8 April 2021

COASTAL WALKWAY UPGRADE
CELL 6 – KURNABINNA GULLY
HALLETT COVE, SA 5158

GEOTECHNICAL ASSESSMENT REPORT

Innovis

ADL2020-0142AF Rev0

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1 EXECUTIVE SUMMARY

This report presents the results of a geotechnical site assessment carried out at Kurnabinna Gully Hallett Cove, Adelaide, SA, with regards to the City of Marion's renewal plan for the Coastal Walking Trial Cell 6.

Based on the assessment results within the area of Cell 6, 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). The risk to landslide has been considered to be low for most of the path alignment except the lookouts where the risk is assigned as Moderate. Additional erosive forces impacting the walking trail/path are surface water flow and tidal activity.

The existing boardwalk footings and our experience suggest that shallow rock anchors would be most suitable in the bedrock expected on site to maximise the benefit of the insitu bedrock. Details of appropriate shallow 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 6. The scope of work and associated terms and conditions of our engagement are as detailed in our services proposal letter ADL2020-0142AA, Rev0 dated 28 May 2020.

Included herein is our report and recommendations pertaining to 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 6 (Kurnabinna Gully), which includess a combined at grade and elevated boardwalk, from Peera Street in the south to Nungamoora Street. 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.

It must be noted that, 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.

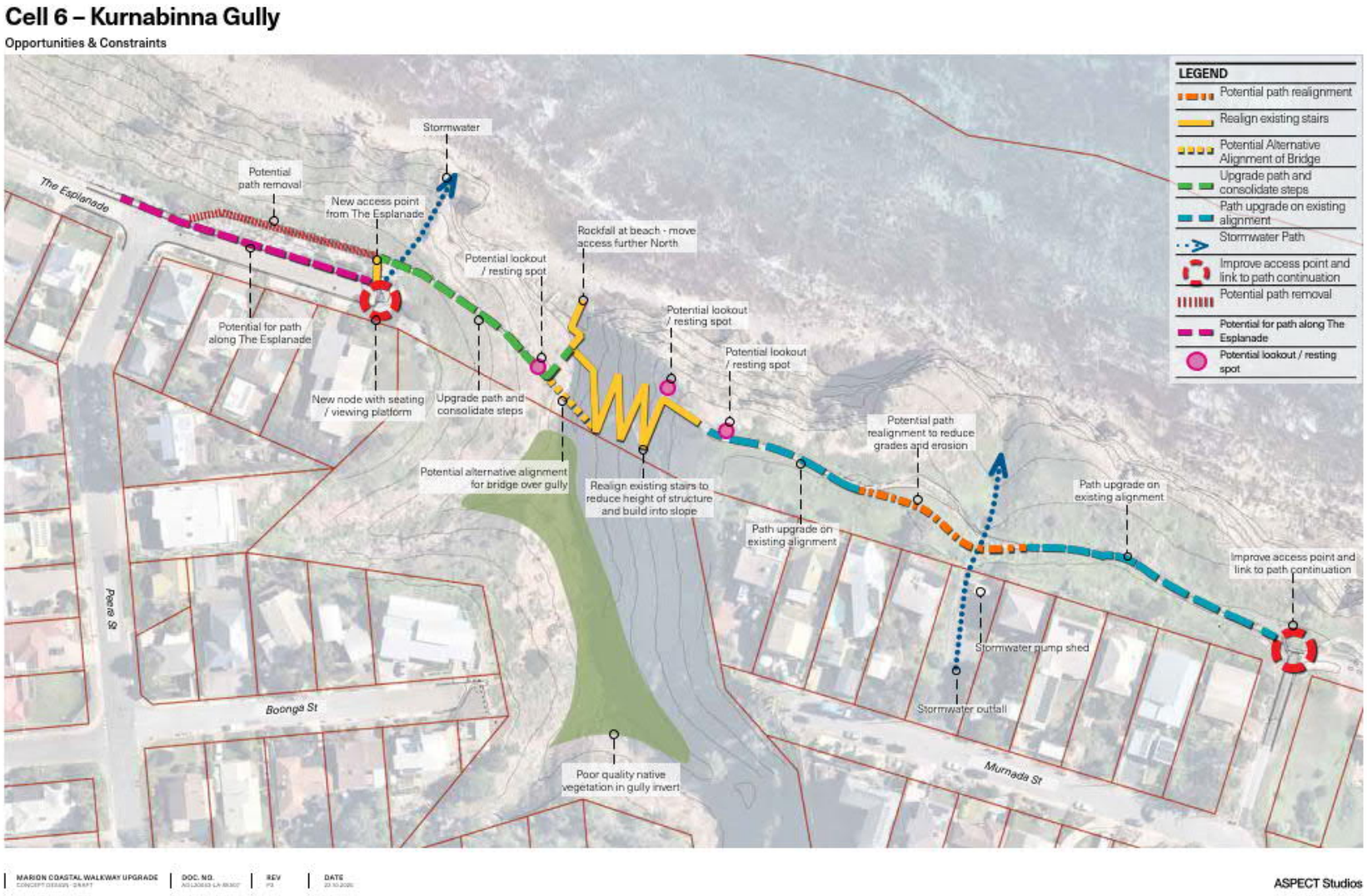


Figure 1: Overall Concept Design by Aspect Studios - Cell 6 – Kurnabinna Gully

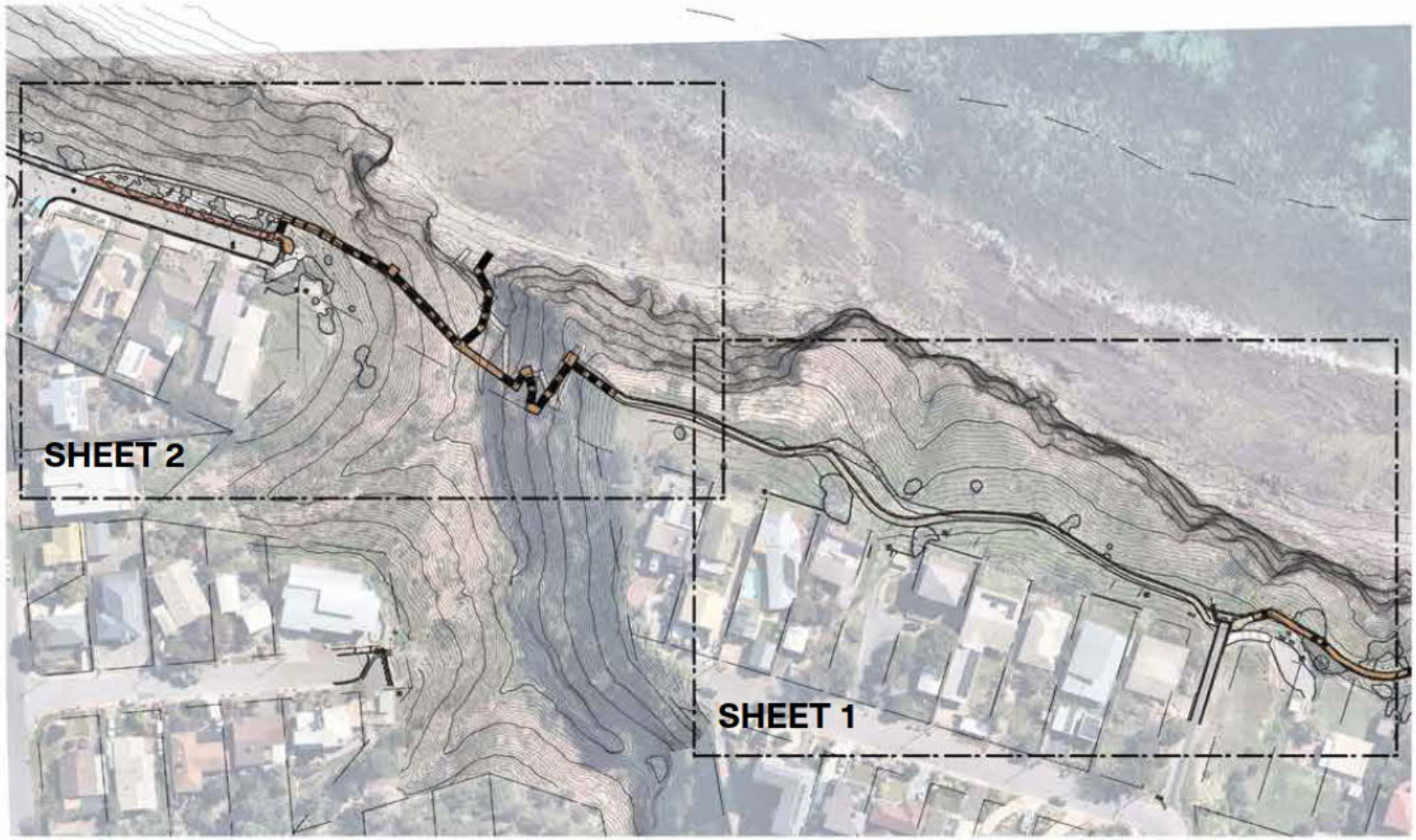


Figure 2: Elevated Board Walk Concept Design Layout by Aspect Studios - Cell 6 – Kurnabinna Gully

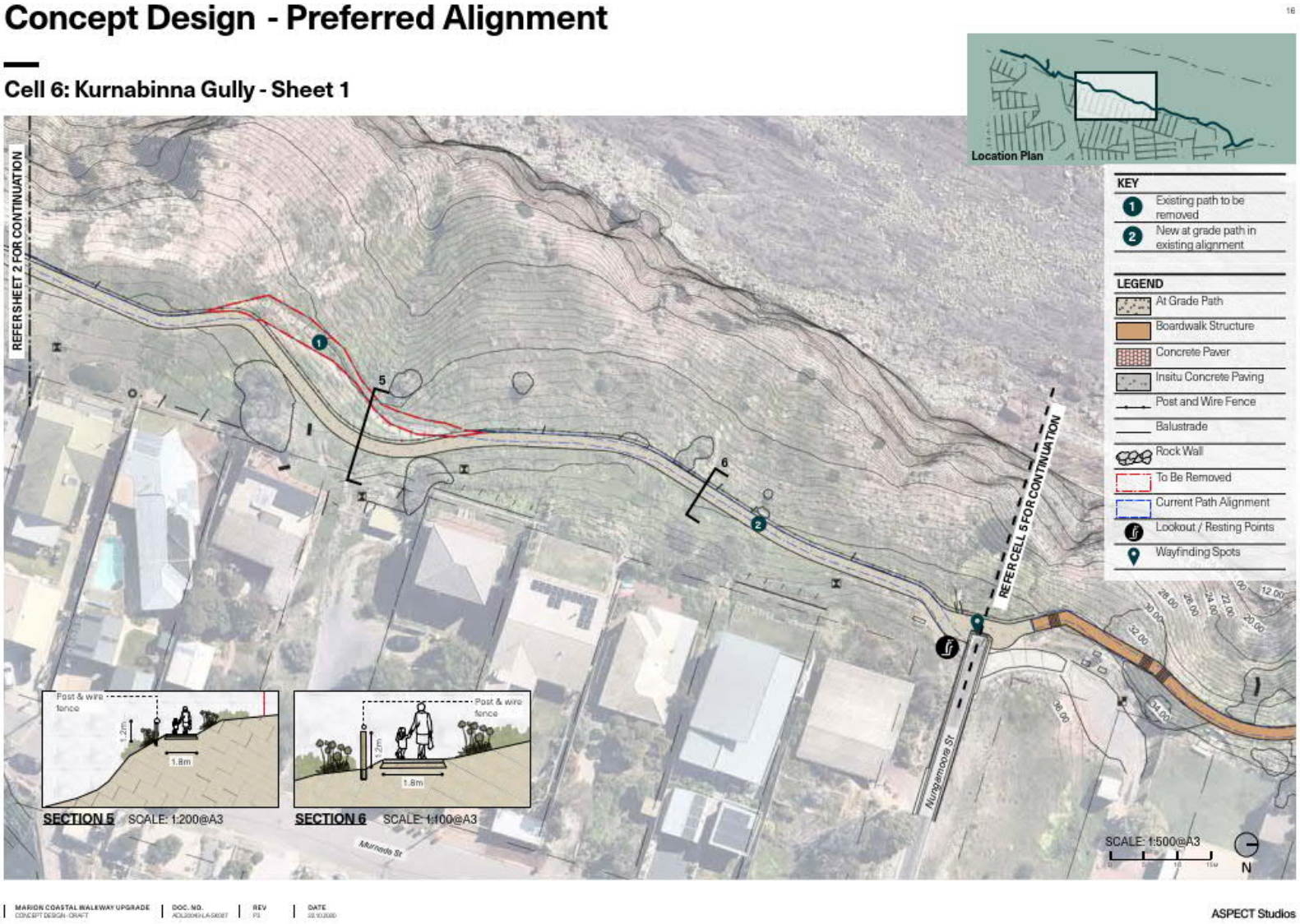


Figure 3: Elevated Board Walk Concept Design Layout by Aspect Studios: Cell 6 – Kurnabinna Gully Sheet 1

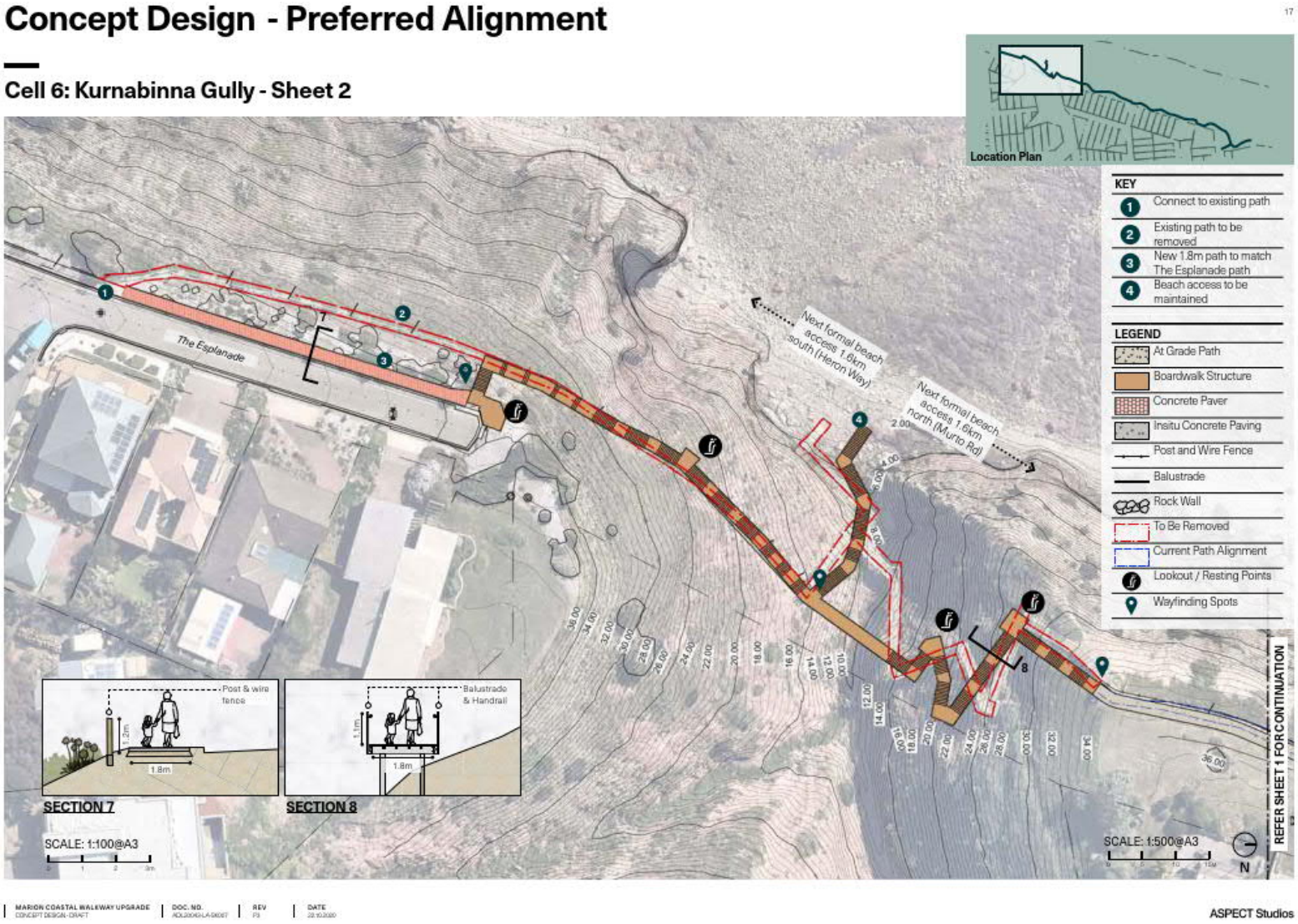


Figure 4: Elevated Board Walk Concept Design Layout by Aspect Studios: Cell 6 – Kurnabinna Gully Sheet 2

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 450m in length from Nungamoora street to the Esplanade adjacent to Peera Street. Truncating the path is the Kurnabinna Gully. This gully is steep with rock exposed in the lower slopes of the gully and creek alignment. To the east of the path a stormwater pipe outlet provides seasonal water flow through the creek.

Previous studies have noted erosion concerns of the gully due to surface runoff. Also, sections of the south western existing board walk cliff face, at the level of wave action, have previously shown signs of rock toppling/instability.

There were no observed signs of present or previous landslides in the area of the path.

The existing path has been recently upgraded to include a modern design compliant handrail and upgrades to steps within the path. Refer to Photographs 1 to 4 for images of the existing path.



Photograph 1 - Kurnabinna Gully, photograph taken facing south. Note the distance of the walkway from the edge of the cliff and the outcropping rock.



Photograph 2 – View looking north at the Kurnabinna Gully. A walkway existing to the south and an elevated boardwalk existing to the north.



Photograph 3 - Boardwalk stairs, photograph taken from bottom of gully, facing east. Note the ground surface in this area is all outcropping rock.



Photograph 4 - Boardwalk and Walkway path, photograph taken from bottom of gully facing east. Note: to the right of the boardwalk there are some boulders that have fallen off the cliff slope.

6 GROUND MODEL

6.1 Desk Top Study and Previous Assessments

Prior to CMW assessing the site, a review of published data, aerial imagery and previous work by the author at the site was undertaken.

In our assessment we have considered the path to be composed of 3 segments: a northern, western and southern alignment.

Published topographical maps show the alignment of the footpath to be located upon slopes of consistent grade to the north and south within the Kurnabinna Gully. Refer to Figure 4 for a topographical plan of the site. The exception being a short sub-vertical section at the base of the boardwalk where the gully meets the wave cut platform within the western alignment of the path.

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

Previous assessments by the author at the site have noted that small scale instabilities had impacted the lower section of the western board walk. These localised failures have indicated the western cliff faces are metastable. Instabilities have been caused by long term wave action at the base of the cliff incrementally eroding and undermining the cliff and weathering/erosion of the blocky rock mass due to the coastal environment and flora and fauna activity. However, no signs of large-scale global slope landslides were evident on these western cliff slopes.

6.2 Regional Geology

Published geological maps on the South Australian Resources Information Gateway (SARIG) indicate that the area is underlain by the Reynella Siltstone Member (Neer) formation comprising dark red siltstone, sandy to gritty in part, with dolomitic lenses and rare small pebbles. Refer to Figure 5 for an image extracted from the published map. Abounding the project area, it is expected that the area is underlain by Seacliff Sandstone (Nss), which is characterized by pale to medium grey quartzite and sandstone, with medium grained and variably cross bedded and lesser reddish siltstone with local thin dolomitic beds.



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 residual soils or highly to moderately weathered siltstone bedrock. Also, only a thin covering of grasses and small plants were present upon the walls of the gully where a thin soil horizon was present. Refer to Photograph 2 for an image of the distribution of exposed rock and grasses. Therefore, 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.

In the areas of the proposed new board walk, similar geological conditions persist.

The soil units exposed at the surface of the Gully, within the footprint of the old and the new path, are generalised according to the following subsurface sequence:

GRAVEL (GP)	medium to coarse grained, sub-angular to angular with fine to coarse grained sand considered as residual soil to extremely weathered siltstone.
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 6, the influence of geomorphological processes needs to be considered for the path selection and footing details for the elevated structure.

Cell 6 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 6 path, there is a dominant process active in each segment of the path. These are:

- Northern segment: surface water flow.
- Western segment: coastal process at the bottom of the structure and surface water at the top portion of the structure ; 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 maybe 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 conditions in high strength rock resulting is additional footings integrated into the design to ensure sufficient redundancy and load spreading throughout the structural footprint.

7.3 Coastal Processes

Consideration of ongoing coastal processes should be made in assessing the appropriate foundation system for the elevated walkway structure at the western segment of the site. CMW note the new alignment is a more sustainable and lower stability risk location than the existing board walk. This is because there is a reduction in the length of the path exposed to the potential of rocks falling from the western cliff faces.

Figure 6 provides an illustration of the erosive processes active upon cliffs exposed to tidal activity. Tidal activity, in particular wave activity, erodes rock or soil at the base of the cliff (Section A of Figure 6). Over time, erosion removes material from the base of a coastal bluff and steepens the face of the bluff (Section B). Continued erosion may overcome the rock or soil material strength, and result in a landslide (Section C). A landslide restores the equilibrium of the cliff, and the slumped materials at the foot of the cliff support a new cliff face with a gentler profile (Section D). Eventually, erosion again destroys the equilibrium of the cliff and leads to another landslide, repeating the cycle shown below.

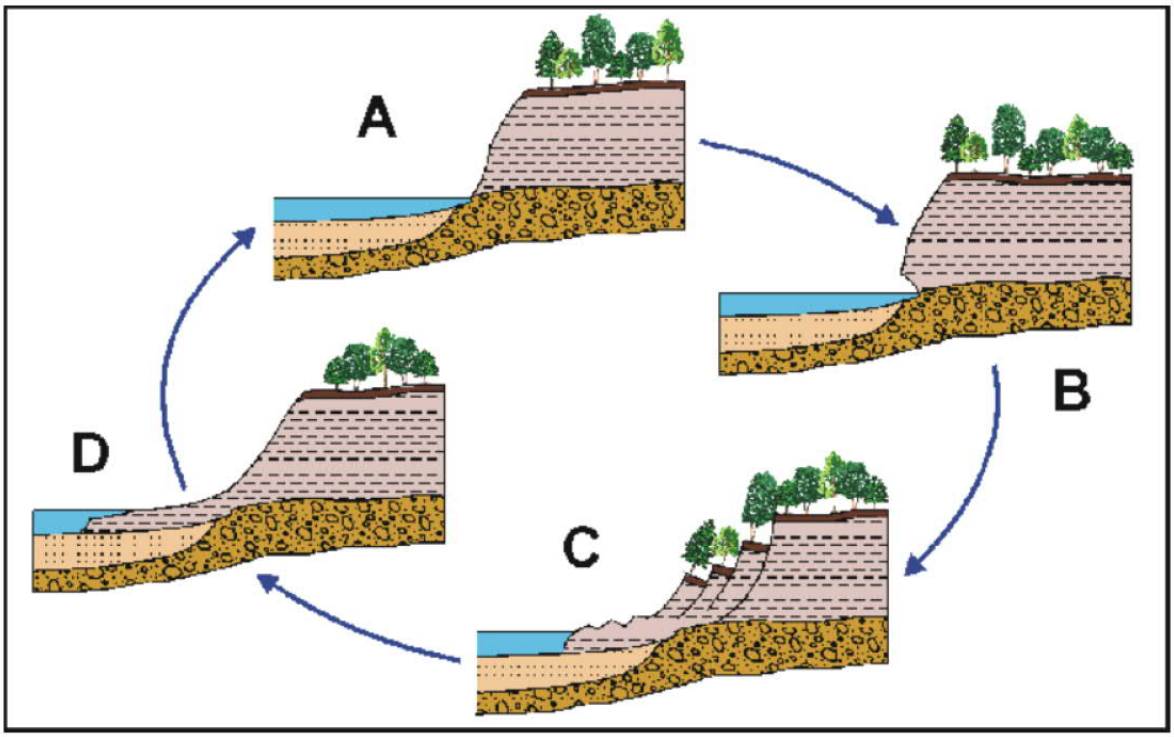


Figure 6: Life cycle of a landslide composed of sediment (modified from Kelley and others, 1989)

7.4 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.

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 for 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 6:

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 need to a landslip of 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 6 structure. The likelihood has been typically assigned as unlikely to occur due to the exposure of competent rock near to the surface.

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.

Refer to Drawing 1 for the consequence assigned for a section of the Cell 6 structure. The consequence to property has been typically assigned as minor to occur due to the estimated small area that would be effected from an anticipated landslide.

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.

Based on the above considerations, Drawing 1 provides 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 rock bolt foundations into the 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 rock bolt design parameters are presented in Table 1.

Detailed 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	0.4	30	15	5
SILTSTONE (HW – MW)	0.4	4.0	40	20	100
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, later and 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, Kurnabinna Gully Cell 6 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.

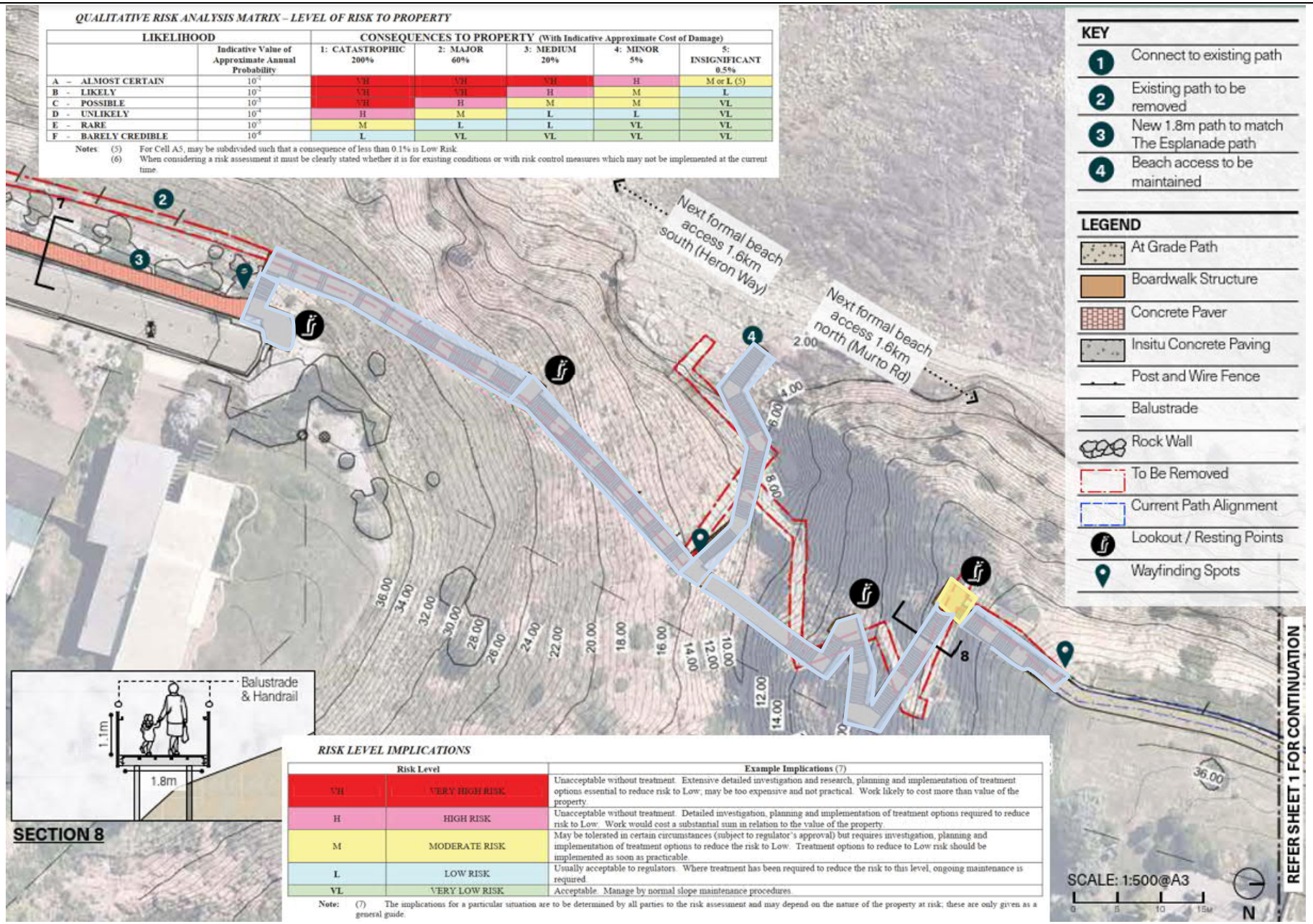
For and on behalf of
CMW Geosciences

Barry Chau
Project Engineering Geologist

John Slade
Principal Geotechnical Engineer, CPEng

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

Drawing 1 – Risk Plan



Client:	INNOVIS
Project:	Coastal Walking Trail – Cell 6 Kurnabinna Gully
Description:	Drawing 1 - Risk Plan
Project No:	ADL2021-00142AF Rev0
Date:	7/04/2020

CMW Geosciences

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.

RISK LEVEL IMPLICATIONS

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

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

APPENDIX 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