology, type of wall construction.	
	Relate these to the length of roads and the number of properties on which they have occurred to assess susceptibility.	
Intermediate	**The same activities as Basic plus**	Budetta (2004) MacGregor *et al.* (2007)
	Include in the inventory the height of cuts, fills and retaining walls, slope angles, basic geology (lithology, depth of soil) and possibly basic geomorphology (e.g. are slides located in gullies, planar slopes or convex slopes), types of retaining walls for failed slopes and the population.	
Sophisticated	**The same activities as Intermediate plus**	
	Include in the inventory details of slope angles, geotechnical properties of typical slopes, drainage and groundwater conditions for the failed slopes and the population.	

C8.5.2 Preparation of landslide susceptibility map

Landslide susceptibility zoning maps may be developed from landslide inventories and geomorphologic maps produced from aerial photos, satellite images, and field work. A relative susceptibility is allocated in a subjective manner by the person doing the study. This often leads to a map which is very subjective and difficult to justify or reproduce systematically.

A more objective way of developing susceptibility zoning is by correlating statistically a set of factors (such as geological-morphological factors) with slope instability from the landslide inventory. The relative contribution of the factors generating slope failures is assessed and the land surface is classified into domains of different susceptibility levels. Finally, the results of the classification are checked by analysing whether the spatial distribution of the existing landslides (landslide inventory) takes place in the classes rated as the most unstable.

It should be kept in mind that the aim of susceptibility mapping should be to include the maximum number of landslides in the highest susceptibility classes whilst trying to achieve the minimum spatial area for these classes.

At large scale, detailed susceptibility maps may be founded on geotechnical models such as the infinite slope with parallel plane failure, provide the landslides in the area are shallow translational slides in rocks or soils (i.e. consistent with infinite slopes). An assessment of geotechnical and pore water pressure parameters is necessary in order to use this approach. The safety factor may be established in a GIS in pixel cells and the results referred to susceptibility depending on the calculated factor of safety. Given the complexity of geotechnical conditions in slopes these methods are unreliable unless calibrated by correlating with the landslide inventory.

Slope failure is caused by the concurrence of permanent conditioning and triggering factors. Permanent factors are terrain attributes (i.e. lithology, soil types and depths, slope, watershed size, vegetation cover, among others) that evolve slowly (i.e. by weathering or erosion) to bring the slopes to a marginally stable state. Triggering events include ground shaking due to earthquakes or rise of groundwater levels and/or pressures due to infiltration of rainfall or snow melt. Only permanent conditioning factors are mapped to assess landslide susceptibility while the recurrence period of the triggers is usually used to assess the landslide hazard.

Some examples of susceptibility mapping are given in Cascini *et al*. (2005), Lee and Jones (2004), and Chacon *et al*. (2006).

C8.6 LANDSLIDE HAZARD ZONING

C8.6.1 Frequency Assessment

(IUGS, 1997) advise that the frequency of landsliding may be expressed in terms of

- The number of landslides of certain characteristics that may occur in the study area in a given span of time (generally per year, but the period of reference might be different if required).
- The probability of a particular slope experiencing landsliding in a given period
- The driving forces exceeding the resistant forces in probability or reliability terms with a frequency of occurrence being determined by considering the annual probability of the critical pore water pressures (or critical ground peak acceleration) being exceeded in the analysis

This should be done for each type of landslide which has been identified and characterized as affecting the area being zoned. Frequency is usually determined from the assessment of the recurrence intervals (the average time between events of the same magnitude) of the landslides. If the variation of recurrence interval is plotted against magnitude of the event, a magnitude-frequency curve is obtained.

Methods of determining frequency include:

- Historical records. When the complete series of landsliding events is available, recurrence intervals can be obtained by assuming that future occurrence of landslides will be similar to the past occurrence. Landslides have to be inventoried over at least several decades to produce a valid estimate of landslide frequency and the stability of temporal series has to be checked.
- Sequences of aerial photographs and/or satellite images. Average frequency of landslides may be obtained dividing the number of new landslides identified or the retreat of a cliff in metres by the years separating the images.
- Silent witnesses. They are features that are a direct consequence of the landslide phenomenon such as tree impacts produced by fallen blocks or organic soils buried by the slide deposits. They provide the age of the landslide event with a precision that depends on the method used to date the feature.
- Correlation with landslide triggering events. Rain storms and earthquakes are the most common landslide triggering mechanisms. Once the critical rainfall and/or earthquake magnitude capable to trigger landslides has been assessed in a region, the recurrence intervals of the landslides are assumed to be that of their triggers.
- Proxy data. They are data used to study the landslide, for which no direct information is available. Proxy data may be, for instance, pollen deposited on the surface of the landslide at any time after its emplacement, lichen colonization of the landslide deposits, or fauna assemblages that lived in a pond generated by the landslide movement, etc. These elements can be dated with a variety of techniques (Lang *et al*., 1999).

- Geomorphologic features which are associated with the degree of landslide activity (presence of ground cracks, fresh scarps, tilted structures).
- Subjective (degree of belief) assessment. If there is little or no historical data it is necessary to estimate frequencies based upon the experience of the person(s) doing the zoning. This is usually done by considering the likely response of the slope to a range of triggering events, such as the 1 in 1; 1 in 10; 1 in 100 AEP rainfall and combining the frequency of the triggering event to the probability, given the trigger occurs, the slope will fail. This should be summed over the full range of trigger frequencies.

Assessing the recurrence periods of the landslide events will usually require using different and complementary methods. The frequency of the small size landslides may be obtained from the statistical treatment of the historical records. For example the frequency of large landslide events having long recurrence periods may be obtained from a series of dated old landslide deposits.

Landslides of different types and sizes do not normally have the same frequency (annual probability) of occurrence. Small landslide events often occur more frequently than large ones. Different landslide types and mechanics of sliding have different triggers (e.g. rainfalls of different intensity, duration and antecedent conditions; earthquakes of different magnitude and peak ground acceleration) with different recurrence periods. Because of this, to quantify hazard, an appropriate magnitude-frequency relationship should in principle be established for every landslide type in the study area. In practice the data available is often limited and this can only be done approximately.

Preliminary landslide hazard zoning maps are often prepared from simple geomorphological maps showing the types of landslides and a qualitative estimation of their activity (i.e. active, dormant or inactive). More elaborated maps are based on the quantitative, or at least semi-quantitative, assessment of frequency-magnitude relationship for different landslide types.

Deterministic approaches for estimating frequency by correlation with rainfall have been mostly performed at a site level (large scale). Recent developments in coupling hydrological and slope stability models have allowed the preparation of landslide hazard maps at a local level. These approaches require data of high quality: detailed DTM, relatively uniform ground conditions, landslide types easy to analyse and a well established relationship between precipitation regime and groundwater level changes (e.g. Baum *et al*. 2005). This is usually only possible for shallow landslides which generally fit these conditions. The frequency of landsliding can be linked to the frequency of the precipitation. The complex geotechnical nature of slopes makes it impractical to use these methods without calibration against field performance with landslide inventories in the study area.

Some useful references on frequency assessment include:

- For assessing geomorphology data: Baynes and Lee (1998), Wieczorek (1984), McCalpin (1984),Carrara *et al.* (1995), Palmquist and Bible (1980), Fell *et al.* (1996).
- For assessing historic data to produce magnitude –frequency curves. Fell *et al.* (1996), Bunce *et al.* (1997), Hungr *et al*. (1999), Remondo *et al.* (2005), Coe *et al*. (2004), Picarelli *et al.* (2005), Moon *et al.* (2005), Evans *et al.* (2005).
- For assessing proxy data: Gardner (1980), Bull *et al.* (1994), Lang *et al.* (1999), Schuster *et al*. (1992), Van Steijn (1996), Alexandrowicz and Alexandrowicz (1999), Gonzalez –Diez *et al*. (1999), Corominas *et al.* (2005)
- For relating landslide frequency to rainfall and other factors: Picarelli *et al*. (2005), Strunk (1992), Wilson and Wieczorek (1995), Crozier (1997), Finlay *et al.* (1997), DUTI (1983), Soeters and van Westen (1996), Baum *et al*. (2005).
- For relating the frequency of rock falls and small slides on natural slopes to seismic loading: Wieczorek (1996), Keefer (1984), Schuster *et al.* (1992), Cascini *et al*. (2005), Harp and Jibson (1995,1996), Jibson *et al.* (1998)
- For assessing the susceptibility of slopes to liquefaction and flow failure: Youd *et al*. (2001), Hunter and Fell (2003)

It should be noted that:

(a) The assessment of frequency of sliding from geomorphology is very subjective and approximate, even if experienced geomorphologists are involved. It should be supported with historic data so far as possible. In principle the method should work best for frequent sliding where fresh slide scarps and other features will be evident. However, such features may be covered within weeks by farming and construction activity.

(b) Most methods for relating landslide frequency to rainfall indicate when landsliding in an area may occur and not whether a particular slope may slide. The figures from these analyses must be adjusted for the

population of slopes to allow estimation of the frequency of sliding. This is discussed in Picarelli *et al*. (2005) and in MacGregor *et al.* (2007).

(c) The incidence of landsliding of slopes to rainfall is usually non-linear. For smaller slides from natural slopes and cuts and fills there is often a "threshold" rainfall below which little or no landsliding will occur and then a greater frequency of sliding for increasing rainfall. This is evident in the data for failures from cuts, fills and retaining walls in Hong Kong (Finlay *et al*., 1997, MacGregor *et al.*, 2007) for cuts and fills in Pittwater shire, Sydney and in small shallow slides from steep natural slopes (Kim *et al.*, 1992).

(d) For larger landslides it is often the combination of rainfall intensity and antecedent rainfall over a period which causes landslides to become active. Leroueil (2001) provides several examples.

(e) When relating the frequency of landsliding to rainfall it should not be assumed that 24 hour rainfall is the critical duration. The effect of shorter duration high intensity rainfall should be assessed if the rainfall data is available. However, pluviograph data is seldom available. The effect of antecedent rainfall should be assessed at least qualitatively (e.g. MacGregor *et al*., 2007; Walker, 2007).

(f) The frequency of seismically induced landsliding is related to the peak ground acceleration at the site, and the magnitude of the earthquake. Studies by Keefer (1984), Harp and Jibson (1995, 1996) and Jibson *et al*. (1998) have shown that there is a critical magnitude and peak ground acceleration (or distance from the earthquake epicentre) above which landsliding will occur. This varies for different classes of landslide. Pre-earthquake rainfall and water tables influence the response of slopes to earthquakes.

(g) Newmark type displacement analysis is described in Newmark (1965) and Fell *et al*. (2005).

(h) The assessment of the frequency of collapse of coastal cliffs is related to coastal erosion processes which may control the frequency of landsliding. This is a specialist area and should be assessed by a multi-discipline team including engineering geologist, rock mechanics engineer and coastal engineer. Similarly, for mapping of coastal sand dunes subject to erosion by the sea a team consisting of geotechnical engineer, engineering geologist and coastal engineer is required.

Because of the complex interaction between the mechanical behaviour of geo-materials and triggering factors it is recommended that a geotechnical engineer familiar with the mechanics of slopes be involved in frequency estimation for zoning studies.

C8.6.2 Intensity assessment

Hungr (1997) defined landslide intensity as a set of spatially distributed parameters describing the destructiveness of the landslide. These parameters are varied with the maximum movement velocity the most accepted one, although total displacement, differential displacement, depth of moving mass, depth of deposited mass and depth of erosion are alternative parameters. Keeping in mind the design of protective structures, other derived parameters such as peak discharge per unit width, kinetic energy per unit area and maximum thrust or impact pressure may be also considered.

Landslide movements can range from imperceptible creep displacements of large and small masses to both large and very fast rock avalanches. The likelihood of damage to structures and the potential for life loss will vary because of this. Intensity is the measure of the damaging capability of the landslide. In slow moving landslides persons are not usually endangered while damages to buildings and infrastructures might be high although, in some cases, only evidenced after long periods of time. By contrast rapid movements of small and large masses may have catastrophic consequences for both persons and structures. For this reason it is desirable to describe the intensity of the landslides in the zoning study.

The same landslide may result in different intensity values along the path (for instance, the kinetic energy of a rock fall changes continuously along its trajectory).

There is therefore, no unique definition for intensity and those carrying out the zoning will have to decide which definition is most appropriate for the study. Useful references include Hungr (1997), Lateltin (1997), Hungr *et al*. (2005), Cascini *et al*. (2005) and Copons *et al*. (2004).

C8.6.3 Preparation of Landslide hazard zoning map

Examples of hazard zoning mapping are given in Cascini *et al*. (2005), Wong (2005) and Corominas *et al*. (2003). Australian examples include the Shire of Lillydale (1993) mapping which was at an intermediate level and classifies hazard (called risk in the scheme documents) into low, low (basalt), medium M1, medium M2 and high. There are other areas classified as not susceptible to landsliding. Depending on the classification, development may proceed without detailed geotechnical assessment or with geotechnical assessment. The scheme is described in Moon *et al*. (1992).

Part of that Shire was also subjected to a sophisticated level study of debris flow hazard. This is described in Moon *et al*. (1992) and in Fell and Hartford (1997) who extended the scheme to risk zoning.

C8.7 LANDSLIDE RISK ZONING

C8.7.1 Elements at risk

The elements at risk are the population, buildings and engineering works, economic activities, public services utilities, infrastructure and environmental features in the area potentially affected by the landslide hazard. These need to be assessed for existing and proposed development.

C8.7.2 Temporal spatial probability and vulnerability

Some useful references include Roberds (2005), Van Westen (2004), Wong (2005) and AGS (2000, 2002, 2007c).

Elements at risk may be damaged in multiple ways (Leone *et al.*, 1996; Glade *et al*., 2005; van Westen *et al*., 2005). In large landslides, there are sensitive areas where damage will be more likely (or much higher), no matter what the total landslide displacement or the released energy will be. This occurs for instance in the landslide boundaries, such as the head or sides or at local scarps where tensile stresses develop with the result of cracks, surface ground depletion and local rotation. Similarly, large differential deformations are expected in the landslide toe where thrusting and bulging of the ground surface might take place.

The resistance of a building is dependant on the landslide mechanism. It might be sufficient to resist the impact of a falling block but it can be insufficient to avoid development of tension cracks due to differential displacements produced by a translational slide. It may be concluded that, for a similar structure or building, the expected damage will depend on: (i) the landslide type (rock fall, debris flow, slide, etc); (ii) the hazard intensity and (iii) the relative location of the vulnerable element in relation to the landslide trajectory or to the position inside the landslide affected area.

The vulnerability of lives and properties are often different. For instance a house may have a similar high vulnerability to both slow-moving and rapid landslides, while a person living in it may have a low to negligible vulnerability in the first case. It is recommended that vulnerability of the elements at risk be estimated for each landslide type and hazard intensity. In order to make reliable estimation of the vulnerability of the elements at risk it is indispensable to carry out the analysis of the performance of structures during past landslide events and the inventory of the observed damages (Faella and Nigro, 2003).

Vulnerability mapping can be performed with the aid of approaches which, depending on both the scale and the intended map application, may be either qualitative or quantitative type. A qualitative approach, coupled with engineering judgement, uses descriptors to express a qualitative measure of the expected degree of loss (Cascini *et al*., 2005). However, qualitative approaches, as recommended by AGS (2000), are only applicable to consideration of risk to property. Quantitative approaches, like that proposed by AGS (2000, 2002, 2007a) for life loss situations and Remondo *et al*. (2005), need data on both landslide phenomenon and vulnerable element characteristics (Leone *et al*., 1996).

Mostly this is empirical data. It should be noted that any errors introduced by uncertainty in vulnerability estimates are usually far outweighed by the uncertainty in frequency estimates.

C8.7.3 Preparation of landslide risk zoning maps

Examples are given in Cascini *et al.* (2005), Bell and Glade (2004), Lee and Jones (2004) Michael-Leiba *et al.* (2003) and Corominas *et al.* (2005).

C9 RELIABILITY OF LANDSLIDE ZONING FOR LAND USE PLANNING

C9.1 POTENTIAL SOURCES OF ERROR

The inability of sophisticated methods to model slopes in zoning studies is discussed further in Picarelli *et al.* (2005) and Fell *et al.* (2000). Where used they should be calibrated against landslide inventories and empirical methods.

C9.2 VALIDATION OF MAPPING

Cascini *et al.* (2005), Remondo *et al.* (2003), Ardizzione *et al.* (2002) and Irigaray *et al.* (1999) give examples of validation.

C10 APPLICATION OF LANDSLIDE ZONING FOR LAND USE PLANNING

C10.1 GENERAL PRINCIPLES

The importance of carrying out the zoning at an appropriate level and scale cannot be over-emphasised.

C10.2 TYPICAL DEVELOPMENT CONTROLS APPLIED TO LANDSLIDE ZONING

No comments or additional information.

C11 HOW TO BRIEF AND SELECT A GEOTECHNICAL PROFESSIONAL TO UNDERTAKE A MAPPING STUDY

C11.1 PREPARATION OF A BRIEF

No comments or additional information.

C11.2 SELECTION OF A CONSULTANT FOR THE MAPPING

No comments or additional information.

C11.3 PROVIDE ALL RELEVANT DATA

No comments or additional information.

C12 METHOD FOR DEVELOPMENT OF THE GUIDELINES, AND ACKNOWLEDGEMENTS

It is emphasised that the guidelines have been subject to extensive review internationally.

C13 REFERENCES

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APPENDIX CA - EXAMPLES OF LANDSLIDE ZONING MAPPING

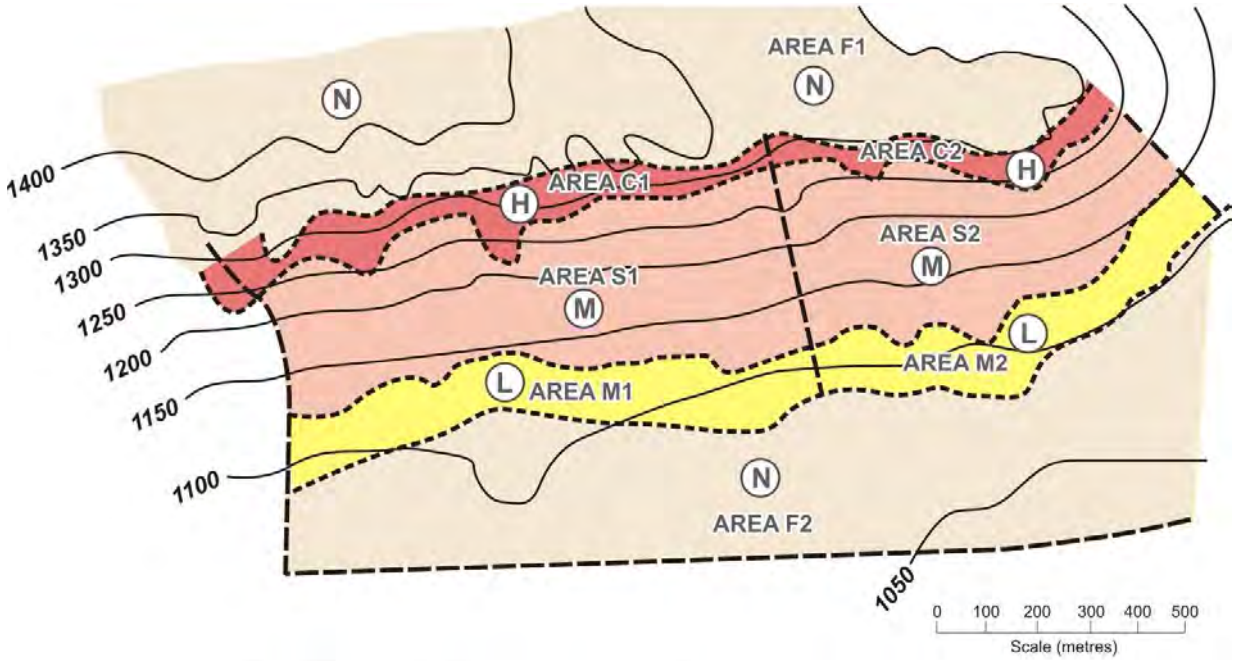

Figure 2A Rockfall Susceptibility

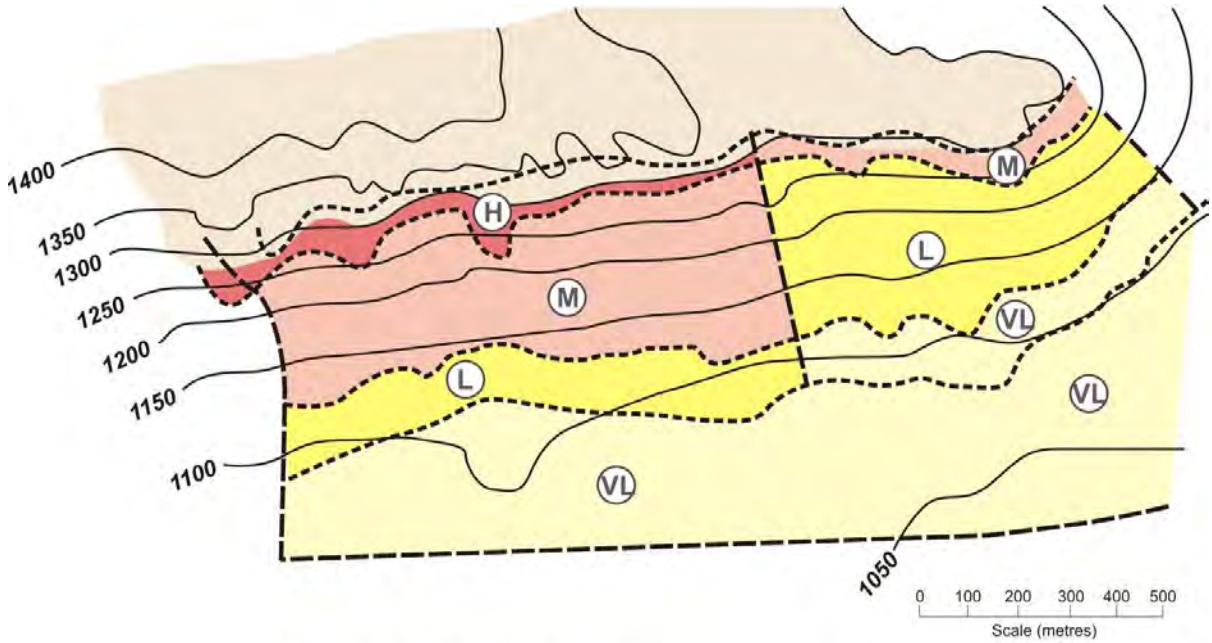

Figure 2B Rockfall Hazard

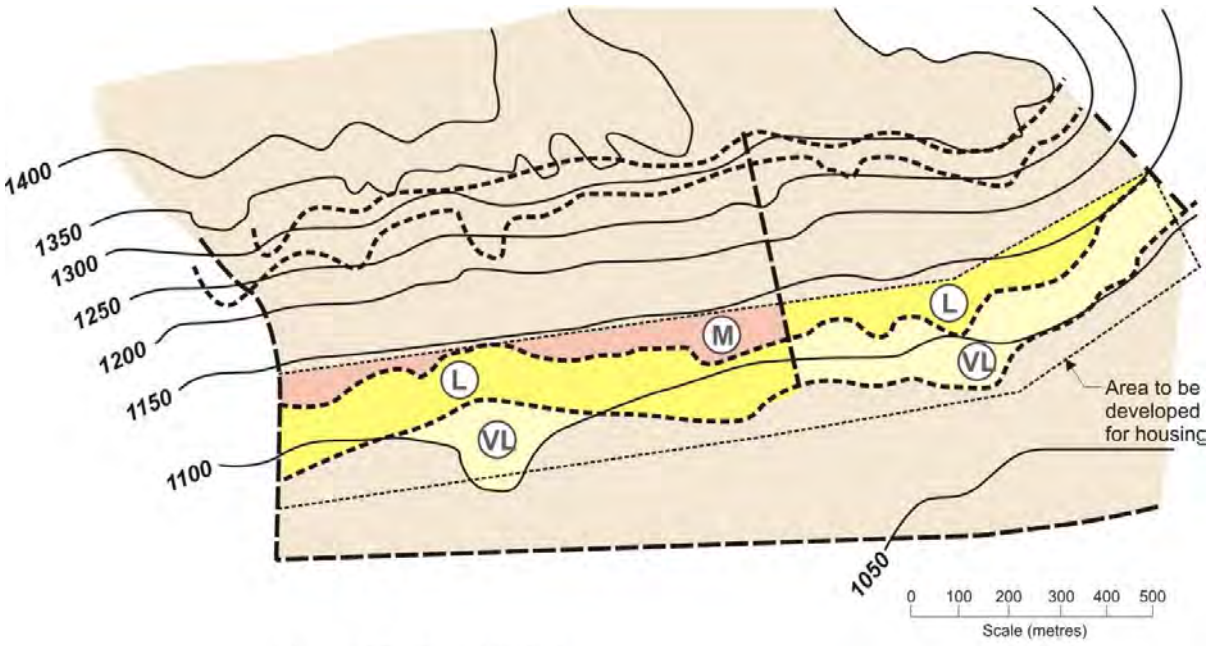

Figure 2C Rockfall Risk

LEGEND

Mapping Area	Landslide Classification	Landslide Susceptibility (1)	Landslide Hazard (2)	Landslide Risk for Life Loss (3)
C1	Rock falls from cliff	High	High	Negligible (4)
C2	Rock falls from cliff	High	Moderate	Negligible (4)
S1	Rock fall travel path	Moderate	Moderate	Moderate (5)
S2	Rock fall travel path	Moderate	Low	Low (5)
M1	Rock fall deposition zone	Low	Low	Low (5)
M2	Rock fall deposition area	Low	Very Low	Very low (5)
F1	Area above cliff	Not susceptible	No hazard	No risk
F2	Area beyond rock fall deposition zone	Negligible	Negligible	Negligible

Notes

(1) Likelihood that rock falls will reach the area if they occur.

(2) The number of rock falls per annum/ km of cliff which will reach this area. The frequency of rock falls is an order of magnitude lower for areas, C2, S2 and M2 than for C1, S1 and M1.

(3) Accounting for the landslide hazard and the persons within the area.

(4) Because there are no elements at risk.

(5) Within the area to be developed for housing, otherwise negligible.

(6) H=high; M=moderate; L=low; VL=very low; N=negligible.

Figure CA1 Example of landslide zoning for rock fall

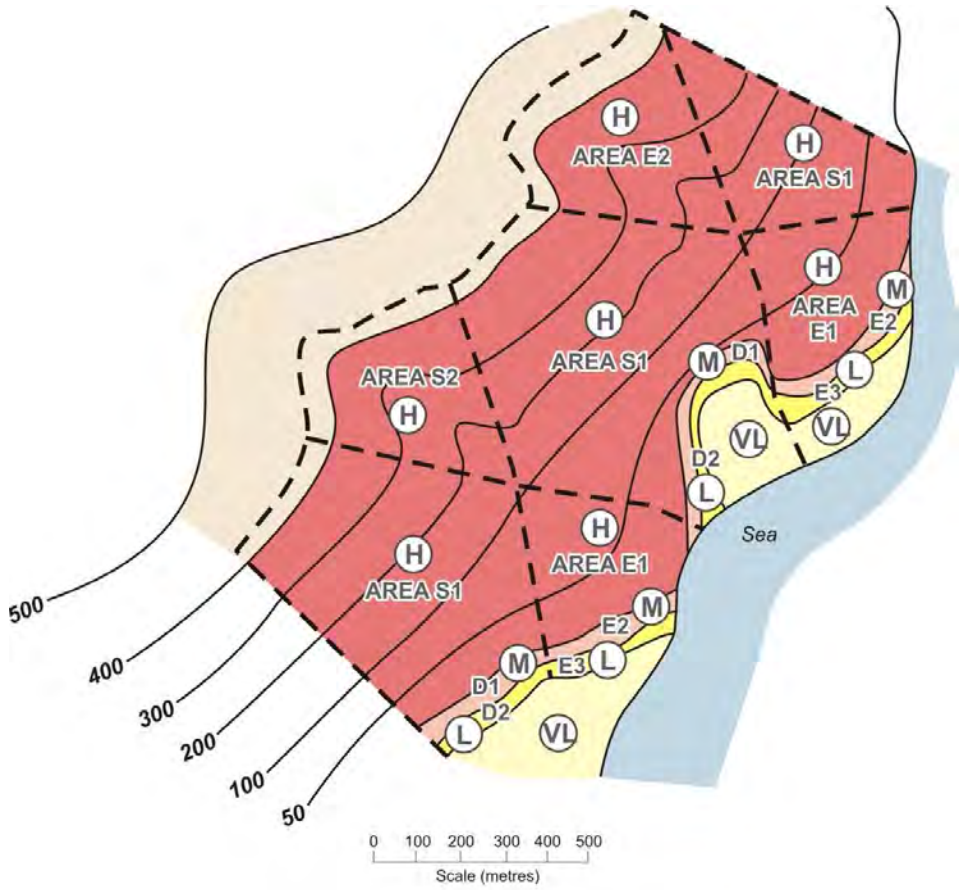

Figure 3A Small Slide Susceptibility

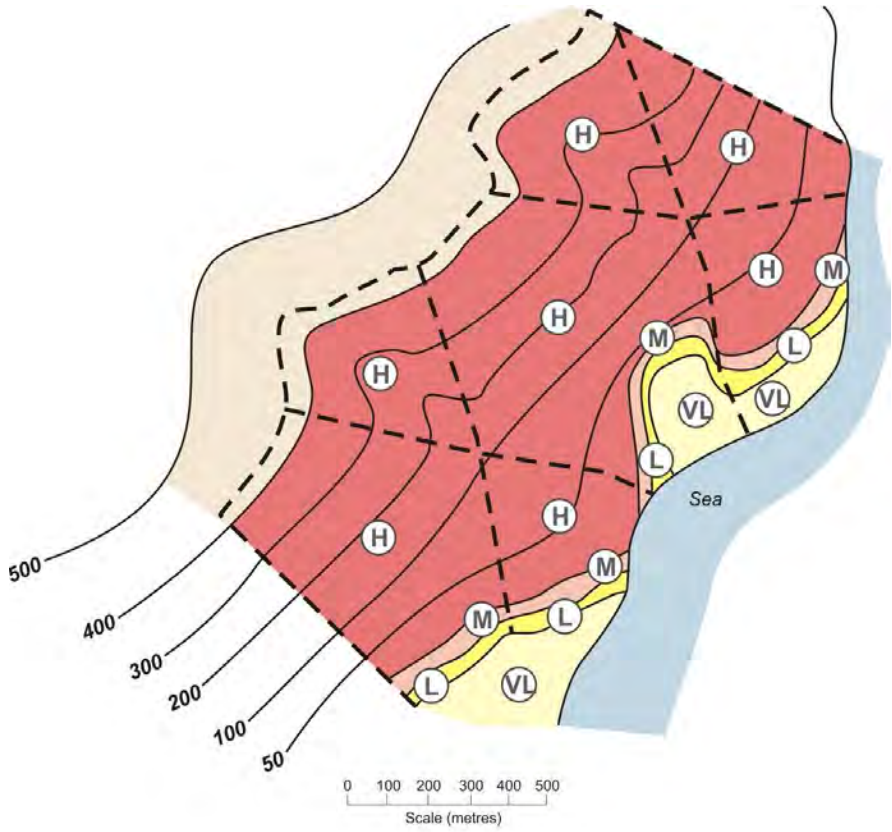

Figure 3B Small Slide Hazard

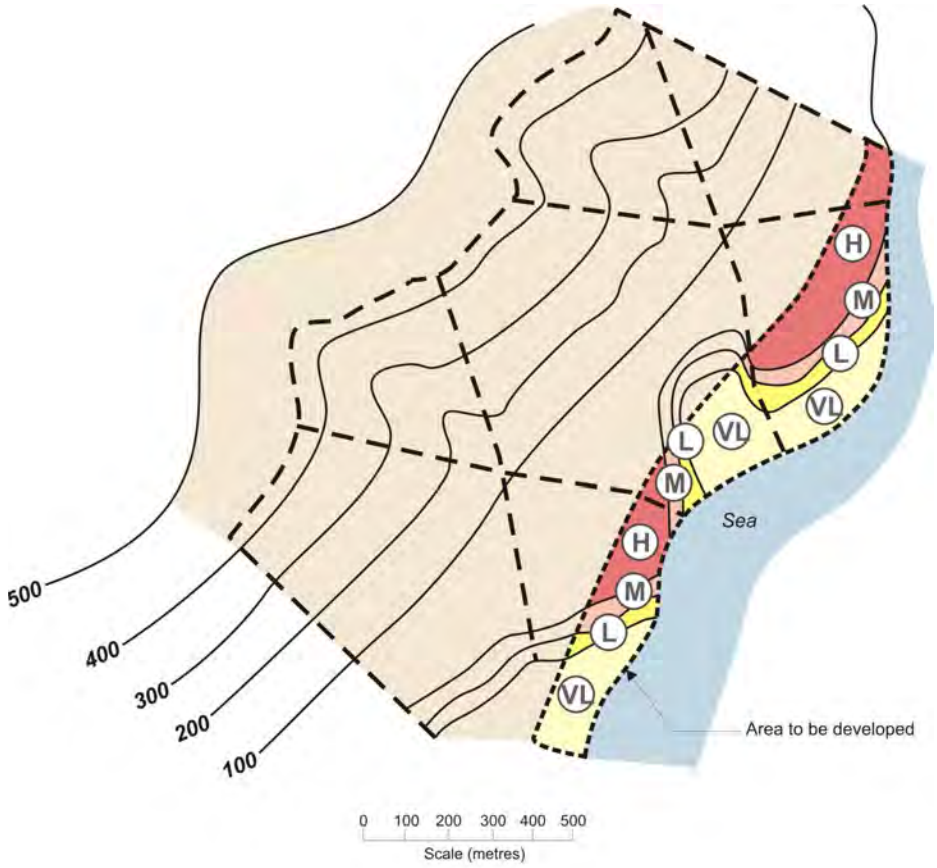

Figure 3C Small Slide Risk

LEGEND

Mapping Area	Landslide Classification	Landslide Susceptibility (1)	Landslide Hazard (2)	Landslide Risk for Life Loss (3)
S1	Rapid earth slides and debris flows up to 200m ^{3}	High	High	Negligible (4)
S2	Rapid earth slides and debris flows up to 2000m ^{3}	Moderate	Moderate	Negligible (4)
D1	Debris flow deposition areas	Moderate	Moderate	Moderate (5)
D2	Debris flow deposition areas	Low	Low	Low (5)
E1	Debris flow deposition areas-fan deposits	Moderate	Moderate	High (5)
E2	Debris flow deposition areas-fan deposits	Low	Low	Moderate (5)
E3	Debris flow deposition areas-fan deposits	Very low	Very low	Low (5)
F	Outside area affected by landsliding	Very low	Very low to negligible	Low to Very low (5)

Notes
(1) Number of small slides per square km
(2) Number of small slides per square km/annum
(3) Accounting for the landslide hazard and the persons within the area.
(4) Because there are no elements at risk.
(5) Within the area to be developed for housing, otherwise negligible
(6) H=high; M=moderate; L=low; VL=very low; N=negligible.

Figure CA2: Example of landslide mapping for small landslides.

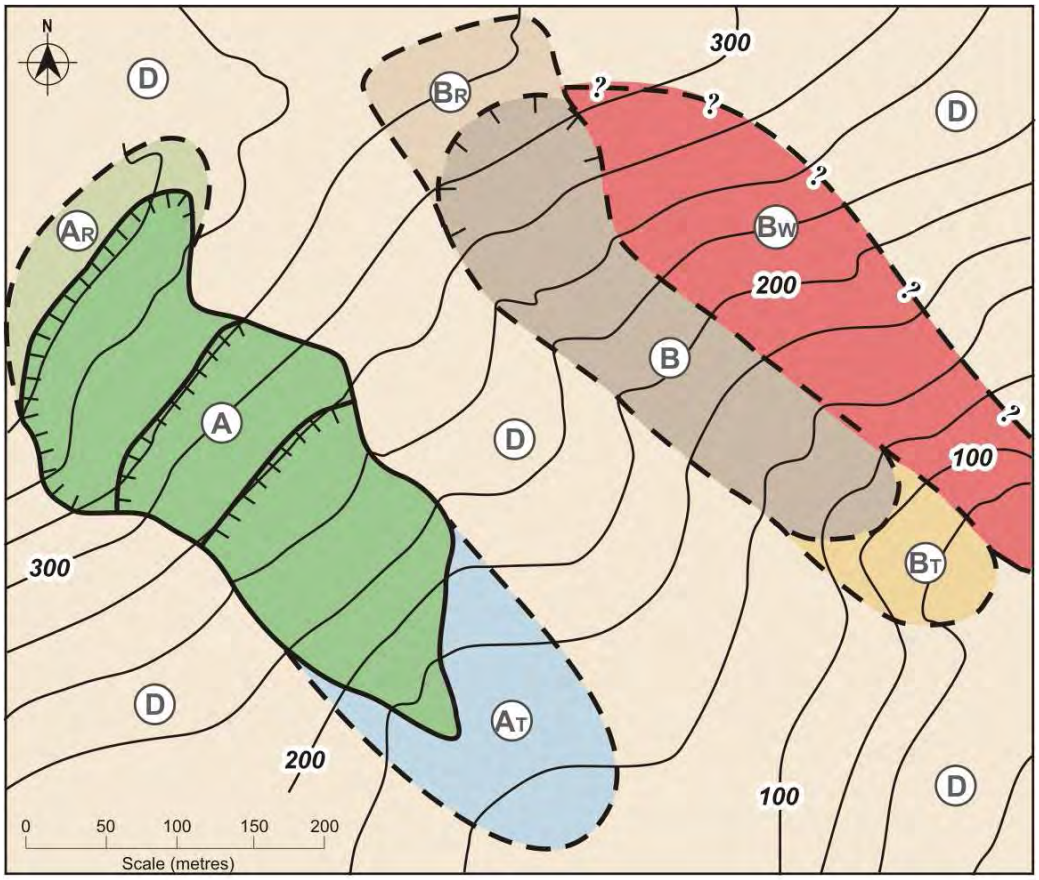

Figure 4 Large Slide

LEGEND

Mapping Area	Landslide Classification	Landslide Susceptibility (1)	Landslide Hazard (2)	Landslide Risk for Property Loss (3),(4)
A	Active very slow earth slide	High	Very high	Very high
A_T	Slope onto which 'A' may travel	Moderate	High	High
A_R	Slope into which 'A' may retrogress	Moderate	Moderate	Moderate
B	Inactive earth slide	Moderate	High	High
B_T	Slope onto which 'B' may travel	Low	Moderate	Moderate
B_R	Slope into which 'B' may retrogress	Low	Low	Low
B_W	Slope into which 'B' may widen	Low	Low	Low
D	Slopes with no geomorphologic characteristics of landsliding	Not susceptible	Very low	Very low

Notes (1) Likelihood large landsides may occur in this area given the topography, geology and geomorphology
(2) Annual probability of active sliding
(3) Accounting for the landslide hazard and the persons within the area. It is assumed that the whole area is available for development
(4) Life loss risk is very low for all areas because of the very low slide velocity

Figure CA3: Example of landslide mapping for large landsliding.

PRACTICE NOTE GUIDELINES FOR LANDSLIDE RISK MANAGEMENT 2007

Australian Geomechanics Society Landslide Taskforce, Landslide Practice Note Working Group

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PART A: BACKGROUND

1 INTRODUCTION

1.1 PREAMBLE

Slope instability occurs in many parts of urban and rural Australia and often impacts on housing, roads, railways and other development. This has been recognised by many local government authorities, and others, and has led to the requirement by many local government councils for stability assessments prior to allowing building development.

In 2000, the Australian Geomechanics Society (AGS) published "Landslide Risk Management Concepts and Guidelines" (AGS 2000). Since then there have been many published papers and discussion which have progressed Landslide Risk Management (LRM) in particular and risk management in general. As a consequence, AGS considered it appropriate to develop more comprehensive guidelines for practitioners and regulators involved in LRM.

This Practice Note Guidelines for Landslide Risk Management (the Practice Note) and its Commentary (AGS 2007d) are one part of a series of three guidelines related to LRM that have been prepared by AGS with funding under the National Disaster Mitigation Programme (NDMP). That programme has been introduced by the Australian Government to fund disaster mitigation, addressing hazards such as flooding, bushfires and landslides.

The associated guidelines which should be read in conjunction with the Practice Note are:-

- AGS (2007a) *"Guideline for Landslide Susceptibility, Hazard and Risk Zoning for Land Use Planning"*.
- AGS (2007e) *"Australian GeoGuides for Slope Management and Maintenance"*.

1.2 PURPOSE

The purpose of this Practice Note is to:

1. Review the Australian Geomechanics Society (AGS) Landslide Risk Management Concepts and Guidelines (AGS 2000) in the light of usage since publication and update accordingly and in addition, to take the opportunity to establish a formal revision process/documentation. Accordingly, a Revision Table is included in the Practice Note.
2. Provide guidance and recommendations on tolerable risk criteria, minimum reporting standards and assessment criteria/options to Local Government and Government bodies who as the regulator, receive Landslide Risk Management (LRM) reports and decide on levels of Tolerable Risk.
3. Provide guidance of a technical nature in relation to the processes and tasks undertaken by geotechnical practitioners who prepare LRM reports including appropriate methods and techniques. The Practice Note is a statement of what constitutes good practice by a competent practitioner for LRM, including defensible and up to date methodologies.
4. Provide guidance on the quality of assessment and reporting, including the outcomes to be achieved and how they are to be achieved. It sets out the functions and responsibilities of the professional carrying out the assessment.
5. Be a reference document for legislative purposes, which has been subject to nation-wide peer review.

1.3 SCOPE

This Practice Note supersedes AGS (2000) as the guideline for good practice and is accompanied by a Commentary (AGS 2007d) which discusses various aspects and gives appropriate references, and which should be read in conjunction with this Practice Note.

AGS (2000) contains much useful and relevant commentary which can (and should) be read in conjunction with the Practice Note. It is not the intention of the Practice Note to supersede this valuable commentary, rather to complement it. AGS (2000) should be regarded as "companion literature". Unless specifically discussed or revised in the Practice Note, the Working Group considers the commentary, examples and references provided in AGS (2000) to constitute appropriate background for the use of the Practice Note.

The emphasis of the Practice Note is on residential subdivision and development, particularly when considering the requirements for assessment on a lot-by-lot basis for either existing or proposed development.

The recommendations are however applicable to all classes of urban and rural building development or the environment.

The risk analysis principles could be adopted for short term risks associated with trenches or excavations during construction projects and for quarries and open cut mines. For such cases, risk tolerance criteria are controlled by occupational health and safety requirements and are not covered here.

The Practice Note can be applied to roads and railways. However, special consideration has to be given to the number of users, their temporal spatial probability and the summation of the risk along the route. This is discussed further in the Commentary.

1.4 CONVENTIONS USED

The Practice Note includes imperative verbs, such as 'establish', 'use', 'identify' and so on. These are to be understood as meaning; *"AGS recommends that you establish…"*, or *"…that you use…."* or *"…that you identify…..."* and so on as the case may be. This form of expression has been used to avoid unnecessary repetition of wording in the sense of 'plain English'.

Paragraphs presented in **bold type** constitute the guideline statement and subsequent sub paragraphs provide discussion of the guideline topic. Further discussion is provided in the Commentary.

In the following, use of the word 'landslide' implies both existing (or known landslides) and potential landslides which a practitioner might reasonably predict based on the relevant geology, geometry and slope forming processes. Such potential landslides may be of varying likelihood of occurrence. 'Landslide' also includes 'landslip' (as used in Victorian legislation), 'slump' and the various landslide forms (see Appendix B).

1.5 STAKEHOLDERS

The various stakeholders who may be affected by landslide risk include:-

- The **landowner** who will frequently be the client in terms of a commission to prepare a LRM report for a site or a development proposal.
- The **occupier** who would most often also be the land owner.
- The **financier** who would often be a financial institution having an interest in the land and any development thereon.
- The **regulator** (Appendix A) who would have responsibility for setting risk acceptance criteria, administering planning controls and approving development proposals as being within the requirements of planning controls, or a policy.
- The **practitioner** (Appendix A) who would have the required expertise for and responsibility of preparing a LRM report and recommending suitable risk control measures, when needed, to achieve the risk acceptance criteria.
- The **design professional** (such as architect or structural engineer) who would be one of the advisors to the client with responsibility for integration of risk control measures recommended by the practitioner into the development scheme, where possible, within the design brief from the client.
- The **insurer** where appropriate may have an interest in providing insurance cover against nominated insurable risks.

Although there is no section in the Practice Note dealing with the Client, clearly the Client is an essential stakeholder in relation to the practitioner. The Client will be relying on unbiased, sound technical advice from the practitioner as to the risk that a development proposal poses to the client and /or his interests. It will be the responsibility of the client to accept the risks involved, subject to the approvals of the regulator.

2 RISK TERMINOLOGY

The framework for the LRM process, as shown in Figure 1 in a simplified flow chart form, should be adopted.

Adopt the recommended terminology for ease of communication and clarity as defined in Appendix A.

As with most areas of expertise, there is a technical jargon associated with LRM. Specialist terminology is used to convey succinct ideas or facts. This cannot be avoided and by necessity is of a technical nature. The relevant terminology is defined in Appendix A. The lay reader is also referred to the Commentary for further discussion and to the GeoGuides (AGS 2007e).

This Practice Note, and the companion AGS guidelines (AGS 2007a, 2007e), use the term 'landslide' rather than 'landslip' or 'slump' or similar, to cover a wide range of failure mechanisms in soil, rock (as discussed in Appendix B) and man made structures such as retaining walls, as implied by the definition in Appendix A.

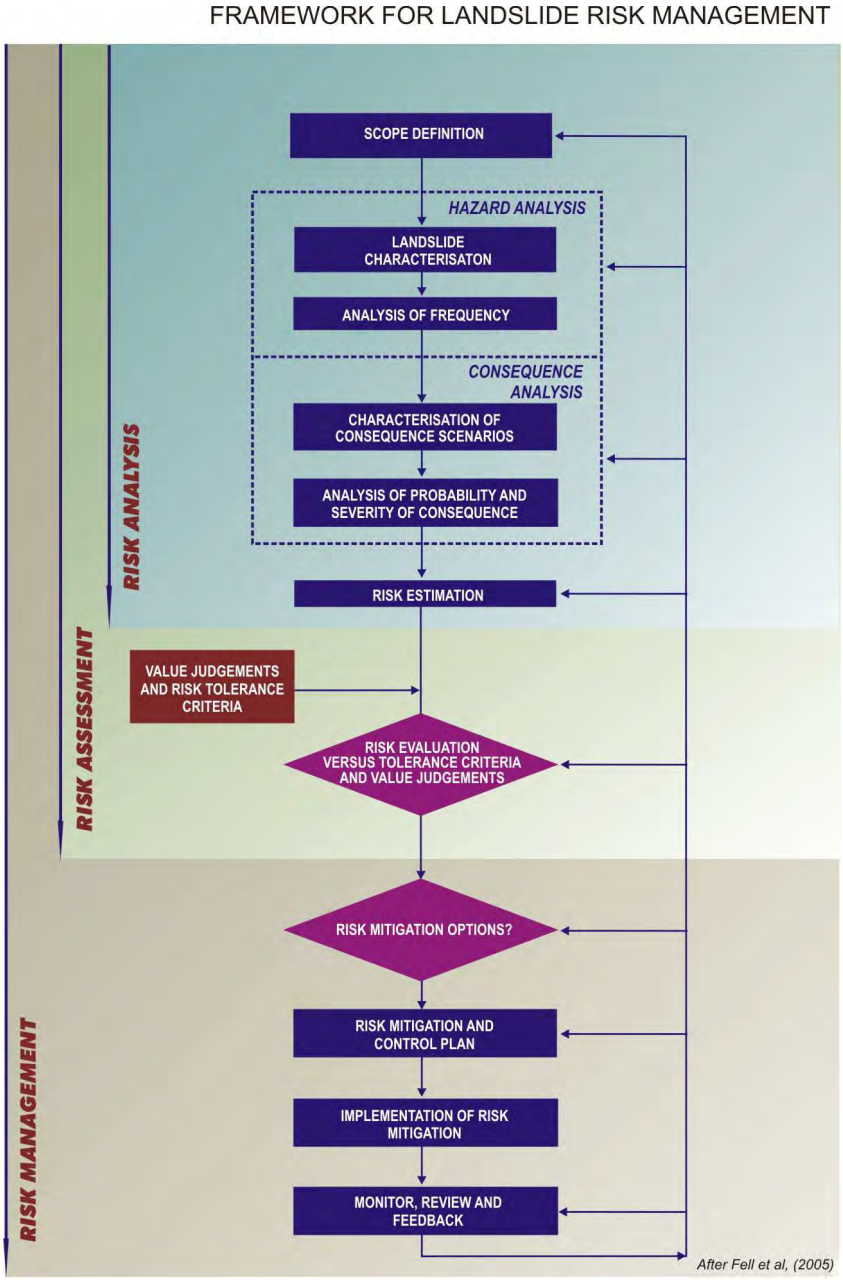


Figure 1.

The Framework for LRM presented in Figure 1 is similar to the flow chart in AGS (2000). However, it has been simplified in presentation and has been amended slightly from AGS (2000) to reflect the inclusion of Frequency Analysis as part of Hazard Analysis (in accordance with the abovementioned definition of hazard and as defined in AGS 2000).

Definitions for associated terminology have also been included in Appendix A together with an explanation of Landslide Risk as presented in AGS Australian GeoGuide LR7.

PART B GUIDELINES FOR REGULATORS

3 GUIDELINES FOR REGULATORS

3.1 BACKGROUND

The term landslide denotes *"the movement of a mass of rock, debris or earth down a slope"*. The phenomena described as landslides are not limited to either "land" or to "sliding" and usage of the word has implied a much more extensive meaning than its component parts suggest. The rates of movement cover the full range from very rapid to extremely

slow. The size, similarly, can vary enormously. The combination of type of landslide, size and rate of movement can determine the destructive power, and hence potential consequences of the landslide in terms of damage to property, loss of life, economic costs and impact on the environment. Subsidence, as a mechanism, is excluded from consideration, though it may be similar in consequence and appear to be of a similar form. Appendix B presents a summary of the terminology used to classify and describe landslides.

Landslides can impact on human development and activity as well as natural areas / features. It is the potential impact on human development which becomes of concern to the planners, regulators and disaster management authorities. Landslides can be just one of a number of threats which have to be considered, others being for example flooding, bush fires, and seismicity.

Examples of where landsliding is potentially an issue include:-

a) Where there is a history of landsliding.
b) Where there is no history of sliding but the topography dictates sliding may occur.
c) When there is no history of landslides but geological and geo-morphological conditions are such that sliding is possible.
d) Where there are constructed features which, if they fail, may travel rapidly.
e) Forestry works and agricultural land clearing which can lead to landslides causing damage to the environment.

Specific examples of the above are given in the AGS Guidelines for Landslide Susceptibility, Hazard and Risk Zoning for Land Use Planning (AGS 2007a). AGS (2007a) also provides detailed guidance to the regulator in relation to landslide zoning for planning purposes.

3.2 RELEVANCE TO APPROVALS PROCESS

Details of the approvals process may vary in detail from state to state. It is understood that in all States and Territories of Australia, the regulator has a statutory responsibility to consider the impact of a number of hazards, including landslides, on potential development of land as a 'duty of care' exercise. The regulator is usually the local government, but may be a State Government department or body. The actual mechanism and regulatory context for dealing with planning controls, building controls and approval process varies from state to state. However, the outcome should be that areas having a landslide risk are properly considered in relation to land use and development proposals.

In order to develop planning controls and building regulations, local government (or other regulators) must ensure that it has the statutory means to:

a) Through a planning scheme and using the principles in AGS (2007a), identify the areas that are susceptible to or at risk from landslides.
b) Require planning and/or building approvals for all land use and development within the areas zoned as susceptible to landslides.
c) Ensure there is a proper process for assessment in relation to existing and proposed development, including the requirement for completion of LRM reports in accordance with this Practice Note.
d) Provide appropriate risk tolerance criteria for loss of life and property so that there is a means to determine whether it is appropriate for development to occur or the required land use to proceed.
e) Apply, if necessary, consent conditions on the land use and/or development approval, including conditions requiring maintenance that will appropriately manage the landslide risk for that use and/or development.

It can be seen from the above that zoning in accordance with AGS (2007a) becomes the 'initiator' under the planning scheme and building approvals process to determine whether LRM controls are required and whether more detailed LRM consideration is required.

3.3 POLICY REQUIREMENTS

The regulator should have a specific policy which sets out the requirements for LRM assessments as part of the development application documentation and process.

The need for such a policy should be determined by zoning studies in accordance with AGS (2007a). Essential components of such a policy will include:

3.3.1 When a LRM assessment is required. This may be related to a Susceptibility or Hazard Zoning Study or some other plan or criteria defining areas or types of development included or excluded.

3.3.2 The necessary competencies of practitioners undertaking LRM assessments. **Such practitioners should be required to have LRM as a core competency.** A method of demonstrating core competency in LRM is being addressed by the Australian Geomechanics Society and Engineers Australia as a specific area of practice within the National Professional Engineers Register (NPER). Some regulators may choose to define another method of demonstrating competency.

3.3.3 The basic requirements of LRM reports which should be based on compliance with the requirements of this Practice Note.

3.3.4 Require assessment of risk to life as part of a LRM report which, as discussed below, should be completed in a quantitative basis.

3.3.5 Suggest adoption of the preferred qualitative terminology given in Appendix C of this Practice Note for risk to property so that the regulator can become accustomed to the terminology adopted and implications arising there from. If alternative terminology is to be adopted for LRM, the regulator should only accept non standard schemes where the terms have been clearly defined, the terms have been explained in relation to the preferred terminology and it can be reasonably demonstrated by the practitioner that the alternative is better suited to the particular circumstances of the assessment.

3.3.6 Provide the required forms to control the submissions and approvals process.

3.3.7 Specify the criteria under which a decision will be made for both the scope/nature of developments and the appropriate tolerable risk criteria being adopted.

3.4 PROCESSING REQUIREMENTS

3.4.1 The regulator should use a number of forms to provide appropriate QA process control and documentation records of the submitted LRM assessment and subsequent compliance with the approval conditions.

The forms need to be appropriate to each stage of the development application, approval, detailed design, construction and maintenance of the development. Essential contents will include:

1. Name and qualification of the practitioner responsible for the LRM assessment.
2. A list of supporting documents including the architectural, civil design and structural engineering design drawings, as appropriate, to fully define the extent and scope of the proposed development.
3. A statement of compliance with the requirements of this Practice Note. In some cases the statements will be required to include details of how compliance is achieved.
4. Document reference details (date, reference number, report title) for the relevant LRM assessment submission.

A suite of example forms is given in Appendix D for modification by each regulator to be consistent with their policy. The aim of the forms is to provide appropriate documentary control of the stages required through to completion of a development.

Processing of the application by the regulator should include, amongst other aspects, confirmation that the submission is in accordance with policy requirements, and that the nature of the development complies with the requirements of the LRM assessment.

Where the regulator has specific concerns in relation to the adequacy of a submission, or the conclusions reached, or if required by a Hazard Zoning study, the submission may be subject to peer review or independent specialist advice to the regulator as an audit process or as part of mediation for an agreement. The reviewer should independently review the LRM assessment report in terms of adequacy of compliance with this Practice Note and the reasonableness of the assessment conclusions and risk control measures specified. The review should also consider the specific development proposals as defined by the design drawings.

3.4.2 Where the recommendations of this Practice Note have not been followed, then the regulator should <u>either</u> reject the application <u>or</u> require provision of further information before approval is given.

It is anticipated that the forms in Appendix D will, in part, constitute a checking template for the regulator. Further discussion is given in the Commentary.

3.4.3 Where construction is completed but all aspects of the Approval Conditions have not been completed with appropriate documentation or justification, then the final approval by the regulator should not be given until sufficient information is provided to demonstrate compliance.

It is anticipated that completion of Forms F and G with suitable annotation would help identify where non compliance exists. If the regulator does not have a strong procedure for enforcement of, or auditing of, compliance with consent conditions, then there may be subsequent liability issues for the regulator if non-compliance becomes an issue at a later date.

3.5 ESTABLISHMENT OF TOLERABLE RISK CRITERIA

The regulator is responsible for setting the Tolerable Risk Criteria for loss of life and property loss. Discussion of the considerations and world practice are given in the Commentary together with the AGS recommendation for consideration by the regulator.

3.6 LANDSLIDE INVENTORY

The local Council, or other regulator, should maintain an inventory of past landslide events as discussed in AGS (2007a) and make this information available to all practitioners.

3.7 ROLE AND RESPONSIBILITY OF THE PRACTITIONER

The practitioner has the role of providing technical input in relation to the specialized aspect of LRM. Such input will be subject to the specific requirements of any policy instituted by the regulator. The regulator may require specific levels of qualification and competence of practitioners providing the regulator with advice in relation to compliance with the risk acceptance criteria.

The qualifications and experience of suitable practitioners are as discussed in Paragraph 3.3.2.

It is the responsibility of the practitioner to carry out LRM assessments in accordance with this Practice Note and within the requirements of his/her professional Code of Ethics. The practitioner must provide advice to the client and regulator in an unbiased manner.

PART C GUIDELINES FOR PRACTITIONERS

4 SCOPE DEFINITION

Establish the purpose and scope of the risk assessment study.

The practitioner needs to take into account the initial brief from the client and the requirements of the regulator. Usually these will be sufficient for the practitioner to decide on the appropriate scope and level of the study which should then be advised to the client as a "reverse brief". In the LRM process, the practitioner will have a role to advise the client as to how the landslide risk can be reduced, avoided or otherwise controlled including options or alternatives.

5 HAZARD ANALYSIS

5.1 DATA GATHERING / DESK STUDY

Assemble relevant data and record their sources.

Often there is a body of local experience which becomes invaluable for the assessment process. Such experience includes published papers, geological maps, aerial photographs and general studies such as Hazard Zoning studies completed for the regulator. Local experience can include previous assessments and knowledge of problematic areas which should be available from the regulator's landslide inventory. Practitioners new to an area should discuss with locals their knowledge and experience.

Preferred data for the assessment will include site specific data, such as survey plan showing existing features, spot heights, contours and location and nature of services. Initial design proposals are required so that the risk assessment may be completed and appropriate risk control measures specified. (It is a necessary requirement in the performance of a risk assessment for there to be an element at risk, hence the need for a preliminary design or for an assumed development which should be defined in the LRM report).

5.2 FIELD INVESTIGATION REQUIREMENTS

5.2.1 Complete investigations sufficient to establish a geotechnical model, identify geomorphic processes and associated process rates.

The investigation may involve a number of methods and may be completed in stages, with each stage sufficiently detailed to provide a model appropriate to the level of study being undertaken. Further discussion is given in the Commentary.

5.2.2 Inspect the site and surrounds including field mapping of the geomorphic features.

This must be completed by the practitioner for every assessment. The field mapping is to document the observations and to enable formulation of the geotechnical model.

Mapping should be completed to scale on an available survey plan and must include the surrounds (above, below and adjacent) to the site as appropriate to define the landslides and the geotechnical model.

Where a survey plan is not available, then simple survey using hand held tape and clinometer methods should be used to draw up a plan, to scale, using standard mapping symbols and terminology to represent the geological and geomorphic features. (Examples of geological and geomorphic mapping symbols are presented in Appendix E.)

5.2.3 Determine the subsurface profile from exposures or subsurface investigation such as by boreholes and/or test pits.

This is necessary as part of the geotechnical model. Often exposures or knowledge from a nearby site may be sufficient.

Where such data is not available or not appropriate, subsurface investigation is required to enable formulation of the model and must include determination of the depth to rock or to below the depth of potential failure surfaces if this is greater.

Where pre-existing landslides are expected or suspected, then where practical, use should be made of either test pits (to enable sufficient sample/material to be seen for identification of shear planes or other relevant structure) or boreholes (with appropriate sampling and installation of inclinometers for monitoring for evidence of movements).

5.2.4 Assess likely groundwater levels and responses to trigger rainfall events.

Consideration of the likely ground water response will enable assessment of response to rainfall trigger events. Use may be made of experience in the area, as observation of site specific data will frequently require prolonged periods of monitoring to enable formulation of a groundwater response model taking into account the statistical significance of rainfall events during the monitoring period. For relatively straightforward projects with low to moderate risks, a basic qualitative estimate of groundwater levels and responses may be appropriate when there is a lack of data. However, other more complicated projects, or where risk levels are higher, will require a greater level of understanding of groundwater levels and responses.

For more detailed analysis, particularly of possible stabilisation measures by subsurface drainage, observation of groundwater levels and their response to significant rainfall events is advisable to enable subsequent assessment of the effectiveness of subsurface drainage measures. Careful consideration must be given to the location of piezometers and their construction details.

5.2.5 Prepare a cross section drawing (to scale) through selected parts of the site to demonstrate the geotechnical model of site conditions and on which landslides may be identified.

The resulting geotechnical model should integrate all the data obtained from the mapping and investigations.

The section should demonstrate the likely variation in subsurface conditions on the section including groundwater levels. On large or complex sites, more than one section may be required. All sections are to be drawn to natural scale. If exaggerated vertical scale is required for clarity, then a summary section at natural scale should also be included.

Adequate investigation has been completed when the geotechnical model is sufficiently defined to understand the slope forming processes relevant to the site and surrounds, the form and extent of landslides, likely triggers for the landslides and process rates associated with the landslides. The report should include explanation of uncertainties associated with the model.

5.2.6 Take into account slope forming process rates associated with the geotechnical model and landslides.

An understanding of the slope forming process relevant to the landslides and associated process rate is fundamental for evaluation of likelihood.

5.2.7 Identify landslides types/locations appropriate to the geotechnical model based on local experience and general experience in similar circumstances.

The types of landslides will be dependent on the geotechnical model and to some extent on the nature of existing and/or proposed development. The expected characteristics of the landslides (such as the size, type of material involved, rate of failure and travel distance) need to be assessed. The range of landslide sizes can vary from the very large landslides, which may encompass a whole hillside or region, to a small site specific landslide. The model should include assessment of the fundamental cause as well as likely trigger events. The report must document the hazard assessment which will include the estimated likelihood for each landslide type.

The hazard assessment must address areas upslope from the site, downslope from the site and across the slope adjacent to the site where these may affect the site.

5.2.8 If required, further detailed investigations should be completed to better define the model, the landslides, the triggers, the frequency (likelihood) or design of stabilisation measures to control the risk.

Such additional investigation is most likely to be required on sites where the risk is judged to be intolerable and/or where further input is required to resolve uncertainties**.**

5.3 LANDSLIDE CHARACTERISATION

Characterise the landslides based on the desk study and field investigations. Use Appendix B for terminology to describe the landslides.

The characterization should include the classification, volume, location and potential travel distance of all landslides which may occur on the site or travel on to or regress into the site.

5.4 FREQUENCY ANALYSIS

5.4.1 Techniques for Frequency Analysis

a) Adopt a frequency analysis technique appropriate to the level of study and complexity of the geotechnical model and slope forming process.

The appropriate technique may change with different levels of study, or for different stages of a project, or with the project brief and available budget. For example, techniques and level of detail may be different for:

- Subdivision stage LRM
- Residential dwellings LRM
- Infrastructure and utilities LRM
- Natural resource and environmental LRM

It is essential that the assessment be based on the best estimates available and that expert judgment be applied to answers so derived.

It is essential to understand the slope forming process before moving on to the frequency assessment.

The assessment must document the reasoning in a transparent manner.

b) Gather local and historical knowledge of slope performance and landslide characteristics and occurrence. The resulting inventory enables assessment of frequency.

This technique is a basic starting point and essential for all studies. However, a common shortcoming is that "local knowledge" is often poorly documented and difficult to collate and assess. Local Council records and experience should be accessed via a landslide inventory made available to practitioners. Analysis of aerial photographs and possibly maps may provide additional data.

Documentation of events by local newspapers may also be a useful source, depending on the quality of reporting and what events are judged at the time to be of local interest.

c) Empirical methods based on slope instability ranking systems.

These methods are often devised by expert groups to assist with prioritisation of treatment measures.

The methods are usually based on subjective judgment of the relative importance of contributory factors. The results obtained may be difficult to calibrate or it may be difficult to obtain consistent results and hence may be inaccurate. The methods do not usually allow assessment of frequencies.

d) Relationship to geomorphology and geology.

This method is based on the principle put forward by Varnes (1984) that the past and present are guides to the future. Hence, this leads to the assumptions that:

1. it is likely that landsliding will occur where it has occurred in the past and
2. landslides are likely to occur in similar geological, geomorphologic and hydrological conditions as they have in the past.

The use of historic records and landslide inventories of past performance are likely to be required to enable frequency values to be assessed. However, it should be noted that landslide frequency, size and intensity may differ from past performance where altered trigger events are introduced, e.g. due to man made changes or climate change. In addition, other factors (such as periodic or seasonal wetting and drying cycles resulting in soil creep, cyclic degradation and strength loss) can also result in failures after relatively "normal" rainfall events.

The use of other slope attribute factors (such as slope angle, slope drainage, slope age, presence of groundwater, slope orientation) may assist with assessment of particular slopes relative to the broad geomorphic model.

e) Prepare a statistical evaluation of rainfall and relate to history of landsliding and population of slopes within area of similar slope type.

Rainfall, and the consequent effect on groundwater levels, is widely recognized as a main trigger event for landsliding. Therefore, indicative frequency values may be related to the frequency of rainfall provided there is sufficient historical data to enable the relationship between rainfall frequency, antecedent rainfall and landslide events to be correlated.

A similar approach may be adopted for other forms of triggering events such as earthquakes.

f) Consider use of simulation models and Monte Carlo sampling analyses to derive a frequency of failure.

These methods (including simulation modelling of groundwater response to rainfall, evapotranspiration, and ground water flows) can be difficult to carry out reliably. Picarelli *et al.* (2005) outline some of the difficulties with these methods. Simulation modelling is most likely to be applicable only to medium to large, deep seated landslides where extensive monitoring data is available to enable calibration over a range of rainfall and piezometric responses.

Experience shows that full probabilistic analysis is difficult and time consuming (Robin Fell personal comm.). Therefore this method should only be carried out for special cases where sufficient data is available to enable the results to be meaningful.

g) Use knowledge based expert judgment or 'degree of belief' method which combines experience, expertise and general principles.

For most assessments this may be the only suitable option to estimate frequency due to the lack of objective data. The assessment relies to a large degree on subjective assessment of available data where other more rigorous methods are not available or viable. The method still requires some degree of research to obtain relevant data and an understanding

of the geological model to qualify the judgment of likelihood. Nonetheless, the approach requires the proposition of various possible scenarios followed by the systematic testing and elimination of options as a result of investigation, discussion and judgment to develop an estimate of frequency (Lee and Jones 2004).

The result is conditioned by the 'degree of belief' of the practitioner. Typically, the resulting accuracy for a frequency assessment and, perhaps, a consequence assessment could vary from half an order of magnitude at best, to one order of magnitude or perhaps two orders of magnitude. As a result, the risk assessment should clearly display its sensitivity to the input parameters and, unless justified by further investigations, a conservative outcome should be adopted.

h) Where appropriate, use event trees to provide a structur

i) ed and auditable approach for the use of expert judgment and subjective probability assessment.

An event tree analysis uses a graphical construct to show the logical sequence of events or considerations that can be used to analyse the system leading to a particular outcome. It can be used for evaluation of probability of failure of a landslide, or consequence of failure, or risk. The logical sequence within the system is mapped as a branching network with conditional probabilities assigned to each branch of a node. The frequency of achieving a certain outcome is the product of the conditional probabilities leading to that outcome times the frequency of the initiating "trigger" such as rainfall.

i) Other methods.

The above may not be an exhaustive list but covers the principal methods/approaches. Specific circumstances of a particular area or project may enable other approaches or combinations of approaches to be used. Field techniques may develop to offer alternatives, for example remote sensing by satellite.

Further comment is given in the Commentary together with some guidance on different site investigation methods.

5.4.2 Estimation of Annual Probability (Frequency) ($P_{(H)}$) of Each Landslide

a) Use 'best estimates' for frequency but consider range / uncertainty / sensitivity.

Suitable methods are outlined in Section 5.2.

It is important not to infer greater accuracy than is reasonably possible. Evaluation of the sensitivity arising from uncertainty is part of the consideration.

A best estimate is to be derived for each landslide which is then applied to both risk to property and risk to life assessments. The estimate may be related to the size of the landslide and/or the expected amount of movement as part of the hazard assessment. The appropriate qualitative term is chosen from the estimated probability based on the frequency assessment. Note that the reverse, the adoption of a probability value from a qualitative term, should not be undertaken as it has been demonstrated that this results in a range of estimates of frequency several orders of magnitude apart depending on the practitioner.

b) Estimates of frequency may be derived by partitioning the problem to (Annual probability of trigger event) x (Probability of sliding given the trigger event) over the range of trigger events.

Landslides of the one 'type', but having varying possible scales (magnitude/travel distance/velocity etc.) need to be assessed separately. Each could well have a different frequency of occurrence. The landslide inventory of performance for an area will provide some basis for the assessment.

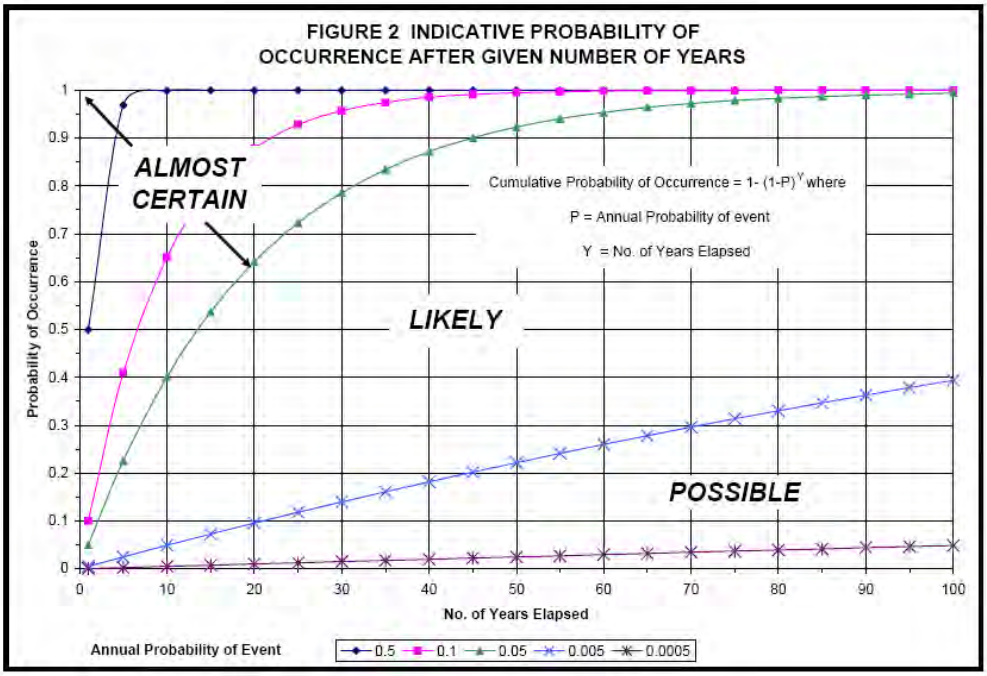
A trigger event for a particular locality (e.g. a certain intensity/duration or recurrence interval of rainfall) will not necessarily cause each potential landslide event in that locality to occur. There will be a finite probability (value) that the landslide under consideration may not be set off by the trigger event.

The frequency of landsliding should be assessed over the full range of the triggering events, and the total frequency carried forward in the risk analysis. In practice this process may be simplified to consider only the highest frequency triggering events. An example is presented in the Commentary.

c) Complete a review of the assessed frequency in relation to the implied cumulative frequency of the event occurring within the design life and known performance within the area.

This is a 'sanity check' on the result of the assessment. It is import to apply judgment or bias on the final outcome only, not on the input estimates.

Values of the cumulative probability are shown on Figure 2 for different annual probability values as a function of time over usual design life intervals. The resulting cumulative probabilities should be checked to confirm they are reasonable in relation to experience. The implications of the cumulative probability values shown in Figure 2 are discussed further in the Commentary.



5.4.3 Assess the Travel Distance and the Probability of Spatial Impact ($P_{(S:H)}$) of the Elements at Risk

When assessing risk arising from landsliding, it is important to be able to estimate the distance the slide mass will travel and its velocity. These factors determine the extent to which the landslide will affect property and persons downslope and the ability of persons to take evasive action.

The travel distance depends on:

- Slope characteristics
  - Height
  - Slope
  - Nature of material
- Mechanism of failure and type of movement such as
  - Slide, fall, topple etc.
  - Sliding, rolling, bouncing, flow
  - Strain weakening or not
  - Collapse in undrained loading (static liquefaction)
  - Influence of surface water and groundwater
  - Comminution of particles
- Characteristics of the downhill path
  - Gradient and gradient direction
  - Channelisation
  - The potential for depletion/accumulation
  - Vegetation

Information on travel distance from previous events on or near the site may be collected during the site inspection. Predictions of travel distance and travel direction should be based on the assessed mechanism of future events and site characteristics.

For rotational landslides which remain essentially intact, the method proposed by Khalili *et al* (1996) or experience with landslides in similar geological, topographic and climatic conditions can be used to estimate the displacement. Further discussion is given in the Commentary.

For slides which break up, and in some cases become flows, and slides from steep cuts, the travel distance is usually estimated from empirical methods, such as Hunter and Fell (2002) and Corominas (1996). These methods are only approximate, and the wide scatter of data on travel distance angles reflects the range of topographical, geological and climatic environments, different slide mechanisms and limited quality of data from which the methods are derived.

If the empirical methods are to be used for predictions of travel distance and the probability of spatial impact of the elements at risk, much judgement will be required and it is important to try to calibrate the methods with landslide

behaviour in the study area. It is often useful to allow for a range of travel distances in the calculation and express that range in probabilistic terms as discussed in the Commentary.

The annual probability of the landslide and probability of spatial impact may be considered together in qualitative terms as likelihood of impact on the element at risk being considered.

6 CONSEQUENCE ANALYSIS

6.1 ELEMENTS AT RISK

The elements at risk will include:

- Property, which may be subdivided into portions relative to the hazard being considered.
- People, who either live, work, or may spend some time in the area affected by landsliding.
- Services, such as water supply or drainage or electricity supply.
- Roads and communication facilities.
- Vehicles on roads, subdivided into categories (cars, trucks, buses).

These should be assessed and listed for each landslide hazard.

For some cases, other risks may also have to be considered. For example:

- Environmental, where the elements at risk are environmental (rather than man made), such as forests or water bodies.
- Social, where the consequences of the landslide may have an impact on social conditions, such as the cost of disruption to traffic where roads are affected.
- Political, where the consequences may not be acceptable in political terms.

6.2 TEMPORAL SPATIAL PROBABILITY ($P_{(T:S)}$)

When the elements at risk are mobile (e.g. persons on foot, in cars, buses and trains) or where there is varying occupancy of buildings (e.g. between night and day, week days and weekends, summer and winter), it is necessary to make allowance for the probability that persons (or a particular number of persons) will be in the area affected by the landslide. This is called the Temporal Spatial Probability**.**

For where the elements at risk are mobile it is proportion of a year (between 0 and 1.0) in which a person, car or bus will be below or on the landslide when it occurs. For occupancy of buildings it is a calculation of the proportion of a year (between 0 and 1.0) which the number of persons being considered occupy the building, or the area of the building likely to be impacted.

These calculations should allow for the possibility that the persons may have warning of trhe impending landslide and may evacuate the area. Each case should be considered by taking account of the details of the situation. Generally persons <u>on</u> a landslide are more likely to observe the initiation of movement and move off the slide, than those who are <u>below</u> a slide which falls or flows onto them unless the rates of movement are slow.

6.3 EVALUATION OF CONSEQUENCE TO PROPERTY

6.3.1 Estimate the extent of damage likely to property arising from each of the landslides.

This requires an understanding of the landslide characteristics and experience in assessing the likely impact on property. The consequences are often calculated using the vulnerability ($\mathbf{V}_{(Prop:S)}$) of the elements at risk to the landslide.

The factors which most affect vulnerability of property are:

- The volume of the slide in relation to the element at risk.
- The position of the element at risk, e.g. on the slide, or immediately downslope.
- The magnitude of slide displacement, and relative displacements within the slide (for elements sited on the slide).
- The rate of slide movement.

It should be noted that the vulnerability refers to the degree of damage (or damage value in absolute or relative terms) which is judged to be likely if the landslide does occur.

As discussed below, the assessment should be based on a quantitative estimate to enable clarification of the judgment which for a qualitative assessment may be subject to considerable interpretation.

6.3.2 Estimate the indicative cost of the damage.

This requires use of indicative costs of building and remedial works. Frequently, broad brush ‘guesstimates’ will suffice, but the ‘guesstimate values’ and basis should be documented. Some guidance is given in the Commentary. It should not be necessary to use a quantity surveyor to establish a more accurate estimate as usually the broad brush guesstimate will suffice for allocation of a consequence term in a qualitative scheme such as in Appendix C.

The indicative cost of damage is to be the Total Cost as this is the most relevant to the owner. Components to be considered comprise:-

- Direct costs related to reinstatement works for damaged portions of the property (structures and the land).
- Stabilization works required to render the site to an tolerable risk level for the landslide.
- Professional and approvals fees.
- Consequential costs (such as legal fees and alternative temporary accommodation).

It does not include additional stabilisation works to address other landslides which may affect the property.

6.3.3 Estimate the market value.

This may be achieved by reference to property sale values within the local area which will reflect the value of the land plus structures. The client is likely to have some knowledge of the local market values. Again, a broad-brush guesstimate should often suffice.

6.3.4 Consider the resulting Consequence classification, such as using Appendix C, and implied accuracy of the above estimates.

It is not expected that the assessor will be a quantity surveyor or have similar experience, but that sensible estimates, possibly as a range, can be made and documented. Statement of limits of accuracy or uncertainty are appropriate for sensitivity and appraisal analysis.

6.4 EVALUATION OF CONSEQUENCES TO PERSONS

The following factors influence the likelihood of deaths and injuries or vulnerability ($\mathbf{V}_{(D:T)}$) of persons who are impacted by a landslide:

- Volume of slide.
- Type of slide, mechanism of slide initiation and velocity of sliding.
- Depth of slide.
- Whether the landslide debris buries the person(s).
- Whether the person(s) are in the open or enclosed in a vehicle or building.
- Whether the vehicle or building collapses when impacted by debris.
- The type of collapse if the vehicle or building collapses.

Persons are very vulnerable in the event of complete or substantial burial by debris, or the collapse of a building. It should be noted that even small slides, and single boulders, can kill people.

Appendix F provides some indicative examples of vulnerability values. The Commentary provides some more detailed discussion.

7 RISK ESTIMATION

7.1 QUANTITATIVE RISK ESTIMATION

Quantitative risk estimation involves integration of the frequency analysis and the consequences.
For property, the risk can be calculated from:

$$\mathbf{R}_{(Prop)} = \mathbf{P}_{(H)} \times \mathbf{P}_{(S:H)} \times \mathbf{P}_{(T:S)} \times \mathbf{V}_{(Prop:S)} \times \mathbf{E} \qquad \textbf{(1)}$$

Where

$\mathbf{R}_{(Prop)}$ is the risk (annual loss of property value).
$\mathbf{P}_{(H)}$ is the annual probability of the landslide.
$\mathbf{P}_{(S:H)}$ is the probability of spatial impact by the landslide on the property, taking into account the travel distance and travel direction.
$\mathbf{P}_{(T:S)}$ is the temporal spatial probability. For houses and other buildings $\mathbf{P}_{(T:S)}$= 1.0. For Vehicles and other moving elements at risk1.0< $\mathbf{P}_{(T:S)}$ >0.
$\mathbf{V}_{(Prop:S)}$ is the vulnerability of the property to the spatial impact (proportion of property value lost).
$\mathbf{E}$ is the element at risk (e.g. the value or net present value of the property).

For loss of life, the individual risk can be calculated from:

$$\mathbf{R}_{(LoL)} = \mathbf{P}_{(H)} \times \mathbf{P}_{(S:H)} \times \mathbf{P}_{(T:S)} \times \mathbf{V}_{(D:T)} \qquad \textbf{(2)}$$

Where

$\mathbf{R}_{(LoL)}$ is the risk (annual probability of loss of life (death) of an individual).
$\mathbf{P}_{(H)}$ is the annual probability of the landslide.
$\mathbf{P}_{(S:H)}$ is the probability of spatial impact of the landslide impacting a building (location) taking into account the travel distance and travel direction given the event.
$\mathbf{P}_{(T:S)}$ is the temporal spatial probability (e.g. of the building or location being occupied by the individual) given the spatial impact and allowing for the possibility of evacuation given there is warning of the landslide occurrence.
$\mathbf{V}_{(D:T)}$ is the vulnerability of the individual (probability of loss of life of the individual given the impact).

A full risk analysis involves consideration of all landslide hazards for the site (e.g. large, deep seated landsliding, smaller slides, boulder falls, debris flows) and all the elements at risk.

For comparison with tolerable risk criteria, the individual risk from all the landslide hazards affecting the person most at risk, or the property, should be summed.

The assessment must clearly state whether it pertains to 'as existing' conditions or following implementation of recommended risk mitigation measures, thereby giving the 'residual risk'.

7.2 SEMI-QUANTITATIVE AND QUALITATIVE RISK ESTIMATION FOR RISK TO PROPERTY

When considering the risk to property, it may be useful to use qualitative terms to report the results of the analysis, rather than quantitative values. The risk calculation may be completed quantitatively or by the use of qualitative terms.

A semi quantitative analysis (where the likelihood is linked to an indicative probability) or a qualitative analysis may be used:

- As an initial screening process to identify hazards and risks which require more detailed consideration and analysis.
- When the level of risk does not justify the time and effort required for more detailed analysis.
- Where the possibility of obtaining numerical data is limited such that a quantitative analysis is unlikely to be meaningful or may be misleading.

Section 7.3 describes a suitable and preferred terminology.

7.3 RISK MATRIX FOR PROPERTY LOSS

a) Adopt a defined qualitative terminology for likelihood, consequence and risk.

Qualitative terminology is presented in Appendix C for property loss. The terminology has been developed from Appendix G in AGS (2000) taking into account the experience and comments as discussed in the Commentary.

For ease of use, the frequency estimate, expressed as an annualized probability and taking into account the probability of spatial impact, is expressed qualitatively as likelihood.

The terminology is aimed primarily at residential development but may also be used for other situations. It is noted that provision of specific numerical values at the Notional Boundaries for the terms adopted does not reduce the uncertainty that may be associated with assessment of appropriate numerical values.

Where sufficient data is available, the risk should be determined from a quantitative analysis. The results can then be objectively compared, especially with quantified allowable risk criteria.

Where there is insufficient data or the study is at a walk over or preliminary design level, then use of qualitative methods or terms may be more appropriate. Use of risk ranking schemes, where component inputs are assigned relative ranks, may be suitable for initial screening. In other cases, it is likely that expression of the likelihood, consequence and risk using qualitative terms is preferable for communication purposes; (for example using terminology as in Appendix C). Selection of the appropriate term should be based on an appropriate evaluation of likelihood or consequence ranges.

Semi-quantitative methods may be a combination of both, for example considering risk to property qualitatively, and risk to life quantitatively based on the appropriate best estimates of likelihood.

b) The practitioner should adopt the preferred risk matrix presented in Appendix C.

The terminology presented in Appendix C of this Practice Note has addressed the shortcomings identified with the scheme in Appendix G AGS (2000). Appendix G of AGS (2000) is now superseded and should no longer be used. Adoption of Appendix C as a preferred risk matrix will assist with uniformity of assessment and interpretation. This is discussed further in the Commentary.

The regulator should only accept non standard schemes where the terms have been clearly defined, the terms have been explained in relation to the preferred terminology, and it can be reasonably demonstrated by the practitioner that the alternative is better suited to the particular circumstances of the assessment.

7.4 ESTIMATION OF RISK OF LOSS OF LIFE

a) Estimate the risk of loss of life quantitatively for the person most at risk.

The annual probability of loss of life for the person most at risk from the landslide(s) should be estimated using the equations in Section 7.1. The person most at risk will often but not always be the person with the greatest spatial temporal probability.

The individual risk, as determined by summing the risk, for the person most at risk, from all the landslide hazards, is used for comparison with the tolerable risk criteria.

b) For situations where there is a potential for large numbers of lives to be lost in a single landslide event, estimate the frequency (f) –number (N) of lives lost pairs and total annual risk.

If the possible loss of large numbers of lives from a landslide incident is high, society will generally expect that the probability that the incident might actually occur should be low. This accounts for society's particular intolerance to incidents that cause many simultaneous casualties and is embodied in the criteria for tolerable societal risk. Societal Risk is discussed further in the Commentary.

In many cases there will be more than one landslide hazard (e.g. rockfall, which may lead to one or two lives lost; medium volume rapid landslide which may lead to several lives lost; and large rapid landslide which may lead to many lives lost). The frequency (annual probability, "f") of the "event" and the number of lives lost (N) should be estimated for each landslide hazard.

The total annual risk = $\sum$ (f x N) should also be estimated.

8 RISK ASSESSMENT

8.1 RISK EVALUATION

Evaluate the risks against Tolerable Risk Criteria for loss of life and property loss.

Accept the risks if tolerable, or seek to reduce risks to tolerable levels by risk mitigation.

The main objectives of risk evaluation are usually to decide whether to accept or treat the risks and to set priorities. The Tolerable Risk Criteria are usually imposed by the regulator, unless agreed otherwise with the owner/client

Non- technical clients may seek guidance from the practitioner on whether to accept the risk. In these situations, risk comparisons, discussion of treatment options and explanation of the risk management process can help the client make his decision.

It is desirable, if not essential, that the practitioner who prepared the risk assessment be involved in the decision making process because the process is often iterative, requiring assessment of the sensitivity of calculations to assumptions, modification of the development proposed and revision of risk mitigation measures.

Risk evaluation involves making judgements about the significance and tolerability of the estimated risk. Evaluation may involve comparison of the assessed risks with other risks or with risk acceptance criteria related to finance, loss of life or other values. Risk evaluation may include consideration of issues such as environmental effects, public reaction, politics, business or public confidence and fear of litigation.

In a simple situation where the client/owner is the only affected party, risk evaluation may be a simple value judgement. In more complex situations, value judgements on acceptable risk appropriate to the particular situation are still made as part of an acceptable process of risk management.

8.2 TOLERABLE RISK CRITERIA

The regulator is to establish the Tolerable Risk Criteria for loss of life and property loss.

As discussed in Section 3.5, the regulator is the appropriate authority to set standards for tolerable risk which may relate not only to perceived safety in relation to other risks, but also to government policy. Implementation of a tolerable risk level has implications to the community at large, both in terms of relative risks or safety and in terms of economic impact on the community.

The Commentary provides discussion and gives the AGS recommendations in relation to tolerable risk for loss of life. These are summarized in Table 1

Table 1: AGS Suggested Tolerable loss of life individual risk.

Situation	Suggested Tolerable Loss of Life Risk for the person most at risk
Existing Slope (1) / Existing Development (2)	10^{-4} / annum
New Constructed Slope (3) / New Development (4) / Existing Landslide (5)	10^{-5} / annum

Notes:

1. "Existing Slopes" in this context are slopes that are not part of a recognizable landslide and have demonstrated non-failure performance over at least several seasons or events of extended adverse weather, usually being a period of at least 10 to 20 years.
2. "Existing Development" includes existing structures, and slopes that have been modified by cut and fill, that are not located on or part of a recognizable landslide and have demonstrated non-failure performance over at least several seasons or events of extended adverse weather, usually being a period of at least 10 to 20 years.
3. "New Constructed Slope" includes any change to existing slopes by cut or fill or changes to existing slopes by new stabilisation works (including replacement of existing retaining walls or replacement of existing stabilisation measures, such as rock bolts or catch fences).
4. "New Development" includes any new structure or change to an existing slope or structure. Where changes to an existing structure or slope result in any cut or fill of less than 1.0m vertical height from the toe to the crest and this change does not increase the risk, then the Existing Slope / Existing Structure criterion may be adopted. Where changes to an existing structure do not increase the building footprint or do not result in an overall change in footing loads, then the Existing Development criterion may be adopted.
5. "Existing Landslides" have been considered likely to require remedial works and hence would become a New Constructed Slope and require the lower risk. Even where remedial works are not required per se, it would be reasonable expectation of the public for a known landslide to be assessed to the lower risk category as a matter of "public safety".

Acceptable risks are usually considered to be one order of magnitude lower than the Tolerable Risks.

It is important to distinguish between "acceptable risks" and "tolerable risks".

Tolerable Risks are risks within a range that society can live with so as to secure certain benefits. It is a range of risk regarded as non-negligible and needing to be kept under review and reduced further if practicable.

Acceptable Risks are risks which everyone affected is prepared to accept. Action to further reduce such risk is usually not required unless reasonably practicable measures are available at low cost in terms of money, time and effort.

AGS suggests that for most development in existing urban area criteria based on Tolerable Risks levels are applicable because of the trade-off between the risks, the benefits of development and the cost of risk mitigation.

The Commentary discusses Individual and Societal risk to loss of life. Usually Societal risk need not be considered for a risk evaluation in relation to a single dwelling. Societal risk should be evaluated for buildings having high numbers of occupants, such as schools, hospitals, hotels or motels where many lives are at risk. This then addresses society's aversion to loss of many lives from single landslide events.

The Tolerable Risk Criteria for property loss may be determined by the Importance Level of the development (Appendix A) as discussed in the Commentary.

9 RISK MANAGEMENT

9.1 RISK MITIGATION PRINCIPLES

9.1.1 Feasible options for risk mitigation for each risk assessment are to be identified and discussed including the reduced risk by adoption of those options.

Alternative methods to be explored include:

a. ***Accept the risk***, which is only an option subject to the criteria set by the regulator. Where the risk is not tolerable then risk mitigation measures are required.

b. ***Avoid the risk***, such as relocation of the site of proposed development, or revise the form of the development, or abandon the development (though this may still require some risks to be controlled due to possible effect on third parties adjacent or nearby).

c. ***Reduce the frequency of landsliding***, by stabilisation measures to control the initiating circumstances, such as by re-profiling the surface geometry where existing slopes are 'over steep', by provision of improved surface water drainage measures, by provision of subsurface drainage scheme, by provision of retaining structures such as retaining walls, anchored walls or ground anchors.

d. ***Reduce the consequences***, by provision of defensive stabilisation measures or protective measures such as a boulder catch fence, or amelioration of the behaviour of the landslide, or by relocation of the development to a more favourable location.

e. ***Manage the risk by establishing monitoring and warning systems,*** such as by regular site visits, or by survey, which enable the risks to be managed as an interim measure in the short term or as a permanent measure for the long term by alerting persons potentially affected to a change in the landslide condition. Such systems may be regarded as a method of reducing the consequences provided it is feasible for sufficient time to be available between the alert being raised and appropriate action being implemented.

f. ***Transfer the risk,*** such as by requiring another authority to accept the risk (possibly via a court appraisal) or by provision of insurance to cover potential property damage.

g. ***Postpone the decision,*** where there is sufficient uncertainty resulting from the available data, provided that additional investigations or monitoring are likely to enable a better risk assessment to be completed. Postponement is only a temporary measure and implies the risks are being temporarily accepted, even though they may not be acceptable or tolerable.

Adoption of particular risk mitigation measures needs to be documented so that the decisions are transparent to future land owners and to the regulator. The documentation will need to make it clear whether there is ongoing maintenance required or not. Responsibility for implementation of the risk mitigation measures (including auditing and reporting) resides with the land owner, particularly where ongoing maintenance is required.

It should be recognized that there may be situations where the risk is such that either no development should occur, or that very strict conditions and/or extensive investigations and implementation of risk control measures will be required. Such risk control measures may render the proposed development unworkable.

9.1.2 Wherever possible the recommended options should be engineered to reduce the uncertainties.

It is not possible to remove risk, but it can be reduced.

Risk mitigation options should include robust engineering design to reduce uncertainties and hence the risk.

Guidance on good engineering practice for hillside design and construction is given in Appendix G which has been reproduced from AGS (2000).

It is necessary that the options considered lower the risk to at least tolerable levels. In many cases, the ALARP principle ("As Low As Reasonably Practicable" as discussed in the Commentary) may apply so that reduction to a tolerable level is a pragmatic result since reduction to acceptable levels is not viable in the context of the cost to the individual or community. In other cases, good practice may suggest that risk reduction be applied since it is relatively cheap or cost effective to implement even though risk levels are assessed to already be at acceptable levels. In other words, risk minimization should be a governing feature or tenet of LRM.

Evaluation of mitigation options may take into account relative costs and effectiveness of the measures and inherent uncertainties. Combinations of mitigation measures may be appropriate.

The options should be reassessed if there is a need to reduce uncertainties or if suitable engineering options cannot be adopted.

An issue will be who decides on what level of risk reduction is appropriate. This is dependent on the risk tolerance criteria set by the regulator. The owner is likely to input into selection of the options, subject to approvals by the regulator. For some cases, there may be discussion between the stakeholders to select a suitable scheme of risk mitigation measures.

9.1.3 The adopted risk mitigation measures are to be detailed in a mitigation plan to explain and document the implementation of the measures.

The mitigation plan should identify responsibilities for each stakeholder during and after implementation. It may also include cost estimates, programme, required inspection regime, performance measures and expected outcomes. The level of detail will depend on the priority for the option and stage of the evaluation and implementation process.

The mitigation plan may include an emergency plan which should establish from the outset the sequence of events or monitoring results that will activate this plan. The plan may include a number of warning levels and consequent actions. The plan must be carefully reviewed to confirm it is workable and will achieve the desired risk mitigation.

The existence of the mitigation plan needs to be readily known to subsequent land owners. The most readily available method for this is to register the mitigation plan details on the land title.

9.1.4 The risk should be subject to monitoring and review during the assessment of options, during implementation of the risk mitigation measures and during the on going monitoring.

Further data may come to light during the management process which enables the risks to be reassessed. Such data may be adverse, requiring more stringent risk mitigation measures, or alternatively may be positive by demonstrating satisfactory slope performance under adverse conditions. It is anticipated that the practitioner would have a primary role in the monitoring and review process and particularly to confirm the requirements of the approval conditions had been fulfilled.

9.2 SITE SPECIFIC DEVELOPMENT CONDITIONS

Identify appropriate site specific development conditions to provide good practice and control the risks to acceptable levels.

In the context of advice from a technical expert (the practitioner) acting in a consultant capacity, development controls would usually constitute 'recommendations', but as they will be integral with the risk assessment of the final development they may not be optional to the client. The practitioner should provide a statement as to the appropriateness of the development proposals in relation to the risk management requirements.

If 'certification' of the completed development is required (by the planning scheme or regulator's approval conditions), then the development conditions and associated inspections and documentation must be sufficient to enable this to be provided at the later date.

The development conditions should be subdivided into those required at each of the stages of detailed design, construction (including appropriate sequencing and temporary works), and for maintenance. The development conditions must address all the factors relevant to controlling the landslide risk.

9.3 DESIGN LIFE

9.3.1 Design of the risk mitigation measures is to be suitable for the time frame of the life of the structure - the design life. The design life is to be clearly stated on the design drawings.

Often the design life will be that specified by relevant design codes such as 40 to 60 years for AS3600 Concrete Code, 50 years for AS2870 Residential Slabs and Footings, or for 5 years to 120 years for temporary site works to major public works respectively for AS4678 Earth Retaining Structures.

A design life of at least 50 years would be considered to be reasonable for permanent structures used by people. Some local government policies may require a longer design life as discussed in the Commentary. However, for some structures, such as timber retaining walls, inherent performance of the materials will limit the effective performance life to less than the required design life.

9.3.2 Where the effective performance life is less than the required design life, then the effective life should be extended by a maintenance regime designed to overcome the limitations and to enable the performance to be assessed throughout the required design life. This is likely to require more extensive repair and replacement as determined by regular maintenance inspections.

For example, experience shows the longevity of timber crib walls is less than for a concrete structure, due to faster degradation of timber with time. Therefore, a more frequent inspection and maintenance / repair / replacement regime will be required for timber crib walls to enable suitable repair and replacement so that a reasonable design life can be achieved. Similar considerations will apply to subsoil drains and stressed anchors.

9.4 MAINTENANCE REQUIREMENTS

9.4.1 The design is to include details of required inspections and maintenance to enable the risk mitigation measures to remain effective for at least the design life of the structure.

Risk mitigation is not just an exercise in LRM documentation, design of the works and construction of the risk mitigation measures. The owner, including all owners subsequent to those responsible for commissioning the risk mitigation measures, has a responsibility to inspect and maintain the risk mitigation measures.

9.4.2 Refer to the AGS Australian GeoGuide LR111 which provides advice on record keeping.

The other GeoGuides (AGS, 2007e) also provide advice on the frequency of maintenance tasks.

9.4.3 Implementation of the maintenance plan may require 'enforcement' by annotation on the land title so that subsequent purchasers become aware of the requirements and that relevant documents are available for the maintenance plan. Such 'enforcement' will be a benefit to subsequent owners as they will be better informed as to their required input responsibilities.

10 REPORTING STANDARDS

10.1 The report on the risk assessment is to document the data gathered, the logic applied and conclusion reached in a defensible manner.

The practitioner will gather relevant data, will assess the relevance of the data and will reach conclusions as to the appropriate geotechnical model and basic assessment of the slope forming processes and rates. Full documentation of these results provides evidence of completion, provides transparency in the light of uncertainty, enables the assessment to be re-examined or extended at a later date and enables the assessment to be defended against critical review. The process often identifies uncertainties or limitations of the assessment which also need to be documented and understood.

10.2 The data to be presented includes:

a. List of data sources.
b. Discussion of investigation methods used, and any limitations thereof.
c. Site plan (to scale) with geomorphic mapping results.
d. All factual data from investigations, such as borehole and test pit logs, laboratory test results, groundwater level observations, record photographs.
e. Location of all subsurface investigations and/or outcrops/cuttings.
f. Location of cross section(s).
g. Cross section(s) (to scale) with interpreted subsurface model showing investigation locations.
h. Evidence of past performance.
i. Local history of instability with assessed trigger events.
j. Identification of landslides, on plan or section or both, and discussed in terms of the geomorphic model, relevant slope forming process and process rates. Landslides need to be considered above the site, below the site and adjacent to the site.
k. Assessed likelihood of each landslide with basis thereof.
l. Assessed consequence to property and life for each landslide with basis thereof.
m. Resulting risk for each landslide.
n. Risk assessment in relation to tolerable risk criteria (e.g. regulator's published criteria where appropriate).
o. Risk mitigation measures and options, including reassessed risk once these measures are implemented.

Where any of the above is not or cannot be completed, the report should document the missing elements, including an explanation as to why.

The report needs to clearly state whether the risk assessment is based on existing conditions or with risk treatment measures implemented. In some cases, the assessment for both existing and after treatment should be documented to demonstrate the effect of risk control measures on reducing risk.

A report which does not properly document the assessment is of limited value and would appear to have no reasonable basis.

11 SPECIAL CHALLENGES

11.1 MINOR WORKS

Adoption of all the provisions of the Practice Note for minor works may not be appropriate or reasonable. However, the basic principles still need to be considered. Although some policies may make provision for less onerous consideration for minor works, the practitioner will still have a duty of care to advise on all aspects and may have other landslides not connected with the proposed works that will still need to be considered.

Minor works should be evaluated on a site by site basis but are likely to comprise proposed works of relatively low monetary value (such as may be completed by an owner builder with appropriate approvals and insurances) or those which do not change the existing risk, provided the existing risk has been assessed to be within the tolerable range. In some cases, the risk to life may be much higher than the risk to property and may dictate the need for risk mitigation to achieve tolerable risk levels.

11.2 PART OF THE SITE NOT ACCEPTABLE

Existing or proposed development may not involve the full site area. Nonetheless, the practitioner's report must address all risks and advise the client and/or regulator of necessary works to control risks on other parts of the site or adjacent/nearby sites upslope or down slope as appropriate (as a primary duty of care issue).

Where additional development is proposed, it may be found that risks associated with the proposed development are tolerable but that landslide risks on other parts of the site are not. These other risks still must be addressed.

11.3 ADJOINING AREAS NOT UNDER RESPONSIBILITY OF THE SITE OWNER

In some cases, the risk posed by landslides in areas beyond the control of the land owner may be intolerable.

The LRM assessment report must identify these landslides and provide a preliminary assessment of appropriate risk mitigation measures, which may require further investigation to better assess the risk.

The regulator may then implement appropriate orders (as appropriate to the legal/regulatory framework) to enforce appropriate risk mitigation measures and/or investigations. Alternatively, it may not be appropriate for development to proceed in such cases.

11.4 COASTAL CLIFFS

LRM reports on coastal cliffs should include consideration of the existing slope profile, evidence of past instability, geology, defects, ground water, degradation cycles, and degradation rates and possible effects of wave attack, wave run-up and sea spray. The cliff areas should be examined from the face side as well as from the land side.

Assessment of coastal cliffs is likely to require special expertise to consider the combined effects associated with recession rates, rock mechanics and wave environment. The LRM assessment may require some input from coastal engineers to address possible effects from storm events in terms of wave heights, run-up and frequency. The most frequent hazard is often boulder falls which will have risk determined by the temporal spatial probability.

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APPENDIX A - DEFINITION OF TERMS AND LANDSLIDE RISK

RISK TERMINOLOGY

Acceptable Risk – A risk for which, for the purposes of life or work, we are prepared to accept as it is with no regard to its management. Society does not generally consider expenditure in further reducing such risks justifiable.

Annual Exceedance Probability (AEP) – The estimated probability that an event of specified magnitude will be exceeded in any year.

Consequence – The outcomes or potential outcomes arising from the occurrence of a landslide expressed qualitatively or quantitatively, in terms of loss, disadvantage or gain, damage, injury or loss of life.

Elements at Risk – The population, buildings and engineering works, economic activities, public services utilities, infrastructure and environmental features in the area potentially affected by landslides.

Frequency – A measure of likelihood expressed as the number of occurrences of an event in a given time. See also Likelihood and Probability.

Hazard – A condition with the potential for causing an undesirable consequence (the landslide). The description of landslide hazard should include the location, volume (or area), classification and velocity of the potential landslides and any resultant detached material, and the likelihood of their occurrence within a given period of time.

Individual Risk to Life – The risk of fatality or injury to any identifiable (named) individual who lives within the zone impacted by the landslide; or who follows a particular pattern of life that might subject him or her to the consequences of the landslide.

Landslide Activity – The stage of development of a landslide; pre failure when the slope is strained throughout but is essentially intact; failure characterised by the formation of a continuous surface of rupture; post failure which includes movement from just after failure to when it essentially stops; and reactivation when the slope slides along one or several pre-existing surfaces of rupture. Reactivation may be occasional (eg seasonal) or continuous (in which case the slide is "active").

Landslide Intensity – A set of spatially distributed parameters related to the destructive power of a landslide. The parameters may be described quantitatively or qualitatively and may include maximum movement velocity, total displacement, differential displacement, depth of the moving mass, peak discharge per unit width, kinetic energy per unit area.

Landslide Risk - The AGS Australian GeoGuide LR7 (AGS, 2007e) should be referred to for an explanation of Landslide Risk.

Landslide Susceptibility – The classification, and volume (or area) of landslides which exist or potentially may occur in an area or may travel or retrogress onto it. Susceptibility may also include a description of the velocity and intensity of the existing or potential landsliding.

Likelihood – Used as a qualitative description of probability or frequency.

Probability – A measure of the degree of certainty. This measure has a value between zero (impossibility) and 1.0 (certainty). It is an estimate of the likelihood of the magnitude of the uncertain quantity, or the likelihood of the occurrence of the uncertain future event.

There are two main interpretations:

(i) Statistical – frequency or fraction – The outcome of a repetitive experiment of some kind like flipping coins. It includes also the idea of population variability. Such a number is called an "objective" or relative frequentist probability because it exists in the real world and is in principle measurable by doing the experiment.

(ii) Subjective probability (degree of belief) – Quantified measure of belief, judgment, or confidence in the likelihood of an outcome, obtained by considering all available information honestly, fairly, and with a minimum of

bias. Subjective probability is affected by the state of understanding of a process, judgment regarding an evaluation, or the quality and quantity of information. It may change over time as the state of knowledge changes.

Qualitative Risk Analysis – An analysis which uses word form, descriptive or numeric rating scales to describe the magnitude of potential consequences and the likelihood that those consequences will occur.

Quantitative Risk Analysis – An analysis based on numerical values of the probability, vulnerability and consequences and resulting in a numerical value of the risk.

Risk – A measure of the probability and severity of an adverse effect to health, property or the environment. Risk is often estimated by the product of probability x consequences. However, a more general interpretation of risk involves a comparison of the probability and consequences in a non-product form.

Risk Analysis – The use of available information to estimate the risk to individual, population, property, or the environment, from hazards. Risk analyses generally contain the following steps: Scope definition, hazard identification and risk estimation.

Risk Assessment – The process of risk analysis and risk evaluation.

Risk Control or Risk Treatment – The process of decision making for managing risk and the implementation or enforcement of risk mitigation measures and the re-evaluation of its effectiveness from time to time, using the results of risk assessment as one input.

Risk Estimation – The process used to produce a measure of the level of health, property or environmental risks being analysed. Risk estimation contains the following steps: frequency analysis, consequence analysis and their integration.

Risk Evaluation – The stage at which values and judgments enter the decision process, explicitly or implicitly, by including consideration of the importance of the estimated risks and the associated social, environmental and economic consequences, in order to identify a range of alternatives for managing the risks.

Risk Management – The complete process of risk assessment and risk control (or risk treatment).

Societal Risk – The risk of multiple fatalities or injuries in society as a whole: one where society would have to carry the burden of a landslide causing a number of deaths, injuries, financial, environmental and other losses.

Susceptibility – see Landslide Susceptibility

Temporal Spatial Probability – The probability that the element at risk is in the area affected by the landsliding, at the time of the landslide.

Tolerable Risk – A risk within a range that society can live with so as to secure certain net benefits. It is a range of risk regarded as non-negligible and needing to be kept under review and reduced further if possible.

Vulnerability – The degree of loss to a given element or set of elements within the area affected by the landslide hazard. It is expressed on a scale of 0 (no loss) to 1 (total loss). For property, the loss will be the value of the damage relative to the value of the property; for persons, it will be the probability that a particular life (the element at risk) will be lost, given the person(s) is affected by the landslide.

ASSOCIATED TERMINOLOGY

Importance Level – of a building or structure is directly related to the societal requirements for its use, particularly during or following extreme events. The consequences with respect to life safety of the occupants of buildings are indirectly related to the Importance Level, being a result of the societal requirement for the structure rather than the reason *per se* of the Importance Level.

Authority or Council] having statutory responsibility for community activities, community safety and development approval or management of development within its defined area/region.

The Regulator will be the responsible body/authority for setting Acceptable/Tolerable Risk Criteria to be adopted for the community/region/activity, which will be the basis for setting levels for Acceptable and Tolerable Risk in the application of the risk assessment guidelines.

Importance Level of Structure	Explanation	Examples (Regulatory authorities may designate any structure to any classification type when local conditions make such desirable)
1	Buildings or structures generally presenting a low risk to life and property (including other property).	Farm buildings. Isolated minor storage facilities. Minor temporary facilities. Towers in rural situations.
2	Buildings and structures not covered by Importance Levels 1, 3 or 4.	Low-rise residential construction. Buildings and facilities below the limits set for Importance Level 3.
3	Buildings or structures that as a whole may contain people in crowds, or contents of high value to the community, or that pose hazards to people in crowds.	Buildings and facilities where more than 300 people can congregate in one area. Buildings and facilities with primary school, secondary school or day-care facilities with capacity greater than 250. Buildings and facilities for colleges or adult education facilities with a capacity greater than 500. Health care facilities with a capacity of 50 or more residents but no having surgery or emergency treatment facilities. Jails and detention facilities. Any occupancy with an occupant load greater than 5,000. Power generating facilities, water treatment and waste water treatment facilities, any other public utilities not included in Importance Level 4. Buildings and facilities not included in Importance Level 4 containing hazardous materials capable of causing hazardous conditions that do not extend beyond property boundaries.
4	Buildings or structures that are essential to post-disaster recovery, or with significant post-disaster functions, or that contain hazardous materials.	Buildings and facilities designated as essential facilities. Buildings and facilities with special post-disaster functions. Medical emergency or surgery facilities. Emergency service facilities: fire, rescue, police station and emergency vehicle garages. Utilities required as back-up for buildings and facilities of Importance Level 4. Designated emergency shelters. Designated emergency centres and ancillary facilities. Buildings and facilities containing hazardous (toxic or explosive) materials in sufficient quantities capable of causing hazardous conditions that extend beyond property boundaries.

(from BCA Guidelines)

Practitioner – A specialist Geotechnical Engineer or Engineering Geologist who is degree qualified, is a member of a professional institute and who has achieved chartered professional status – being either Chartered Professional Engineer (CPEng) within the Institution of Engineers Australia, Chartered Professional Geologist (CPGeo) within the Australasian Institute of Mining & Metallurgy, or Registered Professional Geoscientist (RPGeo) within the Australian Institute of Geoscientists – specifically with Landslide Risk Management as a core competency.

A Practitioner will include persons qualified under the Institution of Engineers Australia NPER – LRM register.

It would normally be required that the Practitioner can demonstrate an appropriate minimum period of experience in the practice of landslide risk assessment and management in the geographic region, or can demonstrate relevant experience in similar geological settings.

Regulator – The regulatory authority [Federal Government/ State Government/ Instrumentality/ Regional/Local.

APPENDIX B - LANDSLIDE TERMINOLOGY

The following provides a summary of landslide terminology which should (for uniformity of practice) be adopted when classifying and describing a landslide. It has been based on Cruden & Varnes (1996) and the reader is recommended to refer to the original documents for a more detailed discussion, other terminology and further examples of landslide types and processes.

Landslide

The term ***landslide*** denotes "the movement of a mass of rock, debris or earth down a slope". The phenomena described as landslides are not limited to either the "land" or to "sliding", and usage of the word has implied a much more extensive meaning than its component parts suggest. Ground subsidence and collapse are excluded.

Classification of Landslides

Landslide classification is based on Varnes (1978) system which has two terms: the first term describes the material type and the second term describes the type of movement.

The material types are ***Rock***, ***Earth*** and ***Debris***, being classified as follows:-

The material is either rock or soil.

Rock: is "a hard or firm mass that was intact and in its natural place before the initiation of movement."

Soil: is "an aggregate of solid particles, generally of minerals and rocks, that either was transported or was formed by the weathering of rock in place. Gases or liquids filling the pores of the soil form part of the soil."

Earth: "describes material in which 80% or more of the particles are smaller than 2 mm, the upper limit of sand sized particles."

Debris: "contains a significant proportion of coarse material; 20% to 80% of the particles are larger than 2 mm and the remainder are less than 2 mm."

The terms used should describe the displaced material in the landslide before it was displaced.

The types of movement describe how the landslide movement is distributed through the displaced mass. The five kinematically distinct types of movement are described in the sequence ***fall***, ***topple***, ***slide***, ***spread*** and ***flow***.

The following table shows how the two terms are combined to give the landslide type:

Table B1: Major types of landslides. Abbreviated version of Varnes' classification of slope movements (Varnes, 1978).

TYPE OF MOVEMENT		**TYPE OF MATERIAL**		
		BEDROCK	**ENGINEERING SOILS**	
			Predominantly Coarse	**Predominantly Fine**
FALLS		Rock fall	Debris fall	Earth fall
TOPPLES		Rock topple	Debris topple	Earth topple
SLIDES	ROTATIONAL	Rock slide	Debris slide	Earth slide
	TRANSLATIONAL			
LATERAL SPREADS		Rock spread	Debris spread	Earth spread
FLOWS		Rock flow (Deep creep)	Debris flow (Soil creep)	Earth flow
COMPLEX	Combination of two or more principle types of movement			

Figure B1 gives schematics to illustrate the major types of landslide movement. Further information and photographs of landslides are available on the USGS website at http://landslides.usgs.gov.

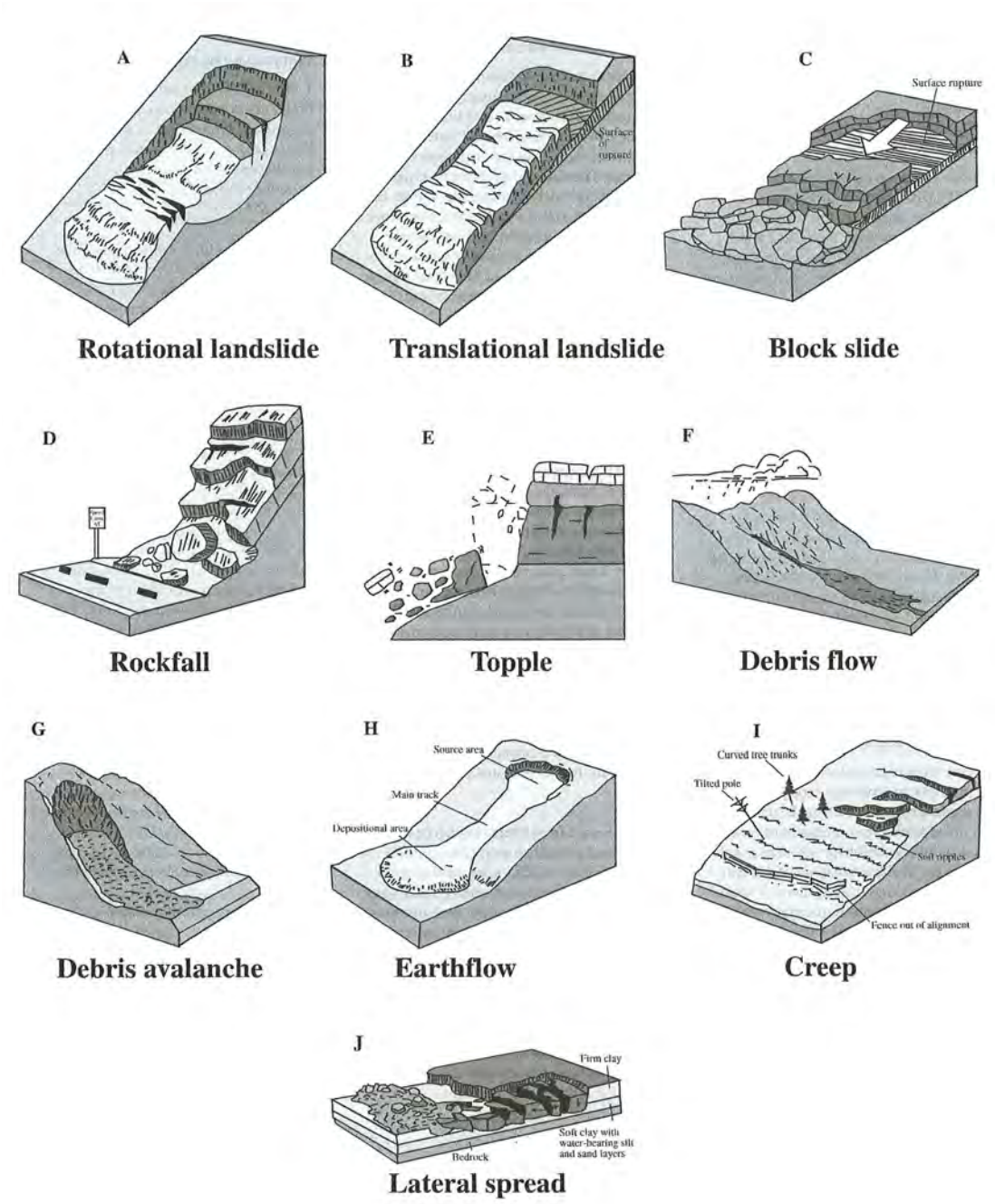

Figure B1: These schematics illustrate the major types of landslide movement.
(From US Geological Survey Fact Sheet 2004-3072, July 2004, with kind permission for reproduction.)

The nomenclature of a landslide can become more elaborate as more information about the movement becomes available. To build up the complete identification of the movement, descriptors are added in front of the two-term classification using a preferred sequence of terms. The suggested sequence provides a progressive narrowing of the focus of the descriptors, first by time and then by spatial location, beginning with a view of the whole landslide, continuing with parts of the movement and finally defining the materials involved. The recommended sequence, as shown in Table B2, describes activity (including state, distribution and style) followed by descriptions of all movements (including rate, water content, material and type). Definitions of the terms in Table B2 are given in Cruden & Varnes (1996).

Second or subsequent movements in complex or composite landslides can be described by repeating, as many times as necessary, the descriptors used in Table B2. Descriptors that are the same as those for the first movement may then be dropped from the name.

For example, the very large and rapid slope movement that occurred near the town of Frank, Alberta, Canada, in 1903 was a *complex, extremely rapid, dry rock fall – debris flow*. From the full name of this landslide at Frank, one would know that both the debris flow and the rock fall were extremely rapid and dry because no other descriptors are used for the debris flow.

The full name of the landslide need only be given once; subsequent references should then be to the initial material and type of movement; for the above example, "the rock fall" or "the Frank rock fall" for the landslide at Frank, Alberta.

Table B2: Glossary for forming names of landslides.

Activity

State	Distribution	Style
Active	Advancing	Complex
Reactivated	Retrogressive	Composite
Suspended	Widening	Multiple
Inactive	Enlarging	Successive
Dormant	Confined	Single
Abandoned	Diminishing	
Stabilised	Moving	
Relict		

Description of First Movement

Rate	Water Content	Material	Type
Extremely rapid	Dry	Rock	Fall
Very rapid	Moist	Earth	Topple
Rapid	Wet	Debris	Slide
Moderate	Very Wet		Spread
Slow			Flow
Very slow			
Extremely slow			

Note: Subsequent movements may be described by repeating the above descriptors as many times as necessary. These terms are described in more detail in Cruden & Varnes (1996) and examples are given.

Landslide Features

Varnes (1978, Figure 2.1t) provided an idealised diagram showing the features for a *complex earth slide – earth flow*, which has been reproduced here as Figure B2. Definitions of landslide dimensions are given in Cruden & Varnes (1996).

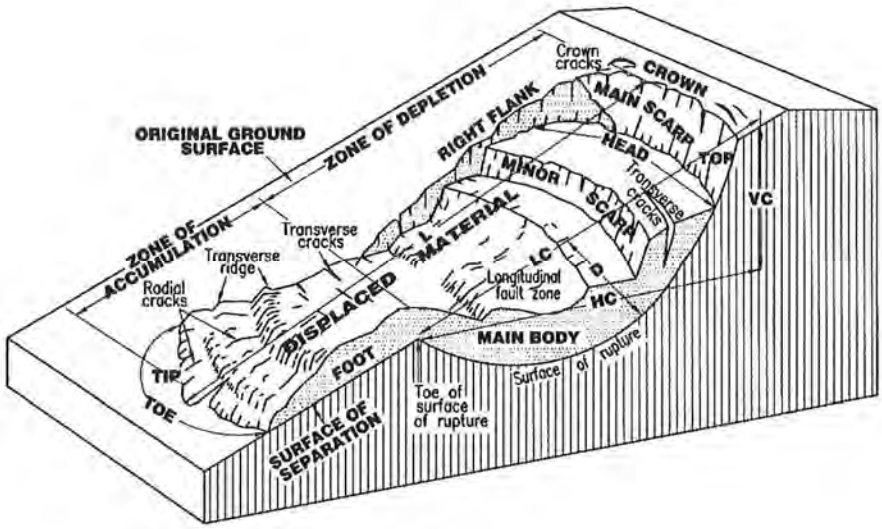

Figure B2: Block of Idealised Complex Earth Slide – Earth Flow

(*Varnes, D J (1978,)Slope Movement Types and Processes. In Special Report 176: Landslides: Analysis and Control(R L Schuster & R J Krizek, eds.), TRB, National Research Council, Washington, DC, pp.11-33).*

Rate of Movement

Figure B3 shows the velocity scale proposed by Cruden & Varnes (1996) which rationalises previous scales. The term "creep" has been omitted due to the many definitions and interpretations in the literature.

Velocity Class	Description	Velocity (mm/sec)	Typical Velocity	Probable Destructive Significance
7	Extremely Rapid			Catastrophe of major violence; buildings destroyed by impact of displaced material; many deaths; escape unlikely
		5×10^{3}	5 m/sec	
6	Very Rapid			Some lives lost; velocity too great to permit all persons to escape
		5×10^{1}	3 m/min	
5	Rapid			Escape evaluation possible; structures; possessions, and equipment destroyed
		5×10^{-1}	1.8 m/hr	
4	Moderate			Some temporary and insensitive structures can be temporarily maintained
		5×10^{-3}	13 m/month	
3	Slow			Remedial construction can be undertaken during movement; insensitive structures can be maintained with frequent maintenance work if total movement is not large during a particular acceleration phase
		5×10^{-5}	1.6 m/year	
2	Very Slow			Some permanent structures undamaged by movement
		5×10^{-7}	15 mm/year	
	Extremely **SLOW**			Imperceptible without instruments; construction **POSSIBLE WITH PRECAUTIONS**

Figure B3: Proposed Landslide Velocity Scale and Probable Destructive Significance.

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APPENDIX C: LANDSLIDE RISK ASSESSMENT

QUALITATIVE TERMINOLOGY FOR USE IN ASSESSING RISK TO PROPERTY

QUALITATIVE MEASURES OF LIKELIHOOD

Approximate Annual Probability		Implied Indicative Landslide Recurrence Interval		Description	Descriptor	Level
Indicative Value	Notional Boundary					
10^{-1}	$5x10^{-2}$	10 years	20 years	The event is expected to occur over the design life.	ALMOST CERTAIN	A
10^{-2}	$5x10^{-3}$	100 years	200 years	The event will probably occur under adverse conditions over the design life.	LIKELY	B
10^{-3}	$5x10^{-4}$	1000 years	2000 years	The event could occur under adverse conditions over the design life.	POSSIBLE	C
10^{-4}	$5x10^{-5}$	10,000 years	20,000 years	The event might occur under very adverse circumstances over the design life.	UNLIKELY	D
10^{-5}	$5x10^{-6}$	100,000 years	200,000 years	The event is conceivable but only under exceptional circumstances over the design life.	RARE	E
10^{-6}		1,000,000 years		The event is inconceivable or fanciful over the design life.	BARELY CREDIBLE	F

Note: (1) The table should be used from left to right; use Approximate Annual Probability or Description to assign Descriptor, not *vice versa*.

QUALITATIVE MEASURES OF CONSEQUENCES TO PROPERTY

Approximate Cost of Damage		Description	Descriptor	Level
Indicative Value	Notional Boundary			
200%	100%	Structure(s) completely destroyed and/or large scale damage requiring major engineering works for stabilisation. Could cause at least one adjacent property major consequence damage.	CATASTROPHIC	1
60%	40%	Extensive damage to most of structure, and/or extending beyond site boundaries requiring significant stabilisation works. Could cause at least one adjacent property medium consequence damage.	MAJOR	2
20%	10%	Moderate damage to some of structure, and/or significant part of site requiring large stabilisation works. Could cause at least one adjacent property minor consequence damage.	MEDIUM	3
5%	1%	Limited damage to part of structure, and/or part of site requiring some reinstatement stabilisation works.	MINOR	4
0.5%		Little damage. (Note for high probability event (Almost Certain), this category may be subdivided at a notional boundary of 0.1%. See Risk Matrix.)	INSIGNIFICANT	5

Notes: (2) The Approximate Cost of Damage is expressed as a percentage of market value, being the cost of the improved value of the unaffected property which includes the land plus the unaffected structures.

(3) The Approximate Cost is to be an estimate of the direct cost of the damage, such as the cost of reinstatement of the damaged portion of the property (land plus structures), stabilisation works required to render the site to tolerable risk level for the landslide which has occurred and professional design fees, and consequential costs such as legal fees, temporary accommodation. It does not include additional stabilisation works to address other landslides which may affect the property.

(4) The table should be used from left to right; use Approximate Cost of Damage or Description to assign Descriptor, not vice versa

APPENDIX C: – QUALITATIVE TERMINOLOGY FOR USE IN ASSESSING RISK TO PROPERTY (CONTINUED)

QUALITATIVE RISK ANALYSIS MATRIX – LEVEL OF RISK TO PROPERTY

LIKELIHOOD		CONSEQUENCES TO PROPERTY (With Indicative Approximate Cost of Damage)				
	Indicative Value of Approximate Annual Probability	**1: CATASTROPHIC 200%**	**2: MAJOR 60%**	**3: MEDIUM 20%**	**4: MINOR 5%**	**5: INSIGNIFICANT 0.5%**
A – ALMOST CERTAIN	10^{-1}	VH	VH	VH	H	M or **L** (5)
B - LIKELY	10^{-2}	VH	VH	H	M	**L**
C - POSSIBLE	10^{-3}	VH	H	M	M	**VL**
D - UNLIKELY	10^{-4}	H	M	**L**	**L**	**VL**
E - RARE	10^{-5}	M	**L**	**L**	**VL**	**VL**
F - BARELY CREDIBLE	10^{-6}	**L**	**VL**	**VL**	**VL**	**VL**

Notes: (5) For Cell A5, may be subdivided such that a consequence of less than 0.1% is Low Risk.
(6) When considering a risk assessment it must be clearly stated whether it is for existing conditions or with risk control measures which may not be implemented at the current time.

RISK LEVEL IMPLICATIONS

Risk Level		**Example Implications** (7)
VH	VERY HIGH RISK	Unacceptable without treatment. Extensive detailed investigation and research, planning and implementation of treatment options essential to reduce risk to Low; may be too expensive and not practical. Work likely to cost more than value of the property.
H	HIGH RISK	Unacceptable without treatment. Detailed investigation, planning and implementation of treatment options required to reduce risk to Low. Work would cost a substantial sum in relation to the value of the property.
M	MODERATE RISK	May be tolerated in certain circumstances (subject to regulator's approval) but requires investigation, planning and implementation of treatment options to reduce the risk to Low. Treatment options to reduce to Low risk should be implemented as soon as practicable.
L	LOW RISK	Usually acceptable to regulators. Where treatment has been required to reduce the risk to this level, ongoing maintenance is required.
VL	VERY LOW RISK	Acceptable. Manage by normal slope maintenance procedures.

Note: (7) The implications for a particular situation are to be determined by all parties to the risk assessment and may depend on the nature of the property at risk; these are only given as a general guide.

APPENDIX D -EXAMPLE FORMS

The following example forms have been prepared as templates to provide appropriate documentation for the control of submissions and approval process.

It is envisaged that the regulator would edit the forms to suit local requirements and to use terminology appropriate to regulatory framework of the regulator's LRM policy. Items between '< >' are to be edited as appropriate. The following terms have been used in a generic sense and should be amended by the regulator accordingly:

<the Regulator> - the authority responsible for the approval of the development application.

<Regulator's geotechnical DCP> - the appropriate LRM policy title/reference, or Development Control Plan (DCP).

<add reference> - the section or page of the geotechnical report which addresses the item.

<PCA> - the Principal Certifying Authority, or the authority who will be responsible for confirmation of compliance with the development approval conditions.

<tolerable risk> - amend to 'acceptable risk' if that is required by the <Regulator's geotechnical DCP> rather than tolerable.

<Construction Certificate> - the approval necessary to start construction which documents that design has complied with the conditions of approval for the development application.

<Occupation Certificate> - the final approval from the Regulator allowing occupation of the development once all required conditions of consent have been shown to be satisfied.

<Subdivision Certificate> - the final approval from the Regulator confirming that subdivision works have been completed in accordance with the conditions of consent such that development on individual lots may proceed.

<Building Certificate> - a certificate issued by the Regulator confirming that either existing development is in accordance with the Regulator's requirements, or confirming that the Regulator is not aware of any non-compliance which will require rectification works.

ACKNOWLEDGEMENT

These example forms have been based on the forms included in the Wollongong City Geotechnical Development Control Plan – Development of Sites which may be subject to Slope Instability, effective from 12 July 2006 with their kind permission. Copies of the Word documents may be obtained from AGS by regulators wishing to prepare their own forms.

FORM	A	Page 1 of 2 **Geotechnical Declaration and Verification Development Application**	
Office Use Only			Regulator: *<Add in or change to appropriate name>*

To be submitted with a development application. If this form is not submitted with the geotechnical report the report will be refused.
This form is essential to verify that the geotechnical report has been prepared in accordance with <*Regulator's geotechnical DCP*> and that the author of the geotechnical report is a geotechnical engineer or engineering geologist as defined by <*Regulator's geotechnical DCP*>. Alternatively, where a geotechnical report has been prepared for subdivision or is greater than two years old or by a professional person not recognised by <*Regulator's geotechnical DCP*> , then this form may be used as technical verification of the geotechnical report if signed by a geotechnical engineer or engineering geologist as defined by <*Regulator's geotechnical DCP*>.

Section 1 Related Application

Reference	What is the Council development application number?
DA Site Address	
DA Applicant	

Section 2 Geotechnical Report

Details	Title:	
	Author's Company/ Organisation Name:	Report Reference No:
	Author:	Dated: / /

Section 3 Checklist

Geotechnical Requirements (Tick as appropriate, either Yes or No)

The following checklist covers the minimum requirements to be addressed in a geotechnical report. This checklist is to accompany the report. Each item is to be cross-referenced to the section or page of the geotechnical report which addresses that item.

Yes	No	
☐	☐	A review of readily available history of slope instability in the site or related land as per <*Add reference*>
☐	☐	An assessment of the risk posed by all reasonably identifiable geotechnical hazards as per <*Add reference*>
☐	☐	Plans and sections of the site and related land as per <*Add reference*>
☐	☐	Presentation of a geological model as per <*Add reference*>
☐	☐	Photographs and/or drawings of the site as per <*Add reference*>
☐	☐	A conclusion as to whether the site is suitable for the development proposed to be carried out either conditionally or unconditionally as per <*Add reference*>
☐	☐	If any items above are ticked No, an explanation is to be included in the report to justify why. <*Add reference*>

Subject to recommendations and conditions relevant to:

Yes	No	
☐	☐	selection and construction of footing systems,
☐	☐	earthworks,
☐	☐	surface and sub surface drainage,
☐	☐	recommendations for the selection of structural systems consistent with the geotechnical assessment of the risk,
☐	☐	any conditions that may be required for the ongoing mitigation and maintenance of the site and the proposal, from a geotechnical viewpoint,
☐	☐	highlighting and detailing the inspection regime to provide the <PCA> and builder with adequate notification for all necessary inspections.
☐	☐	State Design life adopted: Years

Note: <Add reference>: Add in the relevant section or page number of the listed geotechnical report which addresses each item.

FORM **A**

Geotechnical Declaration and Verification Development Application

Section 4 List of Drawings referenced in Geotechnical Report

Design Documents	Description	Plan or Document No.	Revision or Version No.	Date	Author

Section 5 Declaration

Declaration (Tick all that apply) Yes	No	
		I am a geotechnical engineer or engineering geologist as defined by the <*Regulator's geotechnical DCP*> and on behalf of the company below, I:
☐	☐	am aware that the geotechnical report I have either prepared or am technically verifying (referenced above) is to be submitted in a support of a development application for the proposed development site (referenced above) and its findings will be relied upon by <*the Regulator*> in determining the development application.
☐	☐	prepared the geotechnical report referenced above in accordance with the AGS (2007c) as amended and <*Regulator's geotechnical DCP*>.
☐ N/A	☐ N/A	am willing to technically verify that the Geotechnical Report referenced above has been prepared in accordance with the AGS (2007c) as amended and <*Regulator's geotechnical DCP*>.
☐	☐ No	am willing to technically verify that the geotechnical report prepared for the development application for the site confirms the land will achieve the level of <*tolerable risk*> of slope instability as a result of the considerations described in <*add reference to specific section of*> <*Regulator's geotechnical DCP*> taking into account the total development and site disturbances proposed.
☐	☐ No	am willing to technically verify that the geotechnical report prepared for the site and related land being greater than two years old confirms the land will achieve the level of <*tolerable risk*> of slope instability as a result of the considerations described <*add reference to specific section of*> *of* <*Regulator's geotechnical DCP*> *taking into account the total development and site disturbances proposed.*
☐	☐ No	have professional indemnity insurance in accordance with <*Regulator's geotechnical DCP*> of not less than $.... million, being in force for the year in which the report is dated, with retroactive cover under this insurance policy extending back to the engineer's first submission to <*the Regulator*>.

Section 6 Geotechnical Engineer or Engineering Geologist Details

Company/ Organisation Name		
Name (Company Representative)	Surname:	Mr /Mrs /Other:
	Given Names:	
	Chartered Professional Status:	Registration No:
Signature		Dated: / /

Reference: AGS (2007c) *"Practice Note Guidelines for Landslide Risk Management"*. Australian Geomechanics Society, Australian Geomechanics, V42, .N1, March 2007.

Note: N/A = Not Applicable.

FORM	B	Page 1 of 2 **Structural/Civil/Geotechnical Engineering Declaration – <*Construction Certificate*> Application**

Office Use Only		Regulator: *<Add in or change to appropriate name>*

To be submitted with the structural design forming part of an application for a <*construction certificate*>.
This form must be attached with the submission of the structural documentation required for the determination of a <*construction certificate*> or combined development application and <*construction certificate*> submission.
This form is essential, as it provides evidence to the <*PCA*> determining the <*construction certificate*>, that the structural design has been prepared or verified by a structural engineer or civil engineer as defined by <*Regulator's geotechnical DCP*> and that the structural design has been prepared in accordance with the recommendations given in the geotechnical report for the same development. This form also covers additional design documents required to cover other works not shown on the main structural/civil design drawings. This form is also essential to establish that the recommendations given in the geotechnical report have been interpreted and incorporated into the structural design as originally intended by the geotechnical engineer in preparing the geotechnical report.

Section 1 Related Application

Reference	What is the <*Regulator's*> development application number?
DA Site Address	
DA Applicant	

Section 2 Structural/Civil Design Documents

List of Structural/Civil Design Documents *(More space on page two if required)*	Description	Plan or Document No.	Revision or Version No.	Date	Author

Section 3 Geotechnical Report

Details	Title:	
	Author:	Dated: / /
	Author's Company/ Organisation Name:	Report Reference No:

Section 4 Declaration by Structural/Civil Engineer or Designer of Additional Design Documents in Relation to a Geotechnical Report

Declaration (Tick all that apply) Yes	No	
☐	☐	I am a structural or civil engineer as defined by the <*Regulator's geotechnical DCP*> and on behalf of the company below.
☐	☐	I have prepared the structural designs listed in Section 2 above and/or Section 6 below, in accordance with the recommendations given in the above geotechnical report.
☐	☐	I am a design engineer and have prepared Additional Design documents listed in Section 7 below in accordance with the recommendations given in the above geotechnical report.
☐	☐	I am aware that the <*PCA*> will rely on this declaration in granting a <*construction certificate*> for works to which the above structural design documents and geotechnical report relate.
☐	☐	I certify that any residential structure designed or erected in accordance with the structural design prepared by the structural engineer or civil engineer achieves the performance requirements of Clause 1.3 of the current version of AS 2870 (this must be ticked when accompanied by minimal impact certification).
☐	☐	I have professional indemnity insurance in accordance with <*Regulator's geotechnical DCP*> of not less than $.... million, being in force for the year in which the report is dated, with retroactive cover under this insurance policy extending back to the engineer's first submission to <*the Regulator*>.

FORM B — Structural/Civil/Geotechnical Engineering Declaration – <*Construction Certificate*> Application

Section 5 — Structural/Civil/Design Engineer Details

Company/ Organisation Name		
Name (Company Representative)	Surname:	Mr /Mrs /Other:
	Given:	
	Chartered Professional Status:	Registration No:
Signature		Dated: / /

Section 6 — Ancillary Structural/Civil Design Required Prior to Completion of Geotechnical Declaration

List of Structural Design Documents Required

Description	Company Responsible	Plan or Document No.	Revision or Version No.	Date of Additional Form B *	Author
eg. Landscaping retaining walls					
eg. Anchor design					

Section 7 — Additional Design Documents Required Prior to Completion of Geotechnical Declaration

List of Design Documents Required

Description	Company	Plan or Document No.	Revision or Version No.	Date of Additional Form B *	Author
eg. Surface & subsoil drainage design					
eg. Infiltration or effluent disposal					

Section 8 and 9 are not to be completed until each relevant ancillary and additional Form B has been completed and forwarded to the geotechnical engineer/engineering geologist

Section 8 — Declaration in Relation to Structural/Civil Designs and Additional Design Drawings

Declaration (Tick all that apply)

Yes	No	
		I am a geotechnical engineer or engineering geologist as defined by the <*Regulator's geotechnical DCP*> and on behalf of the company below:
☐	☐	I prepared and/or technically verified the above geotechnical report and now declare that I have viewed the above listed design documents prepared for the same development.
☐	☐	I am satisfied that the recommendations given in the above geotechnical report have been incorporated into the design documents as intended.
☐	☐	I consider no additional drawings are required to show all the required works listed in the Geotechnical Report.

Section 9 — Geotechnical Engineer or Engineering Geologist Details

Company/ Organisation Name		
Name (Company Representative)	Surname:	Mr /Mrs /Other:
	Given Names:	
	Chartered Professional Status:	Registration No:
Signature		Dated: / /

Note: * A separate Form B is required to be completed by the design engineer for those works listed in each of Sections 6 and 7 of this Form B.

FORM	C	Page 1 of 2 **Geotechnical Declaration** **Subdivision <*Construction Certificate*> Application**

Office Use Only		Regulator: *<Add in or change to appropriate name>*

To be submitted with an application for an engineering <*construction certificate*> for subdivision of land. This form must be attached to the application for the <*construction certificate*>.
This form is essential to verify that the geotechnical report has been prepared in accordance with <*Regulator's geotechnical DCP*> and that the author of the geotechnical report is a geotechnical engineer or engineering geologist as defined by <*Regulator's geotechnical DCP*>. Alternatively, where a geotechnical report has been prepared by a professional person not recognised by the <*Regulator's geotechnical DCP*>, then this form may be used as technical verification of the geotechnical report if signed by a geotechnical engineer or engineering geologist as defined by <*Regulator's geotechnical DCP*>.

Section 1	**Related Application**
Reference	What is the Regulator's Development Application Number?
DA Site Address	
DA Applicant	

Section 2	**Geotechnical Report**	
Details	Title:	
	Author:	Dated: / /
	Author's Company/ Organisation Name:	Report Reference No:

Section 3	**Declaration**
Declaration (Tick all that apply) Yes No	**I am a geotechnical engineer or engineering geologist as defined by the** <*Regulator's geotechnical DCP*> **and on behalf of the company below:**
☐ ☐	I prepared the geotechnical report referenced above in accordance with the AGS (2007c) as amended and the <*Regulator's geotechnical DCP*>.
☐ ☐	I am willing to technically verify that the geotechnical report referenced above has been prepared in accordance with the AGS (2007c) as amended and <*Regulator's geotechnical DCP*>.
☐ ☐	I have professional indemnity insurance in accordance with <*Regulator's geotechnical DCP*> of not less than $.... million, being in force for the year in which the report is dated, with retroactive cover under this insurance policy extending back to the engineer's first submission to <*the Regulator*>.
☐ ☐	I am aware that the geotechnical report I have either prepared or am technically verifying (referenced above) is to be submitted in support of an engineering <*construction certificate*> for subdivision of land for the proposed development site (referenced above) and its findings will be relied upon by <the *Regulator*> determining the engineering <*construction certificate*>.

FORM **C**

Geotechnical Declaration
Subdivision <*Construction Certificate*> Application

Section 4 Checklist

Geotechnical Requirements (Tick as appropriate, either Yes or No) Yes	No	**The following checklist covers the minimum requirements to be addressed in a geotechnical report in accordance with** <Add reference to specific section of> <*Regulator's geotechnical DCP*>. **This checklist is to accompany the report.**
☐	☐	The extent and stability of proposed embankments including those acting as retarding basins <*Add reference*>
☐	☐	Recommended Geotechnical testing requirements <*Add reference*>
☐	☐	Required level of geotechnical supervision for each part of the works as defined under AS3798 – Guidelines on Earthworks for Commercial and Residential Developments <*Add reference*>
☐	☐	Compaction specification for all fill within private subdivisions <*Add reference*>
☐	☐	The level of risk to existing adjacent dwellings as a result of a construction contractor using vibratory rollers anywhere within the site the subject of these works. In the event that vibratory rollers could affect adjacent dwellings, 'high risk' areas shall be identified on a plan and the engineering plans shall be amended to indicate that no vibratory roller shall be used within that zone <*Add reference*>
☐	☐	The impact of the installation of services on overall site stability and recommendations on short term drainage methods, shoring requirements and other remedial measures that may be appropriate during installation <*Add reference*>
☐	☐	The preferred treatment of any areas of unacceptable risk within privately owned allotments <*Add reference*>
☐	☐	Requirement for subsurface drainage lines <*Add reference*>
☐	☐	Overall suitability of the engineering plans for the proposed development <*Add reference*>
☐	☐	Risk mitigation plan defined <*Add reference*>

Section 5 Geotechnical Engineer or Engineering Geologist Details

Company/ Organisation Name		
Name (Company Representative)	Surname:	Mr /Mrs /Other:
	Given Names:	
	Chartered Professional Status:	Registration No:
Signature		Dated: / /

Reference: AGS (2007c) *"Practice Note Guidelines for Landslide Risk Management"*. Australian Geomechanics Society, Australian Geomechanics, V42, .N1, March 2007.

Note: <Add reference>: Add in the relevant section or page number of the listed geotechnical report which addresses each item.

FORM **D**

Geotechnical Declaration Minor Impact

Office Use Only		Regulator: *<Add in or change to appropriate name>*

This form may be used where minor construction works present minimal or no geotechnical impact on the site or related land. A geotechnical engineer or engineering geologist must inspect the site and/or review the proposed development documentation to determine if the proposed development requires a geotechnical report to be prepared to accompany the development application. Where the geotechnical engineer determines that such a report is not required then they must complete this form and attach design recommendations where required. A copy of this form with design recommendation, if required, must be submitted with the development application.

Note: In all situations, this form will need to be accompanied by Form B where the structural engineer or civil engineer certifies that any residential structure designed or erected in accordance with the plans and specifications prepared by the structural engineer or civil engineer achieve the performance requirements of Clause 1.3 of the current version of AS 2870.

Note: The use of this form does not preclude the geotechnical consultant from requiring a Geotechnical Report.

Section 1 Related Application

Reference	What is the Council Development Application Number?
DA Site Address	
DA Applicant	

Section 2 Documentation

List of Documents Reviewed
(More space on page two if required)

Description	Plan or Document No.	Revision or Version No.	Date	Author

Section 3 Declaration

Declaration
(Tick all that apply)

I am a geotechnical engineer or engineering geologist as defined by the *<Regulator's geotechnical DCP>* **and I have inspected the site and reviewed the proposed development at the DA Site Address described above. As a result of my consideration of the** *<Regulator's geotechnical DCP>*, of my site inspection and review of the documentation listed above, I have determined and declare that, on behalf of the company below**:**

Yes	No	
☐	☐	The current load-bearing capacity of the site will not be exceeded or be adversely impacted on by the proposed development, and
☐	☐	The proposed works are of such a minor nature that the requirement for geotechnical advice in the form of a geotechnical report, prepared in accordance with *<Regulator's geotechnical DCP>* is considered unnecessary for the adequate and safe design of the structural elements to be incorporated into the new works as there is no change to the current landslide risk on the site in accordance with AGS (2007c), and
☐	☐	In accordance with AS 2870 Residential Slabs and Footings, the site is to be classified as a type: _____
☐	☐	I have attached design recommendations to be incorporated in the structural design in accordance with this site classification.
☐	☐	I have professional indemnity insurance in accordance with *<Regulator's geotechnical DCP>* of not less than $.... million, being in force for the year in which the report is dated, with retroactive cover under this insurance policy extending back to the engineer's first submission to *<the Regulator>*.
☐	☐	I am aware that this declaration shall be used by *<The Regulator>* as an essential component in granting development consent for a structure to be erected on the site or related land without requiring submission of a geotechnical report complying with the *<Regulator's geotechnical DCP>* in support of the development application.

Reference: AGS (2007c) *"Practice Note Guidelines for Landslide Risk Management"*. Australian Geomechanics Society, Australian Geomechanics, V42, .N1, March 2007.

FORM **D**

Geotechnical Declaration
Minor Impact

Section 4 **Additional Documentation**

List of Documents Reviewed	Description	Plan or Document No.	Revision or Version No.	Date	Author

Section 5 **Geotechnical Engineer or Engineering Geologist Details**

Company/ Organisation Name		
Name (Company Representative)	Surname:	Mr /Mrs /Other:
	Given Names:	
	Chartered Professional Status:	Registration No:
Signature		Dated: / /

FORM	E	Page 1 of 2 **Geotechnical Declaration Remediation**

Office Use Only		Regulator: *<Add in or change to appropriate name>*

This form must be submitted where development must be staged for geotechnical reasons and remediation of the site to a <*tolerable risk*> is necessary prior to any further development continuing on the site.

This form is essential, as it provides verification at each stage of the development, prior to the next stage commencing, that the remediation of the site to a <*tolerable risk*> has been carried out in accordance with the requirements of the geotechnical report and <*add reference to specific section*> of <*Regulator's geotechnical DCP*> and that no unforeseen ground conditions have been encountered which could impact on the integrity of structures on site or related land or the landslide risk. The geotechnical engineer or engineering geologist who prepared and/or verified the report must carry out site inspections as determined by the report to ensure that the design(s) documented on Form(s) B have been completed prior to signing this form.

Section 1 Related Application

Reference	What is the Development Application number?	
DA Site Address		*Development Stage (s):*
DA Applicant		

Section 2 Geotechnical Report

Details	Title:	
	Author:	Dated: / /
	Author's Company/ Organisation Name:	Report Reference No:

Section 3 Declaration

Declaration (Tick all that apply) Yes	No	
		I am a geotechnical engineer or engineering geologist as defined by the <*Regulator's geotechnical DCP*> **and, on behalf of the company below:**
☐	☐	I inspected and am satisfied that the foundation materials upon which the structural elements of the development have been erected, complied with the requirements and recommendations specified in the geotechnical report for Stage (s) <*add* > of the development.
☐	☐	To the best of my knowledge, I am satisfied that Stage(s) <*add*> of the development referred to above have been carried out in accordance with all the requirements and recommendations of the above geotechnical report, and conditions of development consent relating to geotechnical issues.
☐	☐	To the best of my knowledge, I am satisfied that where changes to the development occurred during construction, those changes were carried out in accordance with all the requirements and recommendations of the above geotechnical report, conditions of development consent relating to geotechnical issues, and any site instructions or site reports issued by me as listed below.
☐	☐	I am aware that the <*PCA*> requires this certificate at the end of stage of the development specified in the development approval and prior to any further development continuing on the site and related land.
☐	☐	I am willing to technically verify that the site or related land will now achieve the level of <*tolerable risk*> of slope instability as defined by <*Regulator's geotechnical DCP*>.
☐	☐	I have professional indemnity insurance in accordance with <*Regulator's geotechnical DCP*> of not less than $.... million, being in force for the year in which the report is dated, with retroactive cover under this insurance policy extending back to the engineer's first submission to <*the Regulator*>.

Note: <*add*> relevant stage numbers to be inserted.

FORM	E	Page 2 of 2 **Geotechnical Declaration Remediation**

Section 4	**List of Site Instructions and/or Site Reports Issued**					
List of Documents Issued	Description/Title	Reference No.	Date	Author	Associated Design Drawings (tick as appropriate) Yes	No

Section 5	**Geotechnical Engineer or Engineering Geologist Details**	
Company/ Organisation Name		
Name (Company Representative)	Surname:	Mr /Mrs /Other:
	Given Names:	
	Chartered Professional Status:	Registration No:
Signature		Dated: / /

FORM	F	Page 1 of 2 **Geotechnical Declaration** **Final Structural/Civil Certificate**

Office Use Only		Regulator: *<Add in or change to appropriate name>*

This form must be submitted to the <*PCA*> at the completion of a project and prior to the issue of an <*occupation certificate*>.

This form is essential, as it provides evidence to the <*PCA*> that the development works have been carried out in accordance with the requirements of the structural design, any site inspections, and that any changes to the development occurring during construction, were carried out in accordance with all the requirements and recommendations of the structural design and geotechnical report, conditions of development consent relating to geotechnical issues, and any site instructions issued.

Section 1 Related Application

Reference	What is <*the Regulator's*> Development Application number?
DA Site Address	
DA Applicant	

Section 2 Geotechnical Report

Details	Title:	
	Author:	Dated: / /
	Author's Company/ Organisation Name:	Report Reference No:

Section 3 Structural Civil Design Documents appropriate to the 'as constructed' development

List of Structural Civil Design Documents
(More space on page two if required)

Description	Plan or Document No.	Revision or Version No.	Date	Author

Section 4 Declaration

Declaration
(Tick all that apply)

Yes	No	
		I am a structural or civil engineer as defined by the <*Regulator's geotechnical DCP*> and I prepared the above structural designs in accordance with the recommendations given in the geotechnical report described above on behalf of the company below. I:
☐	☐	inspected and am satisfied that the structural elements of the above development have been erected, and complied with the requirements and recommendations specified in the structural design and geotechnical report.
☐	☐	to the best of my knowledge, am satisfied that the above development has been carried out in accordance with all the requirements and recommendations of the structural design and above geotechnical report, and conditions of development consent relating to geotechnical issues.
☐	☐	to the best of my knowledge, am satisfied that where changes to the development occurred during construction, those changes were carried out in accordance with all the requirements and recommendations of the structural design and above geotechnical report, conditions of development consent relating to geotechnical issues, and any site instructions issued by me as listed below.
☐	☐	am aware that the <*PCA*> requires this certificate prior to issuing an<*occupation certificate*> for the above development and will rely on this certificate as verification that the above development has been erected, and complied with the requirements and recommendations specified in the structural design and geotechnical report as defined by <*Regulator's geotechnical DCP*> and in determining the <*occupation certificate*>.
☐	☐	have professional indemnity insurance in accordance with <*Regulator's geotechnical DCP*> of not less than $.... million, being in force for the year in which the report is dated, with retroactive cover under this insurance policy extending back to the engineer's first submission to <*the Regulator*>.

FORM **F**

Geotechnical Declaration
Final Structural/Civil Certificate

Section 5 List of Site Instructions Issued

List of Documents Issued

Description/Title	Reference No.	Date	Author	Associated Design Drawings	
				Yes	No

Section 6 Additional Design Documents

List of Additional Design Documents

Description	Plan or Document No.	Revision or Version No.	Date	Author

Section 7 Structural Engineer or Civil Engineer Details

Company/ Organisation Name		
Name (Company Representative)	Surname:	Mr /Mrs /Other:
	Given Names:	
	Chartered Professional Status:	Registration No:
Signature		Dated: / /

FORM	G	Page 1 of 2 **Geotechnical Declaration** **Final Geotechnical Certificate**
Office Use Only		Regulator: *<Add in or change to appropriate name>*

This form must be submitted to the <*PCA*> at the completion of a project and prior to the issue of an <*occupation or subdivision certificate*>.
This form is essential, as it provides verification that the development works have been carried out in accordance with the requirements of the geotechnical report during construction, and any site inspections, and that no unforeseen ground conditions have been encountered which could have an impact on the integrity of structures on site or related land and any subsequent geotechnical requirements introduced during the construction process.

Section 1 Related Application

Reference	What is the Development Application number?
DA Site Address	
DA Applicant	

Section 2 Geotechnical Report

Details	Title:	
	Author:	Dated: / /
	Author's Company/ Organisation Name:	Report Reference No:

Section 3 Work as Executed Drawings & Ongoing Maintenance Plans relevant to Geotechnical Risk Management

List of Documents (more space on page 2 if required)

Description	Plan or Document No.	Revision or Version No.	Date	Author

Section 4 Declaration

Declaration
(Tick all that apply)

Yes	No	
		I am a geotechnical engineer or engineering geologist as defined by the <*Regulator's geotechnical DCP*> and I prepared or verified the geotechnical report as described above on behalf of the company below. I:
☐	☐	inspected and am satisfied that the foundation materials upon which the structural elements of the development have been erected, complied with the requirements and recommendations specified in the geotechnical report.
☐	☐	to the best of my knowledge, am satisfied that the development referred to above has been carried out in accordance with all the requirements and recommendations of the above geotechnical report, and conditions of development consent relating to geotechnical issues.
☐	☐	to the best of my knowledge, am satisfied that where changes to the development occurred during construction, those changes were carried out in accordance with all the requirements and recommendations of the above geotechnical report, conditions of development consent relating to geotechnical issues, and any site instructions or site reports issued by me as listed below.
☐	☐	am aware that the <*PCA*> requires this certificate prior to issuing an occupation or subdivision certificate for the above development and will rely on this certificate as verification that the above development has achieved the necessary level of <*tolerable risk*> as defined by <*Regulator's geotechnical DCP*> and in determining the <*occupation or subdivision certificate*>.

FORM **G**

Geotechnical Declaration
Final Geotechnical Certificate

Section 5 **List of Site Reports or Site Instructions Issued**

List of Documents Issued	Description/Title	Reference No.	Date	Author	Associated Design Drawings Yes	Associated Design Drawings No

Section 6 **Additional Work as Executed Drawings and Ongoing Maintenance Plans relevant to Geotechnical Risk Management**

List of Additional Documents	Description	Plan or Document No.	Revision or Version No.	Date	Author

Section 7 **Geotechnical Engineer or Engineering Geologist Details**

Company/ Organisation Name		
Name (Company Representative)	Surname:	Mr /Mrs /Other:
	Given Names:	
	Chartered Professional Status:	Registration No:
Signature		Dated: / /

FORM	H	Page 1 of 2 **Geotechnical Declaration** **<*Building Certificate*> or Order**	
Office Use Only			Regulator: <*Add in or change to appropriate name*>

This form is to be submitted with Application for a <*Building Certificate*> or in response to an order.

Section 1	**Related Application**
Reference	What is the *Regulator's DA / BA / Order* number?
Site Address	
Applicant	

Section 2	**Geotechnical Report**	
Details	Title:	
	Author:	Dated: / /
	Author's Company/ Organisation Name:	Report Reference No:

Section 3	**Declaration**
Declaration (Tick all that apply) Yes No	**I am a geotechnical engineer or engineering geologist as defined by the <*Regulator's geotechnical DCP*> and I prepared or verified the geotechnical report as described above on behalf of the company below. I:**
☐ ☐	have inspected the site and existing development and am satisfied that both the site and development achieves <*tolerable risk*> level requirement of the <*Regulator's geotechnical DCP*>. The attached report provides details of the assessment in accordance with the <*Regulator's geotechnical DCP*>. The report also contains recommendations as to any reasonable and practical measures that can be undertaken to reduce foreseeable risk.
☐ ☐	have inspected the site of the existing development. The attached report details the remedial actions required to be undertaken prior to me being prepared to certify that the site and the development achieves the <*tolerable risk*> criteria required by the <*Regulator's geotechnical DCP*>.
☐ ☐	to the best of my knowledge, am satisfied that where changes to the development occurred during construction, those changes were carried out in accordance with all the requirements and recommendations of the above geotechnical report, conditions of development consent relating to geotechnical issues, and any site reports or site instructions issued by me as listed below.
☐ ☐	am aware that the <*PCA*> requires this certificate prior to issuing a <*Building Certificate*> for the above development and will rely on this certificate as verification that the development has achieved the necessary level of <*tolerable risk*> as defined by <*Regulator's geotechnical DCP*> and in determining the <*occupation or subdivision certificate*>.
☐ ☐	have professional indemnity insurance in accordance with <*Regulator's geotechnical DCP*> of not less than $.... million, being in force for the year in which the report is dated, with retroactive cover under this insurance policy extending back to the engineer's first submission to <*the Regulator*>.

FORM	H	Page 2 of 2 **Geotechnical Declaration** **<*Building Certificate*> or Order**

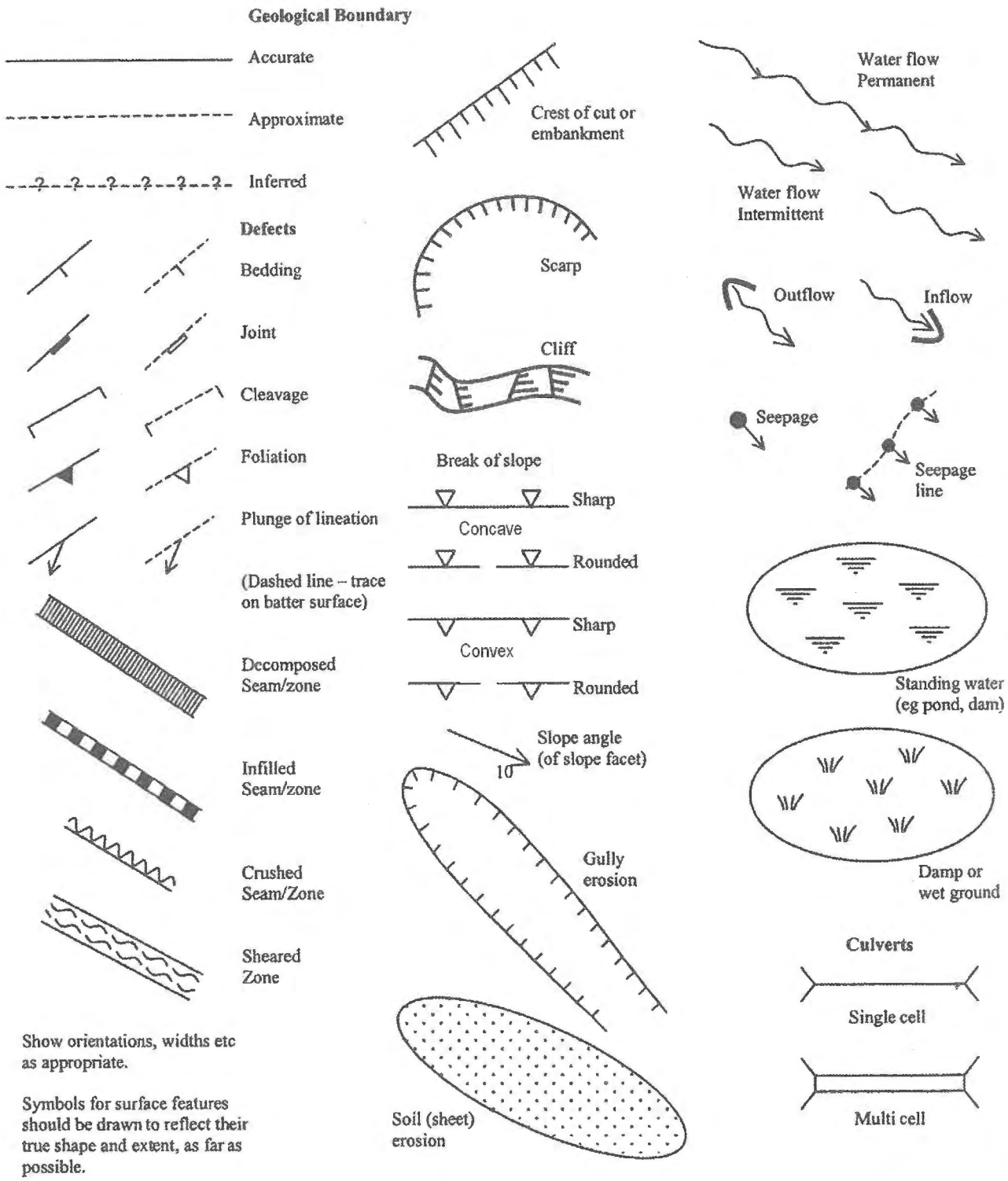
Section 4 **List of Site Reports or Site Instructions Issued**

List of Documents Issued	Description/Title	Reference No.	Date	Author	Associated Design Drawings	
					Yes	No

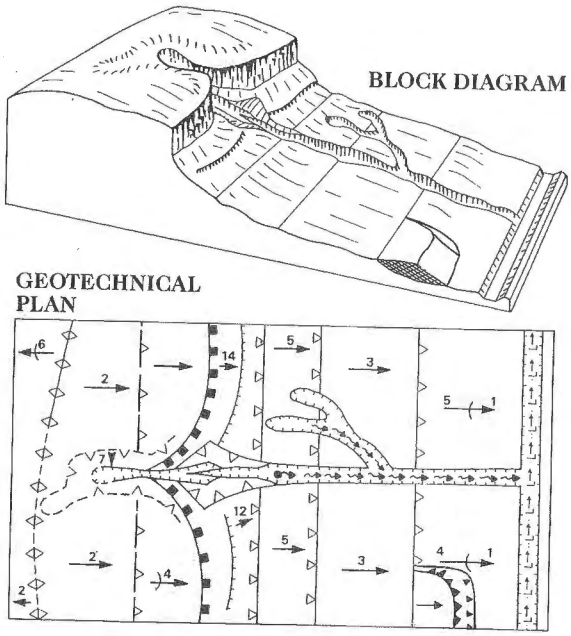
Section 5 **Geotechnical Engineer or Engineering Geologist Details**

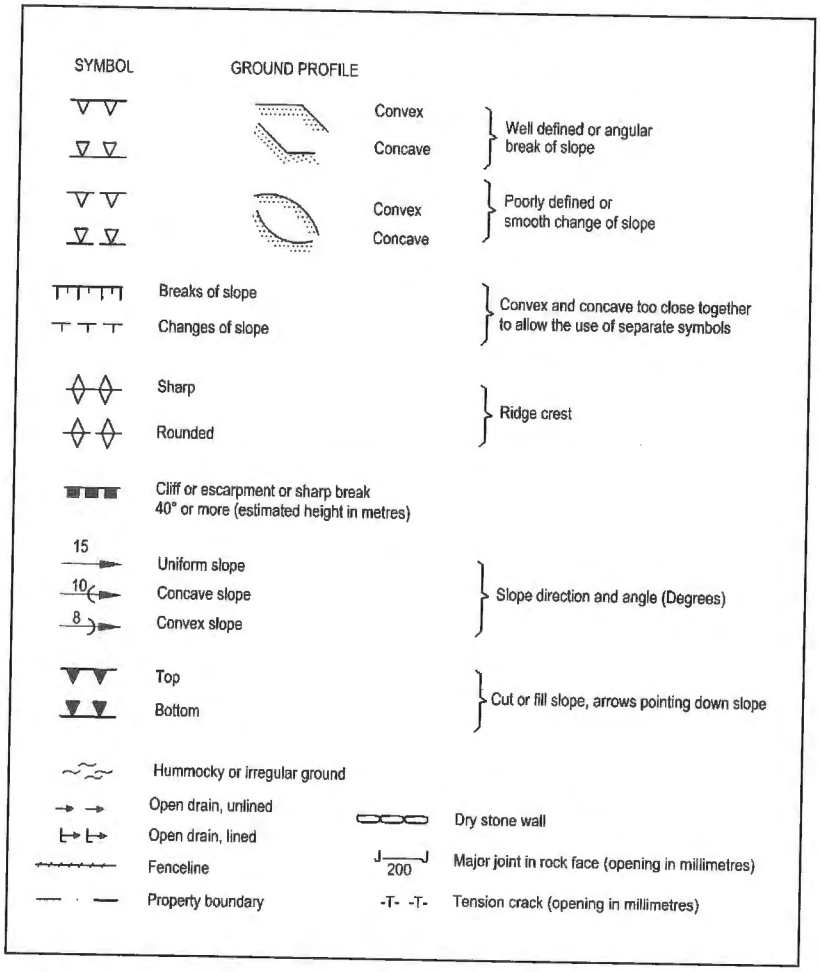
Company/ Organisation Name		
Name (Company Representative)	Surname:	Mr /Mrs /Other:
	Given Names:	
	Chartered Professional Status:	Registration No:
Signature		Dated: / /

APPENDIX E - GEOLOGICAL AND GEOMORPHOLOGICAL MAPPING SYMBOLS AND TERMINOLOGY



Examples of Mapping Symbols (after Guide to Slope Risk Analysis Version 3.1 November 2001, Roads and Traffic Authority of New South Wales).





Example of Mapping Symbols (after V Gardiner & R V Dackombe (1983).Geomorphological Field Manual. George Allen & Unwin).

APPENDIX F- EXAMPLE OF VULNERABILITY VALUES

SUMMARY OF HONG KONG VULNERABILITY RANGES FOR PERSONS, AND RECOMMENDED VALUES FOR LOSS OF LIFE FOR LANDSLIDING IN SIMILAR SITUATIONS

The following table is adapted from P J Finlay, G R Mostyn & R Fell (1999). *Landslides: Prediction of Travel Distance and Guidelines for Vulnerability of Persons.* Proc 8th. Australia New Zealand Conference on Geomechanics, Hobart. Australian Geomechanics Society, ISBN 1 86445 0029, Vol 1, pp.105-113.

Case	Range in Data	Recommended Value	Comments
Person in Open Space			
If struck by a rockfall	0.1 – 0.7	0.5	May be injured but unlikely to cause death
If buried by debris	0.8 – 1.0	1.0	Death by asphyxia almost certain
If not buried	0.1 – 0.5	0.1	High chance of survival
Persons in a Vehicle			
If the vehicle is buried/crushed	0.9 – 1.0	1.0	Death is almost certain
If the vehicle is damaged only	0 – 0.3	0.3	High chance of survival
Person in a Building			
If the building collapses	0.9 – 1.0	1.0	Death is almost certain
If the building is inundated with debris and the person buried	0.8 – 1.0	1.0	Death is highly likely
If the debris strikes the building only	0 – 0.1	0.05	Very high chance of survival

EXAMPLE OF VULNERABILITY VALUES FOR DESTRUCTION OF PEOPLE, BUILDINGS AND ROADS

The following table is adapted from Marion Michael-Leiba, Fred Baynes, Greg Scott & Ken Granger (2002). *Quantitative Landslide Risk Assessment of Cairns.* Australian Geomechanics, June 2002.

Geomorphic Unit	Vulnerability Values		
	People	Buildings	Roads
Hill slopes	0.05	0.25	0.3
Proximal debris fan	0.5	1.0	1.0
Distal debris fan	0.05	0.1	0.3

EXAMPLE OF VULNERABILITY VALUES FOR LIFE FOR ROCKFALLS AND DEBRIS FLOWS FOR LAWRENCE HARGRAVE DRIVE PROJECT, COALCLIFF TO CLIFTON AREA, AUSTRALIA

The following table is adapted from R A Wilson, A T Moon, M Hendricks & I E Stewart (2005). *Application of quantitative risk assessment to the Lawrence Hargrave Drive Project, New South Wales,Australia.* Landslide Risk Management - Hungr, Fell, Couture & Eberhardt (eds) 2005. Taylor & Francis Group, London, ISBN 04 1538 043X.

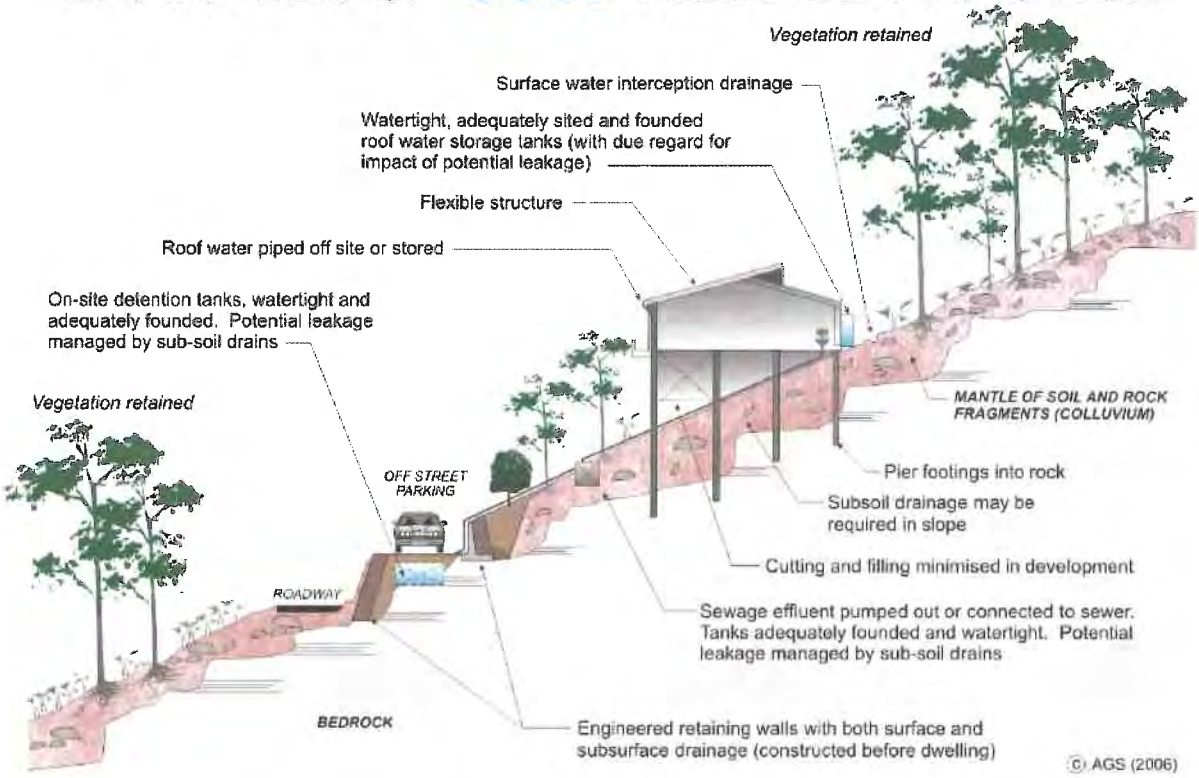
Order of magnitude of landslide crossing road (m^3)	**Rockfalls from Scarborough Cliff**		**Debris flow from Northern Amphitheatre**	
	Landslide hits car	**Car hits landslide**	**Landslide hits car**	**Car hits landslide**
0.03	0.05	0.006	–	–
0.3	0.1	0.002	–	–
3	0.3	0.03	0.001	–
30	0.7	0.03	0.01	0.001
300	1	0.03	0.1	0.003
3,000	1	0.03	1	0.003

NOTE: The above data should be applied with common sense, taking into account the circumstances of the landslide being studied. Judgment may indicate values other than the recommended value are appropriate for a particular case.

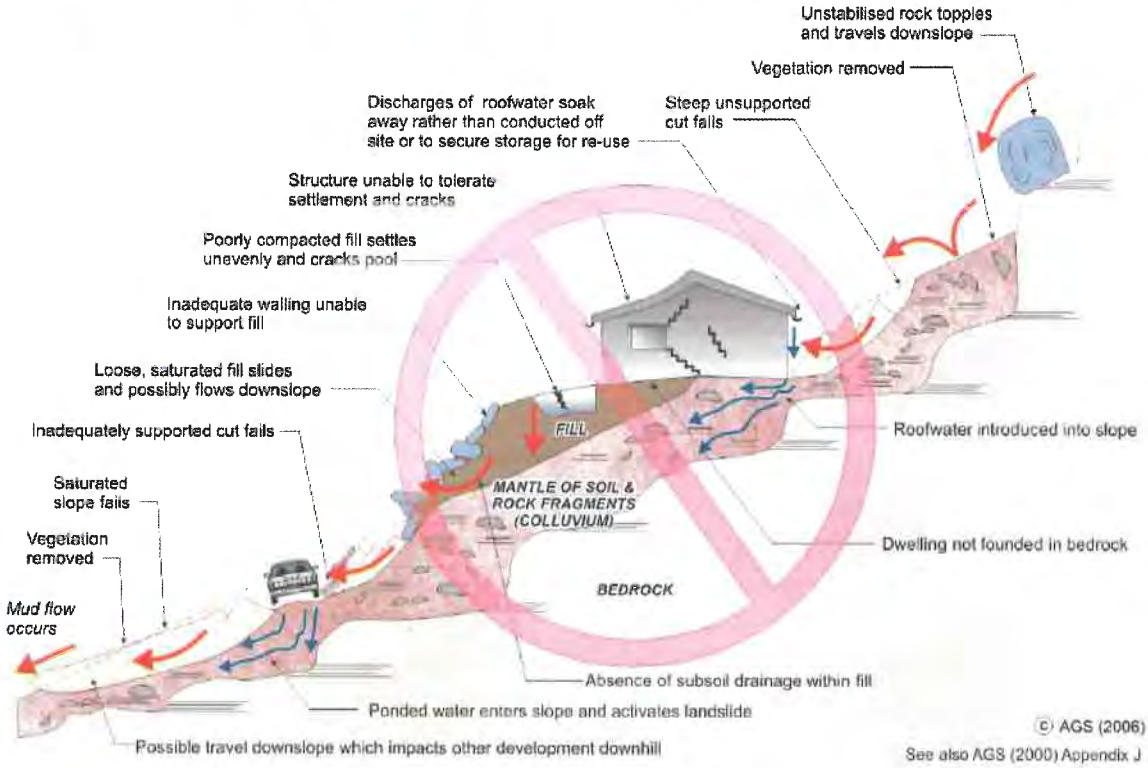
APPENDIX G - SOME GUIDELINES FOR HILLSIDE CONSTRUCTION

	GOOD ENGINEERING PRACTICE	*POOR ENGINEERING PRACTICE*
ADVICE		
GEOTECHNICAL ASSESSMENT	Obtain advice from a qualified, experienced geotechnical practitioner at early stage of planning and before site works.	Prepare detailed plan and start site works before geotechnical advice.
PLANNING		
SITE PLANNING	Having obtained geotechnical advice, plan the development with the risk arising from the identified hazards and consequences in mind.	Plan development without regard for the Risk.
DESIGN AND CONSTRUCTION		
HOUSE DESIGN	Use flexible structures which incorporate properly designed brickwork, timber or steel frames, timber or panel cladding. Consider use of split levels. Use decks for recreational areas where appropriate.	Floor plans which require extensive cutting and filling. Movement intolerant structures.
SITE CLEARING	Retain natural vegetation wherever practicable.	Indiscriminately clear the site.
ACCESS & DRIVEWAYS	Satisfy requirements below for cuts, fills, retaining walls and drainage. Council specifications for grades may need to be modified. Driveways and parking areas may need to be fully supported on piers.	Excavate and fill for site access before geotechnical advice.
EARTHWORKS	Retain natural contours wherever possible.	Indiscriminatory bulk earthworks.
CUTS	Minimise depth. Support with engineered retaining walls or batter to appropriate slope. Provide drainage measures and erosion control.	Large scale cuts and benching. Unsupported cuts. Ignore drainage requirements
FILLS	Minimise height. Strip vegetation and topsoil and key into natural slopes prior to filling. Use clean fill materials and compact to engineering standards. Batter to appropriate slope or support with engineered retaining wall. Provide surface drainage and appropriate subsurface drainage.	Loose or poorly compacted fill, which if it fails, may flow a considerable distance including onto property below. Block natural drainage lines. Fill over existing vegetation and topsoil. Include stumps, trees, vegetation, topsoil, boulders, building rubble etc in fill.
ROCK OUTCROPS & BOULDERS	Remove or stabilise boulders which may have unacceptable risk. Support rock faces where necessary.	Disturb or undercut detached blocks or boulders.
RETAINING WALLS	Engineer design to resist applied soil and water forces. Found on rock where practicable. Provide subsurface drainage within wall backfill and surface drainage on slope above. Construct wall as soon as possible after cut/fill operation.	Construct a structurally inadequate wall such as sandstone flagging, brick or unreinforced blockwork. Lack of subsurface drains and weepholes.
FOOTINGS	Found within rock where practicable. Use rows of piers or strip footings oriented up and down slope. Design for lateral creep pressures if necessary. Backfill footing excavations to exclude ingress of surface water.	Found on topsoil, loose fill, detached boulders or undercut cliffs.
SWIMMING POOLS	Engineer designed. Support on piers to rock where practicable. Provide with under-drainage and gravity drain outlet where practicable. Design for high soil pressures which may develop on uphill side whilst there may be little or no lateral support on downhill side.	
DRAINAGE		
SURFACE	Provide at tops of cut and fill slopes. Discharge to street drainage or natural water courses. Provide general falls to prevent blockage by siltation and incorporate silt traps. Line to minimise infiltration and make flexible where possible. Special structures to dissipate energy at changes of slope and/or direction.	Discharge at top of fills and cuts. Allow water to pond on bench areas.
SUBSURFACE	Provide filter around subsurface drain. Provide drain behind retaining walls. Use flexible pipelines with access for maintenance. Prevent inflow of surface water.	Discharge roof runoff into absorption trenches.
SEPTIC & SULLAGE	Usually requires pump-out or mains sewer systems; absorption trenches may be possible in some areas if risk is acceptable. Storage tanks should be water-tight and adequately founded.	Discharge sullage directly onto and into slopes. Use absorption trenches without consideration of landslide risk.
EROSION CONTROL & LANDSCAPING	Control erosion as this may lead to instability. Revegetate cleared area.	Failure to observe earthworks and drainage recommendations when landscaping.
DRAWINGS AND SITE VISITS DURING CONSTRUCTION		
DRAWINGS	Building Application drawings should be viewed by geotechnical consultant	
SITE VISITS	Site Visits by consultant may be appropriate during construction/	
INSPECTION AND MAINTENANCE BY OWNER		
OWNER'S RESPONSIBILITY	Clean drainage systems; repair broken joints in drains and leaks in supply pipes. Where structural distress is evident see advice. If seepage observed, determine causes or seek advice on consequences.	

EXAMPLES OF GOOD HILLSIDE PRACTICE



EXAMPLES OF POOR HILLSIDE PRACTICE



COMMENTARY ON PRACTICE NOTE GUIDELINES FOR LANDSLIDE RISK MANAGEMENT 2007

Australian Geomechanics Society Landslide Taskforce, Landslide Practice Note Working Group

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COMMENTARY ON PRACTICE NOTE GUIDELINES FOR LANDSLIDE RISK MANAGEMENT 2007

PART A BACKGROUND

C1 INTRODUCTION

C1.1 PREAMBLE

In 2000 the Australian Geomechanics Society (AGS) published "Landslide Risk Management Concepts and Guidelines" (AGS 2000). In 2002 the content and application of AGS (2000) were demonstrated around Australia by "the Risky Roadshow" which was sponsored by Emergency Management Australia and AGS. Papers for the "Roadshow" were published in Australian Geomechanics Vol 37 No 2 May 2002. Since then there have been many published papers and an extensive body of discussion which has progressed the use of Landslide Risk Management (LRM) as discussed further below.

C1.2 PURPOSE

In preparing the Practice Note Guidelines for Landslide Risk Management (AGS 2007c) ('the Practice Note') , the intention has been to limit the document in so far as is possible to a clear and concise set of recommended requirements and principles. The purpose of this Commentary is to provide additional background, relevant references, comments and guidance relevant to the Practice Note.

C1.3 SCOPE

Since publication of AGS (2000) there have been many published papers and discussion which have progressed Landslide Risk Management (LRM) in particular and risk management in general. It would be an almost impossible task to distil all the thoughts and useful developments that are contained in the publications listed below and others. Nonetheless, the interested reader should refer to some, or all, of these to gain a greater understanding.

For example:

- Bowden, Lane and Martin (2001) "Triple Bottom Line Risk Management" which considers risk management in a broader business management context with aims to achieve benefits to the social, environmental and financial accountability of a business.
- Vick (2002) "Degrees of Belief, Subjective Probability and Engineering Judgment" which has extensive discussion of the basis behind LRM and examples. In particular it discusses subjective probability in some detail.
- AGS (2002) "Risky Roadshow" which provides some examples of qualitative and quantitative LRM.
- RTA NSW "Guide to Slope Risk Analysis Version 3.1" (Stewart *et al.*, 2002) which provides a specific LRM methodology for roads.
- ANCOLD (2003) "Guidelines on Risk Assessment" which provides useful guidelines and commentary in relation to dams. As part of the consideration for dams (that is stability of embankment dams) is similar to landslides, this document forms a very useful companion reference and is recommended reading for examples of the detailed assessment process.
- Lee & Jones (2004) "Landslide Risk Assessment" which examines the issues and literature in considerable detail, with numerous examples from various published papers. These examples can provide guidance on how to tackle particular problems and is a valuable reference.
- Standards Australia HB436:2004 "Handbook; Risk Management Guidelines Companion to AS/NZ 4360:2004" which discusses risk management in general terms, including consideration of the elements involved.
- "Landslide Risk Management" (2005) Proc Intl Conference on Landslide Risk Management June 2005 in Vancouver. This volume provides a wealth of up to date information and examples in relation to LRM. It includes six state of the art papers. Picarelli *et al.* (2005) provides a comprehensive discussion of hazard characterization and quantification. Leroi *et al.* (2005) which provides a comprehensive discussion on Acceptable Risk and tolerable loss of life criteria. Knowledge of the contents of this volume is a useful background for an experienced practitioner in LRM. This volume also provides a number of case history type papers and an extensive list of references for the interested reader or practitioner seeking examples or further guidance on specific issues.
- Glade *et al.* Eds (2005) "Landslide Hazard and Risk" which provides further discussion and examples.

In view of the developments included in the above, and as a number of Australian Government bodies have existing geotechnical policies or have developed draft policies which are based on the principles of AGS (2000), it was

considered appropriate to develop updated guidelines and commentary for the use of both regulators and practitioners. In particular, the Practice Note should provide a reference document for legislative purposes. The Practice Note was initially developed as an update of AGS (2000). However, during development it became clear that it would be unworkable to merely update parts of AGS (2000) and leave other parts unaltered. Therefore, the Practice Note supersedes AGS (2000). Consequently, it is anticipated that legislation will refer to and/or be based on the Practice Note.

The Practice Note has been formulated to be prescriptive in content. This has the advantage to the regulator that the scope of LRM reports is better defined and to the practitioner that, in general, the required quality of LRM reports is known. Some practitioners perceive that prescriptive requirements will stifle innovation and ingenuity. The Working Group considers that innovation and ingenuity are an essential part of applying the principles given in the Practice Note. The important message is to document the LRM assessment process including definition of terminology used.

The Practice Note has specifically excluded detailed consideration of roads and railways (or similar). The state–of-the-art paper by Picarelli *et al.* (2005) provides detailed advice on how these should be considered for LRM.

C1.4 CONVENTIONS USED

The Practice Note has been kept to a format similar to that adopted in the ANCOLD (2003). The paragraphs in bold type represent recommendations from AGS. This Commentary has section numbers that correspond directly to those used in the Practice Note.

Further discussion of the issues and considerations relevant to the guidance given in the Practice Note are provided in this Commentary where appropriate. The Commentary may also provide comment on whether the relevant practice is well accepted by experienced practitioners or under discussion with contending points of view.

Throughout the Practice Note and this Commentary, reference to "landslide" includes both existing (or known landslides) and potential landslides, which a practitioner might reasonably predict based on the relevant geometry, geology and slope forming processes and experience.

C1.5 STAKEHOLDERS

No additional comment.

C2 RISK TERMINOLOGY

The technical jargon associated with risk terminology can be confusing initially to the lay person or inexperienced practitioner. However, it is necessary to use such terminology to convey succinct ideas or facts. The main terms can be expressed in simple plain English terms as follows:

What might happen?	What are the landslide types?
How big might they be?	What are the landslide characteristics?
How often do they occur?	What is the Frequency (LIKELIHOOD)?
What damage or injury might result?	What are the CONSEQUENCES?
How important is it?	What is the RISK?
What can be done about it?	What are the RISK TREATMENT options?
Has everyone understood the above?	Has the treatment plan been properly communicated?

A generalised discussion of terminology and concepts is given in "HB 436:2004 Risk Management Guidelines, Companion to AS/NZS 4360:2004" (Standards Australia 2004). The principles of AS/NZS 4360 have been embodied in the Practice Note. However, the terminology has evolved for LRM and Practice Note Appendix A presents the current internationally agreed terminology for landslides.

Usage of the terminology since AGS (2000) was published has shown that the term "hazard" has frequently been used incorrectly to encompass the landslide characteristics but not the likelihood of occurrence (frequency). The definition of hazard in AGS (2000) and in the Practice Note includes the likelihood of the landslide and is consistent with the internationally adopted definition.

The flow chart in Figure 1 of the Practice Note demonstrates how the various terms interrelate. This flowchart is similar to Figure 1 in AGS (2000) but is in a simplified form. Also the Practice Note Figure 1 correctly shows the relationship for Hazard Analysis, which must include the frequency analysis as a result of the formal definition. Landslide Characterisation was previously inferred, incorrectly, to be the Hazard Identification.

The practitioner must be careful to use the terms given in Appendix A of the Practice Note consistently and correctly in relation to their defined meaning. Rigour in their use reduces possible misunderstanding. In this context, it is noted that

frequently the public, the media and published papers colloquially use "risk" when they really mean frequency or probability (likelihood).

Further, the Practitioner should be aware that the literature may be confusing as terms used may not be defined or may have changed their meaning with time.

PART B GUIDELINES FOR REGULATORS

C3 GUIDELINES FOR REGULATORS

C3.1 BACKGROUND

The regulator is the regulatory authority (at Federal Government / State Government / Instrumentality / Regional / Local Authority or Council level) having statutory responsibility for community activities, community safety and development approval or management of development within its defined area / region. (Practice Note, Appendix A).

Where landsliding is a possible threat to development, either planned or existing, then the regulator has a duty of care, if not a statutory requirement, to consider LRM as part of its planning process. The companion AGS Guidelines for Landslide Susceptibility, Hazard and Risk Zoning for Land Use Planning (AGS 2007a) provides detailed guidance in relation to this aspect.

The results of zoning studies will be considered by the regulator and implemented as appropriate controls and regulations to cover approvals for subsequent specific development applications.

It is not the intention of the Practice Note and Commentary to provide regulators with all the detail required for establishment and administering of a planning or control scheme, due to the possible variations from state to state and local considerations. It is, however, expected that the LRM principles will be appropriately considered and implemented.

C3.2 RELEVANCE TO APPROVAL PROCESS

Once planning controls are in place and general constraints are established (based on studies in accordance with AGS 2007a), then, where required by the planning controls, each individual development proposal will require specific consideration by the regulator. The planning controls may require a LRM assessment as part of the proposal application documentation for consideration as part of an approvals process. If so, the LRM assessment will need to consider the specific development proposals in relation to the geotechnical model for the site and its surrounding area to determine appropriate risk reduction and maintenance strategies. The extent of the surrounding area considered must be sufficient to identify those landslides that may impact on or be impacted by the site.

The requirement for an LRM assessment may still be imposed by the regulator where landslide risk is identified as an issue even if there are no broad planning studies to initiate it. The basis for such implementation may be local knowledge and experience or the nature of the proposed development.

The regulator will consider the LRM assessment submission together with other application documentation and will determine whether (having regard to the outcomes of the LRM assessment) the development should proceed and if any consent conditions should be applied to the proposal. Risk control measures will form an essential and integral component of the conditions. The regulator will take into account the subsequent process of documentation and inspection during detailed design and construction. Often these subsequent phases are not under the direct control of the regulator and this lack of control must be reflected in the consent conditions.

Where appropriate, the regulator may engage its own practitioner to provide independent advice on LRM reports submitted before any decision on the use and/or development proposal is finalised and consent conditions are stipulated. Alternatively, the regulator could employ its own practitioner for "in-house review" or require submission of a "peer review" report in addition to the LRM report.

Clients and builders must be aware of the implications of consent conditions in relation to the requirements for inspections, testing and confirmation during construction. The required inspections and testing should be carried out during construction, so that compliance with consent conditions can be demonstrated. Without this inspection and testing, compliance can be very difficult and/or costly, if not impossible, to achieve. This predicament can be problematic for the client and may also cause the practitioner difficulties and unwarranted liability exposure. In accordance with good practice, the practitioner can not approve or "certify" work completed if it was not inspected by the practitioner in accordance with consent conditions, unless additional investigations have been completed to satisfy the practitioner as to the extent and quality of the work completed. The regulator should not give the final completion

certificates if the required work, including inspection and testing, has not been completed in accordance with the consent conditions.

Ongoing maintenance may be a requirement of the risk mitigation strategy. This aspect is discussed in Section 9 of the Practice Note and makes reference to the Geoguides (AGS 2007e). Regulators may require annotation on the land title to draw the attention of future land owners to the need for maintenance and the existence of a risk mitigation strategy.

Existing development may still be subject to LRM assessment by imposition of Orders (or similar statutory instrument) to investigate and rectify situations which may appear, or are known, to be unsatisfactory.

C3.3 POLICY REQUIREMENTS

Policy Requirements are intended to be prescriptive so that the principal elements are covered by each policy. Individual regulators may have specific additional considerations or requirements relevant to specific hazards or planning requirements within their jurisdiction. A policy should advise if one particular qualitative terminology (such as the Practice Note Appendix C) is preferred and whether other terminologies will be accepted and under what circumstances.

In addition, the resulting requirements for the practitioner are also intended to be prescriptive. Such prescription is considered to be appropriate as experience has shown that a number of practitioners do not fully comply with the procedures nor do they justify such non compliance. This is to the detriment of the community.

Such prescription is not to prevent some flexibility or innovation in application of policy requirements where the practitioner provides an appropriate documented justification. Such justification must be technically sound.

Early completion of planning studies in accordance with AGS (2007a) will assist with determining appropriate detail and specific mandatory requirements for individual policies.

The regulators should seek review by and input from local practitioners before final publication of a policy to confirm that particular local needs and conditions have been adequately addressed.

C3.4 PROCESSING REQUIREMENTS

Local government and other regulators must establish strong internal procedures for dealing with land use and development proposals on land situated within a landslide susceptibility zone which requires LRM under legislation / regulation. Staff will require training, not only in the procedures themselves, but also in regards to the basis of landslide mechanisms, LRM and dealing with geotechnical reports and practitioners. Such procedures may include the adoption of peer review or independent advice by appropriately experienced practitioners should sufficient knowledge not be available “in house” or in the event of contentious situations.

The use of recommended processing forms (such as the example forms in the Practice Note Appendix D or similar tailored to suit local specific requirements) should simplify the approval by non technical staff of the regulator by acting as a checking template. (The Working Group notes that similar forms have been successfully used by Pittwater, Gosford and Wollongong Councils and for Kosicuisko area in NSW.) Staff may not be required to understand the technical content of the LRM reports submitted since “self-certification” by the practitioner, via the completed forms, provides a basis, both technically and legally, for the regulator to accept the content. Nonetheless, the regulator should confirm compliance of LRM submissions with the policy requirements. Where the practitioner has to complete declarations, the regulator should confirm that the declaration is appropriately completed and not omitted. For both parties, the forms will assist with quality control and liability issues.

In view of the specialized nature of some LRM aspects, the verification process may rely on confirmation by the practitioner that the design drawings have appropriately incorporated the landslide risk control measures identified in the LRM assessment. The verification process would usually not be a review or check of the structural or civil design and should clearly state this unless commissioned otherwise. The verification process may be documented by control forms covering the scope of design needed to cover the risk control measures, such as Form B in Appendix D of the Practice Note, to cover each design professional’s documents.

Processing of approvals may have costs which regulators may wish to include within the application fee.

Adoption of a NPER (LRM) category will provide a bench mark for regulators to determine the competency of practitioners for submission of LRM assessments. The Regulator may include a requirement for the Practitioner to submit documentary evidence of registration and/or qualifications with the completed forms. Similarly, a client may request such documents.

C3.5 ESTABLISHMENT OF TOLERABLE RISK CRITERIA

The regulator is responsible for setting the Tolerable Risk Criteria within their policy. Consideration has to be given to uniformity of approach and the risk values adopted. The discussion in Section C8.2 is provided to give as much technical guidance as is considered to be currently available from practice and literature. The regulator may wish to seek its own technical advice in relation to adoption of specific Tolerable Risk Criteria and details of the policy.

C3.6 LANDSLIDE INVENTORY

Refer to AGS (2007a) for recommendations in relation to the content of the inventory. Compilation of an inventory will become a valuable tool for both the regulator and the practitioners.

Such an inventory may also refer to LRM reports prepared for development applications, though if there is no known landslide this should be documented to avoid confusion. Although LRM reports may be restricted in use under intellectual property rights (copyright), such documents are in the public domain once included with a formal application and may be referred to.

C3.7 ROLE AND RESPONSIBILITY OF THE PRACTITIONER

The practitioner has the role and responsibility of providing the technical advice to the client, as well as to the regulator. Although the practitioner is responsible to his client, there is an overarching responsibility associated with the Code of Ethics to the public at large. This overarching responsibility is not insignificant. The practitioner must provide his advice in an unbiased manner and with the duty to the public at large in mind in accordance with the Code of Ethics of a professional association.

Compliance by the practitioner with the regulator's policy requirements would be expected unless departures can be justified on sound technical grounds.

Practitioners should be aware of the liability issues associated with signing the declarations on the Forms (Appendix D, Practice Note) submitted with the LRM reports and at subsequent stages. As part of the "in house" risk management procedures, the practitioner should only sign off what is reasonably known by observation and/or testing to be adequate or appropriate to the intent of the design requirements. This would also be in accordance with most Professional Indemnity insurance limitations.

PART C GUIDELINES FOR PRACTITIONERS

C4 SCOPE DEFINITION

Implicit in the scope will be compliance with the requirements of the regulator's policy. Such requirements are likely to be derived from studies in accordance with the AGS (2007a).

Such studies, and resulting policy, may determine a particular minimum scope or level of study, as discussed in Section C5.2. If the minimum scope is not completed, then the reasons for departure from such a scope should be documented by the practitioner.

In more complex studies, staged study may be appropriate, so that increasing complexity of study is only adopted if the results obtained from the initial studies show it to be warranted. It may be appropriate to discuss with the client the alternative levels of study and implications arising therefrom.

Frequently a lay client will not have sufficient knowledge to question whether the scope is appropriate. If there may be a need to extend the scope of the assessment, based on the results of the initial assessment or response from the regulator, then it would be "good practice" to advise the client at the earliest opportunity of the possibility of such an extension

Communication of the scope adopted and inherent limitations arising therefrom becomes "good practice" for the practitioner as a liability risk management issue. It is essential that the client be informed of the limitations of the particular risk assessment and inherent uncertainty.

C5 HAZARD ANALYSIS

C5.1 DATA GATHERING / DESK STUDY

Proper recording of data, including sources, is an aid to subsequent review and possible revision as additional data comes to light.

A useful data source should be the local council (or regulator) who may have a "database" of experience, though it may be somewhat informal. Councils (regulators) are encouraged to set up a landslide inventory in accordance with AGS (2007a) which should be updated with reports of landslides and the damage resulting. Where information becomes available to Council through reports that may have intellectual property rights limitations (copyright), then a summary of salient data and reference to the holder of the copyright would be appropriate. The Council has an obligation to make such data readily available to practitioners working in the area to enable them to be fully informed. Provision of such data enables the practitioner to better understand the local conditions and performance history and will enable the regulator to reduce potential exposure to liability issues. Appropriate disclaimers or privacy considerations may also have to be observed.

Relevant maps and aerial photographs may be available from other government departments/ agencies. Images available on the web, such as from "google earth", may assist.

For studies of larger areas (rather than individual lots), aerial photographs may form a useful data source. Air photo interpretation using stereo pairs can assist with slope morphology and identification of geological features. Examination of aerial photographs, if available, taken over a number of years may assist in determining site and landuse changes that may have occurred with time at the site or surrounding area. Evidence of past instability may be available from such photographs. Often the small scale of available aerial photographs will limit detail, particularly at the level of individual residential lots.

C5.2 FIELD INVESTIGATION REQUIREMENTS

The investigations completed need to be sufficient to provide confidence in the geotechnical model, notwithstanding the uncertainties inherent. Table C1 lists the questions to be addressed in landslide investigations (Fell *et al.*, 2000).

Table C1: Questions to be addressed in slope stability and landslide investigations (Fell *et al.*, 2000)

1	Topography?	1.1	In the landslide source and potential travel path.
		1.2	Effect and timing of natural and human activity on the topography.
2	Geological setting?	2.1	Regional stratigraphy, structure, history (eg. glaciation, sea level submergence and emergence).
		2.2	Local stratigraphy, slope processes, structure, history.
		2.3	Geomorphology of slope and adjacent areas.
3	Hydrogeology?	3.1	Regional and local groundwater model?
		3.2	Piezometric pressures within and around the slide?
		3.3	Relationship of piezometric pressures to rainfall, snowfall and snowmelt, temperature, streamflows, reservoir levels, both seasonally and annually?
		3.4	Effect of natural or human activity?
		3.5	Groundwater chemistry and sources.
		3.6	Annual exceedance probability (AEP) of groundwater pressures.
4	History of movement?	4.1	Velocity, total displacement, and vectors of surface movement?
		4.2	Any current movements and relation to hydrogeology and other natural or human activity?
		4.3	Evidence of historic movement and incidence of sliding (eg. lacustrine deposits formed behind a landslide dam, shallow natural slides, or failures of cuts and fills).
		4.4	Geomorphic or historic evidence of movement of slope or adjacent slopes.
5	Geotechnical characterisation of the slide or potential slide?	5.1	Stage of movement (pre failure, post failure, reactivated, active).
		5.2	Classification of movement (eg. slide, flow).
		5.3	Materials factors (classification, fabric, volume change, degree of saturation).
6	Mechanisms and dimensions of the slide or potential slide?	6.1	Configuration of basal, other bounding, and internal rupture surfaces?
		6.2	Is the slide part of an existing or larger slide?
		6.3	Slide dimensions, volume?
		6.4	Is a slide mechanism feasible?
7	Mechanics of shearing and strength of the rupture surface?	7.1	Relationship to stratigraphy, fabric, pre existing rupture surfaces.
		7.2	Drained or undrained shear?
		7.3	First time or reactivated shear?
		7.4	Contractant or dilatant?
		7.5	Saturated or partially saturated?
		7.6	Strength pre and post failure, and stress-strain characteristics.
8	Assessment of stability?	8.1	Current, and likely factors of safety allowing for hydrological, seismic and human influences?
		8.2	AEP of failure (factor of safety ≤ 1)?
9	Assessment of deformations and travel distance?	9.1	Likely pre failure deformations?
		9.2	Post failure travel distance and velocity?
		9.3	Likelihood of rapid sliding?

Whilst such questions are aimed at the investigation of specific existing landslides of a moderate to large size, they are also useful to keep in mind for an assessment at a walk-over level such as for an individual residential block.

The applicability of various investigation methods is ranked in Table C2 (Fell *et al.*, 2000) for different types of slopes.

Table C2: Application of site investigation methods to slope classes (Fell *et al.*, 2000)

SITE INVESTIGATION METHOD	NATURAL SLOPES			CONSTRUCTED SLOPES				
	Small/ Shallow	Medium	Large	Existing Cut	Existing Fill	New Cut	New Fill	Soft Clay
Topographic mapping and survey	A	A	A	A	A	A	A	A
Regional geology	A	A	A	A	A	A	A	A
Geological mapping of project area	B	B	A	A	B	A	B	C
Geomorphological mapping	A	A	A	B	B	B	B	D
Satellite imagery interpretation	D	D	C	D	D	D	D	D
Air photograph interpretation	A	B	A	C	C	C	C	C
Historic record	A	B	B	A	B	B(2)	B(2)	B(2)
Dating past movements	B	C	B	D	D	D	D	D
Geophysical methods	C	C	B	C	C	C	D	C
Trenches and pits	B	A	B	B	B	B	B	C
Drilling/boring	C	A	A	C	B	B	B	A
Downhole inspection	C	B	B	C	D	C	D	D
Shafts and tunnels	D	C	B	D	D	D	D	D
Insitu testing of strength and permeability	C(3)	C(3)	C(4)	D	B(3)	C	C	A(3)
Strength and permeability monitoring pore pressures, rainfall, etc	C	A	A	A	A	C	C	A(5)
Monitoring of displacements	C	B	A	B	B	B(5)	C(5)	A(5)
Laboratory testing	C	A	B	B	B	B	C	A
Back analysis of stability	C	B	A	C	B	B(2)	C(2)	C(2)

NOTES: (1) A – Strongly applicable, B – Applicable, C – May be applicable, D – Seldom applicable.
(2) In similar areas.
(3) SPT, CPT, CPTU.
(4) Permeability.
(5) During construction.

The driver / purpose of the field investigations is to understand the geotechnical model, possible landslide causes and triggers. Field investigations should start with a walk-over survey, including diligent field mapping to record the geomorphic features. These should be drawn to scale on plans and sections to provide a sound methodology of observation which can then lead to a preliminary geotechnical model and an understanding of the slope forming processes applicable. Subsequent subsurface investigations help refine the preliminary geotechnical model.

Moon and Wilson (2004) advise "particular skills and knowledge bases relevant to developing slope models include understanding of:

- Slope failure mechanisms.
- Landslide travel distances and speeds.
- The relationship between landslides and the intensity and duration of rainfall.
- Landslide hydrogeology.
- Landslide formation process rates."

References are given by Moon and Wilson (ibid) for examples of the above.

The scope of work may vary depending on the level of the study completed, even within the complying scope. Indicative levels of study would be:-

- **Reconnaissance:** to establish the broad topography, evidence of past instability and geology on a regional scale or as a screening process to aid determination of scope of subsequent studies.
- **Walk-over:** to establish site (or area) specific topography and detailed observation of relevant features such as outcrops, topographic form and evidence of past instability. Some initial subsurface investigation may also be completed.

- **Preliminary design:** to provide sufficient data to enable the concept designs to be selected from possible alternatives based on the risk management requirements.
- **Detailed design:** to enable design of risk control measures to be optimised and to remove sufficient uncertainty such that the design will be satisfactory.
- **Construction:** to confirm the design assumptions and allow modification to the design sufficient to address departures from the assumed geotechnical model.

Not all levels of study will be applicable for every project. For example, for some cases completion of a walk-over investigation may be sufficient to allow detailed design to be completed satisfactorily. For more complex projects, the investigations may be completed in stages (for different levels) to enable the geotechnical model to be progressively refined and uncertainties reduced. The levels of study form a continuum and furthermore the scope will vary from project to project.

The appropriate level for residential LRM should be set out in the regulator's policy and should be at least to a walk-over level but with subsurface investigation as needed to establish the subsurface profile. Preliminary and/or detailed design level investigations may only be warranted once the consent conditions have been set. Such consent conditions may include the requirement to complete the more detailed investigations so that the risk control measures may be properly designed and constructed.

The prescriptive requirements given in the Practice Note are considered to be "best practice" for LRM of individual lots or possibly for subdivision assessments. They would also be applicable for investigation of a particular landslide or area, but should be completed to a more comprehensive level.

Monitoring of ground water levels and responses to rainfall events would be ideal. However, practical limitations (including cost and time) limit how often such monitoring is likely to be completed. Frequently a qualitative assessment is likely to be sufficient. For stabilisation by subsurface drainage some monitoring before and after installation of the drainage measures will be required to enable the effectiveness of such drainage to be assessed.

If a practitioner does not comply with the requirements of a policy, then it should be fully documented in the report as to why not.

C5.3 LANDSLIDE CHARACTERISATION

No further comment.

C5.4 FREQUENCY ANALYSIS

5.4.1 Techniques for Frequency Analysis

i) *Main Techniques*

The Practice Note outlines the main techniques which are routinely adopted. AGS (2000) Appendix C provides further discussion. Lee and Jones (2004) and Picarelli *et al.* (2005) provide more detailed discussion and examples from published papers.

ii) *Limitations for Historical Analysis*

The Working Group notes that, in Australia, gathering of historical knowledge is not usually as easy or fruitful as it should be. Experience shows that local government seldom has a complete listing and records become difficult to retrieve, whilst local papers tend to concentrate on "the human aspect" with little factual documentation, not even of date and time of a landslide event, nor the extent and nature of the landslide. Notwithstanding this, a listing of landslide events (as a basic inventory) is of relevance and aids in assessment of likelihood. Much of the data on the incidence of landslides is held by consultants who work in the area. There would be considerable benefits if local government authorities gathered the data held by all the consultants who work in their area and established an inventory which could be accessed by all.

Within Australia an inherent limitation is likely to be the relatively short time period that development has been exposed to landslides. Historically, original development tended to avoid problem areas based on common sense and possibly trial–and-error. If historical records are limited to say 30 years, then the frequency of single events will be limited to a basic 1 in 30 probability (about 0.03), though this may be modified by the probability of trigger events during that period, and response within a population of similar landslides in similar geology and geomorphology. Table C3 shows the length of historical record required to estimate return periods with selected reliability.

Table C3: The length of historical record required to estimate return period events with 95% and 80% reliability.

Return Period (Years)	Length of record in years required to deliver reliability of return period estimate	
	95% reliable	80% reliable
2.33	40	25
10	90	38
25	105	75
50	110	90
100	115	100

From Lee and Jones (2004) after Benson (1960).

With sufficient data it may be possible to formulate Frequency vs Magnitude curves to summarise the data and gain a better understanding of the overall process and associated frequencies. (For example, refer Moon, Wilson & Flentje 2004, and MacGregor *et al.*, 2007).

iii) Evaluation of Rainfall

Statistical evaluation of rainfall data is relatively easy to perform using computer spreadsheets. These statistics can be related to the incidence of landslides. An example is given in MacGregor *et al.* (2007).

Consideration has to be given to possible trigger thresholds which may relate to rainfall, either in the short term (minutes to hours) or the long term, such as antecedent rainfall over weeks to months. Usually, antecedent rainfall will be relevant where rising groundwater levels are seen as the main trigger, and this is frequently applicable for the larger landslides

In addition, there may be a conditional probability of the landslide event occurring during a given rainfall event, or the conditional probability related to the proportion of similar slopes that might be affected by a rainfall event. Such conditional probabilities may be evaluated by considering the proportion of slopes that have failed in a given rainfall event (based on the landslide inventory in conjunction with the rainfall analysis).

Use of simulation models which predict piezometric responses to rainfall events may assist with calibration and extrapolation to extreme rainfall events. However, these require long periods of records of rainfall and piezometric data, and even when this is available simulation is difficult. Fell *et al.* (1991) gives an example. Table C4 indicates the probability of different return period events occurring over different periods of time. It can be seen that the probability of having a low return period event (for example a 1 in 100 year event) over a relatively short monitoring period such as 5 years is quite low (4%). Thus such models and extrapolation will have obvious limitations but may still be a useful tool for understanding a particular scenario.

Table C4: Percentage probability of the N-Year event occurring in a particular period.

Number of years in period	N = Average return period in years							
	5	10	20	50	100	200	500	1000
1	20	10	5	2	1	0.5	0.2	0.1
5	67	41	23	10	4	2	1	0.5
10	89	65	40	18	10	5	2	1
30	99	95	79	45	26	14	6	3
60	>99.9	98	95	70	31	26	11	6
100	>99.9	99.9	99.4	87	65	39	18	9
300	>99.9	>99.9	>99.9	99.8	95	78	45	26
600	>99.9	>99.9	>99.9	>99.9	99.8	95	70	45
1000	>99.9	>99.9	>99.9	>99.9	>99.9	99.3	87	64

After Lee and Jones (2004).

The effects of 'climate change' may show that use of historical rainfall records has an implied limitation. However, at this stage the effect of climate change cannot be predicted. Some predict longer dry periods, whilst others are predicting higher intensity rainfalls. Since it may be that a changed rainfall pattern may in many cases increase the probability of landsliding, whilst dryer periods may decrease the probability for others, it is considered appropriate at this time not to attempt to adjust the assessed frequency for such changes.

iv) "Degree of Belief" or Subjective Probability

For many cases, the practitioner will have to rely on the "degree–of-belief" method or subjective probability. This will be necessary due to the lack of relevant information such as historical records and/or quantitative analysis of trigger events which would enable an objective assessment of event probabilities. The practitioner will have to make best estimates of frequency/likelihood from limited site data, using experience and broad knowledge of an area or other areas of similar slope form and geology.

COMMENTARY ON PRACTICE NOTE GUIDELINES FOR LANDSLIDE RISK MANAGEMENT 2007

Moon and Wilson (2004) provide a useful over-view to developing judgments on landslide likelihood. *"The necessary evidence on which judgments of landslide likelihood are based has to be assembled, understood and interpreted. This process involves developing a slope model that reflects a sound knowledge of how the slope was formed, how it behaved in the past and how it might behave in the future. The ability to build up such a model comes from knowledge of the slope and its surrounds, knowledge of similar slopes in similar environments, and a range of skills and knowledge bases that result from training and experience."* Many useful references are cited.

Vick (2002) discusses the role of evidence and logical inference to subjective probability and engineering judgment. Although the assessed likelihood will be a subjective judgment, it should, like a bookmakers odds, be based on evidence (Moon and Wilson, 2004).

There are undoubted problems associated with use of "degree–of-belief" methods. The following presents a summary of the discussion in Lee and Jones (2004).

The main potential problems identified by Roberds (1990) are, in summary:

- *Poor quantification of uncertainty*, which may result in significant over estimates of likelihood where the slope forming process is ignored or misunderstood.
- *Poor problem definition*, as a result of the practitioner's experience and background, resulting in emphasis on one area or element of the slope at the expense of another.
- *Motivational bias* which may result in over optimistic or overly conservative assessments depending on the purpose of the assessment.
- *Cognitive bias* where the practitioner's judgment does not match the available facts.

The effects of these potential problems can be reduced or eliminated by techniques such as those of Lee and Jones (2004):

- *"Self assessment* where the rationale behind every judgment has to be well documented as required by the Practice Note. The same operator bias is likely to apply, but the documentation process clarifies the logic and results in a more defensible judgment.
- *Independent review or second opinion* which also should be well documented. This may still suffer from bias.
- *Calibrated assessment* where the practitioner's biases are identified and calibrated, and the assessment adjusted accordingly. The biases may be identified by peer group review or objectively by a set of experiments or questionnaires.
- *Probability encoding*, which involves the training of practitioners to produce reliable assessments of the probability of various events in a formal manner. This involves six stages:
    1. Training the practitioner to properly quantify uncertainty.
    2. Identifying and minimizing the practitioner's bias tendencies.
    3. Defining and documenting the item to be assessed in an unambiguous manner.
    4. Eliciting and documenting the practitioner's rationale for the assessment.
    5. Eliciting, directly or indirectly, the practitioner's quantitative assessment of uncertainty and checking for self-consistency. The practitioner's uncertainty can be established by determining the probability of various states through comparison with reference situations, such as poker hands, or by choosing between two lotteries (e.g. probability wheels or intervals) until indifference is achieved.
    6. Verifying the assessment with the practitioner and repeating the process if necessary."

Group consensus about a judgment is desirable but is achieved at increased cost and may not be economic. There may be significant differences of opinion between different practitioners. Where such differences of opinion are identified then they should be attempted to be resolved preferably in an open forum. The outcomes from this resolution process can be:

- *Convergence* to a common belief or assessment agreed to by all practitioners in the group.
- *Consensus*, where a single assessment can be determined but the assessment may not be the exact view of each individual. The consensus assessment may be a compromise derived from the individual assessments of group members but without the express agreement of the individuals concerned (forced), or the group may expressly agree to it for a particular purpose (agreed).
- *Disagreement.* Where convergence or consensus to a single assessment is not possible from the multiple assessments due to the major differences of opinion.

More detailed discussion of the above is presented in Lee and Jones (2004).

The Working Group considers that the Practice Note outlines "best practice" for self assessment where a "degree–of-belief" method is frequently adopted. However, it is anticipated that documentation of the assessment will include reference to known history and trigger events to help calibrate the judgment and provide defensibility.

The assessment of frequency should adopt the best means available given the nature of the landslides, circumstances of the geotechnical model, nature of triggering events and requirements of the risk assessment. Where few data are available, then estimates erring on the conservative side should be adopted to cover inherent uncertainty. More detailed studies may then be required to provide more reliable risk estimates.

In considering the circumstances of the particular assessment, the practitioner has to use best estimates from the available data when assigning likelihood (and consequences) values, but will inevitably be based on a subjective assessment of the practitioner's "belief" of the assessment. The assessment needs to consider range/uncertainty/sensitivity of the assessed values to establish confidence. The practitioner has to apply judgment, but must provide an explicit trail, or explanation, of logic applied to derive the best estimates adopted.

Stewart *et al.* (2002) discuss the RTA Guide to Slope Risk Analysis which provides a systematic procedure for LRM for roads based on defined ratings to derive an Assessed Risk Level. The companion paper (Baynes *et al.*, 2002) discusses the issues of accuracy and precision in use of the procedure by many practitioners on a large number of slopes. The methodology of the procedure is based on principles outlined above. Training in use of the system is required to help calibrate each practitioner and reduce bias. Audit procedures are used to derive consensus where necessary.

The state-of-the-art paper by Picarelli *et al.*, (2005) also provides a further overview and examples.

v) Event trees

Event trees enable the logical sequence of events to be considered in a structured manner. A suitable structured approach might, for example, consider for each scenario sequences such as likely trigger event, slope response, and consequence. An event tree can be used for complex scenarios.

The method has the advantage of enabling the logic adopted to be clearly shown together with each estimate of conditional probability, thereby providing clear documentation for review and appraisal.

This matter is discussed further in Lee and Jones (2004), and provides some examples where the method has been used. Hsi and Fell (2005) give an example where triggering by rainfall, over-taxing of a culvert and earthquake is modelled. Mostyn and Sullivan (2002) provides examples in relation to failure of fill embankments along a road. Hill *et al.* (2002) provides further discussion of issues associated with the principles of event trees.

5.4.2 Estimation of Annual Probability (Frequency) ($P_{(H)}$) of Each Landslide

a) Use best estimates for frequency estimates but consider range/ uncertainty/ sensitivity.

AGS (2000) acknowledged that assessment of frequency, or likelihood, is the most difficult part of the risk assessment process.

Assessment is particularly difficult at the medium to low frequency end (say 10^{-4} pa to 10^{-6} pa) because historic data based methods are not applicable. However, such values may still be appropriate by a combination of understanding the slope forming processes and logical elimination of other values. For some cases, such low frequency values may obviously be appropriate to hazards which could only occur over periods of geological time.

Experience has shown there is an inherent danger with Appendix G of AGS (2000), in that some practitioners assessed the likelihood solely based on the Descriptor. The Indicative Likelihood would then be adopted without due consideration. This procedure is incorrect as described below. An estimate of the probability should be made based on the best estimate of performance, trigger probabilities etc. and then the descriptor may be assigned accordingly.

Words such as "likely" can mean many different things to different people and in various contexts. The likelihood descriptors vary enormously in probability value between different publications as shown in the attached Table C5.

The qualitative terminology for Likelihood adopted for the Practice Note Appendix C is essentially the same as Appendix G, AGS (2000). The lowest category of likelihood has been revised to Barely Credible (from Not Credible).

The Descriptors are given to provide a consistent set of terms to assist the non-practitioner to interpret the assessed annual probability. In addition, the Descriptors provide a useful summary term for discussion purposes with due recognition of the inherent limitation of accuracy that is involved.

Table C5: Some published relationships between verbal descriptor and probabilities.

Verbal Descriptor	Conditional Probability				Annual Probability		
	USBR (2003)	Vick (1992)	Bowden *et al.* (2003)	Reagan *et al.* (1989)	AGS (2000) Appendix G	De Ambrosis & Mostyn (2004)	Moon & Wilson (2004)
Virtually certain	0.999	0.99	0.999	0.9	Approx 0.1 *	>=0.1*	>0.2*
Very likely	0.99	0.9		0.85			0.2 to 0.02
Likely	0.9			0.7	Approx 0.01	>=0.01	0.02 to 0..002
Neutral (even chance)	0.5	0.5		0.5			
Unlikely	0.1		0.001	0.15	Approx 0.0001	>=0.0001	<0.0002
Very unlikely	0.01	0.1	0.0001	0.1			<<0.0002
Virtually impossible	0.001	0.01	0.000001	0.02	<0.000001*	<0.000001*	

Note: * Verbal descriptor similar

Consideration has been given to the cumulative probability associated with each Descriptor and the expectation for the probability of occurrence of the lay user for those terms. For example, on first sight the use of the term ALMOST CERTAIN for an annual probability of greater than 0.05 seems inappropriate. However, examination of the Practice Note Figure 2 shows that within a design life of 60 years the cumulative probability of occurrence is about 0.95, and about 0.99 for 100 years. The apparent anomaly is explained by consideration of performance over the design life (as discussed in Section C9.3 below), and it is considered acceptable The indicative probability of occurrence over various design lives is given for each Descriptor in Tables CC1 and CC2 in Appendix CC attached.

Where knowledge based expert judgment or 'degree of belief' method of assessment of frequency is used, the resulting assessment could only be expected to have a precision within about one order of magnitude as discussed by Baynes *et al.* (2002). A consensus assessment by two or more practitioners can improve the precision to a reasonable level.

Although descriptors may have different meanings in other systems or publications, they are well defined in the Practice Note Appendix C. If an alternative system is to be adopted then the alternative should be similarly well defined and include an explanation as to why the preferred scheme was not adopted for the LRM assessment.

b) Estimates of frequency may be derived by partitioning the problem to (Annual probability of trigger event) x (Probability of sliding given the trigger event) over the range of trigger events.

It is sometimes useful to consider the likely response of a slope to given rainfall events (or other trigger events, such as earthquakes) when assessing frequency. Hence:

Frequency = (Annual probability of trigger event) x (Probability of sliding given the event)

$$= P_T \times P_{S:T}$$

assessed over the range of trigger events.

The probabilities of sliding are assessed judgementally from historic data and the experience of the practitioner. Table C6 provides an example of employment of partitioning to produce an estimate of annual probability over a range of trigger events.

Table C6: Example of the assessment of the annual probability (frequency) of landsliding employing the annual probability of rainfall and the response of the slope to the rainfall.

Annual probability of the rainfall	Annual probability rainfall is exceeded	Probability/annum rainfall is in this range (P_T)	Estimated conditional probability of landsliding given the rainfall is in this range ($P_{S:T}$)	Annual probability (Frequency) of landsliding
1 in 1	1.0			
		0.9	0.001	0.0009
1 in 10	0.1			
		0.095	0.1	0.0095
1 in 200	0.005			
		0.0049	0.9	0.0044
1 in 10,000	0.0001			
		0.0001	0.99	0.0001
			Total	0.0149

Where there is little historic data on which to assess the conditional probabilities ($P_{S:T}$) it is useful to use inferred relationships known as mapping schemes. These link qualitative and quantitative terms for probability. Table C7 shows a scheme which has been used widely in dams risk assessment in Australia.

Table C7 was developed for use in dams risk assessment, by Barneich *et al.* (1996) from Military Standard (1993), using Baysian theory to assess historical data. This was done by a group of dams and geotechnical experts, and reviewed by Professor A. Cornell. It has been used and validated in other areas such as pavement management systems, environmental risks at mine sites and seismic risk analysis projects. Experience shows the table helps in obtaining consistent estimates of conditional probabilities within event trees.

Table C7: Mapping scheme linking description of likelihood to quantitative probability (Barneich *et al.*, 1996)

Description of Condition or Event	**Order of Magnitude of Probability Assigned**
Occurrence is virtually certain	1
Occurrences of the condition or event are observed in the available database	10^{-1}
The occurrence of the condition or event is not observed, or is observed in one isolated instance, in the available database; several potential failure scenarios can be identified.	10^{-2}
The occurrence of the condition or event is not observed in the available database. It is difficult to think about any plausible failure scenario; however, a single scenario could be identified after considerable effort.	10^{-3}
The condition or event has not been observed, and no plausible scenario could be identified, even after considerable effort.	10^{-4}

c) Complete a review of the assessed frequency in relation to the implied cumulative frequency of the event occurring within the design life and known performance within the area.

Practice Note Appendix C Likelihood table has included the "Implied Indicative Landslide Recurrence Interval". The correspondence to the Approximate Annual Probability is not strictly correct, especially at low probability values. As discussed by Moon and Wilson (2004) the recurrence interval has a connotation about long periods of time based on long periods of evidence. The reality is that data in relation to the annual probability values of about 10^{-4} or less will be limited. "However, because likelihood evidence relates to years not abstract numbers (e.g. year of last slope movement, return period of landslide inducing rainstorms), many practitioners find it easier to think in terms of 'landslide recurrence intervals' and then convert the judgments to annual probabilities" (Moon and Wilson, 2004).

The inclusion of likelihood terms for annual probability values of less than 10^{-4} is considered to be appropriate to allow for differentiation, particularly where the probability of spatial impact may be quite different for different hazards. This also offers easy differentiation for hazards where the probability of landsliding is barely credible, for example on a plateau area remote from any escarpment or possible regression (except over geological time) and having relatively gentle slopes underlain by competent strata the probability is likely to be less than 10^{-6}pa.

5.4.3 Assessment of Travel Distance and the probability of spatial impact ($P_{(S:H)}$) of the elements at risk

For most risk assessments it will be adequate to estimate travel distance using empirical or simplified methods. Only in very detailed studies of large and important landslides would it be necessary or useful to use methods such as finite element or distinct element analyses to estimate deformations of individual slides, or to use numerical methods to model debris flows or rock avalanches. Hungr *et al.* (2005) provides an overview of methods for estimating travel distance.

For rotational landslides which remain essentially intact, the method proposed by Khalili *et al.* (1996) or experience with landslides in similar geological, topographic and climatic conditions can be used to estimate the displacement. This method is based on the principle of conservation of energy assuming the factor of safety at failure is unity, adopting the residual strength and the slope geometry to estimate the displacement. The results compare reasonably with case studies. The displacements are greatest for "brittle" failures i.e. where there is a large loss of strength on shearing. The strength loss may be best measured in undrained strength terms, e.g. for soft clays peak and remoulded strengths should be used and for saturated loose (collapsing) granular fills where liquefaction may occur, post liquefaction strengths should be used. For non-circular surfaces, the method may overestimate displacements. Deformation may be modelled for more important projects using finite element, finite difference or distinct element programs.

There is a degree of uncertainty in the methods available for estimating travel distance. Judgment will also have to be applied when consideration of travel direction is relevant in relation to the landslide impacting a particular element at risk. (Such consideration is most likely to be relevant for boulder falls or similar.) For individual allotment assessments, a best estimate or slightly conservative approach may be used, though for more detailed risk assessments,

the uncertainty in travel distance and /or travel direction should be modelled as shown in the example presented in Table C8.

Table C8: Example of modelling uncertainty in travel distance and the probability of spatial impact ($P_{(S:H)}$).

Travel Distance Range metres	Estimated Probability the Travel Distance will be in this Range	Probability of spatial impact ($P_{(S:H)}$) assuming the element at risk is 32 metres below the landslide
<20	0.2	0
20 to 30	0.6	0
30 to 40	0.2	0.2
	Total 1.0	Total 0.2

The probability values could be further modified by the conditional probability associated with travel direction, where this is appropriate. For example, if a rockfall is assessed to have a variety of possible trajectories, only some of which will result in spatial impact on the element at risk, then application of the conditional probability for the trajectory would be applied to the travel distance probability.

C6 CONSEQUENCE ANALYSIS

C6.1 ELEMENTS AT RISK

No further comment.

C6.2 TEMPORAL SPATIAL PROBABILITY ($P_{(T:S)}$)

Roberds (2005) gives a detailed account of how to estimate temporal spatial probability where the elements at risk are mobile. AGS (2000, 2002) Appendix E gives details for the case of traffic travelling on a road.

For most assessments involving persons at risk in a building, the practitioner should make an estimate of temporal spatial probability based on the use of the building. This should include assessment of the probability of non-evacuation which may be used as a conditional probability. The landslide velocity and possibility of forewarning of the landslide failure will be relevant considerations.

The assessment may need to be based on a regulator's notional occupancy for a dwelling, not necessarily the client's proposed occupancy. For example, a client may wish to build a holiday house with relatively low occupancy factors (particularly for the time of year most likely to have a landslide event). However, a subsequent owner may be occupying with an average family on a fulltime residential basis. The later occupancy would be more critical and should be adopted for assessment purposes for the development.

C6.3 EVALUATION OF CONSEQUENCE TO PROPERTY

C6.3.1 Estimate the extent of damage likely to property arising from each of the landslides

The assessment of vulnerability and damage to property is subjective, and there is little published information. The Practice Note Appendix F has some data but note that for property this represents the judgements of those doing the study and is not a record of actual vulnerability. There are some general points which should be considered:

- Landslides which move slowly (particularly those with a near planar, horizontal surface of rupture) may cause little damage to structures on the landslide, though those structures which are on the boundaries of the landslide will experience differential displacement.
- For stuctures on the landslide, the rate of movement is less important for damage to the structures, except insofar as it affects the time rate of damage, than it is for loss of life.
- For stuctures below the landslide, the velocity of the landslide has a major effect on the damage and hence vulnerability. Hence structures which are near the toe of a landslide which will travel a long distance are likely to experience a high velocity impact and will suffer extensive damage (high vulnerability), and structures which are near the limit of the travel (or run-out) of the landslide will experience low velocity impact by only part of the landslide mass and will probably suffer "minor" damage (low vulnerability).

- It will sometimes be appropriate to consider vulnerability of a small part of the element at risk. For example, a room in a house which may be affected by a small landslide such as rock fall, may have a vulnerability of 1.0, whereas this may represent only a proportion of the value of the house as a whole.
- The proportion of a structure damaged is unlikely to represent the same proportion of the value of the structure. For example, damage to 10% of structure may represent 50% of the value of the structure.

C6.3.2 Estimate the indicative cost of the damage

The direct cost of damage to the structure is not the Total Cost to the owner if a landslide occurs. The Practice Note details the costs to be considered to derive an estimate of the Total Cost.

For many risk assessments it will be sufficient to estimate the costs approximately for example by using published construction cost guides which are relatively inexpensive (such as Rawlinson's, Cordell's, Reed's or similar). However, the practitioner is not a quantity surveyor and caution should be used in providing broad brush guesstimates on which legal decisions may be made and enforced. All cost estimates should be well documented and referenced using up to date industry sources appropriate to the location and types of costs involved.

Experience using the qualitative terminology in AGS (2000) Appendix G indicated that evaluation of the meaning of the description of the consequences to property can be subject to wide interpretation. In an effort to narrow the interpretation, de Ambrosis and Mostyn (2004) suggested use of estimates of the cost of damage as a more objective measure so as to limit disputes of interpretation of the description. The Practice Note definition builds on that proposal. Assessment of the consequences to property has been normalised as the Total Cost relative to the Market Value of the property under consideration. AGS recommends adoption of this updated approach using a semi-quantitative method as presented in Appendix C of the Practice Note.

There may be some situations where the regulator will require the risk from all landslide hazards to be brought to tolerable risk levels as part of the remedial works in the event of a landslide on a property. Regulators who will take this approach should make it clear to Practitioners doing risk assessments in their area.

For Practice Note Appendix C, the consequences scale has been adjusted in conjunction with appraisal of the risk categories as discussed in Appendix CC. It is considered that the adopted consequence scale is preferable to the order of magnitude scale in de Ambrosis and Mostyn (2004) as the Appendix C scale enables a more workable subdivision of risk in the Medium and Major categories (10% to 100% consequences) and shifts the descriptors towards the higher consequences, which is more realistic.

There is an obvious limitation in application of the method if the practitioner is not experienced enough to appreciate the civil engineering and structural engineering implications of particular landslide events. However, as consequences are an essential input to risk evaluation, this limitation has to be addressed and may require assistance ffom other experts, such as civil or structural engineers (as appropriate) or quantity surveyors for refinement of cost estimates.

C6.3.3 Estimate the market value

No additional comments.

C6.3.4 Consider the resulting Consequence classification, such as using Practice Note Appendix C, and implied accuracy of the above estimates.

No additional comments.

C6.4 EVALUATION OF CONSEQUENCES TO PERSONS

The assessment of vulnerability to persons is subjective and there is little published information. The Practice Note Appendix F has some data but note that except for the data in Finlay et al (1999) this represents the judgements of those doing the study and is not a record of actual vulnerability. There are some general points which should be considered:-

- For persons below the landslide, the velocity of the landslide has a major effect on the vulnerability. Persons who are near the toe of a landslide which will travel a long distance are likely to experience a high velocity impact and will have a high vulnerability and persons who are near the limit of the travel (or run-out) of the landslide will experience low velocity impact by only part of the landslide mass and will have a lower vulnerability.
- Persons who are in buildings which collapse totally have high vulnerability.
- Persons who are in buildings are less vulnerable than those in the open unless the building collapses.

- Persons in vehicles are less vulnerable than those in the open. Their vulnerability depends on the volume and velocity of the landslide. Experience in Hong Kong (Finlay *et al.*, 1999) indicates that rapid landslides of only a few hundred cubic metres are likely to result in death of the occupants of the vehicle.

It should be noted that whether a person will evacuate from the path of the landslide is covered in temporal spatial probability, not in vulnerability.

C7 RISK ESTIMATION

Standards Australia (2004) HB436:2004 discusses the types of risk analysis which may be summarized as:

- *Qualitative analysis*: "uses words to describe the magnitude of potential consequences and the likelihood that those consequences will occur. These scales can be adapted or adjusted to suit the circumstances, and different descriptions may be used for different risks"
- *Semi-quantitative analysis*: "qualitative scales, such as those described above are given values. The objective is to produce a more expanded ranking scale than is usually achieved in qualitative analysis, not to suggest realistic values for risk such as is attempted in quantitative analysis."
- *Quantitative analysis*: "uses numerical values (rather than descriptive scales used in qualitative and semi-quantitative analysis) for both consequences and likelihood using data from a variety of sources. The quality of the analysis depends on the accuracy and completeness of the numerical values and the validity of the models used."

Appendix G of AGS (2000) presented an example of qualitative terminology and risk matrix that was considered to be suitable for use in landslide risk assessment for property. AGS (2000) recognized that alternative schemes may be used, provided they are defined. As previously noted, AGS (2000) has now been superseded by the Practice Note.

C7.1 QUANTITATIVE RISK ESTIMATION

Reference should be made to Lee and Jones (2004) for a number of examples of risk calculations for a variety of scenarios. Some examples are also given in Roberds (2005) and other invited papers in the same volume. Such examples may be useful for deriving an appropriate model to enable suitable risk estimates.

C7.2 SEMI-QUANTITATIVE AND QUALITATIVE RISK ESTIMATION FOR RISK TO PROPERTY

In the context of risk assessments for residential development with submission to a regulator, adoption of a common preferred qualitative terminology should be mandatory as stipulated in the regulator's policy. If the practitioner considers an alternative scheme to be preferable for a particular hazard/situation, then adoption of this alternative must be justified by detailed documentation of the reasons.

There is considerable benefit to the regulator and the practitioner to use a common terminology. Comparison between different sites and between different practitioners is facilitated. Whilst there may be an inherent difference in assessment between practitioners (for example as shown by Baynes *et al.*, 2002), adoption of a common terminology will facilitate understanding and calibration between practitioners. Use of a scheme developed for a specific site or case makes cross comparisons difficult or confusing.

Although the Practice Note Appendix C scheme uses qualitative terminology to communicate and/or summarise the assessment of risk to property, it is in essence a quantitative scheme since it relies on the best estimates of the likelihood and consequence for the analysis. Risk to life should only be considered quantitatively and the adoption of semi-quantitative methods is considered to be inappropriate.

C7.3 RISK MATRIX FOR PROPERTY LOSS

The preferred Risk Matrix for Property presented in the Practice Note Appendix C has been derived primarily for residential development. It may also be appropriate to apply the scheme to other development,or situations/consequences. If the scheme is modified, or an alternative adopted, then full discussion of the justification and basis for the alternative scheme should be given.

A number of alternative qualitative scales for Likelihood, Consequences and resulting risk matrices and assigned risk levels were examined before deriving the final scheme in the Practice Note. Further discussion is given in Appendix CC of the considerations involved.

The main considerations were:

- The use of the annualised cost of damage to help allocate the risk categories.

- The risk values have been skewed down in favour of consequence (as discussed by de Ambrosis and Mostyn 2004) for the lower value consequences. It is judged that higher consequences are more readily accepted or tolerated at the lower likelihood values.
- Cell A5 (Almost Certain / Insignificant) has been subdivided in recognition of the practicality of hazards that result in very low value consequences and are readily accepted by most owners.
- The recommendation to the regulator that MODERATE risk is tolerable and that LOW (and Very Low) Risk is acceptable for Importance Level 2 and 3 structures (Appendix A, Practice Note) based on the assessment of implied cost impact of damage on most home owners and the fact that most home owners will be risk averse in the light of lack of insurance availability. If insurance was available then an annualised dollar value equivalent to an insurance policy cost would be a reasonable and rational benchmark for acceptability. (Refer to Section C8.2b below).

Alternative qualitative schemas for measures of likelihood and/or consequences may be used but the onus is on the practitioner to fully document the methodology and definitions for the terminology adopted. The documentation should include an explanation as to why the AGS preferred scheme is not appropriate. To avoid confusion, different descriptor terms (words) should be used wherever possible. In addition, the components of any alternative system must be compatible and form a consistent and logical process to allow LRM. It is considered likely that the piecemeal substitution of only one element of the preferred AGS terminology is unlikely to produce a consistent system.

C7.4 ESTIMATION OF RISK OF LOSS OF LIFE

It is widely accepted that Risk to life can only be evaluated quantitatively and this enables direct comparison with tolerable risk criteria. For this reason, AGS (2000, 2002) required life loss risk to be estimated quantitatively as does the Practice Note. Refer also to discussion in Lee and Jones (2004) and Leroi *et al*. (2005).

De Ambrosis and Mostyn (2004) have proposed some qualitative terms for risk to life. This proposal has not been adopted by the Working Group because their table can only be realistically used from right to left. That is, the assessor has to evaluate the conditional probabilities of vulnerability, non-evacuation, temporal probability and spatial probability in order to determine the required value of "Indicative Vulnerability". Since the conditional probabilities are required anyway, it makes more sense to continue to use them for evaluation of the risk to life quantitatively, using the assessed best guess likelihood value applicable to the hazard.

C8 RISK ASSESSMENT

C8.1 RISK EVALUATION

The final step in the Risk Assessment is the Risk Evaluation. The Practitioner has to relate the estimated risks to the risk tolerability criteria and then, if required, determine the appropriate and necessary risk mitigation options to reduce risks to within tolerable limits. The owner and regulator have to decide if risks are tolerable, though pragmatically the ultimate decision resides with the regulator.

If the risk cannot be reliably reduced by mitigation measures to satisfy the tolerable risk criteria, then either the development should not occur or the scope of the development should be modified accordingly.

Individual risk will usually be the governing consideration for most residential developments and should relate to the "individual most at risk". The risk from all landslide hazards which may affect that person should be considered and summed to give the individual risk and this should satisfy the tolerable risk criteria.

In cases where occupancies are likely to include many individuals (such as for schools, hospitals, shopping centres, boarding houses, motels, clubs etc, i.e. Importance Level 3 and Importance Level 4 structures) rather than a family unit in a single residential dwelling, Societal Risk should also be considered. For a family unit in a residential dwelling it is considered to be impractical to consider societal risk for every case and the risk assessment outcome is unlikely to be significantly different.

The example in Appendix CB demonstrates how Societal Risk can be evaluated. More details are given in ANCOLD (2003) and Leroi *et al.* (2005).

Additional considerations by the owner and regulator for determination of whether risks are tolerable may include political issues, social and community considerations, business confidence, environmental impacts and post-disaster uses.

C8.2 TOLERABLE RISK CRITERIA

a) Loss of Life criteria

As discussed in Section C3.5, the regulator is the appropriate authority to set standards for tolerable risk which may relate not only to perceived safety in relation to other risks, but also to government policy. Implementation of a tolerable risk level has implications to the community at large, both in terms of relative risks or safety, but also in terms of economic impact.

Table C9: Individual Loss of Life Risk Criteria. (Leroi *et al.*, 2005)

Organisation	Industry	Description	Risk/annum	Reference
Health and Safety Executive, United Kingdom	Land use planning around industries	Broadly acceptable risk. Tolerable limit	10^{-6}/annum, public and workers 10^{-4}/annum public(1) 10^{-3}/annum workers	HSE (2001)
Netherlands Ministry of Housing	Land use planning for industries	Tolerable limit (2)	10^{-5}/annum, existing installation 10^{-6}/annum, proposed installation	Netherlands Ministry of housing (1989), Ale (2001), Vrijling *et a*l. (1998)
Department of Urban Affairs and Planning, NSW, Australia	Land use planning for hazardous industries	"acceptable" (tolerable) limits (2)	$5x10^{-7}$/annum hospitals, schools, childcare facilities, old age housing 10^{-6}/annum residential, hotels, motels $5x10^{-6}$/annum commercial developments 10^{-5}/annum sporting complexes	
Australian National Committee on Large Dams	Dams	Tolerable limit	10^{-4}/annum existing dam, public most at risk subject to ALARP 10^{-5}/annum new dam or major augmentation, public most at risk, subject to ALARP.	ANCOLD (2003)
Australian Geomechanics Society guidelines for landslide risk management	Landslides (from engineered and natural slopes)	Suggested tolerable limit	10^{-4}/annum public most at risk, existing slope 10^{-5}/annum, public most at risk, new slope	AGS (2000)
Hong Kong Special Administrative Region Government	Landslides from natural slopes	Tolerable limit	10^{-4}/annum public most at risk, existing slope. 10^{-5}/annum public most at risk, new slope	Ho et al. (2000), ERM (1998), Reeves *et al*. (1999)
Iceland ministry for the environment hazard zoning	Avalanches and landslides	"acceptable" (tolerable) limit	$3x10^{-5}$/annum residential, schools, day care centres, hospitals, community centres. 10^{-4}/annum commercial buildings $5x10^{-5}$ recreational homes(3)	Iceland Ministry for the environment (2000), Arnalds *et al.* (2002)
Roads and Traffic Authority, NSW Australia	Highway landslide risk	Implied tolerable risk	10^{-3}/annum(4)	Stewart *et al*. (2002), RTA (2001)

Notes:

(1) But for new developments HSE (2004) "advises against giving planning permission where individual risks are > 10^{-5}/annum".

(2) Based on a temporal spatial probability of 1.0.

(3) Assumes temporal spatial probability of 0.75 for residential, 0.4 commercial, 0.05 recreational.

(4) Best estimate of societal risk for one person killed, top risk ranking. If slope ranks in this range action is taken to reduce risks within a short period. For the second ranking, societal risk is 10^{-4}/annum, and slope is put on priority remediation list.

Table C9 summarises published individual loss of life risk criteria. An overview of the issues in relation to Loss of Life criteria are discussed in Leroi *et al.* (2005).

It is important to distinguish between "acceptable risks" and "tolerable risks".

Tolerable Risks are risks within a range that society can live with so as to secure certain benefits. It is a range of risk regarded as non-negligible and needing to be kept under review and reduced further if possible.

Acceptable Risks are risks which everyone affected is prepared to accept. Action to further reduce such risk is usually not required unless reasonably practicable measures are available at low cost in terms of money, time and effort.

Most organisations listed in Table C9 have adopted Tolerable Risk as the measure to gauge risk. This is because there is a trade-off between the benefits and cost of risk mitigation, and the costs to achieve acceptable risk levels are often high. The Australian National Committee on Large Dams (ANCOLD) has adopted tolerable risk criteria for assessing risks posed by dams. This decision was reached after extensive consultation locally and internationally and after seeking legal opinion.

After due consideration of these factors and taking account of the criteria which were included in AGS (2000, 2002) AGS suggests that **for most development in existing urban areas criteria based on Tolerable Risks levels are applicable because of the trade-off between the risks, the benefits of development and the cost of risk mitigation. The recommended Tolerable loss of life risk values for the person most at risk for different situations are shown in Table 1 of the Practice Note.**

It is recommended that risks be assessed only for the person most at risk, and not for the average person as suggested in AGS (2000, 2002). ANCOLD (2003) reported that the person most at risk always controlled, and that average risks were difficult to define and determine.

The recommended values are higher for existing slopes than for new slopes. This is in keeping with ANCOLD (2003) and general literature on risk tolerability which indicates that persons tolerate risks from existing hazards more than for newly constructed ones. Where development modifies an existing slope, the "new slope" criteria should be applied in accordance with the definitions given for the situation in Table 1 of the Practice Note.

Regulators may decide to apply "acceptable risk" criteria for high consequence cases, such as schools, hospitals and emergency services in recognition of the importance of these structures and as a way of covering societal risk concerns. This is also reflected in the recommended criteria for property loss for different Importance Levels of structures below.

The community may tolerate higher risks from natural hazards than man made hazards (IUGS 1997). Such a consideration by the regulator may result in some natural hazards being tolerated in the face of exceptional expenditure to reduce the risk to tolerable levels. An example of this may be the risks associated with boulder falls from natural cliff lines in a bush reserve adjacent to existing residential development. If the regulator and potentially affected owners were not aware of the circumstances then prior to the LRA they would have been "uninformed". Adoption of such tolerable risks should be made on the basis of an appropriate LRA and assessment of the risk mitigation options.

It is recognised that the recommended criteria are higher than required by NSW Department of Planning (2002) However, their criteria are applied to development such as chemical plants which can be sited in areas where the low risks can be achieved. Urban development is within designated areas, the land owner has no option but to develop (if practical) so the trade-off between risk levels, cost of development and risk mitigation have to be considered. This is a similar situation to dams and is part of the reason ANCOLD have adopted tolerable risk criteria.

Societal Risk may be measured against the ANCOLD (2003) recommended values as given in Figure 4 of Leroi *et al.* (2005). Reference should be made to ANCOLD (2003) when carrying out such assessments.

For special cases of work place related risks, such as in mining and tunnelling, and/or for short term stability in construction sites, then work-place safety requirements will control and those criteria might govern.

b) Loss of Property Criteria

Acceptable (or tolerable) values for Risk to Property are rarely quoted in literature.

Lee and Jones (2004) considers evaluation of such risk in economic terms by evaluating economic indicators such as the Benefit-to-Cost Ratio, Net Present Value and Incremental Benefit-to-Cost Ratio. This allows comparison of alternative risk management strategies. Application of a decision rule allows selection of the most cost effective management option. Various methodologies for evaluation are detailed in Lee and Jones (2004) and are too lengthy to repeat here. Such methods should be investigated for larger projects or where a variety of stabilisation options are possible.

The issue of what might be an acceptable value for risk to property has been subject to considerable discussion following publication of the Pittwater Council Draft policy in 2003. This policy required a Low Risk to property using the qualitative terminology given in Appendix G of AGS (2000).

Discussion of whether this risk criterion should be modified and whether it is in accordance with community expectations was progressed by consideration of the annualised cost of damage to property as discussed in Appendix CC.

Annualised cost of property damage is a useful benchmark for comparison of different hazards. However, adoption of a dollar value based on a cost equivalent to an insurance policy premium is only considered to be appropriate where such policies can be obtained. Where insurance cannot be obtained (which unfortunately is currently the case across Australia), then experience shows that most informed home owners are likely to be risk averse as a result of appreciation of the consequences at a family or personal level, almost regardless of the likelihood of the event. This risk aversion suggests that Low Risk to Property is an appropriate recommendation for acceptable risk to the regulator for domestic dwellings which are of Importance Level 2 (as defined in the BCA, refer to Practice Note Appendix A). Alternative levels are risk are considered reasonable for structures of other Importance Levels as shown in Table C10

Table C10: AGS suggested Acceptable qualitative risk to property criteria.

Importance Level of Structure (1)	Suggested Upper Limit of Acceptable Qualitative Risk Property (2)	
	Existing Slope (3) / Existing Development (4)	New Constructed Slope (5) / New Development (6) / Existing Landslide (7)
1	Moderate	Moderate
2	Low	Low
3	Low	Low
4	Very Low	Very Low

Notes:

1. Refer to Appendix A, Practice Note
2. Based on Appendix C, Practice Note
3. "Existing Slopes" in this context are slopes that are not part of a recognizable landslide and have demonstrated non-failure performance over at least several seasons or events of extended adverse weather, usually being a period of at least 10 to 20 years.
4. "Existing Development" includes existing structures, and slopes that have been modified by cut and fill, that are not located on or part of a recognizable landslide and have demonstrated non-failure performance over at least several seasons or events of extended adverse weather, usually being a period of at least 10 to 20 years.
5. "New Constructed Slope" includes any change to existing slopes by cut or fill or changes to existing slopes by new stabilisation works (including replacement of existing retaining walls or replacement of existing stabilisation measures, such as rock bolts or catch fences).
6. "New Development" includes any new structure or change to an existing slope or structure. Where changes to an existing structure or slope result in any cut or fill of less than 1.0 m vertical height from the toe to the crest and this change does not increase the risk, then the Existing Slope / Existing Structure criterion may be adopted. Where changes to an existing structure do not increase the building footprint or do not result in an overall change in footing loads, then the Existing Development criterion may be adopted.
7. "Existing Landslides" have been considered likely to require remedial works and hence would become a New Constructed Slope and require the lower risk. Even where remedial works are not required per se, it would be reasonable expectation of the public for a known landslide to be assessed to the lower risk category as a matter of "public safety".

Tolerable risk levels would be one class higher (for example Moderate where Low is acceptable). Consideration should be given by regulators to adopting Tolerable risk to property for Existing Slope and Existing Development situations in a similar vein to the recommended differentiation for risk to life.

C9 RISK MANAGEMENT

C9.1 RISK MITIGATION PRINCIPLES

The principal aim of the risk mitigation measures should be to reduce risk, to engineer out uncertainty in the risk and to provide a level of risk satisfying community expectations through the regulator's criteria once properly implemented.

Not all options for risk control methods will be feasible or appropriate for each project/ circumstance.

The issue of whether residual risk (after implementation of risk mitigation measures) is tolerable or acceptable (as appropriate) should take into account the ALARP principle. ANCOLD (2003) defines ALARP (As Low As Reasonably Practicable) principle as "that principle which states that risks, lower than the limit of tolerability, are tolerable only if risk reduction is impracticable or if its cost is grossly disproportionate (depending on level of risk) to the improvement gained." Note that ANCOLD (2003) adopts tolerable risk criteria; where an acceptable risk criterion is adopted, then "acceptable" would replace "tolerable" in that definition. Putting this principle in another way, if risk can be reasonably and cost effectively reduced further than the acceptability criterion, then the additional risk mitigation measures should be adopted also.

Risk control measures are likely to require on-going maintenance in most, if not all, instances.

Detailed specification of the design, construction and maintenance criteria for each risk treatment measure should be appropriately specified or addressed. Feedback is essential throughout the design and construction process to enable re-evaluation of the assessment as appropriate.

C9.2 SITE SPECIFIC DEVELOPMENT CONDITIONS

Site specific development conditions need to be determined such that risk levels are reduced to satisfy the regulator's criteria. They need to take into account uncertainties and limitations of design and construction.

The development conditions may be thought of as recommendations. Recommendations are usually considered to be optional for the client to accept or reject if other factors weigh more heavily. However, the development conditions may not be an option for the owner if they form an essential component of the risk management strategy.

The practitioner should be mindful of the need to sign documentation upon completion of construction of the approved works, such as by submission to the regulator of a completion form (such as the Practice Note, Appendix D, Form G).The experienced practitioner will be aware of the implied liability associated with such forms. Therefore, as a matter of good practice for liability risk management, the practitioner needs to specify appropriate inspection and testing throughout the detailed design and construction phases so that he can sign-off on completion without unnecessary liability exposure.

AS2870 (Standards Australia, 1996) requires sites where the "foundation condition on a sloping site where downhill foundation movement or failure is a design consideration" (clause 1.7.29, AS2870) to be classified as Class P (clauses 2.1.2 and 2.4.4, AS2870). Such sites require design of footings from engineering principles. The design and construction aspects of such footings may form an integral part of the risk mitigation measures. Some general guidance is given in Appendix G of the Practice Note.

C9.3 DESIGN LIFE

The premise behind adoption of a design life may be the community expectation that a residential dwelling frequently, with appropriate maintenance, will have a functional life well in excess of 50 to 60 years. The community can reasonably expect this performance for a well designed and constructed building. Such a design life is consistent with that nominated by relevant Australian Standards and other design guides as summarised in Table C11.

Table C11: Summary of Design Life Requirements.

Standard or Design Guide	Title	Clause/Section	Design Life		
AS 2870–1996	Residential Slabs and Footings - Construction	1.4.2	50 years		
AS 3600–2001	Concrete Structures	4.1	40 – 60 years		
AS 3700–2001	Masonry Structures	Refer to AS 1170.0 and AS 1170.4-	[AS 1170.4 – Appendix F, Table 3.3] <6 months ranging to >= 100 years for varying Importance Levels and varying Annual Probability of Exceedance		
AS 4100–1998	Steel Structures				
AS 1720.1–1997	Timber Structures				
AS/NZ 4676–2000	Structural Design Requirements for Utility Services Poles	Appendix D, Table D2	Varying according to pole construction material and exposure. Galvanised Steel: up to 60 – 100 years and >100 years, down to 3 – 12 years Concrete: 50 – 100 years and >100 years		
AS 4678–2002	Earth Retaining Structures	3.4.1 and Table 3.1	Short	5 years	Temporary site works
			Medium	10 years	Mine structures
				30 years	Industrial structures
			Long	60 years	River and marine structures, residential dwellings
				90 years	Minor public works
				120 years	Major public works
Concrete Masonry Association of Australia 2003/04	Design and Construction Guides: ▪ Reinforced Concrete Masonry Cantilever retaining Walls ▪ Segmental Concrete Reinforced Soil Retaining Walls ▪ Segmental Concrete Gravity Retaining Walls	Appendix C	As above for AS 4678		
Building Code of Australia	Importance Level	Table B1.2a	Read in conjunction with AS 1170.0 and AS 1170.4		

Usually the time-frame for the life of the structure or development, and hence the period over which the landslide risk assessment is relevant, will be based on that specified by relevant design codes or the regulator. For example, Sydney's

Pittwater Council requires a baseline period of 100 years as the context within which the geotechnical risk assessment should be made, broadly reflecting the expectations of the community for the anticipated life of a residential structure.

The practitioner should identify the maintenance required to achieve the required design life in relation to the landslide hazards. The design life should also be nominated, particularly if it is not in accordance with a specific requirement.

On-going maintenance is essential for the effectiveness of the risk control measures. Without such maintenance, the risk may change from acceptable to unacceptable with time.

C9.4 MAINTENANCE REQUIREMENTS

It is essential that the owner (and occupier) be made aware of the necessity of maintenance to provide effective and sufficient risk control over the design life. The Practitioner should advise on appropriate inspection and maintenance to control the risk. Some guidance is given in the GeoGuides (AGS 2007e)

Future owners need to be made aware of the same requirements. One method available to inform future owners is to have annotation on the Land Title so that the details referred to in the annotation become readily known to new owners. Such details should include the reference details of the risk management report and relevant design and construction records, as well as maintenance records.

C10 REPORTING STANDARDS

The report has the overriding function to document the data, assumptions and thought process used for the assessment. Such documentation facilitates subsequent review and revision. The report should be technically rigorous but must also be understood by non-technical people who are required to make decisions based on it.

The report should fully document sources of data, extent of investigations completed, assumptions made and associated limitations. The report is to be clear, unambiguous, stating outcomes from the investigations and assessment, and to make clear recommendations. If there is uncertainty, then such doubt needs to be stated in the report together with what can be done to clear up the doubt. A good principle to adopt for such documentation is to assume that the report may be tendered as an expert report to a subsequent court case. Such documentation is necessary to justify the expert's conclusions if it is not to be rejected on the basis of the "Makita Principle" which, broadly speaking, requires reasons based on facts or calculations or precedents, not simply an unsubstantiated opinion.

The report should document the best estimate results for the risk analysis, based on data available at that stage.

Table C12 presents an example checklist of issues to be addressed / considered by LRM reports. The checklist should also assist the practitioner when preparing reports to confirm that all relevant aspects have been addressed, and the regulator when evaluating reports for compliance with policy requirements.

C11 SPECIAL CHALLENGES

C11.1 MINOR WORKS

No further comment.

C11.2 PART OF THE SITE NOT ACCEPTABLE

The requirement to address other parts of the site is derived from the community expectation that unacceptable risks will be identified and addressed as part of a broad duty of care.

C11.3 ADJOINING AREAS NOT UNDER THE RESPONSIBILITY OF THE SITE OWNER

Again the broad duty of care requires these other such areas to be addressed. Adjoining areas may be under the regulator's control and require direct input.

C11.4 COASTAL CLIFFS

Stability of coastal cliffs (and bluffs) is often not associated with a rainfall trigger (as is usually the case with soil and colluvial slopes). Cliff stability is often triggered by sea conditions, such as undercutting in storms, wetting by run up and spray leading to frequent wetting and drying cycles and possibly temperature.

Access to coastal cliffs is often difficult due to the physical constraints. Nonetheless, where there are elements at risk (being either property or people, above or below the cliff) then the situation needs to be examined from both above and below to confirm the appropriate site details / features since the likelihood and consequences will be highly dependent on those features.

Table C12: Example Checklist for LRM Reports

Items	Check	Response: Yes, No, NA, NK	Comments/ Description (If used by the Regulator, then all except No answers require comment)
Site	Report Reference and date		
	Client's name		
	Site address		
	Date of site visit. Site visit by (name)		
	Weather conditions on date of visit		
Development	Will the proposed development have a degree of use or occupation by humans?		
	Does the development involve significant modification to the landscape, including cut and fill?		
	What is the landslide susceptibility classification for this slope/site? (Assuming the regulator has completed such zoning studies in accordance with AGS 2007a)		
	What is the landslide hazard or risk classification for this? (as above)		
Geology	What is the regional geology according to published maps?		
	Is the site located on surface fill or colluvium?		
	Has the geology been confirmed by inspection or investigation? If not – why not. If Yes – provide basis for confirmation.		
Geomorphology	Are there any indications of possible instability on the site or adjacent to it?		
	Does the site have distinct breaks in slope or benches?		
	Are there terracettes or other signs of creep on the site?		
	Are there signs of tunnel erosion, such as sinkholes or collapse of soils on the site?		
	Are there any tension cracks in the ground surface of the site?		
Adjacent Sites	Do adjacent sites show signs of slope instability as described above?		
	Do adjacent sites have non-retained cuts or fills close to boundaries?		
	Are there steep slopes, different geology or landforms on adjacent sites that may pose a threat to this site?		
	Will the proposed development threaten the stability of adjacent developments via cuts, fill or drainage?		
Slope	What is the overall (natural) slope of the site?		
	Are there changes (breaks) in the slope? Are these man made or natural?		
	What is the maximum slope of the site?		
	Is the slope in an area of development different to elsewhere (large sites)?		
Drainage	Does the site have deeply dissected drainage courses?		
	Is the site likely to receive significant surface water runoff from other sites upslope?		
	Does the site have dams, lakes, ponds, swamps, bogs, seeps or soaks?		
	Does the site receive drainage from road culverts or spoon drains?		
	Will any aspect of the development significantly modify the existing site drainage?		

COMMENTARY ON PRACTICE NOTE GUIDELINES FOR LANDSLIDE RISK MANAGEMENT 2007

Items	Check	Response: Yes, No, NA, NK	Comments/ Description (If used by the Regulator, then all except No answers require comment)
Erosion	Are there any severe forms of erosion including tunnels or gullies on the site?		
	Do any existing cuts and fills show signs of erosion including loss of vegetative cover?		
	Do access tracks show erosion, scouring or signs of uncontrolled runoff?		
	Will the development have the potential to change the current conditions?		
Site Cuts and Fills	Are there existing cuts and/or fill areas on the site?		*(If Yes, attach site sketch showing location, extent, height and batter angles)*
	Are there any existing unsupported cuts or fills that exceed 1.0m in vertical height from toe to crest?		
	Are batter angles steeper than 1V:2H (or 26 degrees or 50%) for any existing cut or fill in soil materials?		
	Are batter angles steeper than 1V:1H (or 45 degrees or 100%) for any existing cut in rock?		
	Do existing cuts and fills have adequate surface or subsurface drainage? Provide details.		
	Were vegetation and topsoil removed prior to filling? If No, provide details.		
	Have suitable fill materials been used and have they been properly compacted (with evidence thereof)?		
	Do any existing cuts and fills show seepage? If Yes, show details on site plan.		
Retaining Walls	Are there any existing retaining walls on the site?		*(If Yes, attach site sketch showing location, extent, height, type, condition and slope of batter above)*
	Are timber or dry rock retaining walls used for any purpose other than minor landscaping of vertical height less than 1.0m?		
	Do existing retaining walls supporting major cuts and fills appear to be unengineered?		
	Do existing retaining walls show signs of distress or movement? If Yes, provide details.		
	Do existing retaining walls have adequate drainage above and below the wall? If No, provide details.		
Groundwater	Are there discharge areas such as springs, seeps, bogs, swamps or constantly wet areas on the site or adjacent to the site?		*(If Yes, provide site sketch showing location and extent)*
	Are there bores intersecting a shallow watertable on the site?		
	Any other evidence of high groundwater levels?		
Rock	Is rock exposed on the site?		
	Do any exposed cuts have rock strata that are dipping out of the slope?		
	Do any exposed rock faces show open joints or loose boulders? If yes, provide site sketch plan and details.		
Soil Profile	Do exposed faces or existing excavations show soil profiles exceeding 1.5m vertical height?		
	Do exposed faces or existing excavations show a mixture of soil and rock, which may be landslide debris or colluvium?		
	Does the soil profile show inconsistent colouring or interbedded layers of differing materials?		

COMMENTARY ON PRACTICE NOTE GUIDELINES FOR LANDSLIDE RISK MANAGEMENT 2007

Items	Check	Response: Yes, No, NA, NK	Comments/ Description (If used by the Regulator, then all except No answers require comment)
	Does the exposed profile show imported materials or fill?		
	Is there significant evidence of yabby holes or other burrowings?		
Vegetation	Has the natural vegetation been substantially cleared from the site?		
	Does the proposed development involve significant clearing of the site?		
	Are any of the plants species on site indicators of waterlogging (eg. spiny rush, swamp gums)?		
	Is revegetation work required?		
	Do existing trees and shrubs show signs of slope instability, such as tilting or bent trunks?		
	Does any existing vegetation show signs of isolated dieback or distress?		
	Will the removal of any vegetation cause increased erosion and degradation to the adjacent area?		
Effluent and Stormwater Disposal	What type of effluent disposal system is currently used? If on site disposal, show discharge area on site plan.		
	Provide details of current discharge point for stormwater. Show location on site plan.		
	Does the geology or stability of the site suggest that septic system absorption trenches are unsuitable?		
	Are there any signs of increased waterlogging or impact from effluent of adjacent sites?		
	Is a new point/area for stormwater discharge proposed? If so, give details and show location (and extent if dispersed on site) on site plan.		
	Is a new on site effluent disposal system proposed? If Yes, give details and show proposed disposal area on site plan.		
Slope Classification	Have landslide hazards been identified and shown on relevant plan or section?		
	Has the risk to property been assessed and is the result in accordance with the acceptance criterion?		
	Has the risk to life been assessed and is the result in accordance with the acceptance criterion?		
	What is recommended to maintain or reduce the landslide risk at this site? Are detailed requirements given?		
OTHER COMMENTS			

Assessed by: …… **Date:** ……..
Company: ……

Note (1) Assessment must be completed by a suitably qualified geotechnical practitioner.
Note (2) Every clear box must be filled in with either Yes (Y), No (N), Not Applicable (NA) or Not Known (NK). Comments could cross reference to specific sections or page of the report.
Note (3) This checklist is intended to document the basic date to facilitate a landslide risk assessment in accordance with the requirements of a regulator's specific policy. The above table may require edits to be suited to local conditions and the requirements of the policy.
Note (4) A comment or full description is required for all Yes responses. Applicant should submit detailed responses in the attached report.

Acknowledgement: This table has been based on the checklist from Yarra Ranges Shire with their kind permission.

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The preparation of the Practice Note and Commentary has been carried out under the auspices of the AGS by a Practice Note Working Group comprising:

Bruce Walker, Working Group Convenor, Jeffery and Katauskas Pty Ltd
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The documents prepared by the Working Group have been subject to peer review and discussion by the AGS Landslides Taskforce who have been listed in the Practice Note

The Working Group considers the Practice Note and Commentary represents a reasonable state-of-the-art at the time of preparation. Future revisions may become appropriate in the light of experience gained in application and other research/publications. Better qualitative schemes may be devised to overcome specific difficulties that come to light in due course; for example, an alternative scheme for assessment of Consequences to Property.

It is recognised that inspiration for the presentation format of the Practice Note and Commentary has been gained from ANCOLD (2003) and has resulted in adoption of a similar methodology and convention.

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APPENDIX CA: EXAMPLES OF RISK CALCULATIONS

The following examples of risk calculations are reproduced from Fell *et al.* (2005) with kind permission from the publisher, Balkema.

Other examples are given in Lee and Jones (2004), in Roberds (2005) and in other invited papers in the Proceedings of the Vancouver 2005 Landslide Risk Management conference (Balkema).

(iv) Risk estimation

The annual probability of the person most at risk losing his/her life is

$$P_{(LOL)} = P_{(L)} \times P_{(T:L)} \times P_{(S:T)} \times V_{(D:T)}$$
$$= (1.33 \times 10^{-3}) \times (0.4) \times (0.83) \times (0.4) / \text{annum}$$
$$= 1.7 \times 10^{-4} / \text{annum}$$

The annual probability of four persons being in the house where it is hit by the slide (assuming the time they spend in the house overlap)

$$= (1.33 \times 10^{-3}) \times (0.4) \times (0.14)$$
$$= 0.74 \times 10^{-4} / \text{annum}$$

Since their vulnerability is 0.4, so 1.6 persons (say 1 to 2) would be killed.

3. RISK ASSESSMENT

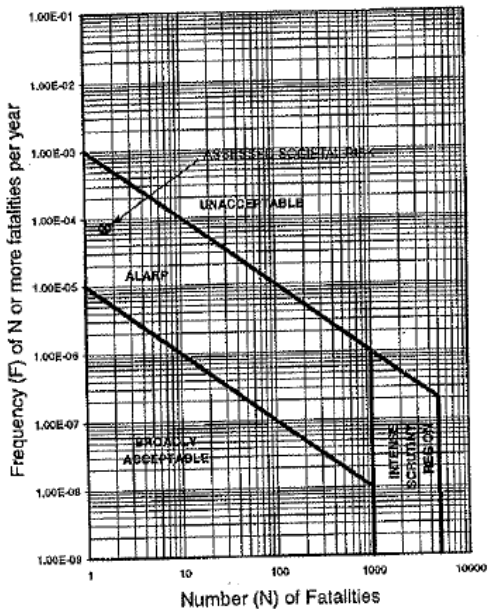
(i) Risk evaluation

(a) Individual Risk

From Table 2, the tolerable individual risk for an existing slope is 1×10^{-4}/annum; so for the individual most at risk, with $P_{(LOL)} = 1.7 \times 10^{-4}$, the risk is just in the intolerable range.

(b) Societal Risk

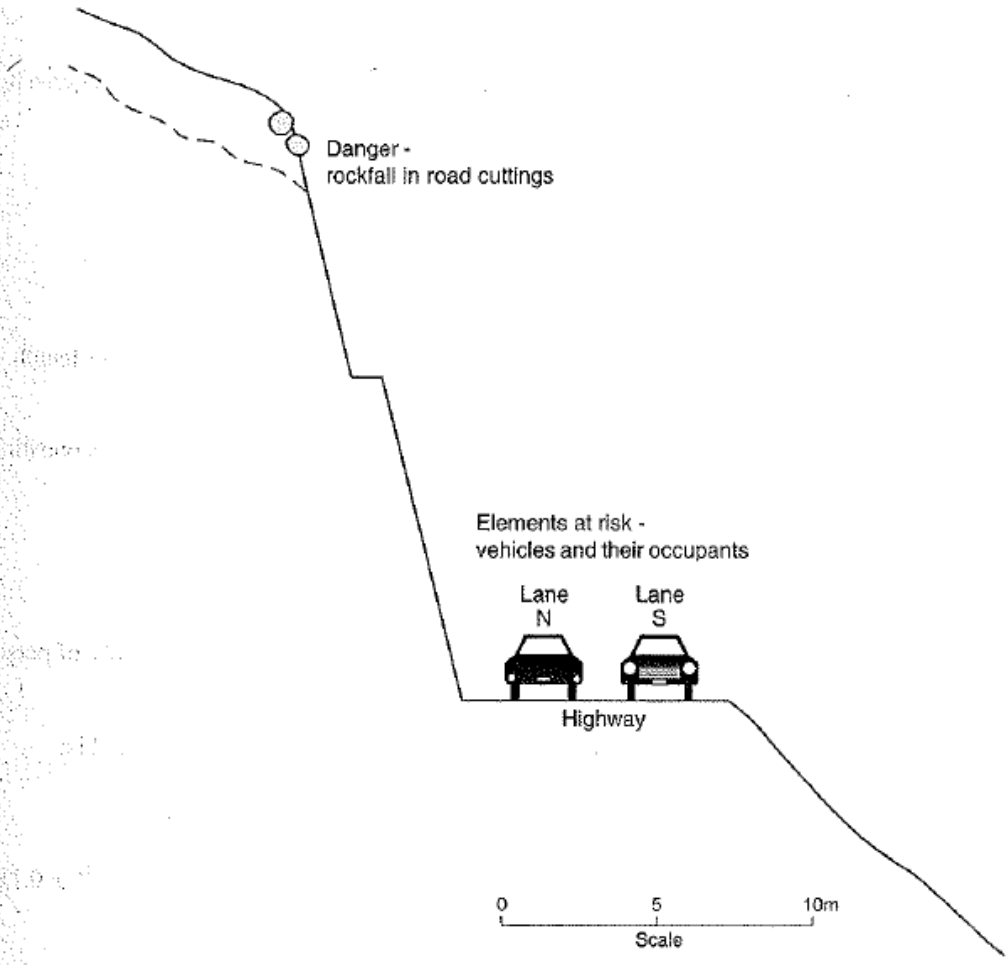
From Figure 4 reproduced below, the societal risk is below the limit of tolerability line, but in the ALARP region.



(ii) Comment

At this time, possible risk mitigation options would be considered, and the risks re-calculated. The ALARP principle might be used along with values judgements to determine a risk mitigation and/or monitoring plan, or to consider doing more geotechnical investigations to get an improved more accurate assessment of the risk.

Figure 5. (*Continued*).



1. SCOPE DEFINITION

Calculate the risk to persons travelling on the highway as shown in the Figure. Assess the tolerability of this risk against the tolerable risk criteria shown in Table 1 and Figure 4. Only consider direct impact falls.

2. RISK ANALYSIS

(i) Danger (landslide) characterisation

The road to a ski resort is privately owned and was built 10 years ago. The 50 cuts in the road were constructed at relatively steep slopes, and without treatment to control weathering, erosion and shallow instability leading to rockfalls.

A thorough search of the maintenance records and observations of boulder impacts on the road surface indicated that for the average cutting on the road, there have been 2 rockfalls per annum, with boulders ranging in size from 0.5 m dia to 1 m dia. The cuttings are in similar topography, geology and climatic conditions. Based on the recorded boulder impacts on the road surface, and the use of rockfall simulation programs, it is assessed that 60% of rocks falling from the slope will impact on Lane N which is closest to the cut, and 10% on Lane S.

(ii) Frequency analysis

The average frequency of rockfalls for each cutting is 2 per annum. There are a total of 50 cuts along the road, giving a total of 100 rockfalls per annum or 0.27/day, the average frequency of rockfalls (N_R) onto lane, N = 0.6 × 0.27 = 0.16/day, and on Lane S, = 0.1 × 0.27 = 0.027/day.

Figure 6. Example II – rockfalls from cuttings on a highway.

(iii) Consequence analysis

(a) Temporal spatial probability ($P_{(S:T)}$) of vehicles

The probability of a vehicle occupying the length of road onto which the rock falls is given by

$$P_{(S:T)} = \frac{N_V}{24} \bullet \frac{L}{1000} \bullet \frac{1}{V_V}$$

where N_V = average number of vehicles/day

L = average length of vehicle (metres)

V_V = velocity of vehicle (km/hour)

For each lane, the average number of vehicles per day over the year is 2000, the average length of the vehicles is 6 metres, and they are travelling at 60 km/hr, ignoring the width of the boulder:

For each lane

$$P_{(S:T)} = \frac{2000}{24} \bullet \frac{6}{1000} \bullet \frac{1}{60} = 0.0083$$

For a particular vehicle travelling once each day in one direction

$$P_{(S:T)} = \frac{1}{24} \bullet \frac{6}{1000} \bullet \frac{1}{60} = 0.0000042$$

(b) Vulnerability of the persons in the vehicles $V_{(D:T)}$

Based on published information and judgement, it is estimated that the vulnerability of persons in vehicles in lane N is 0.3 and in lane S, 0.15.

(iv) Risk estimation

The annual probability of the person most at risk losing his/her life by driving along the road is:

(a) For lane N

$$P_{(LOL)} = P_{(S)} \; x \; V_{D:T} = (1 - (1 - P_{(S:T)})^{N_k}) \; x \; V_{D:T}$$
$$= (1 - (1 - 0.0000042)^{0.16}) \; x \; 0.3$$
$$= 2.0 \; x \; 10^{-7} \; / \; annum$$

(b) For lane S

$$P_{(LOL)} = (1 - (1 - 0.0000084)^{0.027} \; x \; 0.15$$
$$= 0.3 \; x \; 10^{-7} \; / \; annum$$

The total probability of death for the person most at risk is 2.3×10^{-7}/annum. For a person who only travels on the road once per year in each direction, $P_{(LOL)} = 6.3 \times 10^{-10}$/annum ($2.3 \times 10^{-7}$/365). The total annual risk assuming each of the 2000 vehicles/day carries an average of 3 persons is $2000 \times 365 \times 3 \times 6.3 \times 10^{-10}$/annum = 0.0014 persons/annum. The F-N plot has not been determined in this case.

3. RISK ASSESSMENT

(i) Risk evaluation

(a) Individual risk

From Table 1, the tolerable individual risk for existing slopes is 1×10^{-4}/annum. So for the individual most at risk, with $P_{(LOL)} = 2.3 \times 10^{-7}$/annum, the risks are within the tolerable limit. For an individual who drives on the road only once per year, the risk is 6.3×10^{-10}/annum, which would be acceptable. The societal risk limit of tolerability for one life lost is 10^{-3}/annum (see Figure 4). The estimated probability of one or more lives lost is about 5×10^{-4}/annum, near the tolerable limit.

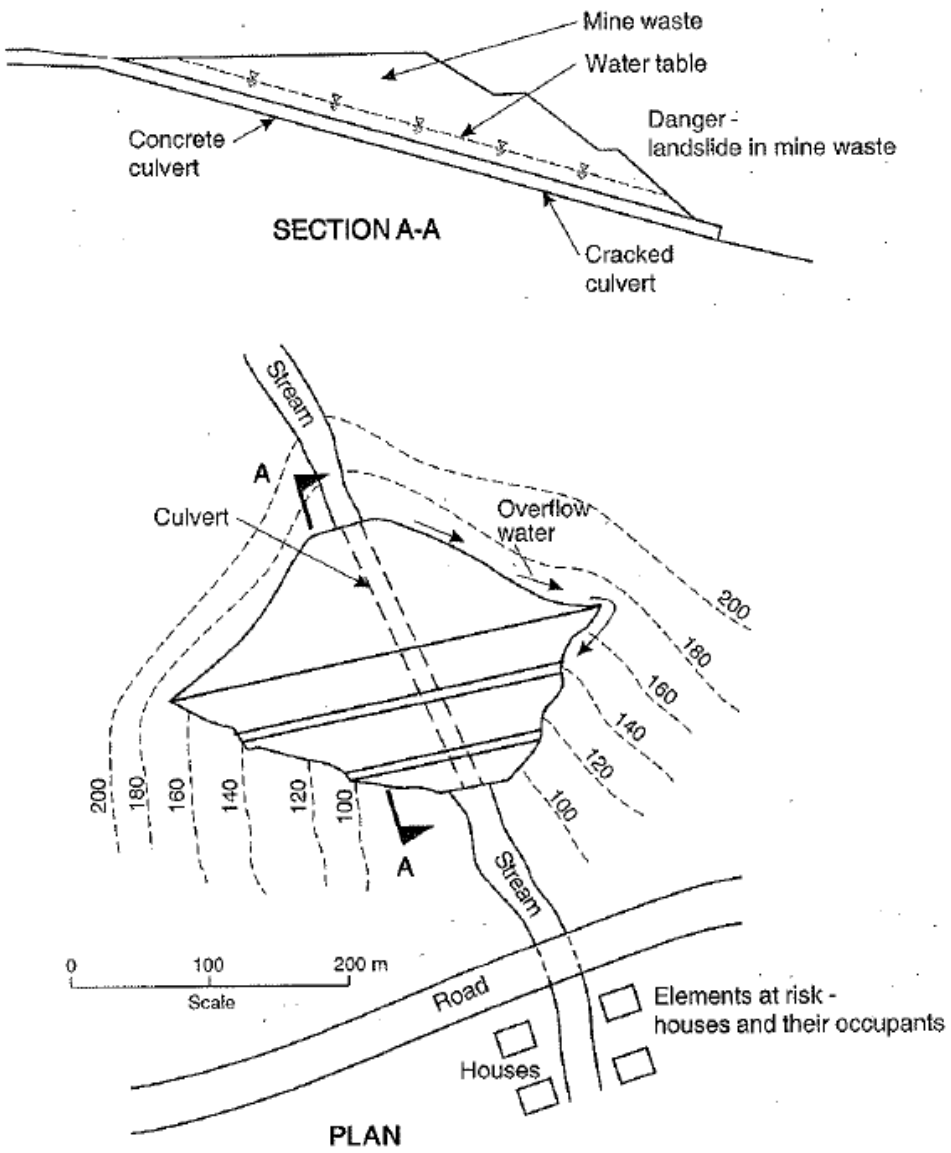
(ii) Comment

(a) It is considered reasonable to sum the risks for all the road cuttings because the road is the responsibility of one organization.

(b) At this time, risk mitigation options would be considered. These could include engineering option to reduce the frequency of rockfalls (rock-bolting, shotcreting, scaling of loose rocks in a regulated manner); reducing the probability the rocks will fall onto the road (e.g. mesh protection over the slope, catch drain); or reducing the probability of vehicles being below a rockfall when it occurs (e.g. closing the road in periods of heavy rain if it could be demonstrated that is when most rockfalls occurred).

(c) See SOA Paper 5 for the equations for estimating risk.

Figure 6. (*Continued*).



1. SCOPE DEFINITION

Calculate the risk to persons living in the houses and travelling on the road below the mine waste dump. Assess the tolerability of these risks against individual and societal tolerable risk criteria.

2. RISK ANALYSIS

(i) Danger (landslide) characterisation

The mine waste is silty sandy gravel and gravelly silty sand coarse reject from a coal washing. It was deposited over 50 years by end tipping. Geotechnical site investigations, hydrological and engineering analyses have shown that:

(a) The waste is loose, and the lower part is saturated.
(b) The waste is likely to liquefy and flow liquefaction occurs for earthquakes loadings larger than 10^{-3} AEP.

Figure 7. Example III – landslinding of mine waste dump.

(c) The culvert through the waste dump exceeds its capacity and runs full for floods greater than 0.1 AEP. For floods larger than this water flows over the sides of the waste dump and leaks onto the waste material through cracks in the culvert, increasing the pore pressures in the waste.
(d) The factor of safety of the dump under static loading is about 1.2 for water table levels which are reached annually.
(e) If the dump slides even under static loading, it is likely to flow because of its loose, saturated granular nature. The probability of this occurring given sliding occurs and the resultant debris flow reaching the houses is 0.5 based on post liquefaction shear strengths, and empirical methods for estimating travel distance.
(f) The volume of the anticipated landslide and resulting debris flow is about 100,000 m^3 and the debris flows are likely to be travelling at a high velocity when they reaches the road and houses.

(ii) Frequency analysis

The potential failure modes are:

(a) Culvert runs full, water leaks, saturates downstream toe, causes slide.
(b) As for (a), but a smaller slide, blocks/shears culvert, causes slide.
(c) Culvert collapses, flow saturates downstream toe, causes slide.
(d) A bigger flood, causes the culvert overflow, saturates fill, causes slide.
(e) As for (d), but scour of flowing water at toe of fill initiates slide.
(f) Rainfall infiltration, remobilizes slide.
(g) Earthquake causes liquefaction.

Based on the hydrology of the catchment, the hydraulics of the culvert, stability analyses and engineering judgement, it is estimated that the frequency of landsliding of the waste for modes (a) to (f) is 0.01/annum.

Based on an analysis of liquefaction using a Youd et al (2001) approach, and post liquefaction stability analysis, it is estimated that the frequency of landsliding for mode G is 0.005/annum.

Hence the total $P_{(L)} = 0.015$/annum.

(iii) Consequence analysis

(a) Temporal spatial probability ($P_{(S:T)}$) of the persons in the houses, and on the road

A survey of occupancy of the houses shows that the person most at risk in one of the houses is in the house on average 18 hours/day, 365 days per year, so $P_{(S:T)} = 0.75$.

Each house is occupied by a further 4 persons, for 10 hours/day, 325 days/year. Assuming they are all in the houses at the same time. So:

$$P_{(S:T)} \text{ for 16 persons} = \frac{10}{24} \times \frac{325}{365} = 0.36$$

Vehicles on the road travel at an average velocity of 30 km/hour as they pass by the 100 metres of road potentially affected by the debris flow. So for each time the vehicle drives along the road,

$$P_{(S:T)} = \frac{100}{30{,}000 \times 365 \times 24} = 3.8 \times 10^{-7}$$

If a vehicle travels along the road 250 times a year (such as the school bus)

$$P_{(S:T)} = 250 \times 3.8 \times 10^{-7} = 9.5 \times 10^{-5}$$

The critical vehicles for risk assessment are buses which travel 250 days/year.

(b) Vulnerability of persons ($V_{(D:T)}$)

Bases on the likely high velocity of sliding and large volume, it is estimated that the vulnerability of persons in the houses is 0.9, and in a bus, 0.8.

Figure 7. (*Continued*).

(iv) Risk estimation

The annual probability of the person most at risk losing his or her life is

$P_{LOL} = p_{(L)} \times P_{(T:L)} \times P_{(S:T)} \times V_{(D:T)}$

$P_{LOL} = (0.015) \times (0.5) \times (0.75) \times 0.9/\text{annum}$

$= 5 \times 10^{-3} / \textit{annum}$

If all four houses are hit by the landslide, 0.9 × 16 or say 14 of the 16 persons would be killed. The annual probability that this would happen is:

$= 0.015 \times 0.5 \times 0.36/\text{annum}$

$= 2.7 \times 10^{-3}/\text{annum}$

If a bus with 40 persons on it is hit by the landslide, 0.8 × 40 = 32 persons would be killed. The annual probability this would happen is:

$= 0.015 \times 0.5 \times 9.5 \times 10^{-5}/\text{annum}$

$= 7.1 \times 10^{-7}/\text{annum}$

So if loss of life of persons in other vehicles on the road is ignored, the cumulative F-N pair are:

One or more lives $F = 5 \times 10^{-3} + 2.7 \times 10^{-3} + 7.1 \times 10^{-7} = 7.7 \times 10^{-3} / \textit{annum}$

15 *or more lives* $= 2.7 \times 10^{-3} + 7.1 \times 10^{-7} = 2.7 \times 10^{-3} / \textit{annum}$

33 lives $F = 7.1 \times 10^{-7} / \textit{annum}$

3. RISK ASSESSMENT

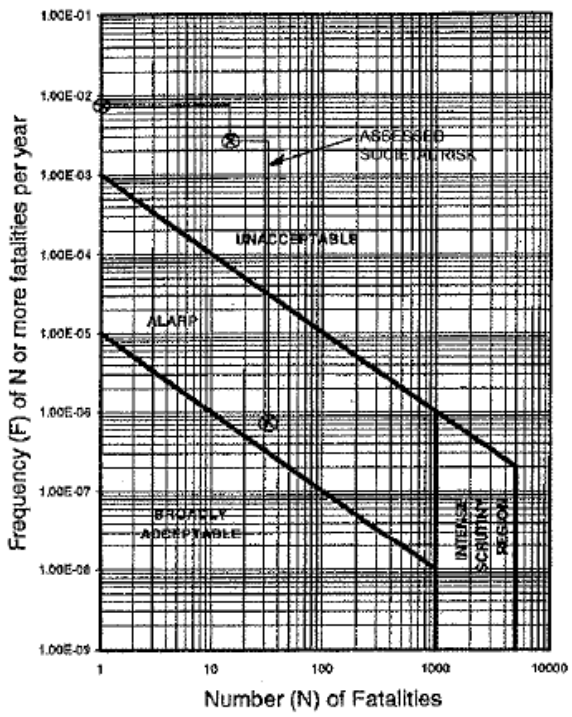


Figure 7. (*Continued*)

(i) Risk evaluation

(a) Individual risk.

The risk for the person most at risk is 5×10^{-3}/annum which is well in excess of the tolerable individual risk in Table 1.

(b) Societal risk

The three points on the F-N curve are shown below. It can be seen that the risks are well in excess of the tolerable for 1 and 15 lives, but in the ALARP range for 33 lives lost in a bus.

(ii) Comment

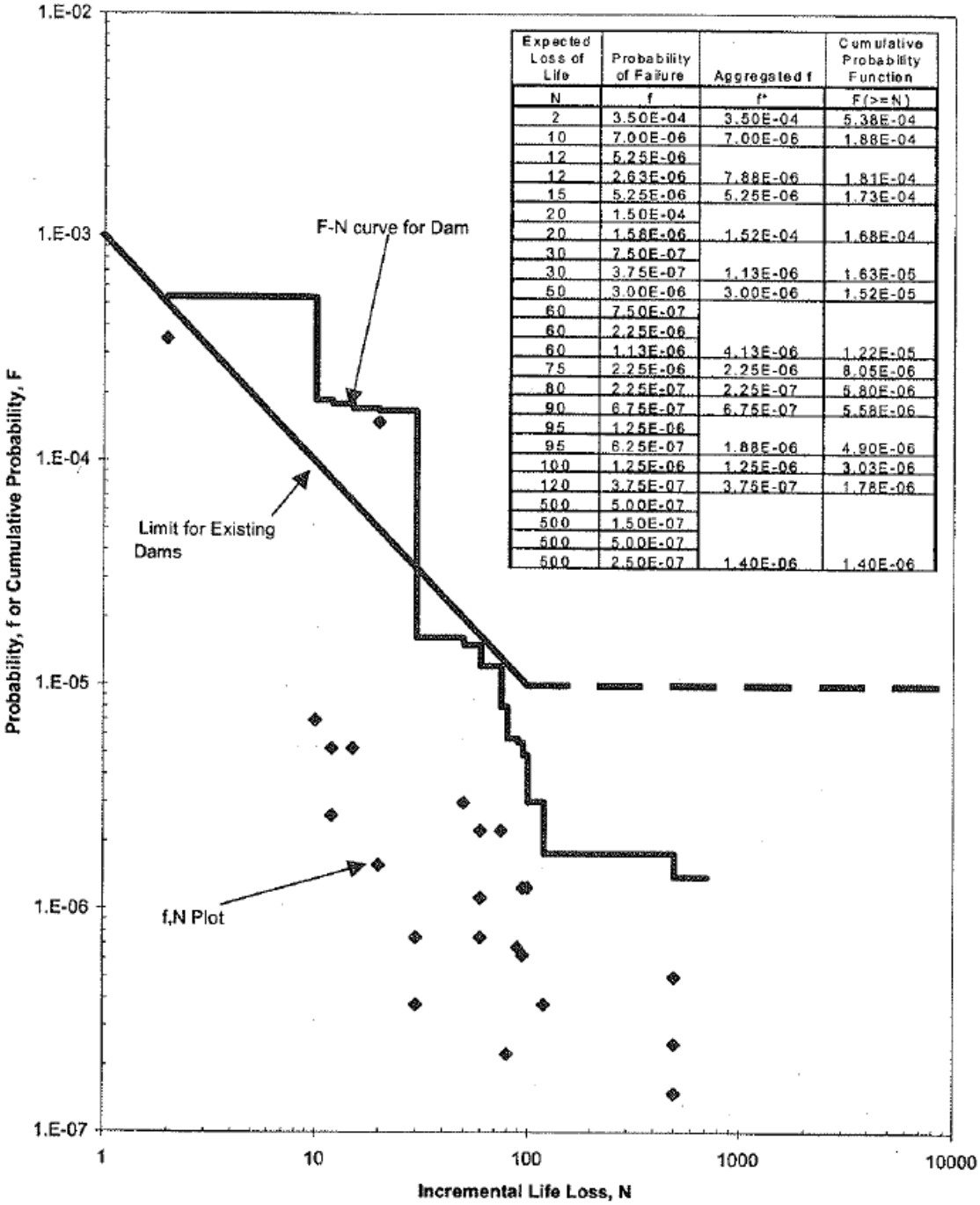
At this point, possible risk mitigation options would be considered, and the risks recalculated. The mitigation options could include reducing the probability of sliding by repairing the cracks in the culvert, controlling water which overflows when the culvert capacity is exceeded; removing and replacing the outer waste well compacted so it will not flow if it fails; adding a stabilizing berm; installing a warning system so persons in the houses can be evacuated and the road blocked to traffic when movement is detected in the waste.

Figure 7. (*Continued*)

APPENDIX CB: EXAMPLE OF SOCIETAL RISK CALCULATION

Calculation of societal risk is discussed in ANCOLD (2003) and this should be referred to if a societal risk calculation is to be performed.

An example plot is given in ANCOLD (2003) as reproduced below.



Expected Loss of Life	Probability of Failure	Aggregated f	Cumulative Probability Function
N	f	f*	F(>=N)
2	3.50E-04	3.50E-04	5.38E-04
10	7.00E-06	7.00E-06	1.88E-04
12	5.25E-06		
12	2.63E-06	7.88E-06	1.81E-04
15	5.25E-06	5.25E-06	1.73E-04
20	1.50E-04		
20	1.58E-06	1.52E-04	1.68E-04
30	7.50E-07		
30	3.75E-07	1.13E-06	1.63E-05
50	3.00E-06	3.00E-06	1.52E-05
60	7.50E-07		
60	2.25E-06		
60	1.13E-06	4.13E-06	1.22E-05
75	2.25E-06	2.25E-06	8.05E-06
80	2.25E-07	2.25E-07	5.80E-06
90	6.75E-07	6.75E-07	5.58E-06
95	1.25E-06		
95	6.25E-07	1.88E-06	4.90E-06
100	1.25E-06	1.25E-06	3.03E-06
120	3.75E-07	3.75E-07	1.78E-06
500	5.00E-07		
500	1.50E-07		
500	5.00E-07		
500	2.50E-07	1.40E-06	1.40E-06

Fig. I.1 Example Plot of F-N Line and f,N pairs

The data used to generate this plot (shown as Figure 5 in Leroi *et al.*, 2005) are presented in the following table from Leroi *et al.*, (2005).

Table 1. Data for the F-N plot in Figure 5 (Fell & Hartford 1997, after D. Bowles).

Failure Mode			Prob (Failure mode) (A)	Exposure			Incremental life loss N(C)	Prob (incremental life loss) f(A × B)	(C) × (D)
Initiating event	Dam component	Failure mechanism		Season	Day/ night	Prob-ability (B)			
Flood	Embankment	Erosion	5.00E-04	Spring	Day	0.7	2	3.50E-04	7.00E-04
				Spring	Night	0.3	20	1.50E-04	3.00E-03
	Stilling basin	Headcut	1.00E-05	Spring	Day	0.7	10	7.00E-06	7.00E-05
				Spring	Night	0.3	50	3.00E-06	1.50E-04
Seismic	Embankment	Liquefaction	1.00E-05	Summer	Day	0.075	60	7.50E-07	4.50E-05
				Summer/open	Day	0.05	500	5.00E-07	2.50E-04
				Summer	Night	0.125	100	1.25E-06	1.25E-04
				Non-summer	Day	0.525	15	5.25E-06	7.88E-05
				Non-summer	Night	0.225	75	2.25E-06	1.69E-04
	Outlet works	Rupture	3.00E-06	Summer	Day	0.075	80	2.25E-07	1.80E-05
				Summer/open	Day	0.05	500	1.50E-07	7.50E-05
				Summer	Night	0.125	120	3.75E-07	4.50E-05
				Non-summer	Day	0.525	20	1.58E-06	3.15E-05
				Non-summer	Night	0.225	90	6.75E-07	6.08E-05
Internal	Embankment	Piping	1.00E-05	Summer	Day	0.075	30	7.50E-07	2.25E-05
				Summer/open	Day	0.05	500	5.00E-07	2.50E-04
				Summer	Night	0.125	95	1.25E-06	1.19E-04
				Non-summer	Day	0.525	12	5.25E-06	6.30E-05
				Non-summer	Night	0.225	60	2.25E-06	1.35E-04
	Outlet works	Piping	5.00E-06	Summer	Day	0.075	30	3.75E-07	1.13E-05
				Summer/open	Day	0.05	500	2.50E-07	1.25E-04
				Summer	Night	0.125	95	6.25E-07	5.94E-05
				Non-summer	Day	0.525	12	2.63E-06	3.15E-05
				Non-summer	Night	0.225	60	1.13E-08	6.75E-05
		Total	5.38E-04				Total	5.38E-04	Total 5.70E-03 Risk

The method of calculation in this table is shown on the column headings. To form the table in Figure I.1, the data pairs for f (probability of incremental life loss, column D) and N (incremental life loss, column C) are sorted by N increasing as shown. Where there are two or more data pairs for the same N, the probability values are aggregated. Then to derive the Cumulative Probability Function F (>=N) the Aggregated probability values are added from the bottom upwards. The resulting F-N line is then plotted from the resulting F-N pairs.

Other example calculations and plots are given in Lee and Jones (2004) and Mostyn and Sullivan (2002).

APPENDIX CC: REVIEW OF APPENDIX G AGS(2000) AND DERIVATION OF THE REVISED RISK MATRIX

CC1 SHORT COMINGS IN APPENDIX G

Experience in use of the terminology in Appendix G of AGS (2000) since publication has shown the system to be reasonable, but that there are a number of short comings. Specifically:

- ***Indicative likelihood values were given at the centre of each "box" or level***. Consequently it could be argued that the boundaries between each level were unclear and subject to challenge. De Ambrosis & Mostyn (2004) proposed assigning the indicative likelihood values at the boundary between each level, thereby removing the uncertainty. However, this may have the result of, in effect, increasing the assessed indicative likelihood by half an order of magnitude. The revised scheme has maintained the indicative likelihood values at the centre of each box.
- ***Experience has shown that practitioners were making a qualitative assessment of likelihood based solely on the Description or Descriptor when considering risk to property*** (as discussed in C5.4.2 above). The associated indicative probability was then used for quantitative risk to life analysis, resulting in a semi quantitative assessment. For this process using the de Ambrosis and Mostyn (2004) scheme, the practitioner may have some uncertainty as to what probability value would be appropriate to use in subsequent risk to life calculations. If the procedure of making a best estimate of likelihood, as outlined in C5.4.2 is adopted, then this should not occur. The revised scheme has adopted both a Notional Boundary between each level and an Indicative Value for each level to clarify this issue where needed.
- ***Consequences to property were poorly defined.*** The descriptions given were subject to interpretation and mean different things to different people, especially if people have different experience and/or knowledge. de Ambrosis and Mostyn (2004) proposed defining the assessment of consequences in relation to Market Value. A subjective assessment of the extent of damage is still required, but for a given assessment a "best estimate" of the cost could be prepared and documented. It has been argued (in discussions) that such a methodology suffers from being a "moving target" with time, since land and property values do not move in the same ratio or at the same rate as the remedial works costs. Whilst this may be true, it is unlikely to be a real constraint in practical terms given the necessary lack of precision of the approximate cost estimates and the relatively broad scale of consequences for a given category. An unambiguous scheme is preferred, even if the input estimates may be subject to debate, and the practitioner has to work with the available "best estimate" possible at the time. With appropriate documentation, the assessment is defensible and able to be reviewed at a later date. The revised scheme has adopted both a Notional Boundary between each level of consequence and an Indicative Value for each level.
- ***Dual risk terms (eg L-M, or VL-L) were included in the matrix.*** This was done intentionally with the intention that the practitioner could use judgment within the range to assign an appropriate term, which may well be a dual term to identify uncertainty in the outcome. However, the dual terms were interpreted as another risk class. Therefore, this became confusing, particularly in relation to acceptance of risk by the regulator based on Low risk. To remove this confusion, the revised risk matrix has been amended to single risk classes for each "box" (though cell A5 may be subdivided as noted).
- ***The term Not Credible is too extreme.*** The lowest level of likelihood has a revised term BARELY CREDIBLE which is more appropriate.
- ***Some practitioners were incorrectly deriving indicative probability values for risk to life analysis.*** Appendix G Likelihood table was being used from left to right; that is a descriptor was selected from the description (or even by preference for the descriptor), and then the indicative probability assigned accordingly. This method is wrong.

  The Likelihood Table has now been reordered to indicate the correct sequence of logic from left to right and as discussed in section C5.4.2, an estimate of the probability should be made based on apparent performance, trigger probabilities etc, and then the descriptor assigned accordingly.

A number of variations have been considered for the boundaries between different levels of Likelihood, Consequence and Risk. Earlier versions were considered by the Landslide Taskforce. The following considerations have been applied in deriving the revised scheme presented in the Practice Note Appendix C which supersedes the Appendix G AGS (2000) scheme which should no longer be used.

CC2 REVISIONS TO LIKELIHOOD TABLE

The Notional Boundary between Likelihood terms has been set at '5' times the exponent. An alternative at 3 times the exponent was considered. The Taskforce favoured 3 times the exponent during discussion of the issue as this value represents the half way on a log scale as identified in Appendix G, AGS (2000).

However, it is now considered that 5 times the exponent is better on a cumulative probability basis. The advantage of the choice is particularly evident at the boundary from Almost Certain to Likely when considering the plots of Indicative Probability of Occurrence after a Given Number of Years (as shown by Figure 2 of the Practice Note for 5 times the exponent). That is, if we adopt 5 times the exponent, then the numerical cumulative probability values after any particular elapsed time period are higher than the values for 3 times so that the 5 times values look more reasonable. The relevant numerical values are included in the side table to the matrix calculation sheet presented in Tables CC1 and CC2.

CC3 REVISIONS TO CONSEQUENCE TABLE

The Consequences table has been revised to use the Approximate Cost of Damage as the basis for deriving the consequence scale and appropriate descriptors.

The Consequence scale has been adjusted based on comments received from the Taskforce. The revised version is considered to give reasonable values within the matrix. The "road testing" of this scale by the Working Group has shown the scale values to be reasonable and the risk outcomes reasonable in relation to experience and expectation.

It is considered that the nominated consequence scale is preferable to the order of magnitude scale in de Ambrosis and Mostyn (2004) as the nominated scale enables a better subdivision of risk in the Medium and Major categories (10% to 100% consequences) and shifts the descriptors towards the higher consequences, which is more realistic.

CC4 REVISED MATRIX FOR RISK TO PROPERTY

As AGS (2000) Appendix G risk matrix has been used extensively, the revisions adopted have not been major though some of the cells in the risk matrix have a revised risk level. It is considered that the revisions have enabled clarification for the use of the system. The AGS (2000) Appendix G risk matrix should no longer be used.

The risk matrix has been evaluated based on an annualised cost of property damage. The annualised cost has been calculated as:

Annualised Cost = (Market Value $) x (Likelihood pa) x (Approximate proportion of damage)

Indicative values of annualised cost are presented for the indicative values of likelihood and consequence (ie at the centre of each matrix box) on the risk matrix tables in Tables CC1 and CC2.

For illustrative purposes the Market Value (MV) has been assumed as $1,000,000 (Table CC1) or $300,000 (Table CC2) to demonstrate the annualised cost values across the risk matrix. These MV are considered to be reasonable for current indicative values in a "prime coastal location" or in "an average suburban" / "country town location" respectively. The resulting annualised costs have been used to assign the risk categories. The assigned risk values within the Matrix have also been "juggled" based on comments from the Taskforce. Summary annualised risk values are given at the bottom of Tables CC1 and CC2.

The risk level has been skewed down in favour of consequence (as discussed by de Ambrosis and Mostyn (2004)) for the lower value consequences. From the values shown on Tables CC1 and CC2 it can be seen that the annual indicative risk to property for Moderate risk increases from 2E-05 for cell E1 to 5E-04 in cells C3 and A5.

Review of earlier drafts raised two examples for consideration being cells C4 (Possible / Minor) and D1 (Unlikely / Catastrophic) which are discussed below in relation to Table CC1.

For cell C4: there is a 1 in 20 chance of up to 10% damage in a 50 year design life for the structure. That implies in a 20 house subdivision, one of them will have up to $100,000 damage (based on $1M MV) or more likely about $50,000 damage over the design life. These dollar values are not the sort of expenditure that an average family will factor into their long term financial plan. Therefore, if you are unlucky enough to be the one affected, the occurrence would be a financial "disaster". Therefore, it would more likely be considered Tolerable (given the chance of it occurring) than Acceptable. Hence Moderate Risk has been assigned based on the recommended criteria given below.

For cell D1: there is a 1 in 200 chance of 100% or more damage in a 50 year design life for the structure. That implies a total loss of $1M MV, or worse, of one house in a 200 house subdivision over the 50 year design life. In Pittwater area of Sydney, there have been three houses lost over about 32 years out of about 7600 properties in the landslide risk zone (MacGregor et al 2007); say about 1 in 2500 chance over a 32 year period. The corresponding cumulative probability over 32 years for the indicative annual probability of 10^{-4} (for row D) is about 1 in 3000, which is a reasonably similar cumulative probability. The community reaction is that this is unacceptable, and therefore cell D1 should be High Risk as adopted.

In addition, cell A5 (Almost Certain / Insignificant)has been subdivided in recognition of the practicality of hazards that result in very low value consequences and are readily accepted by most owners. This subdivision agrees with feed back from practitioners on currently adopted assessments.

Cells B4, C3 and D3 present an uncertainty / dilemma. For consistency of annualised dollar value these should be High, High and Moderate risk respectively. The lower risk levels have been adopted by skewing the risk level down in

favour of consequence. That is, it is judged that higher consequences are more readily accepted or tolerated at the lower consequence values.

Therefore, based on the above considerations, the risk matrix has been revised based on the recommendation that for normal residential dwellings (Importance Level 2 structures) MODERATE risk is only TOLERABLE and that LOW risk is ACCEPTABLE as discussed in section C8.2. The risk levels have been adjusted accordingly on the Practice Note Appendix C risk matrix. The Working Group came to this view following the Taskforce discussions due to the cost impacts of actual damage on most home owners and the fact that home owners are likely to be risk averse due to the lack of insurance availability. If insurance against landslide damage was available, then an annualised cost of damage equivalent to an insurance policy cost would be a reasonable and rational division for acceptability.

It could be argued that it might be more rational to combine our Major and Medium to give a 4 level consequence scheme, with notional boundaries on the order of magnitude as per de Ambrosis and Mostyn (2004). We consider this does not allow sufficient differentiation in the middle of the matrix. The lower risk values for cells C3 and D3 of M and L, (or possibly M and M) as adopted, justify the 5 level scheme.

CC5 OTHER CONSIDERATIONS

At first comparison, the resulting risk matrix appears to be more conservative than the de Ambrosis and Mostyn (2004) version, as the risk levels for Medium and Minor the Practice Note Appendix C risk matrix are higher than theirs for the same descriptors. However, if de Ambrosis and Mostyn is adjusted so that comparison is made for the same percentage damage they are very similar. That is, Medium damage in de Ambrosis and Mostyn is the same as Minor Damage in Practice Note Appendix A matrix, and their Minor is similar to Insignificant. The resulting similarity / consistency is reassuring.

The recommended acceptance criteria for risk to property raises the question as to the possible economic impact on the community. Such a concern was raised when the Draft Pittwater policy was published for comment. Some practitioner's experience within Pittwater is that the need for more extensive stabilisation measures than previously adopted has not been as wide spread as expected. It is not clear whether this has arisen from assigning lower probability values and/or less consequences during the assessments.

Comment has been made on the comparison of risk arising between damage to houses in say Orange (market value say $300,000) and Pittwater (market value say $1,000,000). If landslides of similar likelihood cause a similar dollar value of damage, then the risk is higher for the lower market value property. This is an unavoidable outcome from a dollar value based system. There is implied acceptance of higher dollar values of damage where MV is higher. As an alternative, an index based on percentage area of property affected with a weighting factor for dwellings/structures affected has been suggested as a possibility, but not developed to a workable alternative as yet.

For some cases, such as within subdivisions or even on sites with portions having differing characteristics, it may be appropriate to subdivide the site into areas of different risk, rather than having a single risk for the entire site. Clearly the risk management requirements would similarly vary across the portions depending on the risk and nature of the development affected by the landslide.

Consideration needs to be given to the failure probability of a properly engineered and constructed stabilisation scheme. It has been suggested by some practitioners that Barely Credible would be appropriate. If construction is not rigorously supervised, then Rare may be more appropriate. Other practitioners have the view that Rare was more appropriate for the properly engineered and constructed stabilisation measures. If Rare is more realistic for most cases, then any site for which consequences of failure of the stabilisation scheme is Catastrophic would have a Moderate risk (in accordance with Practice Note Appendix C risk matrix) which is not recommended to be acceptable. To have an acceptable (low) risk, the stabilisation measures would have to have a Barely Credible likelihood of failure. To achieve a likelihood of Barely Credible, the stabilisation design should consider the extremes and still have a design Factor of Safety of greater than 1.0 for all credible combinations of loads and strengths. That is the design must satisfy a credible strength limit state. Necessary supervision and testing during construction must be specified by the designer to achieve the Barely Credible likelihood. This then enables derivation of stabilisation measures having acceptable risk.

In relation to the above it is noted that MacGregor *et al*. (2007) have concluded that the suggested annual probability of failure for all locations in Pittwater for soil cuts with wall support or fills with wall support would be $2x10^{-4}$. That is, a likelihood of UNLIKELY. As these data undoubtedly include a lot of unengineered walls, it would be reasonable to expect engineered walls to be at least one order of magnitude less likely to fail, that is would be RARE. Adoption of appropriate conservative design and supervision during construction should reasonably achieve a lower likelihood again, showing that BARELY CREDIBLE can be achieved.

APPENDIX CC: REVIEW OF APPENDIX G AGS (2000) AND DERIVATION OF THE REVISED RISK MATRIX

TABLE CC1 EVALUATION OF LEVELS OF RISK TO PROPERTY FOR MV = $1M

Assumes Consequence Cost is TOTAL COST
Including consequential costs

CONSEQUENCES (Total Cost as percentage of Market Value = $1,000,000)

LIKELIHOOD (pa)	Indicative Value	Notional Boundary	1: CATASTROPHIC 200% / $1,000,000	2: MAJOR 60% / $400,000	3: MEDIUM 20% / $100,000	4: MINOR 5% / $10,000	5: INSIGNIFICANT 0.5% / $1,000	0.05% Note 1	0.01% / $100
		1	1.0E+00	4.0E-01	1.0E-01	1.0E-02			1.0E-04
A: ALMOST CERTAIN	1.E-01		VH 2.0E-01 $200,000	VH 6.E-02 $60,000	VH 2.E-02 $20,000	H 5.E-03 $5,000	M 5.E-04 $500	L 5.E-05 $50	
		5.E-02	5.0E-02	2.0E-02	5.0E-03	5.0E-04			5.0E-06
B: LIKELY	1.E-02		VH 2.0E-02 $20,000	VH 6.E-03 $6,000	H 2.E-03 $2,000	M 5.E-04 $500	L 5.E-05 $50		
		5.E-03	5.0E-03	2.0E-03	5.0E-04	5.0E-05			5.0E-07
C: POSSIBLE	1.E-03		VH 2.0E-03 $2,000	H 6.E-04 $600	M 2.E-04 $200	M 5.E-05 $50	VL 5.E-06 $5		
		5.E-04	5.0E-04	2.0E-04	5.0E-05	5.0E-06			5.0E-08
D: UNLIKELY	1.E-04		H 2.0E-04 $200	M 6.E-05 $60	L 2.E-05 $20	L 5.E-06 $5	VL 5.E-07 $1		
		5.E-05	5.0E-05	2.0E-05	5.0E-06	5.0E-07			5.0E-09
E: RARE	1.E-05		M 2.0E-05 $20	L 6.E-06 $6	L 2.E-06 $2	VL 5.E-07 $1	VL 5.E-08 $0		
		5.E-06	5.0E-06	2.0E-06	5.0E-07	5.0E-08			5.0E-10
F: BARELY CREDIBLE	1.E-06		L ≤ 2.0E-06 $2	VL 6.E-07 $1	VL 2.E-07 $0	VL 5.E-08 $0	VL 5.E-09 $0		

Implied Probability of Landslide within nominated Design Life

DESIGN LIFE (Years) 20	60	100
100%	100%	100%
1 in 1.1 88%	1 in 1 100%	1in1 100%
64%	95%	99%
1in 6 18%	1 in 2.2 45%	1 in 1.5 63%
10%	26%	39%
1 in 50 2.0%	1 in 17 5.8%	1 in 10 9.5%
1.0%	3.0%	4.9%
1 in 500 0.2%	1 in 167 0.6%	1 in 100 1.0%
0.1%	0.3%	0.5%
1in 5000 0.02%	1 in 1670 0.06%	1 in 1000 0.10%
0.0%	0.0%	0.0%
0.00%	0.01%	0.01%

Showing indicative annualised cost based on Market Value

Note 1 Cell A5 is partitioned at a Consequence value of 0.1% , does not apply to rows below A

Risk Levels	Indicative Annualised Cost	Upper Bound Annualised Cost	Risk Cell	Recommended Risk Evaluation	
VH	$2,000 to $200,000 >	$1,000,000	A1	UNACCEPTABLE	
H	$200 to $5,000	$100,000	A4	UNACCEPTABLE	
M	$20 to $500	$10,000	A5	TOLERABLE	for existing structures, but treatment to reduce risk to L should be identified and implimented as soon as practicable
L	$2 to $50	$1,000	A5 (1)	ACCEPTABLE	for new and existing slopes/works
VL	≤ $5	$50	C5	ACCEPTABLE	for new and existing slopes/works

NOTE: This table supersedes Appendix G in AGS (2000)

TABLE CC2 EVALUATION OF LEVELS OF RISK TO PROPERTY FOR MV = $300,000

Assumes Consequence Cost is TOTAL COST
Including consequential costs

CONSEQUENCES (Total Cost as percentage of Market Value = $300,000)

LIKELIHOOD (pa)	Indicative Value	Notional Boundary	1: CATASTROPHIC 200% 100% $300,000	2: MAJOR 60% 40% $120,000	3: MEDIUM 20% 10% $30,000	4: MINOR 5% 1.0% $3,000	5: INSIGNIFICANT 0.5% 0.1% $300	6: INSIGNIFICANT 0.05% Note 1 0.01% $30	Implied Probability of Landslide within nominated Design Life — DESIGN LIFE (Years) 20	60	100
		1	1.0E+00	4.0E-01	1.0E-01	1.0E-02		1.0E-04	100%	100%	100%
A: ALMOST CERTAIN	1.E-01		VH 2.0E-01 $60,000	VH 6.E-02 $18,000	VH 2.E-02 $6,000	H 5.E-03 $1,500	M 5.E-04 $150	L 5.E-05 $15	1 in 1.1 88%	1 in 1 100%	1in1 100%
		5.E-02	5.0E-02	2.0E-02	5.0E-03	5.0E-04		5.0E-06	64%	95%	99%
B: LIKELY	1.E-02		VH 2.0E-02 $6,000	VH 6.E-03 $1,800	H 2.E-03 $600	M 5.E-04 $150	L 5.E-05 $15		1in 6 18%	1 in 2.2 45%	1 in 1.5 63%
		5.E-03	5.0E-03	2.0E-03	5.0E-04	5.0E-05		5.0E-07	10%	26%	39%
C: POSSIBLE	1.E-03		VH 2.0E-03 $600	H 6.E-04 $180	M 2.E-04 $60	M 5.E-05 $15	VL 5.E-06 $2		1 in 50 2.0%	1 in 17 5.8%	1 in 10 9.5%
		5.E-04	5.0E-04	2.0E-04	5.0E-05	5.0E-06		5.0E-08	1.0%	3.0%	4.9%
D: UNLIKELY	1.E-04		H 2.0E-04 $60	M 6.E-05 $18	L 2.E-05 $6	L 5.E-06 $2	VL 5.E-07 $0		1 in 500 0.2%	1 in 167 0.6%	1 in 100 1.0%
		5.E-05	5.0E-05	2.0E-05	5.0E-06	5.0E-07		5.0E-09	0.1%	0.3%	0.5%
E: RARE	1.E-05		M 2.0E-05 $6	L 6.E-06 $2	L 2.E-06 $1	VL 5.E-07 $0	VL 5.E-08 $0		1in 5000 0.02%	1 in 1670 0.06%	1 in 1000 0.10%
		5.E-06	5.0E-06	2.0E-06	5.0E-07	5.0E-08		5.0E-10	0.0%	0.0%	0.0%
F: BARELY CREDIBLE	1.E-06		L ≤ 2.0E-06 $1	VL 6.E-07 $0	VL 2.E-07 $0	VL 5.E-08 $0	VL 5.E-09 $0		0.00%	0.01%	0.01%

Showing indicative annualised cost based on Market Value

Risk Levels	Indicative Annualised Cost	Upper Bound Annualised Cost	Risk Cell	Recommended Risk Evaluation	
VH	$600 to $60,000 >	$300,000	A1	UNACCEPTABLE	
H	$60 to $1,500	$30,000	A4	UNACCEPTABLE	
M	$6 to $150	$3,000	A5	TOLERABLE	for existing structures, but treatment to reduce risk to L should be identified and implimented as soon as practicable
L	$1 to $15	$300	A5 (1)	ACCEPTABLE	for new and existing slopes/works
VL	≤ $2	$15	C5	ACCEPTABLE	for new and existing slopes/works

Note 1 Cell A5 is partitioned at a Consequence value of 0.1% , does not apply to rows below A

NOTE: This table supersedes Appendix G in AGS (2000)

APPENDIX CC: REVIEW OF APPENDIX G AGS (2000) AND DERIVATION OF THE REVISED RISK MATRIX

THE AUSTRALIAN GEOGUIDES FOR SLOPE MANAGEMENT AND MAINTENANCE

AGS Landslide Taskforce, Slope Management and Maintenance Working Group

The Australian Geomechanics Society (AGS) presents on the following pages a guideline on slope management and maintenance, as part of the landslide risk management guidelines developed under the National Disaster Funding Program (NDMP). This Guideline is aimed at home owners, developers and local councils, but also has applicability to a larger audience which includes builders and contractors, consultants, insurers, lawyers, government departments and in fact any person, or organisation, with a responsibility for the management or maintenance of a slope. The objective is to inform those with little or no knowledge of geotechnical engineering about landslides.

Each GeoGuide is a stand-alone document, which is formatted so that it can be printed on two sides of a single A4 sheet. It is expected that the set of GeoGuides will increase with time to cover a range of topics. As things stand:

- **GeoGuide LR1** is an introductory sheet that should be read by all users, since it explains what the LR (landslide risk) series is about and defines terms.
- **GeoGuides LR2, 3 and 4** explain why landslides occur and provide information on different types of landslide.
- **GeoGuide LR5** discusses the critical part that water often plays in relation to landslide occurrence and discusses measures that can be adopted to limit its effect.
- **GeoGuide LR6** refers to retaining walls and their maintenance.
- **GeoGuide LR7** puts the concept of landslide risk into an everyday context, so users can relate a particular landslide risk to other risks that they know they are prepared to take, sometimes on a daily basis.
- **GeoGuide LR8** retains the ideas of good and poor hillside construction practice originally provided by an AGS sub-committee in 1985.
- **GeoGuide LR9** concentrates specifically on effluent and surface water disposal, which is an important topic in some development areas.
- **GeoGuide LR10** is specifically aimed at those who have property on the coast and could be susceptible to coastal erosion processes.
- **GeoGuide LR11** provides information about the benefits of keeping records on inspection and maintenance activities and provides a proforma record sheet for users.

It is recognised that the GeoGuides are likely to be upgraded from time to time. Feedback on use and suggested changes should be sent to the National Chair of the Australian Geomechanics Society. The latest versions of the GeoGuides will be downloadable from the AGS website www.australiangemechanics.org

Through the NDMP, Australian governments (at Commonwealth, State and Local Government levels) are also funding the development of a Landslide Zoning Guideline (AGS 2007a), and a Practice Note Guideline (AGS 2007c) to which interested readers seeking in-depth information should refer.

ACKNOWLEDGEMENTS

These guidelines have been prepared by The Australian Geomechanics Society with funding from the National Disaster Mitigation Program, the Sydney Coastal Councils Group, and The Australian Geomechanics Society.

The Australian Geomechanics Society established a Working Group within a Landslide Taskforce to develop the guidelines. The development of the guidelines was managed by a Steering Committee. Membership of the Working Group, Taskforce and Steering Committee is listed in the Appendix.

Drafts of these GeoGuides have been subject to review by members of the AGS Landslide Taskforce, members of the geotechnical profession and local government.

REFERENCES

AGS (2007a) Guideline for Landslide Susceptibility, Hazard and Risk Zoning for Land Use Management. Australian Geomechanics Society, *Australian Geomechanics*, Vol 42, No1.

AGS (2007c). Practice Note Guidelines for Landslide Risk Management. Australian Geomechanics Society. *Australian Geomechanics*, Vol 42, No1,

AGS (2007e). The Australian GeoGuides for slope management and maintenance –. Australian Geomechanics Society. *Australian Geomechanics*, Vol 42, No 1, - this paper.

INTRODUCTION TO LANDSLIDE RISK

Photographs courtesy of Greg Kotze and Tony Phillips

AUSTRALIAN GEOGUIDES

The **Australian GeoGuides (LR series)** are a set of information sheets on the subject of landslide risk management and maintenance, published by the Australian Geomechanics Society (AGS). They provide background information intended to help people without specialist technical knowledge understand the basic issues involved. Topics covered include:

LR1 - Introduction	LR2 - Landslides	LR3 - Landslides in Soil
LR4 - Landslides in Rock	LR5 - Water & Drainage	LR6 - Retaining Walls
LR7 - Landslide Risk	LR8 - Hillside Construction	LR9 - Effluent & Surface Water Disposal
LR10 - Coastal Landslides	LR11 - Record Keeping	

The GeoGuides explain why slopes and retaining structures can be a hazard and what can be done with appropriate professional advice and local authority approval (if required) to remove, or reduce, the risk they represent.

Preparation of the GeoGuides has been funded by Australian governments through the National Disaster Mitigation Program (NDMP). This is a national program aimed at identifying and addressing natural disaster risk priorities across Australia. Technical input has been provided by experienced geotechnical engineers, engineering geologists and local government and government agency representatives from around Australia.

BACKGROUND

A number of landslides and cliff collapses occurred in Australia in the 1980's and 1990's in which lives were lost. Of these the Thredbo landslide probably received the most publicity, but there were several others. During this period the AGS issued a number of advisory notes to practitioners in relation to the assessment of landslide risk and its reduction. Building on these notes, and responding to changes in technology, a technical paper known as AGS2000 was prepared. It was followed in 2002 by an intensive nation-wide educational campaign attended by a large number of interested professionals from government departments and private industry. This resulted in an increased awareness of the risks associated with unstable slopes and a changed approach in many government departments responsible for regional planning, domestic development, roads, railways and the maintenance of natural features such as cliffs.

STATUS OF THE GEOGUIDES

The GeoGuides reflect the essence of good practice as perceived by a large number of geotechnical engineers, engineering geologists and other practitioners such as local government planners. **The GeoGuides are generic and do not, and cannot, constitute advice in relation to a specific situation. This must be sought from a geotechnical practitioner with first hand knowledge of the site.** It is expected that some local councils will refer to the GeoGuides and their companion publications in planning and building legislation. Check with your local council to see how it regards these documents. Companion publications to the GeoGuides are:

- AGS (2007a) Guideline for Landslide Susceptibility, Hazard and Risk Zoning for Land Use Management Australian Geomechanics Society, *Australian Geomechanics*, Vol 42, No1 and its associated commentary (AGS 2007b).
- AGS (2007c). Practice Note Guidelines for Landslide Risk Management. Australian Geomechanics Society. *Australian Geomechanics*, Vol 42, No1 2007, and its associated "Commentary" (AGS 2007d).

Copies of the above documents are available on the AGS website www.australiangeomechanics.org

TERMINOLOGY

Terminology tends to change with time and place and with the context in which it is used. The terms listed below have the following meanings in the GeoGuides:

Consequence	the outcome, or potential outcome, arising from the occurrence of a landslide expressed quantitatively, or qualitatively, in terms of loss, disadvantage, damage, injury, or loss of life.
Discontinuity	in relation to the ground is a crack, a bedding plane (a boundary between strata) or fault (a plane along which the ground has sheared) which forms a plane of weakness and reduces the overall strength of the ground.
Equilibrium	the condition when the forces on a mass of soil or rock in the ground, or on a retaining structure, are equal and opposite.
Factor of safety (FOS)	theoretically the forces available to prevent a part of the ground, or a retaining structure, from moving divided by those trying to move it. A FOS of one or less indicates that failure is likely to occur, but not how likely it is. To allow for unknowns and to limit movements engineers always aim to achieve a FOS significantly larger than one.
Failure	when part of the ground experiences movement as a result of the out of balance forces on it. Failure of a retaining structure means it is no longer able to fulfil its intended function.
Geotechnical practitioner	when referred to in the Australian GeoGuides (LR series), is a professional geotechnical engineer, or engineering geologist, with chartered status in a recognised national professional institution and relevant training, experience and core competencies in landslide risk assessment and management. In some government departments, technical officers are specifically trained to undertake some of the functions of a geotechnical practitioner.
Hazard	a condition with the potential for causing an undesirable consequence. In relation to landslides this includes the location, size, speed, distance of travel and the likelihood of its occurrence within a given period of time.
Landslide	the movement, or the potential movement, of a mass of rock, debris, or earth down a slope.
Likelihood	a qualitative description of probability, or frequency, of occurrence.
Partial saturation	the condition in the ground above the water table where both air and water are present as well as soil, or rock.
Perched water table	a water table above the true water table supported by a low permeability stratum.
Permeability	a measure of the ability of the ground to allow water to flow through it.
Risk	a measure of the probability and severity of an adverse effect to life, health, property or the environment.
Slip failure	landslide.
Stable	the condition when failure will not occur. Over geological time no part of the ground can be considered stable. Over short periods (eg the life of a structure) stability implies a very low likelihood of failure.
Retaining structure	anything built by humans which is intended to support the ground and inhibit failure.
Structure	in relation to rock, or soil, means the spacing, extent, orientation and type of discontinuities found in the ground at a particular location.
Tension crack	a distinct open crack that normally develops in the ground around a landslide and indicates actual, or imminent , failure.
Water table	the level in the ground below which it is saturated and the voids are filled with water.


Photograph courtesy of Phil Flentje

LANDSLIDES

What is a Landslide?

Any movement of a mass of rock, debris, or earth, down a slope, constitutes a “landslide”. Landslides take many forms, some of which are illustrated. More information can be obtained from Geoscience Australia, or by visiting its Australian Landslide Database at www.ga.gov.au/urban/factsheets/landslide.jsp. Aspects of the impact of landslides on buildings are dealt with in the book "Guideline Document Landslide Hazards" published by the Australian Building Codes Board and referenced in the Building Code of Australia. This document can be purchased over the internet at the Australian Building Codes Board's website www.abcb.gov.au .

Landslides vary in size. They can be small and localised or very large, sometimes extending for kilometres and involving millions of tonnes of soil or rock. It is important to realise that even a 1 cubic metre boulder of soil, or rock, weighs at least 2 tonnes. If it falls, or slides, it is large enough to kill a person, crush a car, or cause serious structural damage to a house. The material in a landslide may travel downhill well beyond the point where the failure first occurred, leaving destruction in its wake. It may also leave an unstable slope in the ground behind it, which has the potential to fail again, causing the landslide to extend (regress) uphill, or expand sideways. For all these reasons, both "potential" and "actual" landslides must be taken very seriously. They present a real threat to life and property and require proper management.

Identification of landslide risk is a complex task and must be undertaken by a geotechnical practitioner (GeoGuide LR1) with specialist experience in slope stability assessment and slope stabilisation.

What Causes a Landslide?

Landslides occur as a result of local geological and groundwater conditions, but can be exacerbated by inappropriate development (GeoGuide LR8), exceptional weather, earthquakes and other factors. Some slopes and cliffs never seem to change, but are actually on the verge of failing. Others, often moderate slopes (Table 1), move continuously, but so slowly that it is not apparent to a casual observer. In both cases, small changes in conditions can trigger a landslide with serious consequences. Wetting up of the ground (which may involve a rise in ground water table) is the single most important cause of landslides (GeoGuide LR5). This is why they often occur during, or soon after, heavy rain. Inappropriate development often results in small scale landslides which are very expensive in human terms because of the proximity of housing and people.

Does a Landslide Affect You?

Any slope, cliff, cutting, or fill embankment may be a hazard which has the potential to impact on people, property, roads and services. Some tell-tale signs that might indicate that a landslide is occurring are listed below:

- open cracks, or steps, along contours
- ground water seepage, or springs
- bulging in the lower part of the slope
- hummocky ground
- trees leaning down slope, or with exposed roots
- debris/fallen rocks at the foot of a cliff
- tilted power poles, or fences
- cracked or distorted structures

These indications of instability may be seen on almost any slope and are not necessarily confined to the steeper ones (Table 1). Advice should be sought from a geotechnical practitioner if any of them are observed. Landslides do not respect property boundaries. As mentioned above they can "run-out" from above, "regress" from below, or expand sideways, so a landslide hazard affecting your property may actually exist on someone else's land.

Local councils are usually aware of slope instability problems within their jurisdiction and often have specific development and maintenance requirements. **Your local council is the first place to make enquiries if you are responsible for any sort of development or own or occupy property on or near sloping land or a cliff.**

TABLE 1 - Slope Descriptions

Appearance	Slope Angle	Maximum Gradient	Slope Characteristics
Gentle	0°- 10°	1 on 6	Easy walking.
Moderate	10°- 18°	1 on 3	Walkable. Can drive and m anoeuvre a car on driveway
Steep	18°- 27°	1 on 2	Walkable with effort. Possible to drive straight up or down roughened concrete driveway, but cannot practically manoeuvre a car.
Very Steep	27°- 45°	1 on 1	Can only climb slope by cl utching at vegetation, rocks etc.
Extreme	45°- 64°	1 on 0.5	Need rope access to climb slope
Cliff	64°- 84°	1 on 0.1	Appears vertical. Can absei l down.
Vertical or Overhang	84°- 90±°	Infinite	Appears to o verhang. Abseiler likely to lose contact with the face.

Some typical landslides which could affect residential housing are illustrated below:

Rotational or circular slip failures (Figure 1) - can occur on moderate to very steep soil and weathered rock slopes (Table 1). The sliding surface of the moving mass tends to be deep seated. Tension cracks may open at the top of the slope and bulging may occur at the toe. The ground may move in discrete "steps" separated by long periods without movement. More rapid movement may occur after heavy rain.

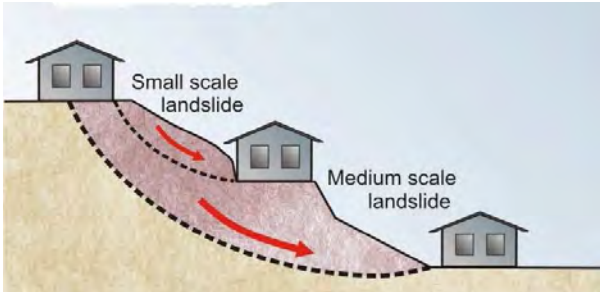


Figure 1

Translational slip failures (Figure 2) - tend to occur on moderate to very steep slopes (Table 1) where soil, or weak rock, overlies stronger strata. The sliding mass is often relatively shallow. It can move, or deform slowly (creep) over long periods of time. Extensive linear cracks and hummocks sometimes form along the contours. The sliding mass may accelerate after heavy rain.

Figure 2

Wedge failures (Figure 3) - normally only occur on extreme slopes, or cliffs (Table 1), where discontinuities in the rock are inclined steeply downwards out of the face.

Rock falls (Figure 3) - tend to occur from cliffs and overhangs (Table 1).

Cliffs may remain apparently unchanged for hundreds of years. Collections of boulders at the foot of a cliff may indicate that rock falls are ongoing. Wedge failures and rock falls do not "creep". Familiarity with a particular local situation can instil a false sense of security since failure, when it occurs, is usually sudden and catastrophic.

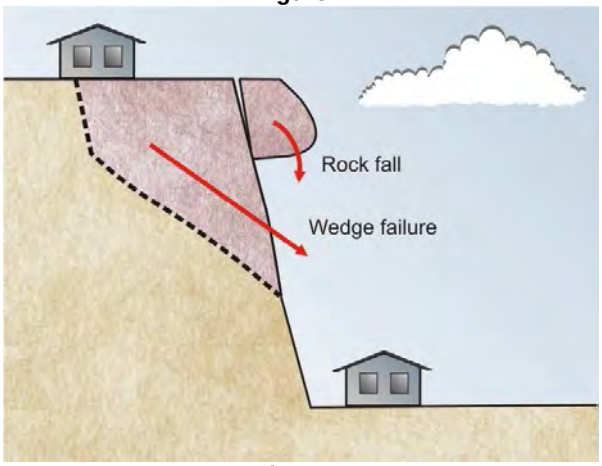


Figure 3

Debris flows and mud slides (Figure 4) - may occur in the foothills of ranges, where erosion has formed valleys which slope down to the plains below. The valley bottoms are often lined with loose eroded material (debris) which can "flow" if it becomes saturated during and after heavy rain. Debris flows are likely to occur with little warning; they travel a long way and often involve large volumes of soil. The consequences can be devastating.

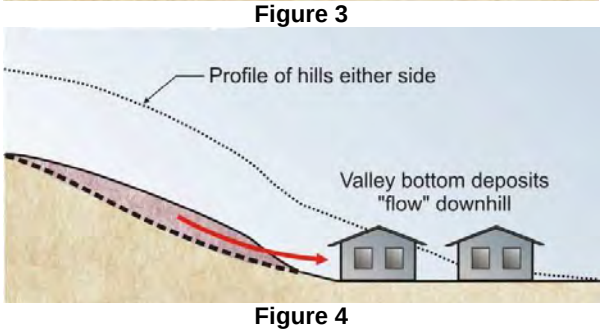


Figure 4

More information relevant to your particular situation may be found in other Australian GeoGuides:

- GeoGuide LR1 - Introduction
- GeoGuide LR3 - Soil Slopes
- GeoGuide LR4 - Rock Slopes
- GeoGuide LR5 - Water & Drainage
- GeoGuide LR6 - Retaining Walls
- GeoGuide LR7 - Landslide Risk
- GeoGuide LR8 - Hillside Construction
- GeoGuide LR9 - Effluent & Surface Water Disposal
- GeoGuide LR10 - Coastal Landslides
- GeoGuide LR11 - Record Keeping

The Australian GeoGuides (LR series) are a set of publications intended for property owners; local councils; planning authorities; developers; insurers; lawyers and, in fact, anyone who lives with, or has an interest in, a natural or engineered slope, a cutting, or an excavation. They are intended to help you understand why slopes and retaining structures can be a hazard and what can be done with appropriate professional advice and local council approval (if required) to remove, reduce, or minimise the risk they represent. The GeoGuides have been prepared by the Australian Geomechanics Society, a specialist technical society within Engineers Australia, the national peak body for all engineering disciplines in Australia, whose members are professional geotechnical engineers and engineering geologists with a particular interest in ground engineering. The GeoGuides have been funded under the Australian governments' National Disaster Mitigation Program.

LANDSLIDES IN SOIL

Landslides occur on soil slopes and the consequences can include damage to property and loss of life. Soil slopes exist in all parts of Australia and can even occur in places where rock outcrops can be seen on the surface. If you live on, or below, a soil slope it is important to understand why a landslide might occur and what you can do to reduce the risk it presents.

It is always worth asking the question *"why is this slope here?"*, because the answer often leads to an understanding of what might happen in the future. Slopes are usually formed by weathering (breakdown) and erosion (physical movement) of the natural ground - the "parent material". Many factors are involved including rain, wind, chemical change, temperature variation, plant growth, animal activity and our own human enthusiasm for development. The general process is outlined in Figure 1.

The upper levels of the parent material progressively weather over thousands, or millions, of years, losing strength. This can result in a surface layer which looks similar to the parent material (although its colour has probably changed) but has the strength of a soil - this is called "residual soil". At some stage the weathered surface layer is exposed to the elements and fragments are transported down the slope. In this context a fragment could be a single sand grain, a boulder, or a landslide. The time scale could be anything from a few seconds to many thousands of years. The transported fragments often collect on the lower slopes and form a new soil layer that blankets the original slope - "colluvium". If material reaches a river or the sea it is deposited as "alluvium" or as a "marine deposit". With appropriate changes in river and sea level this material can again find itself on the surface to commence another cycle of weathering and erosion. In places often, but not only, near the coast, this can include sand sized fragments which form beaches and are sometimes blown back onto the land to form dunes.

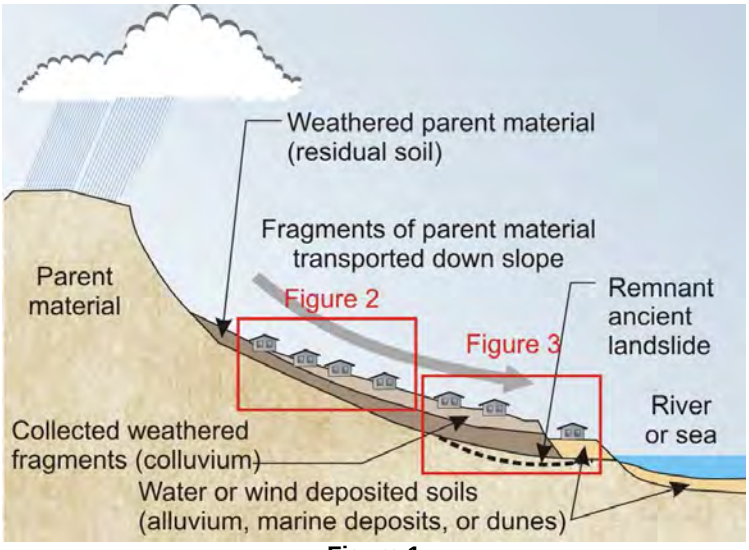


Figure 1

Landslides can occur almost anywhere on a soil slope. Slides can be rotational, translational, or debris flows (see GeoGuide LR2) and may have a number of causes.

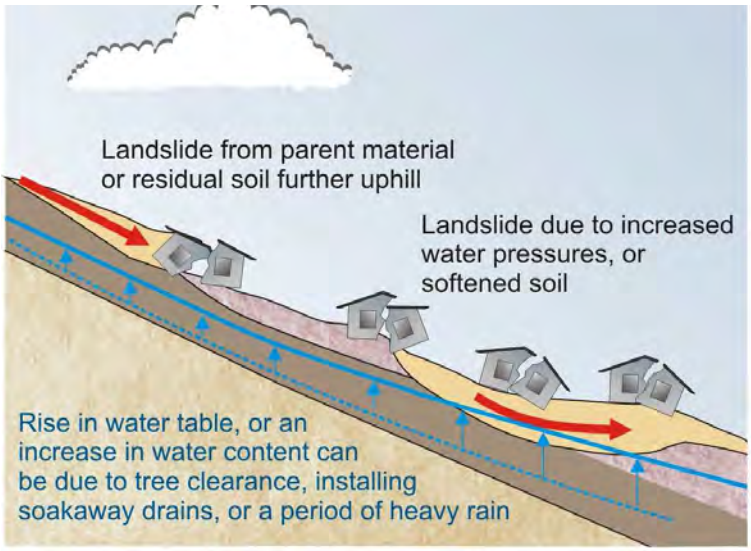


Figure 2

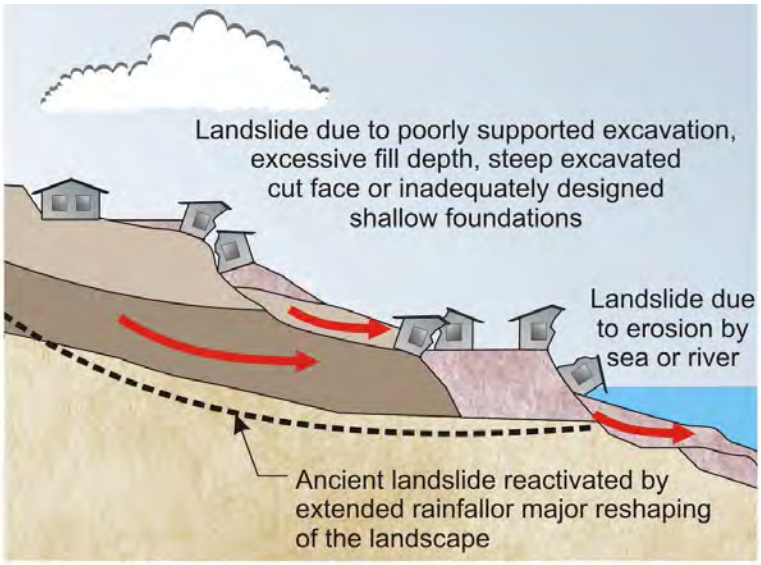


Figure 3

Some of the more common causes of landslides in soil are:

1) Falls of the parent material or residual soil from above, due to natural weathering processes (Figure 2).
2) Increased moisture content and consequent softening of the soil, or a rise in the water table. These can be due to excessive tree clearance, ill-considered soak-away drainage or septic systems, or heavy rainfall (Figure 2).
3) Excavation without adequate support, increased surface load from fill placement, or inadequately designed shallow foundations (Figure 3).
4) Natural erosion at the toe of the slope due to scour by a river or the sea (Figure 3).
5) Re-activation of an ancient landslide (Figure 3).

Most soil slopes appear stable, but they all achieved their present shape through a process of weathering and erosion and are often sensitive to minor changes in the factors that affect their stability. As a general rule, human activities only improve the situation if they have been designed to do so. Once this idea is understood, it is probably easy to see why the following basic rules are so important and should not be ignored without seeking site specific advice from a geotechnical practitioner:

- Do not clear trees unnecessarily.
- Do not cut into a slope without supporting the excavated face with an engineer designed structure.
- Do not add weight to a slope by placing earth fill or constructing buildings with inadequately designed shallow foundations (Note: in certain circumstances weight is added to the toe of a slope to inhibit landslide movement, but this must be carried out in accordance with a proper engineering design).
- Do not allow water from storm water drains, or from septic waste or effluent disposal systems to soak into the ground where it could trigger a landslide.

More information in relation to good and poor hillside construction practice is given in GeoGuide LR8. With appropriate engineering input it is often possible to reduce the likelihood, or consequences, of a landslide and so reduce the risk to property and to life. Such measures can include the construction of properly designed storm water and sub-soil drains, surface protection (GeoGuide LR5) and retaining walls (GeoGuide LR6). **Design should be undertaken by a geotechnical practitioner and will normally require local council approval.**

More information relevant to your particular situation may be found in other Australian GeoGuides:

- GeoGuide LR1 - Introduction
- GeoGuide LR2 - Landslides
- GeoGuide LR4 - Landslides in Rock
- GeoGuide LR5 - Water & Drainage
- GeoGuide LR6 - Retaining Walls
- GeoGuide LR7 - Landslide Risk
- GeoGuide LR8 - Hillside Construction
- GeoGuide LR9 - Effluent & Surface Water Disposal
- GeoGuide LR10 - Coastal Landslides
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LANDSLIDES IN ROCK

Rocks have been formed by many different geological processes and may have been subjected to intense pressure, large scale distortion, extreme temperature and chemical change. As a result there are many different rock types and their condition varies enormously. Rock strength varies and is often significantly reduced by the presence of discontinuities (GeoGuide LR1). You may think that rock lasts forever, but in reality it weathers under the combined effects of water, wind, chemical change, temperature variation, plant growth and animal activity and erodes with time. Rock is often the parent material that ends up forming soil slopes (GeoGuide LR3). Inevitably different rocks have different physical and chemical characteristics and they weather and erode to form different types of soil.

Weathering can lead to landslides (GeoGuide LR2) on rock slopes. The type of landslide depends on the nature of rock, the way it has weathered and the presence or absence of discontinuities. It is hard to generalise, though normally a specific combination of discontinuities and material types will be the determining factor and these are often underground and out of sight. Typical examples are provided in the figures 1 to 4. A geotechnical practitioner can assess the landslide risk and propose appropriate maintenance measures. This often entails making geological observations over an area significantly larger than the site and a review of available background information, including records of known landslides and aerial photographs. Depending on the amount of information available, geotechnical investigation may or may not be needed. Every site is different and every site has to be assessed individually.

It is impossible to predict exactly when a landslide will occur on a rock slope, but failure is normally sudden and the consequences can be catastrophic.

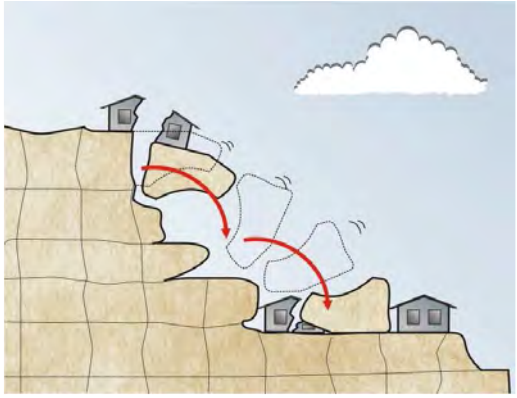

Figure 1 - Failure of an undercut block

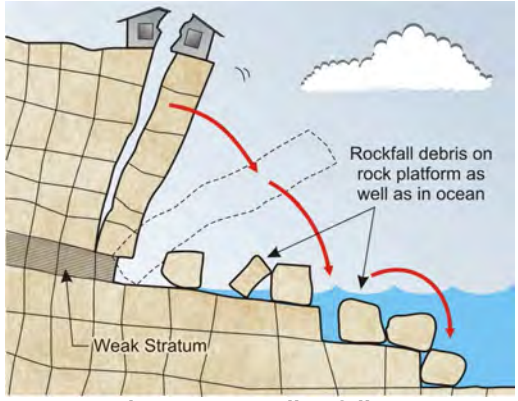

Figure 2 - Toppling failure

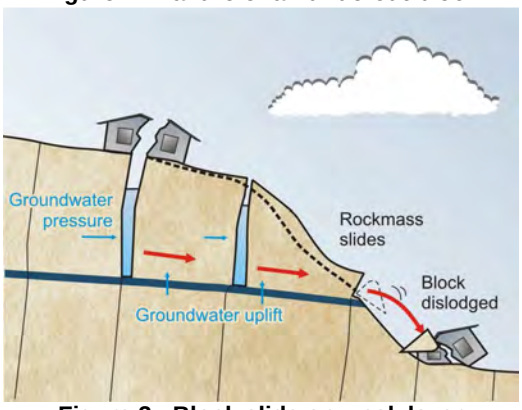

Figure 3 - Block slide on weak layer

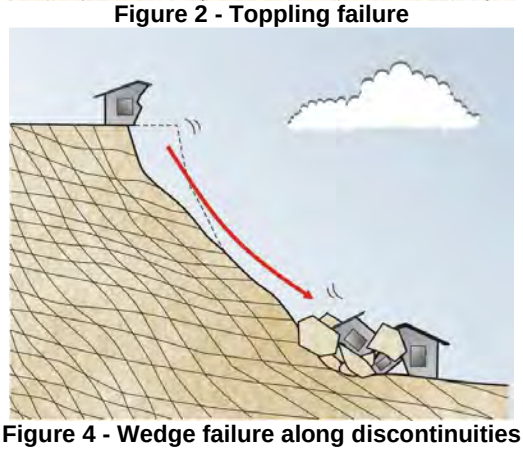

Figure 4 - Wedge failure along discontinuities

If the landslide risk is assessed as being anything other that Low, or Very Low, (GeoGuide LR7) it may be possible to carry out work aimed at reducing the level of risk.

The most common options are:

1) Trimming the slope to remove hazardous blocks of rock.
2) Bolting, or anchoring, to fix hazardous blocks in position and prevent movement.
3) Installation of catch fences and other rockfall protection measures to limit the impact of rockfalls.
4) Deep drainage designed to limit changes in the ground water table (GeoGuide LR5).

Although such measures can be effective, they need inspection and on-going maintenance (GeoGuide LR11) if they are to be effective for periods equivalent to the life of a house. **Design should be undertaken by a geotechnical practitioner and will normally require local council approval.** It should be appreciated that it may not be viable to carry out remedial works in all circumstances: for example where the landslide is on someone else's property, where the cost is out of proportion to the value of the property, or where the risk inherent in carrying out the work is actually greater than the risk of leaving things as they are. In situations such as these, development may be considered inappropriate.

ROCK SLOPE HAZARD REDUCTION MEASURES

Removal of loose blocks - may be effective but, depending on rock type, ongoing erosion can result in more blocks becoming unstable within a matter of years. Routine inspection, every 5 or so years, may be required to detect this.

Rock bolts and rock anchors (Figure 5) - can be installed in the ground to improve its strength and prevent individual blocks from falling. Rock bolts are usually tightened using a torque wrench, whilst rock anchors carry higher loads and require jacking. Both can be designed to be "permanent" using stainless steel, or sheathing, to inhibit corrosion, but the cost can be up to 10 times that of the "temporary" alternative. You should inspect rock bolts and rock anchors for signs of water seepage, rusting and deterioration around the heads at least once every 5 years. If you notice any of these warning signs, have them checked by a geotechnical practitioner. It is recommended that you keep copies of design drawings and maintenance records (GeoGuide LR11) for the anchors on your site and pass them on to the new owner should you sell.

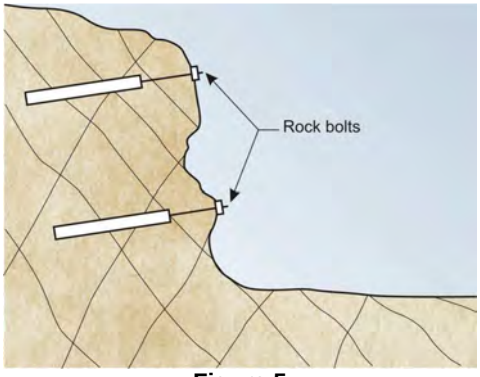

Figure 5

Rock fall netting, catch fences and catch pits (Figure 6) - are designed to catch or control falling rocks and prevent them from damaging nearby property. You should inspect them at least once every 5 years, and after major falls, and arrange for fallen and trapped rocks to be removed if they appear to be filling up. Check for signs of corrosion and replace steel elements and fixings before they lose significant strength.

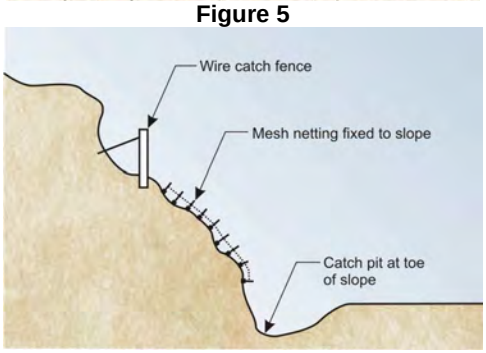

Figure 6

Cut-off drains (Figure 7) - can be used to intercept surface water run-off and reduce flows down the cliff face. Suitable drains are often excavated into the rock, or constructed from mounds of concrete, or stabilised soil, depending on conditions. Drains must be laid to a fall of at least 1% so they drain adequately. Frequent inspection is needed to ensure they are not blocked and continue to function as intended.

Clear trees and large bushes (Figure 7) - from slopes since roots can prize boulders from the face increasing the landslide hazard.

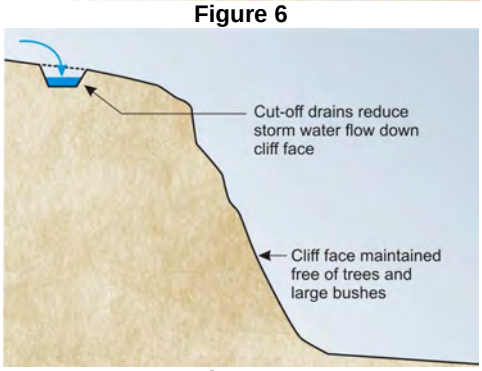

Figure 7

Natural cliffs and bluffs - often present the greatest hazard and yet are easily overlooked, because they have "been there forever". They can exist above a building, road, or beach, presenting the risk of a rock falling onto whatever is below. They also sometimes support buildings with a fine view to the horizon. Cliffs should be observed frequently to ensure that they are not deteriorating. You may find it convenient to use binoculars to look for signs of exposed "fresh" rock on the face, where a recent fall has occurred, or to go to the foot of the cliff from time to time to see if debris is collecting. A thorough inspection of a cliff face is often a major task requiring the use of rope access methods and should only be undertaken by an appropriately qualified professional. If tension cracks are observed in the ground at the top of a cliff take immediate action, since they could indicate imminent failure. **If you have any concerns at all about the possibility of a rock fall seek advice from a geotechnical practitioner.**

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- GeoGuide LR1 - Introduction
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- GeoGuide LR3 - Landslides in Soil
- GeoGuide LR5 - Water & Drainage
- GeoGuide LR6 - Retaining Walls
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WATER, DRAINAGE & SURFACE PROTECTION

One way or another, water usually plays a critical part in initiating a landslide (GeoGuide LR2). For this reason, it is a key factor to be controlled on sites with more than a low landslide risk (GeoGuide LR7).

Groundwater and Groundwater Flow

The ground is permeable and water flows through it as illustrated in Figure 1. When rain falls on the ground, some of it runs along the surface ("surface water run-off") and some soaks in, becoming groundwater. Groundwater seeps downwards along any path it can find until it meets the water table: the local level below which the ground is saturated. If it reaches the water table, groundwater either comes to a halt in what is effectively underground storage, or it continues to flow downwards, often towards a spring where it can seep out and become surface water again. Above the water table the ground is said to be "partially saturated", because it contains both water and air. Suctions can develop in the partially saturated zone which have the effect of holding the ground together and reducing the risk of a landslide. Vegetation and trees in particular draw large quantities of water out of the ground on a daily basis from the partially saturated zone. This lowers the water table and increases suctions, both of which reduce the likelihood of a landslide occurring.

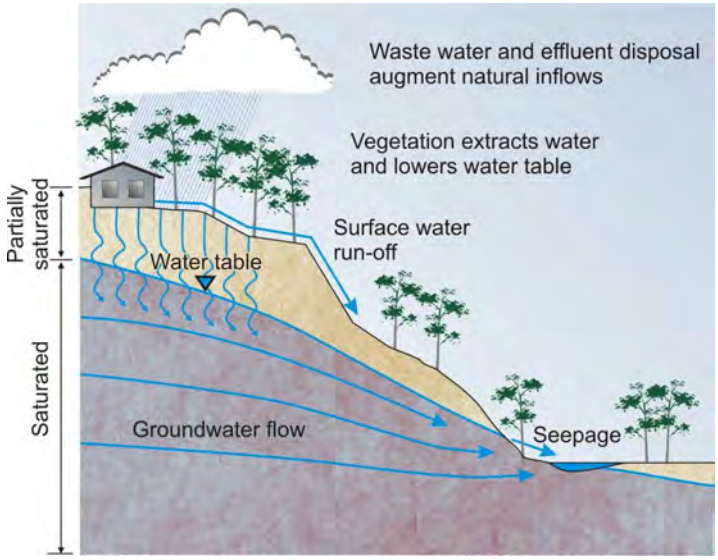

Figure 1 - Groundwater flow

Groundwater Flow and Landslides

The landslide risk in a hillside can be affected by increase in soak-away drainage or the construction of retaining walls which inhibit groundwater flow. The groundwater is likely to rise after heavy rain, but it can also rise when human interference upsets the delicate natural balance. Activities such as felling trees and earthworks can lead to:

- a reduction in the beneficial suctions in the partially saturated zone above the water table.
- increased static water pressures below the water table,
- increased hydraulic pressures due to groundwater flow,
- loss of strength, or softening, of clay rich strata,
- loss of natural cementing in some strata,
- transportation of soil particles.

Any of these effects, or a combination of them, can lead to landslides like those illustrated in GeoGuides LR2, LR3 and LR4.

Limiting the Effect of Water

Site clearance and construction must be carefully considered if changes in groundwater conditions are to be limited. GeoGuide LR8 considers good and poor development practices. Not surprisingly much of the advice relates to sensible treatment of water and is not repeated here. Adoption of appropriate techniques should make it possible to either maintain the current ground water table, or even cause it to drop, by limiting inflow to the ground.

If drainage measures and surface protection are relied on to keep the risk of a landslide to a tolerable level, it is important that they are inspected routinely and maintained (GeoGuide LR11).

The following techniques may be considered to limit the destabilising effects of rising groundwater due to development and are illustrated in Figure 2.

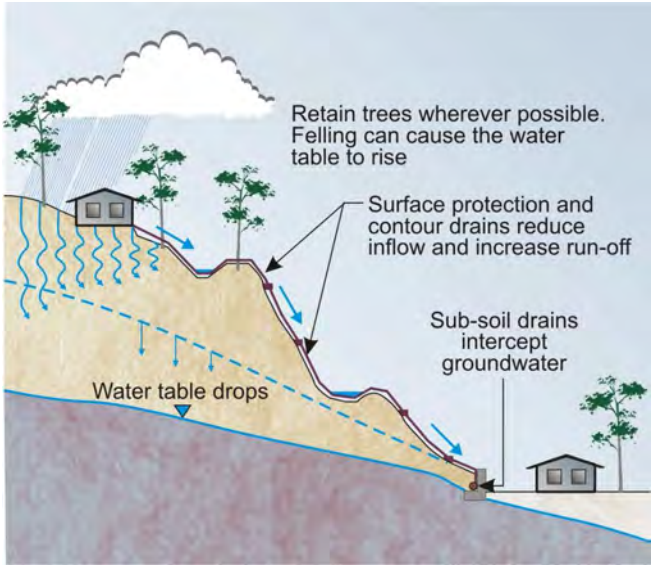

Figure 2 - Techniques used to control groundwater flow

Surface water drains (dish drains, or table drains) - are often used to prevent scour and limit inflow to a slope. Other than in rock, they are relatively ineffective unless they have an impermeable lining. You should clear them regularly, and as required, and not less than once a year. If you live in an area with seasonal rainfall, it is best to do this near the end of the dry season. If you notice that soil or rock debris is falling from the slope above, determine the source and take appropriate action. This may mean you have to seek advice from a geotechnical practitioner.

Surface protection - is sometimes used in addition to surface water drainage to prevent scour and minimise water inflow to a slope. You should inspect concrete, shotcrete or stone pitching for cracking and other signs of deterioration at least once a year. Make sure that weepholes are free of obstructions and able to drain. If the protection is deteriorating, you should seek advice from a geotechnical practitioner.

Sub-soil drains - are often constructed behind retaining walls and on hillsides to intercept groundwater. Their function is to remove water from the ground through an appropriate outlet. It is important that subsoil drains are designed to complement other measures being used. They should be laid in a sand, or gravel, bed and protected with a graded stone or geotextile filter to reduce the chance of clogging. Sub-soil drains should always be laid to a fall of at least 1 vertical on 100 horizontal. Ideally the high end should be brought to the surface, so it can be flushed with water from time to time as part of routine maintenance procedures.

Deep, underground drains - are usually only used in extreme circumstances, where the landslide risk is assessed as not being tolerable and other stabilisation measures are considered to be impractical. They work by permanently lowering the water table in a slope. They are not often used in domestic scale developments, but if you have any on your site be aware that professional maintenance is essential. If they are not maintained and stop working, the water table will rise and a landslide may even occur during normal weather conditions. Both an increase or a reduction in the normal flow from deep drains could indicate a problem if it appears to be unrelated to recent rainfall. If changes of this sort are observed, you should have the drains and your site checked by a geotechnical practitioner.

Documentation - design drawings and specifications for geotechnical measures intended to minimise landslide risk can be of great assistance to a geotechnical specialist, or structural engineer, called in to inspect and report on them. Copies of available documentation should be retained and passed to the new owner when the property is sold (GeoGuide LR11). You should also request details of an appropriate maintenance program for drainage works from the designer and keep that information with other relevant documentation and maintenance records.

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RETAINING WALLS

Retaining walls are used to support cuts and fills. Some are built in the open and backfill is placed behind them (gravity walls). Others are inserted into the ground (cast *in situ* or driven piles) and the ground is subsequently excavated on one side. Retaining walls, like all man-made structures, have a finite life. Properly engineered walls should last 50 years, or more, without needing significant repairs. However, not all walls fit this category. Some, particularly those built by inexperienced tradesmen without engineering input, can deflect and even fail because they are unable to withstand the pressures that develop in the ground around them or because the materials from which they are built deteriorate with time. **Design of retaining walls more than 900mm high should be undertaken by a geotechnical practitioner or structural engineer and normally require local council approval.**

Retaining walls have to withstand the weight of the ground on the high side, any water pressure forces that develop, any additional load (surcharge) on the ground surface and sometimes swelling pressures from expansive clays. These forces are resisted by the wall itself and the ground on the low side. Engineers calculate the forces that the retained ground, the water, and the surcharge impose on a wall (the disturbing force) as well as the maximum force that the wall and ground on the low side can provide to resist them (the restoring force). The ratio of the restoring force to the disturbing force is called the "factor of safety" (GeoGuide LR1). Permanent retaining walls designed in accordance with accepted engineering standards will normally have a factor of safety in the range 1.5 to 2.

Never add surcharge to the high side of a wall (e.g. place fill, erect a structure, stockpile bulk materials, or park vehicles) unless you know the wall has been designed with that purpose in mind.

Never more than lightly water plants on the high side of a retaining wall.

Never excavate at the toe of a retaining wall.

Any of these actions will reduce the factor of safety of the wall and could lead to failure. If in doubt about any aspect of an existing retaining wall, or changes you would like to make near one, seek advice from a geotechnical practitioner, or a structural engineer. This GeoGuide sets out basic inspection requirements for retaining walls and identifies some common signs that might indicate all is not well. GeoGuide LR11 provides information about records that should be kept.

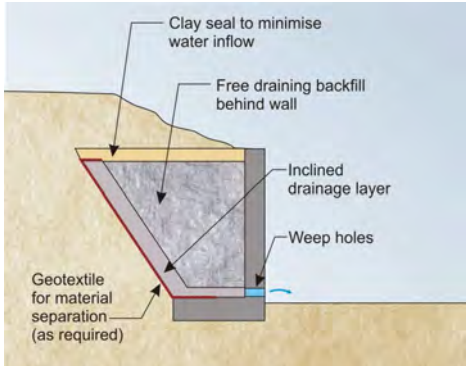

Figure 1- Typical formed concrete wall

GRAVITY WALLS

Gravity walls are so called because they rely on their own weight (the force of gravity) to hold the ground behind in place.

Formed concrete and reinforced blockwork walls (Figure 1) **-** should be built so the backfill can drain. They should be inspected at least once a year. Look for signs of tilting, bulging, cracking, or a drop in ground level on the high side, as any of these may indicate that the wall has started to fail. Look for rust staining, which may indicate that the steel reinforcement is deteriorating and the wall is losing structural strength ("concrete cancer"). Ensure that weep holes are clear and that water is able to drain at all times, as high water pressures behind the wall can lead to sudden and catastrophic failure.

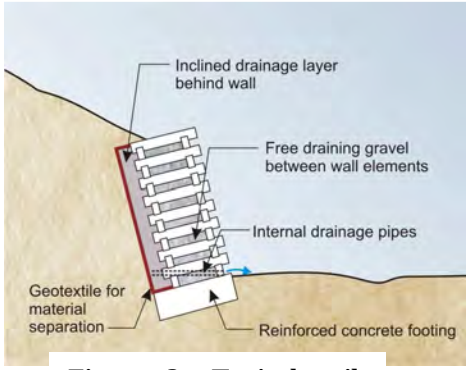

Figure 2 -Typical crib

Concrete "crib" walls (Figure 2) **-** should be filled with clean gravel, or "blue metal" with a nominated grading. Sometimes soil is used to reduce cost, but this is undesirable, from an engineering perspective, unless internal drainage is incorporated in the wall's construction. Without backfill drainage, a soil filled crib wall is likely to have a lower factor of safety than is required. Crib walls should be inspected as for formed concrete walls. In addition, you should check that material is not being lost through the structure of the wall, which has large gaps through it.

Timber "crib" walls - should be checked as for concrete crib walls. In addition, check the condition of the timber. Once individual elements show signs of rotting, it is necessary to have the wall replaced. If you are uncertain seek advice from a geotechnical practitioner, or a structural engineer.

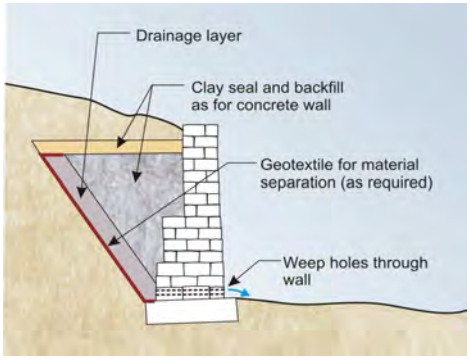

Figure 3 -Typical masonry wall

Masonry walls: natural stone, brick, or interlocking blocks (Figure 3) - more than about 1m high, should be wider at the bottom than at the top and include specific measures to permit drainage of the backfill. They should be checked as for formed concrete walls. Natural stone walls should be inspected for signs of deterioration of the individual blocks: strength loss, corners becoming rounded, cracks appearing, or debris from the blocks collecting at the foot of the wall.

Old Masonry walls (Figure 4) - Many old masonry retaining walls have not been built in accordance with modern design standards and often have a low "factor of safety" (GeoGuide LR1). They may therefore be close to failure and a minor change in their condition, or loading, could initiate collapse. You need to take particular care with such structures and seek professional advice sooner rather than later. Although masonry walls sometimes deflect significantly over long periods of time collapse, when it occurs, is usually sudden and can be catastrophic. Familiarity with a particular situation can instil a false sense of confidence.

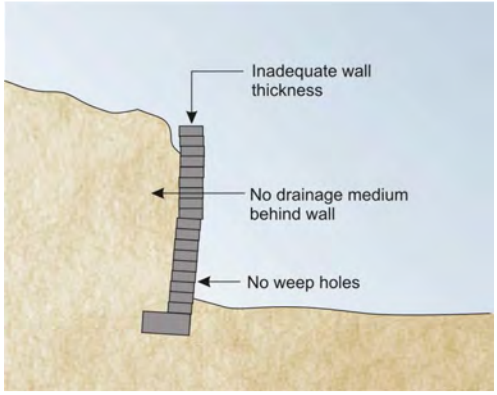

Figure 4 - Poorly built masonry wall

Reinforced soil walls (Figure 5) **-** are made of compacted select fill in which layers of reinforcement are buried to form a "reinforced soil zone". The reinforcement is all important, because it holds the soil "wall" together. Reinforcement may be steel strip, or mesh, or a variety of geosynthetic ("plastic") products. The facing panels are there to protect the soil "wall" from erosion and give it a finished appearance.

Most reinforced soil walls are proprietary products. Construction should be carried out strictly in accordance with the manufacturer's instructions. Inspection and maintenance should be the same as for formed concrete and concrete block walls. If unusual materials such as timber, or used tyres, are used as a facing it should be checked to see that it is not rotting, or perishing.

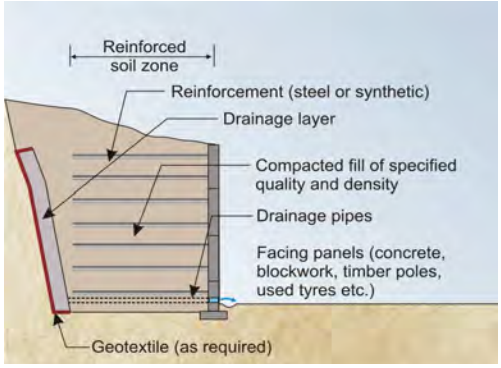

Figure 5 - Typical reinforced soil wall

OTHER WALLS

Cantilevered and anchored walls (Figure 6) **-** rely on earth pressure on the low side, rather than self-weight, to provided the restoring force and an adequate factor of safety. These walls may comprise:

- a line of touching bored piers (contiguous bored pile wall) or
- sprayed concrete panels between bored piers (shotcrete wall) or
- horizontal timber or concrete planks spanning between upright timber or steel soldier piles or
- steel sheet piles.

Depending on the form of construction and ground conditions, walls in excess of 3 m height normally require at least one row of permanent ground anchors.

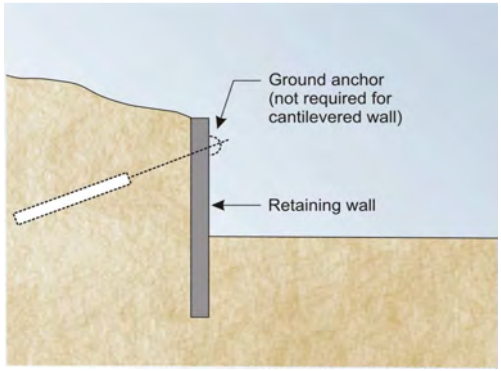

Figure 6 - Typical cantilevered or anchored wall

INSPECTION

All walls should be inspected at least once a year, looking for tilting and other signs of deterioration. Concrete walls should be inspected for cracking and rust stains as for formed concrete gravity walls. Contiguous bored pile walls can have gaps between the piles - look for loss of soil from behind which can become a major difficulty if it is not corrected. Timber walls should be inspected for rot, as for timber crib walls. Steel sheet piles should be inspected for signs of rusting. In addition, you should make sure that ground anchors are maintained as described in GeoGuide LR4 under the heading "Rock bolts and rock anchors".

One of the most important issues for walls is that their internal drainage systems are operational. Frequently verify that internal drainage pipes and surface interception drains around the wall are not blocked nor have become inoperative.

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LANDSLIDE RISK

Concept of Risk

Risk is a familiar term, but what does it really mean? It can be defined as *"a measure of the probability and severity of an adverse effect to health, property, or the environment."* This definition may seem a bit complicated. In relation to landslides, geotechnical practitioners (GeoGuide LR1) are required to assess risk in terms of the likelihood that a particular landslide will occur and the possible consequences. This is called landslide risk assessment. The consequences of a landslide are many and varied, but our concerns normally focus on loss of, or damage to, property and loss of life.

Landslide Risk Assessment

Some local councils in Australia are aware of the potential for landslides within their jurisdiction and have responded by designating specific "landslide hazard zones". Development in these areas is often covered by special regulations. If you are contemplating building, or buying an existing house, particularly in a hilly area, or near cliffs, go first for information to your local council.

Landslide risk assessment must be undertaken by a geotechnical practitioner. It may involve visual inspection, geological mapping, geotechnical investigation and monitoring to identify:

- potential landslides (there may be more than one that could impact on your site)
- the likelihood that they will occur
- the damage that could result
- the cost of disruption and repairs and
- the extent to which lives could be lost.

Risk assessment is a predictive exercise, but since the ground and the processes involved are complex, prediction tends to lack precision. If you commission a landslide risk assessment for a particular site you should expect to receive a report prepared in accordance with current professional guidelines and in a form that is acceptable to your local council, or planning authority.

Risk to Property

Table 1 indicates the terms used to describe risk to property. Each risk level depends on an assessment of how likely a landslide is to occur and its consequences in dollar terms. "Likelihood" is the chance of it happening in any one year, as indicated in Table 2. "Consequences" are related to the cost of repairs and temporary loss of use if a landslide occurs. These two factors are combined by the geotechnical practitioner to determine the Qualitative Risk.

TABLE 2: LIKELIHOOD

Likelihood	Annual Probability
Almost Certain	1:10
Likely	1:100
Possible	1:1,000
Unlikely	1:10,000
Rare	1:100,000
Barely credible	1:1,000,000

The terms "unacceptable", "may be tolerated", etc. in Table 1 indicate how most people react to an assessed risk level. However, some people will always be more prepared, or better able, to tolerate a higher risk level than others.

Some local councils and planning authorities stipulate a maximum tolerable level of risk to property for developments within their jurisdictions. In these situations the risk must be assessed by a geotechnical practitioner. If stabilisation works are needed to meet the stipulated requirements these will normally have to be carried out as part of the development, or consent will be withheld.

TABLE 1: RISK TO PROPERTY

Qualitative Risk		Significance - Geotechnical engineering requirements
Very high	VH	**Unacceptable** without treatment. Extensive detailed investigation and research, planning and implementation of treatment options essential to reduce risk to Low. May be too expensive and not practical. Work likely to cost more than the value of the property.
High	H	**Unacceptable** without treatment. Detailed investigation, planning and implementation of treatment options required to reduce risk to acceptable level. Work would cost a substantial sum in relation to the value of the property.
Moderate	M	**May be tolerated** in certain circumstances (subject to regulator's approval) but requires investigation, planning and implementation of treatment options to reduce the risk to Low. Treatment options to reduce to Low risk should be implemented as soon as possible.
Low	L	**Usually acceptable** to regulators. Where treatment has been needed to reduce the risk to this level, ongoing maintenance is required.
Very Low	VL	**Acceptable**. Manage by normal slope maintenance procedures.

Risk to Life

Most of us have some difficulty grappling with the concept of risk and deciding whether, or not, we are prepared to accept it. However, without doing any sort of analysis, or commissioning a report from an "expert", we all take risks every day. One of them is the risk of being killed in an accident. This is worth thinking about, because it tells us a lot about ourselves and can help to put an assessed risk into a meaningful context. By identifying activities that we either are, or are not, prepared to engage in we can get some indication of the maximum level of risk that we are prepared to take. This knowledge can help us to decide whether we really are able to accept a particular risk, or to tolerate a particular likelihood of loss, or damage, to our property (Table 2).

In Table 3, data from NSW for the years 1998 to 2002, and other sources, is presented. A risk of 1 in 100,000 means that, in any one year, 1 person is killed for every 100,000 people undertaking that particular activity. The NSW data assumes that the whole population undertakes the activity. That is, we are all at risk of being killed in a fire, or of choking on our food, but it is reasonable to assume that only people who go deep sea fishing run a risk of being killed while doing it.

It can be seen that the risks of dying as a result of falling, using a motor vehicle, or engaging in water-related activities (including bathing) are all greater than 1:100,000 and yet few people actively avoid situations where these risks are present. Some people are averse to flying and yet it represents a lower risk than choking to death on food. Importantly, the data also indicate that, even when the risk of dying as a consequence of a particular event is very small, it could still happen to any one of us any day. If this were not so, no one would ever be struck by lightning.

Most local councils and planning authorities that stipulate a tolerable risk to property also stipulate a tolerable risk to life. The AGS Practice Note Guideline recommends that 1:100,000 is tolerable in newly developed areas, where works can be carried out as part of the development to limit risk. The tolerable level is raised to 1:10,000 in established areas, where specific landslide hazards may have existed for many years. The distinction is deliberate and intended to prevent the concept of landslide risk management, for its own sake, becoming an unreasonable financial burden on existing communities. Acceptable risk is usually taken to be one tenth of the tolerable risk (1:1,000,000 for new developments and 1:100,000 for established areas) and efforts should be made to attain these where it is practicable and financially realistic to do so.

TABLE 3: RISK TO LIFE

Risk (deaths per participant per year)	**Activity/Event Leading to Death** (NSW data unless noted)
1:1,000	Deep sea fishing (UK)
1:1,000 to 1:10,000	Motor cycling, horse riding , ultra-light flying (Canada)
1:23,000	Motor vehicle use
1:30,000	Fall
1:70,000	Drowning
1:180,000	Fire/burn
1:660,000	Choking on food
1:1,000,000	Scheduled airlines (Canada)
1:2,300,000	Train travel
1:32,000,000	Lightning strike

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- GeoGuide LR4 - Landslides in Rock
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- GeoGuide LR8 - Hillside Construction
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- GeoGuide LR11 - Record Keeping

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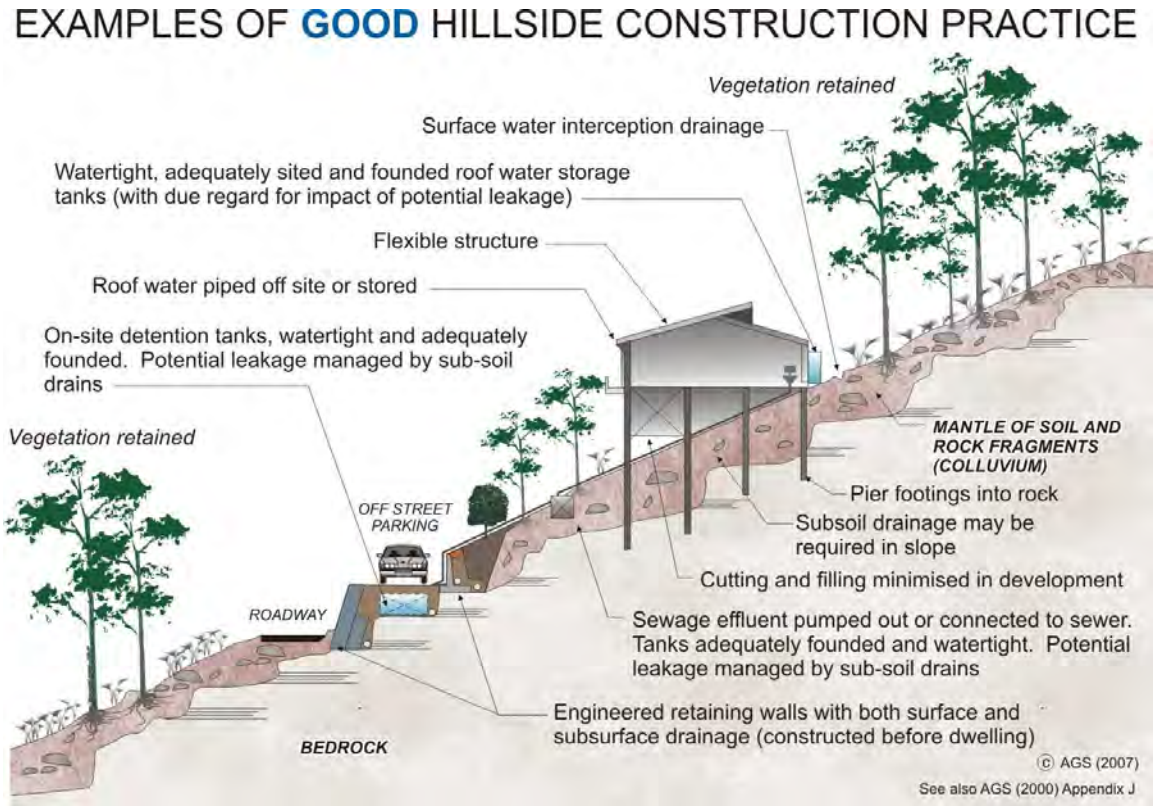
HILLSIDE CONSTRUCTION PRACTICE

Sensible development practices are required when building on hillsides, particularly if the hillside has more than a low risk of instability (GeoGuide LR7). Only building techniques intended to maintain, or reduce, the overall level of landslide risk should be considered. Examples of good hillside construction practice are illustrated below.



WHY ARE THESE PRACTICES GOOD?

Roadways and parking areas - are paved and incorporate kerbs which prevent water discharging straight into the hillside (GeoGuide LR5).

Cuttings - are supported by retaining walls (GeoGuide LR6).

Retaining walls - are engineer designed to withstand the lateral earth pressures and surcharges expected, and include drains to prevent water pressures developing in the backfill. Where the ground slopes steeply down towards the high side of a retaining wall, the disturbing force (see GeoGuide LR6) can be two or more times that in level ground. Retaining walls must be designed taking these forces into account.

Sewage - whether treated or not is either taken away in pipes or contained in properly founded tanks so it cannot soak into the ground.

Surface water - from roofs and other hard surfaces is piped away to a suitable discharge point rather than being allowed to infiltrate into the ground. Preferably, the discharge point will be in a natural creek where ground water exits, rather than enters, the ground. Shallow, lined, drains on the surface can fulfil the same purpose (GeoGuide LR5).

Surface loads - are minimised. No fill embankments have been built. The house is a lightweight structure. Foundation loads have been taken down below the level at which a landslide is likely to occur and, preferably, to rock. This sort of construction is probably not applicable to soil slopes (GeoGuide LR3). If you are uncertain whether your site has rock near the surface, or is essentially a soil slope, you should engage a geotechnical practitioner to find out.

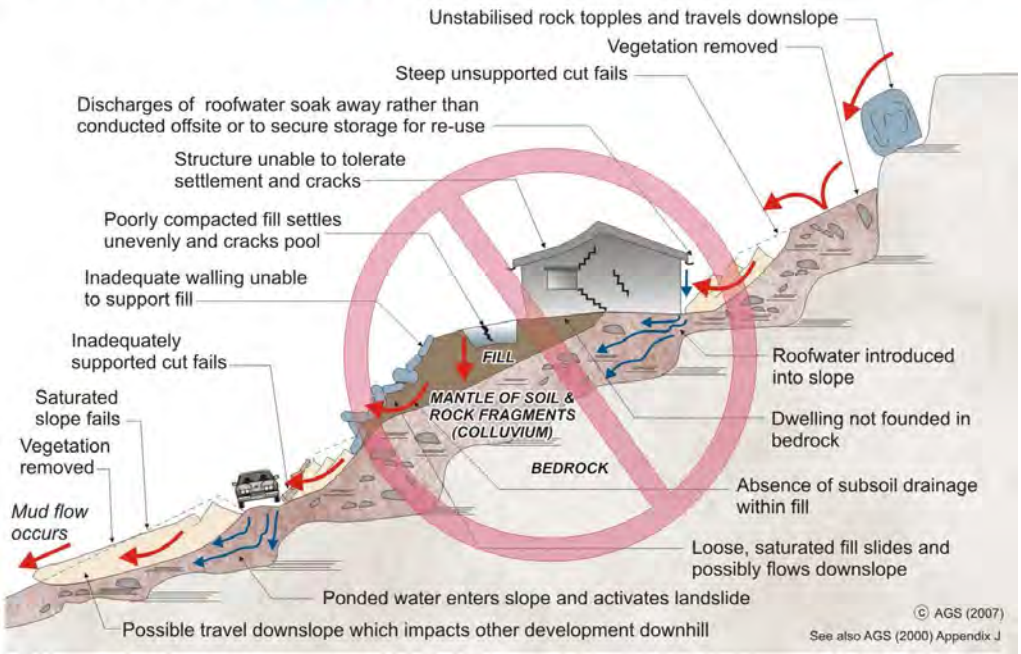
Flexible structures - have been used because they can tolerate a certain amount of movement with minimal signs of distress and maintain their functionality.

Vegetation clearance - on soil slopes has been kept to a reasonable minimum. Trees, and to a lesser extent smaller vegetation, take large quantities of water out of the ground every day. This lowers the ground water table, which in turn helps to maintain the stability of the slope. Large scale clearing can result in a rise in water table with a consequent increase in the likelihood of a landslide (GeoGuide LR5). An exception may have to be made to this rule on steep rock slopes where trees have little effect on the water table, but their roots pose a landslide hazard by dislodging boulders.

Possible effects of ignoring good construction practices are illustrated on page 2. Unfortunately, these poor construction practices are not as unusual as you might think and are often chosen because, on the face of it, they will save the developer, or owner, money. You should not lose sight of the fact that the cost and anguish associated with any one of the disasters illustrated, is likely to more than wipe out any apparent savings at the outset.

ADOPT GOOD PRACTICE ON HILLSIDE SITES

EXAMPLES OF POOR HILLSIDE CONSTRUCTION PRACTICE



WHY ARE THESE PRACTICES POOR?

Roadways and parking areas - are unsurfaced and lack proper table drains (gutters) causing surface water to pond and soak into the ground.

Cut and fill - has been used to balance earthworks quantities and level the site leaving unstable cut faces and added large surface loads to the ground. Failure to compact the fill properly has led to settlement, which will probably continue for several years after completion. The house and pool have been built on the fill and have settled with it and cracked. Leakage from the cracked pool and the applied surface loads from the fill have combined to cause landslides.

Retaining walls - have been avoided, to minimise cost, and hand placed rock walls used instead. Without applying engineering design principles, the walls have failed to provide the required support to the ground and have failed, creating a very dangerous situation.

A heavy, rigid, house - has been built on shallow, conventional, footings. Not only has the brickwork cracked because of the resulting ground movements, but it has also become involved in a man-made landslide.

Soak-away drainage - has been used for sewage and surface water run-off from roofs and pavements. This water soaks into the ground and raises the water table (GeoGuide LR5). Subsoil drains that run along the contours should be avoided for the same reason. If felt necessary, subsoil drains should run steeply downhill in a chevron, or herring bone, pattern. This may conflict with the requirements for effluent and surface water disposal (GeoGuide LR9) and if so, you will need to seek professional advice.

Rock debris - from landslides higher up on the slope seems likely to pass through the site. Such locations are often referred to by geotechnical practitioners as "debris flow paths". Rock is normally even denser than ordinary fill, so even quite modest boulders are likely to weigh many tonnes and do a lot of damage once they start to roll. Boulders have been known to travel hundreds of metres downhill leaving behind a trail of destruction.

Vegetation - has been completely cleared, leading to a possible rise in the water table and increased landslide risk (GeoGuide LR5).

DON'T CUT CORNERS ON HILLSIDE SITES - OBTAIN ADVICE FROM A GEOTECHNICAL PRACTITIONER

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EFFLUENT AND SURFACE WATER DISPOSAL

EFFLUENT AND WASTEWATER

All households generate effluent and wastewater. The disposal of these products and their impact on the environment are key considerations in the planning of safe and sustainable communities. Cities and townships generally have reticulated water, sewer and stormwater systems, which are designed to deliver water and dispose of effluent and wastewater with minimal impact on the environment. However, many smaller communities and metropolitan fringe suburbs throughout Australia are un-sewered. Some of these are located in hillside or coastal settings where landslides present a hazard.

Processes by which wastewater can affect slope stability

As explained in GeoGuides LR3 and LR5, groundwater variations have a significant impact on slope stability. Inappropriate disposal of effluent and wastewater may result in the ground becoming saturated. The result is equivalent to a localised rise of the groundwater table and may have the potential to cause a landslide (GeoGuides LR2, LR5 and LR8).

On-site effluent disposal

In un-sewered areas disposal of effluent must be achieved through suitable methods. These methods usually involve containment within the boundaries of the site ("on-site disposal"). State environment protection agencies and local government authorities can usually provide advice on suitable disposal systems for your area. Such systems may include:

- *Septic systems,* which involve a storage/digestion tank for solids, with disposal of the liquid effluent via absorption trenches and beds, leach drains, or soak wells. Such systems are best suited to areas not prone to landslides.
- *Aerobic treatment units* which incorporate an individual household treatment plant to aid breakdown of the waste into a higher quality effluent. Such effluent is further treated and disposed of by surface or sub-surface irrigation, sub-soil dripper, or shallow leach drain system.
- *Nutrient retentive leaching systems* which utilise septic tanks to process the solid and liquid wastes in conjunction with discharge of the effluent through sand filters, media filters, mound systems and nutrient retentive leaching systems, which strip the effluent of nutrients.

Toilet (and sometimes kitchen) waste is known as *black water.* Other, less contaminated, wastewater streams from showers, baths and laundries are known as *grey water*. *Grey water re-use systems* allow a household to conserve water from bathrooms, kitchens and laundries, for re-use on gardens and lawns.

Recommendations for effluent disposal

In areas prone to landslide hazard, it is recommended that whatever effluent disposal system is employed, it should be designed by a qualified professional, familiar with how such a system can impact on the local environment. Local council, and in some instances state environment protection agency, approval is usually required as well. Many local authorities require a site assessment report, which covers all relevant issues. If approved, the report's recommendations must be incorporated in the system design. Reduction in the volume of effluent is beneficial so composting toilets and highly rated (i.e. low consumption) water appliances are recommended. It should be noted that in some state and local government jurisdictions there are restrictions on the alternative measures that can be applied. Consideration should be given to applying treated wastewater to land at low rates and over as large an area as possible. Further guidance can be found in Australian Standard AS/NZS 1547:2000 On-site domestic wastewater management.

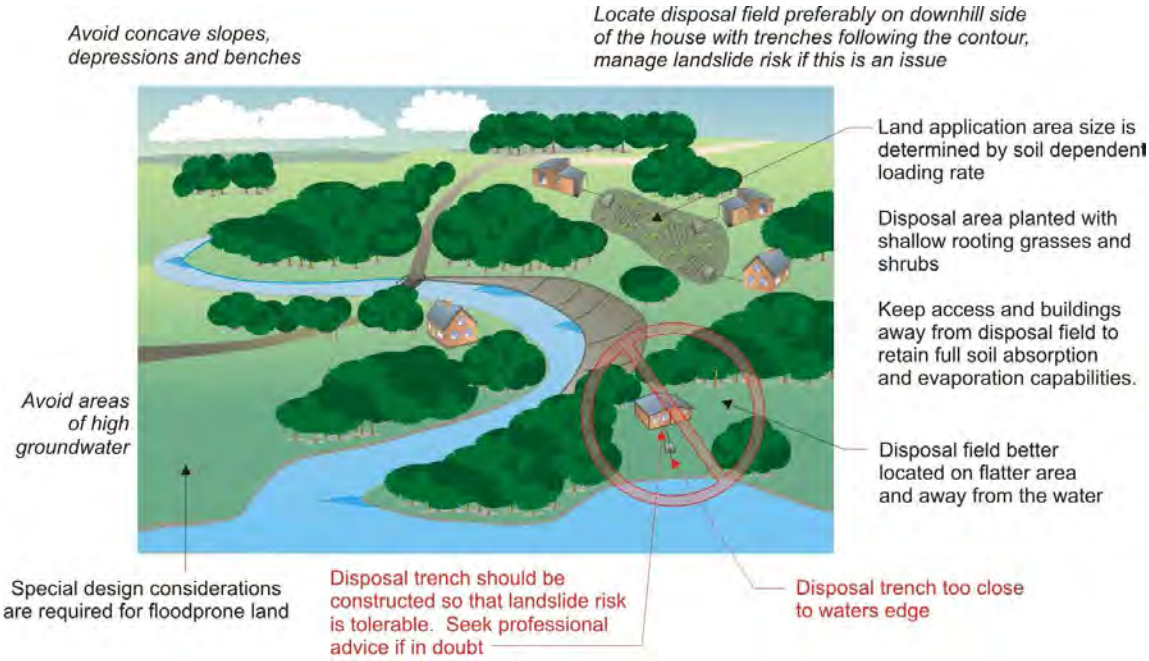
Effluent disposal fields should be sited with due consideration to the overall landscape and the individual characteristics of the property. Some guidance is provided. In particular, effluent fields should be located downslope of the building, away from stormwater, or *grey water*, discharge areas and where there is minimal potential for downstream pollution. Set backs and buffer distances vary from state to state and local requirements should be adhered to. All systems require regular maintenance and inspection. Efficient operation of the system must be a priority for property owners/occupiers to ensure safe and sustainable communities. Responsibility for maintenance rests with owners.

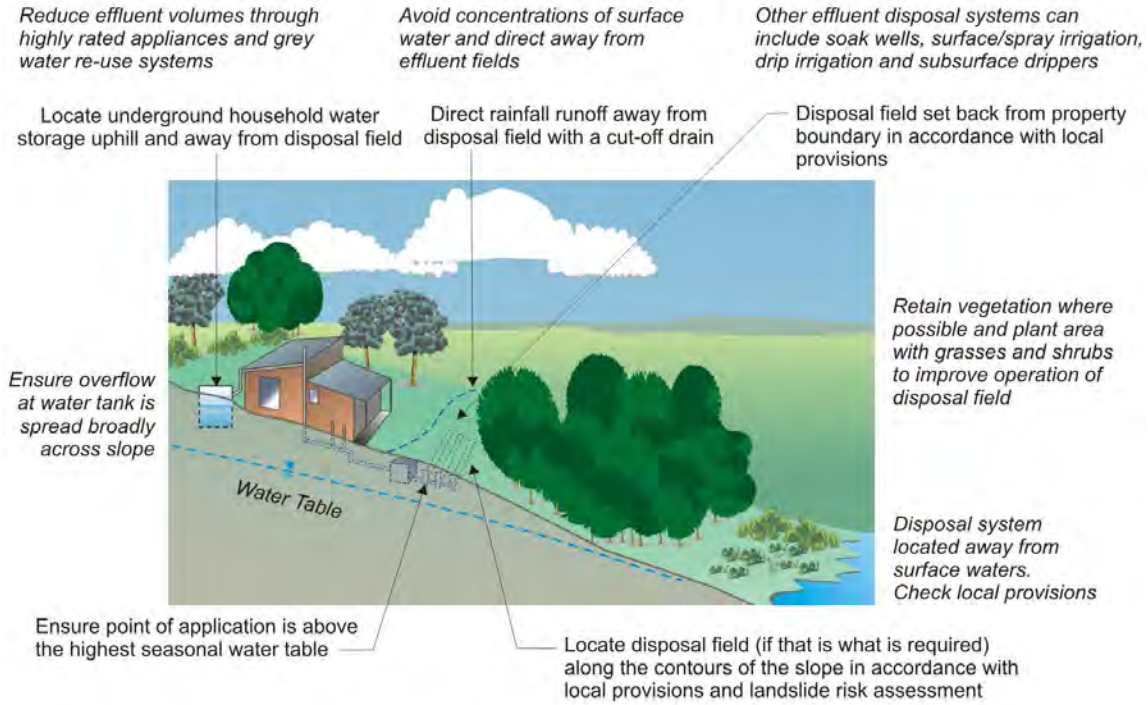
SURFACE WATER DRAINAGE

Attention to on-site surface water management is also important. Runoff from developments, including buildings, decks, access tracks and hardstand areas should be collected and discharged away from the development and other effluent disposal fields. Particular care must be given to the design of overflows on water tanks, as this is often overlooked. Discharge from any development should be spread out as much as possible, unless it can be directed to an existing natural water course. Ponding of water on hillsides and the concentration of water flows on slopes must be avoided.

It is recommended that a specific drainage plan and strategy should be developed in conjunction with the effluent disposal system for sites with a high potential for slope instability. Maintenance of the surface water drainage system is as important as maintenance of the effluent disposal system and again the responsibility rests with owners.

AUSTRALIAN GEOGUIDE LR9 (EFFLUENT DISPOSAL)





Note: Adapted from EPA Vic. Publication 451 (March 1996) "Code of Practice - Septic Tanks", which was sourced from Vic. Department of Planning and Loddon-Campaspe Regional Planning Authority.

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LANDSLIDES IN THE COASTAL ENVIRONMENT

Coastal Instability

The coast presents a particularly dynamic environment where change is often the norm. Hazards exist in relation to both cliffs and sand dunes. The coast is also the most heavily populated part of Australia and always regarded as "prime" real estate, because of the views and access to waterways and beaches.

Photo courtesy Greg Kotze

Waves, wind and salt spray play a significant part, causing dunes to move and cliff-faces to erode well above sea level. Our response is often to try to neutralise these effects by doing such things as dumping rock in the sea, building groynes, dredging, or carrying out dune stabilisation. Such works can be very effective, but ongoing maintenance is usually needed and total reconstruction may be necessary after a relatively short working life.

Of particular significance are extreme events that cause destruction on a scale that ignores our efforts at coastal protection. Records show that cliffs have collapsed, taking with them backyards which had been relied upon as a buffer between a house and the ocean. Sand dunes have also been washed away resulting in the dramatic loss of homes and infrastructure. As with most landslide issues, even though such events may be infrequent, they could happen tomorrow. It is easy to be lulled into a false sense of security on a calm day.

In coastal areas, typical landslide hazards (GeoGuides LR1 to LR4) are compounded by coastal erosion which, over time, undercuts cliffs and eventually results in failure. In the case of sand dunes, dune erosion and dune slumping have equally dramatic effects. Coastal locations are subject to particular processes relating to fluctuating water tables, inundation under storm tides and direct wave attack. Large sections of our more sandy coastline are receding under present sea conditions. The hazards are progressive and likely to be exacerbated through climate change.

Coastal Development

If you own, or are responsible for, a coastal property it is important that you understand that, where the shore line is receding, there is a greater landslide risk than would be the case on a similar site inland. The view may make the risk worthwhile, but does not reduce it.

Coastal Landslides

Coastal landslides are little different from other landslides in that the signs of failure (GeoGuides LR2) and the causes (LR3, LR4 & LR5) are largely the same. The main difference relates to the overriding influence of wave impact, tidal movement, salt spray and high winds.

Cliff failures

In addition to the processes that produce cliff instability on inland cliffs, coastal cliffs are also subjected to repeated cycles of wetting and drying which can be accompanied by the expansive effect of salt crystal growth in gaps in the rocks. These processes accelerate the deterioration of coastal cliffs. At the base of cliffs, direct wave attack and the impact of boulders moved by wave action causes undercutting and hence instability of the overall face. Figure 2 of GeoGuide LR4 provides an example. Whilst the processes leading to coastal cliff collapse may take years, failure tends to be catastrophic and with little warning. In many cases, waves produced by large oceanic storms are the trigger assisted by rainfall to produce collapse. These are also the conditions in which you are more likely to be inside your home and oblivious to unusual noises or movements associated with imminent failure.

Sand dune escarpment and slope failures

An understanding of coastal processes is essential when determining beach erosion potential. Waves produced by large oceanic storms can erode beaches and cut escarpments into dunes. These may be of relatively short duration, when beach re-building happens after the storm, but can be a permanent feature where long term beach recession is taking place. In many locations, houses and infrastructure are sited on or immediately behind coastal dunes. After an escarpment has eroded, those assets may be lost or damaged by subsequent slumping of the dune. It is important that, on erodible coastal soils, the potential for landward incursion of an erosion escarpment is determined. Having done this, the likelihood of slope instability can be established as part of the landslide risk management process. Injury, death and structural damage have occurred around the Australian coast from collapsing sand escarpments.

Photo courtesy DNR NSW

AUSTRALIAN GEOGUIDE LR10 (COASTAL LANDSLIDES)

The large scale and potentially high speed of coastal erosion processes means that major civil engineering work and large cost is normally involved in their control. The installation of rock bolts (LR4), drainage (LR5), or retaining walls (LR6) on a single house site may be necessary to provide local stability, but are unlikely to withstand the attack of a large storm on a beach or cliff-line.

BUILDING NEAR CLIFFS AND HEADLANDS

Coastal cliffs and headlands exist because the rock that they are made from is able to resist erosion. Even so, cliff-faces are not immune and will continue to collapse (Figure 1) by one or other of the mechanisms shown on GeoGuide LR4. If you live on a coastal cliff, you should undertake inspection and maintenance as recommended in LR4 and the other GeoGuides, as appropriate. The top of the cliff, its face, and its base should be inspected frequently for signs of recent rock falls, opening of cracks, and heavy seepage which might indicate imminent failure. Since the sea can remove fallen rocks rapidly, inspections should be made shortly after every major storm as a matter of course. **If collapses are occurring seek advice from an appropriately experienced geotechnical practitioner. Advise you local council if you believe erosion is rapid or accelerating.**

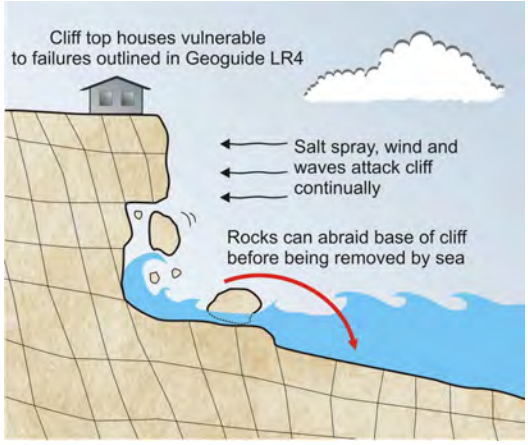

Figure 1

Building on Coastal Dunes

Any excavation in a natural dune slope is inherently unstable and must be supported and maintained (GeoGuide LR6). Dunes are particularly susceptible to ongoing erosion by wind and wave action and extreme changes can occur in a single storm. Whilst vegetation can help to stabilise dunes in the right circumstances, unfortunately a single storm has the potential to cut well into dunes and, in some cases, remove an entire low lying dune system or shift the mouth of a river. **As for cliffs, it is appropriate to observe the effects of major storms on the coastline. If erosion is causing the coastline to recede at an appreciable rate, seek advice from suitably experienced geotechnical and coastal engineering practitioners and bring it to the attention of the local council.**

Photo courtesy DNR NSW

CLIMATE CHANGE

The coastal zone will experience the most direct physical impacts of climate change. A number of reviews of global data indicate a general trend of sea level rise over the last century of 0.1 - 0.2 metres. Current rates of global average sea level rise, measured from satellite altimeter data over the last decade, exceed 3 mm/year and are accelerating. The most authoritative and recent (at the time of writing) report on climate change (IPCC, 2007) predicts a global average sea level rise of between 0.2 and 0.8 metres by 2100, compared with the 1980 - 1999 levels (the higher value includes the maximum allowance of 0.2 m to account for uncertainty associated with ice sheet dynamics).

In addition to sea level rise, climate change is also likely to result in changes in wave heights and direction, coastal wind strengths and rainfall intensity, all of which have the capacity to impact adversely on coastal dunes and cliff-faces. A Guideline for responding to the effects of climate change in coastal areas was published by Engineers Australia in 2004.

References

Engineers Australia 2004 'Guidelines for responding to the effects of climate change in coastal and ocean engineering." The National Committee on Coastal and Ocean Engineering , Engineers Australia , updated 2004.

IPCC (2007) *Climate Change 2007: The Physical Science Basis.* Summary for Policy Makers. Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC).

Nielsen, A.F., Lord D.B. and Poulos, H.G. (1992). 'Dune Stability Considerations for Building Foundations', *Aust. Civil Eng. Transactions* CE No.2, 167-174.

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AUSTRALIAN GEOGUIDE LR11 (RECORD KEEPING)

RECORD KEEPING

It is strongly recommended that records be kept of all construction, inspection and maintenance activities in relation to developments on sloping blocks. In some local authority jurisdictions, maintenance requirements form part of the building consent conditions, in which case they are mandatory.

CONSTRUCTION RECORDS

If at all possible, you should keep copies of drawings, specifications and construction (i.e. "as built") records, particularly if these differ from the design drawings. The importance of these documents cannot be over-emphasised. If a geotechnical practitioner comes to a site to carry out a landslide risk assessment and is only able to see the face of a retaining wall, the heads of some ground anchors, or the outlets of a number of sub-soil drains, it may be necessary to determine how these have been built and how they are meant to work before completing the assessment. This could involve drilling through the wall to determine how thick it is, or probing the length of the drains, or even ignoring the anchors altogether, because it is uncertain how long they are. Such "investigation" of something that may only have been built a few years before is, at best, a waste of time and money and, at worst, capable of coming up with a misleading answer which could affect the outcome of the assessment. Documentary information of this sort often proves to be invaluable later on, so treat it with as much importance as the title deeds to your property.

INSPECTION AND MAINTENANCE RECORDS

If you follow the recommendations of the Australian GeoGuides it is likely that you will either carry out periodic inspections yourself, or you will engage a geotechnical practitioner to do them for you. The collected records of these inspections will provide a detailed history of changes that might be occurring and will indicate, better than your own memory, whether things are deteriorating and, if so, at what rate. Unfortunately, without some form of written record, all information is usually lost each time a property is sold. It is recommended that a prospective purchaser should have a pre-purchase landslide risk assessment carried out on a hillside site, in much the same way that they would commission a structural assessment, or a pest inspection, of the building. If the vendor has kept good records, then the assessment is likely to be quicker and cheaper, and the outcome more reliable, than if none are available. Each site is different, but noting the following would normally constitute a reasonable record of an inspection/maintenance undertaken:

- date of inspection/maintenance and the name and professional status of the person carrying it out
- description of the specific feature (eg. cliff face, temporary rock bolt, cast *in situ* retaining wall, shallow leach drain system)
- sketch plans, sketches and photographs to indicate location and condition
- activity undertaken (eg. visual inspection; cleared vegetation from drain; removed fallen rock about 500 mm diameter)
- condition of the feature and any matters of concern (e.g. weep holes damp and flowing freely; rust on anchor heads getting worse; shotcrete uncracked and no sign of rust stains; ground saturated around leach field)
- specific outcomes (eg. no action necessary; geotechnical practitioner called in to advise on the state of the anchors; cliff face to be trimmed following the most recent rock fall; leach field to be rebuilt at new location)

A proforma record is provided overleaf for convenience. Photographs and sketches of specific observations can prove to be very useful and should be included whenever possible. Geotechnical practitioners may devise their own site specific inspection/maintenance records.

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INSPECTION/MAINTENANCE RECORD

(Tick boxes as appropriate and add information as required) Date.....

Site location (street address / lot & DP numbers / map reference / latitude and longitude)

.....

FEATURE	Inspected	Maintained	Tested	By Owner	By Professional
Slopes & surface protection:					
☐ Natural slope/cliff ☐ Cut/fill slope					
☐ Surface water drains					
☐ Shotcrete ☐ Stone pitching ☐ Other					
Retaining walls:					
☐ Cast in situ concrete ☐ Concrete block					
☐ Masonry (natural stone) ☐ Masonry (brick, block)					
☐ Cribwall (concrete) ☐ Cribwall (timber)					
☐ Anchored wall ☐ Reinforced soil wall					
☐ Sub-soil drains ☐ Weep holes					
Ground improvement:					
☐ Rock bolts					
☐ Ground anchors ☐ Soil nails					
☐ Deep subsoil drains					
Effluent and storm water disposal systems:					
☐ Effluent treatment system					
☐ Effluent disposal field					
☐ Storm water disposal field					
Other:					
☐ Netting ☐ Catch fence ☐ Catch pit					
☐					
☐					
☐					

Observations/Notes (Add pages/details as appropriate)

.....

.....

.....

Attachments: ☐ Sketch(es) ☐ Photograph(s) ☐ Other (eg measurements, test results)

Record prepared by ..... (name): .....(signature)

Contact details: Phone:..... E-mail:.....

Professional Status (in relation to landslide risk assessment):.....

APPENDIX

AUSTRALIAN GEOMECHANICS SOCIETY

STEERING COMMITTEE

Andrew Leventhal, GHD Geotechnics, Sydney, Chair
Robin Fell, School of Civil and Environmental Engineering, UNSW, Sydney, Convenor Guidelines on Landslide Susceptibility, Hazard and Risk Working Group
Tony Phillips, Consultant, Sydney, Convenor Slope Management and Maintenance Working Group
Bruce Walker, Jeffery and Katauskas, Sydney, Convenor Practice Note Working Group
Geoff Withycombe, Sydney Coastal Councils Group, Sydney

WORKING GROUP - Guidelines on Slope Management and Maintenance
Tony Phillips, Tony Phillips Consulting, Sydney, Convenor
Henk Buys, NSW Roads and traffic Authority, Parramatta
John Braybrooke, Douglas Partners, Sydney
Tony Miner, A.G. Miner Geotechnical, Geelong

LANDSLIDE TASKFORCE

Laurie de Ambrosis, GHD Geotechnics, Sydney
Mark Eggers, Pells Sullivan Meynink, Sydney
Max Ervin, Golder Associates, Melbourne
Angus Gordon, retired, Sydney
Greg Kotze, GHD, Sydney
Arthur Love, Coffey Geotechnics, Newcastle
Alex Litwinowicz, GHD Geotechnics, Brisbane
Tony Miner, A.G. Miner Geotechnical, Geelong
Fiona MacGregor, Douglas Partners, Sydney
Garry Mostyn, Pells Sullivan Meynink, Sydney
Grant Murray, Sinclair Knight Merz, Auckland
Garth Powell, Coffey Geotechnics, Brisbane
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ASSESSMENT OF LANDSLIDE LIKELIHOOD IN THE PITTWATER LOCAL GOVERNMENT AREA

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ABSTRACT

The likelihood of landsliding in the Pittwater LGA has been assessed by the compilation of an inventory of landslide events that have occurred in the area over a period of more than 30 years. This inventory indicated that most events were associated with residential development. An indication of the population of slope modification was provided by a survey of several areas selected as representative of the properties within the designated geotechnical risk zone.

Rainfall records for Newport have been used a basis for a review of the relationship between rainfall events and landslide events. The results of this analysis have been combined with the landslide inventory and population survey to provide an assessment of the likelihood of the occurrence of landslides in the Pittwater LGA in the future.

1 INTRODUCTION

The occurrence of landslides in the northern beach suburbs of Sydney has been recognised since the 1970's when a number of homes were damaged or destroyed by landslides. The then Warringah Council first introduced a landslide zoning scheme in 1977. This scheme identified areas for which a geotechnical assessment of the potential for landsliding was required for development applications. The Pittwater area is sought after as a residential location and pressure for more intensive development has resulted in road and building construction in areas with significant geotechnical constraints. In recognition of this problem Pittwater Council established an interim Geotechnical Risk Management Policy that requires geotechnical input to development within a designated zone (PWC, 2003).

As part of the risk management policy Council requires that an assessment of the likelihood of landslides be prepared for proposed development within the zone. These assessments are to be conducted in accordance with the methods presented in the Australian Geomechanics Society Guidelines on Landslide Risk Management (AGS 2000). Practitioners carrying out these assessments have found it difficult to estimate the likelihood (annual probability) of sliding because there is no complete database upon which to make that judgement.

In recognition of this need the Australian Geomechanics Society in association with Pittwater Council sought funds for a research project to gather data on landslide occurrence, the population of slopes which are susceptible to landsliding and rainfall statistics. From this the average probabilities of failure and annual probabilities of failure for typical slopes have been developed.

Funds to assist the study have been made available under the National Disaster Mitigation Program (NDMP) from the Commonwealth Government, the NSW State Government and Pittwater Council. The study has been carried out by the authors under the overall direction of a Steering Committee established jointly by Pittwater Council and the Australian Geomechanics Society

This paper is an abbreviated version of the report on the results of the study prepared as a general reference for use by those involved in risk assessments for Pittwater Council.

2 FEATURES OF PROJECT AREA

2.1 TOPOGRAPHY

Pittwater Shire occupies the 'Peninsula' area of the Northern Beaches of Sydney which extend northward from Narrabeen Lagoon to Barrenjoey Head and covers the western shore of Pittwater as far as West Head Road in the Ku-ring-gai Chase National Park.

Figure 1: Geology of the Pittwater Local Government Area.

East of Pittwater several flat-topped plateaux at Newport, Bilgola, Avalon, Whale Beach and Palm Beach reach an elevation of about 100 m and are separated by deeply incised valleys with narrow coastal flats. On the western side a almost continuous plateau extends from Elanora Heights to West Head reaching elevations of about 150 m.

2.2 GEOLOGY

Figure 1 is based on a portion of the Sydney 1:100,000 Geological Series map 9130 which shows that the Pittwater area is underlain by a near-horizontally bedded sequence of sedimentary rocks of Triassic Age. The flat-capped ridges are formed by the Hawkesbury Sandstone, a uniform medium grained quartzose sandstone with minor shale bands, reasonably distinct bedding and well developed, typically widely spaced, near-vertical joints. Figure 2 presents a typical geological section through the peninsula east of Pittwater.

The slopes surrounding the plateau areas are underlain by an interbedded sequence of laminite, siltstone, shale and quartz sandstone of the Narrabeen Formation which exhibit strongly developed bedding and jointing. On the slopes these rocks are overlain by talus which has fallen from the sandstone uphill and by clayey colluvium derived by weathering of the siltstone and shale. On the lower slopes rock is overlain by Quaternary Age alluvial and marine sands.

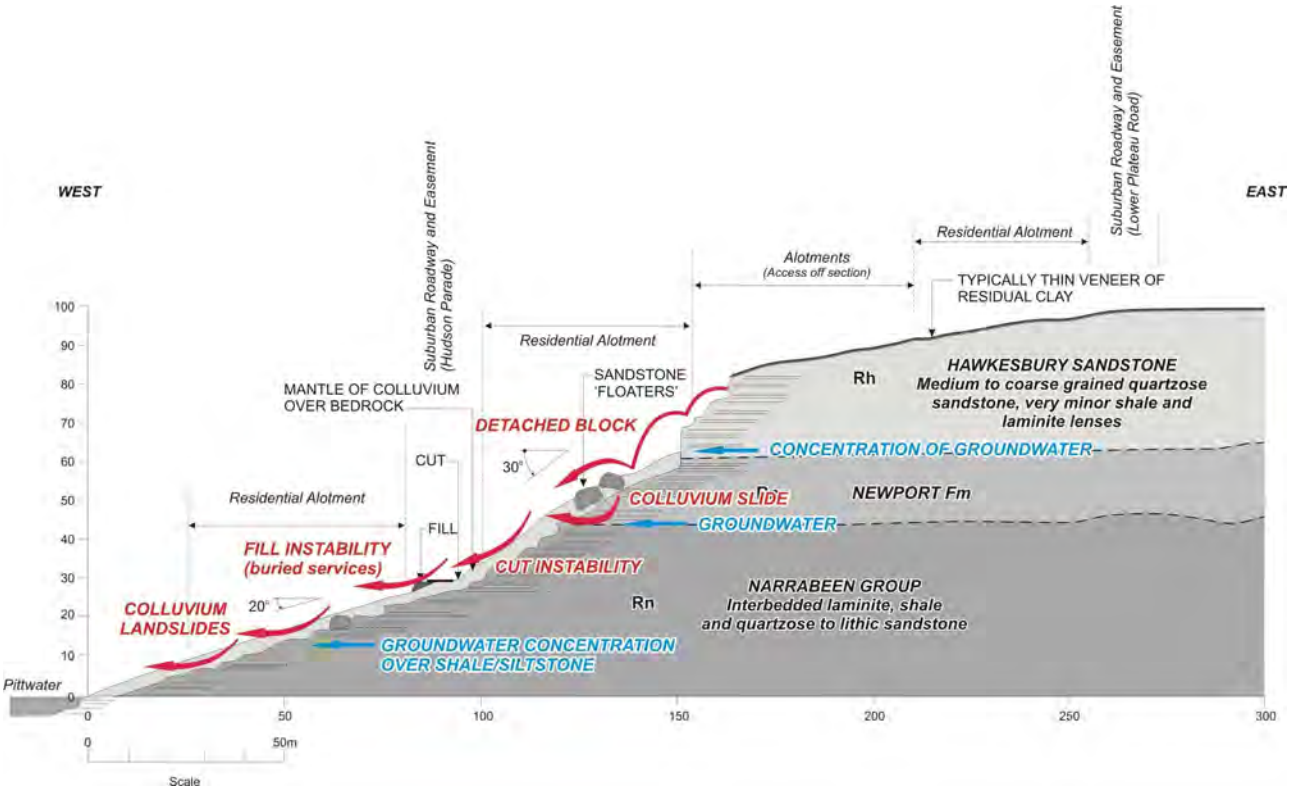

Figure 2: Section showing typical geology in the Pittwater area.

2.3 GEOMORPHOLOGY

Erosion of these rocks has produced a surface profile with a flat crest above steep slopes with relatively narrow terraces. Some of the steep slopes are sandstone cliffs and some of the terraces are underlain by sandstone. Residential development of the area has involved modification of the slopes by excavation into the talus and clayey colluvium and the placement of fill over these materials. Progressive development has transformed the area from 'holiday beach houses' to 'suburbia'.

3 METHODOLOGY

3.1 LANDSLIDE INVENTORY

Information on landslide events in Pittwater Local Government Area has been obtained from the following sources:

- Recollection of past instability in Pittwater LGA from memories of members of the project Steering Committee – originally referred to as 'the Brain Dump'.
- Records of landslide events held by Pittwater Council.
- Records of landslide events held by Warringah Shire Council.
- Reports prepared by geotechnical consultants retained to investigate landslide events in Pittwater LGA.
- Reference to back numbers of 'The Manly Daily'.

The data obtained for each event has been, as far as practicable, composed of:

- The date of the event in day, month and year.
- The location of the event as Suburb, Street and Street Number. It has been assumed that each event is restricted to one property.
- The situation of the event within the property e.g. 'at road' (R), 'within block' (B) and 'at house' (H).
- A brief description of the event with report reference if available.
- Classification of the event type, e.g. for Cut (C), Fill (F), Soil (S), Rock (R), with the height of the disturbance in metres.
- Style of retaining wall if involved in the event, e.g. uncemented rock wall (WR), masonry or concrete block wall (WB), reinforced concrete wall (WC), sawn sandstone block wall (WS), timber wall (WT) and crib-block wall (WCB).
- Classification of size based on estimated volume involved, e.g. Small for <5 m^3, Medium for 5-50 m^3 and Large for >50 m^3.
- Source of information e.g. Pittwater Council (PC), Warringah Shire Council (WSC), CG for Coffey Geotechncis (CG), GHD-LongMac and GHD Geotechnics (LM), Jeffery and Katauskas (J&K), Andrew Shirley (AS).

The landslide inventory initially identified some 270 cases of slope instability. Following review of the information and removal of duplication and instances where no reliable information was available the revised inventory lists 193 landslide events in Pittwater LGA in the 32 years between 1972 and 2004 that were considered acceptable for analysis.

3.2 POPULATION

Almost all the events identified by the landslide inventory fall within the Geotechnical Risk zone marked on Pittwater Council map 03-H001 "Geotechnical Risk Management Map 2003". The Geological Risk Zone generally delineates areas of sloping ground with colluvial cover. Pittwater Council has provided a list of the number of properties within each suburb affected by the Geotechnical Risk Zone and also the total number of properties in each suburb.

It was necessary to establish the population of cuts, fills and walls within the Geotechnical Risk zone. This was done by selecting a number of representative areas within Pittwater and carrying out a "slope modification" survey. In these sample areas the number of cuts, fills and walls and their characteristics were individually counted. For the purpose of this survey it was assumed that cuts and fills were restricted to individual properties i.e. if a cut spanned 6 properties it was recorded as 6 cuts.

Each property within the selected area was inspected and slope modification features classified using the same terminology as in the landslide inventory. A total of 699 properties in 10 streets in 6 suburbs were visited. This limited survey was carried out from the roadway and thus the information is approximate (but sufficient for the purpose). It follows therefore that information on site conditions 'at road' is much more complete than 'in block' or 'at house'.

3.3 RAINFALL

Rainfall records for Newport have been used as a basis for a review of the relationship between rainfall events and landslide events. The study included the daily rainfall and antecedent rainfall which has been recorded when landslides have occurred; the annual probability of the rain events at which some landslides are recorded and where a large number of landslides are recorded.

The rainfall analysis is presented in a separate paper by Walker (2007) and is summarized in Section 4.3.

4 ANALYSIS OF DATA

4.1 LANDSLIDE INVENTORY

The landslide events are located on Figure 3.

The 193 landslides in the developed area have been sorted by suburb, date, type and size with a summary of the features in Figure 4. Information on dates of landsliding is summarised on Figure 5. Table 1 lists those landslides for which the actual date of landsliding is known. Those dates have been used for the analysis of the relationship of landsliding to rainfall.

The inventory indicates that:

- Reported landslides are spread through nine suburbs with most in Newport, Church Point, Bayview and Avalon.
- The landslides in the area are mostly rotational or translational slides of soil or soil and rock. There are some falls of rock and soil from steep cut slopes and natural cliffs.
- Of the 193 landslides 25 are rock falls from coastal cliffs. These are not included in the analysis of landslide occurrence.
- Of the remaining 168 landslides, 161 are in cuts and fills. Only 7 (less than 3%) are “natural” slope failures.
- Two thirds of the reported events occurred ‘at the road’ with a quarter ‘in the block’ and the remainder ‘at house’.
- The reported events appear distributed almost equally between failure of cut and fill soil slopes with less than 8% containing some rock.
- More than 40% of the reported landslides had a slope height of 2 m or less. Almost 40% had a slope height of 3-4 m and the remainder had slope heights between 5 m and 10 m.
- Walls were affected by less than 12% of the reported landslides.
- More than 40% of the reported landslides were estimated to be small, more than 30% medium and about 20% large – as defined in Section 3.1.
- The years 1990 and 1998 each had about 20% of the reported landslides with 15% in 1989 and 10% in 1988. The remaining years each had less than 4% of the reported landslides.

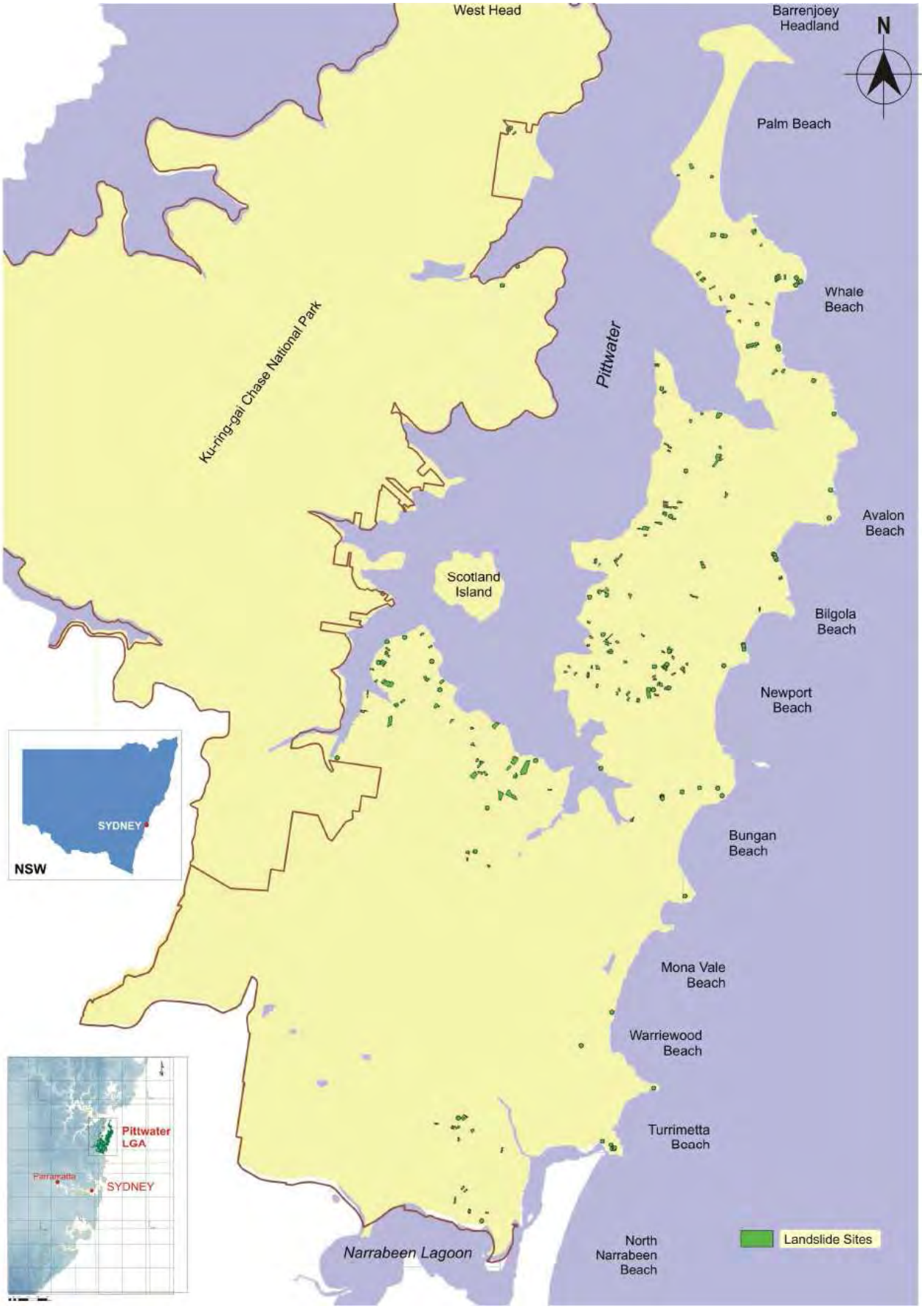

Figure 3: Landslide location map.

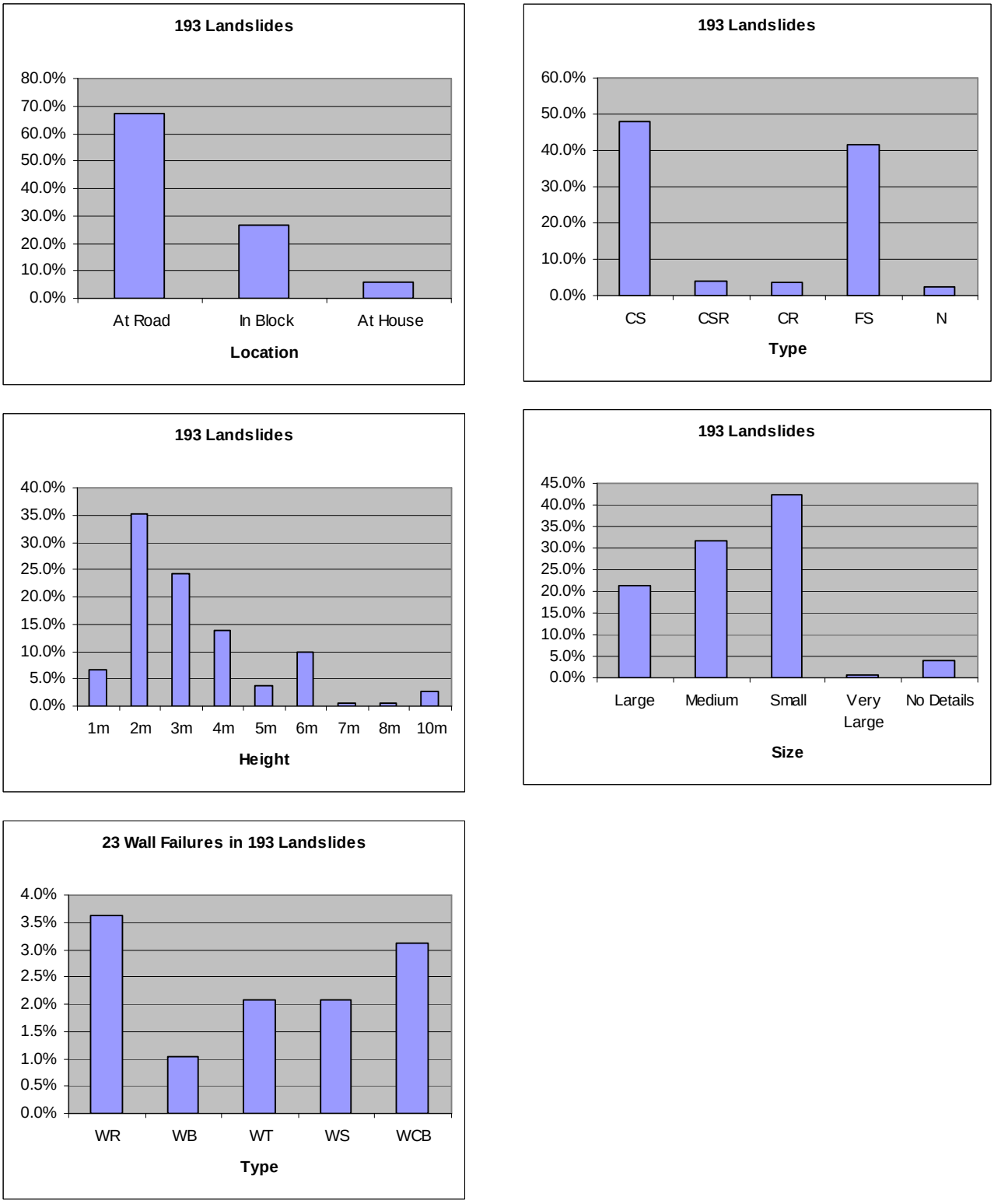

Figure 4: Summary of the characteristics of landslides in the database.

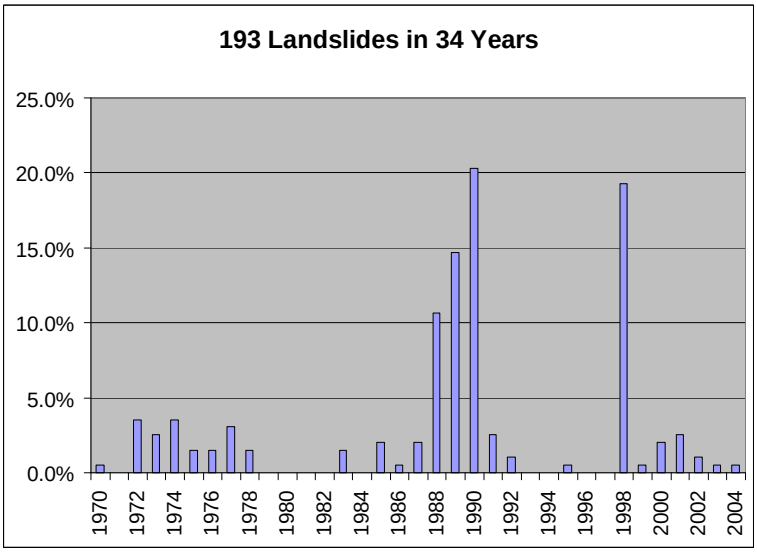

Figure 5: Pittwater landslides occurrence by year.

Table 1: Dates of landslide events where the actual date is known.

DATE	MONTH	YEAR
26-Jan-72	Jan-72	1972
23-May-73	May-73	1973
11-Mar-74	Mar-74	1974
1-Dec-74	Dec-74	1974
4-Mar-77	Mar-77	1977
4-Mar-77	Mar-77	1977
22-May-83	May-83	1983
26-May-83	May-83	1983
15-Jul-85	Jul-85	1985
14-Nov-85	Nov-85	1985
24-Oct-87	Oct-87	1987
30-Oct-87	Oct-87	1987
20-Nov-87	Nov-87	1987
23-Jan-88	Jan-88	1988
24-Jan-88	Jan-88	1988
4-Apr-88	Apr-88	1988
29-Apr-88	Apr-88	1988
30-Apr-88	Apr-88	1988
30-Apr-88	Apr-88	1988
30-Apr-88	Apr-88	1988
1-May-88	May-88	1988
1-May-88	May-88	1988
13-May-88	May-88	1988
13-May-88	May-88	1988
16-May-88	May-88	1988
5-Jul-88	Jul-88	1988
6-Jan-89	Jan-89	1989
6-Jan-89	Jan-89	1989
17-Jan-89	Jan-89	1989
12-Mar-89	Mar-89	1989

DATE	MONTH	YEAR
31-Mar-89	Mar-89	1989
16-May-89	May-89	1989
30-Jun-89	Jun-89	1989
5-Dec-89	Dec-89	1989
1-Feb-90	Feb-90	1990
2-Feb-90	Feb-90	1990
3-Feb-90	Feb-90	1990
5-Feb-90	Feb-90	1990
5-Feb-90	Feb-90	1990
5-Feb-90	Feb-90	1990
5-Feb-90	Feb-90	1990
7-Feb-90	Feb-90	1990
16-Feb-90	Feb-90	1990
11-Apr-90	Apr-90	1990
23-Apr-90	Apr-90	1990
9-May-90	May-90	1990
2-Aug-90	Aug-90	1990
7-Aug-90	Aug-90	1990
15-Sep-90	Sep-90	1990
13-Nov-90	Nov-90	1990
10-Jun-91	Jun-91	1991
11-Jun-91	Jun-91	1991
20-Jun-91	Jun-91	1991
1-Jul-91	Jul-91	1991
9-Feb-92	Feb-92	1992
10-Feb-92	Feb-92	1992
13-May-98	May-98	1998
29-May-98	May-98	1998
7-Aug-98	Aug-98	1998
7-Aug-98	Aug-98	1998

DATE	MONTH	YEAR
7-Aug-98	Aug-98	1998
7-Aug-98	Aug-98	1998
7-Aug-98	Aug-98	1998
7-Aug-98	Aug-98	1998
7-Aug-98	Aug-98	1998
7-Aug-98	Aug-98	1998
7-Aug-98	Aug-98	1998
7-Aug-98	Aug-98	1998
7-Aug-98	Aug-98	1998
7-Aug-98	Aug-98	1998
16-Nov-00	Nov-00	2000
30-Jan-01	Jan-01	2001
6-May-01	May-01	2001
7-May-01	May-01	2001
5-Feb-02	Feb-02	2002
5-Feb-02	Feb-02	2002
15-May-03	May-03	2003

4.2 POPULATION

The number of properties in Pittwater Shire, within the Geotechnical Risk Zone and within the slope modification survey areas is listed in Table 2.

Table 2: Property numbers in the Pittwater shire suburbs (supplied by Pittwater Council) and properties included in the slope modification survey.

SUBURB	Total No. of Properties	No. of Properties within Risk Zone	No. of Properties in Slope Modification Survey	No. of Landslides identified in Suburb
AVALON	3494	1415	177	26
BAYVIEW	1174	665		24
BILGOLA	1486	535		10
CAREEL BAY	100	48		
CHURCH POINT	417	328	104	30
CLAREVILLE	353	178		7
ELANORA HEIGHTS	1364	210		
INGLESIDE	640	69		
KU-RING-GAI CHASE NATIONAL PARK	407	349		
MONA VALE	2901	127		
NORTH NARRABEEN	1971	742	43	15
NEWPORT	2989	1167	233	54
PALM BEACH	1464	968	61	18
SCOTLAND ISLAND	384	376		
WARRIEWOOD	1835	114		
WHALE BEACH	319	303	81	9
Total	**21298**	**7594**	**699**	**193**

The 699 properties inspected during the slope modification survey therefore represent 9.2% of the 7594 properties in the geotechnical risk zone and 3.3% of the total 21298 properties in Pittwater Shire.

In the 699 properties visited slope modification 'at road' included 296 cuts and 362 fills:

- Just under 50% of the cuts were unsupported.
- Less than 45% of the fills were unsupported.
- More than 60% of the cuts were in soil with almost 80% of 3 m or less in height.
- More than 90% of the fills were in soil with almost 50% 2 m or less high and a further 45% of 3-4 m height.

In the 699 properties visited slope modification 'within block' included 202 cuts and 89 fills.

- Just over 20% of the cuts were unsupported.
- About 2% of the fills were unsupported.
- More than 75% of the cuts were in soil with 60% at a height of 2 m or less.
- All the fills were in soil with 75% 2 m or less in height and the remaining 25% of 3-4 m height.

In the 699 properties visited slope modification 'at the house' included 152 cuts and 8 fills.

- Almost 20% of the cuts were unsupported
- All the fills were supported.
- More than 90% of the cuts were in soil with 85% 2 m height or less and the remainder 3 m high. All the fills were in soil with height of 2 m.

The confidence in these figures is affected by the restrictions on access. There are undoubtedly more areas of slope modification 'in the block' and 'at the house' than could be observed from the road during the survey. It should be noted that within the properties the cut height is less and a higher proportion of the cuts are supported. The fill height within the properties is also less and fills are almost entirely supported by a wall of some type.

During the slope modification survey it was observed that, in general, areas of concern in regards to landsliding are related to poorly engineered cuts and fills which may have been formed during the initial construction of road access to

the terrace areas and subsequently modified during mature residential development. Other problem areas have resulted from attempts to construct access through areas of greater geotechnical hazard e.g. steep talus slopes, incised gullies.

Within the properties areas of slope modification are smaller and discontinuous. Many appear related to the capacity of the owner to carry out the work. It was observed that development in the many of the properties with greater geotechnical hazard has avoided slope modification by the use of suspended concrete slabs for driveways and piered foundations for houses. This type of development appears to be more recent than the majority of the area.

4.3 ANALYSIS OF RAINFALLS FOR KNOWN LANDSLIDE EVENTS

The landslide database has a total of 193 landslide events over a 34 year period. As indicated by Table 1, 77 landslides had been reliably identified for 58 actual dates, i.e. about 40% of the landslides.

The assessment of the probable influence of rainfall on the landslide events identified in the Pittwater Local Government Area by Walker (2007) indicates that:

(a) The study has been based on rainfall records at Newport (at the bowling club) where there are 75 years of almost complete record. There are other rain gauges in the area but they have shorter records.

(b) The data from this gauge has been used to determine rainfall duration-frequency distributions. These have been checked for validity against Australian Rainfall and Runoff plots for Sydney and seem reasonable.

(c) For each landslide date, the results have been summarised for the maximum return period (years) and the corresponding critical number of rain days, i.e. the number of days of rainfall with the highest return period.

This data has then been summarised as:

- A histogram showing the distribution of landslide dates for rainfall maximum return periods grouped into 5 year intervals.
- A histogram showing the distribution of landslide dates for critical number of rain days.
- The scatter plot of maximum return period versus critical number of rain days.

Some observations are:

- There is no clear pattern of results from the data.
- The Maximum Return Period for the landslide dates was mostly (about 71%) from 1 to 5 years. Most of these dates have only single landslide events.
- There is a tendency for higher number of rain days, say 60-day to 90-day, to be critical. These account for about 50% of the landslide dates. However, for 5 February 1990 and 7 August 1998 which had 4 and 12 landslide events respectively, the 1-day rainfall was critical. About 20% of the landslide dates have 1-day and 2-day rainfall as critical.
- Considering periods of multiple landslide events, the results are as shown in Table 3.

Table 3: Rainfall maximum return periods and critical number of days rain for periods with multiple landslide events.

Period	Number of landslide events	Rainfall maximum return periods (years)	Critical number of days rain
29 April to 29 May 1988	13	8 to 19	30 and 60
1 February to 16 February 1990	9	1 to 25	1 to 60
7 August to 8 August 1998	12	13 to 19	1 and 2

- There is no relationship apparent between maximum return period and critical number of rain days. It might be concluded that for the longer periods of Critical Number of rain days, the Maximum Return Period is less.
- Examination of the data indicated that frequently the 1-day rainfall was above 70 mm when landslides were recorded. Table 4 shows the top 20 1-day rainfalls within each year from 1972 to 2005, sorted into daily rainfalls and related to the number of days rainfall. The figures are affected by the limited number of landslides for which an exact date is known (about 40%).

Allowing for this it can be concluded that:

- A 50 mm 1-day rainfall has about a 40% chance of resulting in one or more landslides.

- A 70 mm 1- day rainfall has about a 50% chance of resulting in one or more landslides.
- If 125 mm or more rainfall is experienced in one day it is almost certain that there will be one or more landslides in the Pittwater area.

Table 4: Likelihood of one or more landslides in Pittwater versus daily rainfall.

1-Day Rainfall Amount	Approx. Return Period (Years)	Number of Days 1972-2005	Number of Days in which landslides were recorded	Approximate Ratio to Total Number	Likelihood of one or more landslides given the daily rainfall
Greater than 50 mm	About 1.0	131	20	15%	40%
Greater than 70 mm	About 1.3	77	14	18%	50%
Greater than 125 mm	About 3.3	13	7	54%	100%

5 ASSESSMENT OF LANDSLIDE LIKELIHOOD

5.1 METHOD USED TO ASSESS LIKELIHOODS OF FAILURE FOR TYPICAL SLOPES

The method which has been used to assess the average probability a typical slope will fail and the annual frequency of failure of the typical slope is:

- Consider slopes associated with road construction, on the properties and at the houses separately.
- Consider unsupported cuts and fills and walled slopes separately and subdivide into those consisting of or containing soil, soil/rock and rock.
- Use the data from the sample areas to determine the average number of slopes per property in each category.
- Determine the number of each category of slope within the Risk Zone using the average number of slopes per property and the known population of properties in the Pittwater Geotechnical Risk Zone.
- Allocate the landslides in the database into the different slope categories.
- Determine the average probabilities of failure for the typical slope in each category (from the time of construction of the slope to now) from the number of landslides and the number of slopes.
- Determine the average annual probability of failure for the typical slope in each category from these probabilities of failure, assuming 32 years of records.

Table 5: Summary of likelihoods of failure and suggested values.

Slide Type	Probability of failure of slopes 'At Road'	Probability of failure of slopes 'Within Block'	Probability of failure of slopes 'At House'	Suggested Probability of failure for all locations	Suggested annual probability of failure for all locations
Unsupported cuts					
Soil	0.060	0.047	0.036	0.080	2.5E-04
Soil/rock	0.020	0.031	0	0.033	1E-04
Rock	0.020	0.018	0	0.025	8E-05
Cuts with wall support					
Soil	0.008	0.001	0	0.006	2E-04
Soil/rock	0.000	0	0	0.001	3E-05
Rock	0.000	0	0	0.001	3E-05
Unsupported fills					
Soil	0.026	0.783	0	0.040	1.25E-04
Fills with wall support					
Soil	0.004	0.009	0	0.006	2E-04
Totals					
All types	0.018	0.023	0.007	0.030	1E-03

Given the limited database and the potential shortcomings of the 'at house' and 'within block' data because the properties could not be inspected, it is suggested that one set of failure likelihood is adopted. The suggested probability values are based on the assumption that the database is about 80% complete for large landslides, 70% complete for medium landslides and 60% complete for small landslides.

5.2 INFLUENCE OF SLOPE HEIGHT AND LOCATION ON THE LIKELIHOOD AND SIZE OF LANDSLIDING

5.2.1 Influence of slope height on likelihood of landsliding.

Table 6 summarises the incidence of landsliding compared with the heights of the different cuts, fills and walls in the sample area. These are considered as one category as there is not sufficient data to treat them separately, The % population is shown and also as a weighted version according to the size of the sample.

Table 6: Influence of height of slope on likelihood of landsliding, cuts, fills and walls.

Height	% Population in sample area	% Population weighted	% Landslides in the database	Ratio % landslides to % population sample area	Ratio % landslides to % population weighted	Suggested Slope Height Factors
1 m	13.5	13.4	6.7	0.50	0.50	0.5
2m	33.1	33.5	35.2	1.06	1.05	1.0
3m	31.8	34.1	24.4	0.77	0.72	1.0
4m	9.5	9.7	14.0	1.47	1.44	1.5
5m	6.8	5.3	3.6	0.53	0.68	1.5
6m	4.1	2.2	9.8	2.39	4.45	1.5
7m	0.3	0.2	0.5	1.67	2.50	3.0
8m	0.7	0.4	0.5	0.71	1.25	3.0
10m	0.3	0.2	2.6	8.67	13.0	3.0

Table 6 shows that higher slopes are more likely to fail than low ones. Suggested "slope height factors" which may be applied to the typical slope likelihoods are suggested. The slope heights have been grouped to give a reasonable progression of factors.

5.2.2 Influence of slope location on the likelihood of landsliding.

Table 7 presents the landside database information grouped according to the suburb within Pittwater and shows that that there are some suburbs such as Church Point, Newport, Clareville and Whale Beach which have more landslides per property than the average and others such as Avalon, Bilgola, North Narrabeen and Palm Beach which have fewer landslides per property than the average.

This appears to reflect the geology, topography and construction practices applied when the suburbs were developed. The results agree with common perceptions amongst Geotechnical Professionals familiar with the Pittwater area. Suggested "suburb factors" which can be applied to the likelihoods of typical slopes are shown in Table 7. The factors for suburbs for which there is no landslide information in the database have been assessed from knowledge of the geology and topography of these suburbs in relation to those for which data is available.

Table 7: Influence of location on the likelihood of landsliding.

Suburb	Number of properties within risk zone	Number of Landslides			Probability of Landsliding			Suburb Factor			
		Total	Cuts	Fills	Total	Cuts	Fills	Total	Cuts	Fills	Suggested Suburb Factors
AVALON	1415	26	14	12	0.018	0.010	0.008	0.60	0.56	0.66	0.5
BAYVIEW	665	24	12	12	0.036	0.018	0.018	1.19	1.00	1.49	1.0
BILGOLA	535	10	3	7	0.019	0.006	0.013	0.63	0.33	1.08	0.5
CAREEL BAY	48	0	0	0	0	0	0	-	-	-	1.0
CHURCH POINT	328	30	20	10	0.091	0.060	0.031	3.02	3.32	2.57	3.0
CLAREVILLE	178	7	5	2	0.039	0.028	0.011	1.29	1.55	0.91	1.25
ELANORA HEIGHTS	210	0	0	0	0	0	0	-	-	-	0.5
INGLESIDE	69	0	0	0	0	0	0	-	-	-	0.5
KU-RING-GAI CHASE NATIONAL PARK	349	0	0	0	0	0	0	-	-	-	1.0
MONA VALE	127	0	0	0	0	0	0	-	-	-	1.0
NORTH NARRABEEN	742	15	7	8	0.020	0.010	0.010	0.66	0.55	0.83	0.5
NEWPORT	1167	54	36	18	0.046	0.031	0.015	1.53	1.72	1.25	1.5
PALM BEACH	968	15	9	6	0.015	0.009	0.009	0.50	0.50	0.75	0.5
SCOTLAND ISLAND	376	0	0	0	0	0	0	-	-	-	1.0
WARRIEWOOD	114	0	0	0	0	0	0	-	-	-	0.5
WHALE BEACH	303	12	11	1	0.039	0.036	0.003	1.29	1.99	2.99	1.25
TOTALS	**7594**	**193**	**117**	**76**	**0.025**	**0.015**	**0.010**				

5.2.3 Influence of slope height on the size of landsliding

The database of landsliding has been analysed to determine the relationship between the height of the slope and the likely size of landslide which would result if the slope failed. This showed there was a similar relationship for unsupported cuts and fills, and walled slopes. Table 8 shows suggested likelihoods which can be applied based on the data analysis.

Table 8: Influence of slope height on likely size of landslide.

Slope Height	Likelihood of size of landslide		
	Small	Medium	Large
< 2m	0.75	0.25	
3m	0.3	0.5	0.2
4m	0.1	0.5	0.4
> 4m		0.4	0.6

5.3 ASSESSMENT OF LANDSLIDE FREQUENCY FROM RAINFALL AND LANDSLIDING STATISTICS

As an alternative to the method described in Section 5.2, or as a supplement to it, the annual probability of landsliding can be estimated from the data in Tables 3 and 4. Table 9 summarises the results.

Table 9: Estimated frequency of failure for the average typical slope based on rainfall-landslide occurrence data.

Return Period of Rainfall in years	Annual probability this rain is exceeded	Annual probability rainfall is in this range	Likely number of landslides based on Tables 3 and 4	Estimated population of slopes affected by the rainfall	Estimated annual probability of failure from rainfall in this range for any one slope
1 in 1	1.0				
		0.80	1	8000	1.0E-04
1 in 5	0.2				
		0.16	12	6000	3.2E-04
1 in 25	0.04				
		0.02	25	4000	1.25E-04
1 in 50	0.02				
		0.01	50	3000	1.67E-04
1 in 100	0.01				
		0.01	100	3000	3.33E-04
Total		1.0			1.05E-03, Say 1.0E-03

It should be noted that it has been necessary to estimate the number of landslides likely to occur for lower frequency rainfall events and the number of slopes in the area affected by the rainfall. This assessment has assumed a non-linear response of landsliding to rainfall return period and that more intensive long return period events are localised rather than over widespread areas. This has been observed in sliding of cuts, fills and retaining walls in Hong Kong.

The data in Table 9 is for all slopes. The annual probability the average typical unsupported cut slope would fail is 5E-04.

6 SUGGESTED APPLICATION OF THE DATA TO LANDSLIDE RISK ASSESSMENTS

The suggested application of the data in this paper for assistance in estimating the annual probability of failure of slopes in the Pittwater Local Government area is:

a. Take the average annual probability of failure for the average typical slope for the category of slope under consideration from Table 5.

b. Apply the slope height and suburb factors from Tables 6 and 7.

This suggestion is for the average typical slope. The Geotechnical Professional carrying out the risk assessment should estimate whether the slope in question is more or less likely to fail than the average typical slope. To do this he/she will need to take account of the site factors, history of instability and his/her knowledge of other slopes in the area.

It will be useful also to pose the question; "Given the occurrence of a 1 in 100 year rain event, what is the probability of failure of a particular slope that might be triggered by a 1 in 100 year event?" This value should be compared with the values in Table 9, where the assumed conditional probability is 1 in 30.

The assessment should consider, as shown in Table 9, that rainfall contributes only to part of the overall probability of landsliding.

The information presented in the paper is applicable to the particular geological, topographical and urban development conditions which apply to Pittwater Local Government area. The data is not applicable to other areas."

7 ACKNOWLEDGEMENTS

The support of the Commonwealth Government, The Government of the State of New South Wales and Pittwater Council in assisting this study is acknowledged, as is the support of the Australian Geomechanics Society.

The input to the study is acknowledged from the steering committee members, Mr Andrew Leventhal, GHD Geotechnics, Professor John Carter, University of Newcastle, Mr Garry Mostyn, Pells Sullivan Meynink and Messrs Angus Gordon and Paul Hardie, Pittwater Council. The initial work on the project by Dr Kurt Douglas, University of New South Wales is also acknowledged.

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8 REFERENCES

Walker, B.F. (2007) Rainfall data analysis and relation to the incidence of landsliding at Newport. *Australian Geomechanics* Volume 42 No 1 March 2007.

PWC, (2003) Interim Geotechnical Risk Management Policy, Pittwater Council. <*downloadable from www.pittwater.nsw.gov.au*>

RAINFALL DATA ANALYSIS AT NEWPORT AND THE RELATIONSHIP TO LANDSLIDING IN PITTWATER

Bruce F. Walker
Jeffery and Katauskas Pty Ltd

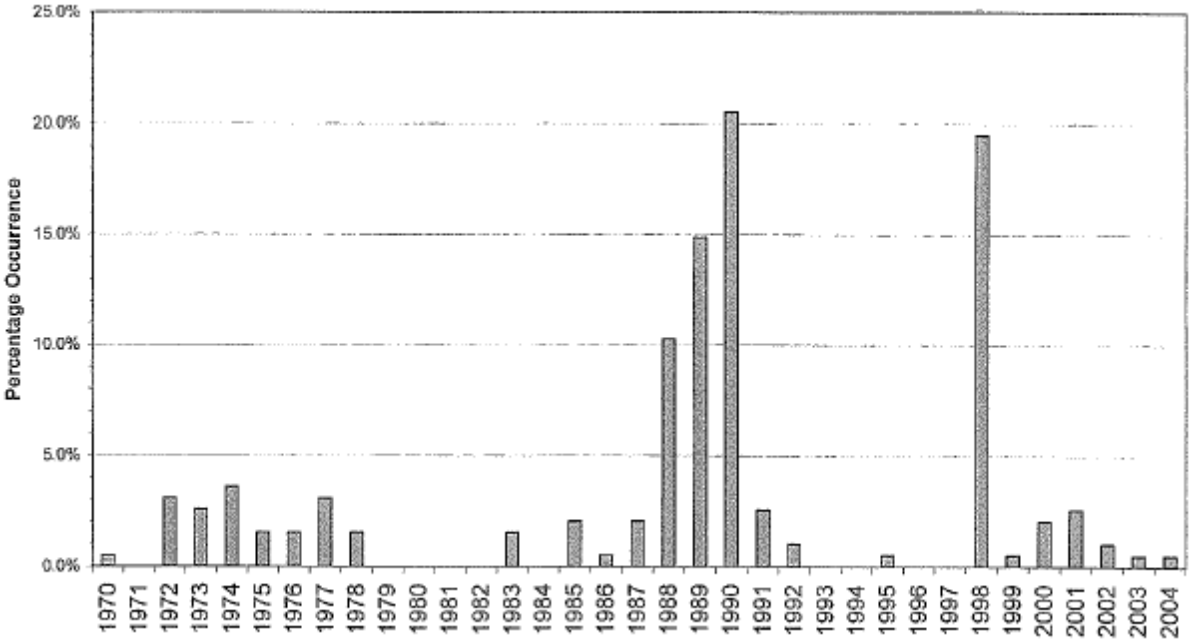
ABSTRACT

It is well recognised that the most common natural triggering factor for landslides is rainfall. A general relationship of more landslide events in wetter than average years was apparent from initial examination of the 195 landslide events on the database gathered as part of the National Disaster Mitigation Programme project to study the likelihood of landsliding in the Pittwater area. This paper reports the results of a more detailed analysis of rainfall data using daily rainfall and cumulative rolling totals from 2-day to 90-day periods. The resulting rainfall data was related to the landslide events on known dates which comprises only about 40% of the landslide database. No single pattern of results was available from the data. The chance of landslides occurring in Pittwater increases with higher 1-day rainfall. There is probably almost 100% chance of one or more landslides in the Pittwater area when the 1-day rainfall is 125mm or more. Days on which multiple landslides are likely to occur are often related to a maximum return period associated with 30 to 60 day antecedent rainfall. All the multiple landslide days are related to relatively long recurrence period rainfalls of about 20 years.

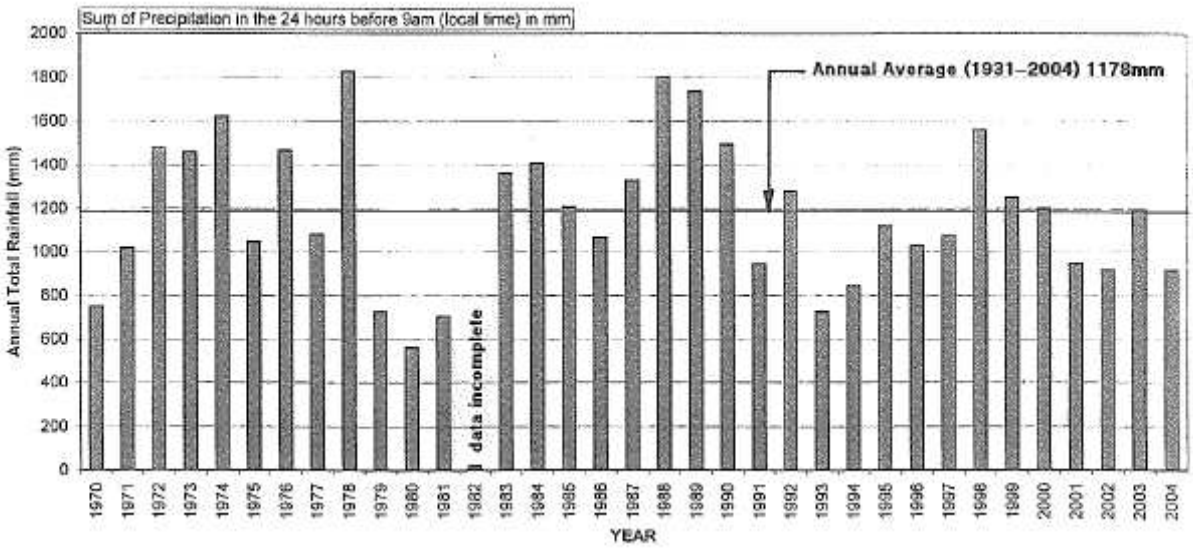
1 INTRODUCTION

This paper presents the results of rainfall data analysis carried out on behalf of the Australian Geomechanics Society as a part of the Landslide Likelihood Research project for Pittwater, which is being completed under a National Disaster Mitigation Programme (NDMP) grant. The paper is based on Jeffery and Katauskas (2006). Other work under the project has included the gathering of a database of known landslide events (MacGregor *et al*., 2007)

It is well recognized that the most common natural triggering factor for landslides is rainfall. The distribution of 195 landslide events in the project area over the period 1970 to 2004 is shown in Figure 1. Also shown is the annual total rainfall for Newport. It can be seen that the wetter than average years in 1988, 1989, 1990 and 1998 had significantly more landslide events than the other years. Therefore, as a general hypothesis, it would reasonable to expect that there may be a relationship between the return period or probability of rainfall events and the likelihood of landslides. Similarly, the effect of antecedent rainfall (the rainfall in the period prior to the event) may be significant in relation to the occurrence of landslides.



Distribution of landslides in PittwaterCouncil area between between 1970 and 2004.



Annual rainfall at Newport between 1970 and 2004

Figure 1: Comparison of landslide events with annual rainfall.

The objective of the study described in this paper is to analyse the available rainfall data from rainfall stations in the study area of Pittwater and relate this to the incidence of landslides The analysis has been based on a published statistical method (as discussed in Section 4 below) and has compared the results obtained with those available from Australian Rainfall and Runoff (ARR, 1987) The rainfall records for dates of known landslide events (as collated during the NMDP project) have been examined to determine whether any indicative return periods for the rainfall at the time of the landslides can assessed.

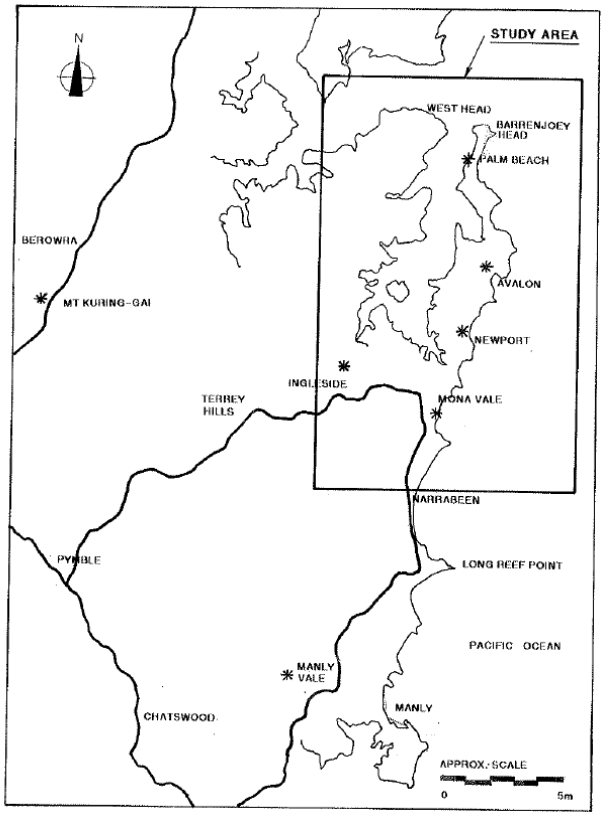


Figure 2: Study area with Rainfall Stations marked.

2 DATA AVAILABLE FOR RAINFALL ANALYSIS

Daily rainfall records have been obtained from the Bureau of Meteorology. Table 1 summarises the daily rainfall records available. The approximate locations of these rainfall stations are shown on Figure 2.

Table 1 shows the commencement and termination dates for each station record and the resulting number of years spanned by each record. For Newport, Palm Beach, Manly Vale and Ingleside the latest records available at the time of the analysis were for January 2006. On scanning through the data files it was noted that all of the data files had missing records. Table 1 also includes a summary of the missing data for each station.

Table 1: List of provided daily rainfall for analysis

No.	Rainfall Station	Commencement Date	End Date	No of Years Spanned	Missing Data
1	Newport (Newport Bowling Club)	01-Jul-31	30-Nov-05	75	Jan 32; Feb & Nov & Dec 70; Jul & Sept & Dec 75; from 1-Dec-81 to 30-Apr-82; from 1-Jun-82 to 31-Dec-82; Nov 96; and many scattered daily missing data
2	Avalon Beach	01-Oct-58	30-Jun-98	40	from 01-Feb-71 to 1-Sep-92; and some scattered daily missing data
3	Mount Kuring-Gai (Ledora Farm)	13-May-64	31-May-98	34	May 87; 18-Jan-92 to 30-Jan 92; Jan 94; Sep 94; Nov and Dec 95; Dec 97; and a few scattered daily missing data
4	Palm Beach (Golf Club)	01-Sep-65	30-Nov-05	40	from 1-Mar-66 to 31-May-66; 20-Jul-66 to 3-Sep-66; and 01-Nov-89 to 28-Feb-98; and a few scattered daily missing data
5	Mona Vale Golf Club	01-Feb-69	31-Dec-97	29	from 1-Apr-71 to 30-Sep-71; Nov and Dec 71; Nov 76; Aug 81; Feb 82; Apr 82; 1-Aug-82 to 31-Dec-87; Jun 87; 1-Aug-92 to 31-Dec-92; Aug 93; 1-Sep-94 to 28 Feb 95; and a few scattered daily missing data
6	Manly Vale (Manly Dam)	09-Jun-06	30-Apr-03	98	1-Mar-72 to 7-Jan-73; Oct 86; 30-Apr-03 to 30-Nov-05 and many scattered daily missing data
7	Ingleside Walter Avenue	01-Jan-84	30-Nov-05	22	A few scattered daily missing data

Manly Vale (Manly Dam) has the longest record but is remote from the study area.. It is known from experience that there can be significant variation between the rainfall within the study area and elsewhere in Sydney. The Newport station was selected for analysis as it had the longest record for the stations within the study area and has relatively less missing data.

3 RAINFALL INTENSITY IN THE VICINITY OF NEWPORT

Data on rainfall intensities frequencies and duration throughout Australia are presented in Australian Rainfall and Runoff (ARR, 1987). The maps presenting the relevant data enable Intensity-Frequency-Duration (IFD) design curves to be prepared for any location using interpolated values and the procedure set out in ARR.

The procedure set out in ARR has been adopted to derive 'benchmark' design curves for the study area using Newport as the location. For comparison purposes the same procedure was used for Sydney, since the Sydney rainfall record is much longer, hence may be more 'reliable' on a statistical basis. The rainfall intensities (mm/hour) have been derived for durations ranging from 5 minutes to 72 hours (3 days) with Average Recurrence Intervals (ARI) of 1 year through to 100 years. The data for Newport are presented as IFD curves in Figure 3.

Comparison of the results for Sydney and Newport showed that the rainfall intensity in Sydney is slightly greater than at Newport. However the difference is only about 10% for durations of 1 hour or less, and the differences are insignificant (less than 2%) for durations greater than 12 hours.

4 ANALYSIS OF DAILY RAINFALL DATA

The daily rainfall data for Newport has been analysed using the Gumbel distribution for extreme events (Kennedy and Neville, 1986). The procedure adopted was as follows. It has been applied to data series formed from the daily rainfalls and rolling cumulative totals for 2 day, 5 day, 10 day, 20 day, 30 day, 60 day and 90 day periods.

1 Using an Excel spreadsheet of consecutive date and daily rainfall in column format, the SUM function was used to calculate the rolling cumulative totals for 2 day, 5 day, 10 day, 20 day, 30 day, 60 day and 90 day periods. This function substitutes zero rainfall for not available (n/a) data entries. There has been no attempt to synthesise rainfall for dates where 'n/a' entries occur.

2 Another column was added to the data showing the year for each day by the use of YEAR function.

3 Independently for each data series (daily to 90 – day), the data was sorted by Year ascending and then by Rainfall descending.

4 The annual maximum for each calendar year was then extracted to give one data point for each year.

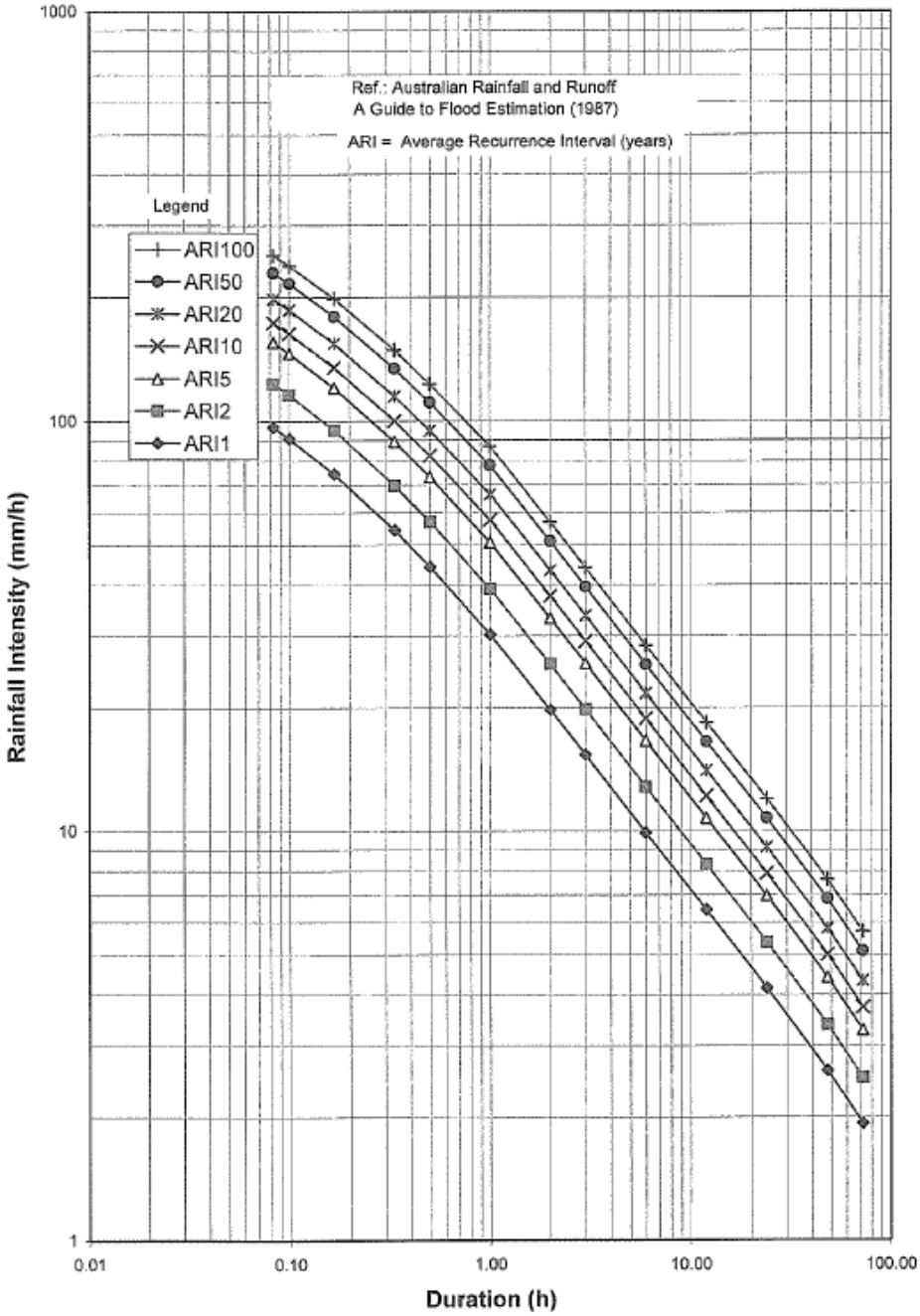


Figure 3: Rainfall Intensity vs. Duration and ARI in the vicinity of Newport

5 The annual maxima were then sorted by descending magnitude and a column added to show the rank of each annual maxima from 1 to 74 (for the adopted record).

6 The return period of annual maxima in years ($T_r = \frac{N+1}{m}$), where m is the rank and N is the length of the record in years, was then calculated.

7 The probability of non-exceedance for each event (in an annual rainfall series was also calculated using: $\overline{P} = [100 - \frac{100m}{N+1}]$

8 The resulting data was then plotted on the Gumbel or extreme probability paper using $\log_{10}$ (rainfall) versus return period, *Tr*. Comparative plots were also prepared using Excel chart function for normal log-log and log-linear plots.

Table 2 presents the date and total rainfall obtained for the top 34 ranking events for each of the data series examined. These data correspond to the results having a return period of about 2 years or more. The maximum daily rainfall is 295 mm for 2 May 1953. For the cumulative 90 – day rainfall the maximum is 1107 mm on 26 July 1950. These values have a calculated probability of non-exceedance of 98.7% with an equivalent return period of 75 years.

Table 2: Date of events from rainfall analysis (Newport).

	1 Day Annual Maximum		**2 Day Annual Maximum**		**5 Day Annual Maximum**		**10 Day Annual Maximum**	
Rank	**Date**	**Rainfall (mm)**	**Date**	**Rainfall (mm)**	**Date**	**Rainfall (mm)**	**Date**	**Rainfall (mm)**
1	2-May-53	295	11-Mar-58	384	9-May-53	422	9-May-53	803
2	10-Mar-58	271	7-Jul-31	349	11-Mar-58	392	17-Jun-50	436
3	5-Feb-90	237	8-May-53	332	9-Jul-31	370	15-Mar-58	428
4	10-Feb-92	233	8-Aug-98	330	21-Nov-61	354	26-Nov-61	423
5	26-Jul-52	216	11-Feb-56	250	8-Aug-98	331	4-Mar-77	395
6	7-Aug-98	214	29-Mar-42	248	6-Mar-77	325	12-Feb-90	388
7	18-Jan-88	187	6-Feb-90	239	9-Feb-90	308	29-Mar-42	373
8	7-Jul-31	184	19-Nov-61	236	28-Jul-52	296	10-Jul-31	370
9	28-Mar-42	179	11-Feb-92	235	30-Mar-42	295	16-Aug-98	356
10	10-Jan-49	175	26-Jul-52	228	13-Jun-64	294	4-Aug-52	355
11	14-Jan-72	173	30-Apr-88	221	13-Feb-56	285	13-Jun-64	340
12	2-Mar-77	171	6-Aug-86	217	19-Jun-50	285	10-Apr-88	330
13	19-Nov-61	164	20-Mar-78	216	1-May-88	283	1-May-85	329
14	29-Jan-78	163	11-Jan-49	205	22-Mar-78	281	26-Mar-78	324
15	10-Feb-56	163	14-Jan-72	205	20-Apr-46	261	26-Jan-51	307
16	24-Jan-55	158	11-Jun-91	190	8-Aug-86	251	11-Feb-56	299
17	19-Feb-59	157	19-Feb-59	185	11-Feb-92	249	20-Apr-46	283
18	6-Aug-86	141	3-Mar-77	185	12-Feb-69	238	8-Feb-02	282
19	26-Oct-87	140	13-Feb-97	181	6-Feb-02	233	23-Jun-49	273
20	9-Mar-00	129	25-Jan-55	174	17-Jan-72	227	22-Jun-75	269
21	22-Feb-54	128	17-Apr-46	171	12-Jan-49	225	16-Feb-92	265
22	7-Jan-89	127	5-Feb-02	168	11-Jun-91	223	10-Sep-34	264
23	31-Jan-38	120	14-May-62	167	15-May-62	220	26-Oct-87	256
24	26-May-74	119	30-Aug-63	167	22-Jun-79	215	11-Aug-86	254
25	16-Apr-46	118	12-Nov-87	157	17-May-03	200	15-Nov-84	249
26	31-Aug-96	109	16-Jun-50	156	9-Nov-84	199	19-Jan-72	246
27	2-Sep-70	107	9-Mar-00	156	1-Feb-73	194	15-Jun-91	245
28	14-Nov-69	106	12-Feb-69	155	22-Jan-51	194	14-Feb-69	245
29	27-Apr-66	105	12-Mar-74	154	20-Feb-59	191	3-Feb-73	241
30	12-Feb-97	105	7-Jan-89	150	14-Feb-97	188	26-May-74	237
31	19-Jan-50	105	7-Aug-67	148	29-Apr-63	188	29-Apr-63	233
32	21-Oct-60	101	8-Nov-84	148	11-Mar-00	186	23-Mar-83	229
33	10-Jun-91	100	10-Jun-64	146	26-Jan-55	185	5-Mar-76	229
34	13-May-62	98	1-Feb-38	140	7-Jan-89	179	20-May-62	225

Table 2 continued: Date of events from rainfall analysis (Newport).

	20 Day Annual Maximum		30 Day Annual Maximum		60 Day Annual Maximum		90 Day Annual Maximum	
Rank	Date	Rainfall (mm)	Date	Rainfall (mm)	Date	Rainfall (mm)	Date	Rainfall (mm)
1	9-May-53	815	9-May-53	840	9-May-53	941	26-Jul-50	1107
2	26-Jun-50	640	22-Jun-50	716	22-Jul-50	932	9-May-53	1078
3	14-Aug-52	580	10-Mar-56	700	20-Mar-56	917	17-Mar-56	1039
4	2-Dec-61	513	1-May-88	659	6-May-88	733	3-May-88	903
5	28-Feb-56	473	23-Aug-52	613	11-Mar-58	708	23-Jun-89	891
6	11-Mar-58	460	11-Mar-58	536	22-Mar-55	708	5-Jun-63	852
7	9-Mar-77	433	15-Dec-61	529	8-May-63	694	7-Jun-74	845
8	26-Aug-98	432	18-Aug-98	496	13-Jan-62	693	21-Apr-90	801
9	18-Feb-90	429	26-Feb-73	490	14-Aug-52	690	12-Apr-55	800
10	30-Mar-42	420	20-Apr-46	459	8-Mar-72	665	28-Apr-58	791
11	16-Feb-73	397	12-Jun-74	454	5-Apr-90	652	2-Apr-78	769
12	5-Jun-74	391	6-Mar-77	452	2-May-89	639	23-Oct-52	766
13	22-Jul-31	386	25-Feb-90	450	2-Dec-61	611	4-Apr-72	753
14	20-Apr-88	376	16-Mar-55	442	8-Jun-98	583	13-Jan-62	723
15	23-Jun-49	370	15-Apr-78	439	25-Mar-73	573	7-Jun-83	707
16	24-Apr-46	365	12-Nov-87	436	26-Mar-78	570	13-Nov-87	694
17	26-Jan-72	364	20-May-63	435	17-Jun-74	558	12-Apr-73	693
18	2-Apr-78	359	18-Jun-49	427	5-Mar-77	556	8-Aug-98	689
19	10-May-63	356	30-Mar-42	421	23-Jun-49	543	21-Nov-61	683
20	26-Jan-51	352	22-Apr-89	420	20-Mar-67	538	18-May-03	668
21	4-May-85	352	11-Feb-72	413	11-Sep-34	527	22-Jun-46	652
22	13-Mar-75	350	4-Aug-31	394	20-May-46	526	27-Aug-49	648
23	25-Feb-92	348	18-May-03	383	28-May-03	525	22-Jun-45	638
24	18-Jun-64	343	11-Sep-34	382	3-May-83	522	19-May-77	617
25	18-Feb-02	322	26-Jan-51	381	6-Apr-76	518	30-Mar-59	613
26	9-Sep-34	322	21-May-85	375	18-Dec-60	507	10-Sep-34	612
27	16-Mar-55	321	25-Mar-76	373	23-Apr-75	494	25-Feb-92	612
28	11-Mar-67	321	16-Mar-75	369	4-Apr-92	492	21-Mar-51	603
29	12-Nov-87	316	25-Feb-92	361	21-Nov-87	484	21-Dec-60	600
30	24-Mar-00	305	15-Mar-67	355	12-Mar-51	478	22-Apr-76	596
31	13-Apr-89	302	12-Jun-91	353	20-Mar-59	477	23-Apr-67	591
32	15-Jun-91	301	13-Apr-83	352	13-Jun-64	469	3-Oct-31	583
33	13-Feb-97	298	20-Feb-02	343	7-Jun-85	468	10-Jun-42	573
34	5-Feb-38	297	18-Jun-64	342.7	15-Jun-45	461	19-Jul-85	558

Figure 4 presents the results of the analysis on the Gumbel plot using Log Rainfall. It is noted that only selected data points have been plotted for probability of non-exceedance less than 90%.

The data has been analysed assuming a full record. As noted in Table 1, the data for Newport has a number of months missing. In addition, 1931 has only 6 months of data and 1982 is largely missing. With the exception of 1932, the years of incomplete data are mostly ranked in the bottom half. If the plots are adjusted by calculating the probability of non-exceedance or return period, using say only 72 years (instead of 74 years) then the plots move marginally to the left. It was considered that it was reasonable to include all the available data and plot based on the 74 year period. If required, consideration could be given to construction of synthetic rainfall data for the missing periods based on the Sydney data or some other rainfall station, but it is considered unlikely that this refinement would alter the overall conclusions.

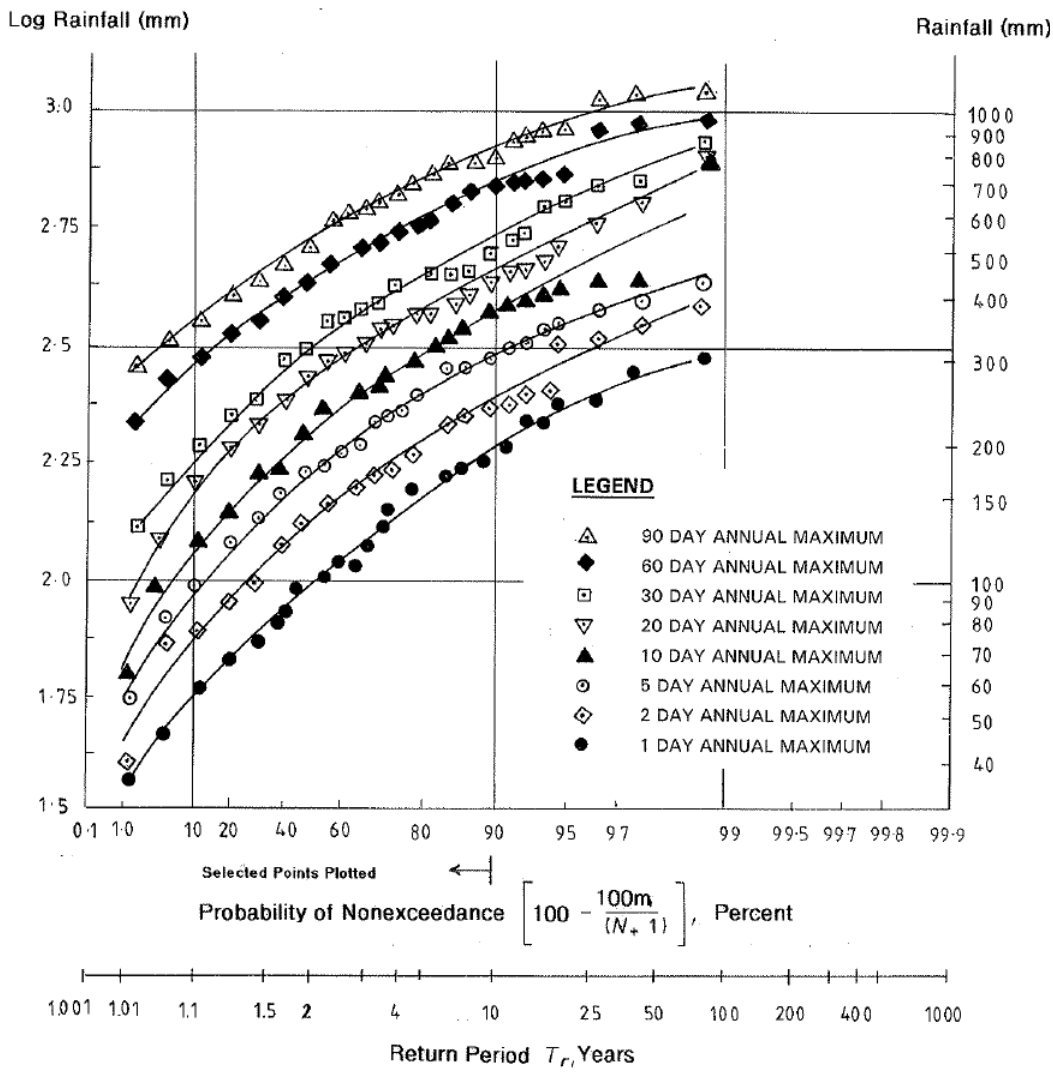


Figure 4: Gumbel probability plots for rainfall at Newport.

Figure 4 shows that there are some irregularities in the data. The most obvious is the large 'step' in the 10 – day rainfall data where the highest ranking total of 803mm on 9 May 1953 is significantly higher than the next total of 436 mm on 17 June 1950. These 'steps', and others, imply the record is not a rigorously representative statistical record. For example, the highest 10 – day rainfall is plotted at a return period of 75 years (in accordance with the procedure) but would appear more likely to represent say a 1000 year event assuming the other data are representative. The design curves shown for the data on Figure 4 have not been adjusted statistically, but do offer some 'smoothing' of the data.

The data obtained from the analysis have been compared in with the 'benchmark data' from ARR as given in Figure 3. This showed that the results of the daily rainfall analysis for 1-day and 2-days:

- Give lower rainfall values than ARR for the 2 year and 5 year return periods
- Give higher rainfall values than ARR for the 20 year, 50 year and 100 year return periods.
- Whilst the comparative values are different, the ARR data plot typically within the scatter of the rainfall data.

Thus it is considered reasonable to adopt the curves on Figure 4 derived from the Gumbel analysis as being indicative of the rainfall return periods and hence frequencies for the longer antecedent rainfall periods.

5 KNOWN LANDSLIDE EVENTS AND ASSOCIATED RAINFALL

5.1 LIST OF KNOWN LANDSLIDE EVENTS

The NMDP project has involved collating data on known landslide events as discussed by MacGregor *et al.* (2007). In early March 2006 the landslide database had a total of 195 landslide events over a 34 year period. The dates of each event had been reliably identified for 77 (about 40%) of the landslides. These landslides occurred on 58 dates.

The date (when known), the number of landslides and comment on the landslides are shown in Appendix A along with the associated rainfalls for that date from rainfall stations in the study area including Newport.

It is important to note that the standard practice is to record the 24 hour rainfall at 9 am every day. Therefore, for heavy rainfalls on a particular day after 9 am, the rainfall is attributed to the next day. Consequently the rainfall records were also checked for the day after the nominated date of the landslide event. It was found that for some events the recorded rainfall for the next day was more justifiable / realistic, since the daily rainfall was considerably higher on the next day than on the nominated date of the event. In addition, in some cases there was 'n/a' – not available – recorded for the nominated date. The specific dates used for the rainfall are indicated in Appendix A if different to the nominated date of the landslide event.

Subsequent analysis of the rainfall data in relation to landslides is limited by the lack of known date for the other 60% of the landslides.

5.2 ANALYSIS OF RAINFALLS FOR KNOWN LANDSLIDE EVENTS

From Appendix A it can be seen that some events had high daily rainfall (e.g. for Newport 157 mm on 30 April 1988; 237 mm on 5 February 1990 and 214 mm on 7 August 1998).

Figure 5 shows Newport rainfalls for 30 April 1988, (a day on which 5 landslide events occurred), plotted on the curves from Figure 4. From this plot the return period for the rainfall for this landslide event varied from about 2 years at 10-days and 20-days to about 15 years at 30-days. An indicative return period could be assessed as about 10 years with either the long term (30-day to 90-day) rainfall or the short term (1-day and 2-day) rainfall being the more critical and hence likely triggers for the landslides on that date.

Similar figures have been plotted for actual rainfalls for other selected dates, but are not included in this paper.

The data in Appendix A have been extended in Appendix B to derive an indicative return period for the rainfall for each known landslide date. The results are shown in Appendix B.

For each landslide date, the results have been summarised in Appendix B for the Maximum Return Period (years) and the corresponding Critical Number of Days Rain. That is the Number of Days Rain with the highest Return Period. These data have then been summarised as:

- A histogram showing the distribution of rainfall maximum return periods of the grouped into 5 year intervals. (Figure 6)
- A histogram showing the distribution of the number of days rain which gives the maximum return period for the landslides. (Figure 7)
- A plot of maximum return period versus the number of days rain these correspond to. (Figure 8)

There is no single pattern of results from these data.

Some observations are:

- The maximum return period for the landslide dates was mostly (about 71% of dates) 1 to 5 years. Most of these dates have only single landslide events.
- There is a tendency for the 60-day and 90-day rainfalls to be the maximum return period, accounting for about 50% of the landslide dates. This indicates that the incidence of landsliding is influenced by the 60 to 90 day antecedent rainfall, i.e those are the critical periods. However, for 5 February 1990 and 7 August 1998 which had 4 and 12 landslide events respectively, the 1-day rainfall was critical. About 20% of the landslide dates have 1-day and 2-day rainfall as critical.
- Rainfall maximum return periods and critical periods when multiple landslide events occurred are shown in Table 3. It can be seen that either short or long period rains appear to be controlling these events, but all have critical durations with a return period of around 20 to 25 years.

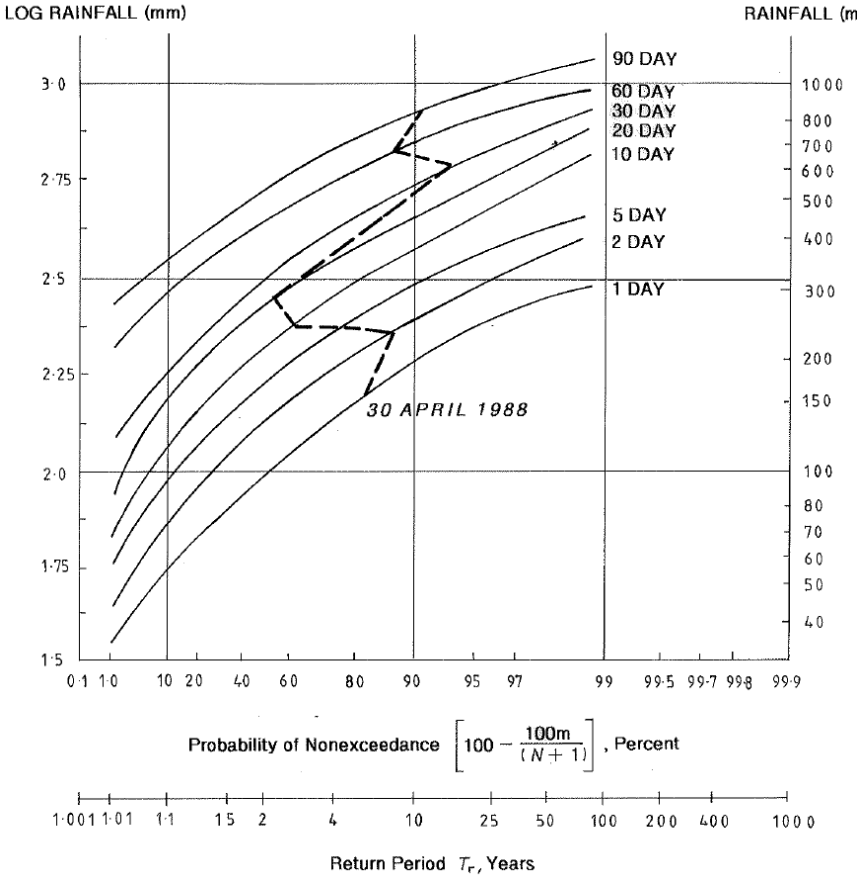


Figure 5: Newport rainfall record for 30 April 1988.

- There is no relationship apparent between maximum return period and critical number of days rain summary plot (Figure 8).
- Examination of the data indicated that frequently the 1-day rainfall was above 70 mm when landslides were recorded. Table 4 shows the results of analysis after sorting the top 20 1-day rainfalls within each year from 1972 to 2005 (the period of known landslide events). The data have been subdivided into groups of greater than 50mm, 70mm and 125mm 1-day rainfall. The resulting approximate return period (Figure 4) and number of days in the data record are shown. Also shown are the number of days where data in Appendix A shows that landslide events are known to have occurred. The figures are affected by the limited number of landslides for which an exact date is known (about 40%). Allowing for this, it can be concluded that 50 mm or more 1-day rainfall has about a 40% chance of resulting in one or more landslides, 70 mm or more about 50% chance, and if 125 mm or more rainfall is experienced, the chance is probably almost 100% that there will be one or more landslides in the Pittwater area.

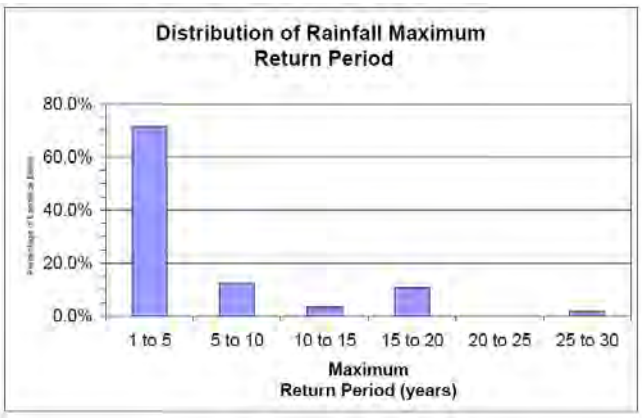


Figure 6: Distribution of rainfall maximum return period for known landslide events.

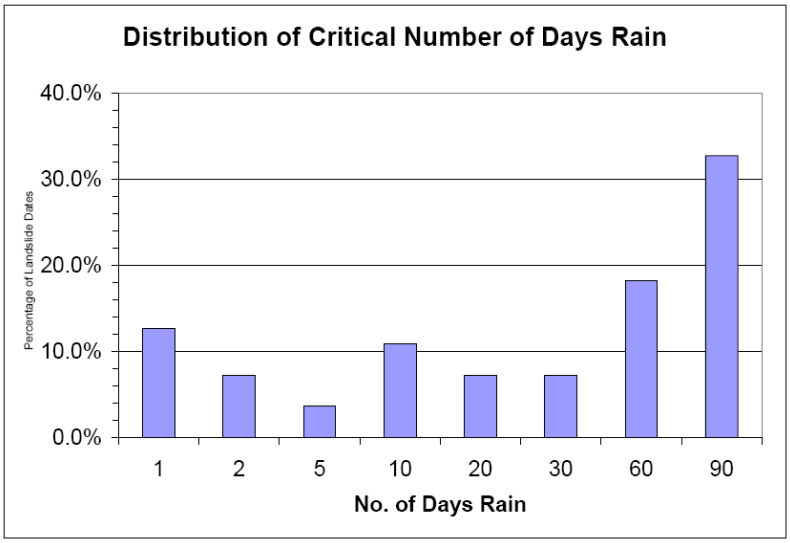


Figure 7: Distribution of critical number of days rain for the critical return period for known landslide events.

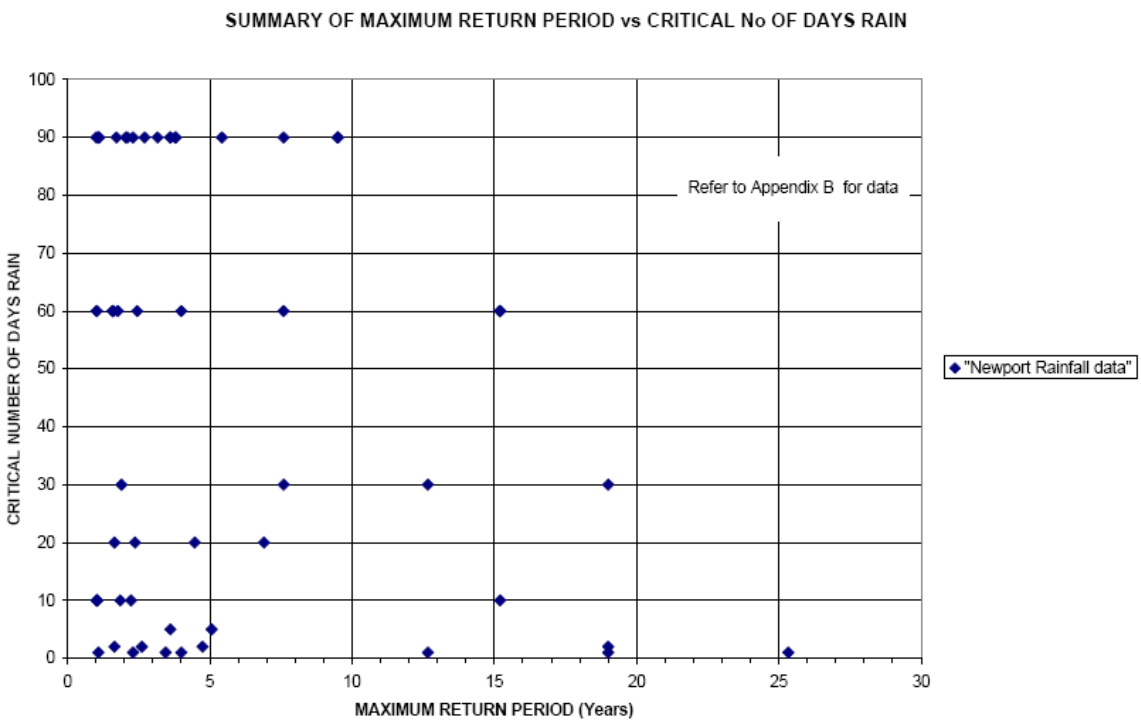


Figure 8: Summary of maximum return period vs critical number of days rain.

Table 3 Rainfall maximum return periods and critical periods when multiple landslide events occurred.

Period	Number of Landslide Events	Rainfall Maximum Return Periods (years)	Critical Number of Days Rain
29 April to 29 May 1988	13	8 to 19	30 and 60
1 February to 16 February 1990	9	1 to 25	1 to 60
7 August to 8 August 1998	12	13 to 19	1 and 2

Table 4: Likelihood of one or more landslides in Pittwater versus daily rainfall.

1-Day Rainfall Amount	Approximate Return Period (Years)	Total Number of Days 1972-2005	Number of Days included in Appendix A	Approximate Ratio Appendix A Number to Total Number
Greater than 50 mm	About 1.0	131	20	15%
Greater than 70 mm	About 1.3	77	14	18%
Greater than 125 mm	About 3.3	13	7	54%

6 CONCLUDING REMARKS AND GENERAL COMMENTS

It is apparent that the incidence of landsliding in Pittwater can be related to rainfall but from the data currently available there is no clear single pattern. The chance of landslides occurring in Pittwater increases with higher 1-day rainfall. There is probably almost 100% chance of one or more landslides in the Pittwater area when the 1-day rainfall is 125mm or more.

Days on which multiple landslides are likely to occur are often related to a maximum return period associated with 30 to 60 day antecedent rainfall. All the multiple landslide days are related to relatively long recurrence period rainfalls of about 20 years.

These data allow rainfall to be used to asses the frequency of landsliding as detailed in MacGregor *et al*. (2007)

Although assessment of the rainfall return period (or implied frequency) may give an indicative frequency for a landslide occurrence, it is only part of the assessment. Together with rainfall data, the site specific soil-water status, site geology and soil properties, ground water hydrology, as well as site topography and morphology may have an effect on when a landslide is triggered. However, these other factors were beyond the scope of this project.

7 ACKNOWLEDGEMENT

Analysis of the rainfall data was carried out by Dr Haddi Khabbaz under the direction of Bruce Walker. The useful suggestions and help from Robin Fell in concluding the study is gratefully appreciated.

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APPENDIX A SUMMARY OF SPECIFIC DATES INCLUDING NUMBER OF LANDSLIDE EVENTS AND THE ASSOCIATED RAINFALLS.

			Rainfall Date		Rainfall (mm)							
Date	No of Events	Comment	(if different)	Station	1 Day	2 Day	5 Day	10 Day	20 Day	30 Day	60 Day	90 Day
26-Jan-72	1	Also leaking pipe		Newport	72	101	112	144	364	377	518	596
				Palm Beach	70	94	103	139	364	375	510	580
				Manly Vale	74	96	110	249	364	389	493	571
				Ingleside	n/a							
22-Oct-72	1	Belinda Place		Newport	0	0	7	71	74	108	114	221
				Palm Beach	0	0	5	51	58	101	116	166
				Manly Vale	n/a							
				Ingleside	n/a							
23-May-73	1	Grandview Drive		Newport	0	0	0	0	0	29	151	282
				Palm Beach	0	0	0	0	0	30	106	212
				Manly Vale	0	0	0	0	0	22	81	234
				Ingleside	n/a							
11-Mar-74	1	Small fill	12-Mar-74	Newport	97	154	160	160	164	249	378	530
			12-Mar-74	Palm Beach	82	125	129	129	134	198	307	427
			12-Mar-74	Manly Vale	76	155	155	155	162	260	350	450
				Ingleside	n/a							
4-Mar-77	2	Riverview Road, tennis court		Newport	125	139	319	395	414	438	554	571
				Palm Beach	117	128	229	296	310	370	440	473
				Manly Vale	107	109	198	299	322	352	429	452
				Ingleside	n/a							
22-May-83	1	Crib Wall, Careel Bay	23-May-83	Newport	56	56	83	83	83	179	375	610
			23-May-83	Palm Beach	44	67	71	71	82	177	421	651
			23-May-83	Manly Vale	75	75	80	80	80	172	293	552
				Ingleside	n/a							
26-May-83	1	Crib Wall, Riverview Road		Newport	50	69	125	152	152	223	444	679
				Palm Beach	42	63	116	142	144	221	409	721
				Manly Vale	14	35	121	125	125	202	338	594
				Ingleside	n/a							
15-Jul-85	1	May be water main excavation		Newport	0	0	23	57	57	79	182	535
				Palm Beach	0	0	38	64	64	80	207	604
				Manly Vale	0	0	22	50	50	78	187	517
				Ingleside	0	0	23	52	56	78	196	511
14-Nov-85	1	Reactivation, small		Newport	0	2	2	18	46	68	283	327
				Palm Beach	0	2	2	19	41	74	267	329
				Manly Vale	0	2	13	67	118	118	277	341
				Ingleside	3	5	5	26	66	87	316	359
24-Oct-87	1	Avalon ? Date	26-Oct-87	Newport	140	140	147	256	279	295	397	582
			25-Oct-87	Palm Beach	139	144	189	239	248	261	364	522
			26-Oct-87	Manly Vale	107	107	107	210	231	241	326	453
			25-Oct-87	Ingleside	119	126	193	252	268	281	406	609

			Rainfall Date		Rainfall (mm)							
Date	No of Events	Comment	(if different)	Station	1 Day	2 Day	5 Day	10 Day	20 Day	30 Day	60 Day	90 Day
30-Oct-87	1	Small		Newport	0	5	145	211	284	297	303	585
				Palm Beach	0	1	24	213	272	282	292	542
				Manly Vale	0	0	108	169	232	240	247	453
				Ingleside	0	3	14	207	281	292	300	618
20-Nov-87	1	Fallen tree broke water main		Newport	0	0	9	169	177	330	477	579
				Palm Beach	0	0	14	294	300	468	584	694
				Manly Vale	0	0	3	201	209	379	451	537
				Ingleside	6	6	17	253	271	410	565	691
23-Jan-88	1	Sandstone fall ? Date		Newport	0	32	32	219	238	271	332	661
				Palm Beach	0	5	5	170	179	209	274	603
				Manly Vale	n/a	8	8	236	239	273	319	645
				Ingleside	0	27	27	259	293	328	385	669
24-Jan-88	1	Sandstone fall ? Date		Newport	8	8	40	227	246	277	341	530
				Palm Beach	8	8	13	178	186	214	282	589
				Manly Vale	n/a	0	8	236	236	273	319	538
				Ingleside	16	16	43	276	309	340	401	676
4-Apr-88	1	Retaining wall. Small		Newport	114	114	195	197	249	258	420	672
				Palm Beach	87	111	139	147	212	221	388	583
				Manly Vale	n/a	0	5	18	86	93	197	461
				Ingleside	93	131	180	181	238	242	406	699
29-Apr-88	1	Retaining wall. Small		Newport	64	76	76	85	150	459	536	693
				Palm Beach	49	87	87	98	192	465	550	722
				Manly Vale	74	88	89	92	200	354	448	564
				Ingleside	72	82	82	85	178	484	555	719
30-Apr-88	5	Valley Close, McCarrs Creek, Narrabeen		Newport	157	221	233	233	279	609	679	850
				Palm Beach	150	200	238	238	327	612	700	872
				Manly Vale	100	174	189	192	300	449	547	654
				Ingleside	167	239	249	249	327	645	716	886
1-May-88	2	Small, may be related to septic		Newport	50	207	283	283	328	659	729	900
				Palm Beach	93	243	330	330	397	690	793	964
				Manly Vale	n/a	100	189	189	240	449	547	653
				Ingleside	68	235	316	317	380	713	784	950
13-May-88	3	Newport, Bayview. Large		Newport	0	0	0	1	288	317	724	867
				Palm Beach	0	0	0	2	334	363	784	936
				Manly Vale	0	0	1	1	298	338	645	739
				Ingleside	0	0	0	2	320	353	781	916

APPENDIX A CONTINUED

Date	No of Events	Comment	Rainfall Date (if different)	Station	Rainfall (mm) 1 Day	2 Day	5 Day	10 Day	20 Day	30 Day	60 Day	90 Day
16-May-88	1	Small		Newport	0	0	0	0	288	317	724	767
				Palm Beach	0	0	0	1	334	363	784	813
				Manly Vale	0	0	0	1	298	324	645	669
				Ingleside	0	0	0	1	320	352	779	823
29-May-88	1	Mudslide. Leaking water main		Newport	0	0	15	15	15	227	686	763
				Palm Beach	0	2	20	23	26	272	737	823
				Manly Vale	n/a	0	37	38	41	250	604	698
				Ingleside	1	2	17	20	23	262	746	817
6-Jul-88	1	Small crib wall	06-Jul-88	Newport	66	96	100	100	139	164	209	632
			06-Jul-88	Palm Beach	154	186	189	189	239	272	335	849
			06-Jul-88	Manly Vale	98	125	134	134	170	181	261	685
			06-Jul-88	Ingleside	116	156	162	162	203	278	337	856
6-Jan-89	2	Medium log wall Church Point	07-Jan-89	Newport	127	150	179	199	234	303	437	444
			07-Jan-89	Palm Beach	88	98	111	136	171	254	387	392
				Manly Vale	15	15	64	86	102	193	306	313
			07-Jan-89	Ingleside	154	174	199	228	268	366	523	529
17-Jan-89	1	Small		Newport	0	0	2	10	209	245	372	454
				Palm Beach	1	1	6	19	155	190	320	411
				Manly Vale	0	0	9	112	198	214	342	425
				Ingleside	0	0	4	16	244	284	451	545
12-Mar-89	1	Retaining wall. Medium		Newport	0	0	27	58	110	132	242	499
				Palm Beach	1	1	16	28	109	130	215	420
				Manly Vale	0	0	22	50	107	143	237	458
				Ingleside	3	6	40	72	120	148	280	597
31-Mar-89	1	Small during construction	01-Apr-89	Newport	50	51	57	136	207	265	358	654
			01-Apr-89	Palm Beach	47	50	59	139	205	233	353	569
				Manly Vale	20	23	82	85	135	186	290	536
			01-Apr-89	Ingleside	73	75	81	159	233	305	397	748
16-May-89	1	Jendi Avenue, medium	17-May-89	Newport	31	40	77	90	152	292	614	816
			17-May-89	Palm Beach	30	32	54	65	103	170	481	670
			17-May-89	Manly Vale	43	47	70	86	136	234	541	712
			17-May-89	Ingleside	38	46	73	96	136	288	612	830
30-Jun-89	1	Coasters Retreat, no rain		Newport	0	10	30	105	175	292	449	817
				Palm Beach	0	15	36	179	252	358	479	742
				Manly Vale	0	21	58	109	170	322	463	812
				Ingleside	0	10	38	142	226	342	513	852
5-Dec-89	1	McCarrs Creek, reactivation		Newport	58	61	61	61	71	94	132	132
				Palm Beach	n/a							
				Manly Vale	76	89	89	93	128	158	178	180
				Ingleside	106	128	129	130	143	178	210	213

Date	No of Events	Comment	Rainfall Date (if different)	Station	Rainfall (mm) 1 Day	2 Day	5 Day	10 Day	20 Day	30 Day	60 Day	90 Day
1-Feb-90	1			Newport	0	0	4	12	24	102	221	254
				Palm Beach	n/a							
				Manly Vale	1	1	6	6	23	92	256	325
				Ingleside	1	1	10	11	30	129	335	385
2-Feb-90	1	Palm Beach, small		Newport	13	13	17	25	37	115	231	267
				Palm Beach	n/a							
				Manly Vale	13	14	18	18	36	105	256	338
				Ingleside	22	24	33	33	52	151	335	408
3-Feb-90	1	Reactivation		Newport	n/a	13	17	25	37	115	173	267
				Palm Beach	n/a							
				Manly Vale	n/a	13	16	18	36	105	180	338
				Ingleside	250	273	281	283	298	402	480	658
5-Feb-90	4	McCarrs Creek, medium to large		Newport	237	237	250	262	266	352	375	502
				Palm Beach	n/a							
				Manly Vale	203	203	217	222	230	308	335	540
				Ingleside	12	186	460	469	479	587	621	843
7-Feb-90	1	Hudson Parade, Large		Newport	40	41	279	296	307	360	414	538
				Palm Beach	n/a							
				Manly Vale	23	26	229	247	255	316	355	561
				Ingleside	71	74	510	543	552	635	686	910
16-Feb-90	1	Nullaburra Road, Large		Newport	0	0	72	150	405	417	507	632
				Palm Beach	n/a							
				Manly Vale	0	1	116	158	382	390	472	670
				Ingleside	0	1	13	204	675	685	800	1015
11-Apr-90	1	Chisholm Ave. Fill and retaining walls		Newport	0	0	26	100	136	206	385	738
				Palm Beach	n/a							
				Manly Vale	21	26	49	151	182	236	443	730
				Ingleside	33	36	47	154	205	263	485	1075
23-Apr-90	1	Hudson Parade. Cut and fill failures		Newport	0	0	30	70	171	199	360	797
				Palm Beach	n/a							
				Manly Vale	14	14	96	171	307	347	462	879
				Ingleside	0	0	110	249	395	446	586	1305
9-May-90	1	Paradise Avenue, small		Newport	4	31	31	31	59	101	309	517
				Palm Beach	n/a							
				Manly Vale	1	31	31	32	104	229	439	659
				Ingleside	1	25	25	25	106	311	540	776
2-Aug-90	1	McCarrs Creek, Crib wall, large		Newport	71	129	138	206	206	230	259	408
				Palm Beach	n/a							
				Manly Vale	35	111	131	150	158	175	206	374
				Ingleside	70	131	135	192	200	221	262	422
7-Aug-90	1	Whale Beach, retaining wall		Newport	0	0	39	177	245	269	287	416

APPENDIX A CONTINUED

Date	No of Events	Comment	Rainfall Date (if different)	Station	Rainfall (mm) 1 Day	2 Day	5 Day	10 Day	20 Day	30 Day	60 Day	90 Day
				Palm Beach	n/a							
				Manly Vale	0	10	32	163	189	207	232	375
				Ingleside	0	4	30	165	229	250	274	427
15-Sep-90	1	Small		Newport	0	0	1	12	39	40	294	334
				Palm Beach	n/a							
				Manly Vale	n/a	7	9	20	40	42	236	274
				Ingleside	39	47	49	57	75	79	316	351
13-Nov-90	1	Cannes Drive, medium fill, gabion walls		Newport	0	0	5	9	12	18	42	91
				Palm Beach	n/a							
				Manly Vale	0	10	10	19	24	40	179	223
				Ingleside	0	9	9	19	22	35	154	196
10-Jun-91	1	Makerel Beach, large		Newport	100	100	134	134	205	256	314	343
				Palm Beach	n/a							
				Manly Vale	n/a	0	38	38	93	137	186	193
				Ingleside	103	115	152	152	245	281	305	326
11-Jun-91	1	Nullaburra Road, wall, small		Newport	90	190	223	224	280	346	397	433
				Palm Beach	n/a							
				Manly Vale	211	211	249	249	290	347	377	404
				Ingleside	156	259	304	308	385	436	460	482
20-Jun-91	1	Cheryl Crescent, cut		Newport	0	0	0	111	245	316	418	431
				Palm Beach	n/a							
				Manly Vale	0	0	1	239	278	332	402	432
				Ingleside	0	0	0	164	316	409	465	476
1-Jul-91	1	Warriewood, broken pipe		Newport	0	0	0	0	22	247	416	426
				Palm Beach	n/a							
				Manly Vale	0	0	0	0	29	278	394	426
				Ingleside	0	1	1	1	10	318	461	472
9-Feb-92	1	Retaining wall, small		Newport	n/a	8	26	26	34	34	246	306
				Palm Beach	n/a							
				Manly Vale	n/a	0	0	14	16	93	292	319
				Ingleside	212	218	239	243	255	258	541	610
10-Feb-92	1	Retaining wall, small		Newport	233	233	247	259	267	267	437	539
				Palm Beach	n/a							
				Manly Vale	212	212	219	249	263	264	486	568
				Ingleside	132	344	356	375	387	390	615	742
13-May-98	1			Newport	0	0	0	86	131	214	394	421
				Palm Beach	0	0	0	78	125	202	433	441
				Manly Vale	0	0	0	66	101	181	367	395
				Ingleside	0	0	0	109	160	286	614	645

Date	No of Events	Comment	Rainfall Date (if different)	Station	Rainfall (mm) 1 Day	2 Day	5 Day	10 Day	20 Day	30 Day	60 Day	90 Day
29-May-98	1			Newport	0	0	0	14	177	293	546	581
				Palm Beach	0	0	0	7	199	306	621	640
				Manly Vale	0	0	0	19	174	258	521	550
				Ingleside	0	0	0	15	228	373	815	849
7-Aug-98	12	Avalon to Narrabeen, walls, cuts and fills		Newport	214	214	215	215	307	308	357	573
				Palm Beach	117	191	191	191	272	275	329	561
				Manly Vale	111	175	175	175	250	254	325	559
				Ingleside	126	258	259	259	348	353	417	720
8-Aug-98		(Rainfall reported day following 7 Aug 1998)		Newport	116	330	331	331	412	424	473	689
				Palm Beach	112	229	303	303	372	387	441	673
				Manly Vale	151	262	326	326	387	405	476	710
				Ingleside	0	0	12	12	46	177	661	722
16-Nov-00	1	Temporary cut, small		Newport	75	123	127	129	129	154	305	317
				Palm Beach	19	31	34	39	41	59	131	151
				Manly Vale	39	89	101	106	108	121	208	218
				Ingleside	51	104	117	121	123	140	262	286
30-Jan-01	1	Temporary cut, small		Newport	0	0	10	10	67	67	138	361
				Palm Beach	0	0	10	10	46	47	108	219
				Manly Vale	0	0	7	10	47	49	80	244
				Ingleside	0	0	12	12	57	59	108	295
8-May-01	1	Retaining wall, Whale Beach		Newport	0	0	29	58	88	93	151	249
				Palm Beach	36	36	78	123	189	195	278	339
				Manly Vale	53	53	77	127	195	213	248	328
				Ingleside	35	35	68	109	183	197	273	395
7-May-01	1	Nullaburra Road, Large, reactivation		Newport	19	19	19	77	107	112	154	253
				Palm Beach	48.6	85	85	171	238	244	301	376
				Manly Vale	27	79	79	153	221	240	271	339
				Ingleside	21	57	57	131	204	219	285	386
5-Feb-02	2	Cut, small, North Narrabeen		Newport	94	168	227	240	249	291	320	402
				Palm Beach	56	171	217	221	227	264	312	405
				Manly Vale	91	141	219	222	249	292	340	427
				Ingleside	124	230	321	325	338	382	432	527
15-May-03	1	Seawall, Newport		Newport	26	93	121	131	215	330	426	583
				Palm Beach	41	87	113	126	164	285	387	499
				Manly Vale	n/a							
				Ingleside	42	130	165	177	241	342	487	690

Based on Landslide Database at 2/3/06

APPENDIX B: SUMMARY OF NEWPORT RAINFALL DATA ON LANDSLIDE DATES AND MAXIMUM RETURN PERIODS.

		Rainfall (mm)								RETURN PERIOD (years) via LOOKUP table								SUMMARY RESULTS	
DATE	No Of Events	1 Day	2 Day	5 Day	10 Day	20 Day	30 Day	60 Day	90 Day	1 Day	2 Day	5 Day	10 Day	20 Day	30 Day	60 Day	90 Day	Maximum return period (Years)	Critical No Days Rain
26-Jan-72	1	72	101	112	144	364	377	518	596	1.310	1.462	1.188	1.267	4.471	2.923	2.923	2.452	4	20
22-Oct-72	1	0	0	7	71	74	108	114	221	1.000	1.000	1.000	1.041	1.013	1.013	1.013	1.013	1	10
23-May-73	1	0	0	0	0	0	29	151	282	1.000	1.000	1.000	1.000	1.000	1.013	1.013	1.013	1	90
11-Mar-74	1	97	154	160	160	164	249	378	530	2.111	2.621	1.689	1.407	1.134	1.434	1.583	2.111	3	2
04-Mar-77	2	125	139	319	395	414	438	554	571	3.304	2.054	10.857	15.200	6.909	4.750	4.000	2.235	15	10
22-May-83	1	56	56	83	83	83	179	375	610	1.070	1.041	1.041	1.041	1.013	1.086	1.583	2.714	3	90
26-May-83	1	50	69	125	152	152	223	444	679	1.056	1.041	1.333	1.288	1.070	1.288	2.111	3.800	4	90
15-Jul-85	1	0	0	23	57	57	79	182	535	1.000	1.000	1.013	1.013	1.013	1.013	1.013	2.111	2	90
14-Nov-85	1	0	2	2	18	46	68	283	327	1.000	1.000	1.000	1.013	1.013	1.013	1.070	1.056	1	90
24-Oct-87	1	140	140	147	256	279	295	397	582	4.000	2.235	1.520	3.304	2.054	1.617	1.689	2.303	4	1
30-Oct-87	1	0	5	145	211	284	297	303	585	1.000	1.000	1.520	2.111	2.054	1.652	1.118	2.375	2	20
20-Nov-87	1	0	0	9	169	177	330	477	579	1.000	1.000	1.000	1.434	1.152	2.054	2.452	2.303	2	60
23-Jan-88	1	0	32	32	219	238	271	332	661	1.000	1.013	1.013	2.171	1.652	1.490	1.246	3.619	4	90
24-Jan-88	1	8	8	40	227	246	277	341	530	1.013	1.000	1.027	2.235	1.652	1.551	1.288	2.111	2	10
04-Apr-88	1	114	114	195	197	249	258	420	672	2.923	1.617	2.815	1.689	1.689	1.490	1.810	3.800	4	90
29-Apr-88	1	64	76	76	85	150	459	536	693	1.188	1.101	1.041	1.041	1.070	7.600	3.619	4.471	8	30
30-Apr-88	5	157	221	233	233	279	609	679	850	4.471	6.909	3.800	2.452	2.000	12.667	7.600	10.857	13	30
01-May-88	2	50	207	283	283	328	659	729	900	1.056	5.429	5.846	4.222	3.040	19.000	15.200	15.200	19	30
13-May-88	3	0	0	0	1	288	317	724	867	1.000	1.000	1.000	1.000	2.111	1.900	15.200	12.667	15	60
16-May-88	1	0	0	0	0	288	317	724	767	1.000	1.000	1.000	1.000	2.111	1.900	15.200	6.333	15	60
29-May-88	1	0	0	15	15	15	227	686	763	1.000	1.000	1.000	1.000	1.000	1.310	7.600	5.846	8	60
05-Jul-88	1	66	96	100	100	139	164	209	632	1.226	1.407	1.134	1.070	1.056	1.056	1.013	3.167	3	90
06-Jan-89	2	127	150	179	199	234	303	437	444	3.455	2.533	2.235	1.727	1.617	1.689	2.054	1.434	3	1
17-Jan-89	1	0	0	2	10	209	245	372	454	1.000	1.000	1.000	1.000	1.362	1.407	1.583	1.490	2	60
12-Mar-89	1	0	0	27	58	110	132	242	499	1.000	1.000	1.013	1.027	1.041	1.027	1.041	1.727	2	90
31-Mar-89	1	50	51	57	136	207	265	358	654	1.056	1.041	1.041	1.206	1.362	1.490	1.462	3.619	4	90
16-May-89	1	31	40	77	90	152	292	614	816	1.013	1.027	1.041	1.041	1.070	1.617	5.846	9.500	10	90
30-Jun-89	1	0	10	30	105	175	292	449	817	1.000	1.000	1.013	1.086	1.152	1.617	2.111	9.500	10	90
05-Dec-89	1	58	61	61	61	71	94	132	132	1.086	1.041	1.041	1.041	1.013	1.013	1.013	1.000	1	1
01-Feb-90	1	0	0	4	12	24	102	221	254	1.000	1.000	1.000	1.000	1.013	1.013	1.027	1.013	1	60
02-Feb-90	1	13	13	17	25	37	115	231	267	1.013	1.000	1.013	1.013	1.013	1.013	1.027	1.013	1	60
03-Feb-90	1	n/a	13	17	25	37	115	173	267	#N/A	1.000	1.013	1.013	1.013	1.013	1.013	1.013	#N/A	
05-Feb-90	4	237	237	250	262	266	352	375	502	25.333	9.500	4.471	3.304	1.767	2.375	1.583	1.727	25	1
07-Feb-90	1	40	41	279	296	307	360	414	538	1.041	1.027	5.067	4.471	2.533	2.533	1.727	2.171	5	5
16-Feb-90	1	0	0	72	150	405	417	507	632	1.000	1.000	1.041	1.288	6.909	3.619	2.815	3.167	7	20
11-Apr-90	1	0	0	26	100	136	206	385	738	1.000	1.000	1.013	1.070	1.056	1.169	1.617	5.429	5	90
23-Apr-90	1	0	0	30	70	171	199	360	797	1.000	1.000	1.013	1.041	1.152	1.134	1.462	7.600	8	90
09-May-90	1	4	31	31	31	59	101	309	517	1.000	1.013	1.013	1.013	1.013	1.013	1.134	2.054	2	90
02-Aug-90	1	71	129	138	206	206	230	259	408	1.310	1.810	1.462	1.854	1.362	1.333	1.041	1.267	2	10
07-Aug-90	1	0	0	39	177	245	269	287	416	1.000	1.000	1.027	1.490	1.652	1.490	1.086	1.267	2	20
15-Sep-90	1	0	0	1	12	39	40	294	334	1.000	1.000	1.000	1.000	1.013	1.013	1.101	1.056	1	90
13-Nov-90	1	0	0	5	9	12	18	42	91	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1	
10-Jun-91	1	100	100	134	134	205	256	314	343	2.303	1.462	1.434	1.206	1.362	1.434	1.169	1.070	2	1
11-Jun-91	1	90	190	223	224	280	346	397	433	1.767	4.750	3.455	2.171	2.054	2.303	1.689	1.357	5	2
20-Jun-91	1	0	0	0	111	245	316	418	431	1.000	1.000	1.000	1.086	1.652	1.900	1.810	1.333	2	30
01-Jul-91	1	0	0	0	0	22	247	416	426	1.000	1.000	1.000	1.000	1.013	1.434	1.767	1.310	2	60
09-Feb-92	1	n/a	8	26	26	34	34	246	306	#N/A	1.000	1.013	1.013	1.013	1.013	1.041	1.027	#N/A	
10-Feb-92	1	233	233	247	259	267	267	437	539	19.000	7.600	4.222	3.304	1.810	1.490	2.054	2.171	19	1
13-May-98	1	0	0	0	86	131	214	394	421	1.000	1.000	1.000	1.041	1.056	1.206	1.617	1.288	2	60

		Rainfall (mm)								RETURN PERIOD (years) via LOOKUP table								SUMMARY RESULTS	
DATE	No Of Events	1 Day	2 Day	5 Day	10 Day	20 Day	30 Day	60 Day	90 Day	1 Day	2 Day	5 Day	10 Day	20 Day	30 Day	60 Day	90 Day	Maximum return period (Years)	Critical No Days Rain
29-May-98	1	0	0	0	14	177	293	546	581	1.000	1.000	1.000	1.000	1.152	1.617	4.000	2.303	4	60
07-Aug-98	12	214	214	215	215	307	308	357	573	12.667	5.429	3.040	2.111	2.533	1.767	1.462	2.303	13	1
08-Aug-98	0	116	330	331	331	412	424	473	689	2.923	19.000	15.200	6.333	6.909	4.000	2.375	4.222	19	2
16-Nov-00	1	75	123	127	129	129	154	305	317	1.434	1.652	1.357	1.206	1.056	1.041	1.134	1.056	2	2
30-Jan-01	1	0	0	10	10	67	67	138	361	1.000	1.000	1.000	1.000	1.013	1.013	1.013	1.118	1	90
06-May-01	1	0	0	29	58	88	93	151	249	1.000	1.000	1.013	1.027	1.027	1.013	1.013	1.013	1	10
07-May-01	1	19	19	19	77	107	112	154	253	1.013	1.013	1.013	1.041	1.041	1.013	1.013	1.013	1	10
05-Feb-02	2	94	168	227	240	249	291	320	402	1.900	3.455	3.619	2.533	1.689	1.617	1.206	1.226	4	5
15-May-03	1	26	93	121	131	215	330	426	583	1.013	1.382	1.267	1.206	1.434	2.054	1.900	2.303	2	90

No of dates = 58

Notes:

1: Conversion of daily rainfall values to return period using lookup table for Newport data as based on Table E.

2: Excludes the Rock falls

3: Dates from database at 2/3/06

Note: Return Period not adjusted to graph on Figure 5; values are reasonable for Return Periods of less than about 10 years

AN ASSESSMENT OF ROCKFALL FREQUENCY FOR THE COASTAL CLIFF-LINES OF PITTWATER LOCAL GOVERNMENT AREA, SYDNEY

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SYNOPSIS

The Australian Geomechanics Society (AGS), in association with Pittwater Council, has performed an assessment of the likelihood of landslide occurrence throughout the Pittwater Council Local Government Area (LGA). Pittwater Council LGA has a significant coastline with the Tasman Sea of the southern Pacific Ocean. To complement the assessment of the frequency of earth slides, cut and fill failures and retaining wall instability, this study was conducted of the frequency of rockfalls from the near vertical, coastal cliff-lines.

1 INTRODUCTION

The governments throughout Australia recognised the risks posed to property and life from landslides and provided funding for research into the likelihood of landslide occurrence under the Australian Governments' National Disaster Mitigation Program (NDMP). The landslide likelihood research was conducted with NDMP support under the 2003-2004 funding round, with funding support from the Australian Commonwealth Government, the New South Wales State Government and with the support of both Pittwater Council (PWC) and the Australian Geomechanics Society (AGS).

A comprehensive study of the likelihood of earth slides, cut and fill failures, and retaining wall distress has been conducted by MacGregor *et al.* (2007). This study addresses rockfall frequency along the coastal cliff-lines of PWC and is a companion to Macgregor *et al. (ibid)* such that both earth slides within the steep terrain of the Council area and the rockfall mechanisms of the coastline are addressed.

2 COASTAL ROCKFALLS

2.1 GEOLOGICAL SETTING

Pittwater LGA is located within the northern beaches area of metropolitan Sydney, New South Wales. The Pittwater environment is characterised by a dominant capping of Middle Triassic Hawkesbury Sandstone. The Hawkesbury Sandstone comprises horizontally to sub-horizontally bedded quartz sandstone strata with some shale lenses and interbeds. The Hawkesbury Sandstone has a total stratigraphic thickness of over 200 metres and it has weathered to produce extensive sub-vertical cliff-lines that are topographically dominant in the Pittwater LGA.

The Hawkesbury Sandstone is underlain by the Early Triassic Narrabeen Group of strata that are composed predominantly of quartz and lithic sandstones, siltstones, shales and laminites. The uppermost stratigraphic unit of the Narrabeen Group is the Newport Formation, which comprises a horizontally to sub-horizontally bedded and interbedded sequence of sandstone, shale, laminite and carbonaceous/fossiliferous shale strata. The Newport Formation, which has a local stratigraphic thickness of up to 49 metres, is the dominant cliff forming unit along the coast in the Pittwater LGA. The spectacular sub-vertical headlands and coastal bluffs that typify the area generally range in height from 40 to 50 metres, in Newport Formation strata. At the northern end of the Pittwater LGA peninsula, the inclusion of a Hawkesbury Sandstone capping produces vertical coastal cliffs to heights of about 80 metres. A schematic section depicting the general geological setting is presented as Figure 2.

2.2 ROCKFALL INVENTORY

Listed in Table 1 and shown located on Figure 1, are coastal cliff-line rockfall events that have occurred in Pittwater LGA, from December 1991 to December 2006. This inventory comprises rockfalls with a minimum threshold volume of 1 m^3, that have been observed by or reported to Pittwater Council and have been referred to the author for assessment. Rockfall events less than 1 m^3 in magnitude have been excluded, as have been rockfalls created or triggered by people. Only cliff-lines adjoining the ocean have been included in this review. It is also to be noted that progressive fretting, ravelling and weathering/decompositional mechanisms have not been recorded.

Figure 1: Location of coastal rockfalls in the Pittwater LGA.

Table 1: Recorded coastal rockfalls 1991-2006 in Pittwater Council LGA.

Reference Number on Figure 1	Location	Date of occurrence	Approximate rockfall volume m^3 (w x d x h)	Approximate magnitude of local regression	Governing mechanism
1	Turrimetta Head	Dec 91	85 (3 x 4 x 7)	4 m	Undercut by wave action during severe storm
2	North Narrabeen	Oct 92	4 (2 x 1 x 2)	1 m	Natural weathering
3	Bilgola, southern headland	Feb 95	2 (1 x 1 x 2)	1 m	Natural weathering
4	South Avalon	Aug 99	400 (8 x 4 x 12)	4 m	Natural weathering locally exacerbated by cliff top developments
5	Whale Beach, northern headland	Feb 01	20 (4 x 1 x 5)	1 m	Natural weathering
6		Oct 96	12 (4 x 1 x 3)	1 m	
7		Nov 96	1 (1 x 1 x 1)	1 m	
8		Apr 05	6 (3 x 1 x 2)	1 m	
9	Whale Beach, southern headland	Aug 98	100 (5 x 4 x 5)	4 m	Natural weathering, triggered by severe rainfall
10		Jan 99	12 (3 x 1 x 4)	1 m	Natural weathering
11		Feb 01	100 (10 x 2 x5)	2 m	Natural weathering/erosion
12	Avalon, southern headland	Nov 95	4 (2 x 1 x2)	1 m	Natural weathering exacerbated by cliff-top access
13	South Mona Vale	May 00	2 (2 x 1 x 1)	1 m	Natural weathering
14		Mar 04	10 (2 x 2 x 2)	2 m	Natural weathering exacerbated by cliff top developments
15		1998	180 (6 x 3 x 10)	3 m	Natural weathering

Note: This table should be read in conjunction with the accompanying text.

It has not been practicable to monitor the full length of the coastal cliff-lines in Pittwater LGA as sea access only would enable the review of some locations. It is further noted that rockfalls from some cliff-lines fall directly into the ocean with no debris preservation to enable quantification or assessment. Variously discernable cliff face scars at some locations have indicated that (unrecorded) rockfall activity has occurred.

The rockfall events listed in Table 1 have been discrete, rapid events. They occurred at locations that were not subject to recent disturbance, that is, excavation or construction activities were not involved.

3 MECHANISMS OF INSTABILITY

The dominant mechanisms of instability that have manifested at the rockfall sites listed in Table 1 may be summarised as follows:

3.1 UNDERCUTTING

As low strength bedding plane seams and less resistant strata such as shale and siltstone, are subject to preferential weathering and erosion with ongoing exposure to the elements, overlying more resistant sandstone beds become undercut. As undercutting advances, the overlying sandstones eventually collapse, due to sudden brittle failures occurring along prevalent rock mass defects that act as release planes. The defect types that combine to facilitate this mechanism include sub-vertical orthogonal joint sets and sub-horizontal bedding plane partings. The size of the resultant rockfall is dependant upon the extent of undercutting and the localised defect spacings.

3.2 TOPPLING

Two regional joint sets characterise the strata in Sydney including Pittwater LGA. They are steeply dipping to sub-vertical and orthogonal and under the effects of weathering, in combination with horizontal bedding plane seams or partings, they can effectively divide an otherwise competent sandstone bed into a series of contiguous blocks or slabs. Dependant on the dip direction of joints and possible influences of creep, these blocks and slabs can be subject to toppling failure. The potential for toppling to develop can be exacerbated by the penetrative growth of the tree roots into open joint plane defects.

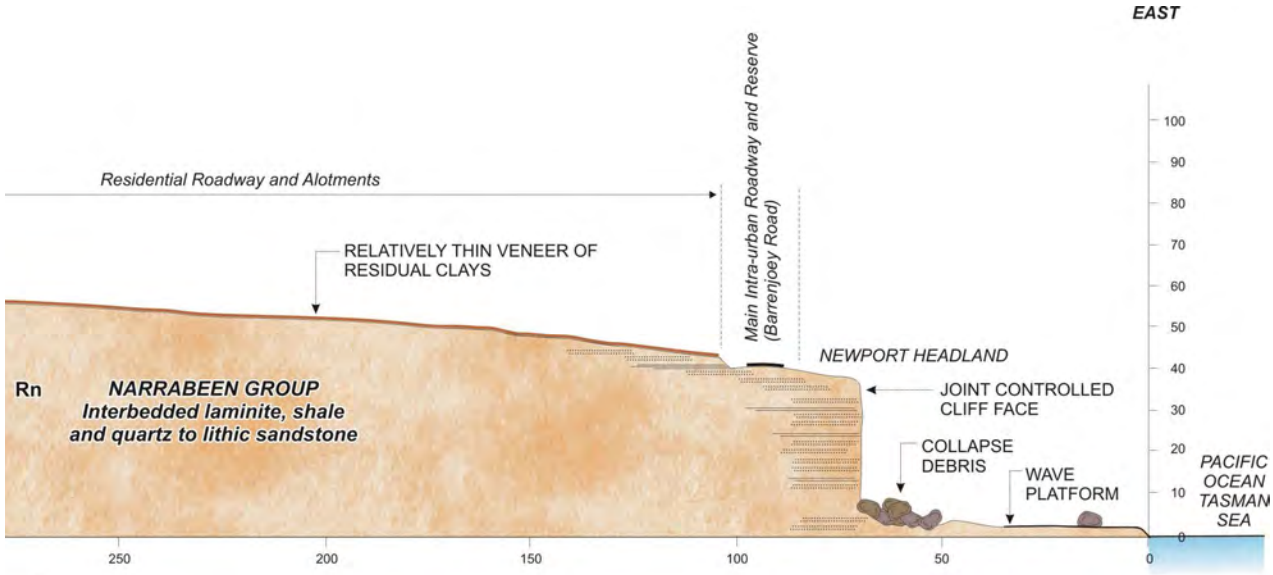

Figure 2: Depiction of typical geological setting of the coastal cliff lines and headland bluffs within Pittwater LGA.

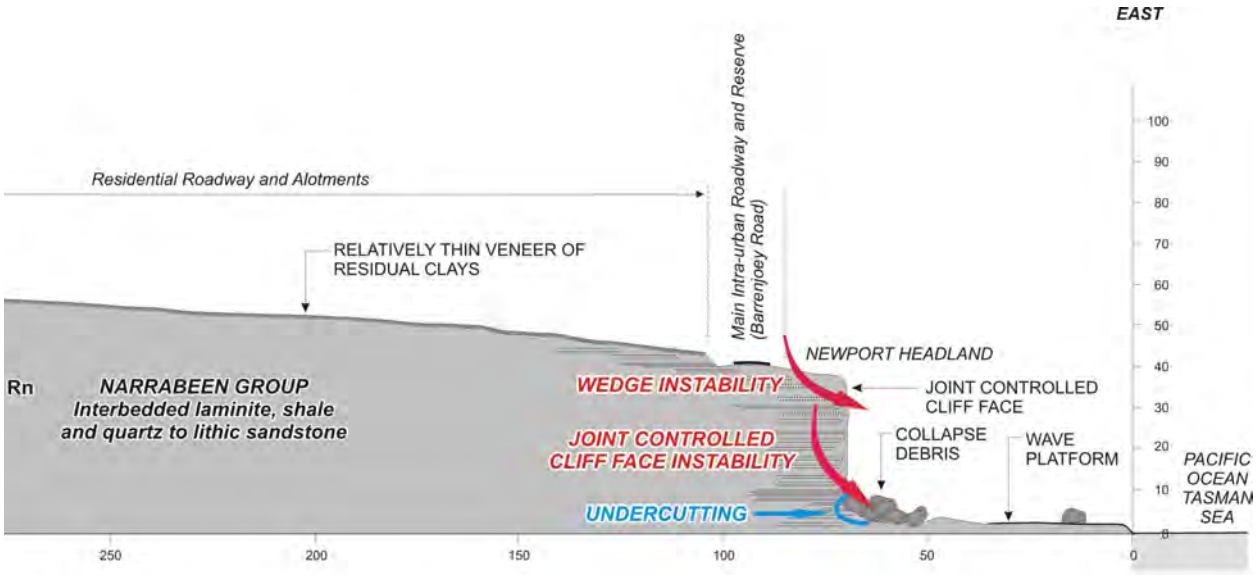

Figure 3: Depiction of typical landslide types within the coastal cliff lines of Pittwater LGA.

3.3 SLIDING

Sliding of rock wedges formed by intersecting joint planes, and/or on weathered cross-bed partings, can result in singular or multiple rock mass failures, particularly when combined with undercutting.

Sliding failures also occur in soil and rock debris/scree accumulations on crestal slopes and cliff-line ledges. The rock masses released during sliding failures can vary in size and number. Sliding failures generally occur during or immediately following wet weather periods.

3.4 DEVELOPMENT INTERVENTION

The naturally occurring failure mechanisms described above can be exacerbated or accelerated by development intervention at or adjacent to the crests of cliff-lines. Activities such as the placement of fill for increased cliff-top access and the direction of stormwater drainage or swimming pool backwash discharges into cliff top environments, has locally contributed to rockfalls from underlying sections of cliff-line.

Figure 4: Photographs of the coastal headland (Newport Formation) between Newport and Bilgola Beaches within Pittwater LGA and some of the rockfall features present.

Note: (Top photograph) Rockfall remediation works designed by the author and undertaken by Pittwater Council immediately above and adjacent to Bilgola Beach Ocean Pool and walkway.

4 ROCKFALL FREQUENCY

The statistics of this study include:

i) Total length of coastal cliff-line and bluffs (excluding Barrenjoey Head: 9,100 m)
ii) Inaccessible / unknown cliff-line length: 2,300 m
iii) Cliff-line sample length: 6,800 m
iv) Assessment period: 15 years
v) Number of rockfalls reported: 15
vi) Total volume of reported rockfalls (rounded): 950 m^3
vii) Total mass of reported rockfalls: 2,375 tonnes
viii) Total width (equivalent cliff-line length) of reported rockfalls (rounded): 60 m

The above data can be manipulated in a number of ways in relation to rockfall frequency, as follows:

- 1 coastal rockfall per annum reported to Pittwater Council
- 0.15 rockfalls per annum per kilometre of coastal cliff-line
- 10m^3 of rockfall volume per kilometre of coastal cliff-line per annum
- 25 tonnes of rockfall mass per kilometre of coastal cliff-line per annum
- 600 mm (lineal) of rockfall per kilometre of coastal cliff-line per annum

In accordance with Reference AGS (2007a) the above data equates with a rockfall frequency at the low end of the "moderate" descriptor (0.1 to 1 rockfalls per annum per kilometre).

5 DISCUSSION

The rockfall frequency data presented above must be regarded as a lower bound indicator, due to the exclusion of rockfalls with a volume less than 1 m^3 and the absence of rockfalls that have gone unreported. It is considered however, that the frequency of the reported rockfalls is also related to geology.

As mentioned above, the Newport Formation comprises the coastal cliff-lines in Pittwater LGA, with the exception of some Hawkesbury Sandstone capping to the north of Avalon. The Newport Formation is an interbedded sequence of sandstone, shale, laminite and carbonaceous shale strata. Whilst the author has not carried out any analyses of the relative percentages of the rock types that make up the Newport Formation, it is observable at many coastal cliff locations that thick sequences of fine grained shale and laminite occur. These strata are subject to progressive fretting and ravelling as regressional mechanisms and small sized weathering products are generally produced. These strata can actively regress through progressive small scale fragmentation, without being obviously noticed by members of the public and without being reported as rockfall incidents to Council. Similarly, a joint controlled failure of a large mass of shale or laminite, will typically result in fragmentation upon impact on an underlying rock shelf or the wave cut platform and again, may not be readily noticed by members of the public or necessarily reported to Council as a rockfall incident. Furthermore, accumulations of small fragments of shale and laminite on the wave cut platform can be readily removed by wave action, thereby resulting in the relatively rapid disappearance of the evidence of the rockfall.

By comparison, the sandstone strata in the Newport Formation can comprise competent beds ranging in thickness to 1.5 m. When these strata fail through the mechanisms that have been described above, large and multiple blocks/slabs of sandstone are generally produced. The sandstone failure masses are large enough to be more readily seen and also to be visually related to a resultant fresh scar at the source location on the cliff face. The strength characteristics of the sandstone failure masses are also such that they are less prone to fragmentation and to short-term destruction by wave action. The sandstone failure masses are therefore more likely to be observed and reported as rockfall events.

It has been the author's experience that sandstone strata have been prominent in the majority of the rockfalls listed in Table 1. The rockfall frequency data presented above may therefore be conservative not only through data limitations, but also by a factor related to the percentage make-up of non-sandstone strata in the Newport Formation.

6 CONCLUSION

The data presented in Table 1 and Section 4 above, represents the available data on coastal cliff-line rockfalls in Pittwater LGA over the last 15 years. For the reasons outlined above, the frequency data presented should be regarded as a lower bound indicator. Ongoing documentation and engineering geological assessment of rockfall events is encouraged by the author, so that frequency data can be refined, through a closer understanding of the relationship between rockfalls and coastal geological models.

7 ACKNOWLEDGEMENTS

The permission of Pittwater Council to present this data is gratefully acknowledged.

Acknowledgment is also given to Andrew Leventhal (Senior Principal Geotechnical Engineer, GHD Geotechnics) for the preparation of Figures 2, 3 and 4.

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Geomorphology is the study of landforms and landform change. The application of geomorphology in engineering and the aims of this book are explained in an excellent opening chapter. The editors aim to present a basic yet authoritative handbook of geomorphology for geotechnical engineers. The book is intended to help geotechnical engineers and others to understand the subject and to appreciate the part that geomorphology and geomorphologists can play in engineering. The editors also stress the importance of first understanding a site in broad context before engaging in detailed investigations and predictions.

The book is divided into three parts. The first part (Chapters 2 to 7) is concerned with the major factors which control the materials, forms and processes on the Earth's surface and includes chapters on climate and weathering, sedimentology, tectonics, stratigraphy and the Quarternary. There is also a chapter on the engineering behaviour of soils and rocks which includes useful information on how the engineering properties of soils are related to their origins. The second part (Chapters 8 to 12) deals with the geomorphological processes which help shape land surfaces and influence their engineering characteristics. There are chapters on landslides, active tectonic environments and seismic hazards, rivers, soil erosion and subsidence. The final part (Chapters 13 to 27) is concerned with various environments and landforms. This is the longest part of the book and includes chapters on glacial environments, hot drylands, savanna, hot wetlands, mountain environments, estuaries and deltas, coastal environments, continental shelves, volcanic landscapes, karst terrains, loess, chalk landscapes and urban geomorphology.

Overall there are 22 different authors, mostly from Britain, but examples are drawn from all over the world. Most chapters are well illustrated with maps, sections, schematic drawings and photographs. Chapter lengths vary from 12 to 47 pages (including references). With so many different authors the approach, content and level of detail vary. Some chapters emphasise applied geomorphology and provide useful case histories while others are more theoretical. In a basic or introductory text book references are particularly important and some of the chapters would have benefited by having more (and more up to date) references.

In their preface and introduction the editors explain that the book is not a text book of geomorphology, that it does not attempt to be comprehensive and is not particularly systematic. They also explain that the main purpose of the book is to act as an aide-memoir, on a world-wide scale, of the many different landscapes in which engineers may find themselves working. In my opinion the editors have achieved their aim. Every chapter contains worthwhile information which will help practitioners understand and anticipate ground conditions and it is an excellent book to browse.

In geotechnical practice, we have to become the experts on the ground conditions wherever we work. Most practitioners in Australia understand how geological knowledge and skills improve their ability to predict, interpret and understand ground conditions. Hopefully this book will help us understand the importance of geomorphology. It is, as the editors explain, a starting point, and while it will not tell us everything we need to know about every site, it will encourage us to read further, and expand our own libraries with other relevant material.

Reviewed by Alan Moon

MANUAL OF SOIL LABORATORY TESTING

VOLUME 1: SOIL CLASSIFICATION AND COMPACTION TESTS

by K H Head, Third Edition (2006)

Published by Whittles Publishing (UK)

Available for A300.00 from:
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Since K H Head first produced his manuals on soil laboratory testing in 1980 they have been an essential reference in all good soil testing laboratories. In these manuals the basic theory and general application of each of the tests is explained clearly and step by step procedures for testing and calculations, together with diagrams and photographs, are given for each of the tests.

The manual covers tests specified in the British Standard on soil testing, BS1377:1990 and also makes reference to some ASTM standards, but is equally useful in explaining soil tests covered within the Australian Standard AS1289. This third edition has been updated to reflect changes in the British Standard and includes some new tests, such as the soil suction test and a section on calibration. The text has been thoroughly reviewed and revised by the author to include additional notes on areas which are often difficult to interpret. It is obvious from the text that the author has an extensive understanding of the details of soil testing and vast experience to draw upon.

This volume covers moisture content, index tests, density, particle size, chemical tests, compaction tests and visual description of soils. Volumes 2 and 3 cover the more specialized tests, such as triaxial testing and it is understood that these volumes are also being updated.

This book should be an essential reference for all engineers and technicians who carry out soil testing and also for those engineers who just use the test results for use in analysis and design. I thoroughly recommend it to anyone who has not come across previous editions. It is very clear in its descriptions of the tests and easy to read. I hope that the new editions of Volumes 2 and 3 are not far behind.

Reviewed by Fiona MacGregor

Sam Mackenzie

Coffey Geotechnics has appointed Sam Mackenzie to the position of general manager – technical development. Sam will be responsible for fostering technical learning and making efficient use of the company's specialist knowledge.

Sam's previous role was as associate geotechnical engineer at Coffey, where he has worked for six years, particularly in the area of mine subsidence risk assessments.

"Acquiring and applying specialist technological knowledge is the fundamental role of Coffey Geotechnics and is our source of competitive advantage and value creation. As the company grows, our collective knowledge and learning potential also grows."

To foster Coffey Geotechnics' technical learning and make efficient use of its knowledge, Sam will focus on three key areas:

- developing dynamic knowledge storage and transfer systems
- engaging in innovation and experimentation in strategic fields
- developing a culture of knowledge sharing across individuals and groups.

Strategic partnerships with universities will play a key role in the company's technical development. Already, partnerships with the University of Sydney and Newcastle University have been established.

"By tapping into the expertise and research capacity of universities we can work towards gaining solutions to challenging real-life problems, ultimately achieving cost-savings for our clients and improving the capability of our industry."

For further information regarding Coffey Geotechnics, please contact Sukumar Pathmanandavel, general manager business development, email: Sukumar@coffey.com.au or phone: 02 9911 1000.

Jay Ameratunga

Dr Jay Ameratunga has recently been promoted to senior principal at Coffey Geotechnics, which is the highest professional grade within Coffey. As senior principal Jay will be a member of the Council of Senior Principals, a high level 'think tank' comprising some of the most technically advanced practitioners in geotechnical engineering in Australia and internationally. The expertise of the Council's members is used as a resource for Coffey Geotechnics and to mentor the company's next generation of leaders.

Jay is a graduate of the University of Ceylon and was granted his Masters in Engineering from AIT in Bangkok, before studying for his PhD with Ian Johnston at Monash University.

Jay has over 30 years of experience as a geotechnical engineer. He has been with Coffey for the past 17 years, initially in Sydney and since 1993 in Brisbane. He has been instrumental in delivering the geotechnical design of the Singapore Circle Line Stage 3, Port of Brisbane Motorway and the gold engineering award winning Future Port Expansion (FPE) Seawall alliance at the Port of Brisbane. He is currently the Geotechnical Manager for the $1.88 billion Gateway Upgrade Project in Brisbane.

Jay has been involved in the design and construction of major infrastructure projects throughout Australia and overseas. He is the chair of the Queensland Chapter of the Australian Geomechanics Society and is on the organising committee of the 2007 Australia New Zealand Conference on Geomechanics.

STANDARDS AUSTRALIA GEOTECHNICAL COMMITTEES - NEW PROJECTS, PUBLIC COMMENT DRAFTS AND PUBLICATIONS.

The following new projects, public comment drafts and publications have been released in the past three months by Standards Australia geotechnical committees. Standards Australia would like to thank the numerous technical experts that have contributed to the development of these standards. Standards Australia is a not for profit organization that develops Australian Standards® of public benefit and national interest.

CE-009 Testing of Soils for Engineering Purposes

The following new reviews have been commenced:

AS 1289 Methods of testing soils for engineering purposes

Project 8291 **AS 1289.3.5.1** (Correction Amendment) Soil classification tests - Determination of the soil particle density of a soil - Standard method

Project 8292 **AS 1289.0** (Review) Methods of testing soils for engineering purposes - General requirements and list of methods

Project 8293 **AS 1289.3.6.3** (Correction Amendment) Methods of testing soils for engineering purposes - Soil classification tests - Determination of the particle size distribution of a soil - Standard method of fine analysis using a hydrometer

Project 8294 **AS 1289.3.9.1** (Review) Methods of testing soils for engineering purposes - Soil classification tests - Determination of the cone liquid limit of a soil

AS 5101 Methods for preparation and testing of stabilized materials

Public Comment closed 19 Jan 2007

DR 06655 **Part 3.3:** Cement content of cement stabilized materials
DR 06656 **Part 2.2:** Sampling - Preparation of stabilized pavement materials
DR 06657 **Part 5:** Absorption, swell and capillary rise of compacted materials
DR 06658 **Part 4:** Unconfined compressive strength of compacted materials
DR 06659 **Part 3.1:** Lime or cement content of uncured stabilized pavement materials (EDTA method)
DR 06660 **Part 3.2:** Lime or cement content of stabilized pavement materials (EDTA method)

AS 1289 Methods of testing soils for engineering purposes – Soil Classification tests

Public Comment and Ballot closed 20 Dec 2006

DR06690CP **Method 3.1.1:** Determination of the liquid limit of a soil-Four point Casagrande method
DR06691CP **Method 3.1.2:** Determination of the liquid limit of a soil-One point Casgrande method (subsidiary method)
DR06692CP **Method 3.2.1:** Determination of the plastic limit of a soil-Standard
DR06693CP **Method 3.3.1:** Calculation of the plasticity index of a soil
DR06694CP **Method 3.3.2:** Calculation of the cone plasticity index of a soil
DR06695CP **Method 3.4.1:** Determination of the linear shrinkage of a soil-Standard method
DR06696CP **Method 3.6.1:** Determination of the particle size distribution of a soil-Standard method of analysis by sieving
DR06697CP **Method 3.6.2:** Determination of the particle size distribution of a soil-Analysis by sieving in combination with hydrometer analysis (subsidiary method)

CE-012 Aggregates and Rock for Engineering Purposes

DR06727 **AS 2758.6** Aggregates and rock for engineering purposes - Part 6: Guidelines for the Specification of Armourstone **Public Comment closed 16 Feb 2007**

Please go to http://www.standards.org.au and then choose Standards Development/Current Drafts to download Public Comment drafts and submit comments. Further information on committees is available from committees.standards.org.au

To receive immediate notification of all items for publication and public comment, go to http://www.saiglobal.com/shop and choose Services, then choose Standards Watch. Other geotechnical engineering related standards committees include BD-025 (Residential Slabs and Footings), CE-015 (Site Investigations), CE-018 (Piling), CE-020 (Geosynthetics), CE-027 (Earthworks) and CE-032 (Reinforced Soils and Retaining Structures).

GEODIARY

Title	Date	Place	Contact
16th Southeast Asian Geotechnical Conference	May 8-11 2007	Selangor Darul Ehsan Malaysia	Dr Ooi Teik Aun Email: 16seagc@iem.org.my Website: www.16seagc.com
3rd International Geomechanics Conference -The role of geomechanics in the stability of development of mining industry	June 11-15 2007	Nessebar, Bulgaria	Prof.D.Sc. Eng. Nikolai Nikolaev Web site: www.confgeomech.info E-mails: geomechanics@abv.bg conf_geomech@yahoo.com
4th CECAR Conference	June 2007	Taipei, Taiwan	Website: www.elitepco.com.tw/4cecar
XIII Panamerican Conference on Soil Mechanics and Geotechnical Engineering	July 16-20 2007	Isla de Margarita Venezuela	Isaura Romero Requena Website: www.xiiicpmsig.org
11th Congress of the ISRM	July, 2007	Lisbon, Portugal	Conference Secretariat Email: isrm2007@lnec.pt
1st Sri Lankan Geotechnical Society International Conference on Soil and Rock Engineering	August 7-11 2007	Colombo Sri Lanka	Prof P Kulatilake Website: www.slgssr2007.org
10th Australia New Zealand Conference on Geomechanics "Common Ground"	October 21-24 2007	Brisbane, Queensland	Website: www.anzgeo2007.com
International Symposium on Geotechnical Engineering, Ground Improvement and Geosynthetics for Human Security and Environmental Preservation	December 6-7 2007	Bangkok, Thailand	Prof. Dennes T. Bergado Email: bergado@ait.ac.th
12th ICAMAG Conference	February –March 2008 or October November 2008	Goa, India	Dr D.N. Singh E-mail: dns@civil.iitb.ac.in
VI International Symposium Geotechnical Aspects of Underground Construction in Soft Ground	April 10-12 2008	Shanghai, China	Website: www.tc28-shanghai.org
10th International Symposium on Landslides and Engineered Slopes	June 30-July 4 2008	Xian, China	Zuyu Chen Email: chenzy@iwhr.com Website: landslide.iwhr.com
Sixth International Conference on Case Histories in Geotechnical Engineering	August 11-16, 2008	Arlington, Virginia (USA)	Website: http://www.6icchge2008.org
BAPV 5th International Geotechnical Seminar"Deep Foundations on Bored and Auger Piles"	September 8-10 2008	Gent, Belguim	Karla.Crombeen@UGent.beLinda.VanCauwenberge@UGent.beHilde.DeCooman@UGent.be

EDITORIAL POLICY

Australian Geomechanics is published quarterly, in March, June, September and December, by the Australian Geomechanics Society. The magazine is edited and produced by the Australian Geomechanics Society. It provides a journal and news magazine for matters of interest to the Australian geotechnical community. The statements made or opinions expressed do not necessarily reflect the views of the AGS.

The Editorial Panel of Australian Geomechanics seeks contributions for future editions. The following comments are offered to assist would-be contributors.

Contributions can include: refereed technical papers; technical papers or notes; or news items and reports.

Technical papers can be refereed to ensure that they are of a standard similar to those published in international geotechnical journals. Authors should aim for a maximum overall length of no more than 3500 words, although shorter papers or technical notes are particularly welcome. Authors should indicate if they want their submission to be refereed; the status of the paper will be indicated on publication.

Refereed technical papers should be original and:

- Papers on geotechnical engineering, engineering geology and environmental geomechanics. Papers should be topical, practically oriented and preferably of national interest. Case studies describing innovative geotechnical work are particularly encouraged.
- Papers on geotechnical or geoscience research undertaken in Australia or of relevance to Australian geomechanics. These should clearly indicate their practical relevance and limitations.
- Authoritative reviews of aspects of geotechnical practice or aspects of geotechnical education.

Technical papers or notes can be:

- Items as above but submitted for rapid publishing. These will not be refereed but will be reviewed. They will be accepted at the discretion of the editorial panel. The intention is to provide a source for rapid dissemination of technical material to the geotechnical community.
- Discussions on papers published in previous editions.

News items and reports can be:

- Items describing significant projects, instructive failures, conferences, courses or other matters of general interest to the Australian geotechnical community.
- Geotechnical book reviews.
- Letters to the Editor.

It is preferable for contributors to submit formatted text, tables and figures in electronic format using Microsoft Word on IBM compatible hardware. Contributions by CD are preferred. Submission of large papers by email should be avoided. **All contributions should be followed by a hard copy.**

Submitted material should be presented in the following format:

- Single column format on A4 paper.
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FIGURES AND TABLES

Where possible figures and tables should be placed at the correct position in the text. Figures should be scanned. Failing this place them together at the back of the text. These should be sharp black on white and of the correct size for incorporation into the finished document. The width of these must be less than or equal to the width of the text column (165 mm). Do not use colour unless you have discussed it with the editor.

Photographs should preferably be good contrast black and white gloss prints and of the correct size for incorporation directly into the copy. Please ensure that all such items are clearly marked to indicate position in paper.

Authors will remain responsible for the integrity of their material and for permission to publish.

Material will be accepted at any time and published in the next available issue.

EDITORIAL CONTACTS

Contributions and other correspondence should be forwarded to:

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The Editor is Patrick MacGregor, and the Editorial Panel consists of the representatives of the State Chapters.

All members of the AGS National Committee have defined roles in providing papers and reports. Contributors are encouraged to liaise with their State Representatives. Contact details for these are listed in this issue.

ADVERTISING RATES

Every three months, Australian Geomechanics reaches more than 1000 professional geotechnical engineers and engineering geologists spread throughout Australia. Most of these are associated with significant site investigations, construction and computer analysis. So Australian Geomechanics provides a very targeted delivery for advertising.

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Inserts into an individual mail-out of Australian Geomechanics can be accepted at a minimum charge of $1100 (including GST).

Advertising queries should be addressed to: Sara Lanesman, Email: **lanesman@optusnet.com.au**

Australian Geomechanics Society

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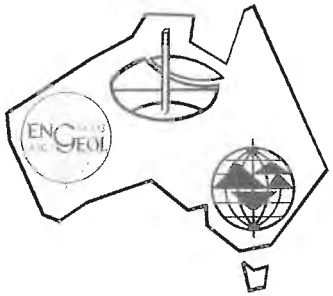

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Australian Geomechanics Society

Geomechanics is the application of engineering and geological principles to the behaviour of the ground and groundwater, and the use of these principles in civil, mining, offshore and environmental engineering in the widest sense.

The Australian Geomechanics Society, founded in 1970, has roots that go back to 1953. It exists under the joint sponsorship of the Institution of Engineers Australia and the Australasian Institute for Mining and Metallurgy, to provide programs of activities, technical conferences, symposia and meetings designed to stimulate, educate and inform all those with an interest in the field. Such activities occur both nationally and through its many active chapters located around Australia.

The Society provides its members with four issues of the journal, *Australian Geomechanics*, each year and offers membership of the international societies for soil mechanics and geotechnical engineering (ISSMGE), rock mechanics (ISRM), and engineering geology and the environment (IAEG) as required.

The Society is run by its members for its members and enthusiastic involvement is encouraged.

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Australian Geomechanics Society

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Activities in Geomechanics

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Name of Tertiary Institution | Full time study at Tertiary Institution **YES / NO**

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I declare that the information given above is correct. I hereby apply for membership of the Australian Geomechanics Society and agree to be bound by the Constitution of the Society as now in force or as amended from time to time.

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