HDB Town Planning and Design

Proposed "Bunderra" Residential Subdivision
Boolaroo

Geotechnical Slope Risk Assessment

Report No. RGS01611.1-AB

10 August 2017

REGIONAL GEOTECHNICAL SOLUTIONS

10 August 2017

HDB Town Planning and Design
1st Floor 44 Church Street (PO Box 40)
MAITLAND NSW 2320

Attention: Mr Kerry Nichols

Dear Kerry

RE: Proposed "Bunderra" Residential Subdivision, Boolaroo

Geotechnical Slope Risk Assessment

Regional Geotechnical Solutions (RGS) has undertaken a slope stability assessment to assess the feasibility of undertaking residential subdivision development on the proposed "Bunderra" development site located on Main Road, Boolaroo.

The site is situated on the mid to lower slopes of Munibung Hill, in an area which has a history of slope instability. Remediation of the site following decommissioning of the adjacent Pasminco smelter involved extensive earthworks that has removed a large proportion of the soil profile formerly present at the site. The proposed residential development will involve further extensive earthworks including cuts and fills of the order of up to 8m. In some parts of the development, the proposed development planning incorporates the use of engineered retaining walls to support some of the proposed cuts and fills. This slope stability assessment takes into consideration the influence of the proposed earthworks and retention works on the post-development landslide risk.

The assessment was undertaken in accordance with the Australian Geomechanics Society 2007 *Practice Note Guidelines for Landslide Risk Management*. Based on the findings of the assessment, it has been concluded that residential development on the site would be feasible from a geotechnical perspective.

This report presents the findings of the assessment, delineates the geotechnical terrain of the area, identifies potential landslide hazards, and provides general recommendations regarding the geotechnical constraints and measures that would be required to allow residential subdivision development of the site.

Further geotechnical investigation work will be required to gather the information needed to design the slope remediation, earthworks, retention, and drainage works within the development, as well as standard geotechnical investigation and testing works for road pavement design and lot classification for the design of slabs and footings.

If you have any questions regarding this development, please contact the undersigned.

For and on behalf of

Regional Geotechnical Solutions Pty Ltd

Steven Morton

Principal Geotechnical Engineer

CONTENTS

Figures:

Appendices:

1 INTRODUCTION

At the request of Mr Kerry Nichols of HDB Planning & Design Pty Ltd, Regional Geotechnical Solutions Pty Ltd (RGS) has undertaken a geotechnical slope stability assessment on an area of land known as the "Bunderra" development site, off the eastern side of Main Road, Boolaroo.

The site is located on the north and west-facing footslopes of a prominent ridgeline that leads up to Munibung Hill. A proposal to subdivide the area for residential development is currently before Lake Macquarie City Council (Council). The Munibung Hill area, in which the proposed development site is situated, has a history of landslide activity. As a result, Council have requested that a landslide risk assessment be undertaken to assist them in assessing the Development Application (DA) for the proposed development.

The site occupies a large area that formed part of the former Pasminco smelter site. Extensive earthworks have been undertaken during the remediation of contamination at the site, effectively removing most of the soil from the site surface. Though there have been several geotechnical reports undertaken on and in the vicinity of the site in the past, the extensive changes to the site surface and the soil profile has affected the geotechnical conditions, and therefore the risk of landslides affecting the site has also changed since the time of the previous reports.

Considering the current condition of the site, the history of instability in the area, and slope stability concerns, the purpose of the work presented herein was to assess the site with regard to the feasibility of the proposed residential development from a geotechnical (landslide hazard) perspective, as well as:

- Assessing the presence of evidence of previous landslide activity on and around the site;
- Identification of potential future landslide hazards on the site;
- The delineation of geotechnical zones or terrains within the site that may be affected by different landslide hazards and associated risks;
- The potential for residential development within different areas of the site with regard to landslide hazards
- General discussion of the requirements for stabilisation, drainage, or other risk management measures to facilitate residential development on the site.

The assessment has been undertaken in accordance with the AGS 2007 *Practice Note Guidelines for Landslide Risk Management* (Ref.1).

2 SITE INVESTIGATIONS

The assessment of the site involved the following:

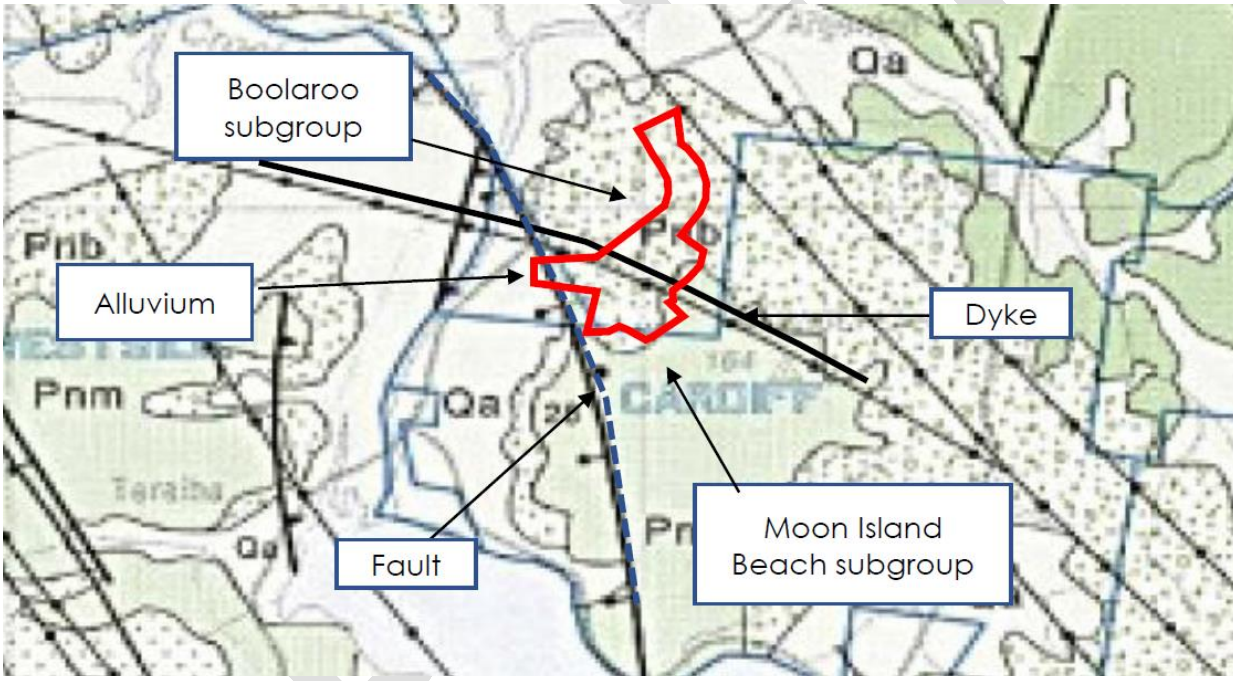
- Review of some previous geotechnical assessment reports provided by the client that relate, in part, to conditions at the site;
- Review of other available reports and published information regarding slope stability and landslide issues in the area;

- Walkover site assessment to observe surface conditions that may be relevant to slope stability – soil types, drainage conditions, rock exposures, evidence of past landsliding, unusual ground formations, drainage conditions, the presence of disturbed or hummocky ground etc.
- Identification, on the basis of the above information, of areas having the potential for residential development.

3 BACKGROUND AND GEOTECHNICAL SETTING

3.1 Regional Geology

The site is situated within an area underlain by the Boolaroo Sub-Group of the Newcastle Coal Measures. The elevated ridges and steep slopes of Munibung Hill to south and east of the site are formed by the rocks of the Moon Island Beach Sub-Group, which encroaches onto the southern end of the site. The geological setting of the site, as indicated by the 1:100,000 Newcastle Coalfields Geology map sheet is shown below:



Geological setting of site (outlined in red).

The dominant rock type within the Boolaroo subgroup is lithic and tuffaceous sandstone, present in thick beds of fine grained sandstone varying from low to high strength.

The sandstone beds are interlayered with thinner profiles of siltstone, claystone, coal, and tuff. These rock types, where present at or near the surface, typically present as highly fractured low strength beds, with an overall gentle dip (approx. 3 to 5 degrees), towards the southwest.

The geology map indicates a north-northwest trending geological fault, likely a 'normal' fault with the downside towards the west, crossing the site near the western limits of the proposed development area. An intrusive igneous dyke, likely to be a dolerite dyke, is shown to be crossing the southern half of the development area, trending generally east-west.

The permanent groundwater table is likely to be well below the ground surface over the development area, however, water which infiltrates through joints and other defects in the overlying rock sequences on the elevated ridge lines to the east and south of the site will flow through rock defects, typically concentrating at the interface of the sandstone and underlying coal or claystone units. The water tends to flow laterally through these layers and daylights as seepage on the slopes below wherever the coal or lower sandstone/conglomerate beds intersect the slope.

3.2 History of Slope Instability in the Area

Numerous studies and reports have been prepared in relation to the landslides in the Speers Point and Boolaroo area. These previous works have indicated that the landslides typically occur due to the sliding of thickly bedded, joint-bound conglomerate and sandstone rock masses over underlying, near horizontal tuffaceous claystone beds due to a combination of concentrated water flows and low shear strengths on the weathered claystone horizons. Some slope instability in the form of translational or rotational slides in colluvial soils on the lower slopes of the hills in the area has also been observed.

Groundwater levels in the area have been shown to be a major contributor to triggering of landslides in the area with landslides triggered when water levels rise to at or near the ground surface level during periods of prolonged heavy rainfall.

4 SITE CONDITIONS

4.1 General

The site is located to the east of Main Road, and the northeast of First Street, Boolaroo, and is situated on the west facing midslopes and footslopes of the prominent ridgeline that forms the northern plunging extremities of Munibung Hill. Overall, site elevations range from 8mAHD at the western boundary, to approximately 75m AHD at the eastern boundary.

Topographically, the site can be divided into two broad zones:

- Zone 1 - The gently undulating, lower lying western half of the site, where ground levels are typically less than 35m AHD; and
- Zone 2 - The elevated, moderately to steeply undulating eastern half of the site where ground levels typically range from 35m to 75m AHD.

The approximate extent of each of these areas is shown on Figure 2.

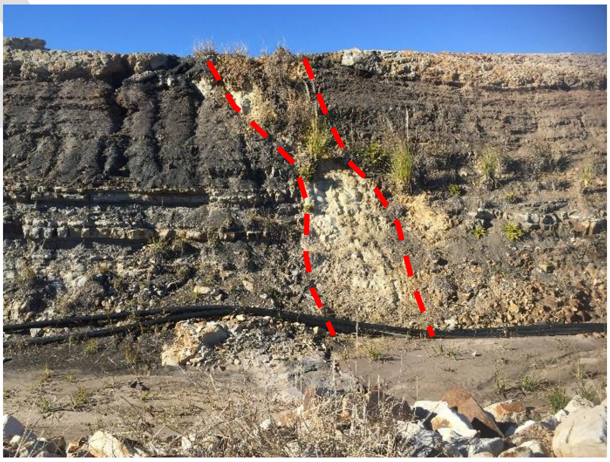
At the time of the fieldwork undertaken for this assessment, remediation works for the Pasminco smelter had been completed, resulting in the majority of site soils having been stripped from the surface and placed in a containment cell outside the boundary of the subject study area.

4.2 Terrain Zone 1 - Low lying western areas

The western part of the site comprised gently undulating slopes with extensive exposures of weathered sandstone and some localised carbonaceous shale and coal. There were localised areas of fill and some ponded water within temporary dams formed during the earthworks.

The area was typically well drained. Some areas of localised seepage though preferential drainage paths within the rock mass were observed.

There was no evidence of slope stability within the low lying western site areas. Selected images of the conditions on the low lying western slopes are presented below:

	
Typical terrain in the low lying western areas of the site. Gently sloping, thin remaining soils (if any), localised areas of fill.	*The thick, gently dipping, jointed sandstone beds that underlie the majority of the low-lying Terrain Zone 1.*
	
Carbonaceous shale, claystone and thin coal plies overlying the sandstone beds at the eastern end of terrain Zone 1. Above these beds the terrain transitions to steeper slopes underlain by beds of sandstone and conglomerate with some coal. Note rocky fill in foreground.	*East-west trending dolerite dyke exposed in cutting within carbonaceous beds in terrain Zone 1, near southern end of site.*

	
Looking towards more elevated Zone 1 terrain at northern end of site. Exposures reveal two coal seams with tuffaceous claystone and siltstone beds between. Note extensive filling in foreground.	*Tuffaceous siltstone overlying coal in crest of broad hill spur, Zone 1 terrain, northern end of site.*

4.3 Terrain Zone 2 – Elevated Eastern Areas

Elevations within terrain Zone 2 typically range from RL 35 to 75m. The terrain comprises moderate slopes, typically ranging from 8 to 15 degrees, but with localised gully side-slopes of up to 25 degrees. The ground comprises the mid to upper slopes of prominent spurs that trend off the main ridgeline leading up to Munibung Hill, located to the southeast of the site. Slopes are generally convex and divergent. The slopes comprise broad spurs separated by deep drainage gullies that contain ephemeral watercourses that were generally dry at the time of the fieldwork other than some minor ponds and localised areas of seepage.

Much of the area has been stripped of soil cover during the Pasminco remediation works, however, there is established grass and weed cover and some tree regrowth in some of the steeper gully areas and eastern extremities of the site.

The area is typically well drained by surface runoff into the deep gullies. There were two dams containing water at the time of the site works. It is understood these are to be re-configured and/or filled as part of the proposed site development.

Over the majority of the site the soil profile had been extensively altered by site remediation works. The natural soil profiles on the elevated areas of the site comprise thin residual clay soils overlying weathered rock. Over much of the Zone 2 area the weathered rock was exposed at the surface at the time of the fieldwork, and predominantly comprised weathered sandstone and conglomerate, with minor coal seams and siltstone beds. The geology had an overall gentle dip towards the southwest – ie, slightly across and out of the dominant slope direction. Areas of deep fill were observed in the base of some of the dominant drainage gullies.

Selected images of the Zone 2 terrain are presented below.

	
Zone 2 terrain, near highest point of proposed development area. Steep slopes, some evidence of movement noted in separation of conglomerate blocks and disturbed bedding.	*Looking across majority of Zone 2 area from the north to south. Steep slope in background (outside but above development area) shows evidence of numerous small scale landslides.*

	
Looking across Zone 2 area at southern end of site. Revegetated hill slope in rear of image shows evidence of past small scale rotational failures.	*Seepage from sandstone joints and beds near boundary between Boolaroo sub group and Moon Island Beach Sub-Group at southern end of site*

5 EVIDENCE OF SLOPE INSTABILITY

No evidence of slope instability was observed in the Zone 1 terrain.

In the Zone 2 terrain, evidence of slope instability was observed in two areas, as shown on Figure 2. At the eastern site boundary, an area of apparent former large scale instability is evidenced by the separation and disturbance of conglomerate blocks over thinly bedded disturbed siltstone and claystone. This area is visible on aerial images and appears to be a large scale lateral movement of the crest and upper slopes of a ridge spur, towards the west. Laterally oriented drainage courses and an area of lush vegetation at the rear of the spur appear to indicate a tension zone caused by the gradual lateral migration of conglomerate blocks over an underlying slide plane. There is no evidence of debris flows below the area of apparent movement, however, this may have been present prior to the extensive disturbance of the site during the Pasminco remediation earthworks. Aerial images of the area of concern are shown below.

Apparent tension zone at rear of possible area of mass movement at eastern site boundary.

The second area of past instability is located at the southern site boundary where there are visible scars of multiple translational and rotational slides in the steep slope just outside the site boundary. There is some evidence of these areas, and the debris from these slides, extending across the site boundary onto the proposed development area. There is also some visible seepage and separation of sandstone blocks on the mid to lower slopes of the ridge spur in the southern corner of the site. Brief observation of some adjacent residential development that appears, from the style of house present, to be over 50 years old, did not reveal visible evidence of damage attributable to lateral ground movement.

6 PROPOSED DEVELOPMENT

The proposed residential subdivision development will involve extensive changes to the site, that will affect the risk of landslide. A preliminary earthworks plan is shown on Figure 3. Of significance to the post-development landslide risk will be:

- Extensive excavation of the elevated ridges and spurs by up to 8m, to win fill material for the filling of the deeper gully areas;
- The use of engineered retaining walls to support cuts and fills adopted to reduce slope angles on the building lots in the final landform;
- The proposed earthworks will incorporate cut batters of up to 3m depth on the steep slopes at the southern and southeastern boundary. As these cuts will effectively remove some toe support for the steep slopes outside the boundary, the cuts will require specific investigation and design, and are likely to require incorporation of support measures such as ground anchors, subsurface drainage measures, or similar, to avoid triggering upslope failures.

The above works will need to be conducted in accordance with good geotechnical and hillside construction practice. As these works will impact on the risk of slope instability at the site the risk assessment presented in the following sections has assumed the following:

- Earthworks involved in the re-configuring of the site landforms prior to development will be undertaken in accordance with good hillside construction practice and site specific geotechnical investigation, design and supervision;
- Placement of fill in gullies and drainage courses will incorporate measures such as drainage blankets, diversion drains, and subsoil drains, designed on the basis of specific geotechnical input, to ensure that the subsurface drainage of the hillside and the soil/rock profile beneath the fill is not impeded;
- Cut batters exceeding 1m deep will not exceed 1V:3H in soil or 1V:2H in rock;
- Cuts and fills that exceed 1.5m depth within the site regrade works will be subject to specific geotechnical design and implementation of appropriate support and/or drainage measures;
- All fill we be placed and compacted in layers in accordance with the requirements of AS3798-2007 Guidelines on earthworks for commercial and residential development, under Level 1 supervision as defined by the standard;
- Site stormwater drainage will be undertaken with appropriate hydrological and geotechnical input.

7 SLOPE STABILITY ASSESSMENT PROCESS

The risk of slope instability at the subject site has been assessed using the principles and protocols of the Australian Geomechanics Society publication *Practice Note Guidelines for Landslide Risk Management, 2007*. This methodology represents the currently accepted state of practice for landslide risk assessment in Australia.

The slope risk assessment process involves identification of a potential slope failure event, or hazard, followed by an estimation of the likelihood of the event occurring, and the potential consequences should the event occur.

The terms used in the risk assessment process are defined below:

Hazard:	A condition with the potential for causing an undesirable consequence.
Likelihood:	The estimated probability that the hazardous event will occur.
Consequence:	Loss or damage resulting from a hazard event.
Risk:	A term combining the likelihood and consequence of an event in terms of adverse effects to property or the environment.

The assessment of slope risk presented herein is takes into account the proposed earthworks shown on Figure 3 and the assumptions outlined in Section 6 of this report. Should any aspect of the proposed earthworks or adopted assumptions differ from those presented herein, further geotechnical advice should be sought.

As the landslide hazards and associated risks in terrain Zones 1 and 2 differ significantly, the following risk assessment addresses Zone 1 and Zone 2 separately.

8 SLOPE RISK ASSESSMENT – ZONE 1

8.1 Hazard Identification

The following potential slope stability hazards were assessed in relation to the site and proposed development:

Hazard 1: Large scale translational slide of sandstone or conglomerate blocks over low strength clay or claystone seams. Such a failure could cause large scale damage of several structures within a typical residential subdivision;

Hazard 2: Translational slide of soil and weathered rock profile on lower slopes resulting from ongoing stress relief due to erosion and valley formation processes. Should such a failure occur it could potentially cause structural damage and require large scale, costly repairs. Maintaining good slope drainage to prevent buildup of water pressures is recommended;

Hazard 3: Small scale slide due to failure of unsupported cuts and fills or poorly designed, constructed, or otherwise inadequate retaining walls. Such a failure could cause localised damage requiring moderate repairs to part of an individual structure or property

8.2 Risk Assessment for Identified Slope Risk Hazards

Table 1 summarises the factors affecting slope stability in relation to each of the hazards identified and assesses the risk of slope instability for each using the risk assessment matrix provided in Appendix C of the Australian Geomechanics Society (AGS) publication *Practice Note Guidelines for Landslide Risk Management, 2007*. A copy of the AGS risk matrix is presented as Appendix A.

Table 1: Zone 1 - Slope Risk Assessment Based on AGS2007 method

Hazard	H1 – Large scale translational landslide and debris flow	H2 – Translational failure of soil over weathered rock profile	H3 - Localised failure of poorly retained cuts
Slope height	10 to 20m	5 - 10m	<5m
Cause or trigger	Slope deterioration and weathering, exceptionally prolonged and intense rainfall	Ongoing erosion, stress release, followed by adverse wet weather event	Unlikely if recommendations of this report are followed and all cuts >1m are either battered as recommended or supported by engineered retaining walls.
Estimated probability	10^{-6} yr (inconceivable except under extreme exceptional circumstances)	10^{-5} yr	10^{-4} yr
Likelihood	Barely Credible	Rare	Unlikely
Consequence	Extensive damage to numerous structures	Damage to one or possibly more structures requiring extensive repair	Localised minor damage to part of individual property or structure, requiring minor repairs
	Major	Major	Medium
Risk	**Very Low**	**Low**	**Low**

8.3 Evaluation of Risk Level

The assessment indicates the risk of slope instability within the Zone 1 terrain to be **Low**. In considering tolerable levels of risk for development, it would be normal practice within Australia for development to be acceptable on sites assessed as Low Risk under the AGS2007 system.

9 SLOPE RISK ASSESSMENT – ZONE 2

9.1 Hazard Identification

The following potential slope stability hazards were assessed in relation to the site and proposed development:

Hazard 1: Large scale translational slide of sandstone or conglomerate blocks over low strength clay or claystone seams. Such a failure could cause complete destruction or large scale damage of several structures within a typical residential subdivision;

Hazard 2: Translational or rotational slide through soil or weathered rock profile. Should such a failure occur it could potentially cause extensive structural damage and require large scale, costly repairs, and possibly temporary evacuation of a typical residential building until repairs are complete. Undertaking all site earthworks under good geotechnical design and construction practices and maintaining good surface and subsurface slope drainage to prevent buildup of water pressures beneath and within the profile is essential;

Hazard 3: Debris flow associated with landslides hazards 1 and 2 above. Debris flows are capable of travelling well beyond the parent landslide and could impact on structures or property located below the zone of instability. Debris flows of the magnitude that would be expected to occur from landslide Hazards 1 and 2, as described above, would typically cause moderate to major damage to structures or property in their path;

Hazard 4: Soil creep. Creep is an imperceptibly slow movement that takes place on sloping soil sites. It is an ongoing, natural slope process involving the progressive downslope movement of soils over the underlying rock profile. Creep can typically be managed by undertaking good hillside construction practice as recommended in this report;

Hazard 5: Small scale slide due to failure of unsupported cuts and fills or poorly designed, constructed, or otherwise inadequate retaining walls. Such a failure could cause localised damage requiring moderate repairs to part of an individual structure or property.

The areas potentially affected by Hazards 1, 2 and are illustrated on Figure 4. Hazards 4 and 5 could affect any part of Zone 2.

9.2 Risk Assessment for Identified Hazards

Table 2 summarises the factors affecting slope stability in relation to each of the hazards identified and assesses the risk of slope instability for each using the risk assessment matrix provided in Appendix C of the Australian Geomechanics Society (AGS) publication *Practice Note Guidelines for Landslide Risk Management, 2007*. A copy of the AGS risk matrix is presented as Appendix A.

Table 2: Zone 2 - Slope Risk Assessment Based on AGS2007 method

Hazard	H1 – Large scale translational landslide	H2 – Translational or rotational failure	H3 – Debris Flow	H4 - Soil Creep	H5 - Localised failure of poorly retained cuts
Assumed Condition	Area of concern to be excavated by up to 8m and re-shaped/ retained in accordance with specific geotechnical design measures	Extensive site regrade to remove upper slopes and fill steep-sided gullies. Cuts and fills to be undertaken in accordance with specific geotechnical design and recommendations	Debris flow generated by Hazard Type 1 or 2. Earthworks and support measures implemented to control or prevent those hazards would reduce likelihood of debris flow.	Majority of site soil profile has been or will be stripped. Placed fill will be benched into slopes and undertaken in accordance with appropriate geotechnical design and construction supervision	Recommendations of this report are followed and all cuts >1m are either battered as recommended or supported by engineered retaining walls.
Cause or trigger	Exceptionally prolonged and intense rainfall	Exceptionally prolonged and intense rainfall	Exceptionally prolonged and intense rainfall	Ongoing process of imperceptibly slow soil movement	Extreme wet weather, overloading of wall/ change to wall
Estimated probability	10^{-5} yr	10^{-5} yr	10^{-5} yr	10^{-2} yr	10^{-4} yr
Likelihood	Rare	Rare	Rare	Likely	Unlikely
Consequence	Extensive damage to numerous structures within downslope area	Damage to one or possibly more structures requiring extensive repair	Damage to one or possibly more structures requiring extensive repair	Slow generally manageable displacement of services, pathways etc.	Localised minor damage to part of individual property or structure, requiring minor repairs
	Major	Major	Major	Insignificant	Medium
Risk	**Low**	**Low**	**Low**	**Low**	**Low**

Notes - Risk assessments as shown in Table 2 assume the conditions outlined in the table, and assume that the development is undertaken in accordance with the recommendations of this report and ongoing appropriate geotechnical design and construction practices.

9.3 Evaluation of Risk Level

The assessment indicates the risk of slope instability within the Zone 2 terrain to be **Low**, provided the development is undertaken in accordance with good hillside construction practice and the specific recommendations of this report.

In considering tolerable levels of risk for development, it would be normal practice within Australia for development to be acceptable on sites assessed as Low Risk under the AGS2007 system.

10 GEOTECHNICAL CONSIDERATIONS FOR DESIGN AND CONSTRUCTION

10.1 General

The proposed earthworks, as shown on Figure 3, will involve extensive regrade of the site which will remove soil and rock from the elevated and more steeply sloping upper slopes, to be used in the filling of the gullies and reduction of steep gully side slopes. The resultant site profile will have lower topographic relief and gentler slopes than the existing profiles and the resultant soil profiles will comprise compacted Controlled Fill, placed in layers and compacted onto level terraces benched into the slope. Provided the earthworks are undertaken in accordance with appropriate geotechnical design and advice, the risk associated with slope instability following bulk earthworks will be Low, and the proposed development is considered feasible from a geotechnical perspective.

The following sections provide geotechnical advice and recommendations for the design and construction of the subdivision, following on from this initial planning/ feasibility stage assessment.

10.2 Investigation of Areas of Potential Slope Instability Identified in this assessment

Prior to final design of development layouts and formulation of earthworks planning and design, additional geotechnical investigation works should be undertaken to assess:

- The presence and extent of slope instability in the areas of concern identified on the eastern and southern boundaries of the site;
- Groundwater levels beneath the site and responses to rainfall;
- Presence of aquifers or natural seepage paths within the subsurface profile. Identification of these zones will be critical in designing subsurface drainage beneath areas of deep fill and control of seepage in areas of cut;
- Modelling of slope profiles proposed, in conjunction with groundwater and subsurface profile data, to evaluate Factor of Safety against slope failure in the modified landforms;
- Materials available for proposed earthworks program and development of earthworks management plans for optimising use of available materials;
- Excavatability of the rock profiles in deeper cut areas;

- Design and planning of road and lot construction works with regard to foundation and pavement design/construction conditions on completion of the works.

10.3 Earthworks and Site Regrade

The following measures should be employed in all regrade works undertaken on the site:

- All areas of cut and fill should be thoroughly investigated prior to the works to identify geotechnical issues in relation to the proposed cut and fill works;
- All unsuitable material including topsoil and vegetation should be stripped to spoil or stockpiled for future use in landscaping only;
- Where fill is to be placed on slopes exceeding five degrees, a prepared surface should be benched or terraced into the slope to provide a level surface for fill compaction and avoid generation of sloping foundation layers beneath the fill;
- All gully areas and watercourses that are to be filled must be provided with drainage blankets or other geotechnically designed under-drainage measures to promote free drainage of the slope and the subsurface profile underlying the fill;
- A site specific earthworks management plan needs to be developed for the site overall and for each specific area, with geotechnical input, to allow proactive management of geotechnical risk.

10.4 Types of structure

There are no specific constraints regarding the type of structure considered suitable for the site, provided design and construction is undertaken in accordance with good hillside practice and the recommendations of this report and appropriate ongoing or subsequent geotechnical advice.

10.5 Support of Excavations and Filling

Cuts or fills exceeding 1m in height should be avoided where practicable. Cuts and fills of up to 1m can be battered at 1V:2H or flatter. Deeper cuts and fills should be supported by engineer designed and properly constructed retaining walls.

All retaining walls should be provided with complete drainage at the back of the wall that drains to an ag drain, weep-hole or similar that allows free discharge of water from behind the wall.

Retaining walls must be designed to accommodate surcharge loading from all slopes, structures, or foreseeable traffic above the wall.

Further recommendations and design advice for retaining walls can be provided once the layout and configuration of the proposed development are known.

11 LIMITATIONS

The findings presented in the report and used as the basis for recommendations presented herein were obtained using normal, industry accepted geotechnical practises and standards. To our knowledge, they represent a reasonable interpretation of the general condition of the site. Under no circumstances, however, can it be considered that these findings represent the actual state of the site at all points. If site conditions encountered during construction vary significantly from those discussed in this report, Regional Geotechnical Solutions Pty Ltd should be contacted for further advice.

This report alone should not be used by contractors as the basis for preparation of tender documents or project estimates. Contractors using this report as a basis for preparation of tender documents should avail themselves of all relevant background information regarding the site before deciding on selection of construction materials and equipment.

If you have any questions regarding this project, or require any additional consultations, please contact the undersigned.

For and on behalf of

Regional Geotechnical Solutions Pty Ltd

Steven Morton

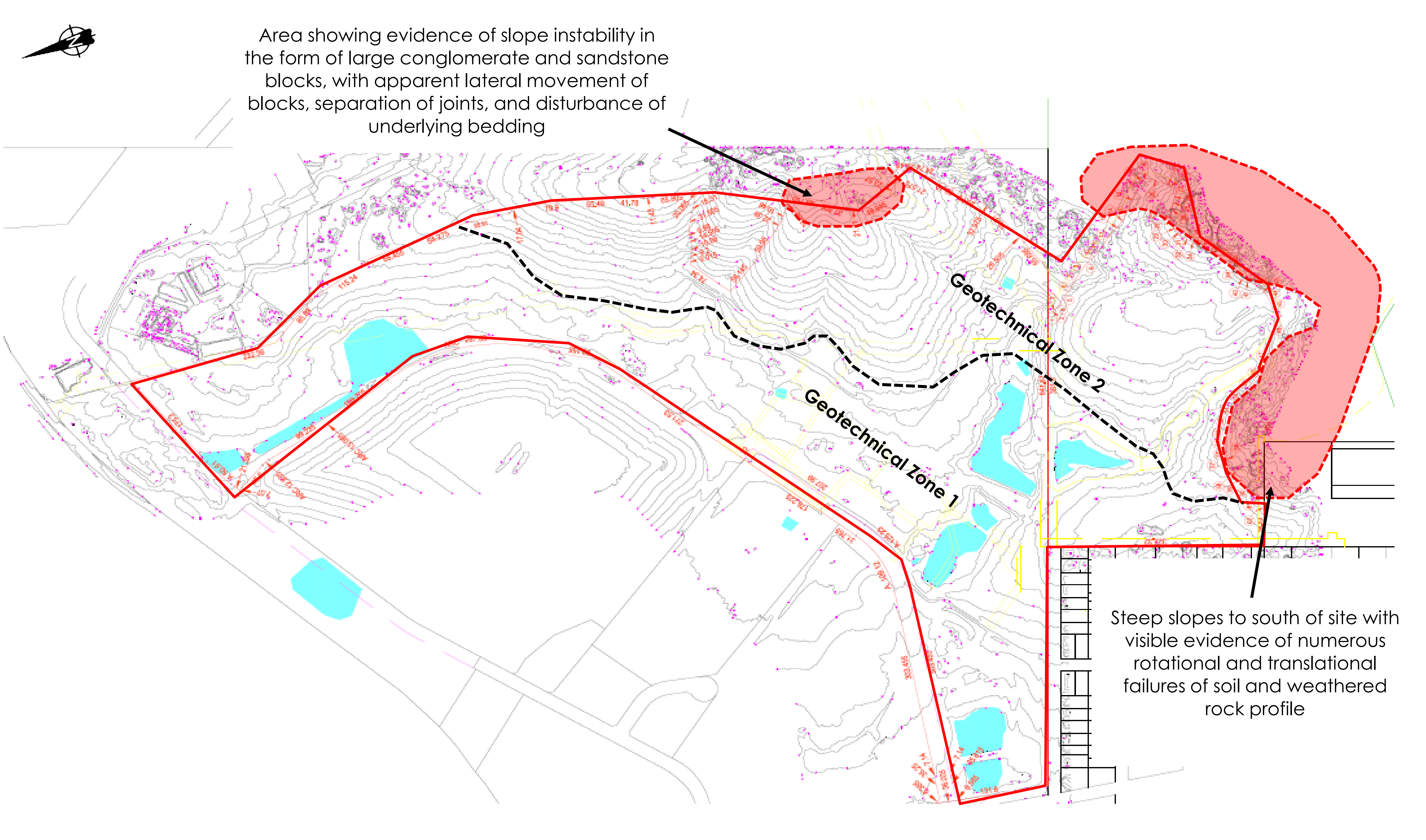
Principal

References:

1. Australian Geomechanics Society *Practice Note Guidelines for Landslide Risk Management,* Journal and News of the Australian Geomechanics Society, Vol 42, No 1, March 2007
2. Bashi & Associates Pty Ltd 19 *Daydawn Avenue, Warners Bay, Site Stability – Design Report*, 7 October 2016
3. Fell, R, Sullivan, TD, and Parker, C *The Speers Point Landslides* in Soil Slope Instability and Stabilisation, Walker & Fell eds, 1987

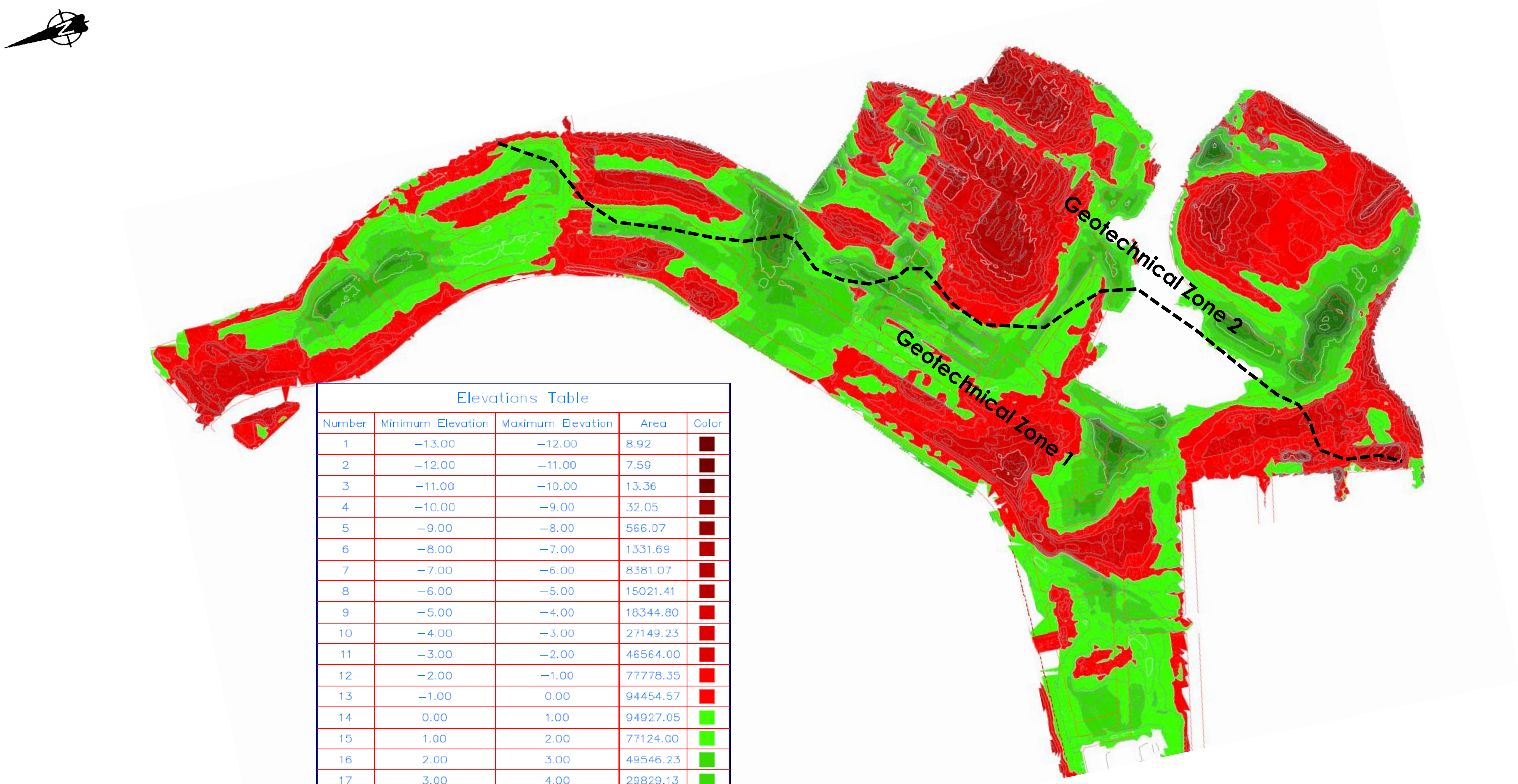
Figures

REGIONAL GEOTECHNICAL SOLUTIONS	**Client**	HDB Town Planning and Design	Job No.	RGS01611.1
	Project:	Residential Subdivision Geotechnical Assessment "Bunderra" site, Main Road Boolaroo	Drawn By:	SRM
			Date:	11-Aug-17
	Title:	Approximate Extent of Bunderra Site	Drawing No.	**Figure 1**



REGIONAL GEOTECHNICAL SOLUTIONS

Client	HDB Town Planning and Design	Job No.	RGS01611.1
Project:	Residential Subdivision Geotechnical Assessment	Drawn By:	SRM
	"Bunderra" site, Main Road Boolaroo	Date:	11-Aug-17
Title:	Geotechnical Zones and Areas with Evidence of Slope Instability	Drawing No.	**Figure 2**

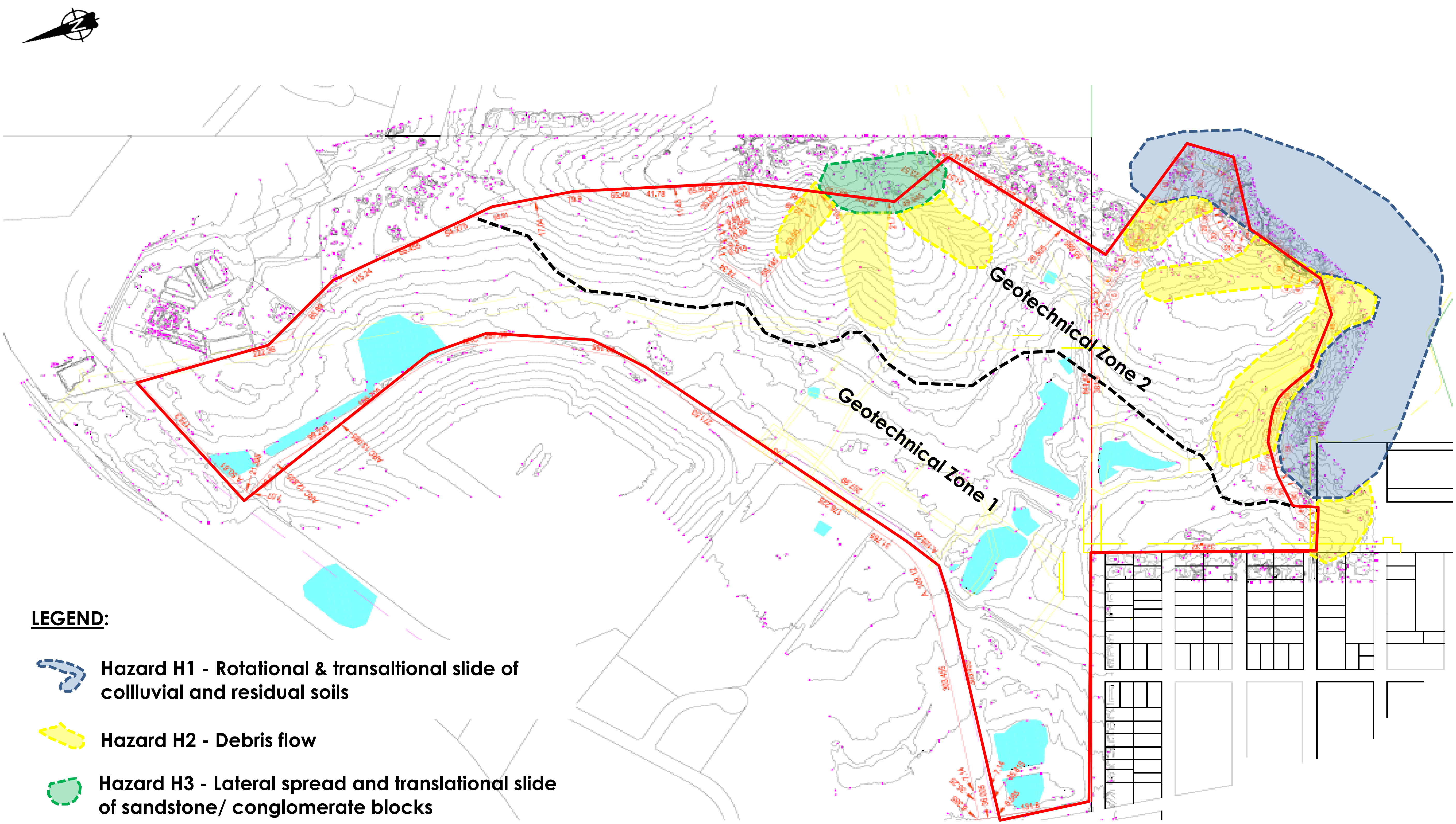


Elevations Table

Number	Minimum Elevation	Maximum Elevation	Area	Color
1	−13.00	−12.00	8.92	
2	−12.00	−11.00	7.59	
3	−11.00	−10.00	13.36	
4	−10.00	−9.00	32.05	
5	−9.00	−8.00	566.07	
6	−8.00	−7.00	1331.69	
7	−7.00	−6.00	8381.07	
8	−6.00	−5.00	15021.41	
9	−5.00	−4.00	18344.80	
10	−4.00	−3.00	27149.23	
11	−3.00	−2.00	46564.00	
12	−2.00	−1.00	77778.35	
13	−1.00	0.00	94454.57	
14	0.00	1.00	94927.05	
15	1.00	2.00	77124.00	
16	2.00	3.00	49546.23	
17	3.00	4.00	29829.13	
18	4.00	5.00	19340.67	
19	5.00	6.00	10219.60	
20	6.00	7.00	5424.00	
21	7.00	8.00	3922.63	
22	8.00	9.00	1730.54	
23	9.00	10.00	1415.33	

REGIONAL GEOTECHNICAL SOLUTIONS

Client	HDB Town Planning and Design	Job No.	RGS01611.1
Project:	Residential Subdivision Geotechnical Assessment	Drawn By:	SRM
	"Bunderra" site, Main Road Boolaroo	Date:	11-Aug-17
Title:	Proposed Bulk Earthworks	Drawing No.	**Figure 3**



REGIONAL GEOTECHNICAL SOLUTIONS	Client	HDB Town Planning and Design	Job No.	RGS01611.1
	Project:	Residential Subdivision Geotechnical Assessment	Drawn By:	SRM
		"Bunderra" site, Main Road Boolaroo	Date:	11-Aug-17
	Title:	Landslide Hazards present in Geotechnical Zone 2	Drawing No.	**Figure 4**

Appendix A

AGS2007 Risk Matrix & Hillside Guidelines

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	200 years	The event will probably occur under adverse conditions over the design life.	LIKELY	B
10^{-3}	$5x10^{-3}$	1000 years	2000 years	The event could occur under adverse conditions over the design life.	POSSIBLE	C
10^{-4}	$5x10^{-4}$	10,000 years	20,000 years	The event might occur under very adverse circumstances over the design life.	UNLIKELY	D
10^{-5}	$5x10^{-5}$	100,000 years	200,000 years	The event is conceivable but only under exceptional circumstances over the design life.	RARE	E
10^{-6}	$5x10^{-6}$	1,000,000 years		The event is inconceivable or fanciful over the design life.	BARELY CREDIBLE	F

Note: (1) The table should be used from left to right; use Approximate Annual Probability or Description to assign Descriptor, not *vice versa*.

QUALITATIVE MEASURES OF CONSEQUENCES TO PROPERTY

Approximate Cost of Damage		Description	Descriptor	Level
Indicative Value	**Notional Boundary**			
200%	100%	Structure(s) completely destroyed and/or large scale damage requiring major engineering works for stabilisation. Could cause at least one adjacent property major consequence damage.	CATASTROPHIC	1
60%	40%	Extensive damage to most of structure, and/or extending beyond site boundaries requiring significant stabilisation works. Could cause at least one adjacent property medium consequence damage.	MAJOR	2
20%	10%	Moderate damage to some of structure, and/or significant part of site requiring large stabilisation works. Could cause at least one adjacent property minor consequence damage.	MEDIUM	3
5%	1%	Limited damage to part of structure, and/or part of site requiring some reinstatement stabilisation works.	MINOR	4
0.5%		Little damage. (Note for high probability event (Almost Certain), this category may be subdivided at a notional boundary of 0.1%. See Risk Matrix.)	INSIGNIFICANT	5

Notes: (2) The Approximate Cost of Damage is expressed as a percentage of market value, being the cost of the improved value of the unaffected property which includes the land plus the unaffected structures.

(3) The Approximate Cost is to be an estimate of the direct cost of the damage, such as the cost of reinstatement of the damaged portion of the property (land plus structures), stabilisation works required to render the site to tolerable risk level for the landslide which has occurred and professional design fees, and consequential costs such as legal fees, temporary accommodation. It does not include additional stabilisation works to address other landslides which may affect the property.

(4) The table should be used from left to right; use Approximate Cost of Damage or Description to assign Descriptor, not vice versa

APPENDIX C: – QUALITATIVE TERMINOLOGY FOR USE IN ASSESSING RISK TO PROPERTY (CONTINUED)

QUALITATIVE RISK ANALYSIS MATRIX – LEVEL OF RISK TO PROPERTY

LIKELIHOOD		CONSEQUENCES TO PROPERTY (With Indicative Approximate Cost of Damage)				
	Indicative Value of Approximate Annual Probability	1: CATASTROPHIC 200%	2: MAJOR 60%	3: MEDIUM 20%	4: MINOR 5%	5: INSIGNIFICANT 0.5%
A – ALMOST CERTAIN	10^{-1}	VH	VH	VH	H	M or L (5)
B - LIKELY	10^{-2}	VH	VH	H	M	L
C - POSSIBLE	10^{-3}	VH	H	M	M	VL
D - UNLIKELY	10^{-4}	H	M	L	L	VL
E - RARE	10^{-5}	M	L	L	VL	VL
F - BARELY CREDIBLE	10^{-6}	L	VL	VL	VL	VL

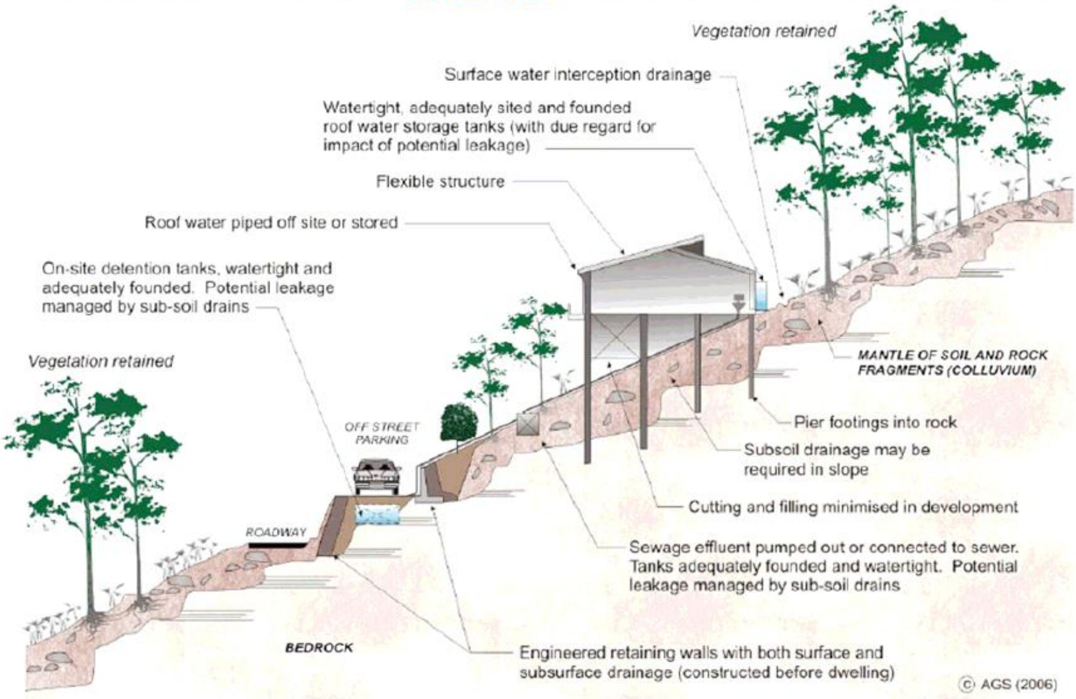
Notes: (5) For Cell A5, may be subdivided such that a consequence of less than 0.1% is Low Risk.
(6) When considering a risk assessment it must be clearly stated whether it is for existing conditions or with risk control measures which may not be implemented at the current time.

RISK LEVEL IMPLICATIONS

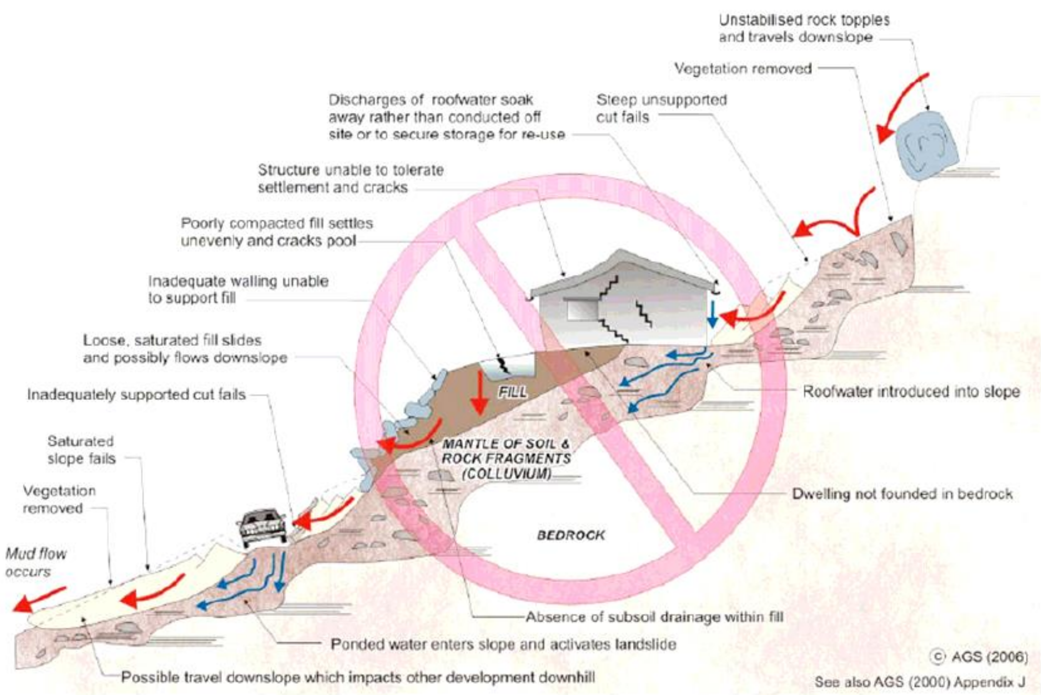
Risk Level		Example Implications (7)
VH	VERY HIGH RISK	Unacceptable without treatment. Extensive detailed investigation and research, planning and implementation of treatment options essential to reduce risk to Low; may be too expensive and not practical. Work likely to cost more than value of the property.
H	HIGH RISK	Unacceptable without treatment. Detailed investigation, planning and implementation of treatment options required to reduce risk to Low. Work would cost a substantial sum in relation to the value of the property.
M	MODERATE RISK	May be tolerated in certain circumstances (subject to regulator's approval) but requires investigation, planning and implementation of treatment options to reduce the risk to Low. Treatment options to reduce to Low risk should be implemented as soon as practicable.
L	LOW RISK	Usually acceptable to regulators. Where treatment has been required to reduce the risk to this level, ongoing maintenance is required.
VL	VERY LOW RISK	Acceptable. Manage by normal slope maintenance procedures.

Note: (7) The implications for a particular situation are to be determined by all parties to the risk assessment and may depend on the nature of the property at risk; these are only given as a general guide.

EXAMPLES OF GOOD HILLSIDE PRACTICE



EXAMPLES OF POOR HILLSIDE PRACTICE



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.	