7 December 2009

REPORT

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CITY OF MORELAND

Landslide Hazard Zoning

Submitted to:
Moreland City Council
90 Bell Street, Coburg
Moreland, Vic, 3058

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Distribution:

2 Copies - Golder Associates Pty. Ltd.
2 Copies - Moreland City Council

Includes accompanying CD with GIS information.

Golder Associates

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1.0 INTRODUCTION

Moreland City Council has engaged Golder Associates Pty. Ltd. (Golder Associates) to undertake landslide hazard zoning within the City of Moreland. This work was authorised in a purchase order from Moreland City Council dated 31 July 2009 (Ref: 132640) in response to our proposal dated 24 July 2009 (Ref: P97613182 Rev 4). The landslide hazard zoning was undertaken in general accordance with the guidelines presented in the Australian Geomechanics Society[1] Guidelines for Landslide Risk Management, 2007 (AGS 2007a).

2.0 AIMS OF LANDSLIDE HAZARD ZONING

The aims of the landslide hazard zoning are as follows:

- To undertake a review of known slope instability within the City of Moreland.
- To identify areas within the City of Moreland that may be susceptible to landslide.
- To undertake a landslide hazard assessment and produce a landslide hazard map for the City of Moreland. This is to be provided in GIS format.
- To discuss implications of the landslide hazard map and provide advice on planning and development controls that may be suitable for the various zones identified on the map.

We understand that the Moreland City Council propose to use the results of this study to produce an Erosion Management Overlay (EMO) and associated schedule to the overlay. A further objective is to review and provide advice on suitable wording of a schedule to the EMO.

3.0 METHOD OF ASSESSMENT

There are a number of stages to the Moreland City Council Landslide Hazard assessment. The procedure followed for the assessment was in general accordance with AGS 2007. In particular, the methods outlined in part (a) of this document (AGS 2007a), the *Guideline for Landslide Susceptibility, Hazard and Risk Zoning for Land Use Planning* were applied.

Stage 1 – Attend kick off meeting with strategic planners from Moreland City Council. This meeting was attended by Dr. Chris Haberfield and Mr. Darren Paul of Golder Associates on 14 July 2009.

Stage 2 – Develop a landslide inventory for the City of Moreland. This is essentially a data base within which relevant known landslides and their attributes are recorded. The locations of landslides, including areas remote from the landslide (run out distances) are plotted on a landslide inventory map.

Stage 3 – Visit areas assessed as susceptible to landslide and undertake geomorphological and geological mapping. During this stage, characteristics of existing landslides are described and areas in which future landslides could occur are assessed. These recorded attributes are added to the landslide inventory.

Stage 4 – Develop a landslide susceptibility plan. This uses the information in the landslide inventory to identify areas with common attributes that could be susceptible to landslide. Attributes common to the known landslides such as underlying geology and slope angle are established in order to assess susceptibility.

Stage 5 – Develop a landslide hazard map. This further builds upon the landslide susceptibility plan to include information relating to the estimated frequency and intensity of landslides. The map is presented in a GIS based format.

[1]Journal of the Australian Geomechanics Society, Vol. 42 No 1, March 2007.

Stage 6 – Present a report which discusses the basis for the landslide hazard zoning and which discusses planning and development implications for each of the landslide zones identified.

The method by which each of these stages was undertaken is set out below.

3.1 Landslide Inventory

A search of both publically available data and Golder Associates internal records was undertaken to identify previous landslide activity within the City of Moreland. Known information on each landslide was recorded in the inventory. The data recorded in the landslide inventory is contained on the attached CD and locations of the recorded landslides shown in Appendix A. The following sources of information were consulted.

Aerial Photography

A senior engineering geologist from Golder Associates visited the Department of Primary Industries Aerial Photography Archive in Laverton. Original stereo copies of aerial photographs of the City of Moreland were observed using a stereographic viewer. Potential landslides observed in the aerial photographs were transcribed on to base plans and relevant information recorded in the landslide inventory. The following sets of aerial photographic information covering all of the City of Moreland were assessed:

- Project 7822-1, Standard Mapsheet Photography, January 1985. Runs 13 to 17.
- Project 7822N12, Outer Ring Road North Project, April 1988. Run 5.
- Project 7822N10, Outer Ring Road Project, October 1987, Run 1.
- Project 1992, Upfield Line Project, May 1988, Run 1.

Golder Associates Records

Golder Associates has been providing geotechnical services within Melbourne for the past 40 years. A search of our archives was undertaken as a means of identifying previous landslide activity within the City of Moreland. Two projects relevant to the current study were reviewed:

- A slope stability assessment undertaken in Devereaux Street, Oak Park.
- A slope stability assessment undertaken along the banks of the Moonee Ponds Creek in Oak Park.

Published Volumes

A paper discussing known landslides in Melbourne is included in the Engineering Geology of Melbourne (Balkema, 1992), Wilson, R.A., *Slope Stability*. This includes a map of the Melbourne area within which known landslides are marked. We note that there are no known landslides marked within the City of Moreland.

Site Walkover Survey

Sites identified in the aerial photographs that appeared to be past landslides or areas potentially prone to landslide were visited by a senior engineering geologist from Golder Associates. Observations pertaining to the following were made:

- Geomorphology, including type and shape of landslide and slope angles. A hand held GPS unit was used to record feature locations and a hand held inclinometer used to measure slope angles.

- Likely trigger mechanism for landsliding and indicative recurrence interval of the trigger mechanism.
- Underlying geology.
- Likely run out distances of the landslide.
- Indications for ongoing or future movement.

Future Development of the Landslide Inventory

The landslide inventory has been developed in database format which has been included on the accompanying GIS package. The locations of the landslides in the database are referenced within the GIS package. The fields within the database have been adopted from recommendations presented in AGS 2007. It is intended that the landslide inventory will be developed further as future landslides occur or as additional landslides are documented. It is unlikely that this study has identified all incidences of slope instability within the City of Moreland.

3.2 Landslide Susceptibility Plan

A landslide susceptibility plan was produced. This plan identifies all areas within the City of Moreland where we consider it possible, based on the underlying geology and slope angle for landslides to occur. For each geological material indicated on geological maps to underlie the City of Moreland, a slope angle was estimated below which we consider the likelihood of landslide to be *rare or barely credible*[2]. Information used to assess this limiting slope angle was obtained from a variety of sources as outlined below. The susceptibility plan is based on two key assumptions:

- Areas which have experienced landsliding in the past could experience landsliding in the future, and;
- Areas with similar topography, geology and geomorphology as the areas which have experienced landsliding in the past could experience landsliding in the future.

We note that the landslide susceptibility plan could form the basis of an Erosion Management Overlay (EMO).

Geology in the City of Moreland

The 1:63,360 geological map of Melbourne indicates the geological materials inferred to underlie the City of Moreland. We have digitised and geo-referenced the geological indications on this mapsheet. The attributes of each of the relevant geological units is discussed in further detail below.

[2] Refer to Appendix H for definition of qualitative terms.

Slope Angle

Contours at 1 m interval based on photogrammetry were provided to us by the Moreland City Council. These contours were used to assess slope angles. A digital GIS based query was run to group areas according to the prevailing slope angle. The maximum and minimum natural slope angles on the various geological units within the City of Moreland were established. This information provides an indication of the steepest long term slope angles that the ground has naturally adopted in response to trigger mechanisms such as toe erosion by creeks. This information has in turn been used to provide an indication of the slope angle above which the ground could be unstable.

Landslide Inventory

The inventory of landslides for the City of Moreland indicates various characteristics of the ground within which the landslide has occurred such as slope angle, travel distance, geology and trigger mechanisms. This was used to provide a further indication of the geological and geomorphological characteristics of areas in which landslides have occurred.

Experience from Other Areas of Melbourne

The geological materials underlying the City of Moreland also underlie other areas of Melbourne. Landslides are known to have occurred in these materials elsewhere in Melbourne. The characteristics of landslides in other areas of Melbourne have been considered in this assessment. In particular, the slope angles at which landslides have occurred on slopes within different geological materials have been assessed.

The landslide susceptibility plan is included in the attached electronic GIS package and presented in Appendix B.

3.3 Landslide Hazard Plan

The landslide susceptibility plan indicates those areas that could feasibly be subject to landslide. The landslide hazard plan refines and further zones the susceptibility plan by considering the frequency and intensity of landslides within susceptible areas. The frequency and intensity were estimated using a variety of techniques as described below.

Assessment of Past Landslide Features

The ‘freshness’ (how well defined landslide features are) of existing landslide scars was assessed. Further to this, the likely trigger mechanism (condition(s) that initiated the landslide) was assessed. From this information, an assessment was made of the frequency that similar future landslides could be triggered and the intensity that they might have.

Geomorphologic Evolution

The geomorphological history of the City of Moreland was reviewed. Landforms such as the creek valleys within Moreland have developed in response to climatic conditions, principally volume and intensity of rainfall and associated flow rate and volume of water in creeks. In relatively recent geological history (past 10,000 years), climatic conditions have been significantly wetter than those prevailing today.

Landslide Inventory

Features of landslides that provide some indication regarding the frequency of their occurrence have been recorded in the landslide inventory. Identification of the landslide trigger mechanism and an assessment as to the likelihood of recurrence of the trigger mechanism has been made.

The landslide hazard plan is included in the accompanying electronic GIS package.

4.0 GEOLOGY AND GEOMORPHOLOGY IN THE CITY OF MORELAND

4.1 Geological and Geomorphologic Development

An understanding of the geological and geomorphological history within the City of Moreland is a key aspect in assessing potential landslide locations and frequency of occurrence. A brief summary of this history is presented in this section.

The bedrock in the City of Moreland area is comprised of Silurian age (430 to 390 Million years ago) siltstone (S_{ud}) and sandstone. During the Tertiary period (65 to 2 Million years ago, the siltstone was subject to extensive physical and chemical weathering. The physical weathering resulted in the surface of the rock being dissected by streams and rivers, including along the approximate alignments of what are now the Moonee Ponds and Merri Creeks. The chemical weathering caused a change in the mineral composition of the siltstone breaking it down into kaolin type clay.

Volcanic eruptions occurred in the Melbourne area during the Tertiary. Lava flowing from volcanoes north of Melbourne flowed along the creek valleys forming the Older Volcanics deposit (T_{vo}). A further period of chemical weathering followed during which the Older Volcanic materials were deeply weathered. Much of this material was reduced to clay during this time.

Sea level rise resulted in shallow marine conditions over the Moreland area and sediments comprising principally sands and clays were deposited over much of the area, infilling the Merri and Moonee Ponds creek valleys. This material is referred to as the Brighton Group (T_b). Another period of physical and chemical erosion followed during which the Brighton Group materials were removed in some places. The Merri and Moonee Ponds creek valleys were reformed as sea level dropped and the Brighton Group sands and clays were eroded out.

Further volcanic eruptions occurred in areas to the north of Moreland during the Quaternary period (last 2 million years). The lava from these eruptions flowed along the Moonee Ponds creek (earlier eruption) and the Merri Creek (later eruption). Plains lava flows covered most of the area that is currently the Moreland City Council.

Ice ages in the past 2 million years have induced relatively rapid rises and falls in sea level. During low sea level stands such as the peak of the last ice age about 20,000 years ago, the sea level was about 120 m lower than it is today. At this time, rainfall in Eastern Australia was higher than it is today. Water would have flowed along the Merri and Moonee Ponds Creek far more rapidly and in greater volume than it does at present. This rapid water flow carved the present day creek valleys down through the pre-existing units. The Merri Creek valley was carved adjacent to the previous creek valley, which by this stage had been filled with the hard rock of the Newer Volcanics basalt. As a result, the Merri Creek now defines a geological contact between Silurian Siltstone and Quaternary Age Newer Volcanics Basalt.

During high sea level stands, flow in the creeks probably had less energy. During flooding, alluvial deposits of clay, silt and sand would have been deposited (Q_{rt}). With continued deepening of the creek valleys, these alluvial deposits remained as higher level alluvial deposits.

As the creeks carved the valleys deeper, relatively frequent landslides would have occurred along the sides of the valleys. The sides of the valley would have steepened by river incision until collapse occurred. Most of the material that collapsed into the valley would have been removed by the rapid water flow in the creek. However, remnant colluvial deposits (Q_{rc}) remain.

With recent sea level rise (past 10,000 years), the velocity of the flow in the creeks slowed. The rate of slope erosion and frequency of landslides on the sides of the creek reduced and the creek became depositional rather than erosional. With periodic flooding alluvial material comprised of silts, sands and clays was deposited in the vicinity of the creek, producing the alluvial deposits (Q_{ra}).

4.2 Summary of Geological Units

The following presents a summary of the geological units encountered at the ground surface within the City of Moreland. The distribution of these materials is included as an overlay in the associated electronic GIS package. The information for this overlay is taken from the 1:63,360 Geological Mapsheets of Melbourne and Sunbury published by the Geological Survey of Victoria.

Silurian Age Siltstone (S_{ud})

This material forms the bedrock within the area. It is exposed at the surface mainly to the east of Merri Creek. It is a sedimentary rock containing numerous discontinuities including bedding planes and joints. This material has been deeply weathered and is typically clay where encountered near surface. The surface of this unit is uneven, dissected with a series of valleys.

Tertiary Age Older Volcanics (T_{vo})

This material is encountered in the sides of the Moonee Ponds Creek Valley. It is deeply weathered to a clayey material within which there are corestones (floaters) of weathered basalt rock.

Tertiary Age Brighton Group (T_b)

The Brighton Group sediments are comprised principally of interbedded dense sands and hard clays in variable proportion. This material has been deeply weathered and has extensive red-brown iron oxide staining and iron concretions. It is exposed mainly along the Moonee Ponds Creek valley.

Quaternary Age Newer Volcanics (Q_{vn})

Most of the City of Moreland area has a capping veneer of Quaternary Age Newer Volcanics Basalt. This material is exposed along almost all the length of the Merri Creek Valley. It is also the material encountered at the ground surface over most of the City of Moreland area.

Quaternary Age Terrace Alluvium (Q_{rt}), Colluvium (Q_c) and Alluvium (Q_{ra})

These materials are associated with recent valley formation. The sediments are derived from flooding of the creek and from material transported downslope. The composition is variable, comprised of silt, sands and gravels. It may also contain some boulders and cobbles of basalt.

5.0 DISCUSSION ON LANDSLIDE INVENTORY

A total of 21 features have been recorded in the landslide inventory. The locations of these features and the data pertaining to them has been included in the associated electronic GIS package and is presented in Appendix A. The following provides a summary of some of the key observations within the landslide directory.

- None of the landslides observed are currently active or appear to have moved very recently (say past 200 years). Almost all of the geomorphologic features identified as landslides are inferred to have occurred during a period of active valley erosion and are probably older than 10,000 years. These features are what could be termed relict landslide scars.
- The only active slope stability hazard observed relates to rockfall from a slope on the banks of the Merri Creek in Fawkner. A catch fence has been installed at the toe of this potentially unstable slope, apparently as a means of mitigating the risk to users of the bicycle path at the toe of the slope.
- In three locations, steep fill batters appear to have formed through material dumped loosely over the banks of the creek. Although no evidence for landslide on these fill batters was observed, we consider them to have marginal stability and to represent landslide hazards.
- There appears to be a relationship between the maximum slope angle on the sides of the creek valleys and the underlying geology.
- None of the landslides observed appear to represent an immediate threat to life and property.
- The trigger mechanism for all of the landslide scars observed is inferred to be erosion and undermining at the base of the creek valley by the Moonee Ponds, Merri and Edgars Creeks. The present day erosion action of these creeks is inferred to be significantly less than what it would have been in the geological past. The Jacana retarding basin now limits flooding along the Moonee Ponds Creek valley. Part of both the Merri Creek and Moonee Ponds Creek have been diverted and flow directed through concrete lined channels. Flow rates are low and there is typically a relatively wide alluvial plain between the creek line itself and residential properties.
- All of the landslides observed are inferred to have occurred prior to human settlement. We note that although erosion by the creeks was previously the primary landslide trigger, new triggers associated with human settlement now exist. For example, poor earthworks practices and poor stormwater drainage/management could induce landsliding.

6.0 DISCUSSION ON LANDSLIDE SUSCEPTIBILITY PLAN

6.1 Landslide Origin

The landslide susceptibility plan identifies the slope angle at which we consider landslide to be feasible on the various different geology types within the City of Moreland. The following outlines the basis for our selection of these slope angles (as measured from the horizontal) on each type of surface geology identified in the City of Moreland.

S_{ud} - Silurian Siltstone - Within the creek valleys, Silurian Siltstone slopes of up to about 85 degrees were observed. The shallowest observed slope angle in Silurian Siltstone, in a location where the siltstone has been eroded through the action of a creek and inferred to have slumped, is 16°. The landslide in Silurian Siltstone that appears to be the most recent (de Chene Avenue) has regressed to a slope angle of about 16°.

Based on our observations within the Moreland City Council area, we consider it feasible that under certain conditions, landslides could occur on slopes formed in Silurian Siltstone steeper than 16°.

T_{vo} – Tertiary Age Older Volcanics

Many of the slopes along the Moonee Ponds Creek Valley are formed from this material. No natural slopes steeper than 20° were measured within Older Volcanics, suggesting that this material is probably not stable at slope angles steeper than this. Based on the landslide inventory, the shallowest slope angle at which past slope instability within this material was observed is 12°.

We note that elsewhere in Melbourne, slope instability within this material is well documented. There are currently active landslides within Older Volcanics in Frankston (Olivers Hill), Chirnside Park, and Silvan. Under (for example) the Shire of Yarra Ranges Planning scheme, landslide is assumed to be feasible on natural slopes in Tertiary Older Volcanics steeper than 9° and there are documented active landslides that have occurred on slopes at about this slope angle. We consider it to prudent to assume that given certain conditions, it could be possible for landslides to occur on slopes steeper than 9°.

T_b – Brighton Group Sediments

This material forms some of the slopes along the Moonee Ponds Creek Valley. The highest measured natural slope angle in the City of Moreland observed in Brighton Group materials is 20°.

Coastal cliffs formed in Brighton Group materials are actively being eroded by wave action at some locations near Black Rock and Sandringham. Regular coastal landslides occur in these areas. These cliffs have been observed to collapse back to a slope angle of 15° to 30°.

We note that the composition of the Brighton Group materials is variable, containing clays and sands. The material composition could have an influence on slope stability. Based on our observations, we consider it feasible that given certain conditions, landslides could occur in Brighton Group materials where slopes are steeper than 15°.

Q_{nv} – Newer Volcanics

The shallowest slope angle observed in the creek valleys in Quaternary Newer Volcanics was 15°. We note that this measurement was made in residual basalt material near the top of this unit. More typically, the Newer Volcanics were observed to adopt a slope angle of about 27°. Where the slope is formed from rock, such as along the Merri Creek valley, subvertical slopes were observed.

The newer volcanics basalt has developed a mantle of highly plastic clay over the surface. This material can be fissured and friable. Golder Associates has been involved in a number of cases around Melbourne (not in the City of Moreland) where slope instability has occurred within basaltic clay at slope angles as shallow as 9°. On the slopes of the Merri and Moonee Ponds Creeks, we infer that whilst residual basaltic clay may have previously developed it has now generally been removed through mechanical erosion.

Based on our observations, we consider it feasible that given certain conditions, instability could occur within this material on natural slope angles steeper than about 15°.

Quaternary Age Terrace Alluvium (Q_{rt}), Colluvium (Q_c) and Alluvium (Q_{ra})

These materials were generally encountered at the base of the creek valleys. No instability was observed in these materials. However, we note that given the variable composition and potentially low degree of consolidation of these materials, we assume slope instability is possible where the slope angle exceeds 9°.

6.2 Buffer Zones

There are inherent inaccuracies in the data used to undertake the landslide susceptibility assessment. This includes potential inaccuracies in the surface contours and potential inaccuracies in the geological map, both of which form the basis of the landslide susceptibility map. To account for this potential inaccuracy, we have applied a 10 m buffer zone to the areas assessed as susceptible to landslide as described above.

We further note that landslides on susceptible slopes could affect areas upslope on areas that may not have been delineated as susceptible on the basis of slope angle. The distance upslope of the area that could be affected depends on the height of the slope on which the landslide occurs and the depth of the soil in which it occurs. In developing the landslide inventory, it was noted that none of the landslide scars observed had an estimated depth of greater than 5 m. A landslide with depth of 5 m could potentially influence an area up to 10 m back from the crest of a 2H:1V slope. The 10 m buffer accounts for areas upslope of those where landslides could potentially occur.

A landslide originating on a susceptible slope could mobilise soil or rock debris which could travel downslope and impact upon areas outside of those assessed as susceptible. We have assessed the potential runout distances for landslides originating on susceptible slopes. The run out distance of a landslide is a factor of the soil properties, the amount of water present in the soil at the time of the landslide and the geometry of the slope below that on which the landslide occurs. The methodology described below has been used for assessing runout distance for landslides originating on areas underlain by various geological units.

S_{ud} - Silurian Siltstone - Where weathered, this material is clayey. The landslide scars in this material appear to be translational type landslides which would typically remain largely intact upon sliding. Our method for estimating run out distance for landslides originating in this material is based on observations of slipped masses in the Siltstone. Our observations suggest that the slipped siltstone material adopts a slope angle approaching about 15°. We have estimated run out distance by assuming that a failed slope will adopt this angle. A line drawn on a cross section of a slope from the top of the slope at 15° is assumed to intersect the ground at the point where the greatest landslide run out distance would reach.

T_{vo} – Tertiary Age Older Volcanics

A similar method has been used as that described above for Silurian Siltstone. Given the high clay content of this material and observations from elsewhere in Melbourne, we assume that this material will remain largely intact during landslide. We have assumed that the failed material could adopt a slope angle of about 12°, the lowest angle observed in this material.

T_b - Brighton Group Sediments

We have assumed that Brighton Group Material could adopt a slope angle of 20° on failure.

Q_{nv} - Newer Volcanics

We have assumed that debris could adopt a 15° slope angle upon failure.

6.3 Summary of Development of Landslide Susceptibility Map

The landslide susceptibility maps presented in Appendix B and included on the accompanying GIS package were developed using the methodology outlined below. We have rounded the estimated limiting slope angles to a convenient angle expressed as a percentage.

- A GIS query was run to identify all areas on which we have assessed that landslides could originate. This includes:
  - Areas underlain by Silurian Age Siltstone and with slope angle steeper than 30% (16.7°).
  - Areas underlain by Tertiary Age Older Volcanics and with slope angle steeper than 15% (8.5°).
  - Areas underlain by Tertiary Age Brighton Group Sediments and with slope angle steeper than 30% (16.7°).
  - Areas underlain by Quaternary Age Newer Volcanics and with slope angle steeper than 30% (16.7°).
  - Areas underlain by Quaternary Colluvium or Alluvium (Qrt, Qrc, Qra) and with slope angle steeper than 15% (8.5°).
- Polygons were established around those areas identified as susceptible in accordance with the above query.
- A 10 m buffer was applied to the polygons to account for vulnerable areas upslope of susceptible areas and potential error in contour and geological information.
- Runout distances were plotted downslope of susceptible areas using the methodology described in Section 6.2. We note that with few exceptions, the assessed run out distance was within the 10 m buffer. There was only one area, in Primula Boulevard, Gowanbrae where the assessed runout distance suggests that areas on relatively flat ground downslope of steeper areas could be vulnerable. Further assessment of these areas suggests that the initiation of landslides upslope is unlikely to be a natural occurrence, but rather caused by inappropriate hillside development. As such, we do not consider it appropriate to include areas assessed as vulnerable only to landslide runout (not initiation) within the landslide susceptible areas as to do so would impose unnecessary development controls.

We consider the areas as shown in Appendix C and included on the accompanying GIS package to be suitable as the basis for an erosion management overlay. Note that areas assessed as being susceptible to landslide were further subdivided into areas Hazard Level 1 and Hazard Level 2 as part of the hazard zoning discussed in the following section.

7.0 DISCUSSION ON LANDSLIDE HAZARD ZONING

The landslide hazard zoning builds upon the landslide susceptibility zoning to include an assessment of the likelihood (frequency) and intensity of a landslide occurring on a susceptible area. The frequency of landslides was assessed on the basis of observations made during the site walkover survey.

No active landslides were observed within the City of Moreland, only landslide scars, (now mostly subdued) were observed. The trigger mechanism for most of the landslide scars observed is inferred to be toe erosion induced by the Moonee Ponds and Merri Creeks. As discussed in Section 4.1, the rate of toe erosion was inferred to be much more aggressive in the geological past (greater than 10,000 years ago) than it is today. Further to this, flood controls such as the Jacana retarding basin have been constructed to control flow in the creeks. The primary mechanism that has induced landslides within the City of Moreland has essentially been removed. We are not aware of any naturally occurring landslides within the City of Moreland that have occurred within recorded history.

No evidence for significant debris travel distance was observed during the walkover survey. We note that the geological materials within the City of Moreland are generally cohesive materials. Upon occurrence of a landslide these materials are likely to stay largely intact and travel relatively short distances at slow velocities rather than develop into rapidly moving debris flows. The only rapid debris flow type landslides that we are aware of within the Melbourne area have either occurred in fill material or weathered felsic rocks (Mt.

Dandenong Volcanics). We note that there are no documented occurrences of igneous rocks within the City of Moreland. However, fill material is present some of which does not appear to have been placed with engineering supervision and which may be subject to slope instability.

We consider the likelihood and intensity of naturally occurring landslides to be very low in most of the susceptible areas, based on the observation that slopes formed on a particular geology have regressed back to a maximum slope angle. There are however, localised instances where the slopes are unusually steep. Some of these unusually steep slopes have formed naturally, and some have formed through man made cut and fill modifications to the slope. Based on the slope angles measured on the contour plans provided to us and on our field observations (landslide inventory), we have identified slope angles underlain by various geology that represent the maximum slope angle typically adopted in these materials. Slope angles steeper than these are considered over steep. These slope angles have been defined as follows:

- Any slope steeper than 50% (26.5°). This classification is expected to capture steep fill embankments.
- Slopes on Tertiary Older Volcanics (T_{ov}) steeper than 30% (16.7°).
- Slopes on Tertiary Brighton Group (T_b) steeper than 35% (19.3°).
- Slopes on Quaternary Age alluvium and colluvium (Qrt, Qrc and Qra) steeper than 30% (16.7°).

Areas underlain by the slopes as described above have been identified using a GIS based query.

7.1 Development of Landslide Hazard Map

Those areas identified using a GIS based query as steeper than the typically naturally occurring maximum slope angle are zoned as ‘Hazard Level 1’ (HL1). The remaining areas susceptible to landslide have been zoned as a ‘Hazard Level 2’ (HL2). The boundaries of the HL1 zones were plotted manually on the basis of the GIS based query results. A second site visit was undertaken to areas classified as HL1 as a means of checking the zoning and adjustments to zone boundaries made as appropriate.

Table 1 below summarises those areas zoned as HL1 which affect residential allotments. Note that areas zoned HL1 within public land have been omitted from the table. The landslide hazard maps are presented in Appendix C and on the accompanying GIS package.

Table 1: Summary of Areas Zoned as Hazard Level 1

Streets Affected	Suburb	Approximate Area (m^2)	Map* Number	Number of Allotments Affected	Comments
Primula Boulevard	Gowanbrae	10,000	01	2	Steep outcrop of basalt. Adjusted from GIS indications based on site visit.
Devereaux St West New St	Oak Park	22,500	08	34	Steep slopes expose Older Volcanics and Brighton Group Sediments. Some poor hillside practice in this area.
Outlook Drive	Glenroy	3,750	08	3	Slope formed in fill placed over pre-existing valley slopes.
Forster Court Wheeler Street	Pascoe Vale South	8,750	19	19	Steep slopes expose older volcanics. Some poor hillside practice in this area.
Turnbull Drive	Pascoe Vale South	6,250	19	3	Cutting associated with creek diversion. Allotments in close proximity to cutting.
TOTALS		**51,520**		**61**	

* Refer to Appendix C

7.2 Summary of Hazard Level 1 and Hazard Level 2 Zones

The following briefly summarises the basis behind the Hazard Levels and the implications of each zoning.

Hazard Level 2 Zones

Areas zoned as Hazard Level 2 are those within which our assessment suggests that landslide could occur given unfavourable conditions. Our assessment suggests that natural trigger mechanisms such as slope undercutting by the creek are unlikely to induce landslides. However, landslide could be induced by man made conditions and development such as:

- Over steep or poorly placed fill materials.
- Over steep unretained cuts.
- Poorly designed or maintained drainage or other concentration of water in the soil.
- Poorly designed or constructed retaining walls.

To manage the risk of landslide on properties classified as HL2 with respect to slope instability, we recommend that planning and development controls are implemented. Suggested controls, including a geotechnical assessment and restrictions on earthworks are discussed in greater detail in Section 8 and tabulated in Appendix F.

Hazard Level 1 Zones

These are areas that our assessment suggests could be affected by naturally occurring landslides, and which due to their higher slope angle are more susceptible to human induced landslides. We recommend that planning controls on these sites include a landslide risk assessment undertaken in accordance with the AGS 2007 guidelines.

Table 2 presents a summary of our basis for zoning sites as either HL1 or HL2.

Table 2: Summary of Basis for Hazard Classifications

Geology	Hazard Level 2 Slope Angles	Hazard Level 1 Slope Angles
Silurian Siltstone (Sud)	> 30% (16.7°)	> 50% (26.5°)
Tertiary Older Volcanics (Tvo)	> 15% (8.5°)	> 30% (16.7°)
Tertiary Brighton Group (Tb)	> 30% (16.7°)	> 35% (19.3°)
Quaternary Newer Volcanics (Qnv)	> 30% (16.7°)	> 50% (26.5°)
Quaternary Alluvium and Colluvium (Qrt, Qrc, Qra)	> 15% (8.5°)	> 30% (16.7°)

8.0 RECOMMENDED DEVELOPMENT CONTROLS

8.1 Basis for Development Controls

Our assessment suggests that most of the natural slopes with the City of Moreland were formed thousands of years ago and that the geological processes leading to their formation are generally no longer active. The most likely cause of slope instability is inappropriate hillside development. AGS 2007 provides a series of 'Geo Guides' which are intended to provide general information on landslides and appropriate hillside development. These have been reproduced and are presented in Appendix E of this report. Geoguide LR8 presents some examples of good and bad hillside construction practice.

Good hillside practice is based around preservation of existing slope conditions. Within the City of Moreland, where slopes are inferred to have remained stable over thousands of years, we consider that preservation of natural slope conditions should be a fundamental guiding principal of planning and development controls. In particular, development should seek to:

- Preserve the natural slope geometry as much as possible by minimising earthworks.
- Preserve the soil groundwater condition by limiting the potential for groundwater ingress and retaining vegetation.

Development on landslide susceptible sites should be undertaken with input from a geotechnical practitioner. The higher the hazard, the greater the importance of observing good hillside practice and obtaining geotechnical advice.

8.2 Planning and Development Controls for Sites Zoned as Hazard Level 2 with Respect to Slope Stability

8.2.1 Application of Planning and Development Controls

The following summarises planning and development controls that we consider suitable for sites zoned as Hazard Level 2. Further planning and development guidelines are presented in Appendix E. We recommend application of these development controls where:

- The proposed development is on or partly on an area zoned as Hazard Level 2.
- No part of the allotment is zoned as Hazard Level 1.

Consideration may be given to exemptions to minor development. Examples of potential exemptions which may be considered by Council are set out in Appendix D..

8.2.2 Planning and Development Controls

The following planning and development controls are recommended on Hazard Level 2 sites.

Site Specific Geotechnical Assessment

Whilst this study provides information on landslide hazard, we note that the information upon which it is based may have some errors associated with it. Potential errors and limitations are discussed further in Section 11. We recommend that a site specific geotechnical assessment is submitted as part of planning applications on HL2 sites. Our recommended requirements for the geotechnical assessment are presented within the draft EMO included in Appendix D.

The objectives of the geotechnical assessment are to:

- Confirm or otherwise that the hazard zoning is appropriate.
- Identify evidence for slope instability on the site.
- Assess the potential impact of the proposed development on the slope stability of the site.
- Determine whether a risk assessment in accordance with AGS2007 is appropriate given the proposed development on the site.

The geotechnical assessment should be undertaken by a "geotechnical practitioner" where a geotechnical practitioner is defined as:

- A Degree qualified Geotechnical Engineer or Engineering Geologist; and
- Has achieved chartered professional status being a Chartered Professional Engineer (CPEng), A Chartered Professional Geologist (CPGeo or CGeol), Registered Professional Geologist (RPGeo); and
- Has experience in the identification and management of slope stability problems and landslide as a core competence.

Appendix G presents a landslide checklist which we recommend is completed by the geotechnical practitioner and submitted with the planning application. In addition, the geotechnical assessment should contain a *Geotechnical Declaration* by the author verifying their expertise, the contents and report conclusion. Copies of the *Geotechnical Declaration* form can be obtained by contacting the Responsible Authority. The geotechnical assessment should also contain recommendations which:

- Support the data and all stated assumptions contained in the assessment and is capable of being verified by peer review.
- State whether or not a Landslide Risk Assessment is required.
- Where it is considered that a Landslide Risk Assessment is not required, states that, in the opinion of the Geotechnical Practitioner, the development can be carried out in a manner that will not adversely increase the landslide risk to life or property affecting the subject lot or adjoining nearby land.
- Provide justification, including any necessary calculations, for the conclusion.
- State whether or not the development should only be approved subject to conditions, and if so state recommendations of what conditions should be required, including, but without limitation conditions relating to:
  - The determination of appropriate footing levels and foundation materials and in any structural works, including all footings and retaining walls;
  - The location/s of and depth/s of earth and rock cut and fill;
  - The construction of any excavations and fill and the method of retention of such works;
  - Any details of surface and subsurface drainage;
  - The selection and design of a building structure system to minimise the effects of all identified geotechnical hazards;
  - Retention, replanting and new planting of vegetation;
  - Any drainage and effluent discharge;
  - Any necessary ongoing mitigation and maintenance measures and any recommended periodic inspections, including performance measures;
  - The time within which works must be completed after commencement and the location/s and period in which materials associated with the development can be stockpiled;
  - Any requirements for geotechnical inspections and approvals that may need to be incorporated into a construction work plan for building approval purposes.

Earthworks

We recommend that earthworks on sites zoned HL2 are undertaken in accordance with the following:

- Retain natural contours where possible. Do not make large cuts or fills. Do not block existing watercourses by earthworks.
- Unsupported cut depths must not exceed 1.0 m and maximum batters should not exceed 1V:2H (V = Vertical, H = Horizontal). Steeper and/or higher cuts should be supported by an engineer designed retaining wall. Drainage measures should be provided to prevent erosion of cuts. Where possible, cut batters should be re-vegetated.

- Unsupported fill thickness must not exceed 1.0 m. and batters must not exceed 1V:2H (V = Vertical, H = Horizontal). Steeper and/or higher fill batters should be supported by an engineer designed retaining wall. Remove vegetation and topsoil before placing fill. Use clean fill materials and compact to appropriate standards. Key fill into the natural slope. Provide surface and subsurface drainage as appropriate.

Drainage and Vegetation

- Retain natural vegetation where appropriate.
- Collect surface run off and discharge to street drainage or natural water courses. Provide drains uphill of structures, cuts and fills. Line drains to minimise infiltration and erosion. Do not allow water to pond on site or to concentrate in soils.
- Provide underdrainage to tanks and swimming pools.
- Dispose of waste water to mains sewer only.

Structures

- Use floor plans that minimise the amount of earthworks required on the site.
- Do not found structures on loose fill, unstable ground or topsoil. Found in rock or competent natural soils.
- Retaining walls should be founded in rock and engineer designed to account for water pressure and sloping backfill.

8.3 Planning and Development Controls for Sites Zoned as Hazard Level 1 with Respect to Slope Stability

8.3.1 Application of Planning and Development Controls

We recommend that the planning and development controls for sites zoned as HL1 are implemented where:

- The proposed development is on or partly on an area zoned as HL1.
- Where a site specific geotechnical assessment recommends a site hazard zoning of HL1 or that a risk assessment in accordance with AGS 2007 is required.

Consideration may be given to exemptions to minor development. Appendix D lists suggested exemptions to development controls..

8.3.2 Planning and Development Controls

The following planning and development controls are recommended. These are also presented in Appendix E as information sheets.

Landslide Risk Assessment

A landslide risk assessment is a more comprehensive assessment of the implications of landslide than a geotechnical assessment. The assessment must be undertaken in accordance with the AGS2007 guidelines, by a geotechnical practitioner (as defined in Section 8.2.2) and should include an assessment of the risk to life and property specific to the proposed development.

The risk assessment report should then present recommendations for the proposed development such that the risk to life and property on the site is within tolerable limits. In some cases the recommendation may be that development not proceed. A landslide risk assessment should contain a conclusion as to whether the subject lot is suitable for the proposed development. This must be in the form of a specific statement that the subject lot is suitable, or can be made suitable, for the proposed development and that the subject lot and/or the proposed development can meet the tolerable risk criteria. We note that AGS 2007 recommends that risk to life for new residential development should be less than 10^{-5} per annum. However AGS 2007 notes that the decision on the level of risk to adopt must ultimately be made by the Responsible Authority.

Development Controls

The landslide risk assessment may recommend site specific development controls. These development controls should not be less onerous than those recommended above for HL2 sites.

9.0 SCHEDULE TO THE EROSION MANAGEMENT OVERLAY

Appendix D to this report contains an example Schedule to the EMO which is provided for Moreland City Council's consideration. It may be modified and used as the basis for interim or permanent planning controls.

10.0 DISCUSSION AND LIMITATIONS

There are a number of important limitations of this study which should be noted. These are explained below.

10.1 Missed Landslides

Landslides recorded in the landslide inventory were located using a combination of air photo assessment, site walkover and review of previous geotechnical assessments. It is unlikely that all landslides within the City of Moreland have been located. The landslide inventory has been established such that additional landslide information can be recorded as required.

However, the basis for the hazard classification reported in this study is an assessment of the geomorphological development of the Moonee Ponds and Merri Creeks. This assessment suggests that the processes which led to landslides in the geological past are not presently active. Whilst the identification of past landslides is important in understanding relevant geomorphological processes and developing limiting slope angles, they may not present a significant present day risk.

10.2 Accuracy of Zone Boundaries

The zoning is based on contour plans provided by the City of Moreland and geological maps obtained from the Geological Survey of Victoria. Inaccuracies in this data may translate into inaccuracies in the overlays presented in this report.

We note that whilst the boundaries of areas zoned as Hazard Level 1 were confirmed by site visit, the boundaries of areas zoned HL2 were not. It is possible that site specific geotechnical assessment may reveal inaccuracies in the boundaries. A revision of the boundaries may be appropriate in some circumstances. Where this is the case, we recommend that Golder Associates be contacted to review the proposed boundary modification.

10.3 Development Types

The development controls included in this report consider only private development, specifically residential type development. We have not made any attempt to consider other types of development such as roads, railways and other public infrastructure. We recommend that project specific geotechnical assessment be undertaken for such development and note that some of the recommended development controls in this report could be inappropriate for such development.

10.4 Landslide Runout Distance

We have estimated landslide runout distances in some areas. Whilst these have not been incorporated into the landslide susceptibility map, they may be useful for planning purposes and we have provided this information accordingly. This information has not been included as we do not consider it appropriate that development controls be imposed on allotments on relatively flat ground. However, they can be used to provide an indication of the off site consequences of poor hillside development in some areas.

10.5 Boulder Dislodgement

A form of slope instability not assessed as part of this study is that of rock boulder dislodgement. It is possible that boulders dislodged on properties located on slopes could roll downslope and impact upon properties or assets. Boulder dislodgement is most to likely occur as a result of site disturbance such as earthworks. The recommended development controls for earthworks may go some way to limiting the likelihood of boulder dislodgement, however this remains and inherent risk not specifically addresses by the landslide hazard mapping.

10.6 Other Limitations

Your attention is drawn to the document - “Limitations” (LEG04, RL1), which is included in Appendix I of this report. The statements presented in this document are intended to advise you of what your realistic expectations of this report should be. The document is not intended to reduce the level of responsibility accepted by Golder Associates, but rather to ensure that all parties who may rely on this report are aware of the responsibilities each assumes in so doing.

We would be pleased to answer any questions the reader may have regarding these ‘Limitations’.

Report Signature Page

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