Townsville City Council

NATURAL DISASTER RISK MANAGEMENT STUDY
CONTRACT T5631
LANDSLIDE HAZARD STUDY

Report PSM1672-004R – 31 August 2011

EXECUTIVE SUMMARY

This report results from a commission by Townsville City Council (TCC) to Pells Sullivan Meynink (PSM) to conduct a regional landslide study of selected urban and rural areas of Townsville. The work was commissioned under Contract T5631 Landslide Hazard Study which forms one of a series of contracts commissioned by TCC to fulfil the requirements of a Natural Disaster Risk Management program sponsored by the Federal, State and Local Governments.

The objective of Contract T5631 is to conduct landslide studies over future growth areas of Townsville (referred to as Category 1 study areas) as well as several road corridors which provide emergency access and evacuation routes servicing Townsville (Category 2 study areas). Category 3 study areas include a re-visit of mainly urban growth areas which have been previously covered by a 2001 regional landslide study to assess any changed conditions.

Contract T5631 is concerned only with the assessment of natural slope instability and specifically does not address the landslide risk associated with constructed slopes which may be formed as part of development.

The study areas are identified as:

- Category 1: Paluma Village, Toomulla, Mount Low, Jensen/Kulburn (Seaview Park Subdivision), Deeragun (Innes Estate Subdivision), and Mount Elliot/Alligator Creek.
- Category 2: Paluma Road (also known as Mount Spec Road), Bruce highway at Rollingstone, and Hervey Range Road.
- Category 3: Castle Hill (Yarrawonga Subdivision), Mount Louisa (Ocean View, Crestbrook, Greenview Subdivisions), Douglas (Riverside Ridge), Wulguru/Roseneath (Wulguru Heights Subdivision), and Oak Valley.

Contract T5631 has used the landslide risk assessment methodology detailed in State Planning Policy (1/03) and followed the process of the Australian Geomechanics Society Landslide Risk Management Document (2007).

Townsville has been impacted by a range of slope instabilities mainly in response to wet season heavy rainfall and tropical cyclone events, including:

- Shallow slumping (generally confined to the near surface regolith).
- Rockfall (associated with rock outcrops).
- Rock roll (associated with rock outcrops).
- Debris flows - which are sediment-laden flood surges. A similar phenomenon described as debris torrent is a flood surge which lacks significant accompanying sediment which is considered to be a hydrological rather than a geological hazard.

Category 1 areas are typically impacted (where instability occurs) only by shallow slope instability, rock roll and localised rock fall. No evidence for deep-seated or large-scale slope instability was observed, no evidence was observed for debris flows. We conclude that the Category 1 areas have a “very low” and “low” landslide risk which, according to the Australian Geomechanics Society (2007), is an acceptable risk generally not requiring landslide mitigation. A series of landslide overlay maps have been produced for the Category 1 areas which provide suburb-scale landslide risk zoning plans for the purposes of land use planning.

Paluma Road (Category 2) has a long and well-established history of landslide activity over its alignment and annually between five (5) to 10 landslides occur in response to severe rainfall, some of which result in road blockage. At least one fatality on Paluma Road has been recorded which occurred in 1997. Either significant engineering physical works are required to mitigate the landslide hazards or an alternative access route should be identified to provide access to Paluma village during road outages.

Hervey Range Road (Category 2) is only rarely closed from landslide activity. We understand there have been no road closures in the last 5 years. There is some ongoing potential for slumping, rockfall and debris flows and associated road closure from rare, large rainfall events but frequency is unknown.

The Bruce Highway and Council pipeline at Rollingstone are considered to be at very low potential to be influenced by landslide and rock roll hazard. A small section of Council’s pipeline crosses the toe of the slope and is considered to be within a low rock roll hazard zone. No mitigation measures are considered necessary.

We have re-assessed the Category 3 areas identified for this study and conclude that the findings of the 2001 study are appropriate.

A Landslides Hazards code is proposed to govern any development occurring on land or part of any land containing steep slopes. The code applies to any development being self, code or impact assessable in the Table of Development in the Zone or Local Area Plan (LAP). The code applies to any development:

- Category 1 areas covered by this report (PSM, 2010);
- All areas covered by the TCC Landslide Hazard Overlay Maps (which are based on the 2001 regional landslide hazard study (Reference 1);
- Any sloping area not covered by either this report or the TCC Landslide Hazard Overlay Maps.

Performance Criteria apply to the Landslides Hazards code for all code and impact assessable development.

The influence of possible climate change on landslide risk has been assessed. Other than a possible increase in the number of severe cyclones which may occur over the next 60 years or so, climate change is unlikely to be a factor which will significantly alter the landslide risk of Townsville.

Minor improvements to the Townsville Local Disaster Management Plan are recommended including improved referencing of landslides as a weather-related hazard within the Plan, and the provision of emergency evacuation routes for rural areas such as Paluma village and Alligator Creek/Mount Elliot.

It is recommended that Australian GeoGuides LR3, LR4, LR5, LR6, LR8 and LR9 as produced by Australian Geomechanics Society (2007) be adopted by Townsville City Council as guidelines for use as landslide mitigation options for implementation as part of any hillside development.

This report was originally submitted to TCC on 15 March 2011 at which time it was referenced as PSM1463.100R. Subsequent to submission of report PSM1463.100R, TCC's City Planning Unit requested PSM to conduct further work to integrate landslide overlay maps of various generations to form new landslide overlays for use with TCC's new City Plan. This report which is now referenced as PSM1672-004R contains – in addition to the contents of the original report referenced as PSM1463.100R - a new Addendum section (Section 10) which details the work carried out to integrate landslide overlays of various generations. A new series of landslide overlays has been prepared to support TCC's Steep Lands Code of the proposed new City Plan which integrates data from three existing sources:

- TCC's Steep or Unstable Land Overlays from the existing City Plan dating from 2001.
- Townsville Steep Slope Risk Assessment Overlay which derives from a 2004 study of Castle Hill.
- PSM's Landslide Risk Assessment Overlays (derived from PSM1463.100R).

As well, the Landslide Hazards code which was prepared as part of PSM1463.100R has been updated in the Addendum section of this report to reflect the new landslide overlays for use with the new City Plan.

Shapefiles have been prepared for incorporation into TCC's Enterprise GIS which reflect the new landslide overlays.

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1. INTRODUCTION

This report results from a commission by Townsville City Council (TCC) to Pells Sullivan Meynink (PSM) to conduct a regional landslide study of selected urban and rural areas of Townsville. The work was commissioned under a publically contestable Contract identified as T5631 Landslide Hazard Study which forms one of a series of separate contracts commissioned by TCC to fulfil the requirements of a Natural Disaster Risk Management program sponsored by the Federal, State and Local Governments.

This report was originally submitted in final form to TCC on 15 March 2011 at which time it was referenced as PSM1463.100R. Subsequent to submission of report PSM1463.100R, TCC's City Planning Unit requested PSM to conduct further work to integrate landslide overlay maps of various generations to form a new integrated landslide overlay for use with TCC's new City Plan. In order to preserve the integrity of the original PSM study (i.e. report referenced as PSM1463.100R dated 15 March 2011), a new Addendum section has been added to the original report which details the work carried out to integrate landslide overlay maps of various generations, which is included as Section 10 of this report. Report PSM1463.100R plus the new Addendum form the contents of this report which is referenced as PSM1672-004R.

2. BACKGROUND AND WORK PROGRAM

2.1. Background

In 2001 TCC commissioned a regional landslide study of selected areas of Townsville City to provide information on the risk of instability of natural slopes which Council could use to assist with preparing guidelines for future development of the Townsville area (referred to hereafter as the **2001 regional landslide study**; Reference 1). The 2001 regional landslide study was commissioned mainly in response to a number of landslides initiated by a January 1988 storm which affected Magnetic Island, as well as Tropical Cyclone Tessa of April 2000 which impacted the Castle Hill and inner city areas.

The 2001 regional landslide study areas included Townsville City, Magnetic Island (outside the National Park), Castle Hill, Mount Louisa, Mount Stuart, Wulguru, Rocky Springs, Valhalla, Oak Valley, Mount Jack, Muntalunga Range, the Sisters Mountains, Roseneath and Middle Sister Mountain (Reference 1). The 2001 regional landslide study provided maps for these areas delineating landslide hazard levels. The study was limited to the identification of natural slope instability meaning that it did not consider the instability of modified slopes attributable to the influence of human activities such as excavated batters and filling formed by earthworks (hereafter referred to as **constructed slopes**).

The results of the 2001 regional landslide study are given on a series of TCC Landslide Hazard Overlay Maps which form part of the City Plan (hereafter referred to as the **TCC Landslide Hazard Overlay Maps**). The 2001 regional landslide study was identified by TCC as being the first stage of several regional landslide studies to provide guidelines for future development of the Townsville area. The current study (Contract T5631) is the second regional landslide study commissioned by TCC. Contract T5631 is similarly also concerned only with the assessment of natural slope instability and specifically does not address the landslide risk associated with constructed slopes formed as part of subdivision development.

2.1.1. Objectives

The regional landslide risk assessment study presented in this report (Contract T5631) is mainly intended to provide further coverage of the Townsville area to support strategic planning in response to future city growth. Thus, the intention is that the study area includes future growth areas as well as road corridors which provide emergency access and evacuation routes servicing Townsville.

Specific objectives of Contract T5631 are to provide:

- Improved knowledge of the landslide and debris flow hazards and risks for selected areas of Townsville City by means of landslide hazard mapping and the assessment of landslide risks.
- Recommendations of development constraints.
- Risk assessment maps for inclusion in the city planning scheme.
- New planning provisions and codes to support the new City Plan for Townsville City and rural areas covered by the former City of Thuringowa.

2.1.2. Deliverables

Contract T5631 (Appendix A) specifies that a final report is to be prepared for TCC using the following document as a reference: *"Natural Disaster Risk Management: Guidelines for Reporting" 2001, Queensland Department of Emergency Services"* (Reference 2).

As well, the final report is to be accompanied by a series of landslide risk overlay maps of the study areas in an electronic spatial format suitable for inclusion into TCC's Enterprise GIS.

2.1.3. Previous Work

The 2001 regional landslide study (Reference 1) arose out of the realisation by TCC that Townsville is at potential risk from landslide hazards, mainly as a result of extreme rainfall events such as Tropical Cyclone Tessi which struck the city on 3 and 4 April 2000. Specific instability events which have been identified for Townsville include:

- 1976 landslide on Castle Hill above Jones Street, following heavy rainfall (Reference 1).
- January 10th 1988 rainfall caused a debris flow at Mandalay Avenue, Nelly Bay on Magnetic Island which was triggered by ex-tropical cyclone Sid (Reference 3).
- Cyclone Tessi of 3rd and 4th April, 2000 triggered instability on the slopes of Castle Hill and inner city areas including shallow sliding in residual and colluvial soils, boulder falls and rolls, debris flows and rock fall. Remedial works were subsequently carried out for specific instability sites (References 4 to 10).

- Rock falls in a steep rock cutting at Sturt Street in December, 2000 and March, 2002 (Reference 11).
- Rock falls in the steep rock face near the waterfall on the Strand (References 4 and 10) and a rock slide in the slope above Eyre Street (Reference 12) following heavy rain.

In 2004, TCC commissioned a slope stability study of Castle Hill and other inner city rock slopes (Reference 13). This work included an assessment of boulder movements, debris flows (17 potential flow paths identified), rock falls from steep rock faces, and instability of excavated cuttings and engineered fills on Castle Hill Road and several inner city rock cuttings.

In addition to the obvious cluster of slope instability hazards on Castle Hill and other inner city steep rock slopes, small to medium-sized landslides and debris flows have been identified in the following localities (Reference 1):

- Magnetic Island (Nelly Bay, Horseshoe Bay, Bolger Bay).
- Mount Stuart (eastern area of Mount Stuart north of Mount Stuart Road).
- Muntalunga Range (Sunmetals access road, Oolbun access road, north side of Muntalunga Range).
- Roseneath (north of the quarry entrance).
- Middle Sister Mountain (isolated steep slopes).

The Paluma Road (also known as Mount Spec Road) which provides access from Bruce Highway to Paluma village has a history of being periodically cut by landslides during high rainfall events. Specific instability events which have been recorded on this road include:

- Cyclone Justin of 23rd March 1997, which caused multiple slips and rockfalls, closed Paluma Road and caused one fatality when a woman got out of her car to clear a windblown branch and was engulfed by a landslide from above the road (reported on Emergency Management Australia (EMA) website and Reference 14).
- Cyclone Sid of 10th January 1998, which closed Paluma Road for several days (reported on EMA website).
- Rockfall on 13 January 2004 which temporarily closed the road (Reference 15).

Hervey Range Road, which provides access to Townsville from the west, is apparently rarely closed by landslides. For example, no road closures have been recorded for the last 5 years, according to TCC road maintenance personnel. Cyclone Sid of 10th January 1998 is understood to have triggered rockslides which closed the road for several days (reference EMA website).

2.2. Scope of Work

Three distinct elements of work are identified in the Scope of Work for Contract T5631:

- Category 1.
- Category 2.
- Category 3.

2.2.1. Category 1

Category 1 areas have been identified by TCC as future growth areas of Townsville that require detailed assessment on the degree of risk posed by landsliding to future and existing developments and posed planning scheme constraints. The scope of work required under Category 1 includes:

a) *Identification and assessment of:*

- *Landslide hazard and debris threats to existing and future residential and rural residential properties and emergency access/evacuation routes;*
- *Landslide hazard areas where new development has occurred;*
- *Elements at risk and their vulnerability to the threat;*
- *The influence of climate change on the landslide hazard threat and*
- *The risks associated with the hazard threat;*
-

b) *Recommendations for*

- *Improvement of the Planning Scheme on:*
  - *land use outcomes;*
  - *assessable developments;*
  - *assessment categories and applicable codes and*
  - *land uses to be exempt, self, code or impact assessable.*
- *Improvement to the Local Disaster Management Plan and*
- *Landslide mitigation options.*

c) *Production of maps of the identified landslide hazard risk areas and zones.*

2.2.2. Category 2

Category 2 areas are mainly rural road corridors - not within the urban growth boundaries - where it is considered there is a potential for landsliding to interrupt emergency service access. The scope of work for this study Category is limited to the identification of landslide locations and extent of landslides.

As well as the identification of landslide hazards in relation to road corridors, the scope of work requires an assessment of climate change on the landslide hazards.

2.2.3. Category 3

The scope of work comprises reassessment of existing landslide zones 2, 3 and 4 (Reference 1) to identify any changed conditions that may affect the risk level and vulnerability of elements. The existing landslide zones 2, 3 and 4 are included in the TCC Landslide Hazard Overlay Maps. If any changed conditions are identified these areas are to be reassessed using the criteria and outcomes described for Category 1 above.

2.2.4. Identification of Study Areas

Table 2.1 provides details of the Category 1, 2 and 3 study areas which were agreed with TCC and Figure 1 shows their individual locations. The Category 3 study areas have been delineated by TCC on a series of aerial photographs, as presented in Appendix G. Relevant geotechnical reports provided by TCC for the study areas are also listed in Table 1.

TABLE 2.1
SUMMARY OF STUDY AREAS INCLUDED UNDER TENDER T5631

CATEGORY	LOCALITY	INFORMAL (SUBDIVISION) NAME IF KNOWN	INCLUDED AS PART OF TENDER T5631	COMMENTS	RELEVANT GEOTECHNICAL REPORTS
Category 1 Study Area	Paluma township		Yes	Possible future peripheral development on gently sloping range top slopes.	
	Toomulla		Yes	Existing beach side development with some infill potential. Two site inspections by PSM have identified no stability issues.	
	Mount Low	Bushland Beach Estate and Kingston Park Estate	Yes	New density intensity residential development on gently to moderately inclined slopes.	Reference 16 Reference 17
	Jensen/Mt Kulburn	Seaview Park Subdivision	Yes	Minor acreage development land on gently to steeply inclined slopes.	
	Deeragun	Innes Estate Subdivision	Yes	Undeveloped potential residential area containing existing industrial estate and quarry at east end of study area.	
Category 1 - additional scope of work.	Mount Elliot/Alligator Creek		Yes	Existing acreage development on gently to steeply inclined slopes.	
Category 2	Paluma Road	Mount Spec Road	Yes	Approximately 17km of narrow windy rural road constructed by cut to spill earthworks in the 1930's to1940's providing access to Paluma township. Maintained by TCC.	Reference 14 Reference 15
	Hervey Range Road		Yes	Approximately 5km of Highway A6 traversing the range front and providing access between Townsville and Charters Towers. Maintained by Department of Main Roads (TMR).	
	Bruce Highway	Rollingstone	Yes	Approximately 500m of Highway A1 at Rollingstone	
Category 3	Castle Hill	Yarrawonga Subdivision	Yes (Yarrawonga subdivision only)	There has been limited new residential development on Castle Hill since completion of the 2001 Coffey reporting.	Reference 1 Reference 13
	Mount Louisa	Ocean View, Crestbrook and Greenview Subdivisions	Yes	Existing and future residential developments.	Reference 1 Reference 18 Reference 19 Reference 20 Reference 21
	Douglas	Riverside Ridge Subdivision	Yes	New residential development. Area has a history of erosion problems during site development.	Reference 1 Reference 22
	Wulguru, Roseneath	Wulguru Heights Subdivision	Yes	Some new residential development identified.	Reference 1
	Oak Valley	Oak Valley	Yes		Reference 1

3. STUDY METHODOLOGY

3.1. Investigations

This section of the report provides details of the investigations undertaken to fulfil the study brief.

3.1.1. Review of Existing TCC Geotechnical Reporting

TCC made available geotechnical reports for sites relevant to the individual study areas (Table 2.1) and for previous specific landslides in Townsville. The reviewed geotechnical reports can be categorised under three broad headings:

- Regional slope stability studies (2001) including TCC Landslide Hazard Overlay Maps (Reference 1).
- Geotechnical reporting on sites affected by specific slope instability events particularly the Castle Hill and inner city areas and Paluma Road (References 3 to 15).
- Geotechnical reporting for development purposes on individual subdivisions or lots which form part of the study areas (References 16 to 22).

3.1.2. Consultation with Road Authorities

PSM conducted discussions with the following road authorities who have responsibility for the road corridors forming Category 2 sites:

- Department of Main Roads and Transport (TMR) (Townsville) who have statutory responsibility for the Bruce Highway at Rollingstone and Paluma Road.
- Roadtek (Townsville) which is the contracting division of TMR who have responsibility for maintenance of the Bruce Highway at Rollingstone and Paluma Road.
- TCC road department who have responsibility for maintenance of Hervey Range Developmental Road.

The road authorities provided anecdotal data on the location and types of landslide hazards affecting the various roads and the frequency of slope instability.

3.1.3. Aerial Photograph Interpretation

Geospatial Solutions Department of TCC provided PSM with digital orthophotos of Townsville which allowed us to view the study areas as a series of overlapping vertical colour aerial photographs with the use of a stereoscopic instrument. This technique allows surface relief to be enhanced and aids the identification of active processes such as landslides. Features that were recorded from aerial photograph interpretation included:

- Gullies,
- Ridges,
- Spatial extent of catchments,
- Rock outcrops,
- Changes in vegetation, and
- Evidence of instability including indications of deep seated failures or shallow sliding/ slumping.

Selected oblique aerial photographs of Townsville were also provided.

3.1.4. Digital Data and GIS Modelling

Geospatial Solutions Department of TCC provided PSM with digital data coverage of the study areas which includes the following attributes: 2009 topographic (lidar) data, Geoscience Australia contours, roads, suburbs, drainage, land parcels, water, wastewater, stormwater, 2001 regional landslide hazard zones, geology, and soils.

These data were used to generate a series of base maps of the study areas including:

- Contours maps showing land parcels and infrastructure.
- Slope angle maps.
- Geology and soils maps.

3.1.5. Site Inspections

Site inspections of the study areas were conducted by two PSM engineering geologists over a 10 day period between 24 June and 4 August 2010 to confirm data from the aerial photograph interpretations (Sections 3.1.3). Mapping of geomorphology and inferred slope processes was also undertaken in accessible parts of the study areas.

Mapping information was obtained by traversing the study area and recording data onto the field mapping sheets (Section 3.1.4). Some in-accessible areas were inspected with binoculars from suitable vantage points. Engineering geology and geomorphology features of interest included:

- Small and large-scale instability features (landslides, slumps, scarps, scars, debris mounds, hummocky ground, transported boulders).
- Slope angles.
- Streams and major flow paths.
- Outcrops (lithology, rock roll source).
- Soil thickness and coverage.
- Interaction of topography and inferred slope processes.
- Existing slope instability remediation measures.

3.1.6. Data Reduction and Interpretation

Factual data collected from the site inspections was used to compile factual landslide hazard maps and subsequently for the assessment of landslide hazard analysis and landslide risk using the methodology detailed in Section 3.2.

3.2. Landslide Risk Assessment Methodology

3.2.1. Methodology

1. **Queensland State Planning Policy**

The landslide risk assessment to be carried out for Contract T5631 is required to follow the methodology of State Planning Policy (SPP) 1/03 guidelines. Of particular relevance to this study, Outcome 4 of the SPP requires natural hazard management areas (landslide) to be identified in planning schemes. Natural hazard management areas (landslide) trigger the development outcomes and development assessment requirements specified in outcomes 1 and 2 of the SPP and are also required to develop planning strategies and detailed measures required by Outcomes 5 and 6 of the SPP.

The SPP is flexible in the methodology to be used for carrying out a landslide hazard assessment which should be tailored to the local conditions of the area under consideration.

2. **Australian Geomechanics Society**

The methodology adopted for Contract T5631 is also required to be in compliance with and follow the process of the Australian Geomechanics Society (AGS), 2007. The following extract is from Reference 23 which provides a background to the development of the AGS landslide risk assessment methodology.

"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 recognized 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* (Reference 24)*, and another for slope management and maintenance (the latter now known as the Australian GeoGuides)* (Reference 28) *and*
> *iii) development of a practice note* (Reference 26)*.*

In addition to the guidelines, two commentaries have been developed to provide further explanation to the Landslide Zoning guideline and the Practice Note (References 25 and 27).

The guidelines, their accompanying commentaries, Australian GeoGuides and technical papers are listed in (Table 3.1). *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."

3.2.2. Definitions

The terminology used in this study is the same as that used by AGS, 2007(c) (Reference 16).

- ***"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.*
- ***Landslide.*** *The movement of a mass of rock, debris, or earth (soil) down a slope**.***
- ***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.*

TABLE 3.1
NDMP LANDSLIDE RISK MANAGEMENT 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 Guidance	AGS (2007a) (Reference 24)	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) (Reference 25)	As above
“Practice Note guidelines for landslide risk management”, *Australian Geomechanics*, Vol 42 No 1, March 2007.	Practice Note 2007	AGS (2007c) (Reference 26) (Reproduced in Appendix B)	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) (Reference 27)	As above
“Australian GeoGuides for slope management and maintenance”, *Australian Geomechanics*, Vol 42 No 1, March 2007.	Australian GeoGuides	AGS (2007e) (Reference 28)	General Public, Regulators, Geotechnical Practitioners

- ***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 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.*

- ***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 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 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".*

3.2.3. Landslide Risk Management Framework

The framework which has been adopted for use on Contract T5631 is illustrated schematically in Figure 2 which is from AGS 2007(c) (Reference 26).

The processes followed for the risk analysis component of this study included:

- Assessment of landslide hazard,
- Assessment of landslide consequence, and
- Assessment of landslide risk for the identified study areas.

The methodology of these processes is described in more detail in the following sections.

3.2.4. Landslide Hazard Assessment

The assessment of landslide hazard for the study areas has comprised:

1 Formulation of a Landslide Inventory

This included compiling evidence for previous landslides using:

- Aerial photograph interpretation,
- Historic records and discussions with local residents/ road maintenance personnel, and
- Field mapping.

This information was collated and identified landslides where characterised by:

- Location,
- Landslide type,
- Inferred volume and travel distance, where relevant,
- State of activity (active or relic), and
- Inferred date of occurrence.

2 Landslide Susceptibility Zoning

The landslide inventory was used in combination with geological experience and observations during site visits to make a qualitative assessment of the susceptibility of different geomorphological and geological environments to landsliding. This assessment is based upon:

- Knowledge based expert judgement including:
  - Professional experience,
  - Professional expertise, and
  - Understanding the general mechanical principles of the observed landslide types.
- The concept of "the past and present are guides to the future" by Varnes 1984 (Reference 30) which leads to the assumption that:
  - *"It is likely that landsliding will occur where it has occurred in the past, and*
  - *Landslides are likely to occur in similar geological, geomorphological and hydrological conditions as they have in the past."*

Qualitative assessments were also made on the potential volume, velocity and intensity of landslide types in different environments.

3 Landslide Frequency Assessment

The collated data was then used to make an assessment of landslide frequency for the identified landslide types in the various geological and geomorphological environments in the study areas. Due to the limited historical records of landslide events in the Townsville area this assessment was qualitative only.

4 Landslide Hazard Zoning

Following the above assessments, landslide hazard zones were then delineated for the study areas, adopting the recommended descriptors from AGS 2007(a) (Reference 24) as outlined in Table 3.2.

TABLE 3.2
LANDSLIDE HAZARD DESCRIPTORS

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 of 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	$<10^{-6}$

3.2.5. Landslide Consequence Assessment

The elements at risk need to be considered when assessing the landslide risk. The Category 1 study areas include a mix of land use types including residential, environmental, park land, large lot, tourism, commercial, rural, natural areas, mixed use and community (Appendix C).

For the purposes of this study PSM have assumed that the Category 1 areas may be entirely developed in the future and have based the consequence assessments on traditional residential density development over the entire study area.

It is considered that there is the potential (however small) that a landslide may cause loss of life.

The potential consequence to property, where assessed, has followed the recommended descriptors outlined in AGS 2007(a) (Reference 24) (Table 3.4).

3.2.6. Landslide Risk Assessment

The landslide risk assessment methodology for this study is in accordance with AGS 2007(a) (Reference 24) and AGS 2007(c) (Reference 26). Risk is assessed by evaluating the landslide hazard and assessing the potential consequence of that hazard occurring.

AGS 2007(a) (Reference 24) states that if loss of life is considered a possible consequence then a quantitative risk assessment should be undertaken. The recommended risk zoning descriptors using loss of life criteria are outlined in Table 3.3.

TABLE 3.3
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

For property loss risks the risk matrix and terms in AGS 2007(c) should be used, as outlined in Table 3.4.

TABLE 3.4
RECOMMENDED DESCRIPTORS FOR RISK ZONING USING PROPERTY LOSS CRITERIA

LIKELIHOOD		CONSEQUENCES TO PROPERTY (WITH INDICATIVE APPROXMATE 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.

3.2.7. Tolerable Risk Levels

AGS (2007b) (Table C1 in Reference 25) outlines acceptable and tolerable risk to life criteria for various international and Australian organizations. These risk levels vary from 10^{-3} per annum to 10^{-7} per annum. The Australian Geomechanics Society guidelines for risk management (2002) suggest a tolerable risk to life for the person most at risk from instability of existing slopes of 10^{-4}. This level has been adopted for the purposes of risk calculations in this study.

4. CHARACTERISTICS OF THE TOWNSVILLE AREA

4.1. Population

The population of Townsville City Council currently stands at approximately 180,000 (sourced from TCC website). This is expected to increase to approximately 220,000 by 2016 and to approach 300,000 by 2030 to 2040. The median age of the population is currently about 34 years which is anticipated to increase to 39 years by 2030.

4.2. Topography

Much of the Townsville City Council area occupies a low lying and flat coastal plain formed by deposition of recent sediments extending inland from the coast for several tens of kilometres. In several places the coastal plain is penetrated by a series of inliers of older rocks which protrude above the flat coastal plain as low hills of modest relief (typically up to 100m in height).

Photograph 1: Mt Louisa looking from Castle Hill (view towards the northwest).

The hills vary from moderate to steeply sloping and examples include Castle Hill, Mount Louisa and Mount Low. Residential development has taken advantage of the elevated topography these inliers offer to provide building sites with coastal views.

Photograph 2: Recent development on the lower flanks of sloping ground (Mt. Louisa).

The protruding inliers contain commonly well-developed gullies which tend to drain directly down slope with no meander. These gullies are the receptacles for runoff during high intensity tropical cyclonic rainfall events.

Photograph 3: Typical flowpaths and gullies on sloping ground.

The coastal plains eventually merge into range fronts which ultimately rise up to the Great Dividing Range to the west of Townsville. The range fronts include those of Hervey Range and Paluma Range and also include isolated range fronts such as Mount Stuart and Mount Muntalunga (Mount Elliot and Alligator Creek areas). The range fronts are typically steep except for their foot slopes where more gentle gradients prevail.

4.3. Geology

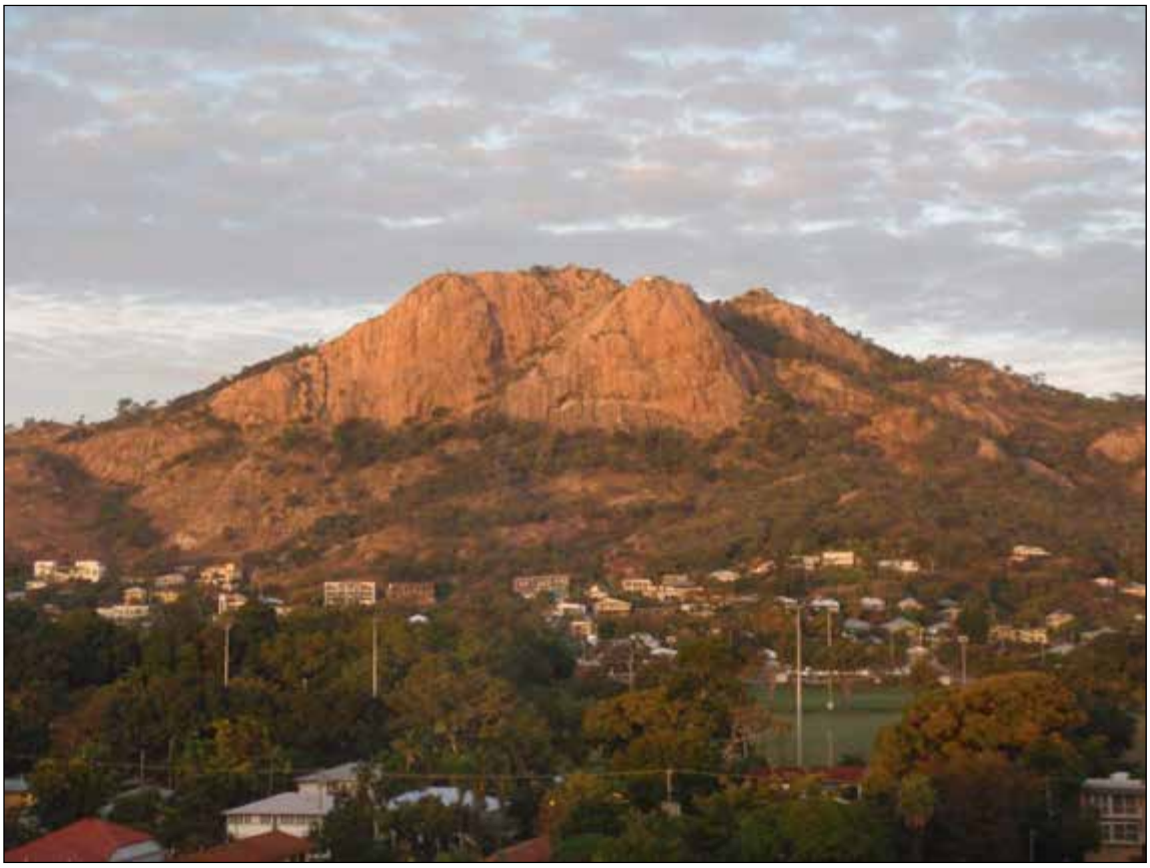
The geology of the study areas is inferred from available Geological Survey maps and notes (Reference 29). These indicate that the inland northwest to southeast trending range front and the various low-lying hills in the coastal plains comprise erosion resistant volcanic and granitic intrusion materials of Carboniferous to Permian geological age.

The volcanics (most commonly Julago Volcanics or Paluma Rhyolite in the study areas) comprise rhyolitic to andesitic lava, tuff, volcanic breccia, ignimbrite and agglomerate deposits. Minor sedimentary deposits including conglomerate, sandstone, siltstone, shale and coal seams are also described as part of this sequence. These materials are inferred to be a result of volcanic activity associated with the Camboon Volcanic Arc which was likely related to a westward dipping subduction zone in the Carboniferous period.

During or following this volcanic activity the emplacement of granitic plutons took place in the Townsville area. The eroded remnants of these plutons make up some of the high relief topography including Castle Hill, Muntalunga, Magnetic Island and Hervey Range. The granites generally comprise biotite granite, minor microgranite, granodiorite and tonalite.

Basic and felsic dykes, post-dating the granite intrusions are present in places.

Erosion and deposition during the Quaternary period has resulted in the sedimentary deposits over the coastal plains.



Photograph 4: Castle Hill – an example of an erosion resistant granite intrusion.

4.4. Soils

The coastal plains include soils derived from both alluvial origin and beach sediments. Those developed on coastal inliers and range fronts include colluvial soils and residual weathered soils. In places on the coastal plains, “gilgai” soils have formed characterised by clays that are affected by shrink swell properties.

4.5. Climate

Townsville's climate is warm and subhumid, with a hot wet summer period of variable duration and intensity, and a warm dry winter season (sourced from TCC website). Temperatures vary from an average maximum of 30.7C and minimum of 24.6C in January to a 24.4C maximum and 15.4C minimum in July. Average relative humidity varies from 69% in January to 59% in July. Temperatures increase and humidity drops with increasing distance inland.

Rainfall is highly seasonal and varies from year to year. Rain is generally associated with tropical cyclones and depressions, south easterly trade wind streams, and north easterly winds during the passage of troughs. The average annual rainfall is 1134 mm, with 80% falling during the wet season from December to March. Rainfall is often concentrated into a relatively small number of high intensity cyclonic events. Rainfall levels are higher near mountains (e.g. Paluma 2770 mm/year), while rainfall generally decreases with increasing distance from the coast. Variability from year to year is high, with 10% of years experiencing less than 600mm of rainfall, and 10% receiving over 1800mm. On average, cyclones affect the region about once every two years.

Winds are generally light to moderate, with occasional strong to gale force winds during storms and cyclones in the wet season and intense high pressure ridges in the cooler months. The dominant wind directions are from the southeast and northeast, with a north easterly afternoon sea breeze near the coast being common.

4.6. Vegetation

The coastal plains, near-coastal inliers and isolated range front hills generally support a range of vegetation types from grasslands to eucalypt woodlands and vine thickets.

The higher rainfall of the range fronts typically allows denser vegetation development such as eucalypt woodlands and rain forests at higher altitudes.

4.7. Review of Slope Instability

The available evidence suggests that the Townsville area is susceptible to four main types of landslides:

- Shallow slumping.
- Rock roll.
- Rockfall.
- Debris flow / debris torrent.

These are outlined and discussed in the following sections with general classification criteria from Varnes & Cruden (Reference 31). Landslide velocity scales are outlined in Table 4.1.

TABLE 4.1
LANDSLIDE VELOCITY SCALE (REFERENCE 31)

DESCRIPTION	VELOCITY (mm/sec)	TYPICAL VELOCITY
EXTREMELY RAPID	$> 5 \times 10^{3}$	> 5 m/sec
VERY RAPID	5×10^{1} to 5×10^{3}	3 m/min to 5 m/sec
RAPID	5×10^{-1} to 5×10^{1}	1.8 m/hr to 3 m/min
MODERATE	5×10^{-3} to 5×10^{-1}	13 m/month to 1.8 m/hr
SLOW	5×10^{-5} to 5×10^{-3}	1.6 m/year to 13 m/month
VERY SLOW	5×10^{-7} to 5×10^{-5}	16 mm/year to 1.6 m/year
EXTREMELY SLOW	$< 5 \times 10^{-7}$	< 16 mm/year

Slope gradient descriptors from AGS 2007 are outlined in Table 4.2.

TABLE 4.2
SLOPE GRADIENT DESCRIPTORS (AGS 2007)

APPEARANCE	SLOPE ANGLE	SLOPE CHARACTERISTICS
GENTLE	0° to 10°	Easy walking.
MODERATE	10° to 18°	Walkable. Can drive and manoeuvre a car on driveway.
STEEP	18° to 27°	Walkable with effort. Possible to drive straight up or down roughened concrete driveway.
VERY STEEP	27° to 45°	Can only climb slope by clutching at vegetation, rocks etc.
EXTREME	45° to 64°	Need rope access to climb slope.
CLIFF	64° to 84°	Appears vertical, can abseil down.
VERTICAL OR OVERHANG	84° to +/-90°	Appears to overhang. Abseiler likely to lose contact with face.

4.7.1. Shallow Slumping

This instability type involves a sliding mechanism (either rotational or translational) with downslope transport of the surficial soil layer, usually between 0.5 to 4m thick, sometimes along the underlying bedrock interface. Movement is generally rapid and is often triggered by saturation of the soil layer on a slope above the bedrock. This landsliding mechanism has occurred on sloping ground in a variety of geomorphological environments in the Townsville area.

Photograph 5: Example of shallow slumping landslide.

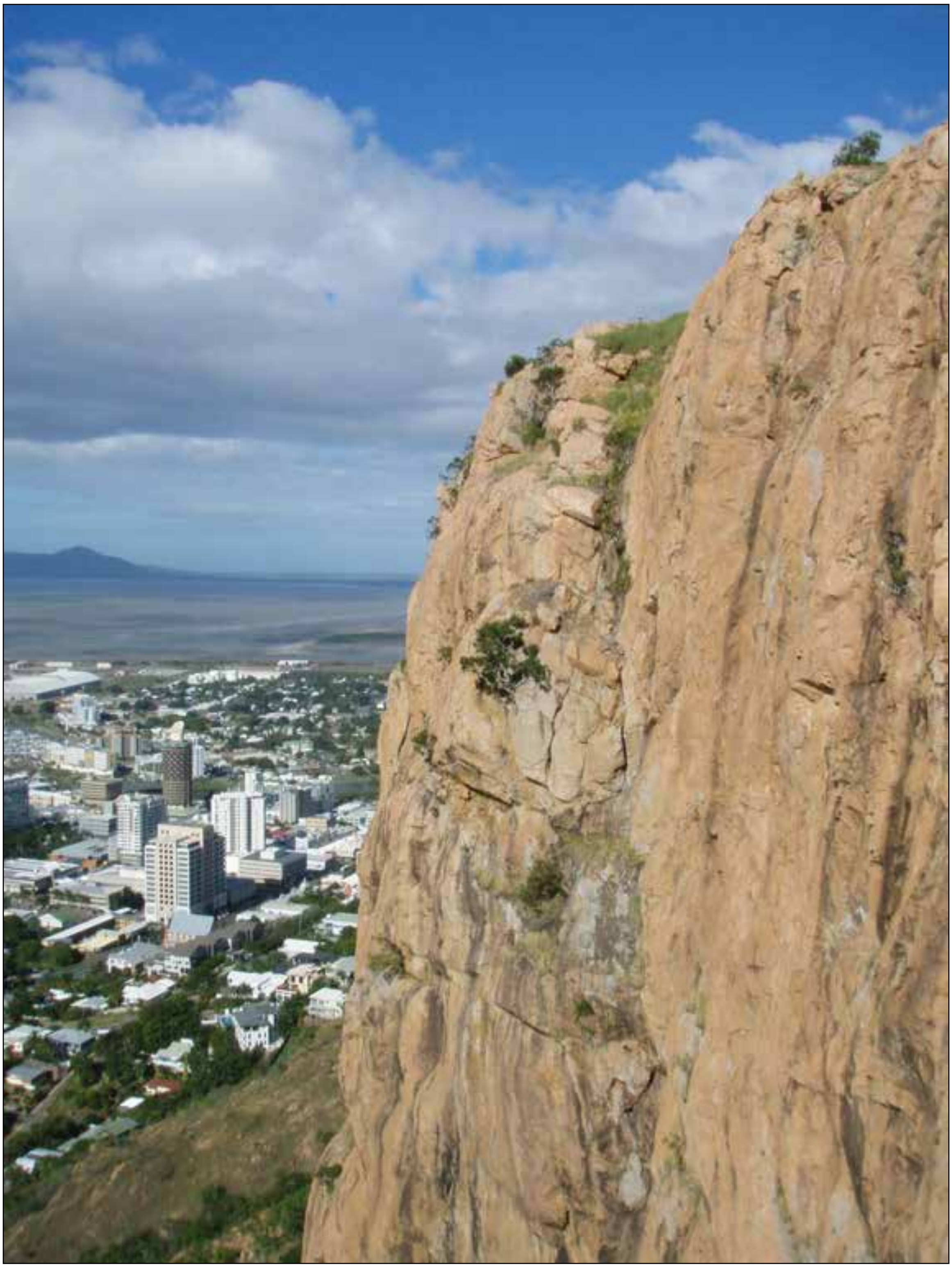
4.7.2. Rock Roll

This mechanism involves the downslope roll of boulders from a rock outcrop source. Movement is generally rapid. Bedrock outcrops are frequent in the Townsville area and when combined with sloping ground form the potential for this landsliding process.

Photograph 6: Example of potential rock roll source.

4.7.3. Rockfall

This mechanism involves the fall of rock material down a steep slope or cliff from a rock outcrop source. Movement is rapid to extremely rapid. This mechanism is limited to bedrock outcrops which have sufficient steepness and height to instigate gravitational fall of a boulder, rather than roll down a slope.

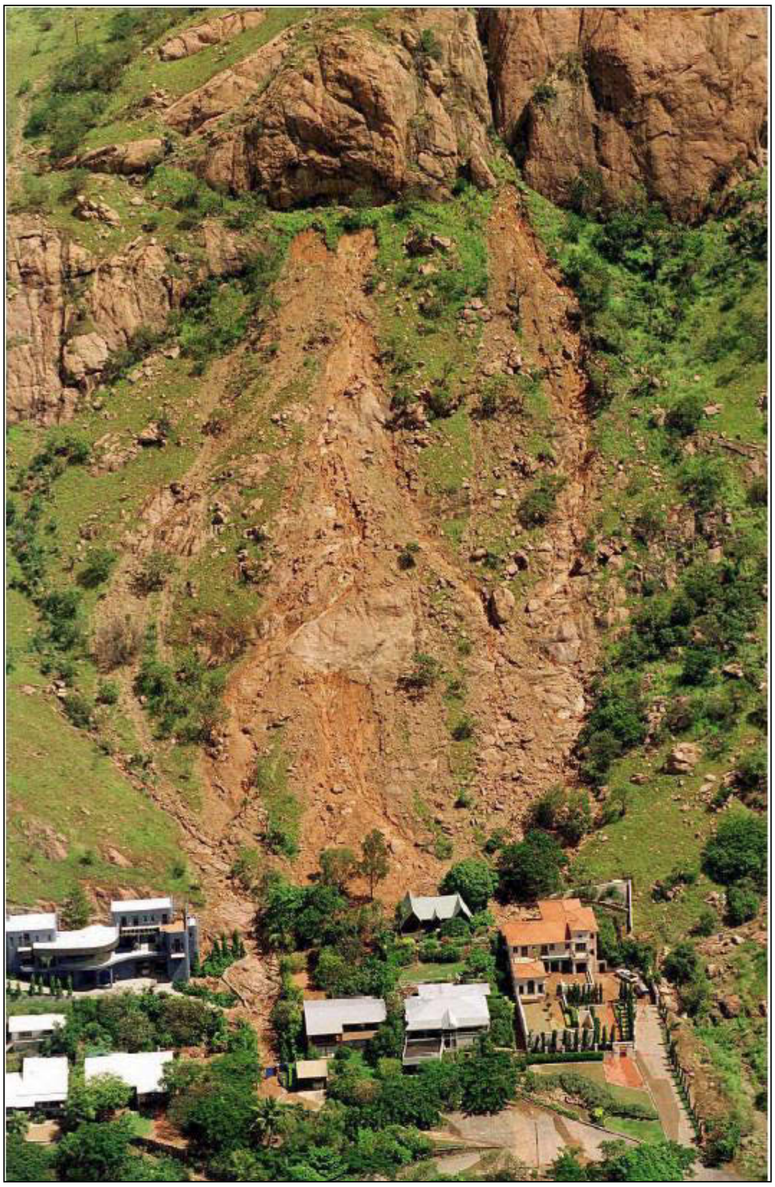


Photograph 7: Example of potential rockfall source (Castle Hill).

4.7.4. Debris Flow

This mechanism involves the flow of material down a slope as a viscous sediment-laden fluid. These appear to be triggered by saturation of a slope during wet season high rainfall and cyclonic events. Movement can be rapid to very rapid and these landslide types can be highly destructive. In Townsville debris flows have generally occurred on very steep to extremely steep ground in colluvium accumulated at the base of bluffs as a result of rockfall/unravelling and triggered by runoff & saturation by rainfall infiltration exacerbated by bare rock upslope (see Photograph 8).

Debris torrents are a sub-set of debris flows and typically involve the transport of much less sediment (than debris flows) and hence are considered to be hydraulic (i.e. flood) hazards rather than landslide hazards.



Photograph 8: Stanton Terrace Debris Flow (Castle Hill) April 2000 (From Coffey 2004)

5. RESULTS OF LANDSLIDE ASSESSMENT

5.1. Category 1

5.1.1. Site Description

Category 1 study areas typically comprise gently to steeply sloping, slightly undulating terrain with some incised flow paths or gullies. The hills in the study areas comprise volcanics, granite or rhyolite outcrops with a thin (0.5 to 4m) covering of residual, colluvial or alluvial soil. Scattered weathered bedrock outcrops are exposed in places with boulders, either weathered *in situ* or transported, observed in various locations. Quaternary sediments overly the plains below the hills. Detailed site descriptions and inferred geology for each study area are outlined in Table 5.1.

Development has been undertaken in places within the Category 1 areas, including infrastructure such as roads, water tanks and water pipelines.

Photograph 9: Jensen hill with coastal plains in foreground.

Photograph 10: Example of typical scattered bedrock outcrops with thin residual soil cover and sparse vegetation.

Photograph 11: Pipeline infrastructure on sloping ground at Jensen. Note small boulders that have rolled into pipeline corridor.

TABLE 5.1
CATEGORY 1 SITE DESCRIPTIONS

STUDY AREA	SITE DESCRIPTION (GEOMORPHOLOGY, SOILS, VEGETATION)	GEOLOGY
PALUMA VILLAGE	Gently sloping, slightly undulating terrain with occasional broad shallow flow paths. A small watercourse is located to the north of the village. Heavily vegetated with rainforest away from the houses. Inferred residual soil cover of unknown depth.	Predominantly Paluma Rhyolite with Rollingstone Granite to northeast of village.
TOOMULLA	Generally gently sloping with some short moderate to steep slopes. Bedrock outcrops in many places, particularly along shoreline. Residual/colluvial soil layer 0.5 to 1.0m thick. Moderately vegetated.	Saint Giles Volcanics with some Quaternary sediments.
MT LOW	Two distinct low-lying hills. Northern side of hills (developed) gently sloping with some broad shallow gully features. South or southwest side of hills moderate to steep and undulating with isolated bedrock outcrops and minor boulders on surface. Around 0.5 to 1.0m of residual soil/colluvium. Locally narrow, slightly incised flow path with loose sediment and small boulders along base. Moderately vegetated.	Porphyritic micro-granite, biotite micro-granite and some Quaternary sediments.
JENSEN (SEAVIEW PARK)	Gently to steeply sloping with some limited very steep slopes. Terrain is slightly undulating with some moderately incised gullies. Residual/colluviual soil generally 0.5 to 1.5m thick. Many bedrock outcrops with numerous boulders scattered below, generally around 0.5m but up to 2.0m. Boulders generally close to bedrock source (weathered core-stones) but some observed to have rolled away from source. Gullies variable with some scoured to bedrock where as others have loose sediments, cobbles and small boulders within base. Moderately vegetated. Drainage/ rock roll catch bench has been constructed on north western slopes.	Julago Volcanics beneath southern part of hill, Hornblende-biotite granite below north part of hill. Quaternary sediments on plains.
DEERAGUN (INNES ESTATE)	Gently to steeply sloping with some limited very steep slopes. Terrain is undulating with some moderately incised gullies. Residual/colluviual soil generally 0.5 to 2.0m thick. Numerous bedrock outcrops with numerous boulders scattered below, typically 0.5m diam. but up to 2.0m. Boulders generally close to bedrock source (weathered core-stones) but some observed to have rolled up to 50m from source. No boulders observed more than 5m from toe of slope. Gullies variable with some scoured to bedrock were as others have loose sediments, cobbles and small boulders along base. Some short steep flanks exist in upper parts of gullies. Some outwash 'fans' observed where gullies reach the base of the slope. These are inferred to be alluvial deposits (bed load from large flow events) rather than debris flows and appear to contain predominantly soil and cobbles. Moderately vegetated. Drainage/ rock roll catch bench has been constructed near base of slope above Oak Ridge subdivision.	Julago Volcanics with Quaternary sediments on plains.
MOUNT ELLIOT/ ALLIGATOR CREEK	Gently to very steeply sloping with some extremely steep slopes (bedrock 'bluffs'). Terrain is undulating with some moderately to deeply incised gullies. A number of watercourses fork together at the study area. Residual/colluviual soil cover generally 0.5 to 2.0m thick. Numerous bedrock outcrops, including some moderately large 'bluffs', with numerous boulders scattered below, generally around 0.5m but up to 2.0m. Boulders generally close to bedrock source (weathered core-stones) but some were observed to have rolled away from source. No boulders were observed more than 5m from toe of slope. Gullies variable with some scoured to bedrock where as others have loose sediments, cobbles and small boulders along base. Some steep flanks exist in upper parts of gullies. Some outwash 'fans' observed where gullies reach the base of the slope. These are inferred to be alluvial deposits (bed load from large flow events) rather than debris flows and appear to contain predominantly soil and cobbles. Moderately vegetated. Low-density development comprising mostly small lifestyle blocks.	Julago Volcanics within study area with Quaternary sediments along valley floors and plains. Mount Storth Granite to east of study area.

5.1.2. Landslide Hazard Analysis

Evidence of relic shallow slumping and rock roll was observed on sloping ground in the Category 1 areas. The range of landslide hazards assessed for each study area is outlined in Table 5.3. A factual plan showing major features, field mapping notes, a slope gradient plan, a geology plan and assessed landslide hazard maps delineating inferred shallow slumping and rock roll hazard are presented for each study area in Appendix D.

Site observations indicated that evidence for relic slumping and rock roll became more frequent as slope inclination increased. General slope angle ranges were assessed to represent different hazard levels for shallow slumping, as outlined in Table 5.2. Note that this characterisation was not totally representative of all slopes but was used as a guide to assist in hazard zoning for the study areas. Some very steep to extremely steep slopes (> 35°) were present in the Category 1 areas however these were of limited extent and length and were not recorded as part of this broad scale study.

TABLE 5.2
RELATIONSHIP BETWEEN SLOPE ANGLE AND HAZARD LEVEL FOR SHALLOW SLUMPING IN CATEGORY 1 AREAS

HAZARD LEVEL	ASSOCIATED SLOPE ANGLE (deg)
Very High	>45
High	35 – 45
Moderate	28 – 35
Low	23 – 28
Very Low	<23

Vegetation, soil cover thickness and geomorphology also contributed to the shallow slumping hazard level.

Rock roll hazard was also related to slope angle although was dependent on the presence of bedrock outcrop sources, the condition of these outcrops and the geomorphology below the outcrop. The exact location of every bedrock outcrop or rolled boulder was not mapped as part of this study; however, zones of inferred higher hazard have been assessed.

The landslide hazard for shallow slumping and rock roll was assessed to be very low to moderate in the Category 1 areas.

Rockfall hazard is inferred to be present in a limited area below extremely steep or cliffed bedrock outcrops. These outcrops occur sporadically in some Category 1 areas and were not mapped in detail as part of the scope of this study. They are generally observed on slopes steeper than 23°.

No evidence of past debris flows was observed in the Category 1 study areas.

5.1.3. Landslide Frequency

The frequency assessment for shallow slumping hazard was based upon the inference that 'recent' evidence of active shallow slumping becomes 'relic' evidence within two years. This is attributed to high rainfall, limited vegetation and potential for high erosion rates in the study areas. The frequency was assessed on the evidence of active slumping observed within the total area inspected.
The frequency for rockfall was based upon a worst case scenario for the Category 1 study areas based upon observations of number of boulders inferred to have rolled downslope.

Details of landslide frequency estimations are presented in the risk assessment document, Appendix E. The observed landslide evidence in the study areas is outlined in Table 5.3. Hazard descriptor levels are in general agreement with AGS 2007(a) (Reference 24), as outlined in Table 3.2.

5.1.4. Landslide Consequence Analysis

The size and intensity of the various landslide hazards identified within the Category One areas were inferred from relic evidence and engineering experience. The potential consequence for the identified hazards was based upon the possible damage that could occur should an occupied residential house be directly affected (based upon the assumption that the Category One areas may be developed in the future). The worst case consequence considered for both shallow slumping and rock roll is a fatality.

Existing elements at risk in each study area are outlined in Table 5.3.

5.1.5. Landslide Risk Estimation

Due to the potential consequence of landsliding involving a risk to life, AGS 2007c (Reference 26) stipulates that a quantitative risk analysis should be undertaken for the 'person most at risk'. Detailed risk estimations undertaken for shallow slumping and rock roll hazards in the Category One study areas are presented in Appendix E.

The rockfall risk was not assessed for this broad study as the risk is highly variable and localised for this hazard and it is considered prudent to assess this risk in more detail at the development stage.

The assessed landslide risk for each study area is outlined in Table 5.3 and is presented spatially as risk zones in the following figures:

- Paluma Village — Figure 3
- Toomulla — Figure 4
- Mount Low — Figure 5
- Jenson (Seaview Park) — Figure 6
- Deeragun (Innes Estate) — Figure 7
- Mount Elliot/ Alligator Creek — Figure 8

The risk level for landsliding (excluding rockfall hazard) for the Category 1 study areas was assessed to be in the low to very low range (10^{-6} to 10^{-7} annual probability of fatality from a landslide). This is within the tolerable range ($<10^{-4}$) as outlined in AGS 2007 (Reference 25).

TABLE 5.3
CATEGORY 1 LANDSLIDE HAZARD ANALYSIS

STUDY AREA	EXISTING AND INFERRED PROPOSED DEVELOPMENT	SLOPE PROCESSES	LANDSLIDE HAZARD	LANDSLIDE FREQUENCY	LANDSLIDE CONSEQUENCE ANALYSIS	LANDSLIDE RISK ESTIMATION
PALUMA VILLAGE	Existing very low density development comprising single to double story dwellings and some public buildings. . Large areas of vacant land. Inferred potential for low to medium density development.	No signs of land instability were observed. Possible soil creep on some localised, short, moderate slopes.	▪ Shallow Slumping – very low. ▪ Rock roll – very low.	No evidence of relic or active landsliding.	Elements at risk: ▪ existing houses ▪ radio mast ▪ future development	Very low risk.
TOOMULLA	Existing low density development comprising single to double story dwellings and some public buildings. . Large areas of vacant land. Potential for low to medium density development.	Shallow regolith failures and soil creep observed in places, particularly where driveways/pads have been excavated. Small relic scarp on shoreline, inferred to be remnant of previous wave erosion during raised sea-level?	▪ Shallow Slumping – very low to moderate hazard. ▪ Rock roll – very low to low hazard.	No evidence of significant recent instability. Some active erosion noted in places.	Elements at risk: ▪ existing houses ▪ future development	Very low to low risk.
MT LOW	Existing low to medium density development comprising single to double story dwellings and some public buildings. Large areas of vacant land. Potential for low to medium density development.	Hummocky ground indicates shallow regolith slumping and soil creep on moderate to steep slopes. Some 'scars' of bedrock inferred to be exposed when soil layer has slid off leaving smooth bedrock mounds. No evidence of debris flows. Some evidence of fluvial depositions along base of small gullies. Some small boulders (up to 0.5m) loose on surface, generally near bedrock source. No signs of instability on gentle slopes apart from isolated small failures related to development earthworks.	▪ Shallow Slumping – very low to low hazard. ▪ Rock roll – very low to low hazard.	No evidence of significant recent instability. Some active erosion noted in places.	Elements at risk: ▪ existing houses ▪ above-ground sewer pipe on northwestern slope of western hill. ▪ water tank on southwestern end of western hill. ▪ future development	Very low to low risk.
JENSEN (SEAVIEW PARK)	Existing low to medium density development comprising single to double story dwellings. Large areas of vacant land. Potential for low to medium density development.	Some hummocky ground in places. 'Scars' of bedrock inferred to be exposed from soil sliding. Limited evidence of rock roll (boulders on ground surface away from bedrock source).	▪ Shallow Slumping – very low to moderate hazard. ▪ Rock roll – very low to low hazard. ▪ Rockfall – inferred to be isolated moderate hazard immediately below bedrock outcrops.	No evidence of significant recent instability. Small (0.3m) boulders observed next to pipeline. Some active erosion noted in places.	Elements at risk: ▪ existing houses ▪ above-ground water pipes on north eastern and north western slopes. ▪ water tank on northern end of hill. ▪ future development	Very low to low risk.

TABLE 5.3
CATEGORY 1 LANDSLIDE HAZARD ANALYSIS (continued)

DEERAGUN (INNES ESTATE)	Existing low to medium density development comprising single to double story dwellings. Large areas of vacant land. Potential for low to medium density development.	Hummocky ground and relic exposed bedrock 'scars' indicates previous shallow slumping/sliding and soil creep on moderate to steep slopes. Numerous boulders observed on ground surface in places, inferred to have rolled from source. Some small fresh boulders observed on catch bench inferred to have fallen from excavated bench.	▪ Shallow Slumping – very low to moderate hazard. ▪ Rock roll – very low to low hazard. ▪ Rockfall – inferred to be isolated moderate hazard immediately below bedrock outcrops.	No evidence of significant recent instability. Some active erosion noted in places. Evidence of previous rock roll but no fresh boulders observed.	Elements at risk: ▪ existing houses ▪ future development	Very low to low risk.
ALLIGATOR CREEK/MOUNT ELLIOT	Existing very low to low density development comprising single to double story dwellings. Large areas of vacant land. Potential for low to medium density development.	Hummocky ground and relic exposed bedrock 'scars' indicates previous shallow slumping/sliding and soil creep on moderate to steep slopes. Frequent boulders observed on ground surface in places, inferred to have rolled from source.	▪ Shallow Slumping – very low to moderate hazard. ▪ Rock roll – very low to low hazard. ▪ Rockfall – inferred to be isolated moderate hazard immediately below bedrock outcrops.	No evidence of significant recent instability. Some active erosion noted in places. Evidence of previous rock roll.	Elements at risk: ▪ existing houses ▪ water tanks ▪ future development	Very low to low risk.

5.2. <u>Category 2</u>

5.2.1. Site Description

The factual data and base plans, air photograph interp and geology plans for the category 2 areas are presented in Appendix F.

The Category 2 study areas have variable geomorphology and terrain. Geology of these areas includes granite and rhyolite with colluvium, alluvium and residual soil cover. Quaternary sediments are located on the plains and within valley bases. Details of the conditions observed at each study area are outlined in Table 5.4.

TABLE 5.4
CATEGORY 2 SITE DESCRIPTION TABLE

STUDY AREA	SITE DESCRIPTION (GEOMORPHOLOGY, SOILS, VEGETATION)	GEOLOGY
PALUMA ROAD	Gently to extremely steeply sloping terrain, with some large cliffs and bluffs away from road. Terrain is variable and comprises slightly undulating to deeply incised terrain with frequent large bedrock outcrops. Soil thickness varies from around 1.0 m to 4m or more. Gullies vary in size, shape, steepness, catchment and sediment load. Some medium to small streams cross under road at various locations, either by culvert or bridge. Boulders observed on ground surface above road in places. Vegetation changes from moderate gum scrub and grass at lower part of road to dense rainforest towards upper part of road. Upper section of road is moister with some seepage occasionally observed from road cuttings.	The upper section of Paluma Road comprises Rollingstone Granite, whereas the lower section comprises Paluma Rhyolite. Quaternary deposits cover the lower lying plains.
HERVEY RANGE ROAD	Gently to extremely steeply sloping terrain, with some large cliffs and bluffs away from road. Terrain is generally undulating with some incised flow paths and gullies. Some large bedrock outcrops are present close to the road in places. Soil thickness varies from around 1.0 m to 3m. Gullies vary in size, shape, steepness, catchment and sediment load. Some medium to small streams cross under road at various locations, either by culvert or bridge. Boulders, some extremely large (up to 15m) were observed on ground surface above road in places. Vegetation generally comprises moderate gum scrub and grass with some denser bush in gullies. Upper section of road has been formed by large benched cutting up to 30 m high.	Comprises Speed Creek Granite, with minor intrusions of Pall Mall Granite. Quaternary sediments are located on the lower lying plains.
ROLLINGSTONE	Gently to steeply sloping undulating terrain to southwest of pipeline and Bruce Highway. Some bedrock outcrops (up to 10m across) with loose boulders on ground surface below. Boulders vary in size from 0.5 to 3m. Open joints and cracks observed on some very to extremely steep bedrock outcrops. A factual plan of the Rollingstone study area is presented as Figure 12.	Raised sloping ground comprises Rollingstone Granite. Lower plains comprise Quaternary sediments.

5.2.2. Landslide Hazards

The potential landslide mechanisms identified in the Category 2 study areas include slumping, rock roll, rockfall and debris flows. The type, size and extent of landslide hazards vary across the study areas. Descriptions of the landslide hazards for each study area are outlined in Table 5.5. For these areas the hazard level was assessed from observations during filed mapping, anecdotal accounts from road maintenance crews and engineering judgement. Assessing the risk for these areas was not included in the scope of this study.

The location of significant gullies on Paluma and Hervey Range Roads and their inferred debris flow or torrent 'susceptibility' are indicated on Figures 9 and15. Previous slumps were recorded for Paluma and Hervey Range Roads and are indicated on Figures 10 and 16.

5.2.3. Landslide Frequency

Accounts from road maintenance personnel and historic records provided an indication of expected frequency for the various landslide hazards at Paluma and Hervey Range Roads. No historic records of landsliding at Rollingstone were found. Sections of the roads that were inferred to be more prone to particular hazard types were identified during the field visit and a hazard level was qualitatively assessed for these zones.

Information from road maintenance crews and data of previous landslides from the EMA website for the category 2 areas are presented in Appendix F.

5.2.4. Category 2 Landslide Hazard Plans

Plans showing qualitative hazard level assessment for both slumping and rock roll hazard along the Category Two Roads are presented as:

- Slumping Hazard – Paluma Road — Figure 10
- Rock Roll/ Rockfall Hazard – Paluma Road — Figure 11
- Slumping Hazard – Rollingstone — Figure 13
- Rock Roll/ Rockfall Hazard – Rollingstone — Figure 14
- Slumping Hazard – Hervey Range Road — Figure 16
- Rock Roll/ Rockfall Hazard – Hervey Range Road — Figure 17

The hazard level is variable from very low to high depending on the study area, section of road and specific hazard. This qualitative hazard level assessment is considered to be in general agreement with the landslide hazard descriptors outlined in Table 3.2. Note that due to the scale of the study areas the hazard zones for Paluma Road and Hervey Range Road are fairly broad. It should be recognised that these zones may contain isolated, localised zones of limited length where a higher hazard level could be expected, the assessment of which would require a study at a more detailed scale and level than applicable for this project.

5.2.5. Potential Impacts on Road Corridors

Bruce Highway at Rollingstone is considered to be exposed to a very low hazard level from landslides. A small section of the above-ground water pipeline is exposed to a low hazard level from possible rock roll, as indicated on Figure 14. The possibility of Bruce Highway being closed at this location from landslides is very low.

Slumping, rock roll, rockfall and debris flows hazards have the potential to close or damage Paluma Range or Hervey Range Road at various locations. It should be noted that some landslide events only partially close the road, which may allow continued emergency vehicle access. As is evident from a previous incident on Paluma Road (Reference 14), landslides have the potential to cause loss of life. These significant events which may close the road or cause harm are generally triggered by extreme rainfall events, sometimes associated with tropical cyclones.

TABLE 5.5
CATEGORY 2 LANDSLIDE HAZARD ANALYSIS

STUDY AREA	LANDSLIDE HAZARD ANALYSIS	LANDSLIDE FREQUENCY	POTENTIAL IMPACT ON ROAD CORRIDORS
PALUMA ROAD	Numerous indications of historic and recent slumping observed along Paluma Road, particularly in the upper half of the road closest to Paluma village. These are predominantly shallow (0.5 to 1.5m thick) soil slides from within or above road cuttings. Most are re-vegetated to some extent (Photograph 13). Leaning trees over road indicate soil creep or previous shallow slumping. Numerous boulders observed in places on slopes above road, some of which are inferred to have rolled or fallen (Photographs 12 and 14). Most are 1 to 2m diam. although larger boulders were noted. Some appeared to be resting against tree trunks. Locally boulders were noted in drains and culverts. Boulders seemed more frequent on lower half of road. The potential for debris flows or torrents out of steep and debris infilled gullies is recognised on Paluma Road. Some gullies have significant sediment and boulder build-up within their base.	The road is closed from slumping around 5 to 10 times per year, usually following heavy rain. Common rockfall and tree fall encroach onto road. Potential for debris flows within gullies and streams although frequency is unknown.	Potential for closure a number of times per annum, particularly following very heavy rainfall events.
ROLLINGSTONE	Some small boulders observed on moderately steep slope immediately above water pipeline where it crosses toe of slope (Photograph 15). Some evidence of relic instability on sloping ground (hummocky ground). Some large boulders are inferred to have rolled a short distance from bedrock source in places.	Evidence of previous rock roll. No evidence of significant recent instability or debris flows. Some active erosion noted in places.	Infrastructure at risk: ▪ Road (Bruce Highway). ▪ Pipeline (water). ▪ New power pylons (currently only pads have been constructed). The road and pipeline are generally away from toe of the slope and are considered to be removed from landslide and rock roll hazard. A small section of pipeline crosses the toe of the slope and is considered to be within a low rock roll hazard zone.
HERVEY RANGE ROAD	Some steep gullies with significant sediment in base were observed which may have potential for debris flow/ torrent (Photograph 16). Local indications of previous slumping and rock roll were noted along Hervey Range Road. Slumping is commonly associated with road cuttings. Some very large boulders on slopes at lower end of road however no evidence of recent movement. Frequent exposed bedrock outcrops above road may be potential source for rock roll/rockfall (Photograph 17)	It is understood that the road is rarely closed from landslide activity (has not been closed in last 5 years). Records state that the road was closed for days following Cyclone Sid in 1998 due to rockslides. There is some potential for slumping, rockfall and debris flows which may close road however frequency is unknown.	Potential for road closure from occasional large rainfall event.

Photograph 12: Typical road cutting through bedrock on Paluma Road. Note the loose block that has the potential to fall onto road shoulder.

Photograph 13: Typical road cutting into base of slope on Paluma Road. Note the new vegetation that indicates previous slumping activity (slip scarp is visible on right hand side of slump).

Photograph 14: Typical sloping ground above Paluma Road. Note the loose boulders on the slope that have the potential to cause rock roll.

Photograph 15: View of Bruce Highway at Rollingstone looking north. Note that road and pipeline are generally removed from slope. Pipeline crosses toe of slope in right hand side of this photo. Note cut to fill pad on sloping ground (shotcreted) understood to be for future pylon construction.

Photograph 16: View of steep gully above Hervey Range Road. Note some loose sediment and debris in gully base, may be susceptible to debris flow/ torrent.

Photograph 17: View looking down Hervey Range Road. Note steep escarpment above road with large bedrock outcrops (potential rock roll source).

5.3. <u>Category 3</u>

5.3.1. Site Description

The factual data, base plans and geology plans for the Category 3 areas are presented in Appendix G.

Category 3 study areas generally comprise gently to very steeply sloping slightly undulating terrain with some incised flow paths or gullies. Some limited extremely steep slopes or cliffs were present in places. The hills in the study areas comprise volcanics, granite or rhyolite bedrock with a relatively thin (0.5 to 4m) covering of residual, colluvial or alluvial soil. Scattered weathered rock outcrops are exposed in places with boulders, either weathered in-situ or transported, observed in various locations. Quaternary sediments overlie the plains below the hills. Detailed site descriptions and geology for each study area are outlined in Table 5.7.

Development has occurred in places within the Category 3 areas, with infrastructure including roads, water tanks and water pipelines, as well as some slope stabilisation measures and large stormwater control systems observed.

Photograph 18: A view of sloping land at Wulguru. This topography and vegetation is common in the Category 3 areas

5.3.2. Landslide Hazard Analysis

Generally the Category 3 areas had similar geomorphology and slope processes to the Category 1 areas, although some higher and steeper slopes were present in places. Evidence of both relic and limited active shallow slumping was observed on sloping ground in the Category 3 areas. Evidence for rock roll and rockfall was also observed.

The general slope angle ranges associated with increasing slumping risk as assessed for Category 1 areas are considered to also be applicable to Category 3 slopes (Table 5.2). The degree of slumping is also inferred to be dependent on vegetation, soil cover thickness and geomorphology.

Rock roll and rockfall hazards are considered to be related to slope angle although these hazards are also dependent on bedrock outcrop sources, the rock mass condition of these outcrops and the slope morphology below the outcrop. Some large bedrock 'bluffs' were observed in places in the Category 3 areas, particularly at Mount Louisa and above Yarrawonga on Castle Hill.

No evidence of past debris flows was observed in the Category 3 study areas. Debris flows have been known to occur previously on very steep slopes on Castle Hill, outside the Yarrawonga Subdivision.

Landslide hazard analysis has been previously undertaken for these areas as shown on TCC Landslide Hazard Overlay Maps (Reference 1). The TCC Landslide Hazard Overlay Maps indicate four landslide hazard zones for these study areas, as outlined in Table 5.6. The 2001 regional landslide study did not assess the risk from landslides on existing or future development of the Category 3 areas.

TABLE 5.6
CATEGORY 3 DEFINITIONS OF LANDSLIDE CATEGORIES (FROM COFFEY 2001)

ZONE	HAZARD CATEGORY	DEFINITION	CHARACTERISTICS	ADDITIONAL FACTS
1	Very Unlikely Landslide Hazard	A landslide is very unlikely.	Slope angles generally 15° or less.	
2	Unlikely Landslide Hazard	A landslide is unlikely, without development.	Slope angles generally less than 25° but greater than 15° residual and colluvial soils,	Unlikely Landslide Hazard areas include isolated slopes of 25° to 30° that are less than approximately 10m high.
3	Potential Landslide Hazard	There is some likelihood of a landslide, without development.	Slopes generally greater than 25° colluvial and residual soils, evidence of previous slope instability.	Potential Landslide Hazard areas include ridges and spurs on hilltops with more moderate slopes, areas with slope angles of 15° or less within 20m downhill of slopes of 25° or more.
4	Potential for Debris Flow	There is some likelihood of a debris flow, with or without development.	Slope angles generally 25° or greater at initiation point, colluvial soils, boulders may be present.	Requires a well-formed gully, potential source of material and sufficient catchment to produce significant water flow in gully. Potential run-out distance discussed in text.

The Coffey (2001) landslide hazard zoning plans for the Category 3 areas were reviewed in the field by PSM. General site descriptions for each area are presented in Table 5.7. The spatial extent and applicability of the hazard levels of these zones was reassessed, taking into account any changed conditions since the Coffey 2001 study. Verification of the Coffey's landslide hazard zones is outlined in Table 5.7.

Based on our review of the Category 3 areas and assessment of any changed conditions, the results of the Coffey hazard assessment study are considered to remain appropriate. No specific landslide risk assessment of the Category 3 areas was undertaken, in accordance with the scope of work agreed for this study (Contract T5631).

TABLE 5.7
CATEGORY 3 SITE DESCRIPTION AND LANDSLIDE HAZARD ANALYSIS

STUDY AREA	SITE DESCRIPTION	GEOLOGY	LANDSLIDE HAZARD ASSESSMENT	VERIFICATION OF 2001 LANDSLIDE HAZARD ZONING
CASTLE HILL (YARRAWONGA SUBDIVISION ONLY)	Gently to very steeply sloping, slightly undulating terrain with minor incised flow paths. Area is almost completely developed with some small empty sections of land. These displayed slightly hummocky terrain suggesting relic shallow instability. Higher slopes of Castle Hill to the south of Yarrawonga are steeper with more deeply incised gullies and frequent bedrock outcrops.	Castle Hill Granite with some Rhyolite volcanics on northwestern flank of Yarrawonga subdivision. Residual or colluvial soil cover. Quaternary sediments are overlying the lower lying plains.	Limited evidence of shallow instability over undeveloped areas. No evidence of rock roll or debris flows observed within Yarrawonga subdivision.	Site inspection confirms the 2001 landslide hazard zoning plan remains appropriate for this area.
MOUNT LOUISA (OCEAN VIEW, CRESTBROOK AND GREENVIEW SUBDIVISIONS)	Gently to very steeply sloping, with limited extremely steep slopes or cliffs. Slopes are generally slightly undulating with incised flow paths and gullies. Residual/colluvial soil generally 0.5 to 4.0m thick. Numerous bedrock outcrops (some very large) with numerous boulders scattered below, generally around 0.5m but up to 4.0m. Boulders generally close to bedrock source (weathered core-stones) but some observed to have rolled away from source. Gullies variable with some scoured to bedrock where as others have significant amounts of sediment, cobbles and boulders within base. Moderately vegetated. Extensive residential development on the northern and southern flanks of Mount Louisa.	Julago volcanics (rhyolitic to andesitic lava tuff) bedrock with residual, alluvial and colluviual soil cover. Quaternary sediments are overlying the lower lying plains.	Evidence of relic and active shallow slumping and rock roll/rockfall. Some active erosion noted in places.	Site inspection confirms that the 2001 landslide hazard zoning plan remains appropriate for this area.
DOUGLAS (RIVERSIDE RIDGE SUBDIVISION)	Gently to steeply sloping, with some limited very steep slopes. Slightly undulating terrain with incised flow paths and gullies. Minor sediment and cobbles along gully bases. A partially developed subdivision is located on the lower slope flanks.	Granite bedrock with residual and colluviual soil cover. Quaternary sediments on lower lying plains.	Hummocky ground indicates shallow regolith slumping and soil creep on moderate to steep slopes. Some 'scars' of bedrock inferred to be exposed when soil layer has slid off leaving smooth bedrock mounds. Limited evidence of rock roll (boulders on ground surface away from bedrock source). No evidence of debris flows.	Site inspection confirms that the 2001 landslide hazard zoning plan remains appropriate for this area.

TABLE 5.7
CATEGORY 3 SITE DESCRIPTION AND LANDSLIDE HAZARD ANALYSIS (continued)

WULGURU, ROSENEATH (WULGURU HEIGHTS SUBDIVISION)	Gently to steeply sloping, with some limited very steep slopes. Slightly undulating terrain with incised flow paths and gullies. Some sediment, cobbles and boulders within base of gullies. Local boulders observed on sloping ground away from bedrock source. Residential development located on the lower slope flanks.	Granite and volcanic bedrock with residual and colluviual soil cover. Quaternary sediments on lower lying plains.	Active erosion and shallow slumping observed in places on steep slopes. Evidence of rock roll.	Site inspection verifies that the 2001 landslide hazard zoning plan remains appropriate for this area.
OAK VALLEY	Gently to very steeply sloping, with some extremely steep slopes or cliffs away from road. Slopes are generally slightly undulating with incised flow paths, gullies and streams. Residual/colluviual soil generally 0.5 to 4.0m thick. Frequent bedrock outcrops (some very large). Boulders up to 2.0m diam. noted on slopes in places. Gullies variable with some scoured to bedrock were as others have significant amounts of sediment, cobbles and boulders along base. Moderately vegetated. Generally comprises lifestyle acreage plots with some pockets of low density residential development.	Julago volcanic bedrock with residual, alluvial and colluviual soil cover. Quaternary sediments on lower lying plains.	Evidence of shallow instability, rock roll and rockfall.	Site inspection verifies that the 2001 landslide hazard zoning plan remains appropriate for this area.

5.4. Influence of Climate Change

The climate factors most likely to influence future landslide risk for Townsville are:

- Change in rainfall patterns (intensity, timing and distribution).
- Change in summer rainfall being the period when tropical cyclones are most likely to be experienced.

Factors such as temperature change are less likely to influence landslide risk, although any increase in the number of hot summer days which are likely related to the number of thunderstorm events and hence the number of high intensity rainfall events could also be a possible indicator of future changed landslide risk.

In 2008 CSIRO produced climate change projections for Townsville based on the most recent generation of climate change predictor models and consistent with the most up to date assessment of climate change in Australia by the CSIRO and Australian Bureau of Meteorology (BOM) (Reference 32). The climate change projections for Townsville for the periods up to 2030 and 2070 take account of:

- Uncertainties associated with future rates of greenhouse gases (low and high carbon dioxide emission scenarios).
- Future global average surface temperatures.
- Regional climates in response to increases in global average surface temperatures.

The findings of the CSIRO study in relation to rainfall scenarios are:

- Annual average rainfall is likely to decrease by 2% (variation -9 to +5%) by 2030, by 4% (-16 to +10%) under a low emission scenario by 2070, and by 8% (-32 to +18%) for a high emission scenario by 2070.
- A slight decrease is likely in the number of rain-days and the intensity of heavy rainfall, although projections are highly uncertain.
- Little change in humidity is likely.

The CSIRO study predicts there to be little change in the number of cyclone days. However, it is suggested severe cyclones may occur more often which is the one factor that has some potential to adversely impact on the landslide risk of Townsville.

Taking all of the above climate change factors into account, little significant change in the landslide risk potential for Townsville arising from climate change is indicated for the period up to about 2070.

6. RISK ASSESSMENT OVERLAY MAPS

6.1. Mapping Scale

The scope of this study is to provide regional-scale landslide risk zoning plans for the Category 1 study areas for the purposes of land use planning. This required air photo interpretation accompanied by large-scale field mapping. The purpose of the field mapping was not to identify the exact location of every landslide hazard, but rather to provide a general indication of hazard potential within the study areas to enable assessment of broad risk level zones.

6.2. Landslide Risk Overlays Maps

Landslide risk overlay maps are presented for the following Category One study areas:

- Paluma Village — Figure 3
- Toomulla — Figure 4
- Mount Low — Figure 5
- Jenson (Seaview Park) — Figure 6
- Deeragun (Innes Estate) — Figure 7
- Mount Elliot/ Alligator Creek — Figure 8.

The intended purpose for these risk overlay maps is to provide a basis for broad scale land use planning and to be utilised to assess potential risk at the development stage. These plans should not be used for assessing the potential risk to single building lots as the scale of this investigation was not undertaken to this degree of detail.

6.3. Limitations of Landslide Risk Overlay Maps

Limitations of the landslide risk analysis should be recognised and taken into account when utilising the risk overlay maps. Limitations include:

- Some assumptions/inferences are made in assessing some of the parameters used in the risk assessment estimations.
- The limited historic records of landsliding in Townsville mean that some inferences are made regarding landslide frequency.
- Landslide risk zones are assessed from air photograph interpretation and broad scale field mapping and therefore should not be used for small-scale risk assessments such as individual building lots.
- These landslide risk maps do not account for localised rockfall risk, which requires site-specific investigation at the time of development (Table 7.1).

7. LANDSLIDE MITIGATION OPTIONS

Landslide mitigation options typically fall into two main categories:

- Avoidance (e.g. relocation of building sites away from landslide instability);
- Engineering intervention to improve slope stability (e.g. retaining walls, drainage) and hence to reduce risk.

This section details a range of mitigation options under the category of engineering intervention that can be implemented to improve slope stability and reduce risk.

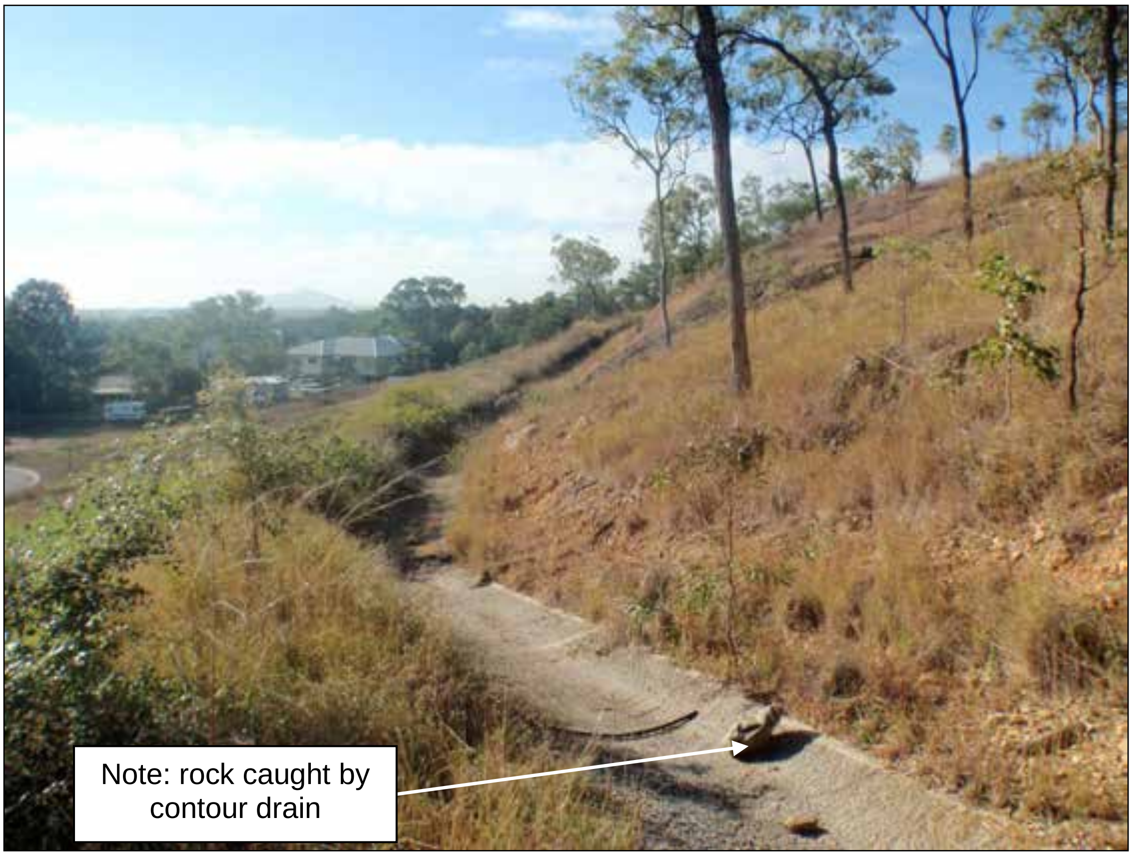
AGS, 2007(e) have developed a series of guidelines on slope maintenance and management as part of the landslide risk management guidelines (Reference 28). The Australian GeoGuides are intended to help with identification of landslide hazards and what can be done to mitigate the landslide risk. Table 7.1 summarises the list of GeoGuides that are currently available:

TABLE 7.1
LIST OF AUSTRALIAN GEOGUIDES

GEOGUIDE	GEOGUIDE DESCRIPTION
GeoGuide LR1	Introduction
GeoGuide LR2	Landslides
GeoGuide LR3	Landslides in Soil
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
GeoGuide LR11	Record Keeping

GeoGuides LR3, LR4, LR5, LR6, LR8 and LR9 are of particular relevance to Townsville and the range of landslides that have been identified as part of this study. GeoGuides LR3, LR4, LR5, LR6, LR8 and LR9 are reproduced in Appendix H and should be consulted to provide guidance by TCC, property owners, developers and their respective professional advisers on landslide mitigation options that should be implemented as part of any development.

By way of example, where future development is undertaken over sloping ground in the Category 1 areas, it would be prudent to construct a rock roll catch bench upslope of the subdivision to reduce the risk of rockfall. Examples of such mitigation measures can be seen at Jenson and Deeragun (see Photograph 19).



Photograph 19: Contour drain at Deeragun which is also acting as a catch ditch for rock roll.

8. PLANNING PROVISIONS

8.1. Background

Sections 8.2 to 8.6 represent the Town Planning component supporting the various TCC landslide studies including this study by PSM and the earlier 2001 Coffey study (Reference 1). The Town Planning component includes a critical evaluation of the current Planning Scheme Provisions for both the former City of Thuringowa (COT) and Townsville City Council (TCC) and provides recommendations for the future planning scheme provisions and associated policy and codes relating to Landslide Hazard within the Townsville LGA.

Section 8.7 presents our review of the Townsville Local Disaster Management Plan and suggestions for review of this document.

8.2. Planning Objectives

The Town Planning objectives of the study include:

- Review and provide an assessment of the current planning scheme provisions relating to Landslide Hazard (i.e. Thuringowa and Townsville Planning Schemes) to identify the strengths and weaknesses of both in regulating development and providing sustainable outcomes.
- Provide a policy direction to regulate Landslide Hazard through the planning scheme and highlight the mandatory supporting information required to complete a comprehensive assessment.
- Develop a classification system to assess the level of risk and subsequent level of assessment required for a development application (e.g. whether development is exempt, self assessable, or subject to code or impact assessment).
- Recommendations for the implementation of a Landslide Hazard Code which clearly identifies the purpose of the code and how this will be achieved through performance criteria and acceptable solutions for compliance with the Landslide Hazard Code
- Review and update constraint mapping to clearly identify and establish areas inappropriate for urban development.
- Alignment of the new planning scheme with State Planning Policy SPP 1/03 and the Queensland Planning Provisions (QPP)

8.3. Assessment of Existing TCC and COT Provisions

8.3.1. City Plan 2005 - Townsville

1. Strengths

The assessment table in Section 5.20 of the Scheme is well presented in a relatively easy to follow format. The code covers a lot of elements allowing the assessment manager a degree of flexibility to identify specific outcomes that need to be achieved.

2. Weaknesses

A weakness is the prescribed level of code assessment for all developments within the overlay. Only one acceptable solution is provided to support one of thirteen specific outcomes and as a result constrains the ability for self assessment.

The overlay code is not proactive towards development and does not give weight to any geotechnical studies previously prepared when considering a subsequent application over the same land. It fails to acknowledge the need to assess the stability of the land and provide construction measures to support a material change of use (MCU) associated with a reconfiguration.

A major weakness of the Scheme is the overlay mapping. At a scale of 1:100,000@A3 the mapping is totally inadequate to clearly identify individual allotments and serves only as a tool to identify a general locality.

The code is over regulated, contains a lot of unnecessary information and is repetitive.
The outcomes within the code tend to be vague and uncertain. It includes terminology such as “manageable gradient” that is undefined and has no measurable solutions to support achievable outcomes.

8.3.2. City of Thuringowa Planning Scheme

1. Strengths

The code in Section 5.4.2 of the Scheme is concise, simple to implement and has limited duplication. The Steep or Unstable Lands section of the Natural Hazards Code and the applicable sections of the General Development Code cover the essential elements to achieve an effective assessment process.

Opportunities for self assessment are incorporated into the code through a two part system. Part A has measurable solutions for each outcome allowing self assessment to occur, while Part B is for assessable development only.

2. Weaknesses

A major weakness resulting from the lack of Natural Hazards Code mapping is the limited amount of clarity concerning the need for assessment against the Steep or Unstable Land Code.

The code assessment trigger only relates to land exceeding a 15% slope. The code does not clarify whether all or portion of the site must exceed 15% before triggering assessment and the lack of certainty provides the opportunity to manipulate the base data to avoid assessment.

Overall the concise nature of the code results in limited guidance and certainty.

8.3.3. Critique of Existing TCC & COT Codes

The schemes have totally different mechanisms to achieve outcomes for mitigating the potential for Landslide Hazards.

The Townsville overlay/code is comprised of an extensive list of provisions with limited scope for measurable/sustainable solutions. It lacks flexibility for self assessment, is difficult to administer and triggers code assessment for all forms of development. The lack of flexibility results in considerable delays and frustration for the development industry and increases workloads on Council to process potentially unnecessary development applications.

The Townsville scheme does not give weight to or recognise geotechnical certification for individual allotments that was required as a condition of reconfiguration. It is considered this could facilitate the opportunity for self assessment in respect to simple development applications such as detached houses.

The use of overlay codes in the City Plan to change the level of assessment classification is considered undesirable as it can affect a development either as a constraint or require additional assessment criteria.

The Thuringowa Code adopts a performance based approach with a more simplified format of assessment structure. The format provides flexibility and aligns with the emerging focus of planning legislation which is to expedite and simplify development processes and reduce the resources burden on Local Governments. In addition the Code provides a good example of where less is more and that over regulation is not always the answer to achieving appropriate outcomes. It however lacks an appropriate assessment trigger and mapping to support and strengthen the provisions which limit the ability to ensure consistency in application across the Planning Scheme.

8.4. Draft Planning Scheme Policy- Landslide Hazard

8.4.1. Purpose

The purpose of this Planning Scheme Policy is to support the Landslide Hazard Overlay Code. The code seeks to ensure that development maintains the safety of people, property and hazardous materials manufactured or stored in bulk from the risk of landslide. The Landslide Hazard code and subsequently this policy, applies to self assessable and assessable development on land identified as being within TCC Landslide Hazard Overlay Map.

8.4.2. Supporting Information

Where a development is subject to the Landslide Hazard Overlay Code, Council may request an assessment of the likely geotechnical impacts of the proposed development and provide recommendations to avoid and mitigate unacceptable risks. Geotechnical investigations must consider the following matters set out below, and may include, but not be limited to:

- Desktop studies include analysis and commentary on matters addressed in the PSM Report (Landslide Hazard Zoning Study, Townsville City Area: September 2010);
- Evaluation of slope instability indicators (including such factors as seepage, soil creep, vegetation and building distress);
- Collection of geological and topographical measurements from the site;
- Consideration of stability and affects to/from land above and below the proposed development site;

- Identification of landslip/subsidence risk areas; and
- Recommendations for building design and construction measures, stormwater disposal, earthworks, retaining walls, inter-allotment drainage, effluent disposal, vegetation retention and site maintenance.
- Development of a geotechnical model for a reconfiguration of a lot and adjacent areas of influence (at least 50m uphill and adjacent to the subject land) in accordance with the site investigation requirements of AS1726-1993.

8.4.3. Information Requirements

Under the Sustainable Planning Act 2009, the Integrated Development Assessment System Council and other referral agencies may request additional information to assist in the assessment of a development proposal.

An information request by Council may include a Geotechnical Assessment Report prepared by a suitably qualified and experienced Engineering Geologist or Geotechnical Engineer or Registered Professional Engineer and any other relevant information pursuant to *State Planning Policy 1/03: Mitigating the Adverse Impacts of Flood, Bushfire and Landslide.*

A Geotechnical Assessment Report may be required to include all or some of the following components:

(a) Site description:

- Location;
- site dimensions;
- contour lines to AHD (500mm vertical intervals);
- existing easements;
- existing services, such as sewer, stormwater, water, gas, electricity, telephone and other utility services;
- drainage;
- vegetation;
- existing development;
- existing/proposed cuts and fills.

(b) Proposed development:

- building location and setback dimensions
- proposed on-site drainage system;
- earthwork details and building pad levels;
- driveway location and slope;
- proposed easements

- landscaping
- ancillary structures, such as pergolas and sheds;

(c) Geotechnical constraints on development:

- Steepened areas and steep-sided gullies;
- Cuts and fills (to be the subject of specific investigation and design);
- Retaining walls;
- Rock outcrops, boulders on or above the site;
- Surface/sub-surface drainage including flow path gullies;
- Septic tank disposal;
- Erosion controls, and
- All construction procedures to be in accordance with Australian GeoGuides LR8 for good hillside construction practice

(d) Geotechnical Assessment

- Regional geological context;
- Engineering geological mapping, geomorphology (i.e. slope forms) and slope angles;
- Sub-surface investigations (factual drillhole/test pit data) and including interpretation of results (interpreted geological profile);
- Groundwater conditions;
- Identification and assessment of geological and hydrological hazards including identification of landslides, subsidence, erosion, and flooding (i.e. hazard analysis);
- Slope stability analyses including numerical analyses and assessment based on geological precedence (i.e. long term performance of slopes)
- Landslide risk assessment in accordance with the procedures of the Australian Geomechanics Society, 2007c

(e) Independent Peer Review

- Independent peer review of development proposals and geotechnical assessment reports is to be encouraged for development on land within Zone 4 of TCC Landslide Hazard Overlay Map, and within land identified as "Gully flow paths" on Overlay Maps provided in Figures 3 to 8 of this report.

8.5. Draft Levels of Assessment – Overlays

Tables 8.1 to 8.2 following identify where an overlay changes the level of assessment from that identified in a Zone or Local plan and the relevant assessment criteria.

TABLE 8.1
OVERLAYS WHICH CHANGE THE LEVEL OF ASSESSMENT

DEVELOPMENT	CHANGE TO LEVEL OF ASESSMENT
Landslide Hazard Code	
Utility Installation	**Exempt**
Material Change of Use	**Self- Assessable** If complying with the assessment criteria being the acceptable solutions listed in the Assessment Criteria. **Code Assessable** If not self-assessable
Reconfiguring a Lot and associated Operational Works	**Code Assessable**

TABLE 8.2
ASSESSMENT CRITERIA FOR OVERLAYS

DEVELOPMENT	CHANGE TO LEVEL OF ASESSMENT
Landslide Hazard Code	
Material Change of Use	(1) A material change of use affected by the Landslide Hazard Overlay is assessed against the following assessment criteria as listed; a) Development identified as self-assessable, only the **acceptable solutions AO1.1-1.2, AO2.1, AO3.1-3.3** listed in Table 8.3 apply. b) Performance Criteria **PC1-PC7** listed in Table 8.3 applies to all code and impact assessable development subject to this code.
Reconfiguring a Lot and associated Operational Works	Performance Criteria **PC1-PC5** listed in Table 8.3 apply to all code and impact assessable development subject to this code

8.6. <u>Code Structure</u>

8.6.1. Purpose

The purpose of the Landslide Hazards code is to regulate development occurring on land, or part of any land, containing steep slopes. This code seeks to minimise the potential for erosion or land slippage;

- Effectively manage stormwater runoff;
- Minimise erosion and slope instability events on slopes exceeding an average gradient of 23°;
- Reduce the visual impacts of buildings and associated works through suitable external building treatment and landscaping; and
- Encourage safe and efficient vehicular access onto steeply sloping land.

8.6.2. Overall Outcomes

This code applies to any development being self, code or impact assessable in the Table of Development in the Zone or Local Area Plan (LAP) within which the development is proposed. In particular, this code applies to development on land that is steep or potentially geologically unstable, as identified as **Zones 1 to 4** on **TCC Landslide Hazard Overlay Map**, and those areas identified as "**Very low landslide risk"**, **"Low landslide risk"** and **"Gully flow paths"** on Overlay Maps provided as Figures 3 to 8 of this report. As well, the code also applies to all other sloping areas of Townsville not covered by either Zones 1 to 4 on TCC Landslide Hazard Overlay Map or those areas identified as "Very low landslide risk", "Low landslide risk" and "Gully flow paths" on Overlay Maps provided as Figures 3 to 8 of this report.

Performance Criteria **PO1-PO7** applies to all code and impact assessable development subject to this code (Table 8.3). For development identified as self-assessable, only the acceptable solutions to Performance Criteria **PO1-PO3** apply (Table 8.3).

Any variation to the acceptable solutions contained in this code must be certified. The long-term stability of any design, beyond the limits specified in this code, is to be certified by an appropriately qualified and experienced engineering geologist, geotechnical engineer or registered professional engineer appropriately experienced in slope stability investigations.

TABLE 8.3

STEEP SLOPES OR UNSTABLE SOILS TABLE 3 FOR SELF-ASSESSABLE AND ASSESSABLE DEVELOPMENT.			
Performance Outcomes		**Acceptable Outcomes**	
Site Slope Constraints			
PO1	Building work must be responsive to the constraints of the land	**AO1**	**AO1.1-** Development is not undertaken on land with a maximum slope exceeding 23°. OR **AO1.2-** The development is for a detached/dual occupancy dwelling associated with a residential reconfiguration approval (i.e. the lot is intended to be serviced by sewerage reticulation) and the development complies with the conditions of the reconfiguration approval and any subsequent operational works approval.

TABLE 8.3 (Cont)

STEEP SLOPES OR UNSTABLE SOILS TABLE 3 FOR SELF-ASSESSABLE AND ASSESSABLE DEVELOPMENT.			
Performance Outcomes		**Acceptable Outcomes**	
Slope Stability			
PO2	All development on land within Zone 1 identified on TCC Landslide Hazard Overlay Map, and within land identified as "Very low landslide risk" on PSM Overlay Maps provided as Figures 3 to 8 of this report.	**AO2**	AO2.1- An engineering Report, prepared by a registered professional engineer appropriately experienced in slope stability matters is used to assess the stability of the land and provide engineering measures to support the construction of the development.
Build Form Character			
PO3	The building style and construction methods used for development on sloping sites must be responsive to the constraints of steep slopes.	**AO3**	**AO3.1-** A split-level building form that generally conforms to the land slope profile is utilised. **AO3.2-** A single plane concrete slab is not used except where the development is for a detached dwelling, associated with a residential reconfiguration approval (i.e. the lot is intended to be serviced by sewerage reticulation) and the development complies with the conditions of the reconfiguration approval and any subsequent operational works approval. **AO3.3-** Areas between the building's floor and the ground level, or between outdoor deck areas and the ground level, are screened from view by using lattice or other appropriate screening devices and/or landscaping.

TABLE 8.3 (Cont)

DEVELOPMENT THAT IS CODE ASSESSABLE OR IMPACT ASSESSABLE			
Storm Water Drainage			
PO4	Development on steep slopes must ensure that the quality and quantity of stormwater traversing the site must not cause any detriment impact to the natural environment or to adjacent properties.	**AO4**	**AO4.1-** All stormwater drainage associated with the site must be discharged to a lawful point of discharge and must not adversely impact upon adjacent properties, downstream properties, upstream or underground streams.
Cut and Fill Work			
PO5	All cut and fill work must not create a detrimental impact on the slope stability, erosion potential or visual amenity. Note; Provisions should be supported by best practice guidelines for storm water management, soil erosion and sediment control.	**AO5**	**AO5.1**- The height of cut and/or fill, whether retained or not, does not exceed: a) 900mm adjoining a public area; b) 1200mm adjoining a residential site; c) 2500mm adjoining a non-residential site. **AO5.2-** Cuts in excess of those stated in AS5.1 are separated by terraces with a minimum width of 1.2 metres that incorporate drainage provisions. **AO5.3-** No crest of any cut or toe of any fill, or any part of any retaining wall or structure, is located closer than 600mm to any boundary of the property, unless the prior approval of both landowners and the Council, or its delegate, has been obtained. **AO5.4-** Constructed slopes (i.e. cuts and fills) exceeding 800m in depth/height respectively shall be the subject of specific engineering investigation and design. *Note: Acceptable Outcomes should be in accordance with Australian GeoGuide LR8 for good hillside practice.*

TABLE 8.3 (Cont)

DEVELOPMENT THAT IS CODE ASSESSABLE OR IMPACT ASSESSABLE			
Geotechnical Assessment			
PO6	All development on land within Zones 2, 3 and 4 identified on **TCC Landslide Hazard Overlay Map** and within land identified as "Low landslide risk" and "Gully flow path" on PSM Overlay Maps provided in Figures 3 to 8 of this report.	**AO6**	AO6.1 A geotechnical Assessment Report is to prepared in accordance with Planning Scheme Policy – Landslide Hazard
Access			
PO7	Development on steep slopes must ensure that vehicle and pedestrian access is achieved in a safe and efficient manner.	**AO7**	**AO6.1-**The development area for each allotment is accessible by a legal road access and/or access easement **AO6.2**- Any section of a driveway(s) internal to a site is not steeper than 25% (1V:4H).

8.7. Local Disaster Management Plan

TCC has a Local Disaster Management Plan which has been prepared in accordance with the requirements of Section 57(1) of the Disaster Management Act 2003. The Local Disaster Management Plan sets out Townsville's response to provide equipment and personnel, using the resources available to the City, to effectively deal with an emergency situation or a disaster within Townsville.

As part of the requirements of Contract T5631, Townsville's Local Disaster Management Plan has been reviewed to ascertain whether there is scope to improve the plan particularly in relation to the City's ability to respond to landslide events (being the subject of this report) which in turn are mainly related to cyclonic rainfall events.

Section 2.5 of Townsville's Local Disaster Management Plan provides a discussion of critical infrastructure and essential services for Townsville. It is noted that all of the infrastructure assessed as part of this report (i.e. Contract T5631) including the road network, water supply pipelines and tanks, sewerage facilities are identified under Section 2.5 of the Local Disaster Management Plan. It is also noted under Section 2.5.10 of the Plan that "some roads may be blocked by landslide debris".

Section 2.7 of the Local Disaster Management Plan provides a description of the hazards affecting Townsville. Section 2.7.1 of the Plan provides a description of climate and weather-related hazards which includes a discussion of related problems such as heavy rain, land floods (including water logging), destructive winds, storm surges on coastal fringes, soil erosion, riverbank and coastal erosion, sedimentation effects on alluvial flood plains, and large scale transport of marine sediments. However, there is no mention of landslides as a related hazard.

Section 2.7.3 of the Plan provides an analysis of the principal hazards in which landslides – at Section 2.7.3.2 – are discussed as being related to wet season heavy rains and cyclones. Section 2.7.3.2 references the landslide risk assessment studies carried out by TCC in 2004 (Reference 13). While the results of the earlier 2001 regional landslide study are included in the 2004 study, the 2001 regional landslide study is not specifically referenced in the Plan.

Section 3 of the Plan details disaster risk treatment options for Townsville. Section 3.1 references the landslide stabilisation work implemented in 2004 for the Castle Hill and inner city areas. Section 3.2 of the Plan provides a list of local and state government agencies that have been identified as having a role and responsibility under the Plan. Significantly, there is no mention of the Department of Main Roads and Transport (TMR) which it is considered would have a role to play and be responsible for some road-related issues (e.g. TMR are responsible for maintenance of Paluma Road).

Section 4 details a number of operational plans prepared (or in preparation) to support Townsville's Local Disaster Management Plan. Two of the operational plans – "Impact Assessment Plan" and "Transport Plan" – are likely to be relevant to the findings of this report, but both are currently in preparation. It is recommended that PSM be given the opportunity to review both these operational plans before completion.

The Townsville Local Disaster Management Plan includes two maps (scale 1:130,000 and 1:30,000) showing amongst other factors evacuation routes for Townsville. The smaller scale map provides coverage of the greater Townsville area while the larger scale map covers the city limits. Our review indicates that the evacuation routes for Townsville are currently restricted to urban areas only. Rural areas such as Paluma village and the Alligator Creek/Mount Elliot area are currently un-serviced under the Plan by identified evacuation routes.

On the basis of this review, minor changes to the Townsville Local Disaster Management Plan are deemed necessary, including improved referencing of landslides as a weather-related hazard, and provision of evacuation routes for rural areas such as Paluma village and the Alligator Creek/Mount Elliot areas.

9. CONCLUSIONS AND RECOMMENDATIONS

9.1. Conclusions

9.1.1. General

This regional landslide risk assessment study has been conducted in accordance with the methodology detailed in State Planning Policy (1/03) and follows the processes recommended by the Australian Geomechanics Society (2007). The study should be considered as being appropriate for assessment of the landslide risk associated with natural slopes and is not applicable to the assessment of constructed slopes (i.e. cuts and fill slopes). This is a regional study and is intended for use as a planning instrument to support the TCC City Plan to identify landslide risks to allow informed development. The study is also considered appropriate as a means of identifying the landslide risk associated with selected road corridors which provide emergency access and evacuation routes for Townsville.

9.1.2. Category 1 Study Areas

Category 1 study areas (including Paluma Village, Toomulla, Mount Low, Jensen, Deeragun, and Alligator Creek/Mount Low) are all potential Townsville growth areas and include a mix of high and low density residential development and Council infrastructure (roads, above ground pipelines, above ground sewer pipes, water tanks and radio masts). This study has shown that the Category 1 areas are typically impacted (where instability occurs) only by shallow slope instability and rock roll and localised rock fall. No deep-seated or large-scale slope instability was identified, nor were areas affected by potential debris flows identified. On the basis of these findings, we conclude that the Category 1 areas have a very low and low landslide risk.

According to the Australian Geomechanics Society (2007), very low and low landslide risks have the following implications (Table 9.1) (Reference 26).

TABLE 9.1
LANDSLIDE RISK LEVEL IMPLICATIONS

RISK LEVEL	EXAMPLE IMPLICATIONS
Low risk	Usually acceptable to regulators (that is, without any treatment). Where treatment has been required to reduce risk to this level, ongoing maintenance is required.
Very low risk	Acceptable. Manage by normal slope maintenance procedures.

Within the low risk landslide areas, in places there may also be localised occurrences subject to rockfall which are likely to exhibit higher risks. These higher risk rockfall areas are too localised to illustrate on the landslide overlay maps. As there is a requirement within low landslide risk areas to conduct detailed geotechnical reporting as part of subdivision approvals, their occurrence will be identified as part of this (subdivision approval) process.

Category 1 areas also include drainage paths which are identified in the study as gully flow paths. There is no evidence of gully flow paths being affected by debris flows but clearly the gullies represent a potential hydraulic (as distinct from geologic) risk to any development in their path. In this context, gully paths could be affected by torrent flows during high intensity rainfall events which could adversely impact on any development through inundation. Gully paths have therefore not been given a landslide risk but separate allowance has been made for these features in the landslide risk overlay maps.

9.1.3. Category 2 Areas.

Paluma Road clearly has a long and well-established history of landslide activity over its alignment. We have been able to ascertain that on average the road is affected by between five (5) to 10 landslide events annually in response to sever rainfall events some of which result in road blockage. At least one fatality on Paluma Road has been recorded (1997) which is a reflection of the high landslide hazard for this road. In its current condition, ongoing instability and associated road blockages must be anticipated for Paluma Road.

Hervey Range Road has apparently only rarely been closed from landslide activity since construction in its current road form and there have been no road closures in the last 5 years. The road was apparently closed for several days following Cyclone Sid in 1998 due to rockslides. It is concluded there is some ongoing potential for slumping, rockfall and debris flows and associated road closure from rare, large rainfall events but frequency is unknown.

The Bruce Highway and TCC pipeline at Rollingstone are generally considered to be removed from any landslide and rock roll hazard. A small section of the TCC pipeline crosses the toe of the slope and is considered to be within a low rock roll hazard zone.

9.1.4. Category 3 Areas

PSM has re-examined Yarrawonga Subdivision (Castle Hill), Ocean View, Crestbrook and Greenview Subdivisions (Mount Louisa), Riverside Ridge Subdivision (Douglas), Wulguru Heights Subdivision (Wulguru, Roseneath) and Oak Valley Subdivision. These areas were included as part of a 2001 regional Townsville landslide hazard study and their respective landslide hazards incorporated on TCC Landslide Hazard Overly Maps. Using the same methodology as the 2001 study (i.e. assessment being restricted to the stability of natural slopes) we conclude that the findings of the 2001 study are appropriate for the areas we have evaluated.

9.1.5. Climate Change

Other than a possible increase in the number of severe cyclones which may occur over the next 60 years or so, climate change is unlikely to be a factor which will alter the landslide risk of Townsville.

9.1.6. Overlay Risk Maps

A series of landslide overlay maps have been produced for the Category 1 areas which provide suburb-scale landslide risk zoning plans for the purposes of land use planning. The purpose of the overlay maps is not to identify the exact location of every landslide hazard, but rather to provide a general indication of hazards within the areas and enable assessment of broad risk level zones. These plans should not be used for identifying the potential risk to single building lots.

9.1.7. Landslide Mitigation Options

Australian GeoGuides LR3, LR4, LR5, LR6, LR8 and LR9 are considered to be appropriate guidelines for use as landslide mitigation options for implementation as part of any hillside development. However, it should be noted that all of the Australian GeoGuides are by their very nature generic and hence there will always be a requirement for site specific geotechnical assessment and engineering design for whatever measure is implemented to mitigate landslide risks.

9.1.8. Planning Provisions

A Landslides Hazards code is proposed to govern any development occurring on land or part of any land containing steep slopes. The code applies to any development being self, code or impact assessable in the Table of Development in the Zone or Local Area Plan (LAP). The code applies to any development:

- Category 1 areas covered by this report (PSM, 2010);
- All areas covered by the TCC Landslide Hazard Overlay Maps (which are based on the 2001 regional landslide hazard study (Reference 1);
- Any sloping area not covered by either this report or the TCC Landslide Hazard Overlay Maps;

Performance Criteria apply to the Landslides Hazards code for all code and impact assessable development.

9.1.9. Local Disaster Management Plan

Some minor changes to the Townsville Local Disaster Management Plan are considered necessary, including improvements with the referencing of landslides as a weather-related hazard within the Plan, and the provision of emergency evacuation routes for rural areas such as Paluma village and Alligator Creek/Mount Elliot.

9.2. Recommendations

9.2.1. Category 1 Areas

No further regional-scale investigations of any Category 1 areas are considered necessary. All Category 1 areas will however need to be the subject of site specific investigations depending on the level of assessment deemed to be necessary for specific development applications in accordance with the requirements of Table 7.1.

9.2.2. Category 2 Areas

If the existing emergency access provisions associated with Paluma Road are to be improved or enhanced, then either:

- There is a requirement to implement a programme of engineering remedial and stabilisation works for the road, or
- An alternative access route should be identified for those situations when the road is blocked and access lost as a result of landslide damage.

Maintenance of Paluma Road is the responsibility of TMR and hence TCC may wish to negotiate directly with TMR to jointly assess the most appropriate of the above two options for Paluma Road. If it is decided to implement a programme of engineering remedial and stabilisation works for the road, the results of this study will not in itself be adequate to allow design of the works. A full engineering study of the road including (but not limited to) evaluation of culvert adequacy, retaining wall stability and road shoulder stability will need to be conducted.

No additional investigations are deemed necessary for either Hervey Range Road or Bruce Highway at Rollingstone.

9.2.3. Category 3

The 2001 regional landslide study as reflected by the TCC Landslide Hazard Overlay Maps indicates four landslide hazard zones. It should be recognised that the 2001 regional landslide study was completed before publication of the 2007 Australian Geomechanics Society landslide risk assessment procedure. As such the 2001 regional landslide study is not based on a risk assessment process using the latest Australian landslide risk assessment methodology. For the sake of consistency with this study, and when funding permits, it is recommended that the current TCC Landslide Hazard Overlay Maps be updated to reflect landslide risks in accordance with the procedures of the Australian Geomechanics Society, 2007.

9.2.4. Landslide Mitigation Options

It is recommended that Australian GeoGuides LR3, LR4, LR5, LR6, LR8 and LR9 be adopted by TCC as guidelines for use as landslide mitigation options for implementation as part of any hillside development.

9.2.5. Planning Provisions

It is recommended TCC review the proposed Landslides Hazards code and if deemed appropriate, adopt the code for the City Plan.

9.2.6. Local Disaster Management Plan

The following recommendations are made in relation to improvements to the Townsville Local Disaster Management Plan:

- Improved referencing of landslides as a weather-related hazard within the Plan.
- Identified evacuation routes be identified for Paluma village and the Alligator Creek/Mount Elliot area and shown on the relevant maps accompanying the Plan.
- Consideration to be given to include Department of Main Roads & Transport (TMR) as having a role to play and being partly responsible for the road network as part of the Plan.
- This report to be included as a reference document when the Plan is next updated.

For and on behalf of
PELLS SULLIVAN MEYNINK

GUY GROCOTT RALPH CAMMACK

10. ADDENDUM

10.1. Background

This section of the report (completed subsequent to preparation of PSM1463.100R in March 2011) details the results of work carried out to integrate landslide overlay maps of various generations and origins relating to Townsville City to form a common integrated landslide risk overlay map for use with the new TCC City Plan. In particular, three (3) generations of landslide overlay maps are identified:

- Coffey, 2001.
- Coffey, 2004.
- PSM, 2011.

In 2001 TCC commissioned Coffey Geoscience Pty Ltd (Coffey) to carry out regional landslide hazard studies for selected areas of Townsville (hereafter referred to as **TCC's 2001 landslide hazard assessment)** (Reference 1). The results of this work now form a series of Steep Or Unstable Land Overlays which are incorporated into the **Current Steep or Unstable Land Overlay Code** of the City Plan (**TCC's Steep or Unstable Land Overlays)**. Further discussion of TCC's Steep or Unstable Land Overlays is given in Section 10.3.3 following.

In 2004, TCC commissioned Coffey to conduct a landslide risk assessment of Castle Hill (**Townsville Steep Slope Risk Assessment**) (Reference 13). This work arose out of ongoing slope instability problems with the Castle Hill area particularly associated with cyclonic rainfall events. Further discussion of the Townsville Steep Slope Risk Assessment is given in Section 10.3.4 following.

In 2011, PSM was commissioned by TCC to conduct a landslide risk assessment of potential growth areas of Townsville not covered by TCC's steep lands overlay maps. Results of this study were reported in March 2011 as PSM1463.100R (**PSM's 2011 landslide risk assessment**) and included a series of landslide risk assessment overlay maps (**PSM's landslide risk assessment overlays**). The PSM study was intended to form part of a new steep lands code for development occurring on sloping ground (**Proposed TCC Steep or Unstable Lands Code**) which is being prepared as part of a new TCC City Plan. Further discussion of PSM's landslide risk assessment overlays is given in Section 10.3.5 following.

10.2. Identification of Issues with TCC's Steep or Unstable Land Overlays

For the following reasons, TCC's steep or unstable land overlays are not directly compatible with PSM's landslide risk assessment overlay maps and hence the two overlays in their current form cannot be used as an integrated overlay:

- PSM's 2011 landslide risk assessment was completed in accordance with the requirements of AGS (2007c) "Practice Note guidelines for landslide risk management" (Reference 26). This was based on a quantitative assessment of the risk posed to human life which requires both landslide frequency and consequence - in the event of a landslide event occurring - to be assessed numerically.
- The risk assessment methodology of AGS (2007c) (Reference 26) is based on a tiered classification system incorporating five (5) risk levels:

- Very high risk.
- High risk.
- Moderate risk.
- Low risk.
- Very low risk.

- For the urban growth areas investigated, PSM's landslide risk assessment overlays include only 2 landslide risk categories ("Very low risk" and "Low risk") with a third separate category for debris flows.
- TCC's steep or unstable land overlays are landslide **hazard** maps (as distinct from landslide **risk** maps). Hazard maps reflect only the type, scale and frequency of instability whereas landslide risk maps also involve assessment of both landslide frequency and the consequences (property damage, death to an individual) in the event of a landslide occurring.
- TCC's 2001 steep and unstable land overlays have been developed using definitions from AGS (2000) (Reference 29) using a simplified classification of landslide hazard as given in Table 1 of Reference 1 (reproduced in Appendix I):

    - Very unlikely landslide hazard (Zone 1).
    - Unlikely landslide hazard (Zone 2).
    - Potential landslide hazard (Zone 3).

  The hazard categories Zones 1, 2 and 3 are the construct of the authors and are not based on a recognised published landslide hazard classification system such as AGS (2000) (Reference 29) or AGS (2007) (Reference 26).

10.3. Review of Data Sources to Support an Integrated Landslide Overlay Mapping System

10.3.1. Data Sources

As detailed above in Section 10.1, there are three (3) sources of landslide overlays covering Townsville City that need to be integrated to form a common overlay mapping system to support TCC's new Steep Lands Code:

- TCC's steep or unstable land overlays (Reference 1).
- Townsville Steep Slope Risk Assessment (overlay map given as Figure 4.2 of Reference 13) and.
- PSM's landslide risk assessment overlay maps (PSM1463.100R).

10.3.2. Need to Establish Landslide Data Consistency

The assumption is that any system of integrated landslide risk overlays for Townsville City will need to be consistent with AGS (2007c) (Reference 26). This means that overlays will need to depict varying degrees of landslide risk as distinct from landslide hazard. Furthermore, it is understood that landslide risk can be expressed either as property risk or as risk to life (which requires a higher level of assessment). Due to limitations in available data for some landslide study areas, for consistency landslide risk has been expressed as risk to property for all study areas.

The remainder of Section 10.3 provides a brief review of each of the above three data sources in terms of the requirements to establish an overlay mapping system based on risk to property in accordance with AGS (2007c) (Reference 26).

10.3.3. TCC's Steep or Unstable Land Overlays

TCC's steep or unstable land overlays are based on regional scale mapping (scale typically 1:10,000 @ A3) and incorporate qualitative descriptive definitions as provided in Table 2 of TCC's 2001 landslide hazard assessment (Reference 1) (reproduced in Appendix J). Table 2 of Reference 1 details the "**Likelihood**" terms for Zones 1, 2 and 3 of TCC's steep or unstable land overlays. **"Consequence"** terms are also provided in Table 2 of Reference 1 for Zones 1, 2 and 3, which are not required as part of a landslide hazard assessment but are probably offered to assist with the subsequent development control discussions in Reference 1.

As the "Likelihood" and "Consequence" definitions of Table 2 of Reference 1 (refer Appendix J) are consistent with both AGS (2000) (Reference 29) and AGS (2007c) (Reference 26), it is considered the definitions which support TCC's steep and unstable land overlays may be able to be used to derive risk to property in accordance with AGS (2007c) (Reference 26). The methodology which PSM has used to derive risk to property from TCC's Steep or Unstable Land Overlays in accordance with the criteria of AGS (2007c) (Reference 26) is described below.

The definitions highlighted in Table 2 of Reference 1 (refer Appendix J) have been plotted onto the AGS (2007c) risk assessment matrix for property risk (refer Appendix K) from which property risk categories have been delimited as per Table 10.1 of this report.

It is noted that cell C3 of the AGS (2007) risk matrix (refer Table 10.1 below) overlaps both the "Low-Medium" category and the "Medium-High" property risk categories (refer Appendix C). In order to resolve the overlapping issue, it would not detract from the intent of the AGS (2007c) risk matrix if Zone 3 was re-classified as "High-very high property risk" (i.e. cells B2, B3, C2); the "lost" C3 cell would be covered by the lower risk "Low – medium" property risk as per Table 10.2. We recommend the AGS (2007c) risk matrix given in Table 10.2 below be adopted by TCC for the assessment of property risk.

TABLE 10.1
PROPERTY RISK MATRIX FOR TCC's STEEP OR UNSTABLE LAND OVERLAYS

TCC STEEP OR UNSTABLE LAND OVERLAYS ZONE	CONSEQUENCES[1]	LIKELIHOOD[1]	AGS (2007) RISK MATRIX[2]	ASSESSED PROPERTY RISK[2]
Zone 1	Insignificant to Minor	Rare	E4, E5	Very low
Zone 2	Minor to Medium	Unlikely to Possible	C3, C4, D3, D4	Low - Medium
Zone 3	Medium to Major	Possible to Likely	B2, B3, C2, C3	Medium – Very high

Note 1: From Table 2, Reference 1 (refer Appendix J of this report)
Note 2: From Qualitative Risk Analysis – Level of Risk to Property, Appendix C, AGS (2007c) (Reference 26) (refer Appendix K of this report)

TABLE 10.2
ADOPTED PROPERTY RISK MATRIX FOR TCC's STEEP OR UNSTABLE LAND OVERLAYS

TCC STEEP OR UNSTABLE LAND OVERLAYS ZONE	CONSEQUENCES[1]	LIKELIHOOD[1]	AGS (2007) RISK MATRIX CELLS[2]	ASSESSED PROPERTY RISK[2]
Zone 1	Insignificant to Minor	Rare	E4, E5	Very low
Zone 2	Minor to Medium	Unlikely to Possible	C3, C4, D3, D4	Low - Medium
Zone 3	Medium to Major	Possible to Likely	B2, B3, C2 (cell C3 dropped)	High – Very high

10.3.4. Townsville Steep Slope Risk Assessment

In 2004, TCC commissioned a detailed risk assessment of steep slopes in the inner Townsville City area particularly Castle Hill (Reference 13). This study addressed a number of distinct landslide hazards affecting both natural and constructed slopes (e.g. road cuttings) including:

- soil slides;
- debris flows;
- rock slide, rock topple, rock fall; and
- boulder movements.

The landslide risk assessment was conducted using terms generally consistent with the definitions of AGS (2000) (Reference 29). Two methodologies were used for the assessment of landslide risk for the study areas:

- Qualitative risk assessment by census district (CCD) for the wider study area utilising property exposure and community vulnerability for each of the CCD's. The methodology is consistent with a qualitative risk to property approach as defined by AGS (2007c) (Reference 26). An overlay map was produced (Figure 4.2 of Reference 13) at scale 1:2,5000 @ A3 depicting landslide risk (reproduced in Appendix L).
- Quantitative risk assessment for five (5) local areas affected by specific slope hazards. The risk to life was assessed numerically for these cases.

The qualitative risk assessment by CCD resulted in a landslide risk overlay map which is identified as Figure 4.2 in Reference 2 (reproduced in Appendix L of this report). Figure 4.2 of Reference 13 resulted in a five (5) tiered landslide risk classification system which is summarised in Table 10.3.

TABLE 10.3
TOWNSVILLE STEEP SLOPE RISK ASSESSMENT CATEGORIES

Townsville steep slope risk assessment[1]
High Risk[2]
Medium high risk[2]
Medium[2]
Medium low risk[2]
Low risk[2]

Note 1: Refer Figure 4.2, Reference 13 (Reproduced in Appendix L).
Note 2: Terms considered to be consistent with AGS (2000) (Reference 29).

We note that the Townsville steep slope risk assessment study differs significantly from both the TCC'S steep or unstable lands overlays and PSM's landslide risk assessment overlays in terms of the mapping scale. TCC's steep or unstable land overlays and PSM's landslide risk assessment overlays are both based on regional scale studies with mapping scales being relatively small. In contrast the Townsville steep slope risk assessment study was a detailed study for a specific area of Townsville (i.e. Castle Hill) and the resulting overlay maps were at larger scale.

Due to the differences in mapping scale and differences in assessment level, we are of the view that it would not be appropriate to attempt to combine the Townsville steep slope risk assessment overlay with the overlays from the other two studies. In other words, Figure 4.2 of Reference 13 which is the overlay for Castle Hill from the Townsville steep slope risk assessment should be allowed to stand on its own within the Proposed Steep or Unstable Land Code of the new City Plan.

10.3.5. PSM's Risk Assessment Overlays

PSM's landslide risk assessment was a regional scale study of urban growth areas not covered by TCC's steep lands overlay maps. PSM's landslide risk assessment overlays were produced at varying scales ranging from 1:2,500 to 1:10,000 @A3 and depict risk to life (Reference 3). The methodology adopted for the risk mapping is consistent with AGS (2007c) (Reference 26) (Section 2).

10.4. Proposed System of Overlay Integration

Based on the preceding discussion above, it is not considered possible to develop a single integrated overlay map system using the three generations of overlays as described above in Section 10.1 and Sections 10.3.3 to 10.3.5 to support TCC's new Proposed Steep or Unstable Lands Code of the new City Plan. This conclusion is reached mainly due to differences in the mapping scale and differences in assessment level adopted by the various generations of overlays (i.e. regional versus local).

However it is considered possible to develop two (2) separate overlay maps each of which can be used in combination to support the Proposed Steep or Unstable Land Code of the new City Plan along the following lines:

- An integrated overlay incorporating TCC's steep or unstable land overlay (Reference 1) and PSM's landslide risk assessment overlays (PSM1463.100R) (being one overlay) (refer Section 10.5).
- Figure 4.2 from Townsville's steep slopes risk assessment (Reference 13) (being a second separate overlay) (Refer Section 10.6).

10.5. Integration of TCC's Steep or Unstable Lands Overlays and PSM Landslide Risk Assessment Overlays

Integration of TCC's steep or unstable lands overlays with PSM's landslide risk assessment overlay maps has been achieved by means of:

- Conversion of PSM's landslide risk to life overlays to property risk overlays.
- Compilation of new GIS property risk overlay maps for those parts of Townsville incorporating TCC's steep land overlay maps and PSM's landslide risk assessment overlay maps (i.e. proposed integrated overlay maps for all steep land areas of Townsville excluding Castle Hill) (Refer Figure 18).
- Preparation of new development controls for each of the property risk categories detailed in Table 4 of this report (Section 10.).

By adopting the highlighted right hand column of the risk matrix in Table 10.2 for TCC's Steep or Unstable Land overlay, it would then be possible to integrate TCC's Steep or Unstable Land overlays and PSM's landslide risk assessment overlays to have a common qualitative property risk classification as shown in the highlighted left hand column of Table 10.4. Correlation of the property risk category between TCC's Steep or Unstable Lands overlays and PSM's landslide risk assessment overlays is also given in Table 10.4.

TABLE 10.4
RECOMMENDED INTEGRATED PROPERTY RISK CATEGORIES

AGS (2007) property risk	AGS (2007) Risk Matrix Cells	TCC's steep or unstable lands overlays	PSM's landslide risk assessment overlays
Very low risk	E4, E5	Zone 1	Very low risk
Low risk	D3, D4, E3	NA	Low risk
Low – medium risk(adopt the term "medium risk")	C3, C4, D3, D4	Zone 2	NA
High – very high risk (adopt the term "high risk")	B2, B3, C2	Zone 3	NA
Debris flow risk	NA	Zone 4	Debris Flow Path

We note that the "Low – medium" risk has cells D3 and D4 which overlap with the "Low risk" property risk (Table 4). It is not possible on the available data to further differentiate the "Low – medium" property risk category to eliminate the overlapping cells of the risk matrix. We see the most appropriate way of dealing with this is for the "Low – medium risk" category to be reassigned as "Medium risk", which is a conservative approach.

Table 10.4 also includes the category identified as "Debris Flow Risk" which is common to both Zone 4 of TCC's Steep or Unstable Lands Overlays and the category identified as "Debris Flow Path" in PSM's landslide risk assessment overlays.

Figure 18 illustrates the integration of TCC's Steep or Unstable Land overlays and PSM's landslide risk assessment overlays. Inspection of Figure 18 shows the legend identifies the different overlay sources:

- 2001 risk categories (i.e. TCC's Steep or Unstable Land overlays)
- PSM (PSM's landslide risk assessment overlays)

10.6. Townsville Steep Slope Risk Assessment Overlay

Figure 4.2 of Reference 13 (reproduced in Appendix L) has also been prepared as a GIS overlay map using the same risk legend as shown on Figure 4.2 of Reference 13. Figure 18 illustrates the various risk categories for Townsville's Steep Slopes Risk Assessment which has been sourced from Figure 4.2 of Reference 13.

10.7. Overlay Outputs

Shapefiles have been prepared of the new landslide overlays for use with TCC's Enterprise GIS. Some of the limitations associated with the use of the new overlays are discussed in Section 10.8 following.

10.8. Limitations of TCC's Landslide Overlay Maps

10.8.1. Hazard Analysis

Ten years have elapsed since completion of TCC's landslide hazard assessment and accompanying steep or unstable land overlays in 2001. It is possible that over this 10 year period, recent landslide activity may have altered the landslide susceptibility within any of Zones 1, 2 and 3, which in turn may affect the landslide risk for those areas.

TCC's GIS will need to note this fact on the integrated overlay maps and in the new Steep or Unstable Lands Code of the new City Plan. This factor also means that at some date in the future, TCC should consider a review of the areas covered by Zones 1, 2 and 3 to assess any changes in landslide susceptibility.

10.8.2. Consequence Analysis

The study of landslide risk requires an assessment of the consequences in the event of a landslide event. Consequence analysis is a function of:

- Identification of the elements at risk (in this case property);
- Temporal probability (i.e. the time and duration over which the element at risk is exposed to a landslide event); and
- Spatial probability (the area of building per unit area of land potentially affected by landslide events)

If there has been significant new development in the intervening period between 2001 and 2011 then this may alter the consequence descriptions within any of Zones 1, 2 and 3 of TCC's Steep or Unstable Lands Overlays, which in turn will alter the landslide risk within any of those areas. Accordingly, the property risk categories indicated in Table 10.4 of this report will reflect the landslide risk **as of 2001** for those areas covered by TCC's Steep or Unstable Lands Overlays. This limitation will also need to be clearly communicated via the Proposed Steep or Unstable Land Code and the integrated overlays presented in Figure 18.

We also note the following comment at page 13, Section 7.1 of TCC's 2001 landslide hazard assessment (Reference 1): "......*the range of damage categories* (i.e. consequence analysis) *from slight to severe may be used as a general guide for assessing the damage potential related solely to landslides and debris flows, as summarised in Table 2*".

From the above statement we are uncertain as to the level of detail carried out by the consultant (i.e. Coffey) to support the "Consequence" analysis provided in Table 2 of Reference 1 (reproduced in Appendix J). We have taken the descriptive terms for the "Consequence" analysis provided in Table 2 of Reference 1 at face value, namely that sufficient investigation work has been conducted such that the descriptive terms are consistent with the definitions of AGS 2000 (Reference 29) and AGS (2007c) (Reference 26).

10.8.3. Precedence Where Overlays Overlap

It should be noted that the Castle Hill area is covered by both TCC's Steep or Unstable Lands Overlays of 2001 (Reference 1) as well as by the Townsville Steep Slope Risk Assessment of 2004 (i.e. Figure 4.2 of Reference 13). With one exception, the larger scale mapping of Figure 4.2 of Reference 13 takes precedence over the regional scale 2001 mapping of TCC's Steep or Unstable Lands Overlays. The exception relates to the identification of debris flow paths which are given on TCC's Steep or Unstable Lands Overlays but are lacking on Townsville Steep Slope Risk Assessment (i.e. Figure 4.2 of Reference 13). GIS shape files given as part of Figure 18 incorporate the debris flow paths covering the Castle Hill area derived from TCC's Steep or Unstable Lands Overlays. The order of precedence for overlapping overlays is noted on Figure 18.

10.8.4. Accuracy of Risk Boundaries

It should be noted that TCC provided PSM with a paper copy of Figure 4.2 of Reference 13 relating to the Townsville Steep Slope Risk Assessment. The risk boundaries depicted on the paper copy of Figure 4.2 of Reference 13 were then geo-referenced and digitised to develop the risk boundaries as given on Figure 18 of this report. Accordingly, it must be recognised there may be a small (but unknown) degree of inaccuracy associated with digitising of the risk boundaries from the paper copy of Figure 4.2 of Reference 13. This limitation is noted on Figure 18.

All other risk boundaries derived from TCC's Steep or Unstable Lands Overlays of 2001 were provided to PSM electronically.

10.9. <u>Code Structure</u>

10.9.1. Update of Landslide Hazards Code

The Landslide Hazards code as presented in Section 8.5 (Draft Levels of Assessment – Overlays) of this report has been updated in Section 10.8.2 of this Addendum, particularly Table 8.3 which is updated as Table 10.5 below. The purpose of the update is to reflect the work presented in this Addendum in regards to developing a landslide overlay for use in the new City Plan.

10.9.2. Update of Overall Outcomes

The Landslide Hazards code applies to any development being self, code or impact assessable in the Table of Development in the Zone or Local Area Plan (LAP) within which the development is proposed. In particular, this code applies to development on land that is steep or potentially geologically unstable, as identified in Figure 18 of this report as:

- PSM debris flow risk
- PSM low risk
- PSM very low risk
- 2001 debris flow risk
- 2001 high risk
- 2001 medium risk
- 2001 very low risk
- 2004 high risk (Castle Hill)
- 2004 low risk (Castle Hill)
- 2004 medium risk (Castle Hill)
- 2004 medium high risk (Castle Hill)
- 2004 medium low (Castle Hill)

As well, the code also applies to all other sloping areas of Townsville not covered by the above landslide risk categories where slope angles exceed 23°.

Performance Criteria **PO1-PO7** applies to all code and impact assessable development subject to this code (Table 10.5). For development identified as self-assessable, only the acceptable solutions to Performance Criteria **PO1-PO3** apply (Table 10.5).

Any variation to the acceptable solutions contained in this code must be certified. The long-term stability of any design, beyond the limits specified in this code, is to be certified by an appropriately qualified and experienced engineering geologist, geotechnical engineer or registered professional engineer appropriately experienced in slope stability investigations.

TABLE 10.5

STEEP SLOPES OR UNSTABLE LANDS FOR SELF-ASSESSABLE AND ASSESSABLE DEVELOPMENT.			
Performance Outcomes		**Acceptable Outcomes**	
Site Slope Constraints			
PO1	Building work must be responsive to the constraints of the land	**AO1**	**AO1.1-** Development is not undertaken on land with a maximum slope exceeding 23°. OR **AO1.2-** The development is for a detached/dual occupancy dwelling associated with a residential reconfiguration approval (i.e. the lot is intended to be serviced by sewerage reticulation) and the development complies with the conditions of the reconfiguration approval and any subsequent operational works approval.

TABLE 10.5 (Cont)

STEEP SLOPES OR UNSTABLE LANDS FOR SELF-ASSESSABLE AND ASSESSABLE DEVELOPMENT			
Performance Outcomes		**Acceptable Outcomes**	
Slope Stability			
PO2	All development on land identified as "PSM very low risk", "2001 very low risk" and "2004 low risk (Castle Hill") on the overlay map provided as Figure 18 accompanying this report.	**AO2**	AO2.1- A geotechnical assessment report, prepared by a registered professional engineer, geotechnical engineer or qualified engineering geologist appropriately experienced in slope stability matters is used to assess the stability of the land and provide engineering measures to support the construction of the development.
Build Form Character			
PO3	The building style and construction methods used for development on sloping sites must be responsive to the constraints of steep slopes.	**AO3**	**AO3.1-** A split-level building form that generally conforms to the land slope profile is utilised. **AO3.2-** A single plane concrete slab is not used except where the development is for a detached dwelling, associated with a residential reconfiguration approval (i.e. the lot is intended to be serviced by sewerage reticulation) and the development complies with the conditions of the reconfiguration approval and any subsequent operational works approval. **AO3.3-** Areas between the building's floor and the ground level, or between outdoor deck areas and the ground level, are screened from view by using lattice or other appropriate screening devices and/or landscaping.

TABLE 10.5 (Cont)

DEVELOPMENT THAT IS CODE ASSESSABLE OR IMPACT ASSESSABLE			
Storm Water Drainage			
PO4	Development on steep slopes must ensure that the quality and quantity of stormwater traversing the site must not cause any detriment impact to the natural environment or to adjacent properties.	**AO4**	**AO4.1-** All stormwater drainage associated with the site must be discharged to a lawful point of discharge and must not adversely impact upon adjacent properties, downstream properties, upstream or underground streams.
Cut and Fill Work			
PO5	All cut and fill work must not create a detrimental impact on the slope stability, erosion potential or visual amenity. Note; Provisions should be supported by best practice guidelines for storm water management, soil erosion and sediment control.	**AO5**	**AO5.1**- The height of cut and/or fill, whether retained or not, does not exceed: a) 900mm adjoining a public area; b) 1200mm adjoining a residential site; c) 2500mm adjoining a non-residential site. **AO5.2-** Cuts in excess of those stated in AS5.1 are separated by terraces with a minimum width of 1.2 metres that incorporate drainage provisions. **AO5.3-** No crest of any cut or toe of any fill, or any part of any retaining wall or structure, is located closer than 600mm to any boundary of the property, unless the prior approval of both landowners and the Council, or its delegate, has been obtained. **AO5.4-** Constructed slopes (i.e. cuts and fills) exceeding 800m in depth/height respectively shall be the subject of specific engineering investigation and design. *Note: Acceptable Outcomes should be in accordance with Australian GeoGuide LR8 for good hillside practice.*

TABLE 10.5 (Cont)

DEVELOPMENT THAT IS CODE ASSESSABLE OR IMPACT ASSESSABLE			
Geotechnical Assessment			
PO6	All development on land identified as "PSM debris flow risk", "PSM low risk", "2001 debris flow risk", "2001 high risk", "2001 medium risk", "2004 high risk (Castle Hill)", "2004 medium risk (Castle Hill)", "2004 medium high risk (Castle Hill)", and "2004 medium low risk (Castle Hill") on the overlay map provided as Figure 18 accompanying this report.	**AO6**	AO6.1 A geotechnical assessment report is to be prepared in accordance with Planning Scheme Policy – Landslide Hazard
Access			
PO7	Development on steep slopes must ensure that vehicle and pedestrian access is achieved in a safe and efficient manner.	**AO7**	**AO6.1-**The development area for each allotment is accessible by a legal road access and/or access easement **AO6.2**- Any section of a driveway(s) internal to a site is not steeper than 25% (1V:4H).

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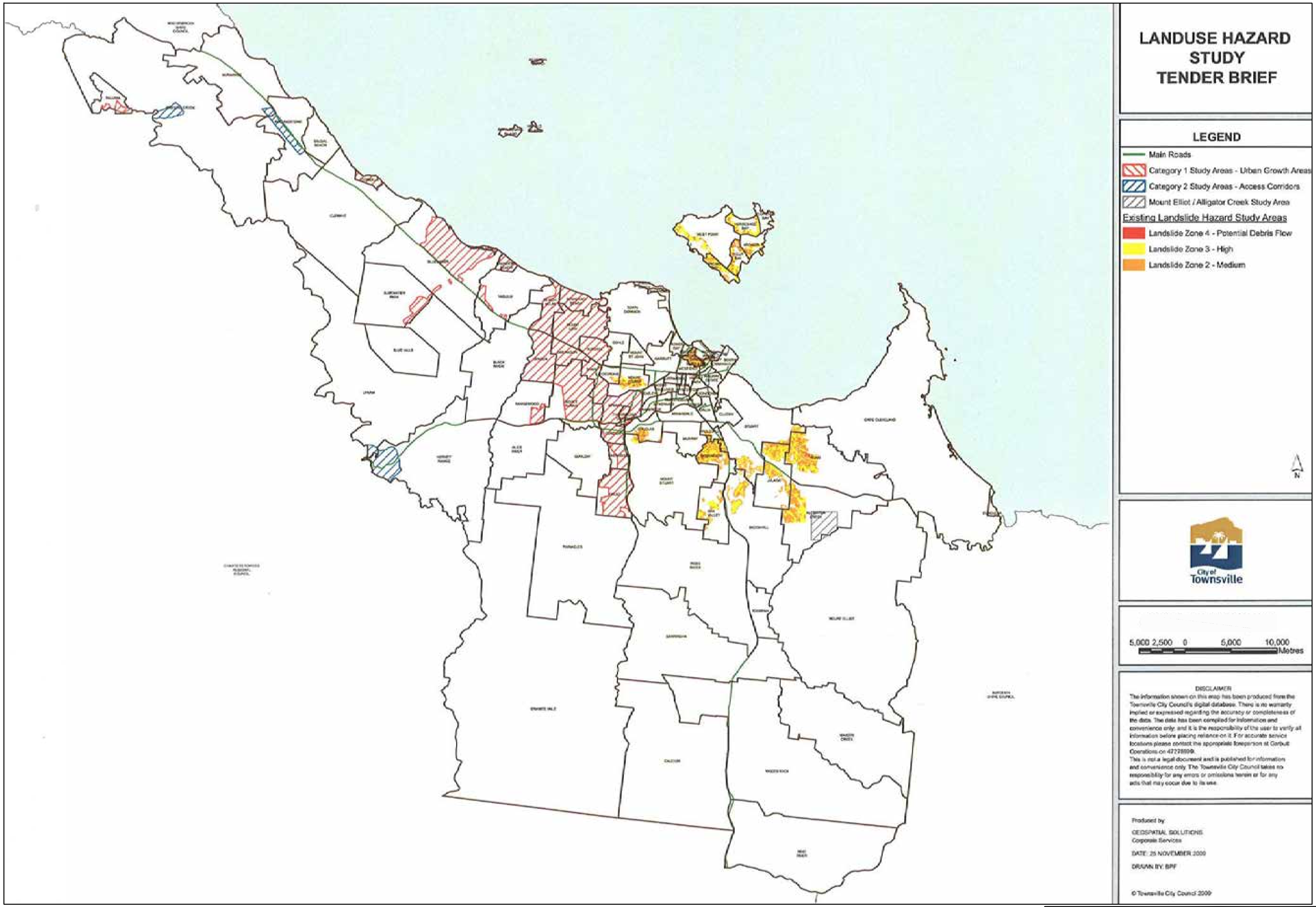
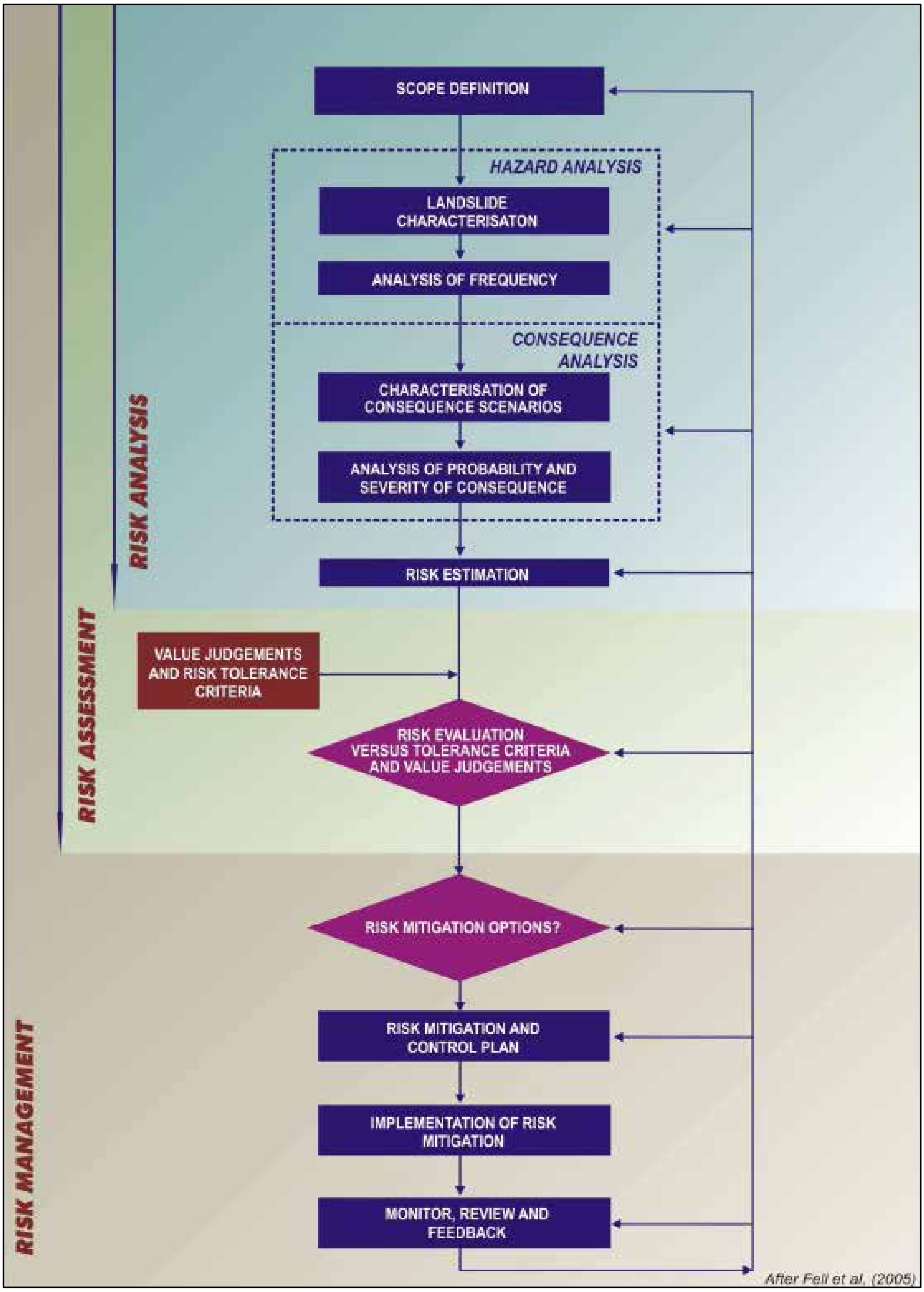


Townsville City Council National Disaster Risk Management Study Landslide Hazard Study STUDY AREA LOCATION PLAN	
PSM 1672-004R	Figure 1

PSM

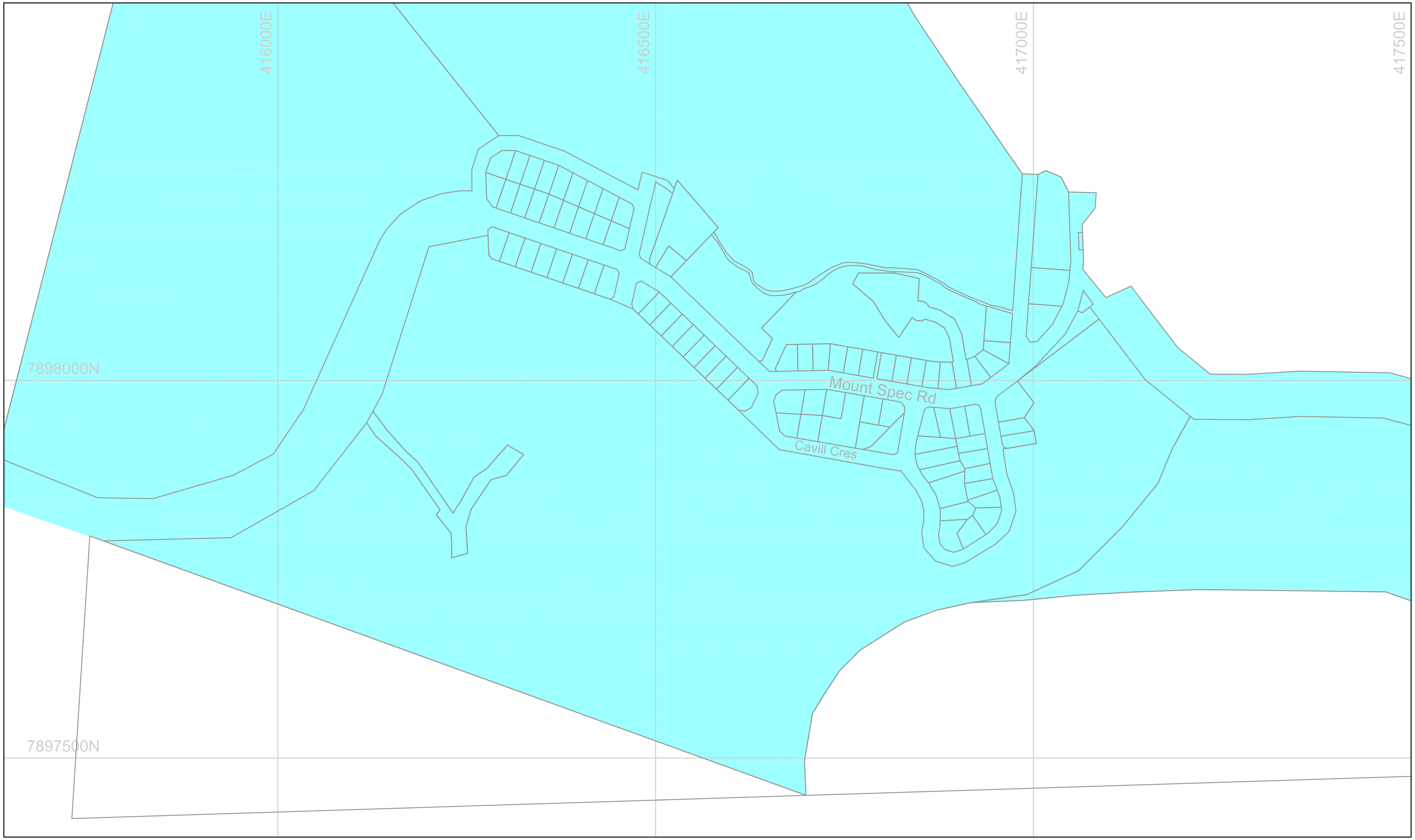
Pells Sullivan Meynink



(From Reference 26)

Pells Sullivan Meynink

Townsville City Council National Disaster Risk Management Study Landslide Hazard Study FRAMEWORK FOR LANDSLIDE RISK MANAGEMENT	
PSM 1672-004R	Figure 2



LEGEND

Landslide Risk

- VERY HIGH
- HIGH
- MODERATE
- LOW
- VERY LOW

0 50 100 150 200

Scale (m)

Note: Base plan from TCC Geospatial Solutions Department
Topographic contours not available

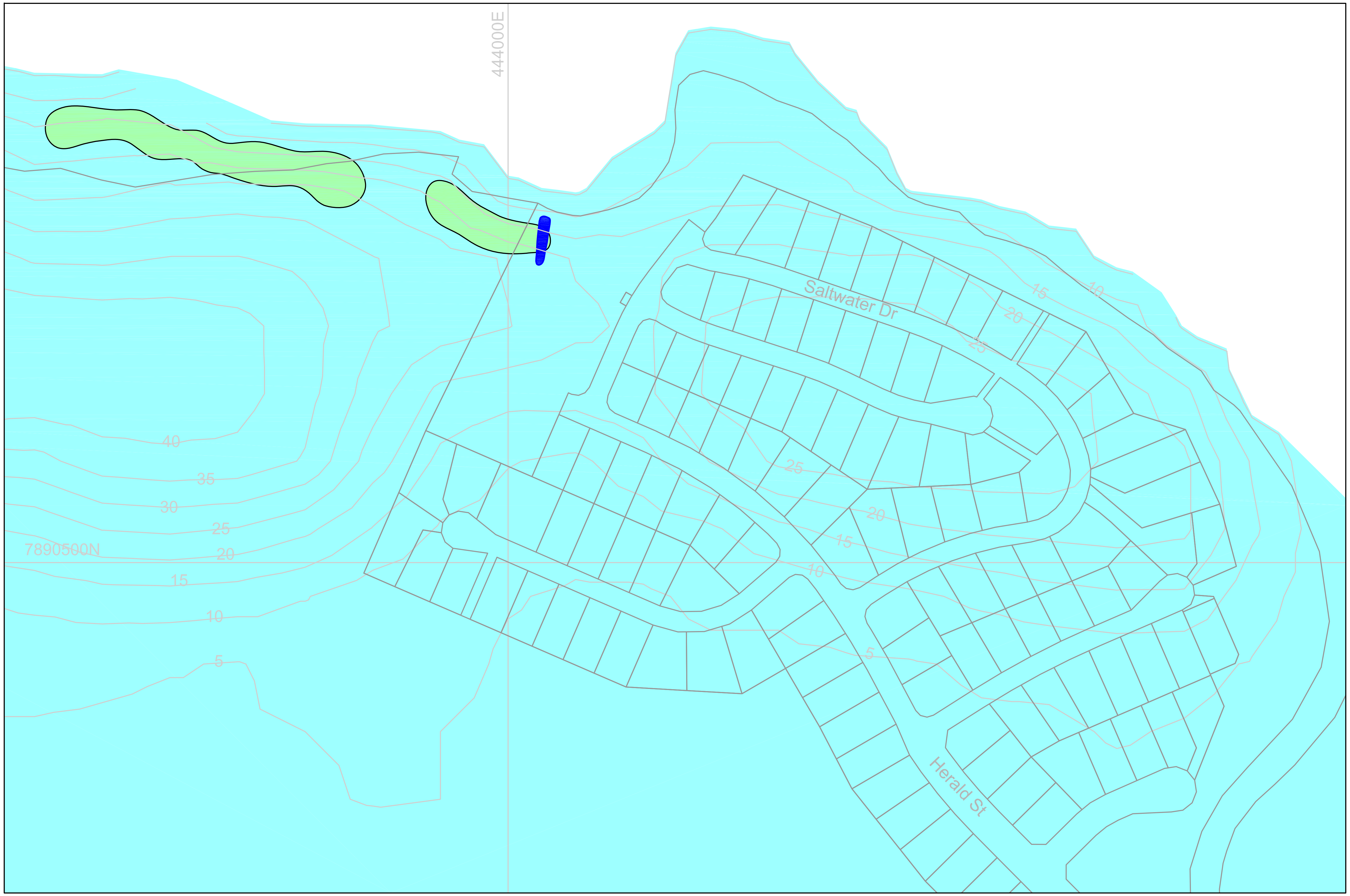
PSM

Pells Sullivan Meynink

Townsville City Council
National Disaster Risk Management Study
Landslide Hazard Study

CATEGORY 1 LANDSLIDE RISK
ASSESSMENT OVERLAY
PALUMA VILLAGE

PSM 1672-004R	Figure 3



LEGEND

Landslide Risk

- VERY HIGH
- HIGH
- MODERATE
- LOW
- VERY LOW
- GULLY / FLOWPATH

0 50 100

Scale (m)

Note: Base plan from TCC Geospatial Solutions Department

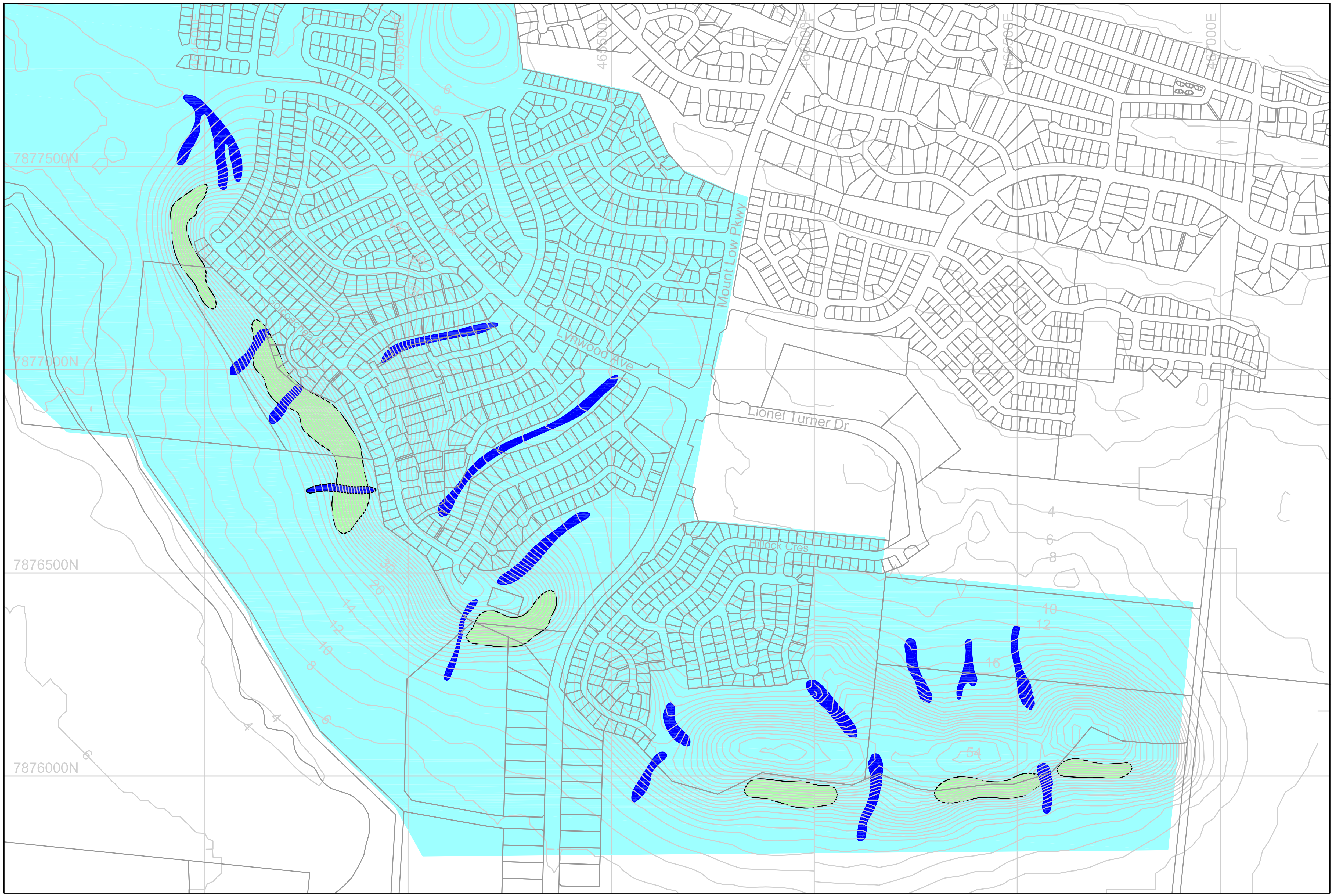
PSM

Pells Sullivan Meynink

Townsville City Council
National Disaster Risk Management Study
Landslide Hazard Study

CATEGORY 1 LANDSLIDE RISK
ASSESSMENT OVERLAY
TOOMULLA

PSM 1672-004R	Figure 4



LEGEND

Landslide Risk

- VERY HIGH
- HIGH
- MODERATE
- LOW
- VERY LOW
- GULLY / FLOWPATH

0 100 200 300 400 500

Scale (m)

Note: Base plan from TCC Geospatial Solutions Department

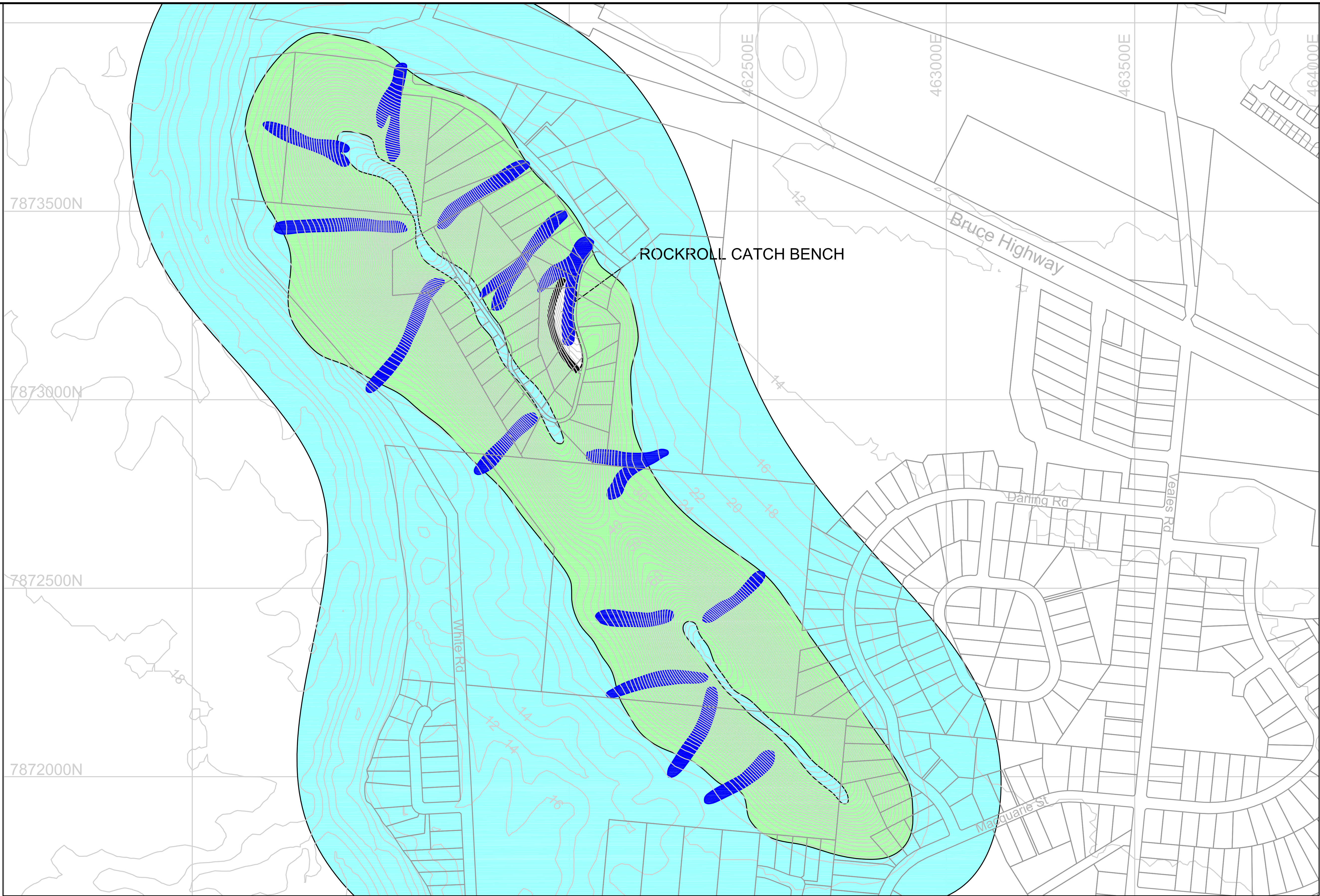
PSM

Pells Sullivan Meynink

Townsville City Council
National Disaster Risk Management Study
Landslide Hazard Study

CATEGORY 1 LANDSLIDE RISK ASSESSMENT OVERLAY
MT LOW

PSM 1672-004R	Figure 5



LEGEND

Landslide Risk

- VERY HIGH
- HIGH
- MODERATE
- LOW
- VERY LOW
- GULLY / FLOWPATH

0 100 200 300 400 500

Scale (m)

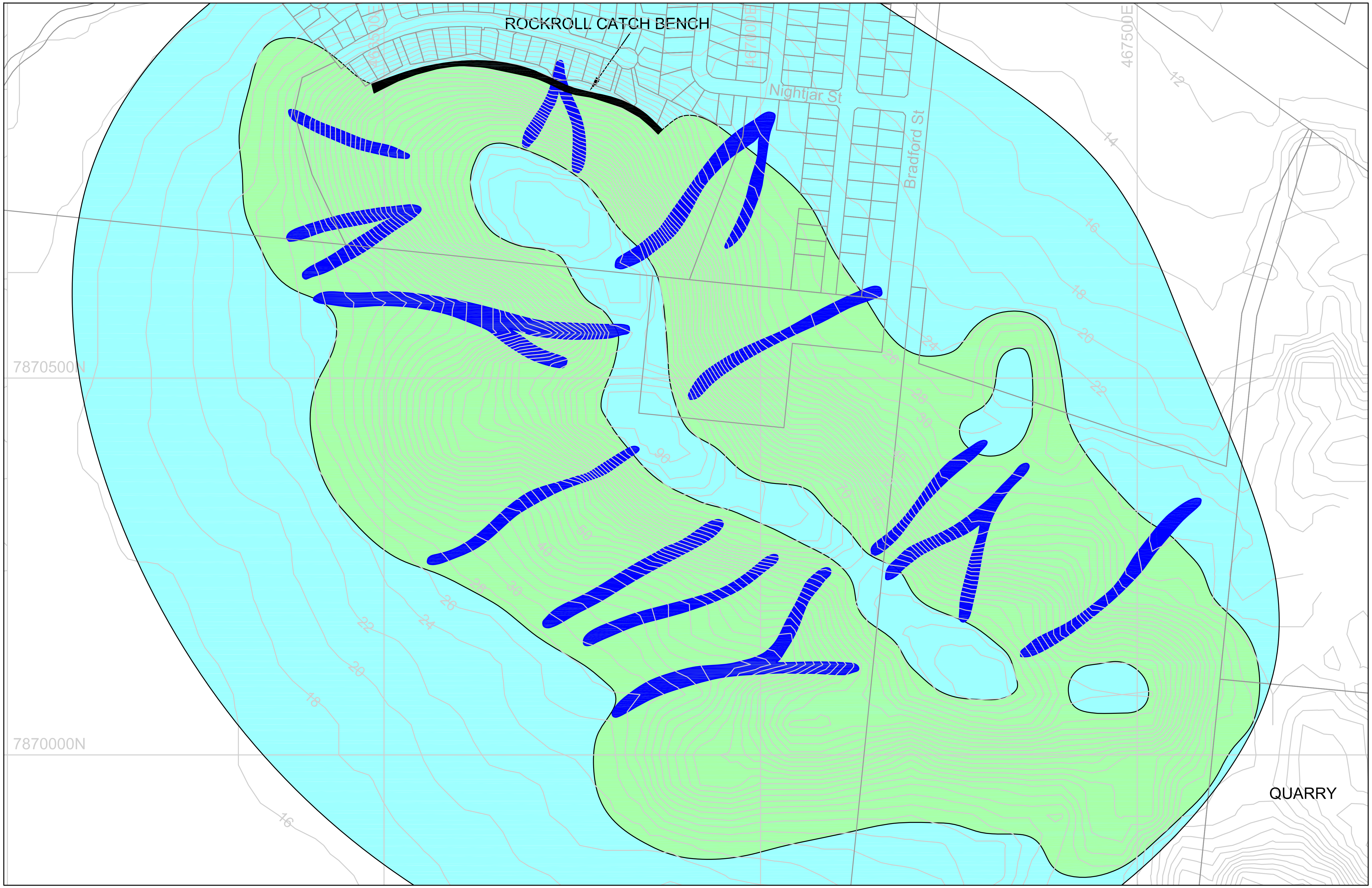
Note: Base plan from TCC Geospatial Solutions Department

PSM Pells Sullivan Meynink

Townsville City Council
National Disaster Risk Management Study
Landslide Hazard Study

CATEGORY 1 LANDSLIDE RISK ASSESSMENT OVERLAY
JENSON (SEAVIEW PARK)

PSM 1672-004R	Figure 6



LEGEND

LANDSLIDE RISK

- VERY HIGH
- HIGH
- MODERATE
- LOW
- VERY LOW
- GULLY / FLOWPATH

0 50 100 150 200
Scale (m)

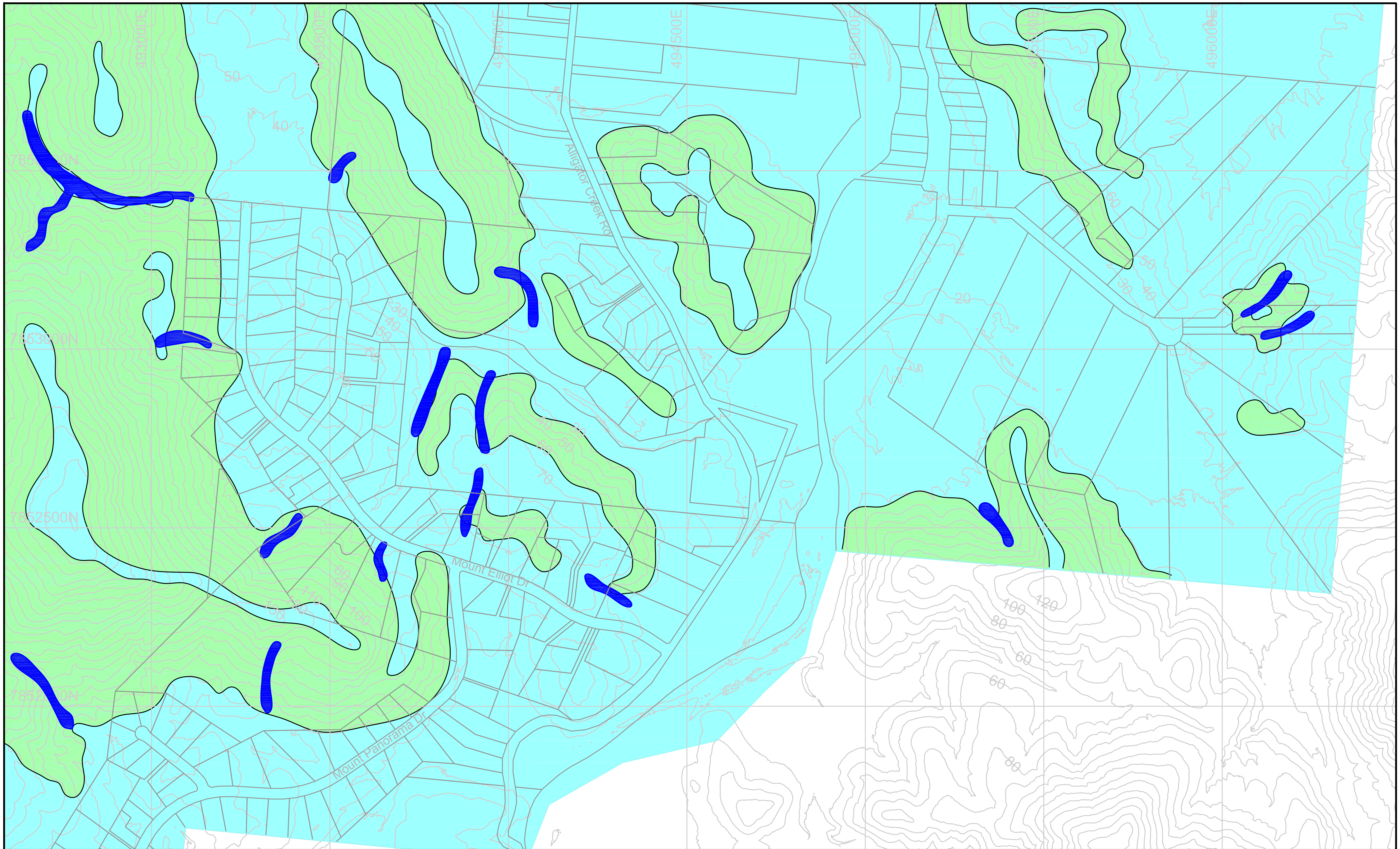
Note: Base plan from TCC Geospatial Solutions Department

PSM
Pells Sullivan Meynink

Townsville City Council
National Disaster Risk Management Study
Landslide Hazard Study

CATEGORY 1 LANDSLIDE RISK ASSESSMENT OVERLAY
DEERAGUN (INNES ESTATE)

PSM 1672-004R	Figure 7



LEGEND

Landslide Risk

- VERY HIGH
- HIGH
- MODERATE
- LOW
- VERY LOW
- GULLY / FLOWPATH

0 100 200 300 400 500

Scale (m)

Note: Base plan from TCC Geospatial Solutions Department

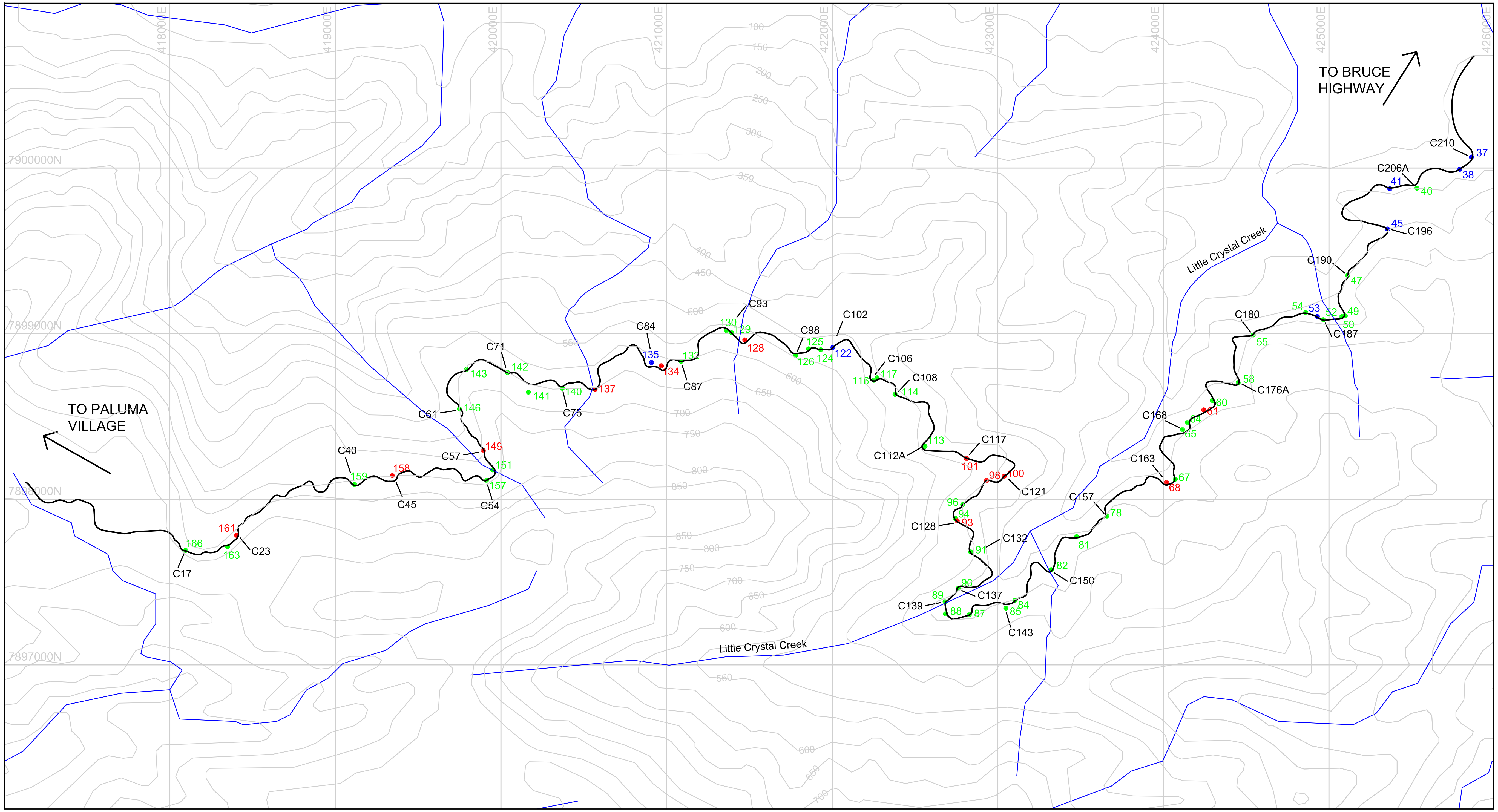
PSM

Pells Sullivan Meynink

Townsville City Council
National Disaster Risk Management Study
Landslide Hazard Study

CATEGORY 1 LANDSLIDE RISK
ASSESSMENT OVERLAY
MOUNT ELLIOT / ALLIGATOR CREEK

PSM 1672-004R	Figure 8



LEGEND

GULLY LOCATIONS (Waypoint Number) &
INFERRED DEBRIS FLOW / TORRENT
SUSCEPTIBILITY

- HIGH
- MODERATE
- LOW

C17 — CULVERT NUMBER (See Paluma Road Gullies Table in Appendix E)

0 200 400 600 800 1000

Scale (m)

Note: Contour base plan from GeoScience Australia
Paluma Road alignment from Department of Main Roads and Transport.

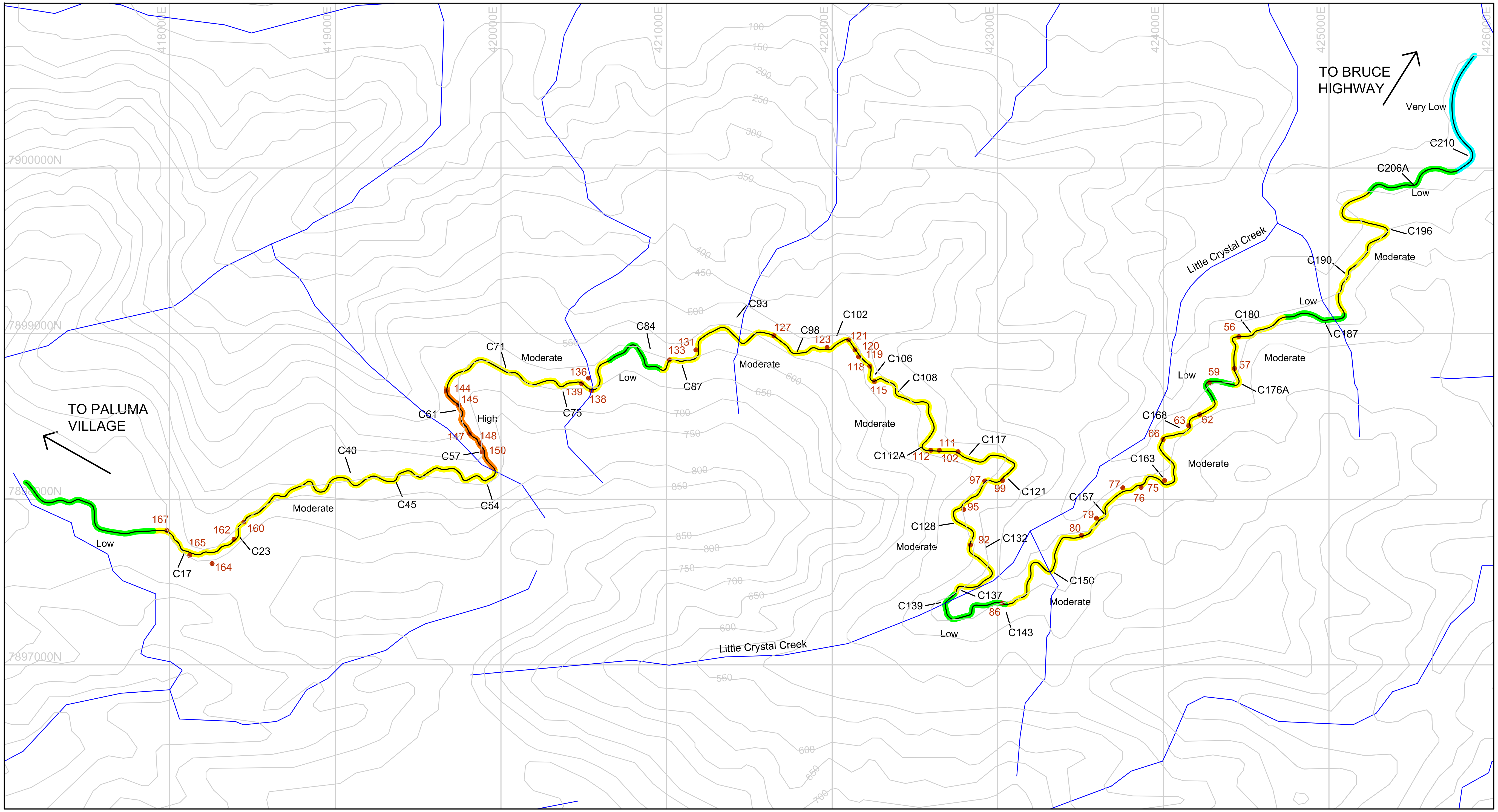
PSM

Pells Sullivan Meynink

Townsville City Council
National Disaster Risk Management Study
Landslide Hazard Study

CATEGORY 2 GULLY LOCATIONS &
INFERRED DEBRIS FLOW SUSCEPTIBILITY
PALUMA ROAD

PSM 1672-004R	Figure 9



LEGEND

SLUMPING HAZARD

- VERY HIGH
- HIGH
- MODERATE
- LOW
- VERY LOW

- INFERRED PREVIOUS SLUMP LOCATIONS & WAYPOINT NUMBERS (See Paluma Slumps / Other Table in Appendix E)
- C17 CULVERT NUMBER

0 200 400 600 800 1000
Scale (m)

Note: Contour base plan from GeoScience Australia
Paluma Road alignment from Department of Main Roads and Transport.

PSM
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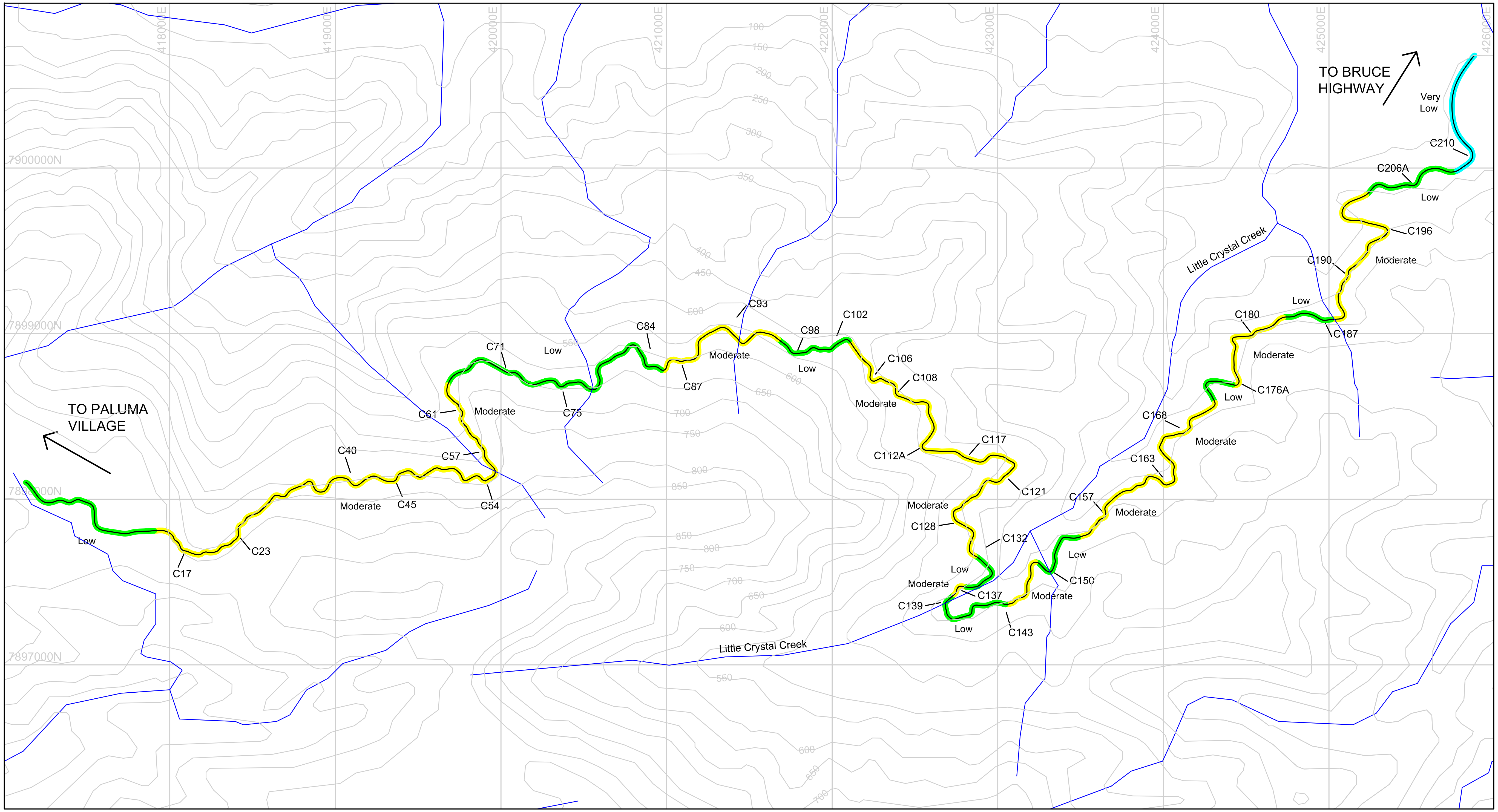
Townsville City Council
National Disaster Risk Management Study
Landslide Hazard Study

CATEGORY 2 SLUMPING HAZARD ASSESSMENT PLAN
PALUMA ROAD

PSM 1672-004R | Figure 10



LEGEND

ROCK ROLL / ROCKFALL HAZARD

VERY HIGH

HIGH

MODERATE

LOW

VERY LOW

C17 CULVERT NUMBER

0 200 400 600 800 1000

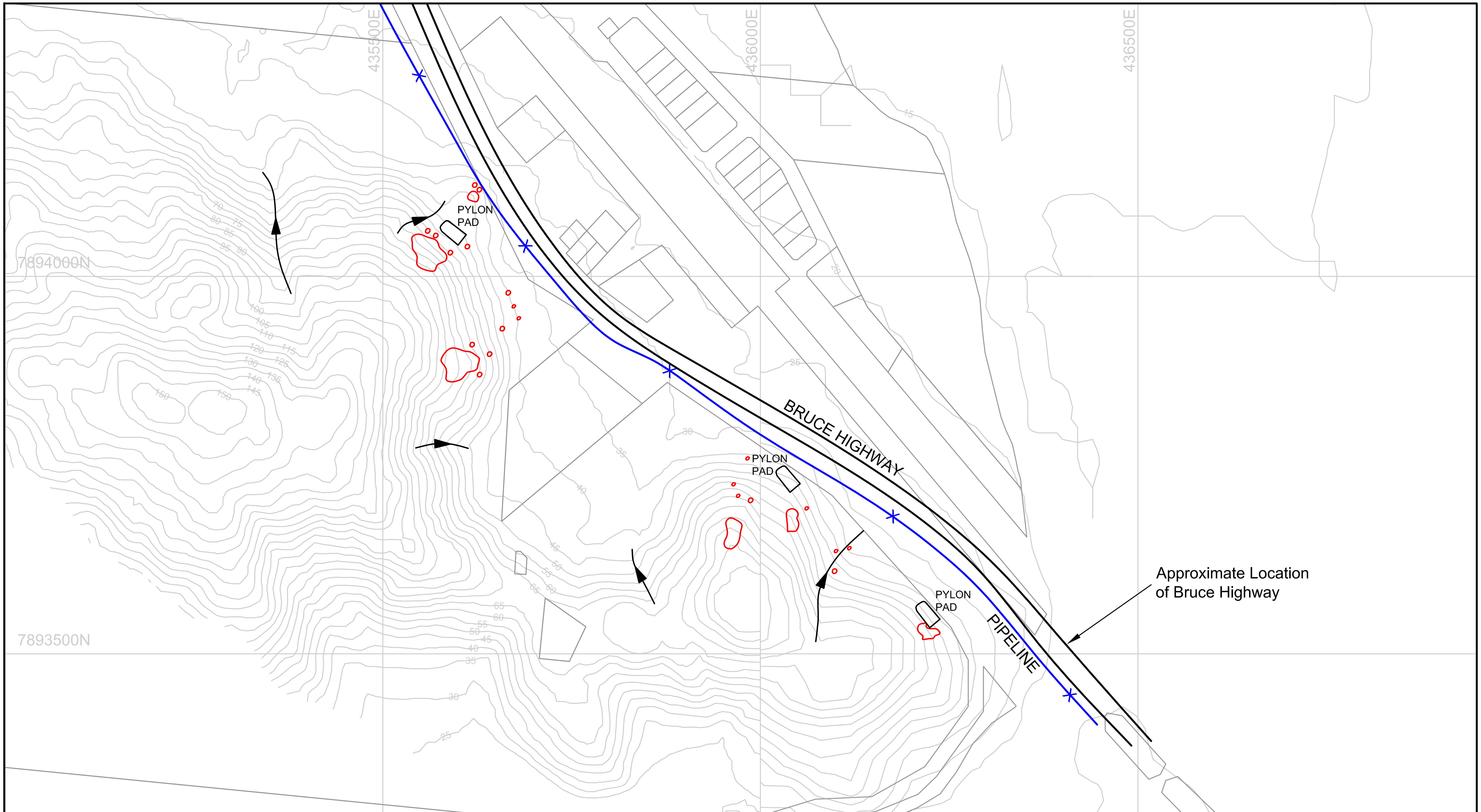
Scale (m)

Note: Contour base plan from GeoScience Australia
Paluma Road alignment from Department of Main Roads and Transport.

Pells Sullivan Meynink

Townsville City Council
National Disaster Risk Management Study
Landslide Hazard Study
CATEGORY 2 ROCK ROLL / ROCKFALL HAZARD ASSESSMENT PLAN
PALUMA ROAD

PSM 1672-004R | Figure 11



LEGEND

- FLOW PATH
- EXPOSED BEDROCK
- BOULDERS ON SURFACE
- PIPELINE
- ROAD

0 50 100 150 200
Scale (m)

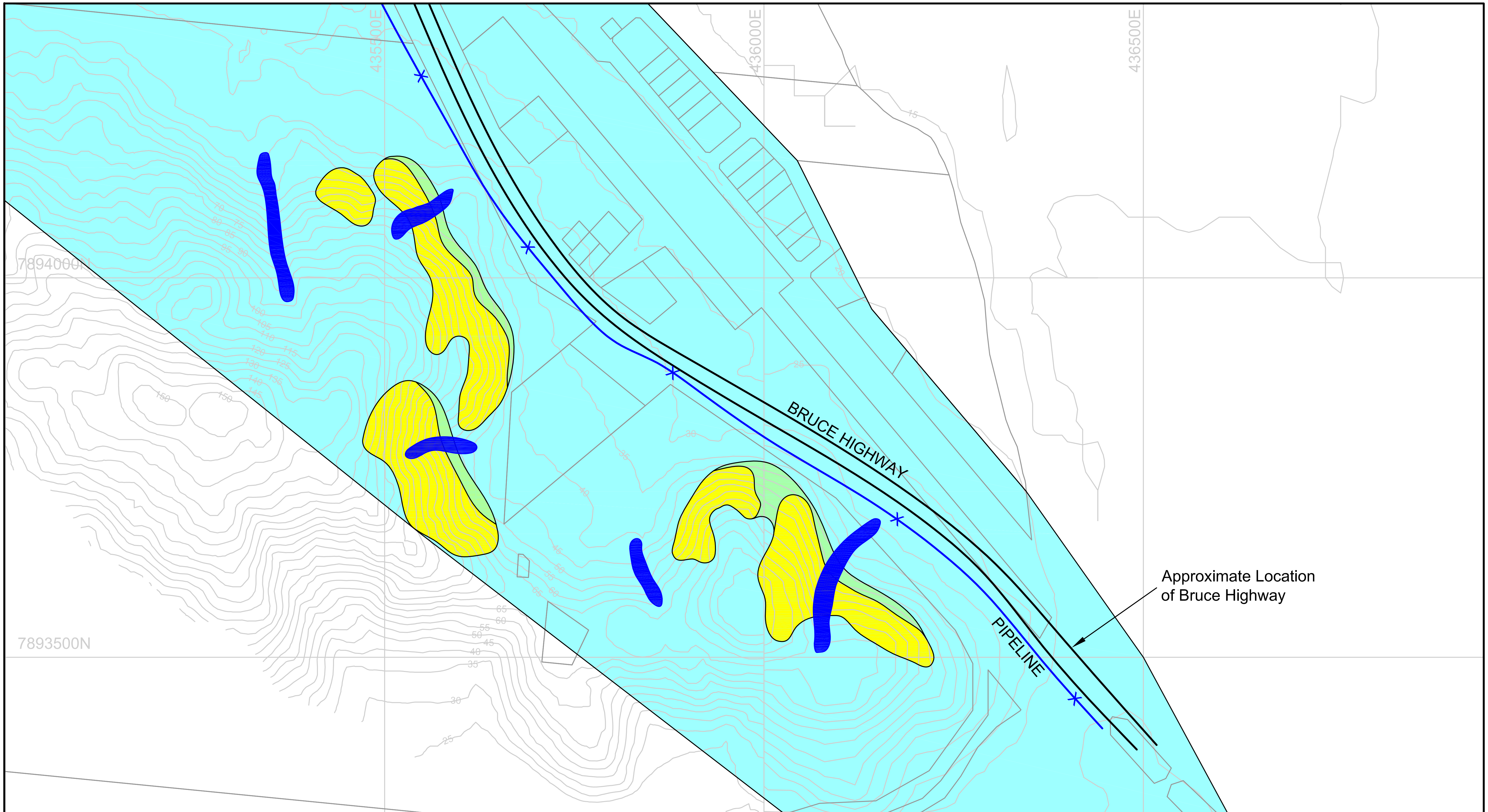
Note: Base plan from TCC Geospatial Solutions Department

PSM Pells Sullivan Meynink

Townsville City Council
National Disaster Risk Management Study
Landslide Hazard Study

CATEGORY 2 FACTUAL PLAN
ROLLINGSTONE

PSM 1672-004R | Figure 12



LEGEND

SLUMPING HAZARD

- VERY HIGH
- HIGH
- MODERATE
- LOW
- VERY LOW
- GULLY / FLOWPATH

0 50 100 150 200
Scale (m)

Note: Base plan from TCC Geospatial Solutions Department

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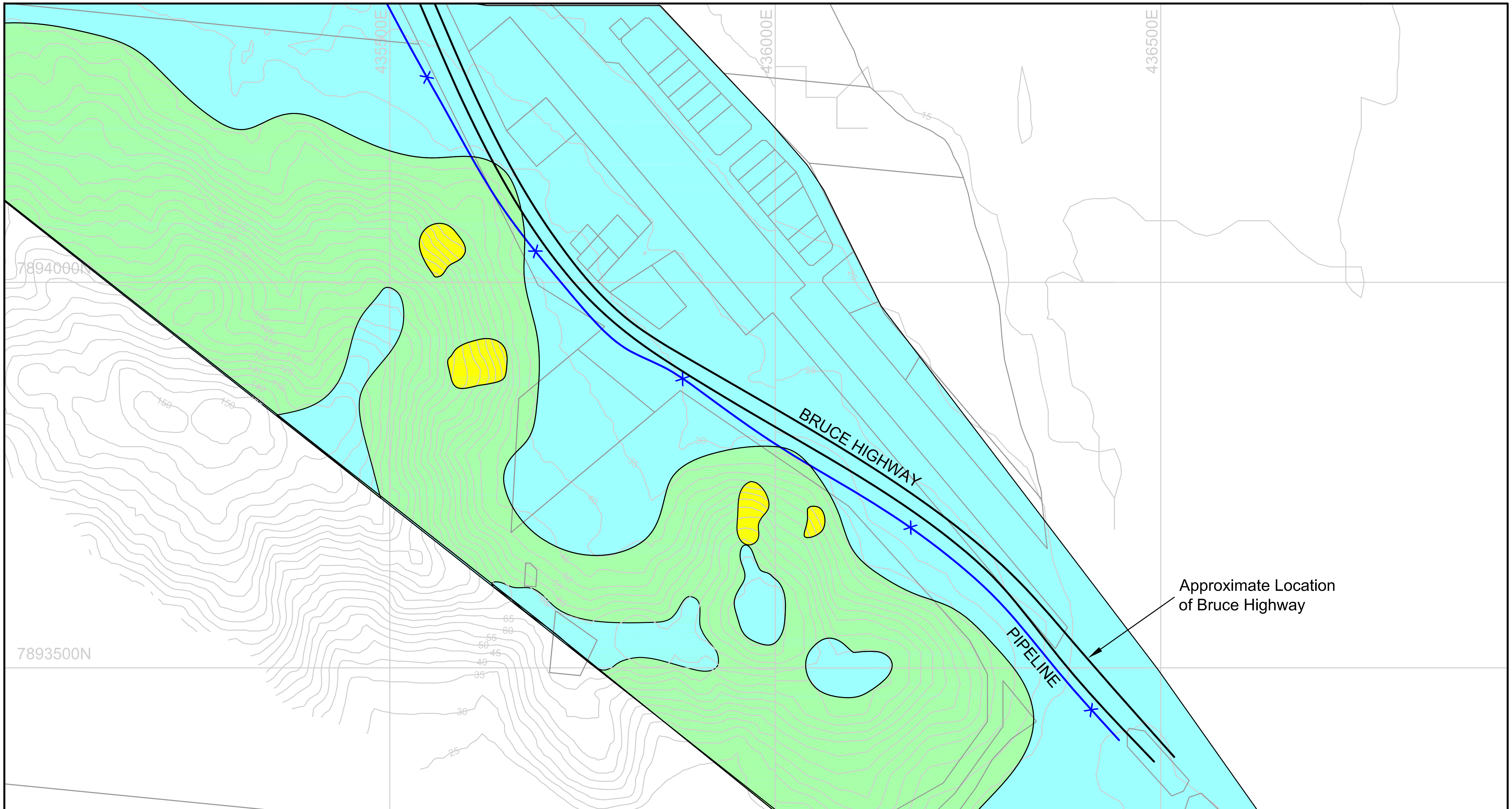
Townsville City Council
National Disaster Risk Management Study
Landslide Hazard Study
CATEGORY 2 SLUMPING HAZARD
ASSESSMENT PLAN
ROLLINGSTONE

PSM 1672-004R | Figure 13



LEGEND

ROCK ROLL / ROCKFALL HAZARD

- VERY HIGH
- HIGH
- MODERATE
- LOW
- VERY LOW

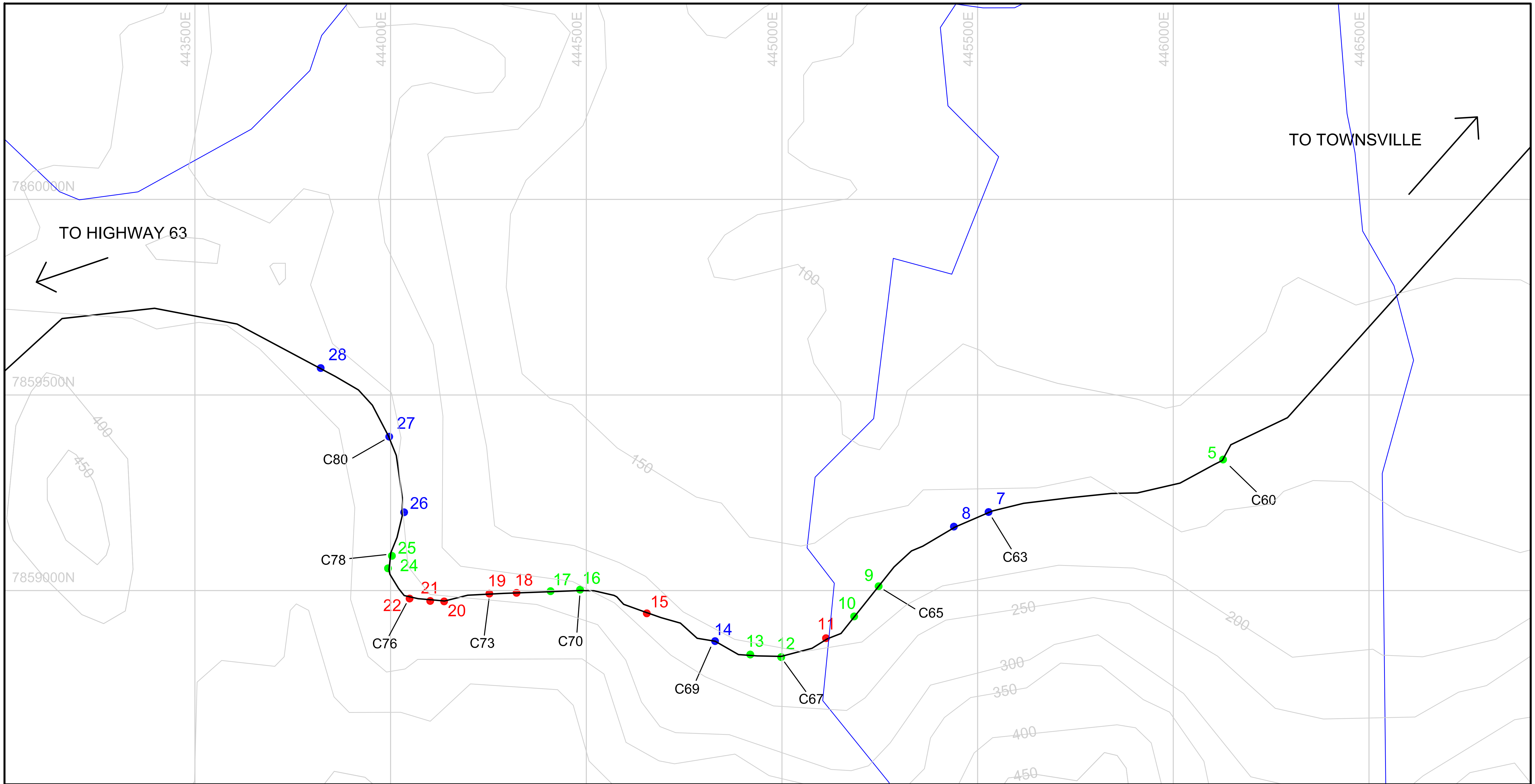
0 50 100 150 200
Scale (m)

Note: Base plan from TCC Geospatial Solutions Department

PSM Pells Sullivan Meynink

Townsville City Council
National Disaster Risk Management Study
Landslide Hazard Study
CATEGORY 2 ROCK ROLL / ROCKFALL HAZARD ASSESSMENT PLAN
ROLLINGSTONE

PSM 1672-004R | Figure 14



LEGEND

GULLY LOCATIONS (Waypoint Number) & INFERRED DEBRIS FLOWS / TORRENT SUSCEPTIBILITY

- HIGH
- MODERATE
- LOW

C17 CULVERT NUMBER (See Hervey Range Road Gullies Table in Appendix E)

0 100 200 300 400 500

Scale (m)

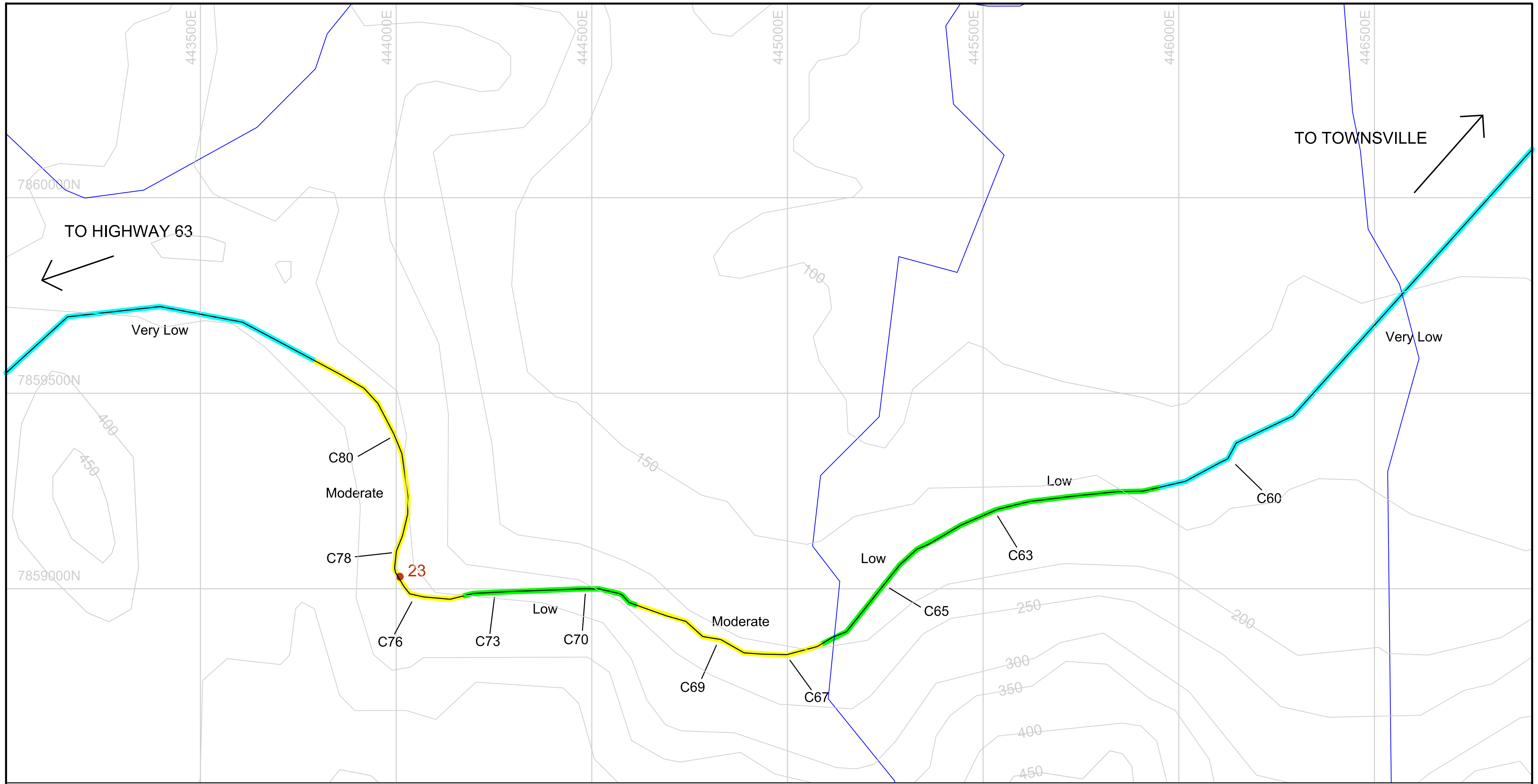
Note: Contour base plan from GeoScience Australia
Hervey Range Road alignment from GPS data collected in field by PSM.

PSM Pells Sullivan Meynink

Townsville City Council
National Disaster Risk Management Study
Landslide Hazard Study

CATEGORY 2 GULLY LOCATIONS & INFERRED DEBRIS FLOW SUSCEPTIBILITY HERVEY RANGE ROAD

PSM 1672-004R	Figure 15



LEGEND

SLUMPING HAZARD

VERY HIGH

HIGH

MODERATE

LOW

VERY LOW

INFERRED PREVIOUS SLUMP LOCATIONS & WAYPOINT NUMBERS (See Hervey Range Road / Slumps / Other Table in Appendix E)

C17 CULVERT NUMBER

0 100 200 300 400 500

Scale (m)

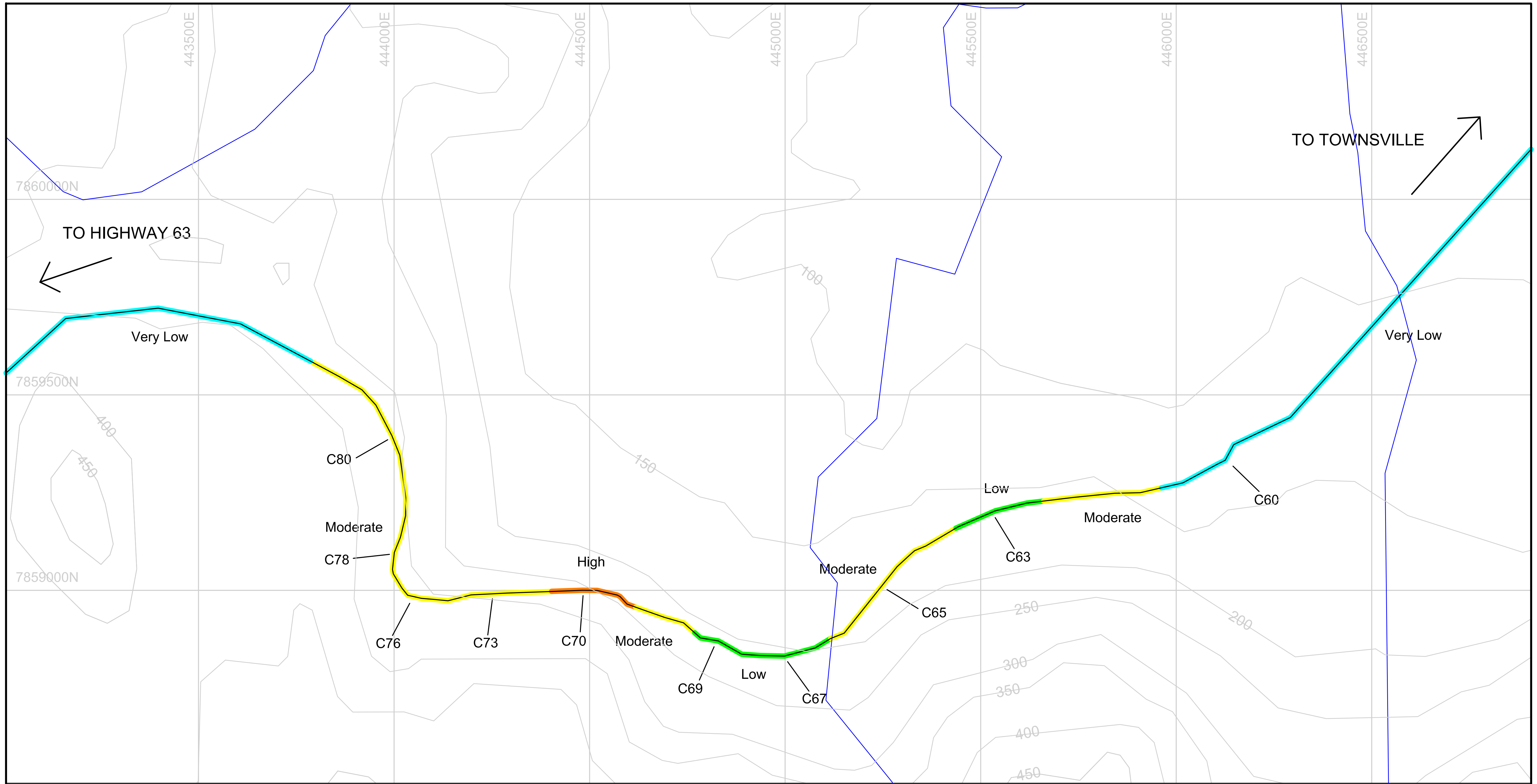
Note: Contour base plan from GeoScience Australia Hervey Range Road alignment from GPS data collected in field by PSM.

PSM Pells Sullivan Meynink

Townsville City Council
National Disaster Risk Management Study
Landslide Hazard Study

CATEGORY 2 SLUMPING HAZARD ASSESSMENT PLAN
HERVEY RANGE ROAD

PSM 1672-004R | Figure 16



LEGEND

ROCK ROLL / ROCKFALL HAZARD

- VERY HIGH
- HIGH
- MODERATE
- LOW
- VERY LOW
- C73 CULVERT NUMBER

Note: Contour base plan from GeoScience Australia
Hervey Range Road alignment from GPS data collected in field by PSM.

0 100 200 300 400 500

Scale (m)

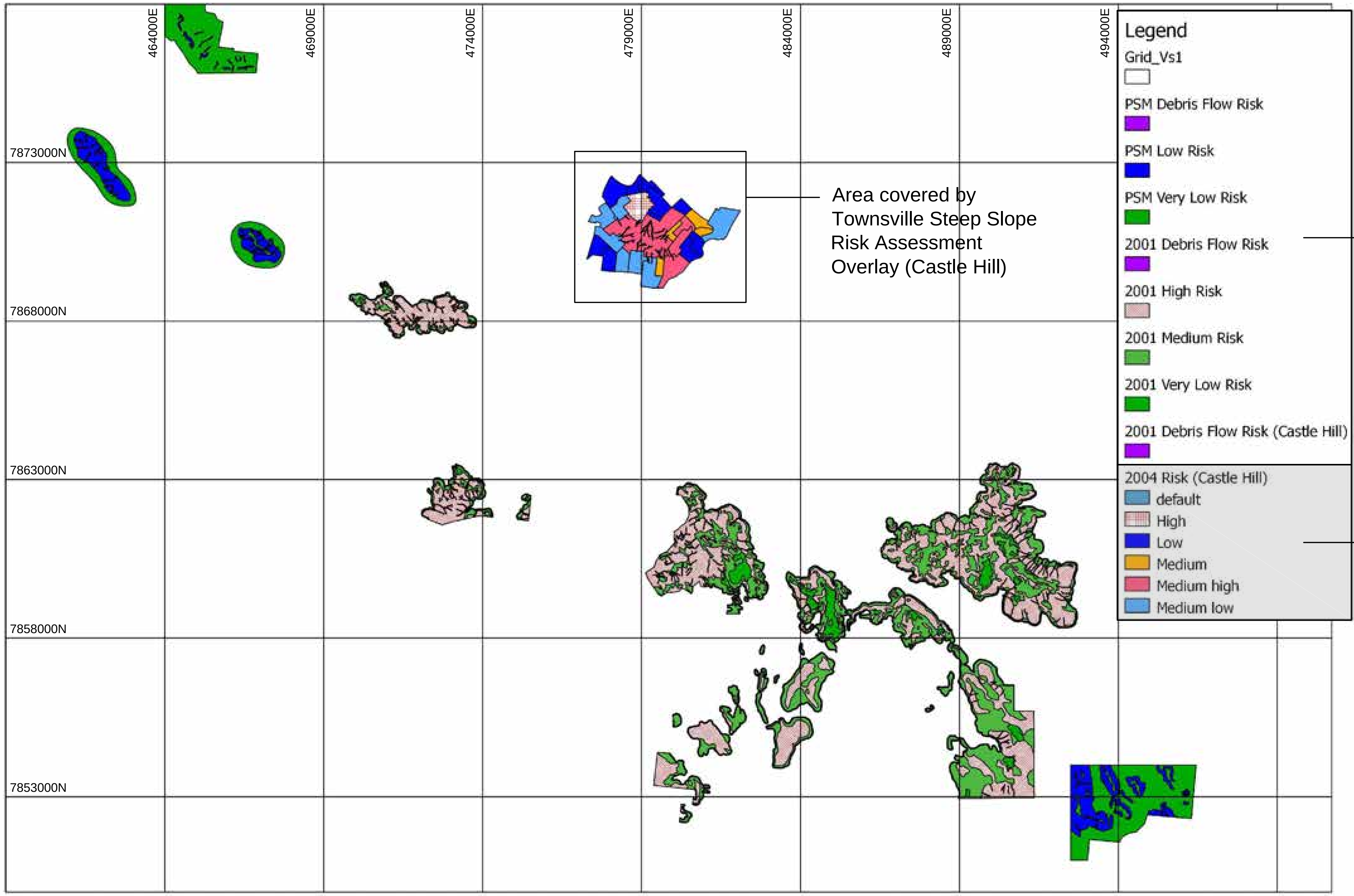
PSM

Pells Sullivan Meynink

Townsville City Council
National Disaster Risk Management Study
Landslide Hazard Study

CATEGORY 2 ROCK ROLL / ROCKFALL HAZARD ASSESSMENT PLAN HERVEY RANGE ROAD

PSM 1672-004R	Figure 17



Notes:

1. Where overlays overlap (e.g. Castle Hill), Townsville Steep Slope Risk Assessment Overlay takes precedence, except for areas covered by 2001 Debris Flow Risk Overlay which takes precedence.
2. Risk boundaries for the Townsville Steep Slope Risk Assessment Overlay are created by georeferencing of paper copy of Figure 4.2 of Reference 13 and digitising of risk boundaries. This process wil introduce small (but unknown) inaccuracies in boundaries.
3. All landslide risk boundaries represent risk to property boundaries based on terminology consistent with AGS (2007c) (Reference 26)

PSM

Pells Sullivan Meynink

Townsville City Council National Disaster Risk Management Study Landslide Hazard Study TCC LANDSLIDE RISK MAP	
PSM 1672-004R	Figure 18

APPENDIX A

CONTRACT T5631 SPECIFICATION

Townsville

TOWNSVILLE CITY COUNCIL

PART 2 >>

SPECIFICATION

NATURAL DISASTER RISK MANAGEMENT STUDY

Council Reference Number >> T5631

Title >> Landslide Hazard Study

TOWNSVILLE CITY COUNCIL >>

103 WALKER STREET, TOWNSVILLE QLD 4810 ♦ PO BOX 1268, TOWNSVILLE QLD 4810 ♦
(p) 07 4727 9000 ♦ (f) 07 4727 9050 ♦ (e) enquiries@townsville.qld.gov.au ♦ (w) www.townsville.qld.gov.au

1. INTRODUCTION

The City of Townsville has a regional population of about 175,000. As the largest provincial population centre outside the south east corner and the administrative “capital” of North Queensland, it is important that this region have current accurate data to predict the impact of Landslide activity and to assist in strategic planning for existing and future development. The Areas of concern are those close to the residential areas of Townsville and isolated residential communities at risk from a landslide event.

Under the Natural Disaster Risk Management program sponsored by the Federal, State and Local Governments the need for a Landslide Study has been identified. It is anticipated that the study will consist of the following elements within the Townsville City area:

- Identification of the latest studies undertaken by various government departments and emergency service organisations;
- Identification of areas needing further study;
- Carrying out a further landslide hazard study;
- Map the area based on the landslide hazard risks identified.

2. BACKGROUND INFORMATION

The objectives of the study are to provide:

- Improved knowledge of the landslide and debris flow threat;
- Hazard mapping of the land subject to different levels of risk from landslide;
- Recommendations of landslide hazard management strategies;
- Recommendation of development constraints and
- Production of maps for inclusion in the city planning scheme.

3. SCOPE OF SERVICES

The study is to be in compliance with *“Practice Note Guidelines for Landslide Risk Management 2007”* produced by Australian Geomechanics and to include the following:

Three levels of assessment have been identified namely:

Category 1

a) Identification and assessment of
   - Landslide hazard and debris threats to existing and future residential and rural residential properties and emergency access/evacuation routes;
   - Landslide hazard areas where new development has occurred;
   - Elements at risk and their vulnerability to the threat;
   - The influence of climate change on the landslide hazard threat and
   - The risks associated with the hazard threat;

b) Recommendations for
   - Improvement of the Planning Scheme on
     - land use outcomes;
     - assessable developments;
     - assessment categories and applicable codes and
     - land uses to be exempt, self, code or impact assessable.
   - Improvement to the Local Disaster Management Plan and
   - Landslide mitigation options.

c) Production of maps of the identified landslide hazard risk areas and zones.

Category 2

Landslide hazard and debris threats only to existing emergency access / evacuation routes and the influence of climate change on the landslide hazard threat.

Category 3

a) Reassessment of existing landslide zones 2, 3 and 4 to identify any changed conditions that may effect the risk level and vulnerability of elements.

b) Any identified locations to then be reassessed using the criteria and outcomes described for category 1 above.

The locations of the category 1 and 2 and the existing landslide hazard zones are shown on the map enclosed with the quotation documentation.

The Landslip risk assessment is required to follow the methodology detailed in State Planning Policy (1/03) and its associated guidelines and to follow the process recommended by the Australian Geomechanics Society as quoted above.

4. SPECIFIC REQUIREMENTS OF THE CONTRACT

STUDY ADVISORY GROUP MEETINGS

It is anticipated that the Study Advisory Group (SAG) will meet approximately bimonthly during the term of this contract. It is a requirement that the successful tenderer be present at the initial meeting after award of the tender and again at the presentation of the draft report to the SAG. At other SAG meetings either a verbal or written progress report be prepared for presentation.

INFORMATION SUPPLIED BY COUNCIL

Council will supply:

- Relevant special datasets to the successful tenderer, as identified and agreed, to enable the supply of the required maps, on the provision of a signed digital data licence. Spacial Datasets are supplied for the sole purpose of conducting this study.
- Copy of report Landslide Hazard Zoning Study by Coffey Geoscience (2005)

AREAS TO BE INCLUDED IN STUDY

The areas to be included in this study are shown on the attached map.

These areas have been divided into three categories as follows:

- Category 1 Areas that require detailed investigation and advice on the degree of risk to future and existing development and proposed planning scheme constraints.

- Category 2 Areas not within the urban growth boundaries but are likely to interrupt emergency service access. This study category to be limited to possible locations and extent of landslides.

- Category 3 Existing landslide zones 2, 3 and 4 as shown in the former Townsville City Planning Scheme.

PROJECT MANAGEMENT

Refer to Part 4 – AS4122-2000 General Conditions of Contract Annexure A Item 9.

Project Manager will be:

Allen Morris
Executive Officer
Emergency Management Unit & TLDMG

P 07 4727 9477
F 07 4722 0053
M 0407 694 992
E allen.morris@townsville.qld.gov.au

Townsville City Council

P O Box 1268

TOWNSVILLE QLD 4810

PROJECT DELIVERABLES

The report shall be established using:

"Natural Disaster Risk Management: Guidelines for Reporting" 2001, Queensland Department of Emergency Services as the reference document and

Three (3) bound colour copies and an electronic form of the **Draft Report** shall be provided.
Three (3) bound colour copies, one (1) loose leaf copy and an electronic form of the **Final Report** shall be submitted.

The electronic format of the Draft Report shall be a pdf format suitable for viewing on the internet. The electronic format of the Final Report shall be:

a) pdf format for reproduction purposes (including all electronic files necessary to reproduce the document) and
b) pdf format suitable for viewing on the internet.

Mapping of the identified landslide hazard risk areas to conform and be compatible with the standard planning scheme template produced by the Queensland Government, Department of Infrastructure and Planning.

In addition to the report format, the electronic format of the Landslide hazard map(s) shall be in a spatial format suitable for inclusion into Council's Enterprise GIS. Suitable formats include File Geodatabase, Personal Geodatabase or ESRI Shapefile format.

PROGRAM OF WORKS

The consultant shall submit a proposed program of work that identifies all tasks to complete the study together with milestones and dates.

Project Plan to include, but not limited to:

- Desktop report on current report(s) and identification of areas needing further study
- Study Advisory Group advice on desktop report
- Complete field inspections
- Further Study Advisory Group progress advices
- Draft study report to Council
- Draft study report review by Study Advisory Group
- Final study report to Council

The project plan is to be approved by the Project Manager prior to commencement of the works.

To meet the NDRM timetable it is a tender requirement that the final report be delivered to Council no later than Friday 9th July 2010.

REVIEW OF SUBMISSIONS

The submissions are to be reviewed on selection criteria as detailed in part 3 of this document.

Consultants should address the selection criteria in their submissions.

PROGRESS PAYMENTS

Not withstanding the Price Information submitted in section 3.3 of Part 3 of the documentation, progress payments will be made up to a maximum value of 80% of the tender submission with the submission of the final report. The final payment will be made upon acceptance of the works by resolution of Council.

PROJECT BUDGET

The budget for this commission will be broadly allocated as follows:

• Establish recent reports by other agencies and report to SAG	10%
• Undertake hazard and vulnerability assessment	10%
• Undertake a risk analysis of the landslip threat	15%
• Mapping of assessment results	15%
• Preparation and review of report including planning scheme recommendations	50%

Prices quoted for the work are to be firm and are to include all aspects of the work required to complete the study including site visits, accommodation, disbursements, printing costs and the like.

In the event that the successful consultant identifies that additional work beyond the scope of the brief and priced submission is necessary, then the successful consultant shall seek permission from Council. The work shall not begin until the approval in writing is obtained from Council.

COPYRIGHT

Notwithstanding clauses in the consultant's terms and conditions of engagement, the copyright of all work required to complete this project shall be assigned to Council upon completion of the project. Submission of a tender is an acceptance of assigning such copyright to the Council.

5. TIMETABLE FOR PROCUREMENT

Place Advertisement in Newspaper*	**5th December 2009**
Issue Request for Tender	**5th December 2009**
Closing Time*	**3 pm 29th January 2010**
Evaluation of Tender Responses*	**26th February 2010** **(Up to 90 days after the Closing Time)**
Submission to the Principal*	**26th February 2010**
Acceptance of Tender*	**26th February 2010**

**Dates are subject to alteration by the Principal in its discretion.*

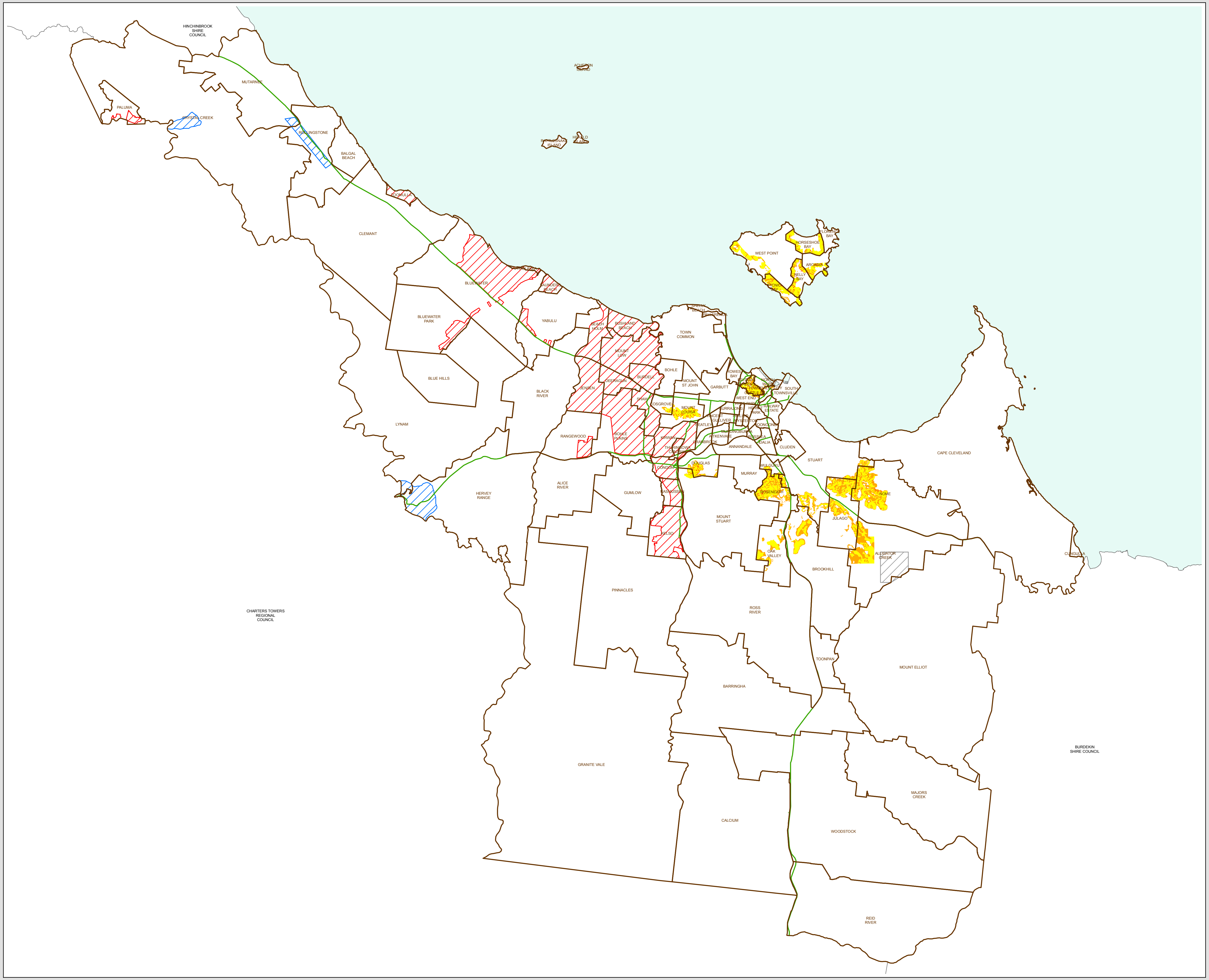
6. IMPLEMENTATION TIMETABLE

Milestone >>	Commencement date	Completion Date >>	Comments >>
Draft report submitted		9th June 2010	
Final Report submitted to Council		9th July 2010	

7. STANDARDS

The study is to be in compliance with:

- "Practice Note Guidelines for Landslide Risk Management 2007" produced by Australian Geomechanics and
- "Natural Disaster Risk Management: Guidelines for Reporting" 2001, Queensland Department of Emergency Services as the reference document.



LANDUSE HAZARD STUDY TENDER BRIEF

LEGEND

- Main Roads
- Category 1 Study Areas - Urban Growth Areas
- Category 2 Study Areas - Access Corridors
- Mount Elliot / Alligator Creek Study Area

Existing Landslide Hazard Study Areas

- Landslide Zone 4 - Potential Debris Flow
- Landslide Zone 3 - High
- Landslide Zone 2 - Medium

N

City of Townsville

SCALE: 1:360,000@ **A3**

5,000 2,500 0 5,000 10,000 Metres

DISCLAIMER
The information shown on this map has been produced from the Townsville City Council's digital database. There is no warranty implied or expressed regarding the accuracy or completeness of the data. The data has been compiled for information and convenience only, and it is the responsibility of the user to verify all information before placing reliance on it. For accurate service locations please contact the appropriate foreperson at Garbutt Operations on 47278999.
This is not a legal document and is published for information and convenience only. The Townsville City Council takes no responsibility for any errors or omissions herein or for any acts that may occur due to its use.

Produced by:

GEOSPATIAL SOLUTIONS
Corporate Services

DATE: 25 NOVEMBER 2009

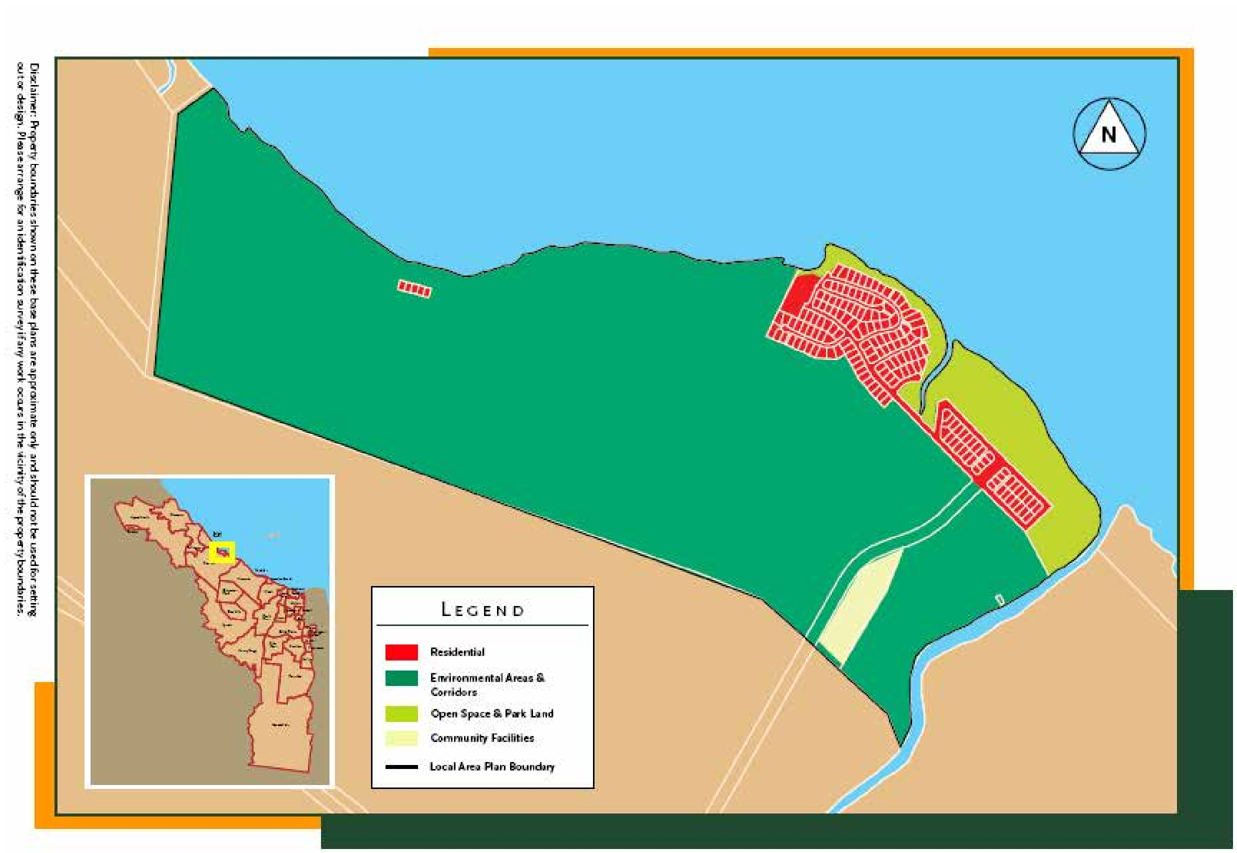
DRAWN BY: BPF

APPENDIX B

STUDY AREA LAND USE ZONING PLANS

Toomulla Local Area Plan

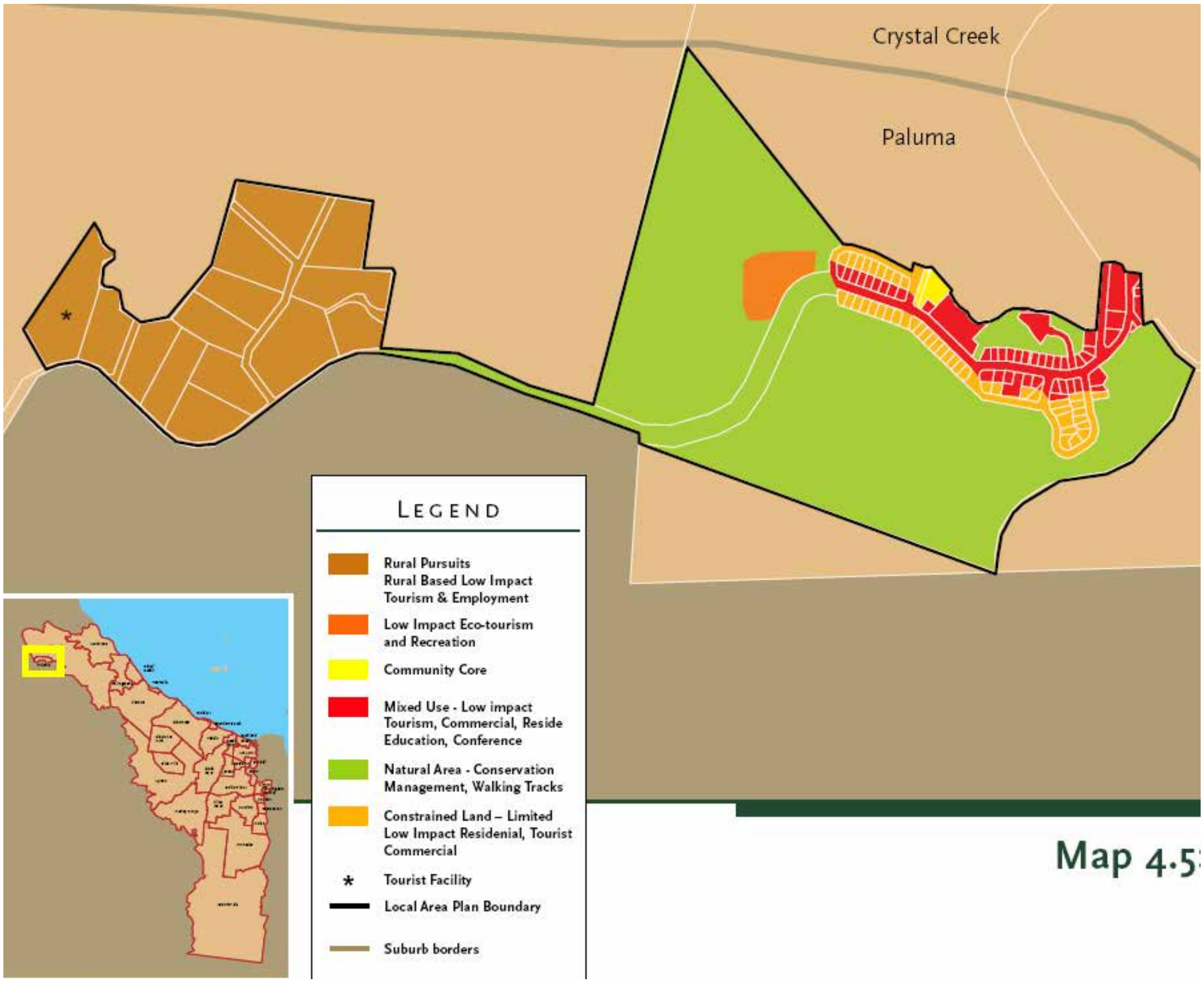
Residential= Traditional Residnetial density



Map 4.2: Toomulla

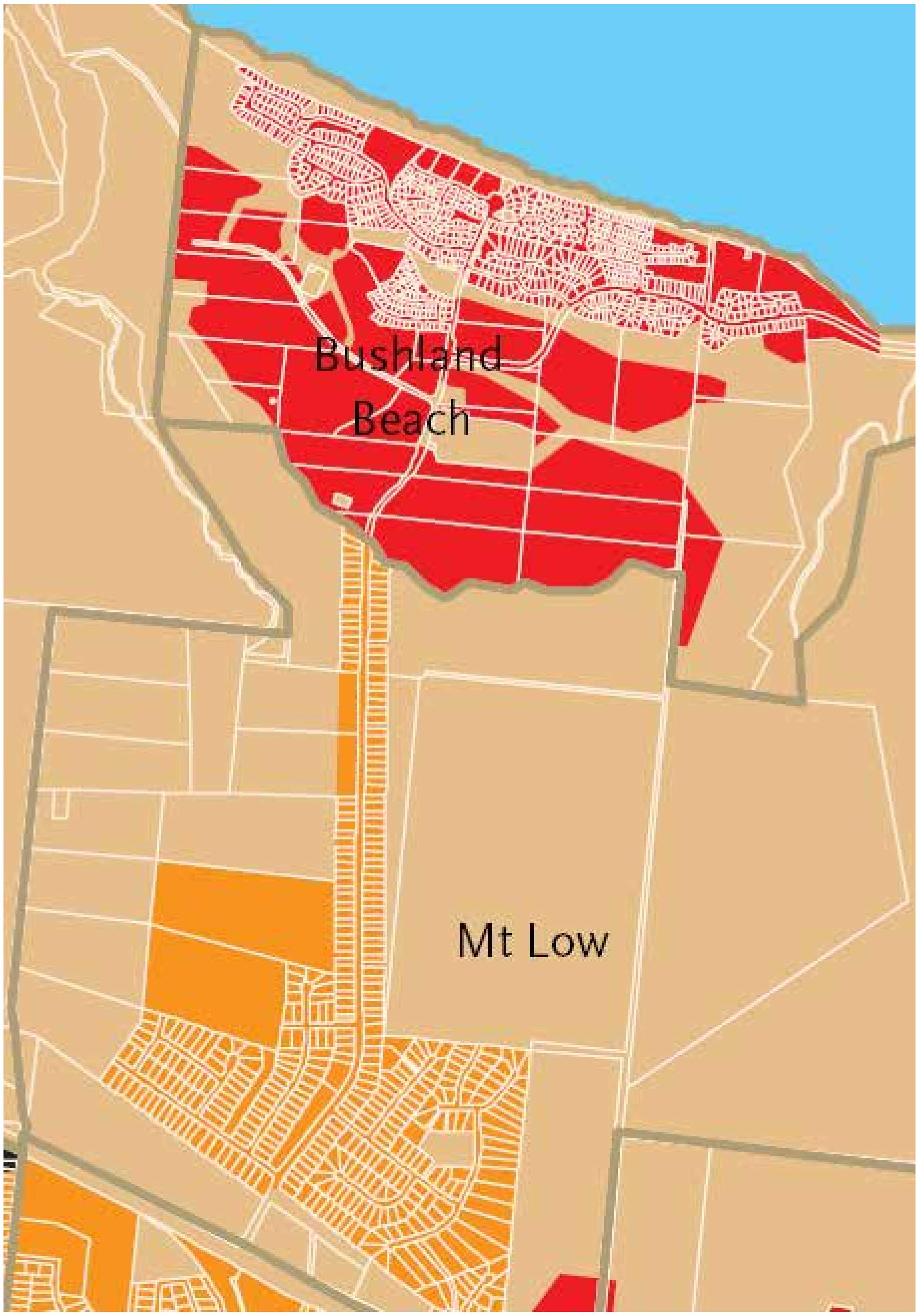
Paluma Local Area Plan

Low Imapct Residential= Traditional Residential



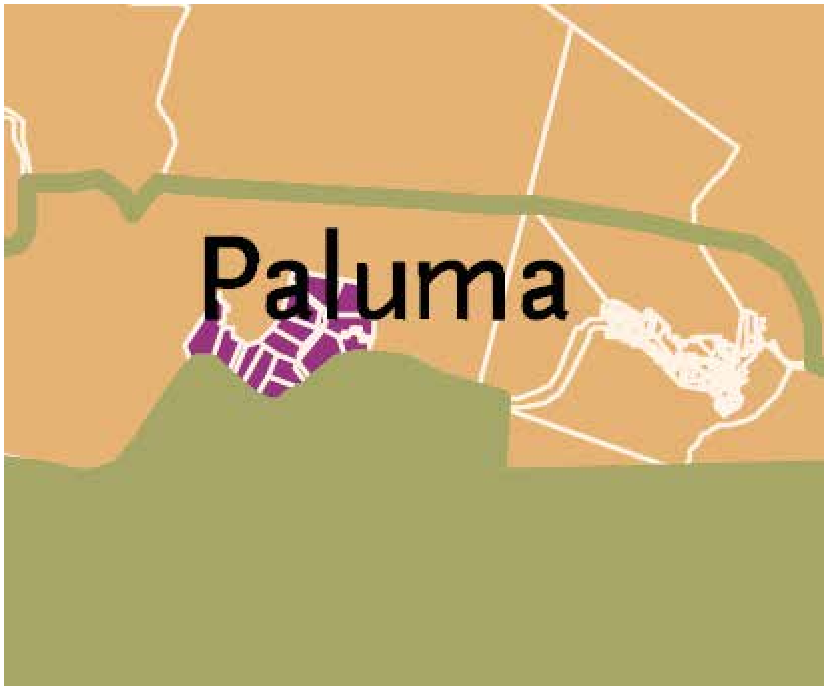
Bushland Beach and Mt Low

Red= Traditional Residential, Orange= Park Residential



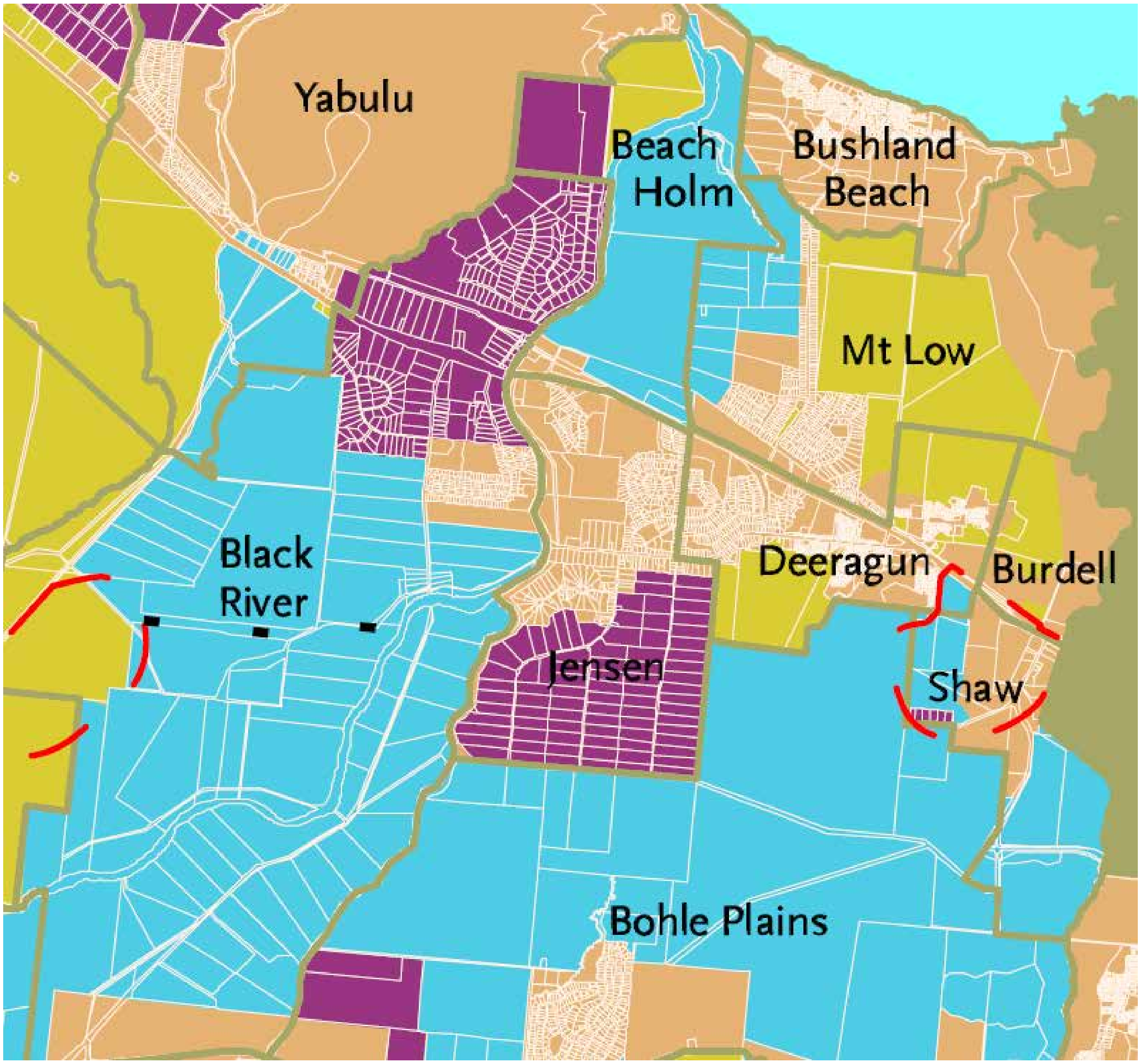
Paluma Rural Zones

Purple= Rural 10ha



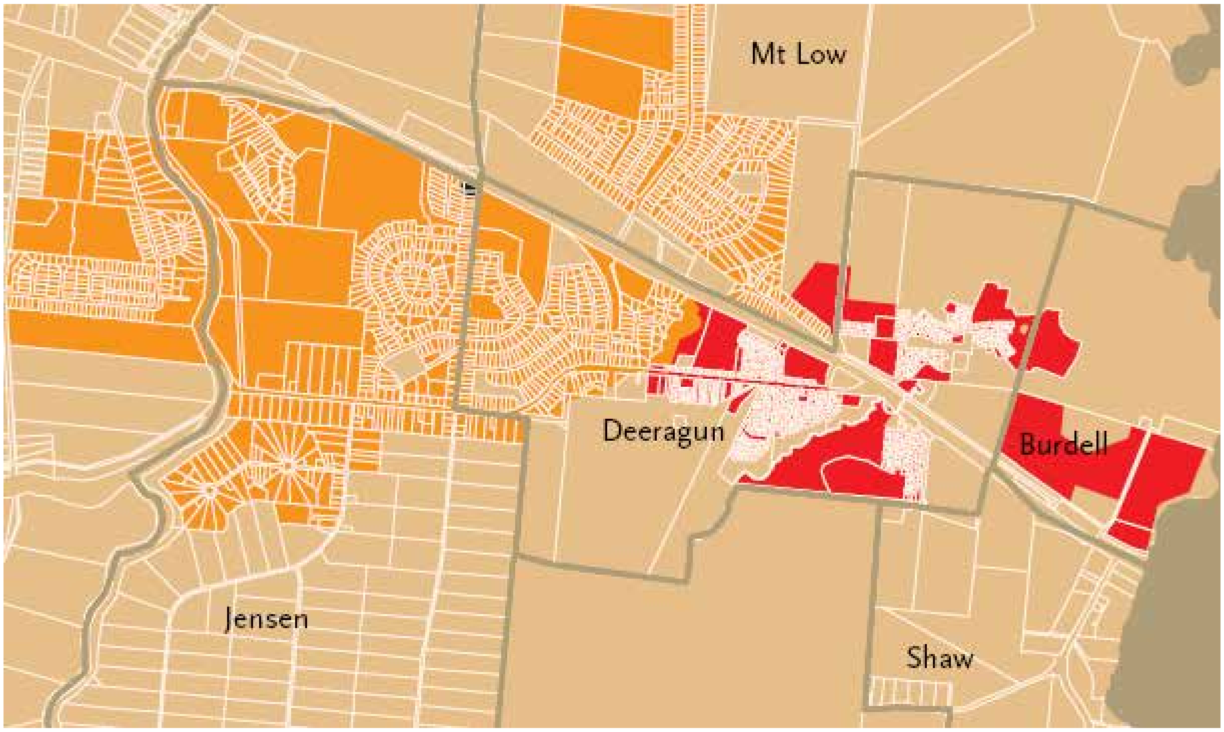
Bushland Beach, Beach Holm, Mt Low, Jensen, Burdell, Deeragun, Bohle Plains Black River, Shaw

Purple= Rural 10ha, Blue=Rural 40ha, Yellow Rural 400ha



Jensen, Deeragun, Burdell

Red= Traditional Residential, Orange= Park Residential



APPENDIX C

REPRODUCTION OF AGS PRACTICE NOTE GUIDELINES FOR LANDSLIDE RISK MANAGEMENT (AGS 2007c)

Australian Geomechanics Society

Extract from

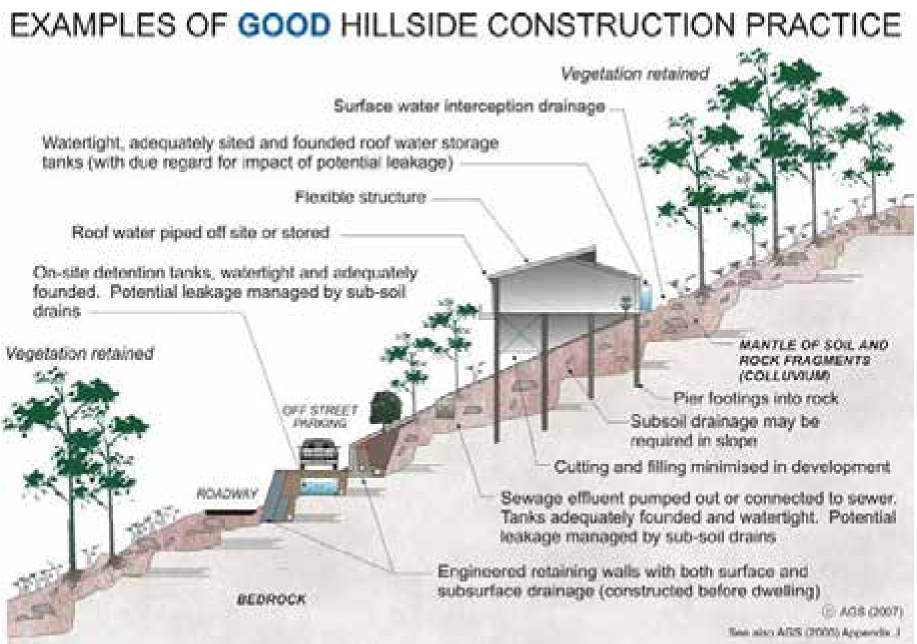
Australian Geomechanics

Journal and News of the Australian Geomechanics Society
Volume 42 No 1 March 2007

Extract containing:

"Practice Note Guidelines for Landslide Risk Management 2007"

Ref: AGS (2007c)



Landslide Risk Management

ISSN 0818-9110

PRACTICE NOTE GUIDELINES FOR LANDSLIDE RISK MANAGEMENT 2007

Australian Geomechanics Society Landslide Taskforce,

Landslide Practice Note Working Group

TABLE OF CONTENTS

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.

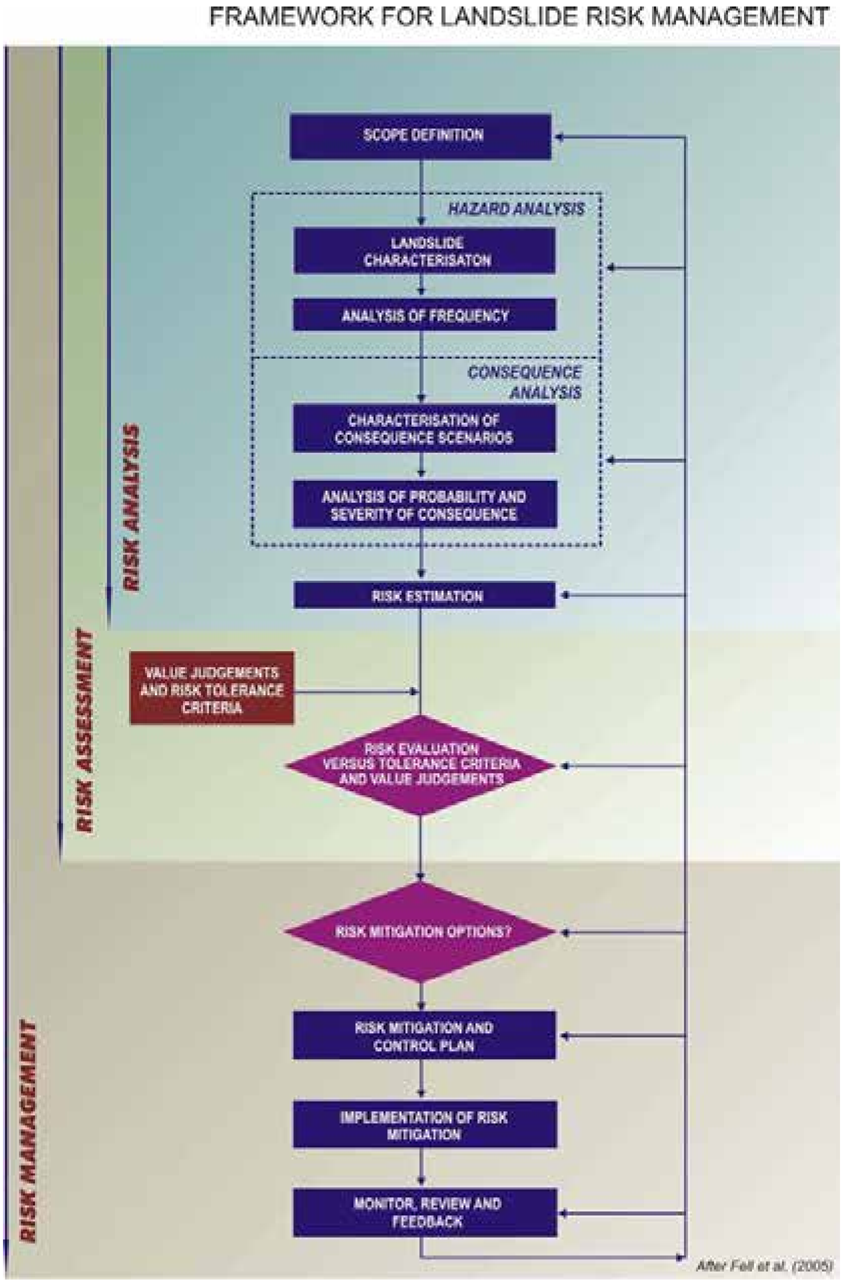


Figure 1.

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.

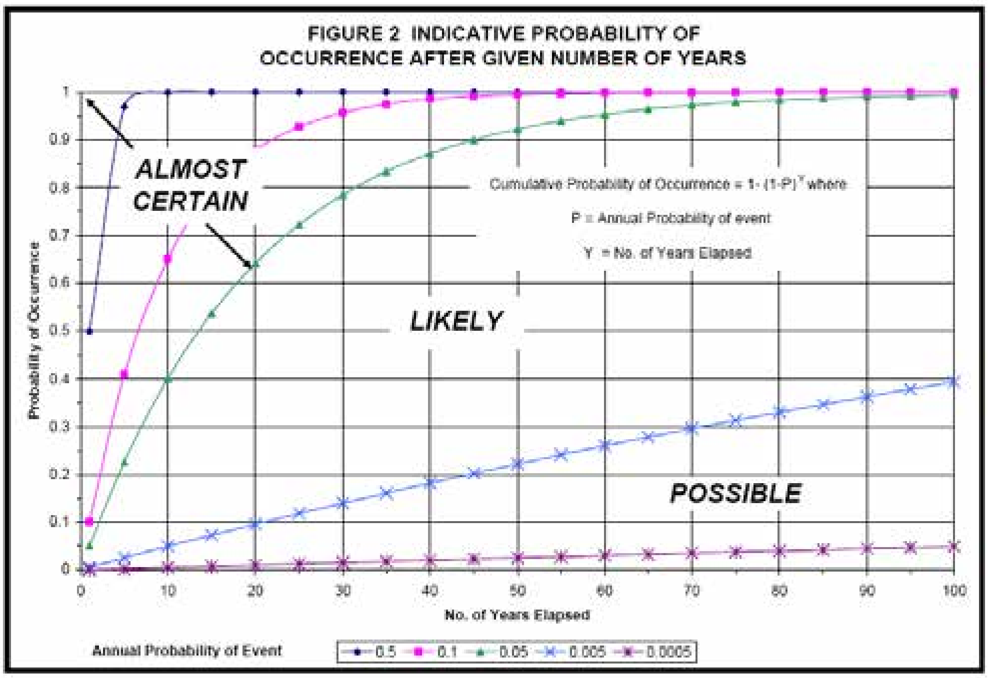
A trigger event for a particular locality (e.g. a certain intensity/duration or recurrence interval of rainfall) will not necessarily cause each potential landslide event in that locality to occur. There will be a finite probability (value) that the landslide under consideration may not be set off by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

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

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 risk$1.0< \mathbf{P}_{(T:S)} >0$.

$\mathbf{V}_{(Prop:S)}$ 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:

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

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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Standards Australia (2001) *"Steel Structures"* Australian Standard AS4100

Standards Australia (2002) *"Earth Retaining Structures"* Australian Standard AS4678.

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	Earth flow
			(Soil creep)	
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.

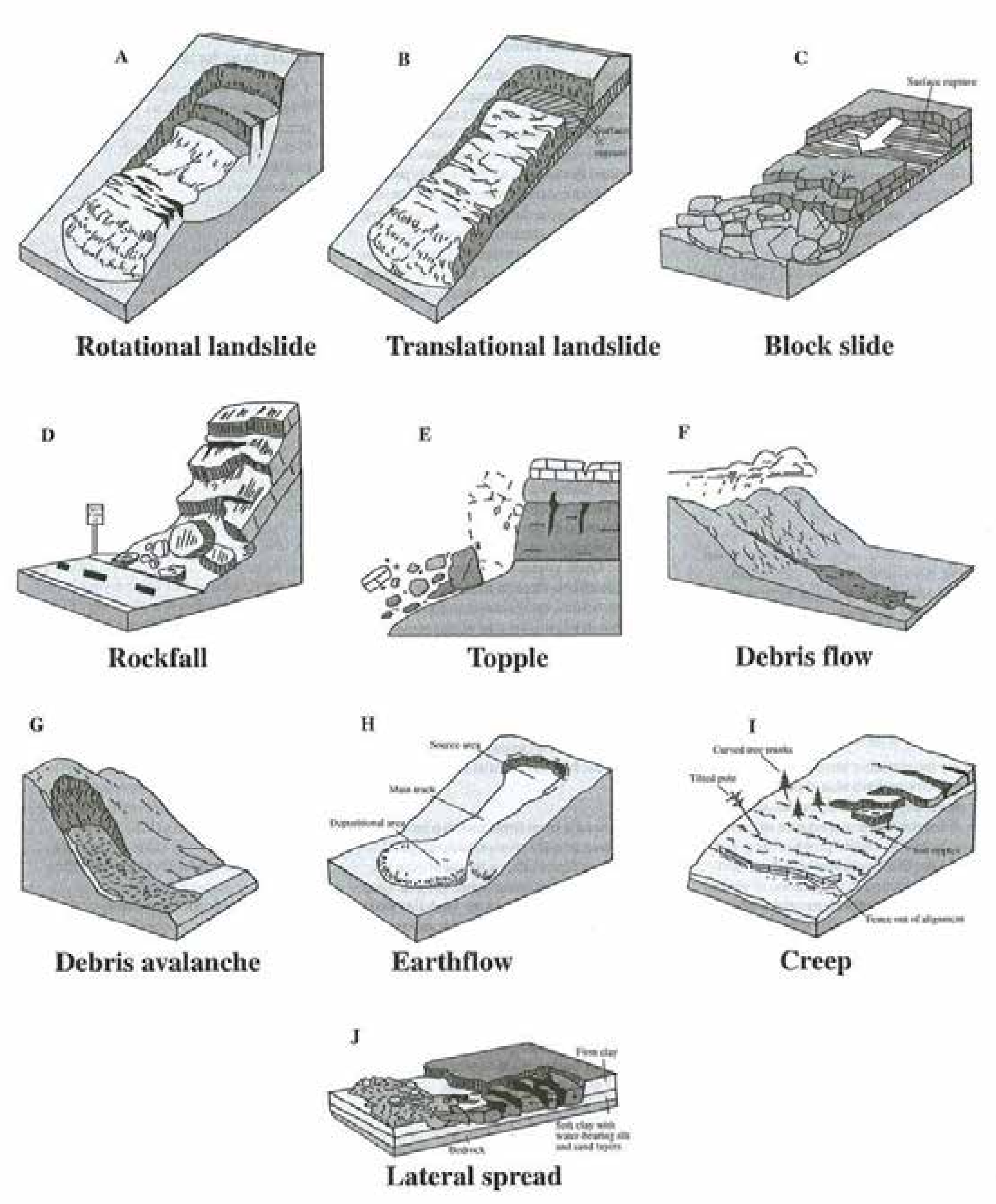


Figure B1: These schematics illustrate the major types of landslide movement.
(From US Geological Survey Fact Sheet 2004-3072, July 2004, with kind permission for reproduction.)

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).

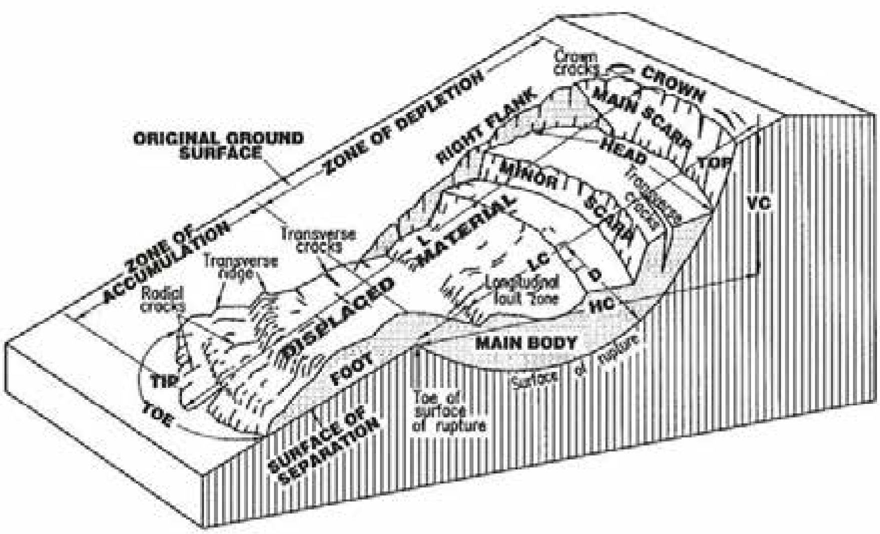


Figure B2: Block of Idealised Complex Earth Slide – Earth Flow

(*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.

REFERENCES AND ACKNOWLEDGEMENT

Cruden, D.M., & Varnes, D.J. (1996), "Landslide Types and Processes", Ch.3 in "Landslides. Investigation and Mitigation", Eds Turner, A.K. and Schuster, R.L. Special Report 247, Transport Research Board, National Research Council, Washington D.C. Extracts reprinted above by kind permission of the authors and publishers. Copies of the publication can be obtained from "Transport Research Board, National Research Council, 2101 Constitution Avenue, N.W., Washington D.C. 20418, USA.

IAEG (International Association of Engineering Geology) Commission on Landslides, (1990). Suggested nomenclature for landslides, Bulletin IAEG, No. 41, pp.13-16.

Varnes, D.J. (1978). Slope Movement Types and Processes. In *Special Report 176: Landslides: Analysis and Control* (R.L. Schuster and R.J. Krizek, eds.), TRB, National Research Council, Washington, D.C., pp.11-33.

WP/WLI (International Geotechnical Societies' UNESCO Working Party on World Landslide Inventory) (1990). A suggested method for reporting a landslide. Bulletin IAEG, 41, pp.5-12

WP/WLI (International Geotechnical Societies' UNESCO Working Party on World Landslide Inventory) (1993). A suggested method for describing the activity of a landslide. Bulletin International Association of Engineering Geology, 47: 53-57.

WP/WLI (International Geotechnical Societies' UENSCO Working Party on World Landslide Inventory) (1994). Multilingual Glossary for Landslides, Bitech Press, Vancouver, in press.

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}		100 years		The event will probably occur under adverse conditions over the design life.	LIKELY	B
10^{-3}	$5x10^{-3}$	1000 years	200 years	The event could occur under adverse conditions over the design life.	POSSIBLE	C
10^{-4}	$5x10^{-4}$	10,000 years	2000 years	The event might occur under very adverse circumstances over the design life.	UNLIKELY	D
10^{-5}	$5x10^{-5}$	100,000 years	20,000 years	The event is conceivable but only under exceptional circumstances over the design life.	RARE	E
10^{-6}	$5x10^{-6}$	1,000,000 years	200,000 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%		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%	100%	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%	40%	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%	10%	Limited damage to part of structure, and/or part of site requiring some reinstatement stabilisation works.	MINOR	4
0.5%	1%	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	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	Page 2 of 2

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		I am a geotechnical engineer or engineering geologist as defined by the <*Regulator's geotechnical DCP*> and on behalf of the company below, I:
☐	No ☐	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.
☐	N/A ☐	prepared the geotechnical report referenced above in accordance with the AGS (2007c) as amended and <*Regulator's geotechnical DCP*>.
☐	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**

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)

I am a geotechnical engineer or engineering geologist as defined by the <*Regulator's geotechnical DCP*> and on behalf of the company below:

Yes	No	
☐	☐	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	Page 2 of 2 **Geotechnical Declaration** **Subdivision <*Construction Certificate*> Application**

Section 4 Checklist

Geotechnical Requirements (Tick as appropriate, either Yes or 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.
Yes	No	
☐	☐	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	Page 1 of 2
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**

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 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 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)

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:

Yes	No	
☐	☐	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**

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)

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:

Yes	No	
☐	☐	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	**Geotechnical Declaration** **<*Building Certificate*> or Order**	Page 1 of 2
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

Geotechnical Declaration
<*Building Certificate*> or Order

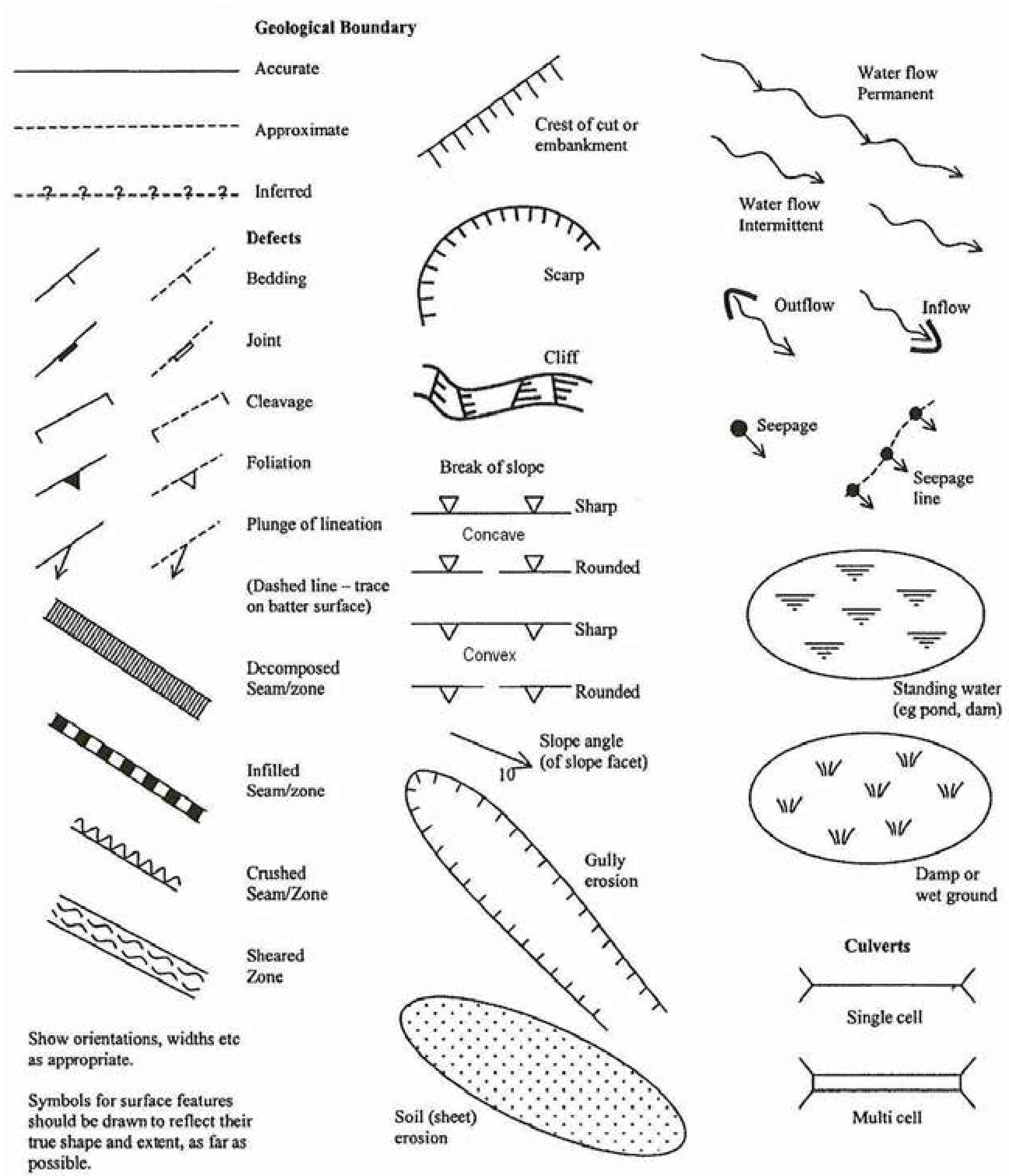
Section 4 List of Site Reports or Site Instructions Issued

List of Documents Issued	Description/Title	Reference No.	Date	Author	Associated Design Drawings	
					Yes	No

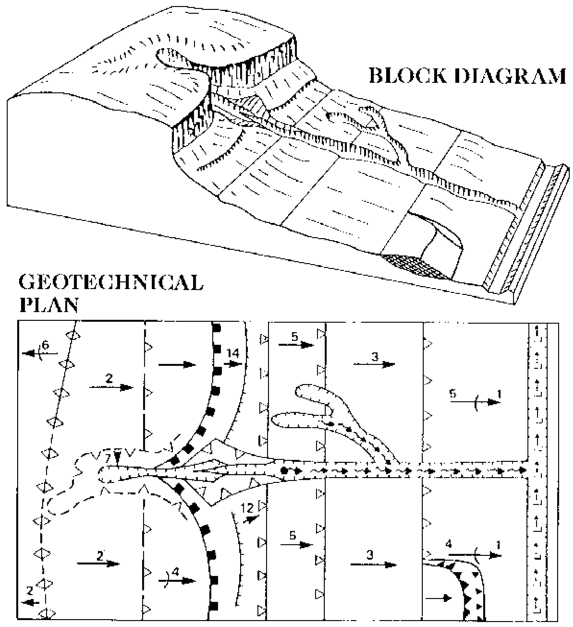
Section 5 Geotechnical Engineer or Engineering Geologist Details

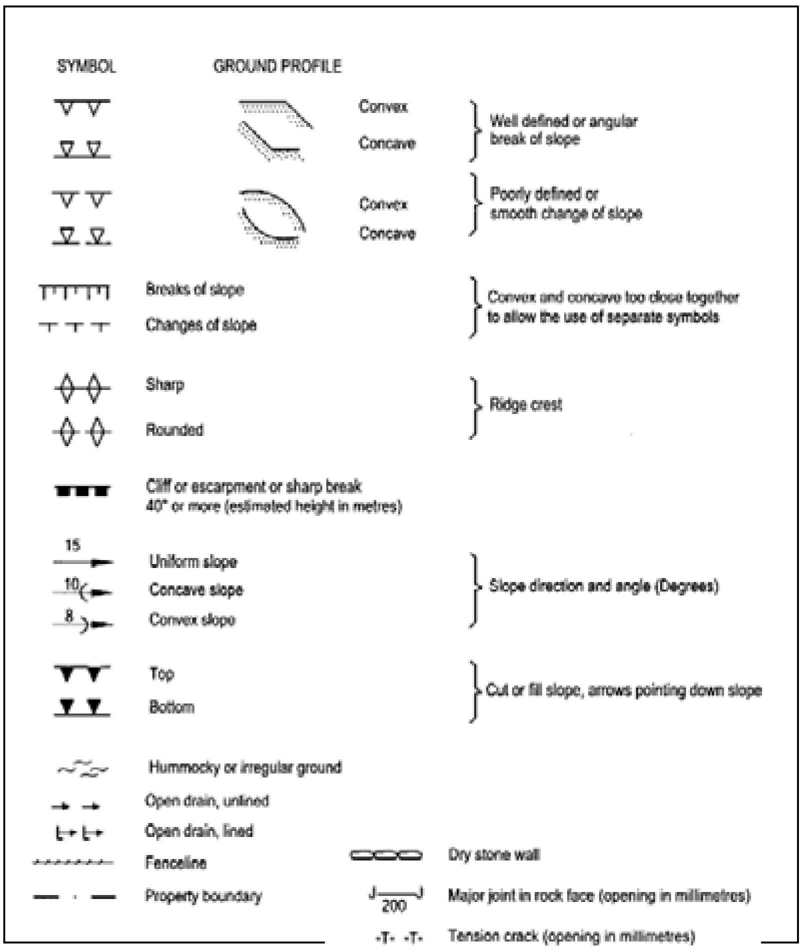
Company/ Organisation Name		
Name (Company Representative)	Surname:	Mr /Mrs /Other:
	Given Names:	
	Chartered Professional Status:	Registration No:
Signature		Dated: / /

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

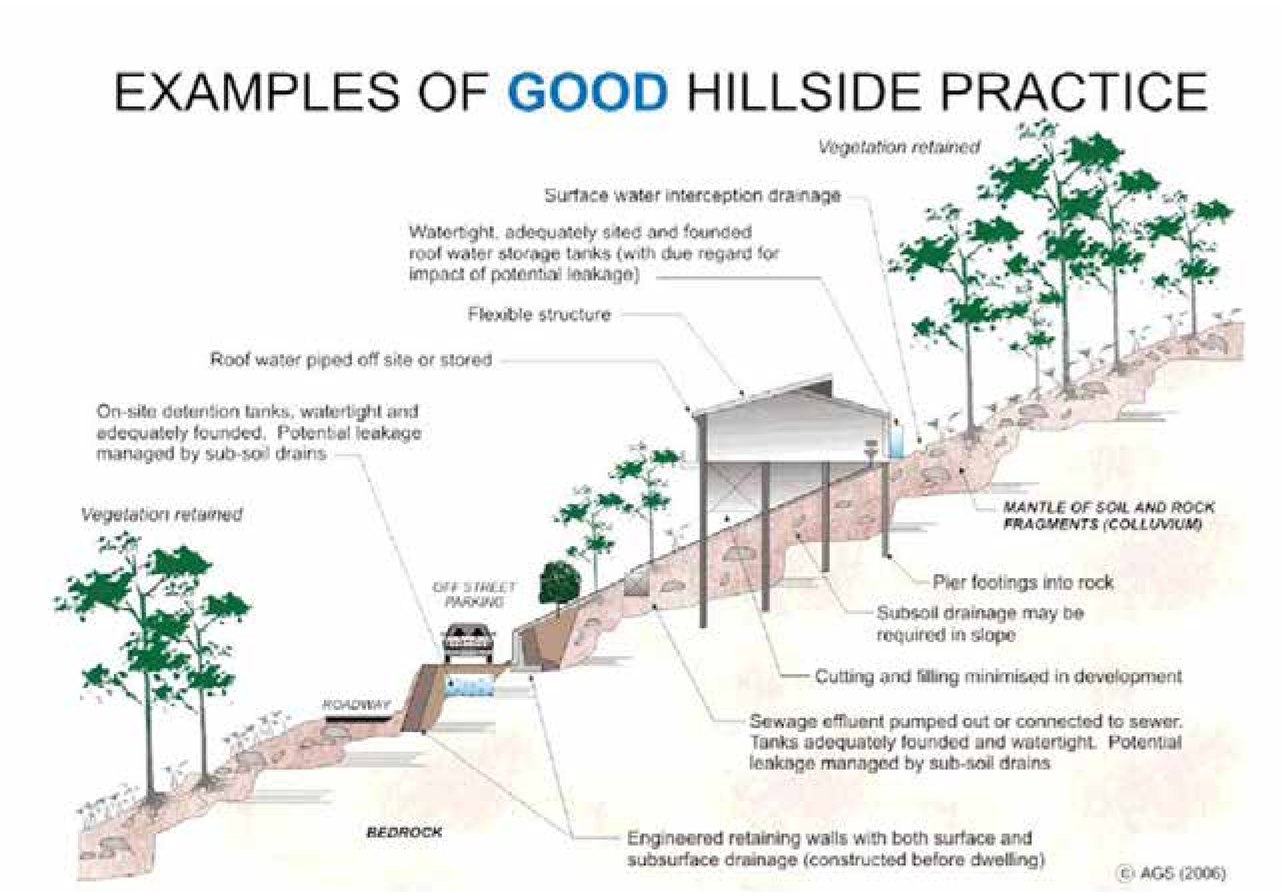
The following table is adapted from R A Wilson, A T Moon, M Hendricks & I E Stewart (2005).
Application of quantitative risk assessment to the Lawrence Hargrave Drive Project, New South Wales,Australia.
Landslide Risk Management - Hungr, Fell, Couture & Eberhardt (eds) 2005. Taylor & Francis Group, London, ISBN 04 1538 043X.

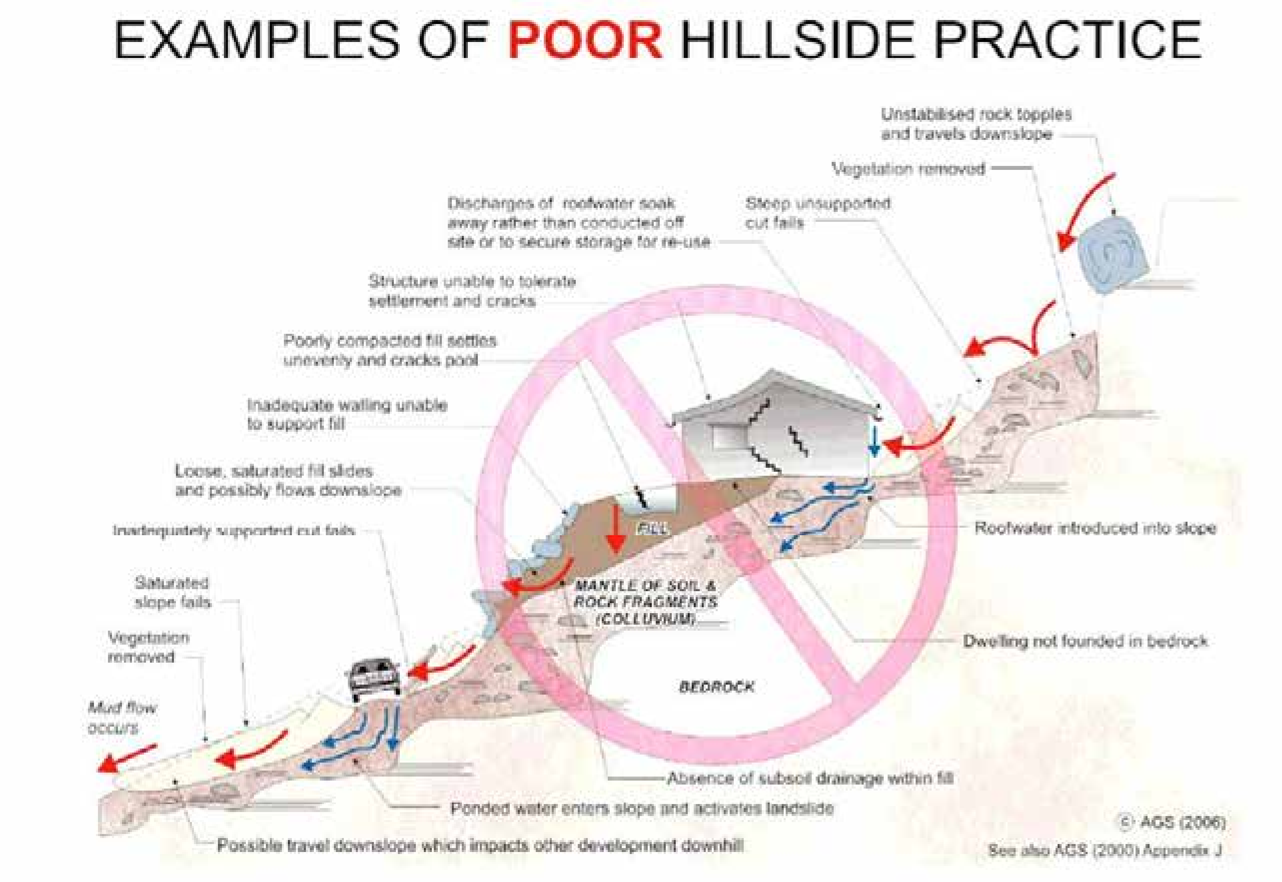
Order of magnitude of landslide crossing road (m^3)	**Rockfalls from Scarborough Cliff**		**Debris flow from Northern Amphitheatre**	
	Landslide hits car	**Car hits landslide**	**Landslide hits car**	**Car hits landslide**
0.03	0.05	0.006	–	–
0.3	0.1	0.002	–	–
3	0.3	0.03	0.001	–
30	0.7	0.03	0.01	0.001
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
Vegetation retained
Surface water interception drainage
Watertight, adequately sited and founded roof water storage tanks (with due regard for impact of potential leakage)
Flexible structure
Roof water piped off site or stored
On-site detention tanks, watertight and adequately founded. Potential leakage managed by sub-soil drains
Vegetation retained
OFF STREET PARKING
ROADWAY
MANTLE OF SOIL AND ROCK FRAGMENTS (COLLUVIUM)
Pier footings into rock
Subsoil drainage may be required in slope
Cutting and filling minimised in development
Sewage effluent pumped out or connected to sewer. Tanks adequately founded and watertight. Potential leakage managed by sub-soil drains
BEDROCK
Engineered retaining walls with both surface and subsurface drainage (constructed before dwelling)
© AGS (2006)


EXAMPLES OF POOR HILLSIDE PRACTICE
Unstabilised rock topples and travels downslope
Vegetation removed
Discharges of roofwater soak away rather than conducted off site or to secure storage for re-use
Steep unsupported cut fails
Structure unable to tolerate settlement and cracks
Poorly compacted fill settles unevenly and cracks pool
Inadequate walling unable to support fill
Loose, saturated fill slides and possibly flows downslope
Inadequately supported cut fails
FILL
Roofwater introduced into slope
Saturated slope fails
MANTLE OF SOIL & ROCK FRAGMENTS (COLLUVIUM)
Vegetation removed
Dwelling not founded in bedrock
BEDROCK
Mud flow occurs
Absence of subsoil drainage within fill
Ponded water enters slope and activates landslide
© AGS (2006)
Possible travel downslope which impacts other development downhill
See also AGS (2000) Appendix J

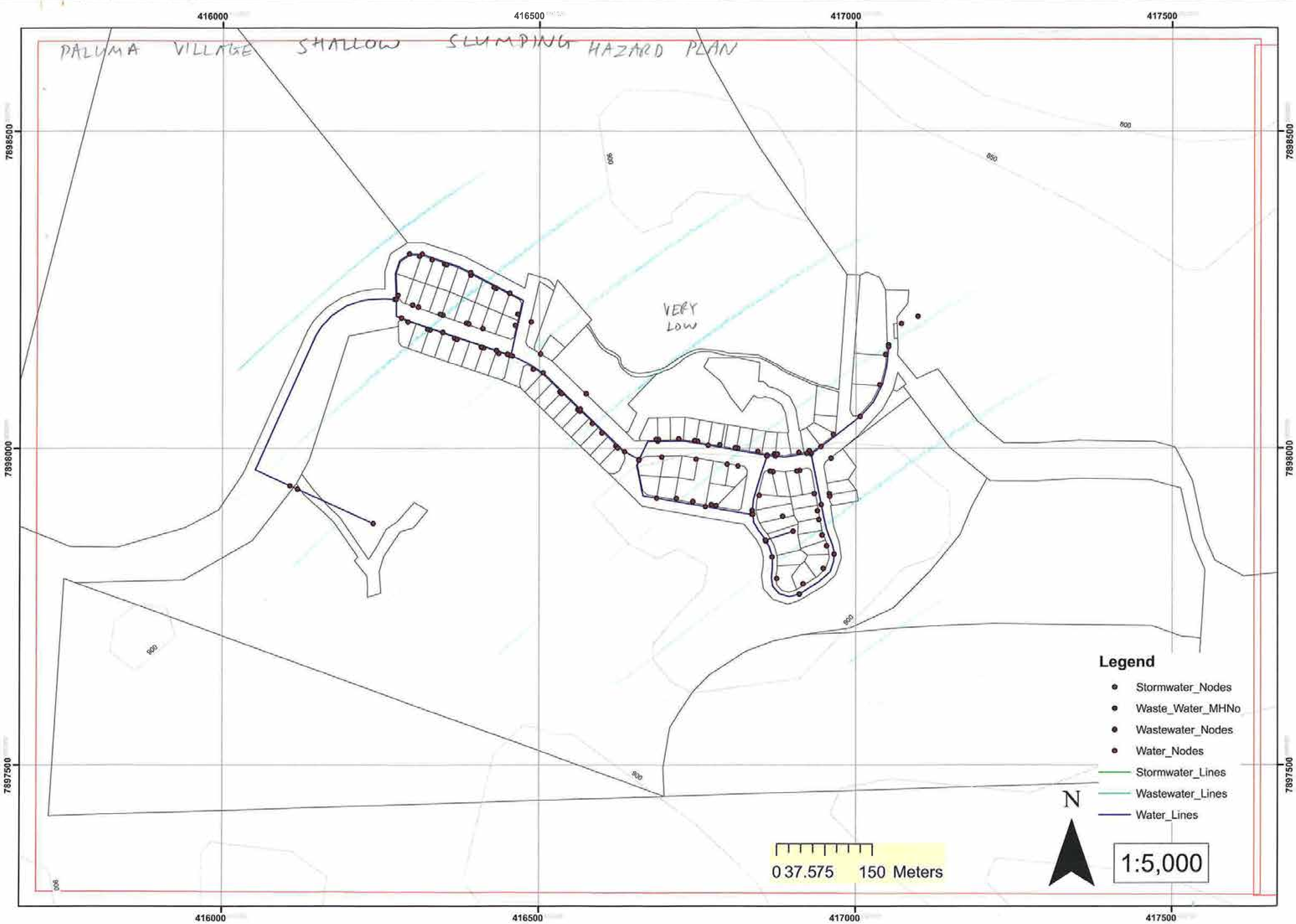
APPENDIX D

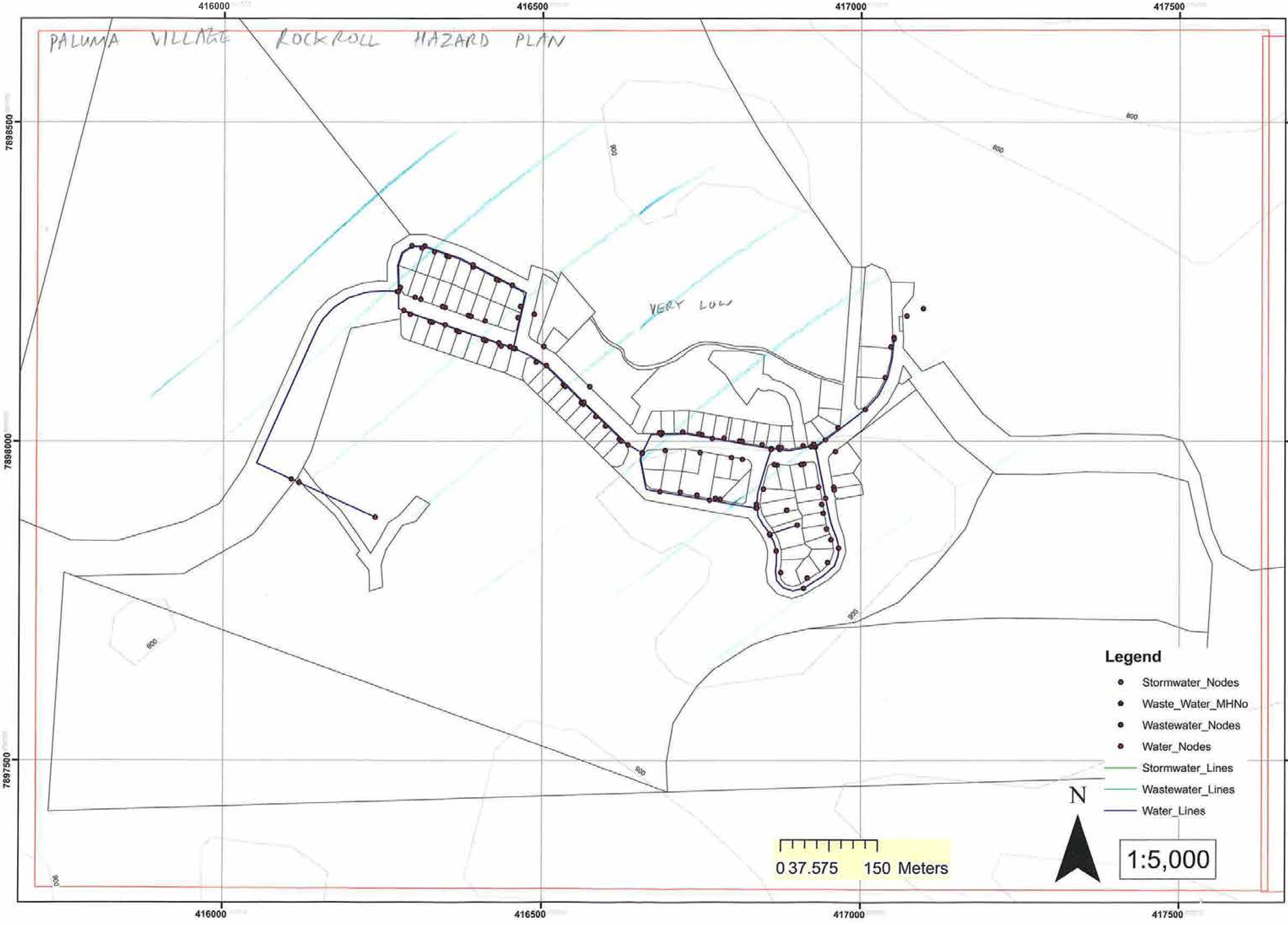
CATEGORY 1 WORK PLANS

FACTUAL PLAN LEGEND

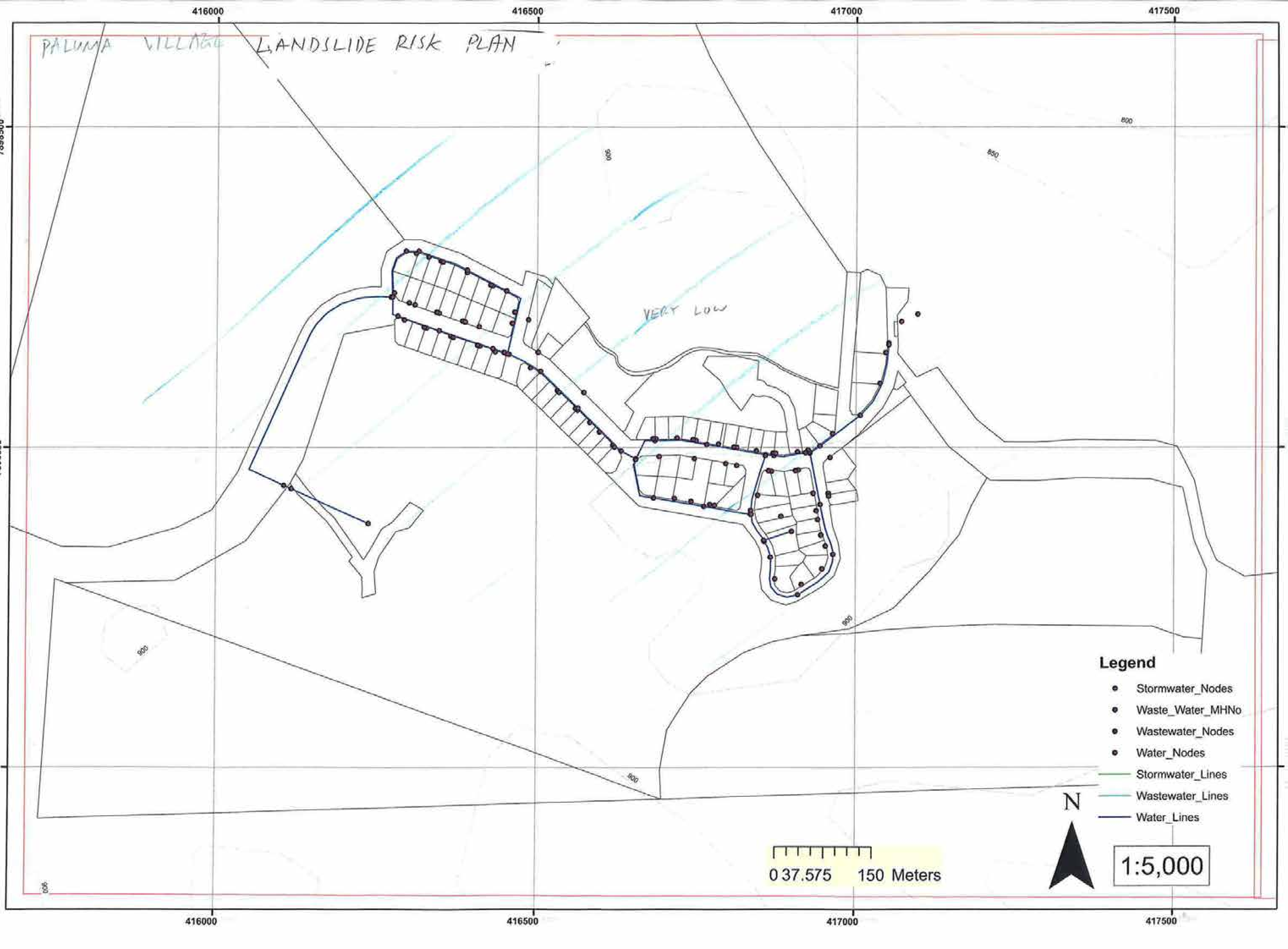
- FLOW PATH
- STREAM / WATERCOURSE
- EXPOSED BEDROCK
- BOULDERS ON SURFACE
- RELIC SCARP
- ACTIVE SCARP
- PIPELINE
- ROAD
- WATER TANK

P□□□M□ □□□□□□□

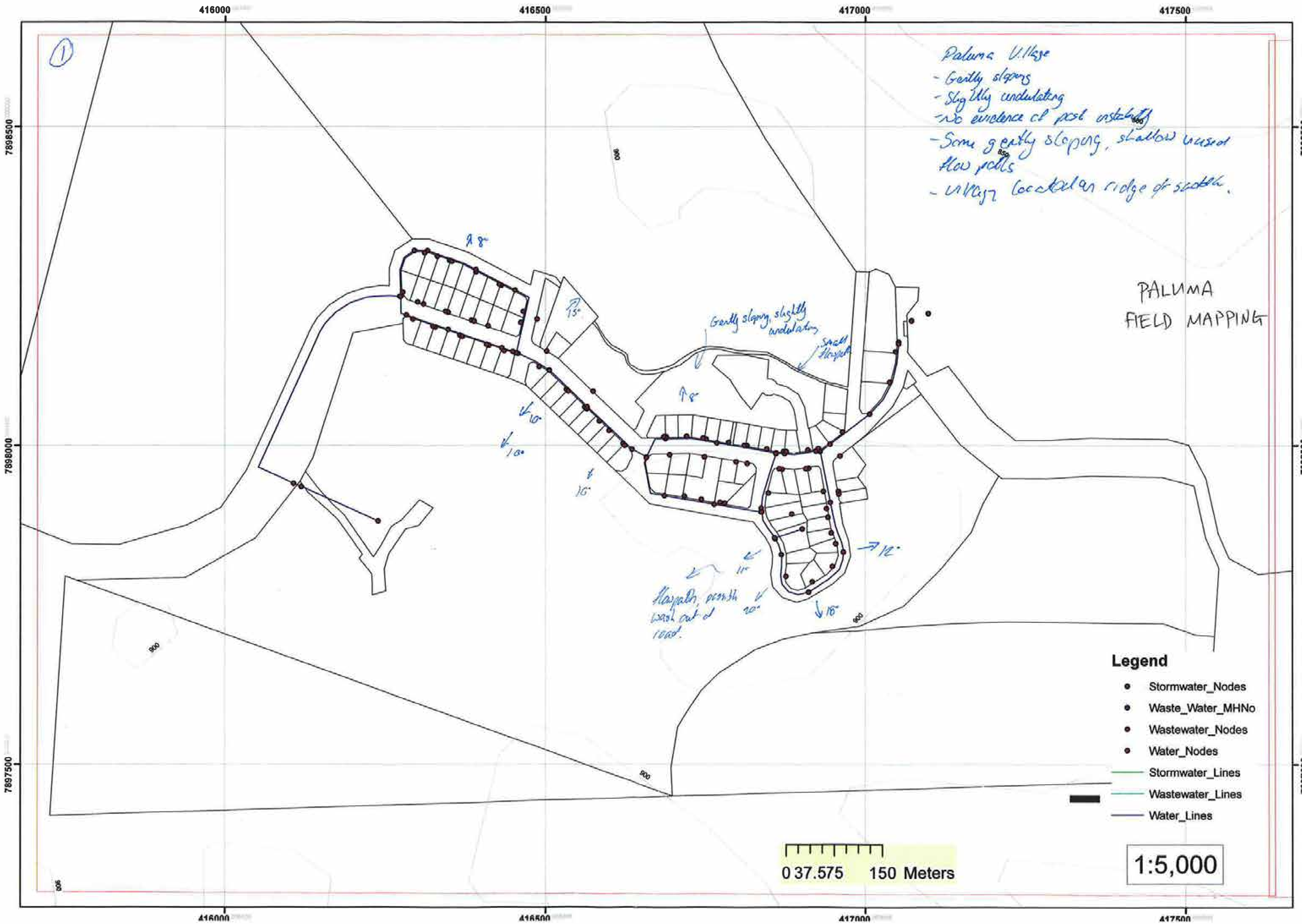

PALUMA VILLAGE SHALLOW SLUMPING HAZARD PLAN
VERY LOW
416000
416500
417000
417500
7898500
7898000
7897500
900
850
800
Legend
Stormwater_Nodes
Waste_Water_MHNo
Wastewater_Nodes
Water_Nodes
Stormwater_Lines
Wastewater_Lines
Water_Lines
N
0 37.575 150 Meters
1:5,000

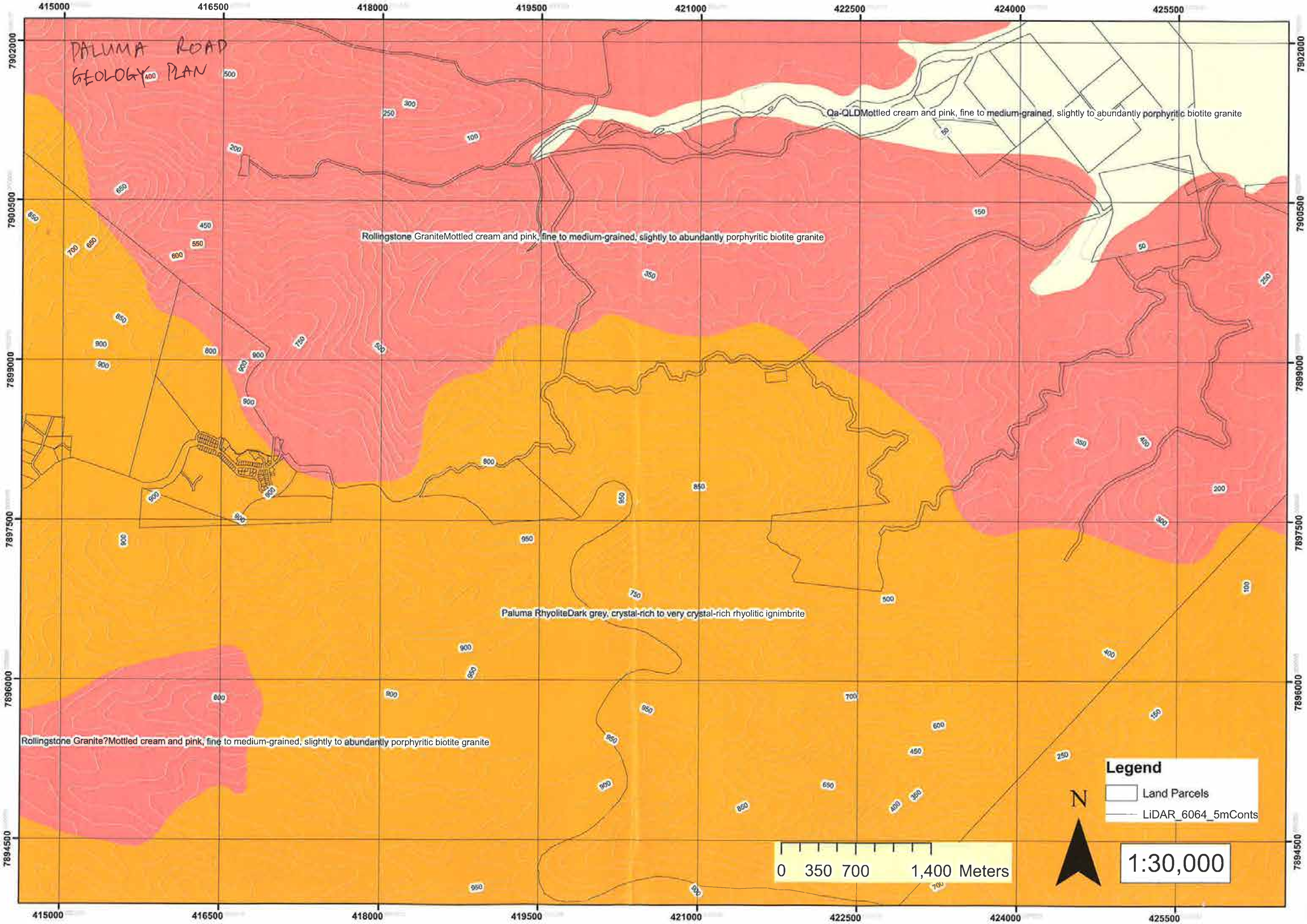


PALUMA VILLAGE ROCKROLL HAZARD PLAN
VERY LOW
416000
416500
417000
417500
7898500
7898000
7897500
900
850
800
Legend
Stormwater_Nodes
Waste_Water_MHNo
Wastewater_Nodes
Water_Nodes
Stormwater_Lines
Wastewater_Lines
Water_Lines
N
0 37.575 150 Meters
1:5,000

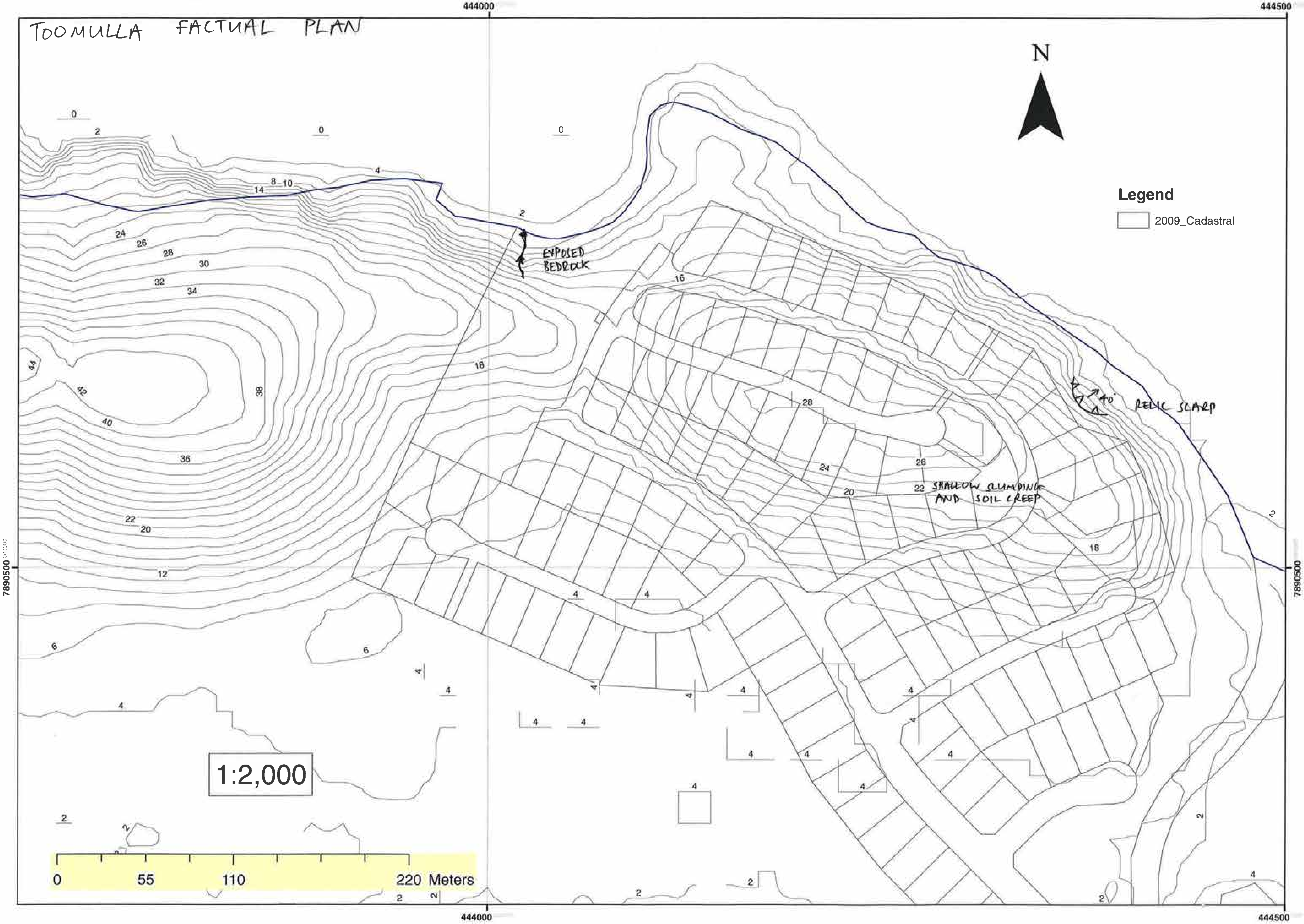


PALUMA VILLAGE LANDSLIDE RISK PLAN
416000
416500
417000
417500
7898500
7898000
7897500
VERY LOW
800
850
900
Legend
Stormwater_Nodes
Waste_Water_MHNo
Wastewater_Nodes
Water_Nodes
Stormwater_Lines
Wastewater_Lines
Water_Lines
N
0 37.575 150 Meters
1:5,000

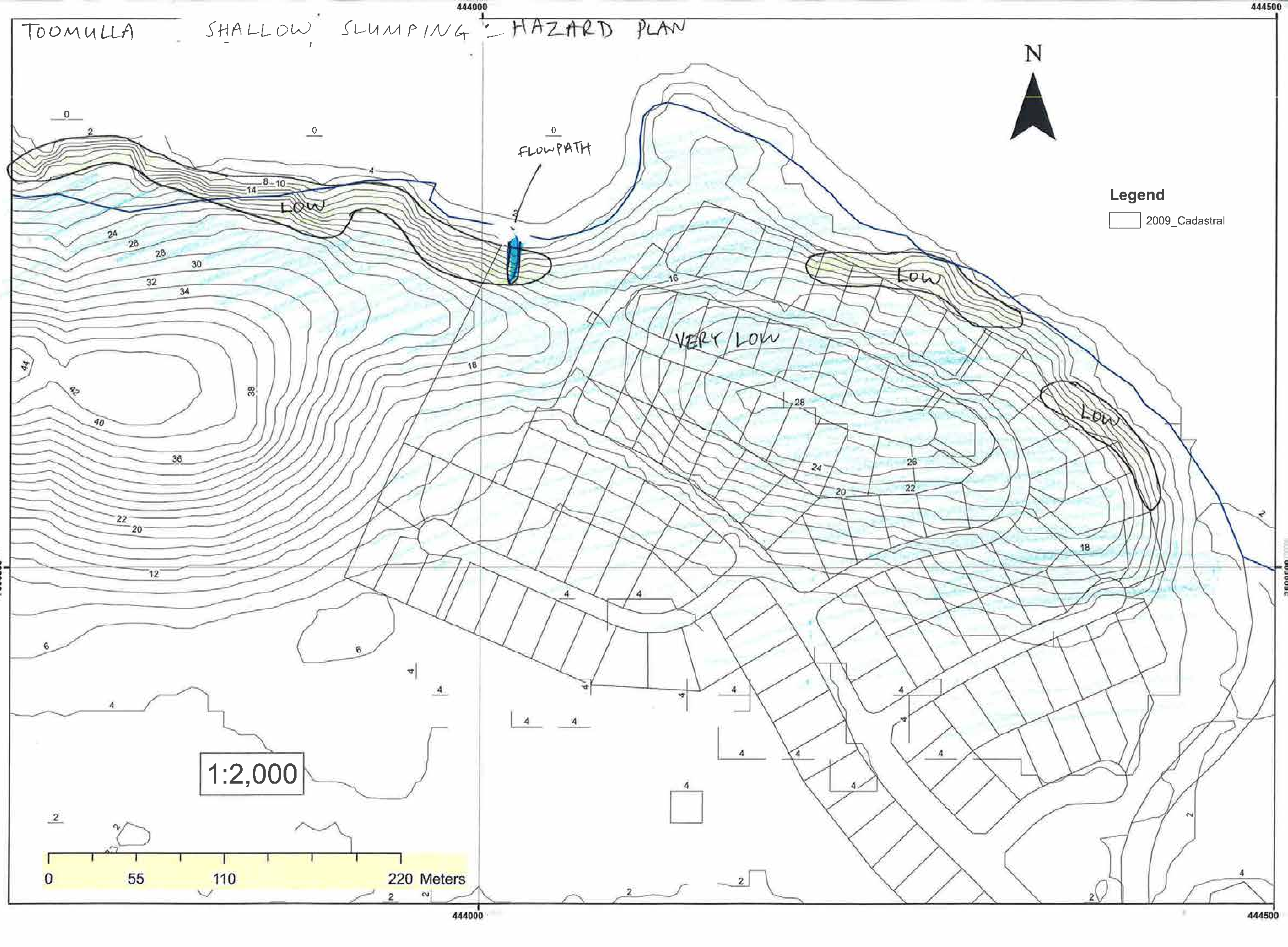

416000
416500
417000
417500
7898500
7898000
7897500
Paluma Village
- Gently sloping
- Slightly undulating
- No evidence of past instability
- Some gently sloping, shallow incised flow paths
PALUMA
FIELD MAPPING
Gently sloping, slightly undulating
Legend
Stormwater_Nodes
Waste_Water_MHNo
Wastewater_Nodes
Water_Nodes
Stormwater_Lines
Wastewater_Lines
Water_Lines
0 37.575 150 Meters
1:5,000
900



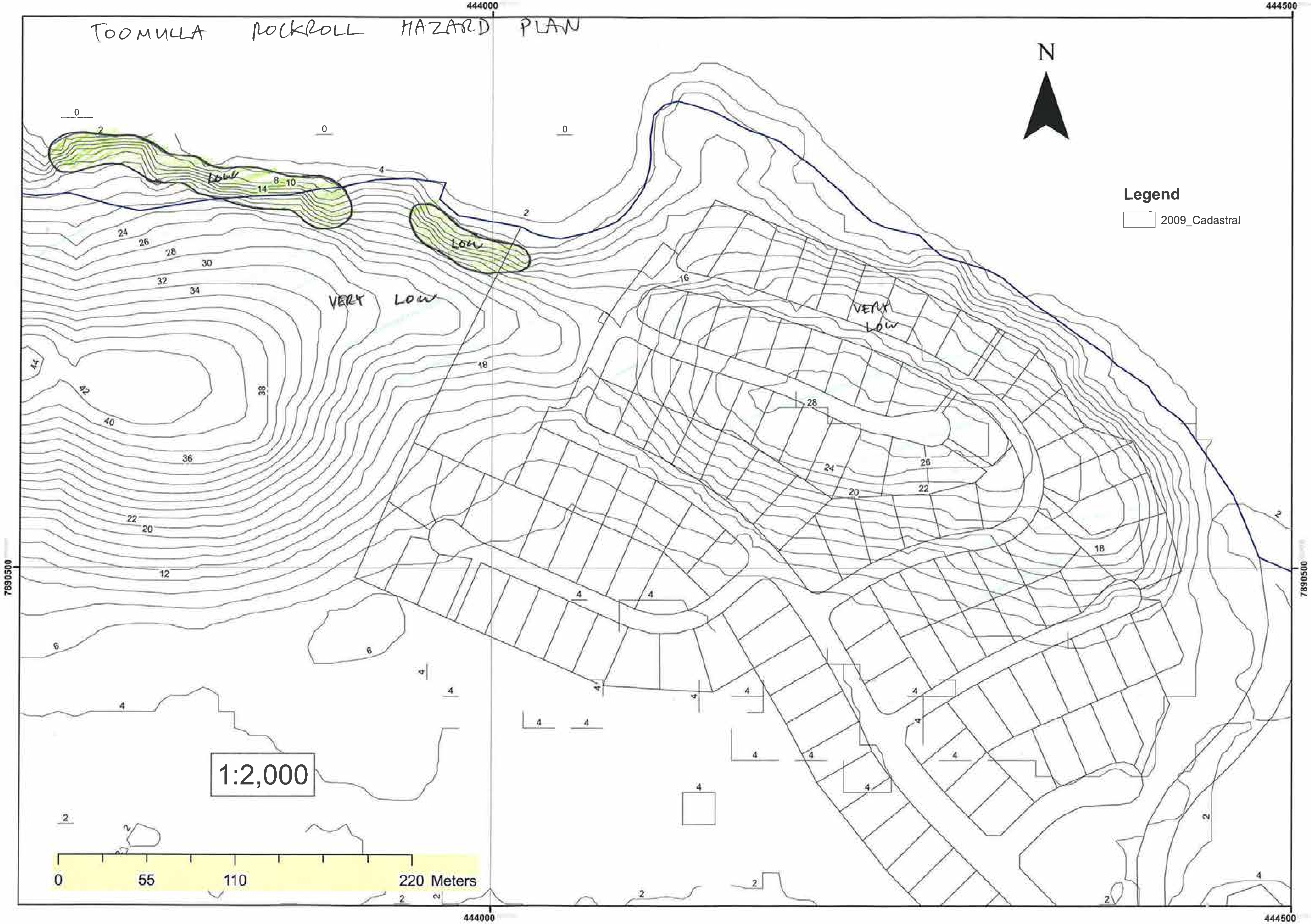
PALUMA ROAD
GEOLOGY PLAN
Qa-QLDMottled cream and pink, fine to medium-grained, slightly to abundantly porphyritic biotite granite
Rollingstone GraniteMottled cream and pink, fine to medium-grained, slightly to abundantly porphyritic biotite granite
Paluma RhyoliteDark grey, crystal-rich to very crystal-rich rhyolitic ignimbrite
Rollingstone Granite?Mottled cream and pink, fine to medium-grained, slightly to abundantly porphyritic biotite granite
415000
416500
418000
419500
421000
422500
424000
425500
7902000
7900500
7899000
7897500
7896000
7894500
Legend
Land Parcels
LiDAR_6064_5mConts
N
0 350 700 1,400 Meters
1:30,000

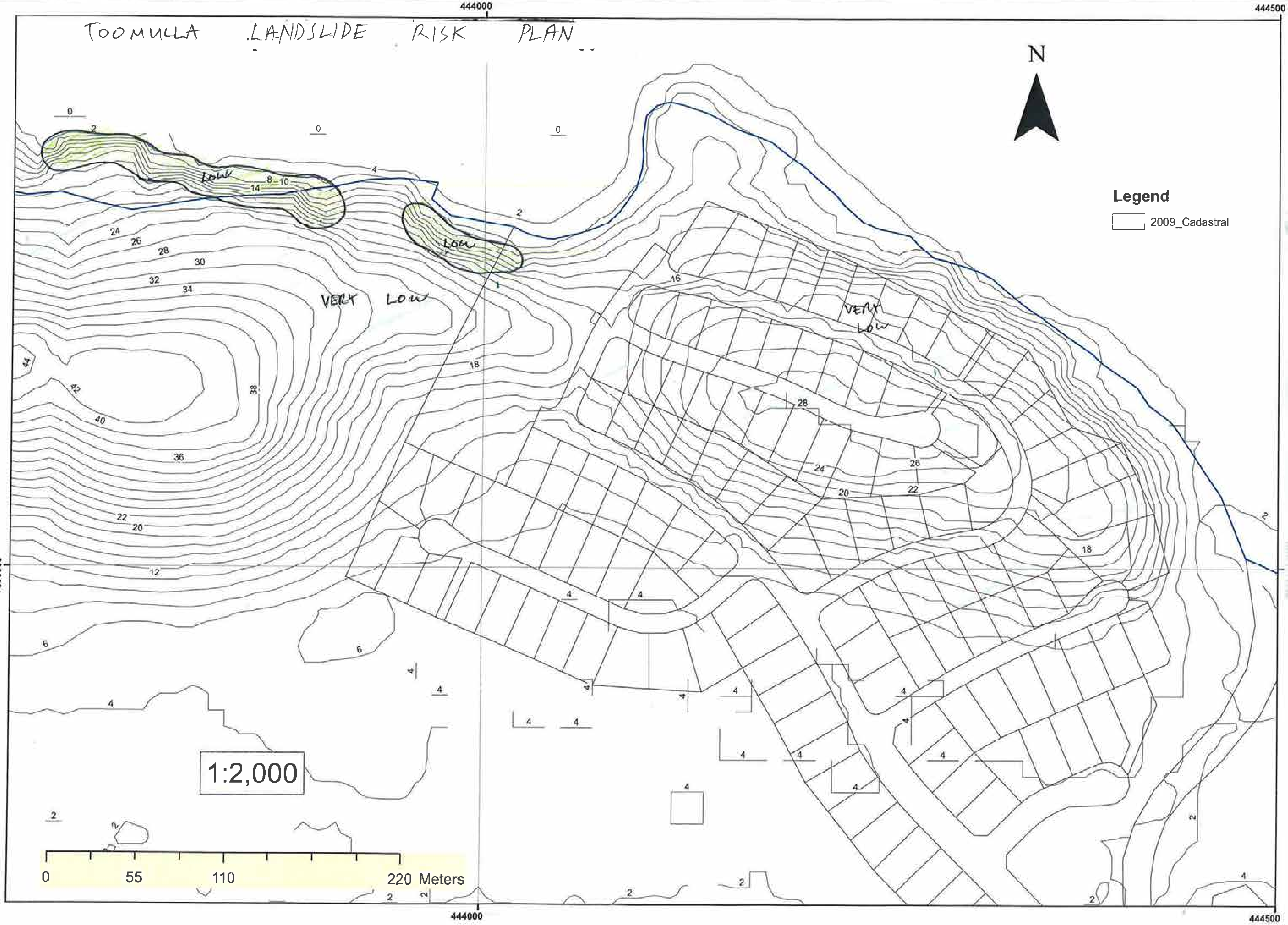


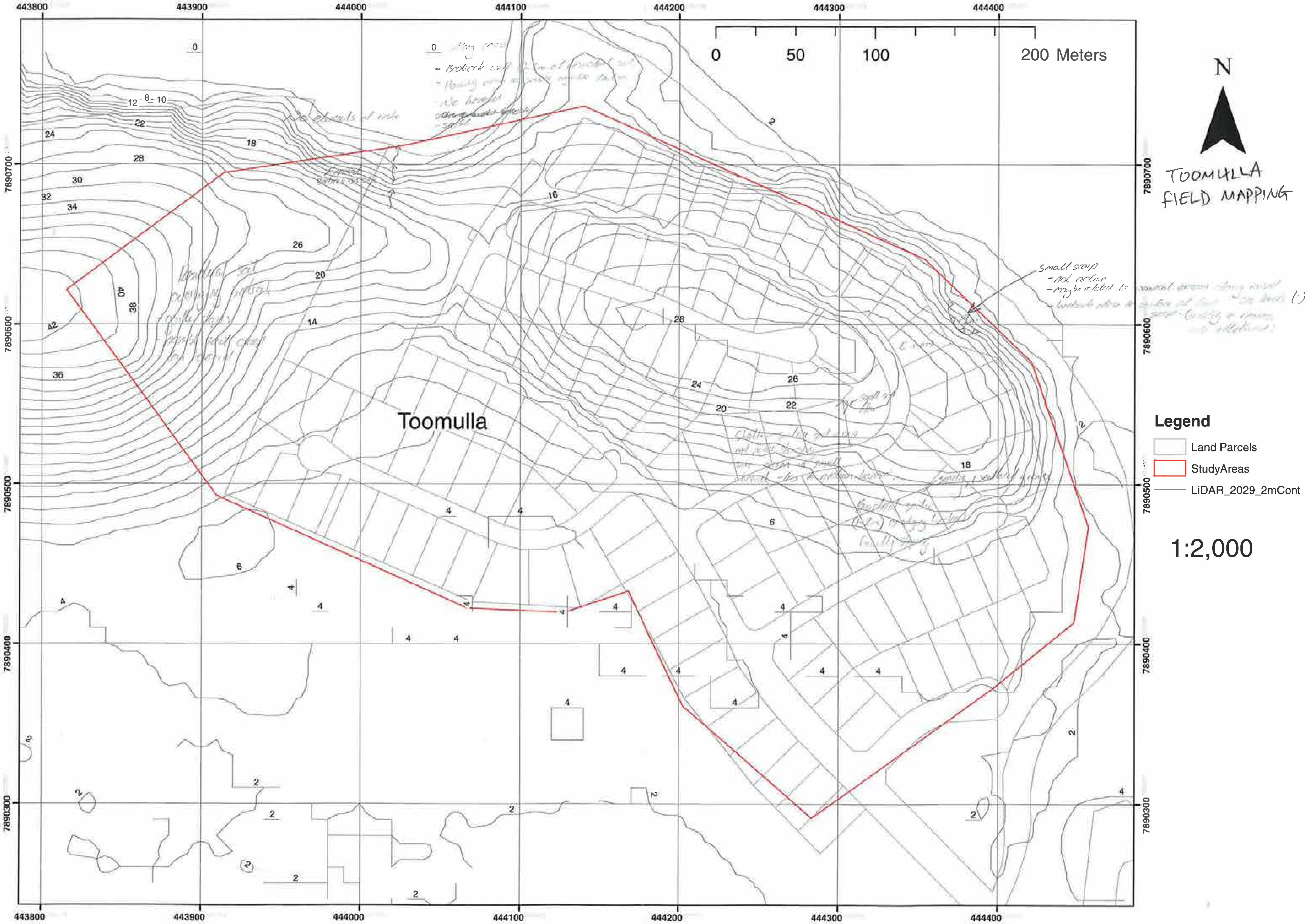
TOOMULLA FACTUAL PLAN
444000
444500
7890500
N
Legend
2009_Cadastral
EXPOSED BEDROCK
40°
RELIC SCARP
SHALLOW SLUMPING AND SOIL CREEP
1:2,000
0
55
110
220 Meters



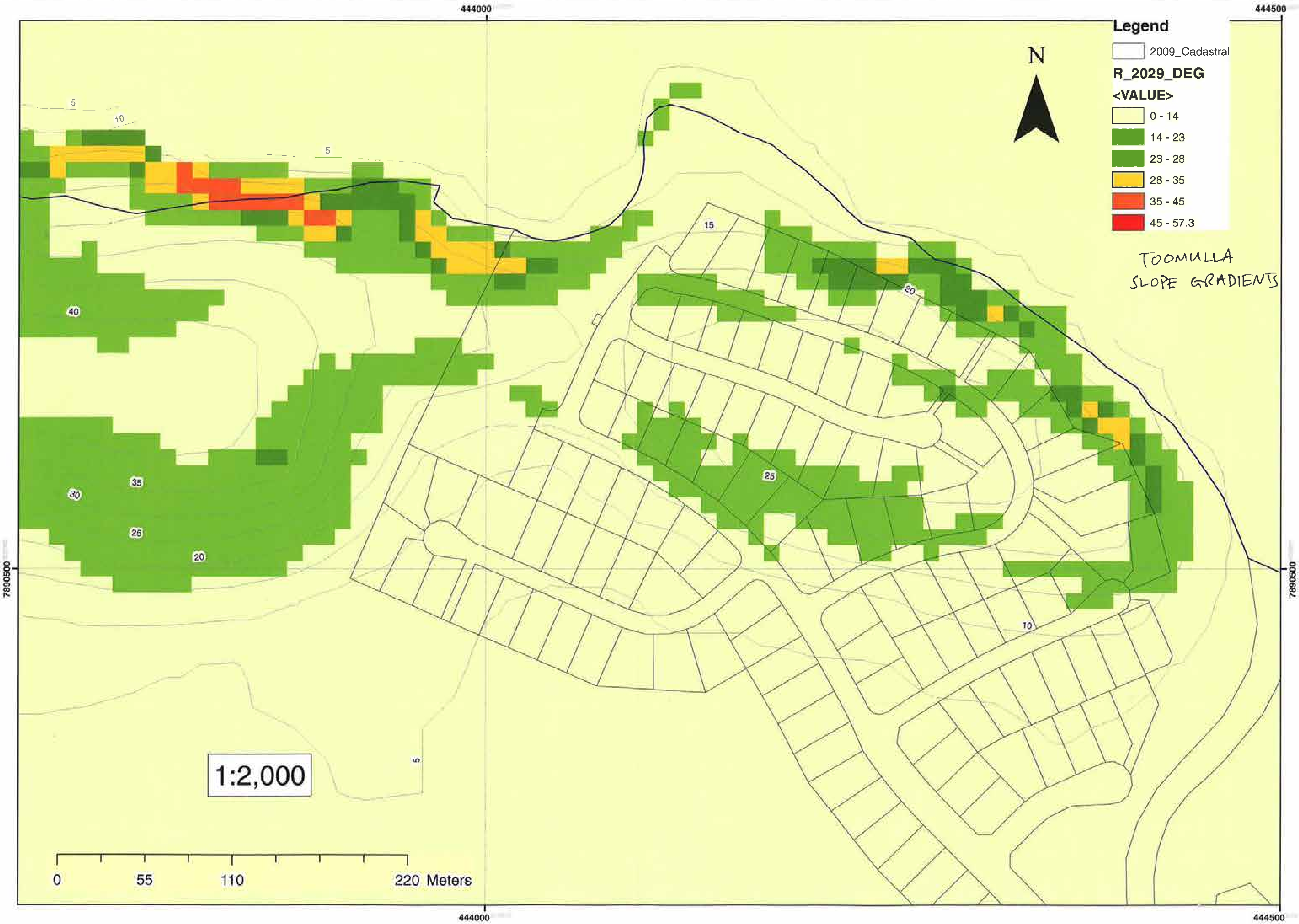
TOOMULLA SHALLOW SLUMPING HAZARD PLAN
444000
444500
N
Legend
2009_Cadastral
FLOWPATH
LOW
VERY LOW
LOW
LOW
7890500
1:2,000
0
55
110
220 Meters


TOOMULLA ROCKROLL HAZARD PLAN
444000
444500
7890500
N
Legend
2009_Cadastral
LOW
LOW
VERY LOW
VERY LOW
1:2,000
0
55
110
220 Meters

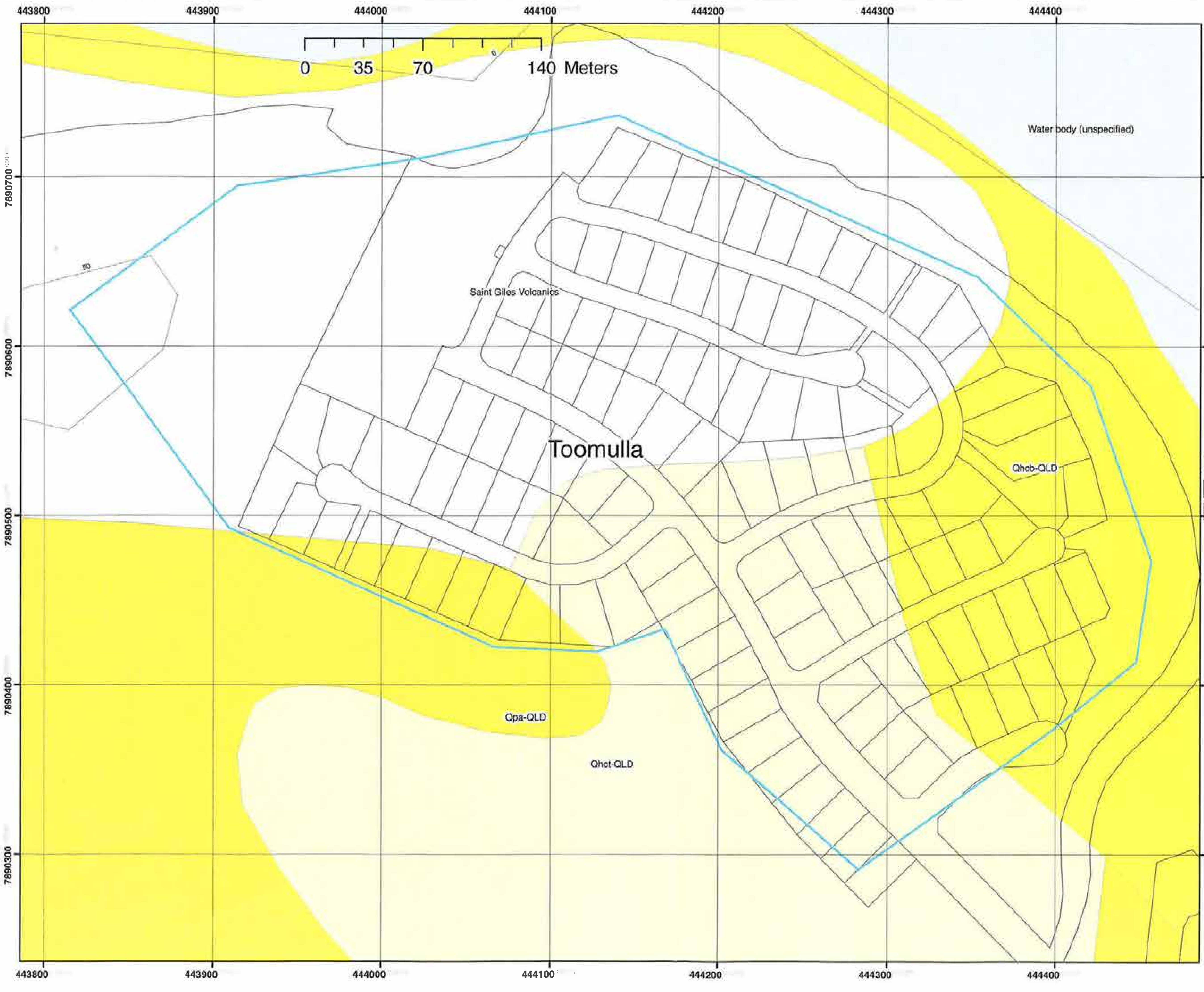

TOOMULLA LANDSLIDE RISK PLAN
N
Legend
2009_Cadastral
LOW
LOW
VERY LOW
VERY LOW
1:2,000
0
55
110
220 Meters
444000
444500
7890500


TOOMULLA FIELD MAPPING
N
0 50 100 200 Meters
Toomulla
Legend
Land Parcels
StudyAreas
LiDAR_2029_2mCont
1:2,000
443800
443900
444000
444100
444200
444300
444400
7890700
7890600
7890500
7890400
7890300
small scarp
- not active

443800
443900
444000
444100
444200
444300
444400
7890700
7890600
7890500
7890400
7890300
0
50
100
200 Meters
N
Toomulla
Legend
Land Parcels
StudyAreas
LiDAR_2029_2mCont
1:2,000



444000
444500
Legend
2009_Cadastral
R_2029_DEG
<VALUE>
0 - 14
14 - 23
23 - 28
28 - 35
35 - 45
45 - 57.3
N
TOOMULLA SLOPE GRADIENTS
7890500
1:2,000
0
55
110
220 Meters



TOOMULLA GEOLOGY PLAN

1:2,000

M□ □N□ □□ □