12 April 2021

COASTAL WALKWAY UPGRADE
CELL 5 – GREY ROAD GULLY
HALLETT COVE, SA 5158

GEOTECHNICAL ASSESSMENT REPORT

Innovis

ADL2020-0142AE Rev0

ADL2020-0142AE		
Date	**Revision**	**Comments**
12 April 2021	0	First Issue

Table of Contents

1 EXECUTIVE SUMMARY 3
2 INTRODUCTION 3
3 PROJECT DESCRIPTION 3
4 SCOPE OF WORK 8
5 SITE DESCRIPTION 8
6 GROUND MODEL 10
6.1 Desk Top Study 10
6.2 Regional Geology 10
6.3 Site Assessment 11
7 ELEVATED WALKWAY STRUCTURE GEOTECHNICAL ASSESSMENT 11
7.1 General 11
7.2 Walkway Structure 11
7.3 Coastal Processes 11
7.4 Surface Water Process 11
7.5 Landslide Risk Assessment 12
7.6 Foundation Options and Parameters 13
8 FURTHER WORK 14
9 CLOSURE 14

Figures

Figure 1 – Risk Plan Cell 5

Appendices

Appendix A – AGS Landslide Risk Assessment

1 EXECUTIVE SUMMARY

This report presents the results of a geotechnical site assessment carried out at Grey Road Gully Hallett Cove, Adelaide, SA, with regards to the City of Marion's renewal plan for the Coastal Walking Trial Cell 5.

Based on the assessment results within the area of Cell 5, where elevated boardwalk and walkway structures are proposed, the materials beneath the anticipated wooden pier footings are a thin veneer of residual soils composed of loose to medium dense gravels underlain by subvertical laminated low strength sedimentary rock units (Siltstone/Sandstone) in only a small portion of the alignment. The risk to landslide has been considered to be current moderate for the path alignment and low for the potential alternative alignment. An additional erosive force impacting the walking trail/path are surface water flows, these impacts are reduced when constructing a path aligned to the contours of the existing slope.

The existing boardwalk footings and our experience suggest that shallow bored piles would be most suitable in the gravels and sands and rock anchors in bedrock expected on site to maximise the benefit of the soil strength soils and underlying in-situ bedrock. Details of appropriate shallow bored piles or rock anchor foundation parameters for the elevated boardwalk and an AGS landslide assessment are include herein.

2 INTRODUCTION

CMW Geosciences (CMW) was authorised by Innovis to assess the geotechnical conditions for the proposed upgrade of the Coastal Walking Trail (CWT) at Cell 5. The scope of work and associated terms and conditions of our engagement were detailed in our services proposal letter ADL2020-0142AA, Rev0 dated 28 May 2020.

Included herein is our report and recommendations pertaining the proposed elevated boardwalk.

3 PROJECT DESCRIPTION

The Marion Coastal Walkway covers an 8km section from Marino to Hallett Cove and was constructed in the mid-late 1990's. The City of Marion's Coastal Walkway Plan provides a renewal plan that prioritises sections for upgrade and repair. A high priority has been placed on Cell 5 (Grey Rd Gully), Cell 6 (Kurnabinna Gully) and Cell 10 (Field River).

This walkway has strategic importance as a key link in the 70km Coast Park Trail from North Haven to Sellicks Beach. The upgrade works will enable it to become an important and iconic connecting piece to other major open space networks, including Marino Conservation Park, Hallett Cove Conservation Park and Glenthorne National Park.

This report provides a description of Cell 5 (Grey Road Gully), which is a combined at grade and elevated boardwalk, from Nungamoora Street in the south to Grey Road in the north. Refer to Figure 1 for an image of the overall concept design of the footpath alignment. Refer to Figure 2, Figure 3 and Figure 4 for the area of concept design provided by Aspect Studios.

Noting in this report and overall project engagement CMW are only undertaking an assessment of the alignment that is an elevated walkway boardwalk structure. The at grade sections of the footpath do not require geotechnical assessment.

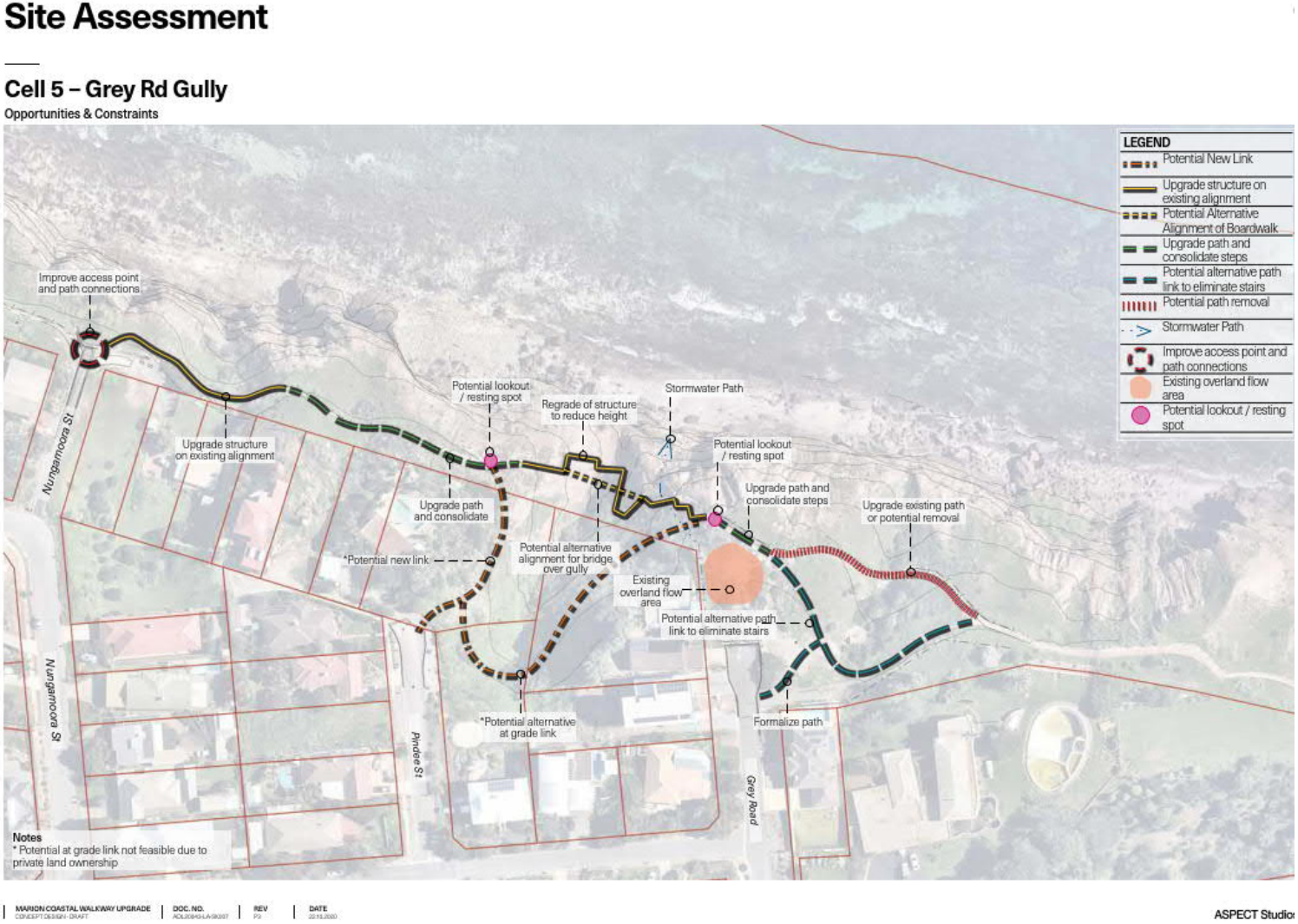


Figure 1: Overall Concept Design by Aspect Studios - Cell 5 – Grey Road Gully

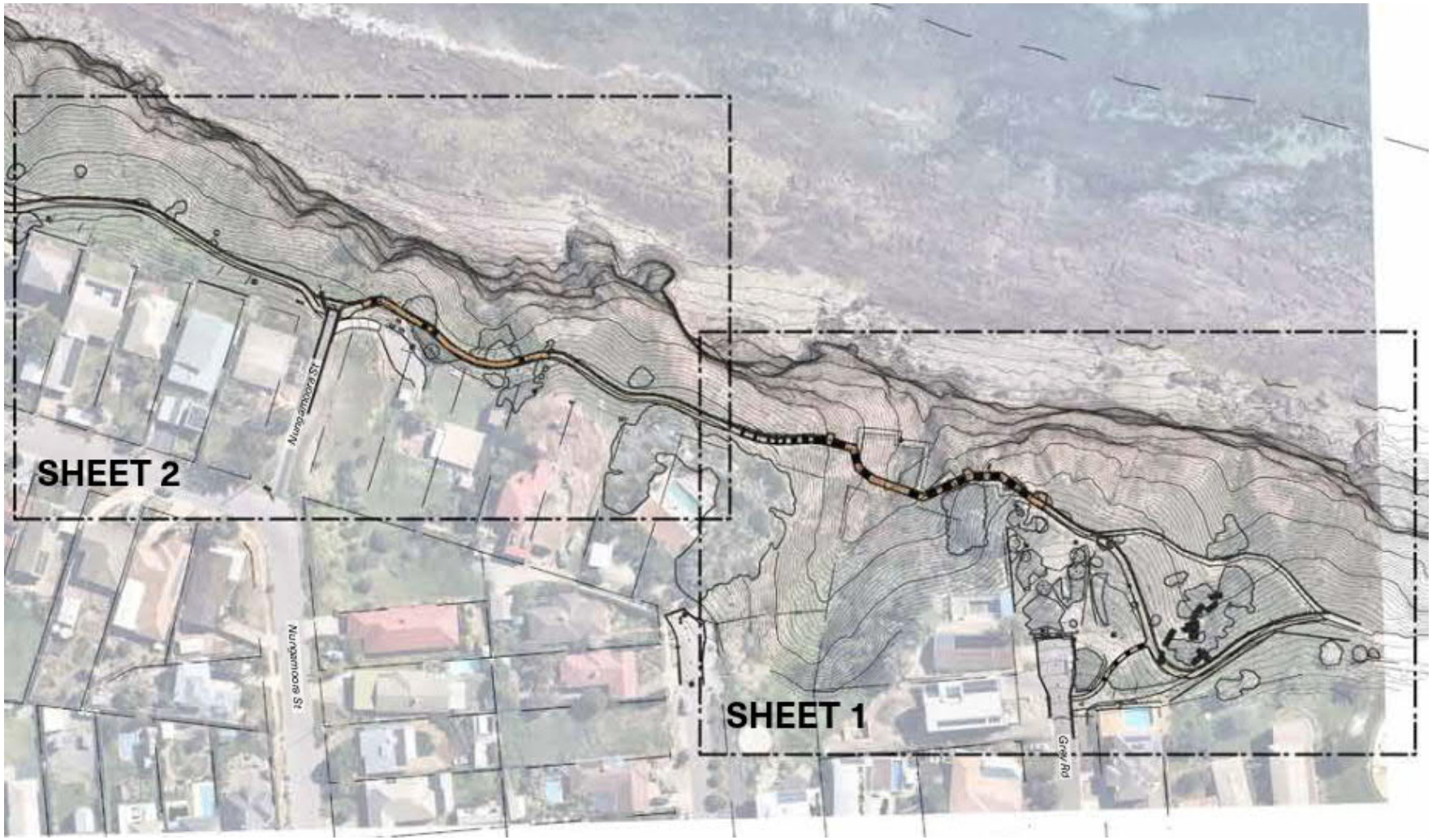


Figure 2: Elevated Board Walk Concept Design Layout by Aspect Studios - Cell 5 – Grey Road Gully

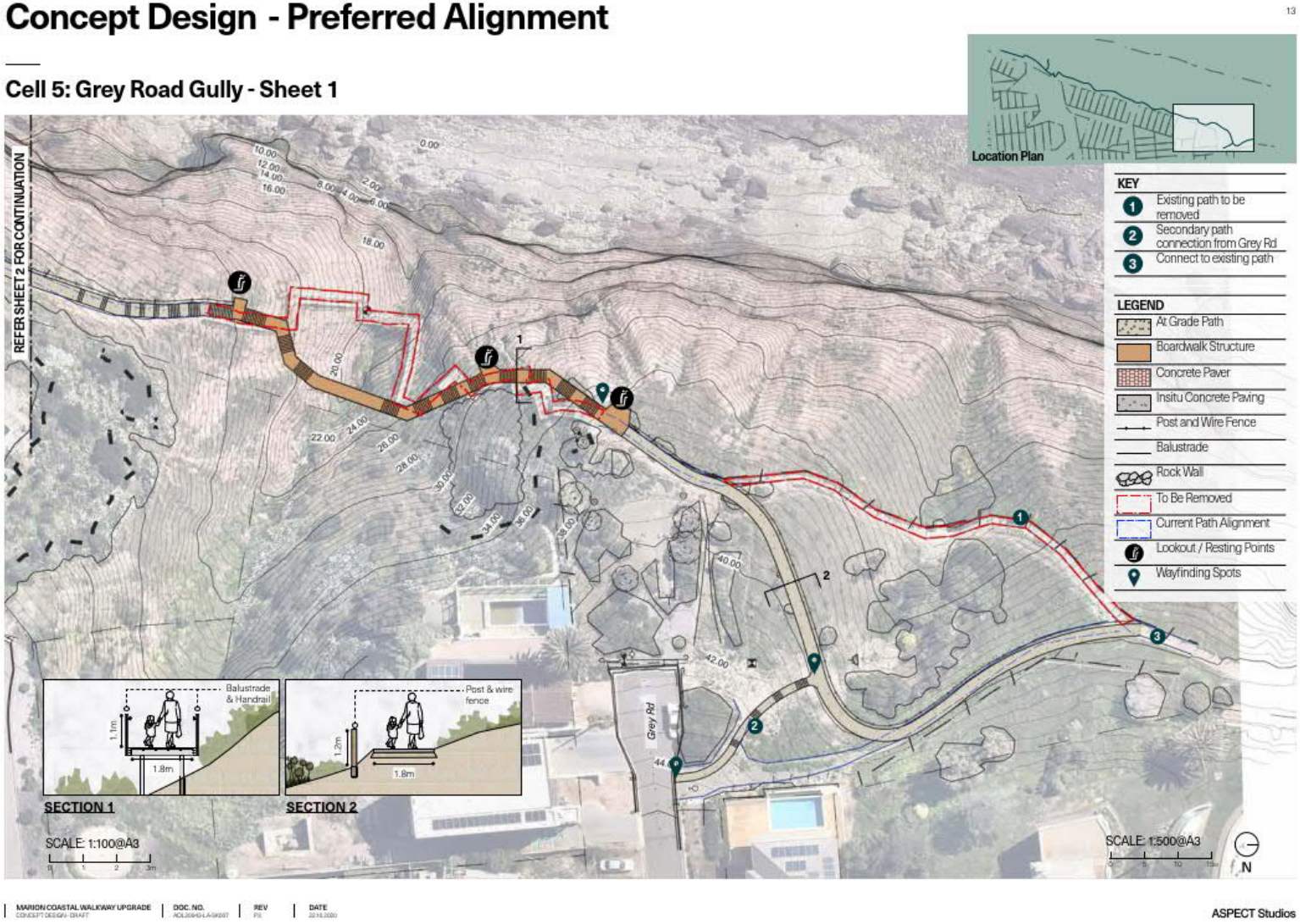


Figure 3: Elevated Board Walk Concept Design Layout by Aspect Studios: Cell 5 – Grey Road Gully Sheet 1



Figure 4: Elevated Board Walk Concept Design Layout by Aspect Studios: Cell 5 – Grey Road Gully Sheet 2

4 SCOPE OF WORK

As detailed in our proposal letter, the instructed scope of work to be conducted by CMW was defined as follows:

- Desk top study of available information relevant to the proposed development.
- Undertake a geotechnical mapping assessment of slope stability and associated risks at the elevated board walk sites.
- Provide an assessment of suitable shallow foundations types and design parameters; and
- Compile all of the above detail into a geotechnical report, incorporating relevant plans, field assessments and parameters.

5 SITE DESCRIPTION

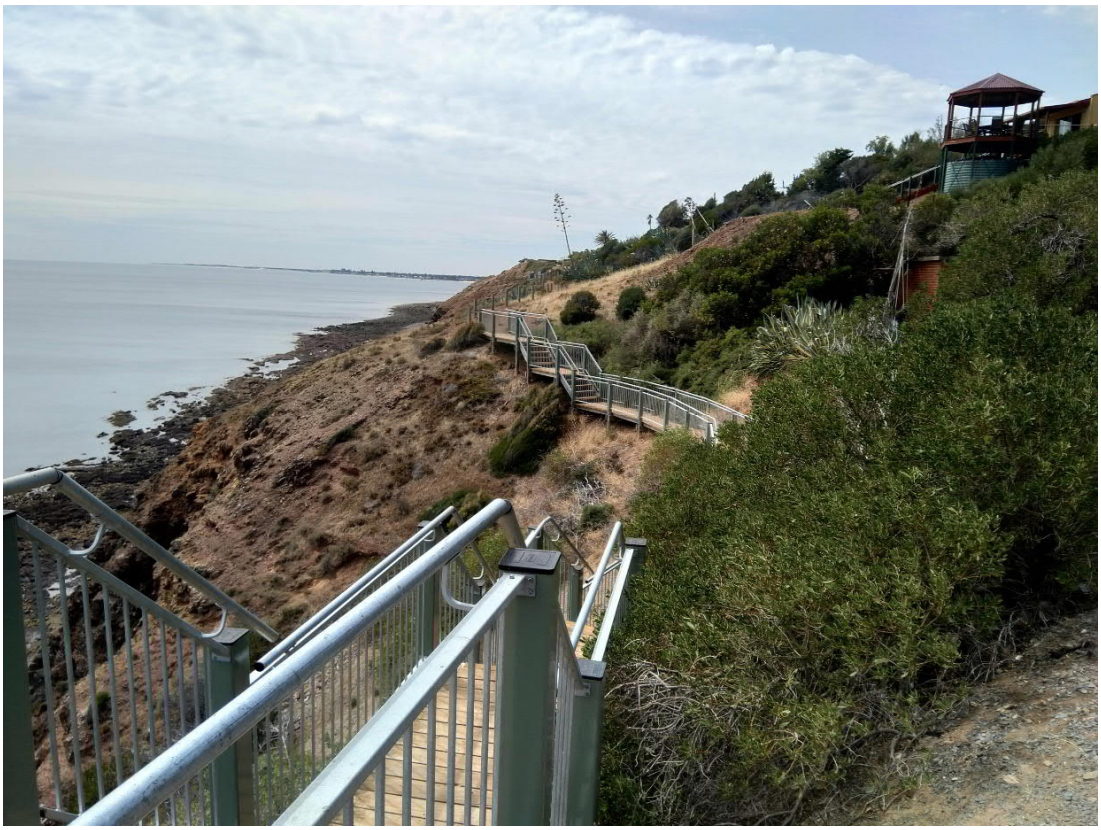
The site is an approximately 250m of walkway stairs between Nungamoora street that crosses Grey Road Gully. In this section there are 2 separate segments. Refer to Figure 3 (Photograph 1 and 2) and Figure 4 (Photograph 3) for the location of these path segments assessed in this report. Each of the segments are steep with reported erosion due to stormwater pipe outlets, hard surface runoff and residential development adjacent or flowing in the path.

There were no observed signs of present or previous landslides in the 2 separate segments of the path.

The existing path has been recently upgraded to include a modern complaint hand rail and upgrades to steps within the path. Refer to Photographs 1 to 3 for images of the existing path.



Photograph 1 -Southern segment of the path. Photograph taken at the bottom of gully facing east



Photograph 2 - Southern segment of the Walkway stairs, photograph taken facing north.



Photograph 3 - Grey Road Gully Walkway stairs, photograph taken facing south

6 GROUND MODEL

6.1 Desk Top Study

Prior to CMW assessing the site, a review of published data and aerial imagery was undertaken.

In our assessment we have considered the elevated path to be separated into a northern and southern segment each with gullies that warrant elevated paths.

Published topographical maps and Figure 3 and 4 show the southern path alignment to be continuous along a gradeline with a constant slope to the west. But the northern alignment travels down and up the steep sided Grey Road Gully. This difference in path creates a greater slope stability risk for the northern path.

Aerial imagery shows no signs of landslides where the path is aligned.

6.2 Regional Geology

Published geological maps on the South Australian Resources Information Gateway (SARIG) indicate that the area is underlain by Tertiary Carisbrooke Sand and sediments of the Ochre Cove Formation (TpQa5). To the south of the project area, it is expected to be underlain by Reynella Siltstone Member (Neer) formation comprising dark red siltstone, sandy to gritty in part, with dolomitic lenses and rare small pebbles. To east and northeast of the site, it is expected to be underlain by Wilmington Formation comprising fine to medium grained grey-green sandstones interlayered with coarse-grained lithic sandstone, grey-green to red-brown siltstone and dolomite, basal conglomeratic beds. Refer to Figure 5 for a reproduction of the SARIG map.

Based on the known history of the site and surrounding land levels, some superficial depths of fill could be anticipated in the southern gully that truncating the existing path.

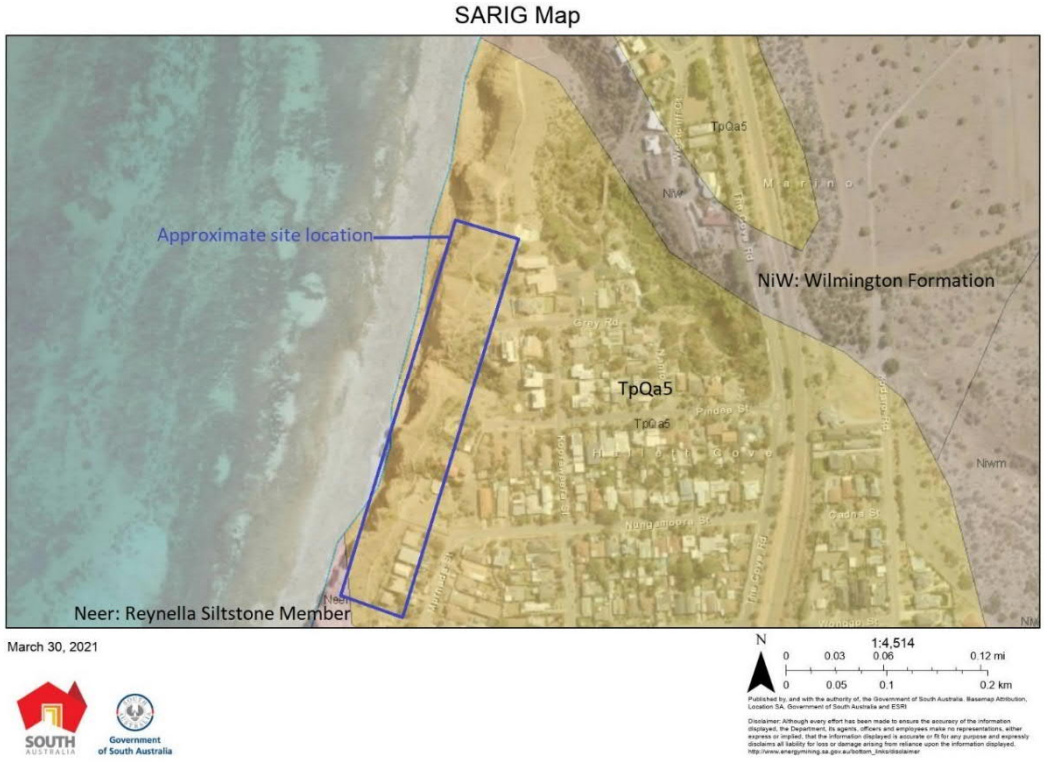


Figure 5: Regional Geological Map overlain on Aerial Imagery

6.3 Site Assessment

CMW undertook a site walkover assessment of the existing boardwalk on 2nd March 2021. In general, the area of the path alignment was embedded into a thin veneer of sandy gravel and there is a good correlation of the observed site conditions with the Regional Geology described in Section 6.2 above.

Where water courses were present, erosional scour of the bedrock was evident, but not significant, indicating that the bedrock is an erosion resistant stratum. But the Tertiary Sand/ Gravel was eroded in places.

Subsurface conditions below the southern portion are:

SANDY GRAVEL (GP) medium to coarse grained, sub-angular to angular, fine to coarse grained sand, red brown, Tertiary Sand.

While conditions below the northern portion are a combination of

SANDY GRAVEL (GP) medium to coarse grained, sub-angular to angular, fine to coarse grained sand, red brown, Tertiary Sand.

And at the base of Grey Road Gully

SILTSTONE (HW – MW) fine grained, laminated, red brown, highly to moderately weathered siltstone. Rock strengths increase and weathering decreases with depth.

7 ELEVATED WALKWAY STRUCTURE GEOTECHNICAL ASSESSMENT

7.1 General

In addition to the topography of the path alignment in Cell 5, the influence of geomorphological processes needs to be considered for the path selection and footing details for the elevated structure.

Cell 5 is influenced by both surface water flow and the coastal environment. Both of these processes impart different rates of erosion. While there is some overlap of these 2 processes for the Cell 5 path, there is a dominant process active in each segment of the path. These are:

- Northern segment: surface water flow; and
- Southern segment: surface water flow.

7.2 Walkway Structure

It is understood the walking trail is composed of steps and a path embedded into the soil or bedrock or be an elevated structure. Both forms of the trail may be impacted by instabilities.

For the elevated structure the following is anticipated

- Relatively light loading - Dead loads (from a wooden structure) and live loads (from pedestrians only).
- Steep slopes with steps and changes in direction of the path, warranting many small footings closely spaced.
- Difficult foundation drilling conditions in gravels or high strength rock resulting is additional footings integrated into the design to ensure sufficient redundancy and load spreading throughout the structural footprint.

7.3 Surface Water Process

For the north and south segments of the site, water flowing through the gully will generate the greatest erosive force that may affect the elevated board walk and walkway.

CMW are not hydrological engineers but we note that the footings to be installed for the elevated board walk need to consider or have protection from the erosive influence of flowing water. It is recommended that the design account for a 1:100 year flooding event.

CMW note the new alignment has a similar risk of slope instability than the existing board walk. However, the option of a potential alternative alignment as shown in Figure 1 is considered a lower risk to slope instability due to surface water flows.

7.4 Coastal Processes

The proposed Cell 5 path alignment only has a minor influence from coastal erosion processes given the short life duration of the elevated structure and the western slope, composed predominantly of high strength rock, adjacent to the path.

7.5 Landslide Risk Assessment

Risk is the combination of the likelihood, the consequences, and the exposure to the hazard in question. All these factors are considered when evaluating a risk and deciding whether treatment is required. The relevant risk assessment principles are described in Standards Australia and Standards New Zealand (1999). The application of these principles to landslide risk management is explained in a succession of Australian Geomechanics Society (AGS) documents, the latest of which is dated 2007.

As a part of the CMW work scope, we provide the following stability assessment based on the qualitative AGS risk assessment process. The qualitative likelihood, consequence and risk terms used in this report are for the risk to property, and notes that help explain the risk assessment and management process, are as presented in Appendix A

The risk assessment and management principles aim to address the following questions for this elevated board walk and walkway in Cell 5:

Scope Definition - What are the issues?

The key issue for this path is the loss of integrity of a group of boardwalk foundations/footings at the same time. This event would pose the highest risk to personnel upon the structure. This would require a landslip over several square meters and the depth of the unstable zone be deeper than the footing for the structure. This would require both soil and rock to become unstable.

Hazard Identification - What might happen?

At worst the elevated boardwalk structure may unravel and any personnel standing upon the structure at that time could slide or fall a significant height to the bottom of the slope. Alternatively, for the at-grade walkway the ground may subside, and a similar hazard could be applicable.

Likelihood - How likely is it?

The distance of potential sliding or falling is greatest at the highest boardwalk elevations. Consequently, the likelihood changes along the alignment. This is also a temporal item so where there is a place of resting or sitting there is a higher likelihood of someone being present and therefore lookouts have a greater likelihood than other sections of the path.

Refer to Drawing 1 for the likelihood assigned for a section of the Cell 5 structure. It has been typically assigned as likely to occur due to the exposure of sand and gravel near to the surface but where rock unlikley.

Consequence - What damage or injury might result?

Damage and injury are also directly related to the distance of sliding or falling. In most cases the consequence to personnel is severe injury or at worst death. The consequence to property would be damage to the path infrastructure which is a considerably lower consequence.

Risk Evaluation - How important is it?

Safety in design is a requirement as defined in Standards Australia. Risks must also consider safety in construction and in the maintenance of the structure.

Risk Treatment - What can be done?

For this project potential ways to treat risk are to control water flow/impacts on the path and to construct more pole footings for the elevated structure and therefore have redundancy in the design. Also, where lookouts are proposed to be constructed additional redundancy in the design should be applied. Or construct the path on a different alignment parallel to the grade of the slope (i.e. potential alternative alignment as shown in Figure 1).

Based on the above considerations, Drawings 1a and 1b provide a risk assessment for the proposed path alignment.

7.6 Foundation Options and Parameters

Based on the nature of the site (i.e. shallow rock cover) it is recommended that shallow pile foundations/rock bolt into the gravel or bedrock be installed for the proposed elevated walkway, assuming the design requires limited lateral load and uplift capacity.

Pad foundations are also considered suitable but also must be embedded and/or pinned into the bedrock and be designed based on the parameters provided in Table 1.

Preliminary indicative shallow pile foundations/rock bolt design parameters are presented in Table 1.

Detailed shallow pile foundations/rock bolt foundation design, including the design geotechnical strength reduction factor (Øg), must be carried out in accordance with AS2159. Based on the level of investigation completed at the site, we recommend that a preliminary conservative geotechnical strength reduction factor (Øg) of 0.42 is adopted. The rock bolt designer must ensure that the design, testing and installation process is consistent with the Øg value adopted with respect to Table 4.3.2(A) of AS2159. The Øg value may be increased where pile testing is carried out preferably prior to or during the initial stages of pile installation. It is noted that the testing may also be used to optimise the pile design at that stage.

As the project is located in an exposed coastal area issues around design life, durability and corrosion protection will be critical factors to consider in the selection, design, detailing and installation of any rock bolt foundation system.

Table 1: Preliminary geotechnical design parameters

Unit	**Depth range (mBGL)**		**Φ' (°)**	**γ** (kN/m^3)	E' (MPa)
GRAVEL	0.0	1.0	32	19	35
SILTSTONE (HW – MW)	1.0	4.0	40	22	120
Where; Φ' = angle of internal friction, γ = bulk unit weight, Su = undrained shear strength, E = Youngs Modulus,					

fs – skin friction stress, fb – end bearing stress and Py – lateral bearing stress values can be assigned following further design information regarding anticipated vertical, lateral and uplift loads.

8 FURTHER WORK

CMW has extensive experience in the design of foundations and would be pleased to offer design support services to review the foundation drawings prior to construction.

9 CLOSURE

The findings contained within this report are the result of limited discrete investigations conducted in accordance with normal practices and standards. To the best of our knowledge, they represent a reasonable interpretation of the general condition of the site. Under no circumstances, can it be considered that these findings represent the actual state of the ground conditions away from our investigation locations.

If the ground conditions encountered during construction are significantly different from those described in this report and on which the conclusions and recommendations were based, then we must be notified immediately.

This report has been prepared for use by Innovis in relation to the Coastal Boardwalk Upgrade, Hallett Cove Cell 5 project in accordance with generally accepted consulting practice. No other warranty, expressed or implied, is made as to the professional advice included in this report. Use of this report by parties other than Innovis and their respective consultants and contractors is at their risk as it may not contain sufficient information for any other purposes.

For and on behalf of
CMW Geosciences

Barry Chau
Project Engineering Geologist

John Slade
Principal Geotechnical Engineer, CPEng

Distribution: 1 copy to Innovis (electronic)
Original held by CMW Geosciences

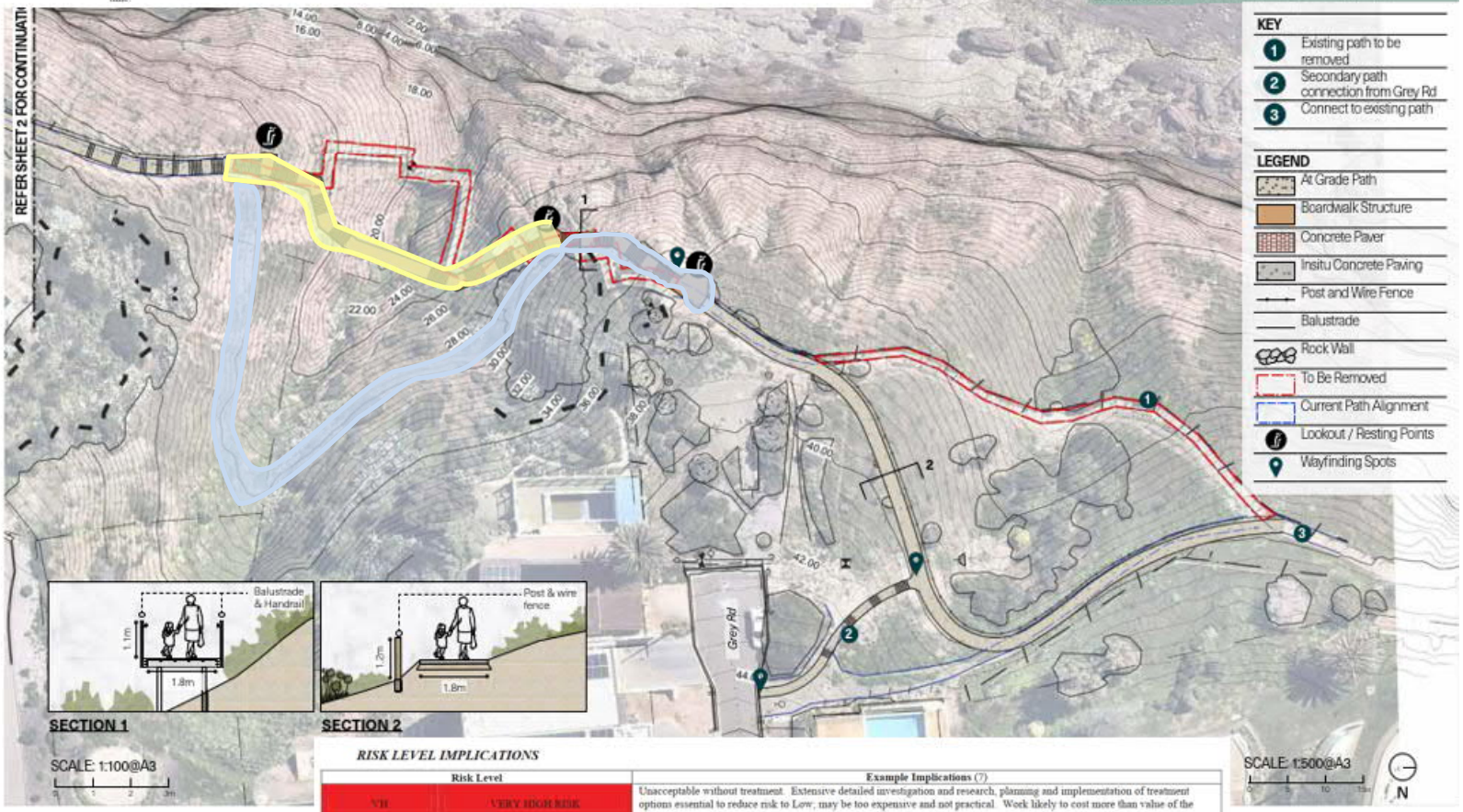
Figure 1 – Risk Plan

QUALITATIVE RISK ANALYSIS MATRIX – LEVEL OF RISK TO PROPERTY

LIKELIHOOD	Indicative Value of Approximate Annual Probability	CONSEQUENCES TO PROPERTY (With Indicative Approximate Cost of Damage) 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.

MARION COASTAL WALKWAY UPGRADE | DOC. NO. | REV

ASPECT Studios

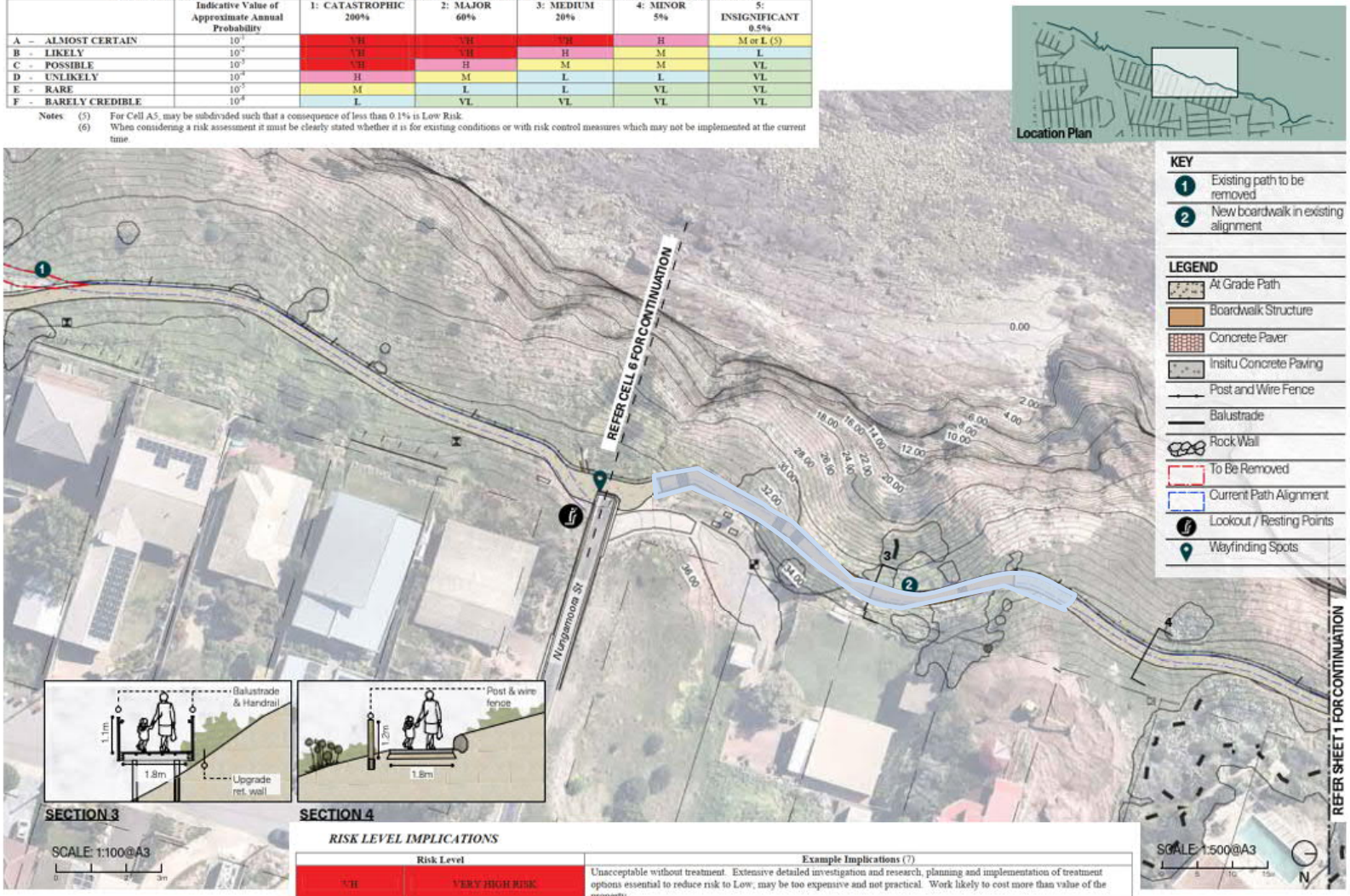
Client:	INNOVIS
Project:	Coastal Walking Trail – Cell 5: Grey Road Gully
Description:	Drawing 1a - Risk Plan
Project No:	ADL2021-00142AE Rev0
Date:	30/03/2020

CMW Geosciences

QUALITATIVE RISK ANALYSIS MATRIX – LEVEL OF RISK TO PROPERTY

LIKELIHOOD	Indicative Value of Approximate Annual Probability	CONSEQUENCES TO PROPERTY (With Indicative Approximate Cost of Damage) 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.
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Client: INNOVIS
Project: Coastal Walking Trail - Cell 5: Grey Road Gully
Description: Drawing 1b - Risk Plan
Project No: ADL2021-00142AE Rev0
Date: 30/03/2020

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Appendix A
AGS Landslide Risk Assessment

PRACTICE NOTE GUIDELINES FOR LANDSLIDE RISK MANAGEMENT 2007

APPENDIX C: LANDSLIDE RISK ASSESSMENT

QUALITATIVE TERMINOLOGY FOR USE IN ASSESSING RISK TO PROPERTY

QUALITATIVE MEASURES OF LIKELIHOOD

Approximate Annual Probability		Implied Indicative Landslide Recurrence Interval		Description	Descriptor	Level
Indicative Value	Notional Boundary					
10^{-1}	$5x10^{-2}$	10 years	20 years	The event is expected to occur over the design life.	ALMOST CERTAIN	A
10^{-2}	$5x10^{-3}$	100 years	200 years	The event will probably occur under adverse conditions over the design life.	LIKELY	B
10^{-3}	$5x10^{-4}$	1000 years	2000 vears	The event could occur under adverse conditions over the design life.	POSSIBLE	C
10^{-4}	$5x10^{-5}$	10,000 years	20,000 years	The event might occur under very adverse circumstances over the design life.	UNLIKELY	D
10^{-5}	$5x10^{-6}$	100,000 years	200,000 years	The event is conceivable but only under exceptional circumstances over the design life.	RARE	E
10^{-6}		1,000,000 years		The event is inconceivable or fanciful over the design life.	BARELY CREDIBLE	F

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

QUALITATIVE MEASURES OF CONSEQUENCES TO PROPERTY

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

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

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

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

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

QUALITATIVE RISK ANALYSIS MATRIX – LEVEL OF RISK TO PROPERTY

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

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

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Risk Level		Example Implications (7)
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VL	VERY LOW RISK	Acceptable. Manage by normal slope maintenance procedures.

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

APPENDIX F- EXAMPLE OF VULNERABILITY VALUES

SUMMARY OF HONG KONG VULNERABILITY RANGES FOR PERSONS, AND RECOMMENDED VALUES FOR LOSS OF LIFE FOR LANDSLIDING IN SIMILAR SITUATIONS

The following table is adapted from P J Finlay, G R Mostyn & R Fell (1999). *Landslides: Prediction of Travel Distance and Guidelines for Vulnerability of Persons*. Proc 8th. Australia New Zealand Conference on Geomechanics, Hobart. Australian Geomechanics Society, ISBN 1 86445 0029, Vol 1, pp.105-113.

Case	Range in Data	Recommended Value	Comments
Person in Open Space			
If struck by a rockfall	0.1 – 0.7	0.5	May be injured but unlikely to cause death
If buried by debris	0.8 – 1.0	1.0	Death by asphyxia almost certain
If not buried	0.1 – 0.5	0.1	High chance of survival
Persons in a Vehicle			
If the vehicle is buried/crushed	0.9 – 1.0	1.0	Death is almost certain
If the vehicle is damaged only	0 – 0.3	0.3	High chance of survival
Person in a Building			
If the building collapses	0.9 – 1.0	1.0	Death is almost certain
If the building is inundated with debris and the person buried	0.8 – 1.0	1.0	Death is highly likely
If the debris strikes the building only	0 – 0.1	0.05	Very high chance of survival

EXAMPLE OF VULNERABILITY VALUES FOR DESTRUCTION OF PEOPLE, BUILDINGS AND ROADS

The following table is adapted from Marion Michael-Leiba, Fred Baynes, Greg Scott & Ken Granger (2002). *Quantitative Landslide Risk Assessment of Cairns*. Australian Geomechanics, June 2002.

Geomorphic Unit	Vulnerability Values		
	People	Buildings	Roads
Hill slopes	0.05	0.25	0.3
Proximal debris fan	0.5	1.0	1.0
Distal debris fan	0.05	0.1	0.3

EXAMPLE OF VULNERABILITY VALUES FOR LIFE FOR ROCKFALLS AND DEBRIS FLOWS FOR LAWRENCE HARGRAVE DRIVE PROJECT, COALCLIFF TO CLIFTON AREA, AUSTRALIA

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

Order of magnitude of landslide crossing road (m^3)	**Rockfalls from Scarborough Cliff**		**Debris flow from Northern Amphitheatre**	
	Landslide hits car	**Car hits landslide**	**Landslide hits car**	**Car hits landslide**
0.03	0.05	0.006	–	–
0.3	0.1	0.002	–	–
3	0.3	0.03	0.001	–
30	0.7	0.03	0.01	0.001
300	1	0.03	0.1	0.003
3,000	1	0.03	1	0.003

NOTE: The above data should be applied with common sense, taking into account the circumstances of the landslide being studied. Judgment may indicate values other than the recommended value are appropriate for a particular case.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

5.3 LANDSLIDE CHARACTERISATION

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

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

5.4 FREQUENCY ANALYSIS

5.4.1 Techniques for Frequency Analysis

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

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

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

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

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

The assessment must document the reasoning in a transparent manner.

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

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

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

c) Empirical methods based on slope instability ranking systems.

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

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

d) Relationship to geomorphology and geology.

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

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

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

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

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

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

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

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

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

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

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

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