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Report on
Geotechnical Assessment
Longwalls W1 and W2, Picton

Prepared for
Tahmoor Coal Pty Ltd

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Report on Geotechnical Assessment

Longwalls W1 and W2, Picton

1. Introduction

This report presents the results of a geotechnical assessment undertaken for the Extraction Plan prepared for Longwalls (LW) West 1 (W1) and West 2 (W2). The report provides a high level slope stability risk assessment and outlines the monitoring program for the surface features within the area of study. The investigation was commissioned in an email dated 16 May 2019 by Ron Bush of Tahmoor Coal Pty Ltd (Tahmoor Coal) and was undertaken in accordance with Douglas Partners' proposal WOL190014.P.003 dated 11/05/2019. It is understood that this information is required by Tahmoor Coal as part of application for the Extraction Plan for LW W1 and W2.

It is understood that the development of roadways along LW W1 has commenced and it is proposed to commence longwall mining of LW W1 in October 2019. LW W1 and W2 panels are in the Western Domain of Tahmoor Mine

It is anticipated that the site will be subjected to surface subsidence caused by the longwall mining that may have impacts on the surface features lying within the Study Area, as outlined on Figure 1.

The purpose of this assessment is to identify and assess the surface features such as clifflines, steep slopes and farm dams, which may be influenced by the longwall mining. A risk assessment of these features along with a monitoring program and Trigger Action Response Plan (TARP) are discussed in the document.

This report is based on a high-level study conducted for the area; and a detailed assessment will be required to be undertaken in future to evaluate the features which are currently inaccessible.

2. Scope of work

The aim of this Geotechnical Assessment for LW W1 and W2 was to assess the potential risks to identified land features and recommend monitoring programs to manage these features during the mining of LW W1 and W2. The study is divided into following parts:

- Summarise the geology and geomorphology;
- Review the studies related to subsidence and its impact on surface features for LW W1 and W2;
- Identify and classify the landform features based on failure potential;
- Conduct a risk assessment of these features and identify the likely consequence of such instability; and
- Outline a monitoring program and TARP.

This study is applicable to identified surface features such as steep slopes, cliff line features and farm dams within the Study Area. The Study Area is demarcated as the surface area located within the 20 mm predicted subsidence contour and/or 35^0 angle of draw from the extents of LW W1 and W2 (Figure 1).

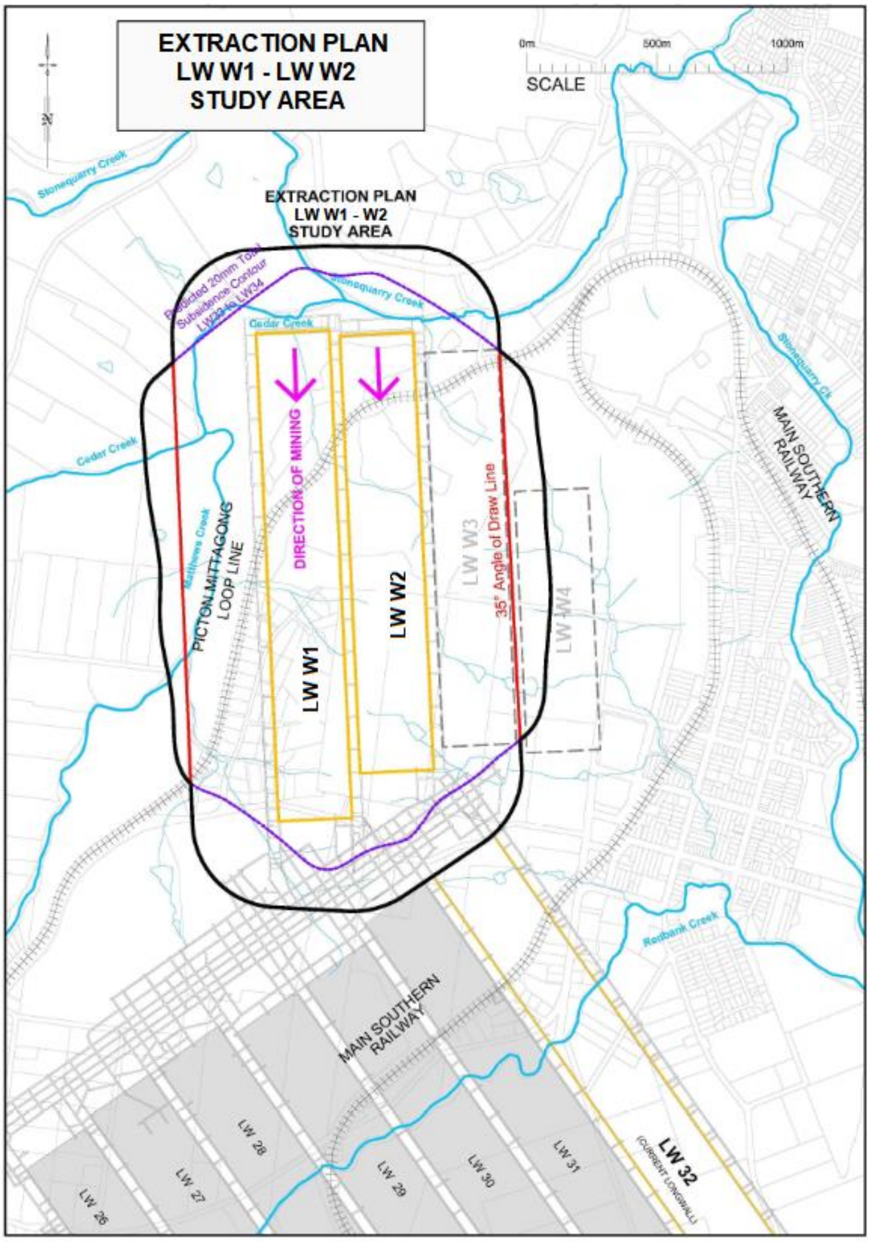

Figure 1: Study Area for subsidence effect on land features

The site contains the Picton – Mittagong heritage railway loop line that is the subject of a separate geotechnical assessment.

3. Site Location

The Tahmoor Mine is located approximately 75 km south of Sydney in the Township of Tahmoor, New South Wales (NSW). The LW W1 and W2 are located to the north of Tahmoor. The Tahmoor Mine is operated by Tahmoor Coal and produces a primary hard coking coal product and a secondary higher ash coking coal product that are used predominantly for steel production. The mine has used longwall mining methods since 1987.

Tahmoor Coal has mined 31 longwall panels in the area and is in the process of extraction of LW32 in accordance with Development Consent (DA 67/98) and Subsidence Management Plan Approvals.

Tahmoor Coal proposes to extend underground coal mining to the north-west of the Main Southern Railway at Picton and Thirlmere into the Western Domain and are preparing an Extraction Plan for the extraction of LW W1 and W2. These longwall panels are located between Matthews, Cedar and Stonequarry Creeks in the western and northern side, respectively. The panels are planned to the west of Picton township (Figure 2).

3.1 Mining Geometry and Topography

The foot print of LW W1 and W2 is shown in Figure 2. Both the longwalls are 283 m wide (including workings) with a 39 m wide chain pillar in between. The total length of each longwall is 1875 m and 1685 m for LW W1 and W2, respectively, and extracting the Bulli Seam from north to south. The extraction height is proposed to be 2.1 m. The Bulli Seam dips towards the north east with an average gradient of 5% across the mining area. Based on the seam floor contours as shown in Figure 3, the lowest level is around -310 m AHD. The depth of cover directly above the proposed longwall varies between a minimum of 455 m above the commencing end of LW W1 and a maximum of 535 m on the eastern edge of LW W2.

The surface level contours of the study area indicate that the highest point of topography is 286 m above Australian Height Datum (m AHD) at the southernmost corner (Figure 4). The surface topography is moderately hilly with valleys and ridges with the lowest level being 166 m AHD at Stonequarry Creek towards the north. The surface area is primarily used for rural residential and residential development with properties used for housing, pet farms, stock grazing and orchards. Water is obtained generally from the town water supply and to a degree from farm dams or groundwater bores.

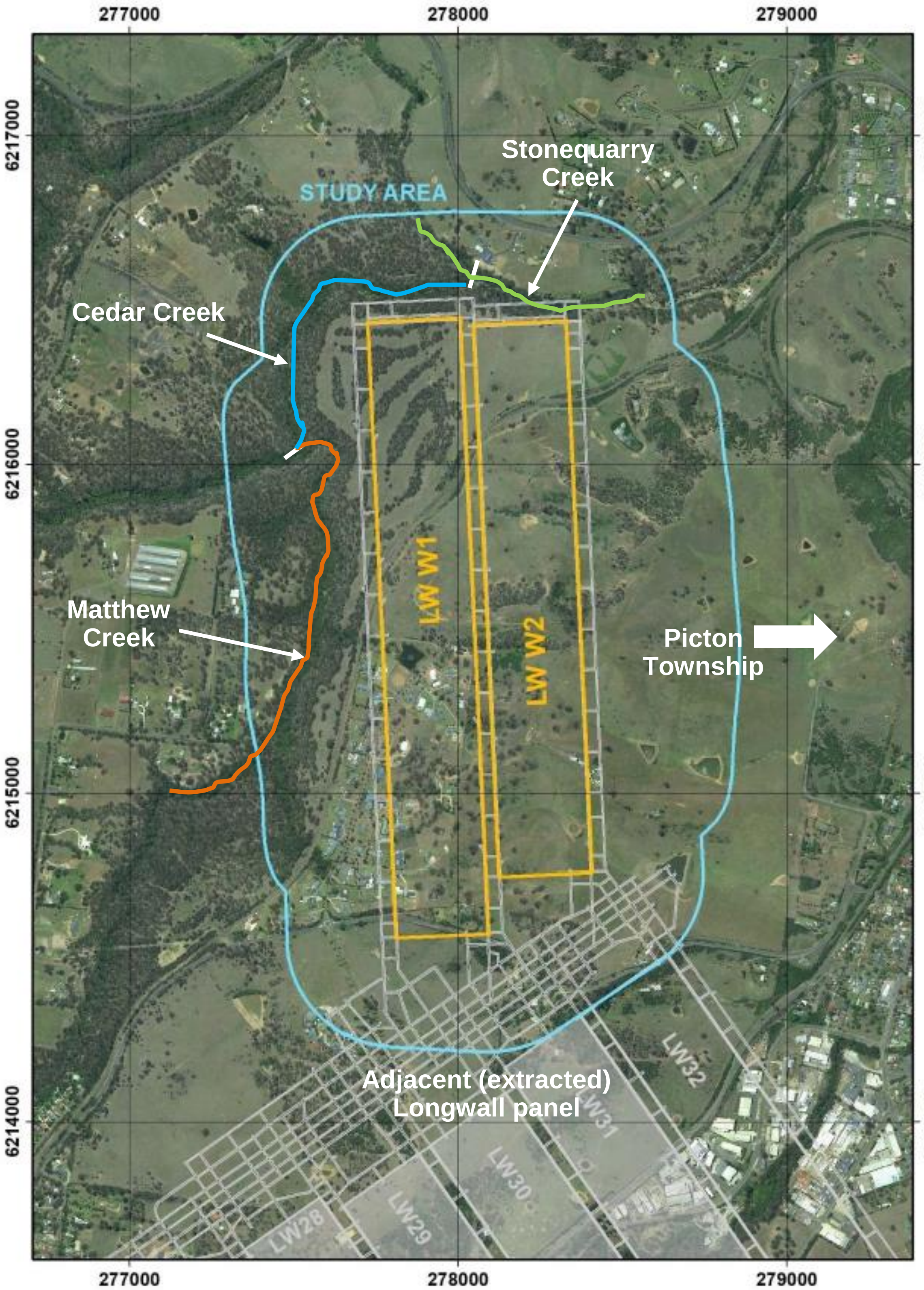

Figure 2: Location of Longwall panels LW W1 and W2 (Courtesy MSEC report, 2019)

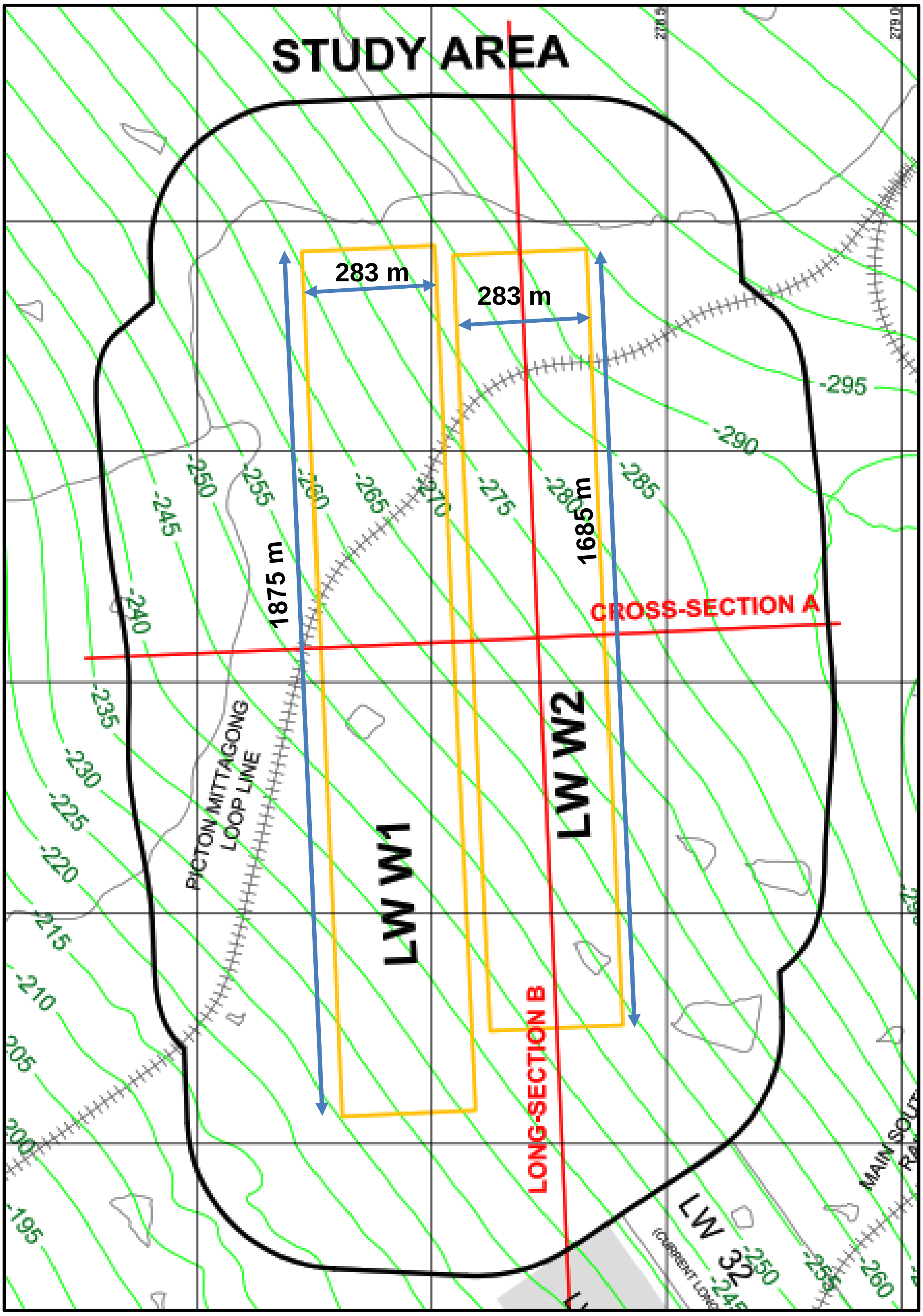

Figure 3: Bulli seam floor contours (Courtesy MSEC report, 2019)

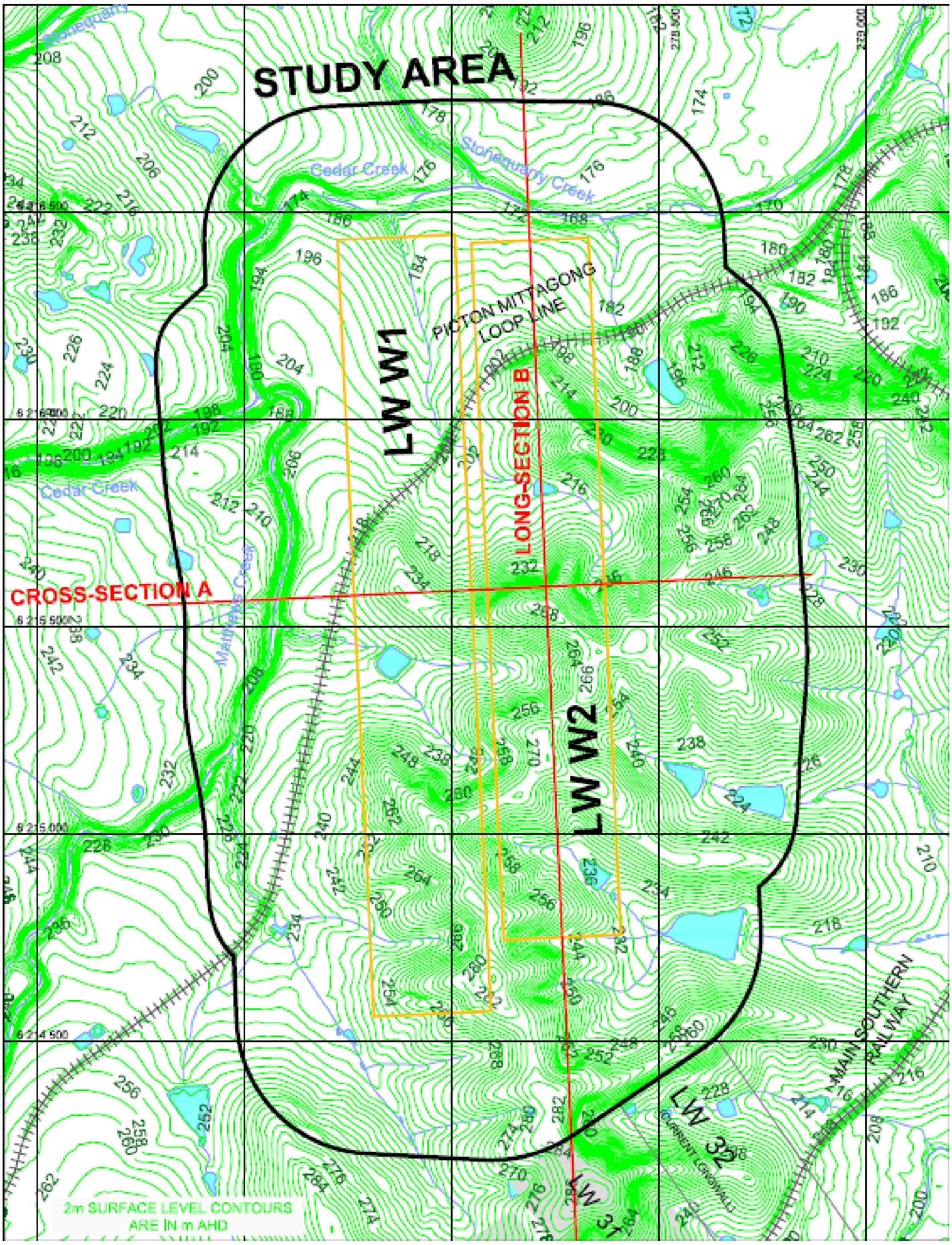

Figure 4: Surface topography contours and farm dams (Courtesy MSEC report, 2019)

3.2 Geological Setting

The Permo-Triassic Sydney Coal basin extends roughly 300 km along the coast of New South Wales and inland for a distance of up to 200 km. The principal coal-bearing sequence in the Southern Coal Field of the Sydney Basin is the Illawarra Coal Measures which consist of four coal seams. The uppermost seam is the Bulli Seam which has been extensively mined in the northern part of the coalfield.

The Bulli Seam is immediately overlain by the Narrabeen Group which consists of a series of major sandstone and shale units. The Wombarra Shale and Coal Cliff Sandstone form the immediate and main roof, respectively. The Wombarra Shale consists of siltstones and form the thin interbeds of fine-grained sandstone. The Coal Cliff Sandstone comprises medium grained sandstone with thin beds of grey shale and shaly sandstone. Overlying the Narrabeen Group is the Hawkesbury Sandstone, a series of bedded sandstone units which date from the Middle Triassic and which has a thickness of up to 185 m. Much of the ground surface is underlain by Ashfield Shale of the Wianamatta Group having thickness of a few tens of metres. The Wianamatta Group is underlain by the Mittagong Formation which consists of interbedded shale, laminite and fine grained sandstone underlain by medium grained Hawkesbury Sandstone. These crops out along the incised and downstream sections of the creeks. The typical stratigraphic section in the study area is shown in Figure 5.

The Ashfield Shale forms the upper surface of the study area, which is deeply dissected by numerous streams exposing sandstone of Hawkesbury Sandstone formation. Incision tends to follow the dominant joint directions in the rock, i.e., northwest and northeast, and it is possible that this influences the orientation of the long axis of the valley in which the creeks are found. The sandstone rocks tend to break up into large blocks due to weathering along the joint planes and sub-horizontal bedding planes.

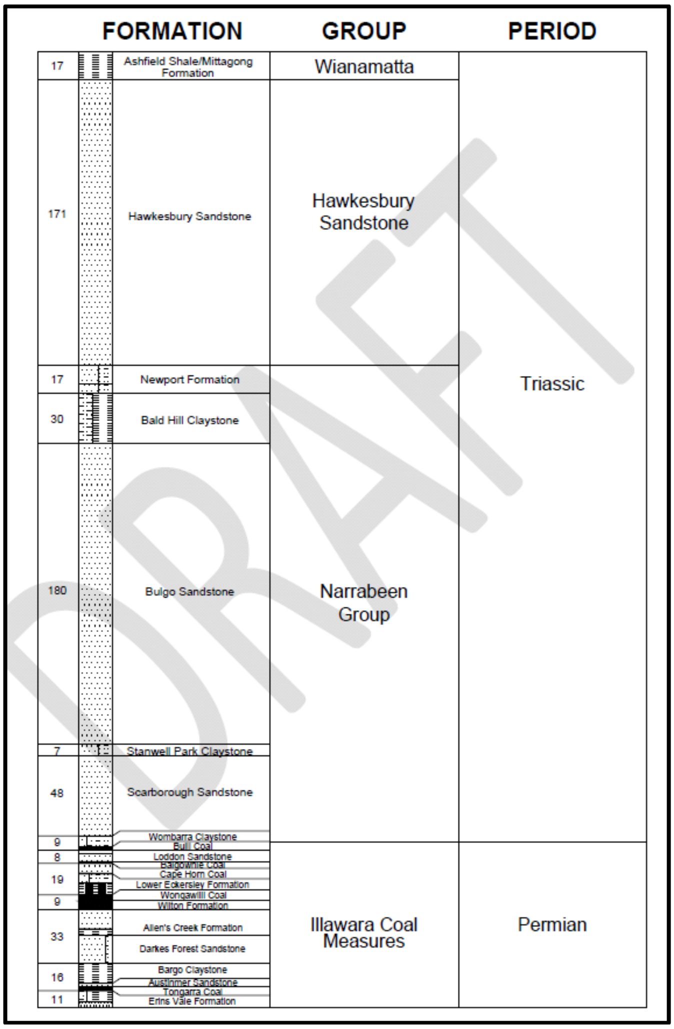

Figure 5: Typical Geological stratification at Tahmoor (Courtesy MSEC report, 2019)

4. Relevant Data Available for Review

4.1 Reports, Drawings and Data bases

Tahmoor Coal provided copies of reports and data from a number of previous investigations, conducted as part of the ongoing planning and operation of the longwall panels. These include:

- GeoTerra report titled "Longwall Panels 31 to 37 - Streams, Dams & Groundwater Assessment";
- WRM Water & Environment Pty Ltd report titled "Matthews Creek Catchment Flood Impact Study for LW W1-W2";
- GHD report titled "Landslide risk assessment of identified 'steep slopes' principally affected by retreat of LW 28";
- GHD report titled "Landslide risk assessment of identified 'steep slopes' specific properties in environs of LW 32";
- Glencore report titled "Tahmoor Colliery – Longwall 30 – First 300 m of extraction, Management Plan for Potential Impacts on Dam at No. 2990 Remembrance Drive";
- HEC Pty Ltd titled "Tahmoor Mine Extraction Plan LW W1 – W2 – Surface Water Technical Report";
- GHD report titled "Tahmoor Colliery Subsidence impact upon 'steep slopes' over LW 24 to LW26";
- SCT report titled "Tahmoor Coal – Investigation into the Potential impact on the Nepean Fault on Subsidence adjacent to LW 32; and
- MSEC report entitled "Subsidence Predictions and Impact Assessments for Natural and Built Features due to the extraction of the Proposed Longwalls W1 and W2 in support for the Extraction Plan Application".

4.2 Survey

Tahmoor Coal have undertaken a LIDAR survey of the Study Area to identify various surface features. The topographical as well as subsidence contour profiles for the planned and adjacent longwall panels discussed in this report are based on the information in the reports provided by Tahmoor Coal and MSEC.

4.3 Summary of Data reviewed

The following comments are based on the data review with regards to subsidence:

- The predicted subsidence results due to extraction of LW W1 and W2 (studies on calibrated numerical model by MSEC) are reported in Table 1.

Table 1: Predicted subsidence details for LW W1 and W2 (MSEC report, 2019)

Longwall	Maximum predicted total subsidence (mm)	Maximum predicted total tilt (mm/m)	Maximum predicted total hogging curvature (km^{-1})	Maximum predicted total sagging curvature (km^{-1})
LW W1	475	3.0	0.03	0.06
LW W2	750	5.5	0.06	0.11

- Gale and Sheppard (2011) reported significantly higher displacements (nearly twice) than the predicted subsidence results in Longwall 24A. This abnormality was suggested to be due to the weakening of rock material due to weathering, causing reduction in spanning capacity of the weathered section.
- The predicted maximum total strains in the study area likely to be experienced at any time during mining are given in Table 2.

Table 2: Details of predicted maximum strains for survey bays during extraction of LW W1 and W2 (MSEC report, 2019)

Longwall	Above goaf		Above solid coal	
	Compressive strain (mm/m)	Tensile Strain (mm/m)	Compressive strain (mm/m)	Tensile Strain (mm/m)
95% confidence level	1.8	1.0	0.7	0.5
99% confidence level	3.4	1.6	1.0	0.8

- There are no rivers within the study area. The closest river is situated more than 3 km south-east of LW W1-W2, beyond the zone of subsidence influence
- The NSW Government's Strategic Review (DoP, 2008) recommended that risk management zones (RMZs) be applied to all streams of third order or above, in the Strahler stream classification. Three creeks, i.e., Matthews, Cedar and Stonequarry Creeks are partly located within the study area. The details of these creeks are given in Table 3.

Table 3: Details of the Creek

Water body	Strahler stream order within study area	Total length within the study Area (km)
Matthews Creek	Third and fourth order	1.14
Cedar Creek	Fourth and fifth order	1.30
Stonequarry Creek	Fourth and fifth order	0.93

- These creeks are predicted to undergo low-levels of vertical subsidence, but are not expected to experience measurable conventional tilts, curvatures or strains. The predicted effects of subsidence on the creeks are shown in Table 4:

Table 4: Details of the Creek (MSEC, 2019)

Water body	Longwall	Maximum predicted total subsidence (mm)	Maximum predicted total upsidence (mm)	Maximum predicted total closure (mm)
Matthews Creek	After LW W1	70	50	120
	After LW W2	90	90	170
Cedar Creek	After LW W1	40	90	130
	After LW W2	60	160	180
Stonequarry Creek	After LW W1	< 20	30	30
	After LW W2	60	90	60

- The mining-induced changes in grade along these creeks are predicted to be negligible and unlikely to cause adverse impacts due to increased levels of ponding, increased levels of scouring of the banks for changes in stream alignment. The maximum predicted compressive strain due to valley closure effects is 6 mm/m based on the 95% confidence level.
- It is anticipated that due to the ephemeral nature of the streams and the generally low flow volumes in the creeks, the effects will be localised around the point of discharge and will not adversely affect the overall water quality discharging out of the Study Area. Based on observations from the already mined out panels, it was reported that groundwater levels may reduce by up to 15 m and may stay at that reduced level until maximum subsidence develops at a specific location. It is anticipated that groundwater levels will generally recover over a few months to a year or so as the secondary void space is recharged by rainfall infiltration.
- Based on the bores in the study area, it was reported that the Hawkesbury Sandstone generally provides low yielding aquifers with low hydraulic conductivities, whilst the Wianamatta Shale does not provide a groundwater supply. Groundwater is obtained from the Hawkesbury Sandstone with yields ranging up to 6.6 L/sec from aquifers located 21 m to 161 m below surface. Permeability is more variable vertically than horizontally and is extremely variable in the Hawkesbury Sandstone.
- In total 11 cliffs were identified within the study area. The cliffs and rock outcrops have predominantly developed in the Hawkesbury Sandstone. The exposed rock faces demonstrate various stages of weathering or erosion, with many overhangs and undercuts. The list of these cliffs and maximum predicted total vertical subsidence is reported in Table 5:

Table 5: Predicted subsidence on Cliff lines (MSEC, 2019)

Reference	Valley	Maximum predicted total vertical subsidence (mm)	Far field horizontal movements with 99% confidence (mm)
C_M01	Matthews Creek	100	200
C_M02		80	185
C_C01		< 20	110

Reference	Valley	Maximum predicted total vertical subsidence (mm)	Far field horizontal movements with 99% confidence (mm)
C_C02	Cedar Creek	< 20	115
C_C03		40	145
C_C04		30	140
C_C05		40	158
C_C06		50	172
C_C07		30	160
C_C08		30	157
C_C09		< 20	167

- The identified cliffs along the creeks are predicted to experience tilts up to but generally less than 0.5 mm/m (i.e. 0.05%, or 1 in 2000). The maximum predicted total hogging and sagging curvature was reported to be less than 0.01 km^{-1}. The cliffs and minor cliffs are located on the valley sides and, therefore, they are not expected to experience the upsidence or compressive strains that will occur near the bases of the valleys.
- Based on 1 m surface level contours that were generated from the LIDAR survey of the area, natural steep slopes were reported along the banks of Matthews, Cedar and Stonequarry Creeks. Natural steep slopes are also located on the sides of ridges above the proposed longwalls, where the near surface lithology is part of the Wianamatta Shale. Steep slopes such as dam walls, embankments and cutting faces were also identified by the survey.
- Nearly 46 structures, including eleven (11) houses, twenty one (21) rural structures and thirteen (13) Public utilities were identified. The maximum predicted tilt for the steep slopes within the study area was reported to be 5.5 mm/m (i.e. 0.55%, or 1 in 180). The natural surface grades (1 in 3) are steeper than the predicted changes in grade due to mining. No slope instabilities were reported in adjacent mining areas. Soil cracking up to 65 mm wide was reported on both the upper banks and flanks of Myrtle Creek at one location above Longwall 23B. The cracks extended into the soil to depths of approximately 1.5 m to 2.0 m and over a length of approximately 40 m.

5. Studies conducted

The subsidence due to longwall mining of LW W1 and W2 could result in surface cracking, heaving, buckling and stepping which can influence various landscape features. DOP (2008) provided a comprehensive summary of the range of potential mine subsidence effects on the environmental management techniques. It recommends that a subsidence RMZ be defined around sensitive features within the mining lease before subsidence occurs. Out of the various features mentioned in DOP (2008), this study focusses on cliff lines, steep slopes and farm dams. The location of these features is considered to be the first step in managing prediction uncertainties and potential impacts associated with subsidence. The final step is to identify the methods of monitoring and mitigation in order to reduce the subsidence effect to 'repairable level' or to as low as practicable. The features within the Study Area are assessed in the following sections of this report.

Due to the High Level nature of assessment, it was decided to adopt a risk management approach to evaluate the impact of subsidence on the features. The features to be assessed are very distinct in nature and hence the approach also varied. The cliff lines were analysed through the procedure presented in ACARP C9067 (Subsidence Impacts on River Valleys, cliffs, Gorges and River System). The procedure recommended by Australian Geomechanics Society publication "Practice Note Guidelines for Landslide Risk Management 2007" (AGS 2007) was used to evaluate steep slopes. Two different approaches were used since ACARP C9067 specifically provides tools to evaluate the influence of underground excavation, whereas, AGS 2007 focusses on the effect on slope instability on property and human life. The farm dams are evaluated using the Small Dam Consequence Screening tool (DEPI, 2014).

5.1 Definition of cliffs and steep slopes

The survey and Lidar data of the surface within the study area identified site features such as water bodies, cliffs and steep slopes. As per the Landslide Risk Management Guidelines prepared by the Australian Geomechanics Society (AGS, 2007), the definitions of cliffs and steep slopes are as under:

- Cliff – Slope appears vertical and ranges between 64° and 84°;
- Extreme Slope – need rope access to climb slope and ranges between 45° and 64°;
- Very Steep Slope – Can climb by clutching at vegetation. Rocks etc and ranges between 27° and 45°;
- Steep Slope - Walkable with effort and ranges between 18° and 27°;
- Moderate Slope - Walkable and ranges between 10° and 18°; and
- Gentle Slope - Easy walking and ranges between 0° and 10°.

In order to incorporate the effects of mine subsidence on the landscape features and maintain consistency with impact assessment methodology used on cliffs and slopes, Table 6 was adopted in this report based on the precedents in other coal fields with similar mining conditions and surface conditions. The Study Area consists of cliffs, rock outcrops, steep slopes and is devoid of any pinnacles.

Table 6: Definition of terminology used to describe surface features

Feature	Definition by geometry	Impacts due to subsidence
Cliff	A continuous rock face, including overhangs, greater than 20 m in length, a minimum height of 10 m and a minimum slope of 2V:1H (> 63.4°)	Tilting and cracking resulting in collapse of overhangs, wedge and toppling failures; rock fall roll outs, felling trees and public safety hazards. Permanent landscape changes.
Minor cliff	A continuous rock face, having a minimum length of 20 m, heights between 5 m and 10 m and a slope greater than 2V:1H (>63.4°) or a rock face having a maximum length of 20 m and a height between 10 m and 20 m.	Tilting and cracking resulting in collapse of overhangs, wedge and toppling failures; rock fall rollouts, felling trees and public safety hazards. Temporary landscape changes.
Cliff terrace	A combination of two to five minor cliffs in close proximity, which results in a stepped surface profile. The average slopes between upper and lower cliffs range between 50° and 60° with a cliff height of 10 m and 25 m.	Tilting and cracking resulting in collapse of overhangs, wedge and toppling failures: rockfall outs, felling trees and public safety hazards. Temporary to permanent landscape changes.

Feature	Definition by geometry	Impacts due to subsidence
Rock outcrop	A discontinuous rock face (<20 m in length) having heights < 5 m and slope > 63.4°	Tilting and cracking resulting in collapse of overhangs, wedge and toppling failures: rock fallouts, felling trees and public safety hazards. Temporary landscape changes.
Very Steep Slopes*	An area of land having a gradient of between 1V:1H (45°) and 2V:1H (63.4°). This includes precariously located boulders fallen from cliffs..	Tilting and cracking resulting in landslip failures; felling trees and public safety hazards, Permanent to temporary landscape changes.
Steep Slopes+	An area of land having natural gradient ranging between 18.4° and 45° (1V:3H to 1V:1H). This includes precariously located boulders fallen from cliffs.	Tilting and cracking resulting in landslip failures; felling trees and public safety hazards. Permanent to temporary landscape changes.

* Very steep slopes are generally located within cliff line terraces.

+ Steep slopes generally exist below the cliff terraces, minor cliffs and rock outcrops and extend for 100 m or more

5.2 Field work

Site inspections of the landscape features within the study area were undertaken by a Principal along with a Senior Geotechnical Engineer on 28 May 2019 and 6 June 2019. The team undertook a walk-through in the Study Area for the current scope of works. Due to the constraints of accessibility and lack of permissions from land owners, only parts of features were observed, and, in some areas, the inspection was undertaken at a distance from the feature. The Study Area comprises cliff lines, steep slopes, residential structures and farm dams. The aim of these site inspections was to become familiar with site conditions and identify the following:

- Features of the cliff rock faces related to risk of boulders or rock blocks dislodging and toppling;
- Steep slopes overlying the LW W1 and W2 panels and assessing the consequence of landslide on property and human life; and
- Location of farm dams and assessing the probable impacts of dam breaks.

The major natural features within the Study Area are Matthews Creek, Cedar Creek and Stonequarry Creek. A walk-through along Matthews Creek, Cedar Creek and Stonequarry Creek was conducted to identify the potential area for rock fall and slides. These creeks are ephemeral, meandering watercourse flowing from south to north and west to east located along the west and northern side of the LW W1 and W2 panels. These creeks appear to be third to fourth order streams. There are few shallow ponds located within the creek beds on the general flood plain. A walk-through was also conducted for identifying houses and other structures which may be under risk due to steep slope failure. Since the physical access to the residential structures and private property was not permitted, structural evaluation was not possible. The information from previous survey data and LIDAR was also studied.

The various features were identified and presented in the following sections. There are a number of farm dams located above the mining panel. These farm dams are basically man-made structures and rely on rainfall for their impoundment. These farm dams are about 2 m to 3 m in height and appear to have been constructed by forming shallow embankments across dry valleys. Digital photographs of the cliffs steep slopes were recorded, and details are provided in Appendix B.

There are numerous slopes overlying the LW W1 and W2 as shown in Figure 4. There are several residential houses which have been constructed along the slopes at different levels. These slopes can generally be classified into gentle to moderate slopes with very few slopes that would be considered as steep slopes.

5.3 Assessment of subsidence impacts on Cliff lines

Subsidence can trigger slope failure in the form of local rock face instability due to tilting and bending of the rock mass beds. Overhangs and joint planes are particularly susceptible to collapse leading to rock falls and toppling failures. The cliffs along Matthews Creek and Cedar Creek are susceptible to natural rock falls caused due to weathering by undercutting of shale beds. Weathering of more clayey sandstone beds has also contributed to localised overhang development.

5.3.1 Mechanism of slope instability in Cliffs

Creeks and cliffs are formed by the process of weathering and erosion. The cliff face contains rocks with differing strengths and competency. It is well known that the horizontal stress is higher than the vertical stress at shallow depth in the Sydney Basin. As cliff faces start forming, by downcutting of creeks, the rock dilates due to stress relief, moving towards the valley on the lower strength bedding planes. This stretches the more competent rock and eventually causes it to fracture in tension. These, generally vertical tension fractures, form normal to the direction of stress relief. If the valley wall is uniform, the fracture pattern is usually parallel with the valley. When side valleys intersect the main valley, the fracture pattern near the intersection will have a tangential direction. The spacing of these fractures is a function of the competency and thickness of the beds within shales and sandstones. The steeply dipping joints next to the cliff faces open up due to the expansion of rock layers under influence of horizontal stresses both across and parallel to the valley. The valley wall continues to yield under this process, until the mass of stressed relieved rock is large enough to confine the underlying rock. The stresses concentrated beneath the valley floor are relieved by bulging of the valley floor. The possible failure mechanism in the bottom of a valley includes bulging, wedging and shear on low angle discontinuities (Hutchinson, 1987). Horizontally bedded layers under the valley floor bend upwards and horizontal voids within them are filled with depositional materials (Figure 6).

In more plastic, shaly rocks, the rock slowly weathers to clay. On steep slopes, practically during or following periods of heavy and/or continuous rainfall, the build-up of a perched water table within the clayey soils reduces the shear strength of the material leading to downhill creep or landsliding of the clay soil on either inclined planes near parallel to the slopes or on a circular failure surfaces.

During the extraction of longwall panels, the immediate roof collapses into the goaf, forming a zone of collapse (highly fractured) above the extracted area. This zone extends up to a height of about 5 times the seam thickness above the seam in the case of competent strata. Above this collapse zone, a fractured zone characterised by significant cracking and bed separation is formed. The fractured zone can extend up to about 20 times the seam thickness in a competent rock mass. Above this zone, the rock mass beds are in compression, devoid of large scale cracks. The rock mass permeability in different zones varies as per the development of cracks, with insignificant change in permeability in the compression zone. There is a possibility of surface strata cracking due to subsidence induced bending strains which tend to increase the permeability of the surface strata in the tensile zone. Bed separation may occur at some locations causing dilation of the strata, which could link to drainage paths.

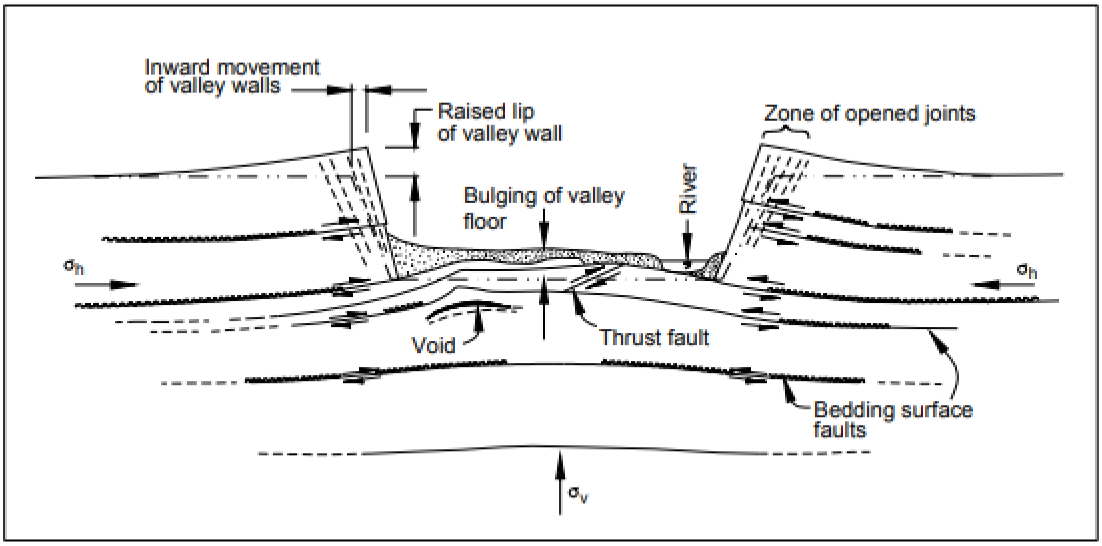

Figure 6: Development of valley structures due to high in situ horizontal stress

The high in-situ horizontal stress in the surface strata tends to close tension cracks, occurring due to subsidence induced movements and reduce the impact on the structure. The movements along cliffs and slopes can be a combination of following components:

- Normal mining-induced horizontal movements on the surface, around an extracted panel, as subsidence occurs towards the centre of the extracted goaf area;
- Upsidence and closure of creeks due to valley bulging, caused by redistribution of in-situ stress as mine subsidence occurs;
- Horizontal displacements of surface strata due to release and redistribution of pre-existing regional in situ stress as goaf area increases in size; and,
- Slippage movement in a downhill direction due to topographic factors.

5.3.2 Identification of structures

There was no line of sight to the cliffs and steep slopes along the creeks from roads. No dwellings or man-build structures were present along these creeks. On the day of inspection, Matthews Creek, Cedar Creek and Stonequarry Creek had recorded very shallow levels of surface water.

Aerial laser scanning (LIDAR survey) data was used to develop a visual digital terrain model (DTM) of the topography and landscape features in the underground mining area. The Matthews Creek, Cedar Creek and Stonequarry Creek extend for an approximate length of 3 km lying to the west and north of the proposed longwalls. The surface topography along Stonequarry Creek classifies as steep to very steep slopes with few outcrops whereas cliffs having face angles of between 65° and 80° and heights up to 30 m were observed in Matthews and Cedar Creek. These cliffs generally consist of blocky to thinly bedded Hawkesbury Sandstone of medium to high strength. The exposed rock faces are variably weathered with many overhangs and undercuts.

Bedrock is exposed at a number of places along the water courses. The outcrops are jointed. The hydrology of the creek is controlled by both overland flow and inflow from ground water. Should subsidence cause surface cracks within the creek bed, it could change flow paths and potentially cause local loss of surface flows. However, the mining has been laid out to prevent extraction from directly below these creeks.

The summary of cliffs located in the Study Area is given in Table 7 and their locations are shown on Figure 7. Reference structures C_C01 and C_C02 are located beyond the Study Area but are located within the 600 m zone and have been included within Table 7.

Table 7: Details of Cliffs along Matthews Creek and Cedar Creek (MSEC report, 2019)

Reference	Valley	Distance from panels (m)	Maximum height (m)	Overall length (m)	Maximum predicted total vertical subsidence (mm)
C_M01	Matthews Creek	100	10	21	100
C_M02		145	10	23	80
C_C01	Cedar Creek	535	13	57	< 20
C_C02		515	16	33	< 20
C_C03		315	11	35	40
C_C04		335	15	73	30
C_C05		260	11	24	40
C_C06		205	12	49	50
C_C07		250	11	24	30
C_C08		260	12	29	30
C_C09		210	12	55	< 20

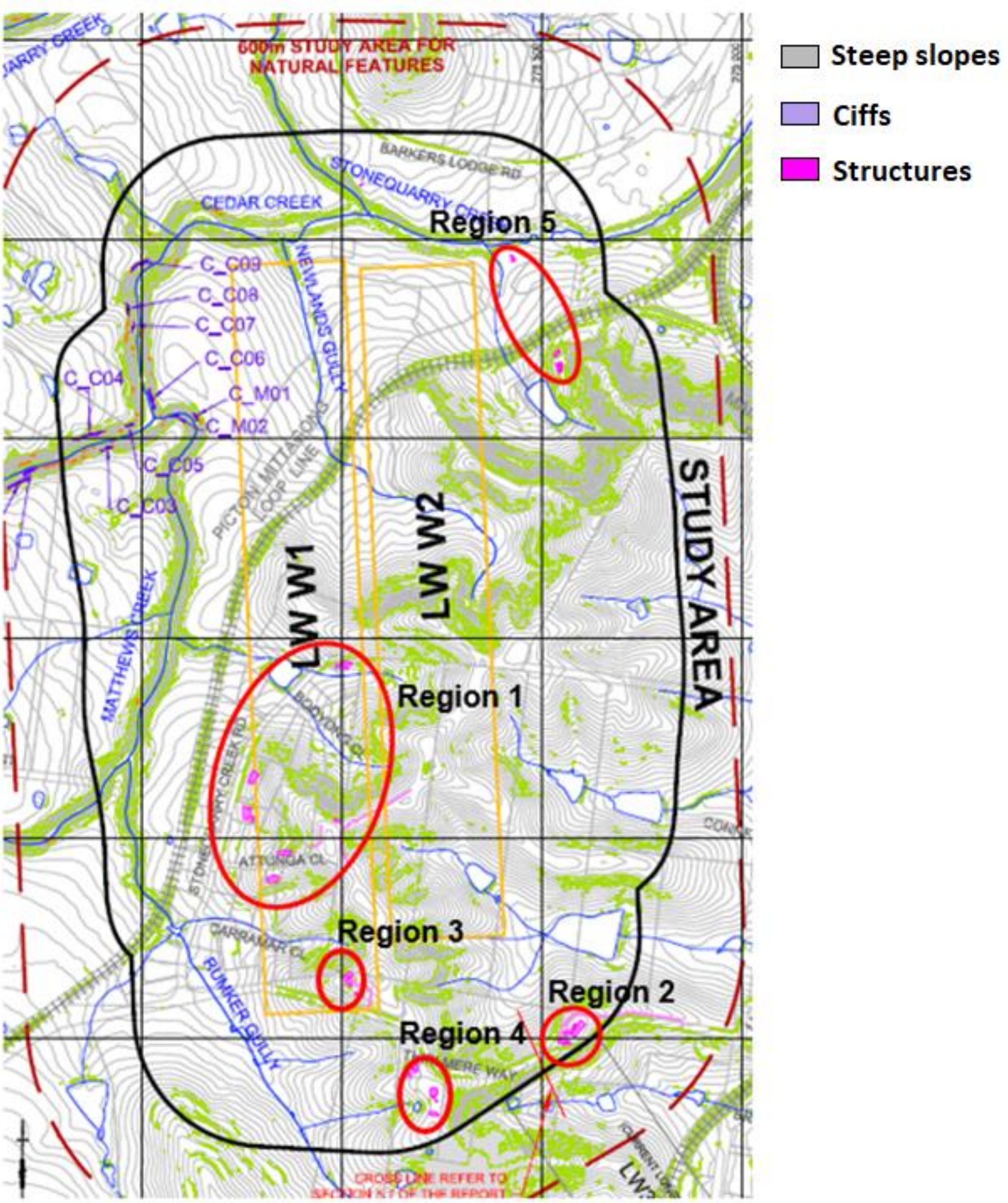

Figure 7: Location of cliffs and structures in the study area (MSEC report, 2019)

5.3.3 Risk assessment

ACARP (2002) rating and ranking system is an empirical model that was developed based on similar assessment methods used by the Roads and Maritime Services (RMS) for managing man-made and natural slopes. The model was developed to provide a holistic approach to the response of cliff faces to mine subsidence. The method was developed for cliffs up to heights of 150 m. It includes the following three impact categories:

a. The impacts of mining induced deformation (i.e. expressed in terms of the % length of cliff line affected by rock falls);

b. Exposure of the public (and mining personnel) to rock falls and the potential loss of aesthetic appeal of the cliffs; and

c. The contribution of the natural instability of the cliffs (i.e. the ongoing weathering and cliff adjustment process).

Impacts from each of the above categories are assigned a score according to various factors. These scores are multiplied by a weighting value and ranked as a proportion of the maximum possible score for each category. It is not possible in every assessment to have all the factors catered for before mining activity, hence any attempt to assess the likelihood of a cliff collapse or rock fall at a particular location is not possible. The predicted % length of cliff line affected by rock falls due to mining are worst case values and also include rock falls due to weathering process. Furthermore, ACARP 2002 was developed for aesthetically pleasing cliff lines in the southern and western coalfields of NSW.

The predicted subsidence along Matthews Creek and Cedar Creek is presented in Table 8 (MSEC, 2019).

Table 8: Predicted subsidence along Matthews Creek and Cedar Creek (MSEC report, 2019)

Reference	Valley	Maximum predicted total vertical subsidence (mm)	Maximum Predicted total tilt (mm/m)	Maximum predicted total hogging curvature (km^{-1})	Maximum predicted total sagging curvature (km^{-1})
C_M01	Matthews Creek	100	0.5	< 0.01	< 0.01
C_M02		80	0.5	< 0.01	< 0.01
C_C01	Cedar Creek	< 20	< 0.5	< 0.01	< 0.01
C_C02		< 20	< 0.5	< 0.01	< 0.01
C_C03		40	< 0.5	< 0.01	< 0.01
C_C04		30	< 0.5	< 0.01	< 0.01
C_C05		40	< 0.5	< 0.01	< 0.01
C_C06		50	< 0.5	< 0.01	< 0.01
C_C07		30	< 0.5	< 0.01	< 0.01
C_C08		30	< 0.5	< 0.01	< 0.01
C_C09		< 20	< 0.5	< 0.01	< 0.01

Based on the field inspection and data from the LIDAR map, the assessment of subsidence impacts on cliff lines was conducted in accordance with the procedure given in ACARP C9067. The details of the assessment are presented in Table 9. In general, the cliffs in the Study Area can be categorised as "Insignificant" and less than 3% of the cliff lines are predicted to be damaged. The stretch of Cedar Creek closer to the north west edge of LW W1 may experience destressing and possible toppling of minor sections of the cliffs due to mining activity.

Table 9: Assessment of Cliffs as per ACARP C9087

Reference	Aesthetic Quality	Natural instability	Mining Impact	Mining impact proportion	Overall assessment	% Rock falls
C_M01	Insignificant	low	Insignificant	0.08	Insignificant	3%
C_M02	Insignificant	low	Insignificant	0.08	Insignificant	3%
C_C01	Insignificant	low	Insignificant	0.08	Insignificant	3%
C_C02	Insignificant	low	Insignificant	0.08	Insignificant	3%
C_C03	Insignificant	low	Insignificant	0.08	Insignificant	3%
C_C04	Insignificant	low	Insignificant	0.08	Insignificant	3%
C_C05	Insignificant	low	Insignificant	0.08	Insignificant	3%
C_C06	Insignificant	low	Insignificant	0.08	Insignificant	3%
C_C07	Insignificant	low	Insignificant	0.08	Insignificant	3%
C_C08	Insignificant	low	Insignificant	0.08	Insignificant	3%
C_C09	Insignificant	low	Insignificant	0.08	Insignificant	3%

5.4 Assessment of steep slopes

As discussed in Section 5.1, steep slopes are defined as an area of land having a natural slope angle of between 18.4° and 45°. The 1 m surface level contours, generated from the LIDAR survey of the area, provided information regarding the steep slopes in the Study Area. The Study Area above LW W1 and W2 consists of numerous steep slopes on the side of ridges with shallow residual soil cover underlain by Ashfield Shale. In this section, assessment of steep slopes is discussed with reference to the presence of structures and human life near the slopes. Residential structures constructed along the steep slopes were identified during the walk-through as well from the LIDAR data. Natural steep slopes have been identified along the banks of Matthews, Cedar and Stonequarry Creeks where the near surface lithology is part of the Hawkesbury Sandstone formation. No structures are reported along these creeks and accessibility to creeks is restricted.

The soils in the Study Area may be differentiated in terms of the parent material from which they are derived. On the one hand are the residual soils on the shale ridge-tops and on the other, weakly developed soils in the colluvial material of the lower slopes and the alluvial material within the creeks. The ridge-top soils appear to be generally shallow (20 - 300 mm) and undifferentiated into horizons, except for the accumulation of organic matter at the surface.

The landslide risk assessment conducted for this study involved the following steps:

- Identify the landslide processes occurring, factors contributing to instability, and likely triggers to future instability;
- Assess the likelihood that these landslide hazards or events will occur in the future;
- Assess the potential consequences in terms of potential damage to property;
- Combine the estimates of likelihood and consequence to derive an assessed risk of slope instability in the pre-mining state;

- Review the estimated subsidence effects on the LW W1 and W2 Study Area; and
- In light of the above, assess the risk of slope instability post-mining.

The slope risk assessment was undertaken in accordance with the methods and principles presented in the Australian Geomechanics Society publication "Practice Note Guidelines for Landslide Risk Management 2007" (AGS, 2007). The risk assessment takes into account the current site surface conditions and potential effects of future mining. Future changes to the surface profile due to building development and site excavations are not considered in this risk assessment. Each of the sites was assessed on the basis of the estimated likelihood and extent of landsliding in relation to infrastructure that was able to be identified from aerial photographs and from the site walkover assessment. Due to the non- accessibility of the properties, the specifics of impacts like cracking is beyond the scope of the assessment. The structures considered in the assessment include assets identified in the MSEC (2019) subsidence assessment report.

5.4.1 Definitions

The qualitative terminology for use in assessing risk to property in the report is as follows:

- Risk - A measure of the probability and severity of an adverse effect to health, property or the environment. Risk is often estimated by the product of probability and consequence. However, a more general interpretation of risk involves a comparison of the probability and consequences in a non-product form.
- Acceptable Risk – A risk which, for the purposes of life or work, society is prepared to accept as is with no regard to its management. Society does not generally consider expenditure justifiable in further reducing such risks.
- Annual Exceedance Probability (AEP) – The estimated probability that an event of specified magnitude will be exceeded in any one year.
- Consequence – The outcomes or potential outcomes arising from the occurrence of a landslide expressed qualitatively or quantitatively, in terms of loss, disadvantage or gain, damage, injury or loss of life.
- Danger – The natural phenomenon that could lead to damage, described in terms of its geometry, mechanical and other characteristics. The danger can be an existing one (such as a creeping slope) or a potential one (such as a rock fall).
- Elements at Risk – The population, buildings and engineering works, economic activities, public services utilities, infrastructure and environmental features in the area potentially affected by landslides.
- Frequency – A measure of likelihood expressed as the number of occurrences of an event in a given time.
- Hazard – A condition with the potential for causing an undesirable consequence. The description of landslide hazard should include the location, volume (or area), classification and velocity of the potential landslides and any resultant detached material, and the probability of their occurrence within a given period of time.
- Individual Risk to Life – The risk of fatality or injury to any identifiable (named) individual who lives within the zone impacted by the landslide or who follows a pattern of life that might subject him or her to the consequences of the landslide.

- Landslide Intensity – A set of spatially distributed parameters related to the destructive power of a landslide. The parameters may be described quantitatively or qualitatively and may include maximum movement velocity, total displacement, differential displacement, depth of the moving mass, peak discharge per unit width, kinetic energy per unit area.
- Landslide Susceptibility – A quantitative or qualitative assessment of the classification, volume (or area) and spatial distribution of landslides which exist or potentially may occur in an area. Susceptibility may also include a description of the velocity and intensity of the existing or potential landslide.
- Probability – A measure of the degree of certainty. This measure has a value between zero (impossibility) and 1.0 (certainty). It is an estimate of the likelihood of the magnitude of the uncertain quantity or the likelihood of the occurrence of the uncertain future event.
- Risk Assessment – The process of risk analysis and risk evaluation.
- Risk Control or Risk Treatment – The process of decision making for managing risk and the implementation or enforcement of risk mitigation measures and the re-evaluation of its effectiveness from time to time, using the results of risk assessment as one input.
- Risk Estimation – The process used to produce a measure of the level of health, property or environmental risks being analysed. Risk estimation contains the following steps: frequency analysis, consequence analysis and their integration.
- Risk Evaluation – The stage at which values and judgments enter the decision process, explicitly or implicitly, by including consideration of the importance of the estimated risks and the associated social, environmental and economic consequences, in order to identify a range of alternatives for managing the risks.
- Tolerable Risk – A risk within a range that society can live with so as to secure certain net benefits. It is a range of risk regarded as non-negligible and needing to be kept under review and reduced further if possible.
- Vulnerability – The degree of loss to a given element or set of elements within the area affected by the landslide hazard. It is expressed on a scale of 0 (no loss) to 1 (total loss). For property, the loss will be the value of the damage relative to the value of the property; for persons, it will be the probability that a particular life (the element at risk) will be lost, given the person(s) is affected by the landslide.
- Zoning: The division of land into homogeneous areas or domains and their ranking according to degrees of actual or potential landslide susceptibility, hazard or risk.

AGS (2007a) recommends a series of descriptors to evaluate the Landslide hazard perception. The recommended descriptors are outlined in Tables 10 to 13.

Table 10: Landslide Hazard Descriptor

Hazard Descriptor	Rock falls from natural cliffs or rock cut slope	Slides of cuts and fills on roads or railways	Small landslides on natural slopes	Individual landslides on natural slopes
	Number/annum/km of cliff or rock cut slope	Number/annum/km of cut of fill	Number/square km/annum	Annual probability of active sliding
Very High	> 10	> 10	> 10	10-1
High	1 to 10	1 to 10	1 to 10	10-2
Moderate	0.1 to 1	0.1 to 1	0.1 to 1	10^{-2} to 10^{-4}
Low	0.01 to 0.1	0.01 to 0.1	0.01 to 0.1	10-5
Very Low	<0.01	<0.01	<0.01	10-8

Table 11: Descriptor for risk zoning using life loss criteria

Annual probability of death of the person most at risk in the zone	Risk zoning descriptors
> 10^{-3}/annum	Very High
10^{-4} to10^{-3}/annum	High
10^{-5} to 10^{-4} /annum	Moderate
10^{-6} to 10^{-5} /annum	Low
< 10^{-6}/annum	Very Low

Table 12: Descriptor for risk zoning using property loss criteria

Likelihood		Consequences to property (with indicative approximate cost of damage as a percentage of the replacement cost)				
	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
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

Table 13: Slope gradient descriptor

Appearance	Slope angle	Slope characteristics
Gentle	0° to 10°	Easy walking
Moderate	10° to 18°	Walkable. Can drive and manoeuvre a car on driveway
Steep	18° to 27°	Walkable with effort. Possible to drive straight up or down roughened concrete driveway
Very Steep	27° to 45°	Can only climb slope by clutching at vegetation, rocks etc.
Extreme	45° to 64°	Need rope access to climb slope
Cliff	64° to 84°	Appears vertical
Overhangs	84° to +/-90°	Appears to overhang

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

5.4.2 Structures at risk

Based on the MSEC report and the site walk-through, a total of 46 structures were identified in the vicinity of steep slopes (Table 14). These structures are concentrated along the areas west of Stonequarry Creek Road, north and east of Thirlmere Way and a few other individual locations. (Figure 7). The details of the topography in these regions are presented in Table 15.

Table 14: Details of structures in the Study Area

Description	Numbers
Houses	11
Pool	1
Rural structures	21
Public utilities	13

Table 15: Details of areas containing structures at risk in the Study Area

Region	Details of the slope		Height of the slope (m)	Horizontal extent of the slope (m)
	Maximum elevation of slope (RL m)	Minimum elevation of slope (RL m)		
1	280	240	40	38
2	232	220	12	6
3	286	270	16	6.5
4	260	252	8	4
5	202	184	18	10

5.4.3 Factors affecting Landslide

Slope instability is governed by slope angle, soil strength, and concentrations of water within the potentially unstable soil or rock mass. Instability within the LW W1 and W2 Study Area may occur in a variety of forms and incorporate varying proportions of soil, rock, and water. Based on the field observation and understanding of the area, the types of slope instability that the identified steep slopes may undergo is described as follows:

- Type 1 – Toppling of rock blocks associated with rockmass degradation and cliff line regression due to erosion, and undercutting or softening of low strength bedding planes beneath prominent sandstone blocks;
- Type 2 – Translational soil slides occurring over low angle failure planes, typically occurring on low strength relict bedding planes or where water concentrates on the soil/rock interface;
- Type 3 – Debris flows associated with downslope movement of material disturbed by translational slides as outlined above; and
- Type 4 – Mass soil creep in accumulated colluvium triggered by saturation, prolonged waterlogging, erosion, and progressive strength loss of soils;

Type 1 instability can be associated to the cliff lines along Matthews, Cedar and Stonequarry Creeks. Since there are no structures and access is restricted to these areas, the potential for loss of property or life is very low. All the regions identified in previous section have potential slope instability Types 2,3 and 4. The trigger for such failures can be major rainfall or earthquake events.

5.4.4 Mine subsidence effect on the landslide risk

The potential increased risk of slope stability associated with the expected mine subsidence impacts can be caused due to following conditions:

- Tilting – During the subsidence, minor tilts may alter the angle of potential slide planes. In situations where sliding could occur on low angle slide planes, such as Type 2 slides, sliding can be triggered where tilts increases the angle of the slide planes in the down-slope direction. In the identified area, Type 2 sliding is likely to occur on the soil-rock interface or along the bedding planes. The predicted tilts are less than 5 mm/m at the identified locations within the Study Area (Table 16). These tilt movements are not expected to be sufficient to trigger soil movement or a landslide, although low shear strength on some bedding planes could make them sensitive to some movement in combination with other contributing factors such as undercutting, or prolonged rainfall events;

Table 16: Predicted effects of subsidence after mining

Maximum tilt (mm/m)	Number of houses	Mean tensile strain (mm/m)	Number of houses	Mean compressive strain (mm/m)	Number of houses
0 – 1	28	0 – 0.25	27	0 – 0.25	49
1 – 2	15	0.25 – 0.5	32	0.25 – 0.5	8
2 – 3	11	0.5 – 0.75	3	0.5 – 0.75	5
3 – 4	8	0.75 – 1	0	0.75 – 1	0
4 – 5	0	1 – 1.25	0	1 – 1.25	0

- Reduced Shear strength – Subsidence movements can reduce the shear strength of a slope or rock mass by introducing cracking. Tensile cracks can form in bulged areas. Also, differential movement along low angle bedding planes, which can occur during relaxation of the ground towards a subsidence bowl, can introduce shearing along the plane. These shear movements reduce the available shear strength of the plane and can contribute to slope failure. The expected subsidence effects on the potential instability for identified within this study area are minor and are not expected to produce significant cracking or differential lateral movements (Table 16);
- Water concentration – The cracks developed due to tensile or shear failures can allow ingress of water into a slope. This can potentially trigger instability due to loss of cohesion due to piping effects. The water in these cracks may also apply additional pressure to potential failure planes and increase the size of the cracks. The estimated subsidence movements on the surface within the study area are unlikely to produce cracking of significant dimension in the identified regions except in Region 1. In the case of non-systematic (down slope) movements, there is potential for increased tension and cracking at the tops of slopes which, if not mitigated, could increase water infiltration and associated increase in pore water pressures, which could potentially lead to landslips.

Subsidence predictions for the site indicate maximum subsidence of the order of 425 mm to 750 mm through the central part of the LW W1 and W2. Subsidence will take place over a broad subsidence bowl such that incrementally the changes in relief across the area will be minor. Most of slope instability incidents may occur in the area where subsidence is expected to be up to 425 mm for LW W1. During the mining of LW W2, the full subsidence bowl is expected to expand into this area up to a maximum of 750 mm. The subsidence study conducted by MSEC (2019) indicated that the tilting or changes in slope angle would be less than 5 mm/m in the identified areas. There are other possible mechanisms that may affect landslide risk due to mine subsidence such as curvature, stress and strains, however tilt (or slope change) was considered more likely to influence landslide risk rather than these other mechanisms. The structures directly above the longwall excavation could experience cracking and damage. The subsidence effects could take place over a broad area, and due to the depth of mining (greater than 450 m), and localised changes in slope, such damage is likely to vary between insignificant to minor, as defined in Table 17. The identified Region 1 could experience mass soil movements due to subsidence. If this was to occur it is anticipated that surface expressions of systematic subsidence, in the form of cracking or similar, would be minor. However, non-systematic movements such as down slope movements could result in increased tension and cracking at the tops of ridges. The risk assessment of identified regions from a landslide event is presented in Table 17. Based on the high-level desktop study, it is recommended that more detailed investigation be carried out, including structural inspections of the structures in Region 1 as the potential for landslide in this region can be categorised as medium.

Table 17: Assessment of steep slope failures on structures

Region	Geotechnical Landslide Hazard	Before Mining				Post Mining	
		Likelihood of hazard occurring	Consequence to the property		Assessed risk to the property	Likelihood	Assessed risk to the property
1	Toppling of rock block	Unlikely	Houses close to cliff. Ongoing regression will eventually reach property.	Minor	Low	Unlikely	Low
	Translational soil slides	Likely	Likely to come to rest on slopes above developed areas	Insignificant	Low	Likely	Moderate
	Mass soil movement	Unlikely	Likely to come to rest on slopes above developed areas - some debris may reach residence and cause minor damage	Minor	Low	Likely	Moderate
2	Translational soil slides	Unlikely	Likely to come to rest on slopes above developed areas - some debris may reach residence and cause minor damage	Insignificant	Low	Unlikely	Low
3	Translational soil slides	Unlikely	Likely to come to rest on slopes above developed areas - some debris may reach residence and cause minor damage	Insignificant	Low	Unlikely	Low

Region	Geotechnical Landslide Hazard	Before Mining				Post Mining	
		Likelihood of hazard occurring	Consequence to the property		Assessed risk to the property	Likelihood	Assessed risk to the property
4	Translational soil slides	Unlikely	Likely to come to rest on slopes above developed areas - some debris may reach residence and cause minor damage	Insignificant	Low	Unlikely	Low
5	Translational soil slides	Unlikely	Likely to come to rest on slopes above developed areas - some debris may reach residence and cause minor damage	Insignificant	Low	Unlikely	Low

5.5 Assessment of Farm Dams

Site inspection of the farm dams was not possible as they are located in private properties. The following information was obtained by a walk-through along public roads, the LIDAR survey, Google Maps, contour and topographic maps.

In total, nineteen (19) small farm dams are located within the study area of LW W1 and W2 (Figure 8). According to the ANCOLD, a small dam refers to a dam that does not meet the ANCOLD definition of a large dam having a volume of greater than 500 ML. The characteristics of these farm dams are given in Table 18. The farm dam capacities vary from about 0.02 ML to 30.76 ML. The topography around the identified farm dams can be classified as steep, however, most of the dams are situated at the toe of the slope. The predicted subsidence that the farm dams located above the longwall panels will be subjected to is in the range of 450 mm to 750 mm. The dams are typically of earth fill construction and have been established by localised cut and fill operations within valley floors. The farm dams are shallow with the wall heights being up to about 2 m. MSEC (2019) indicates that the farm dams within the Study Area are predicted to experience total tensile strains of between 0.3 mm/m and 1.1 mm/m and total compressive strains of between 0.2 mm/m and based on a 95% confidence levels. The predicted mean values range between 0.2 mm/m and 0.8 mm/m tensile and compressive strain. The predicted changes in freeboard were reported as varying from 20 mm to 140 mm.

Table 18: Details of farm dams

General Reference	Reference	Northing	Easting	Surface area (m^2)	Volume (m^3)	Volume (ML)
PSC_004_d01	FD-10	277590	6214768	460	909	0.91
PSC_019_d01	FD-5	277857	6215418	3670	7340	7.34
PSC_080_d01	FD-6	278221	6215832	1380	2760	2.75
PSC_090_d01	FD-7	278513	6216093	5670	1140	11.34
PSC_100_d01	FD-11	277570	6214996	200	390	0.39
PSR_010_d03	FD-8	278740	6215573	150	2960	2.96
PTH_031_d01	FD-12	278350	6214905	3130	6270	6.27
PTH_031_d02	FD-2	278390	6214848	130	250	0.25
PTH_055_d01	FD-4	278547	6215155	3830	7670	7.67
PTH_080_d01	FD-1	278583	6214761	15040	30080	30.08
PTH_105_d01	FD-3	278720	6215094	7280	14560	14.56
TAD_005_d01	FD-9	277334	6215659	1900	3790	3.79
V04ax	FD-13	277913	6214240	15	30	0.03
V04ay	FD-14	277900	6214265	36	70	0.07
V04az	FD-15	277878	6214309	38	80	0.08
V04ba	FD-16	277787	6214438	100	190	0.19
V04bd	FD-17	277758	6214505	480	970	0.97
V04be	FD-18	277727	6214523	90	180	0.18
V06f	FD-19	278188	6214326	300	600	0.59

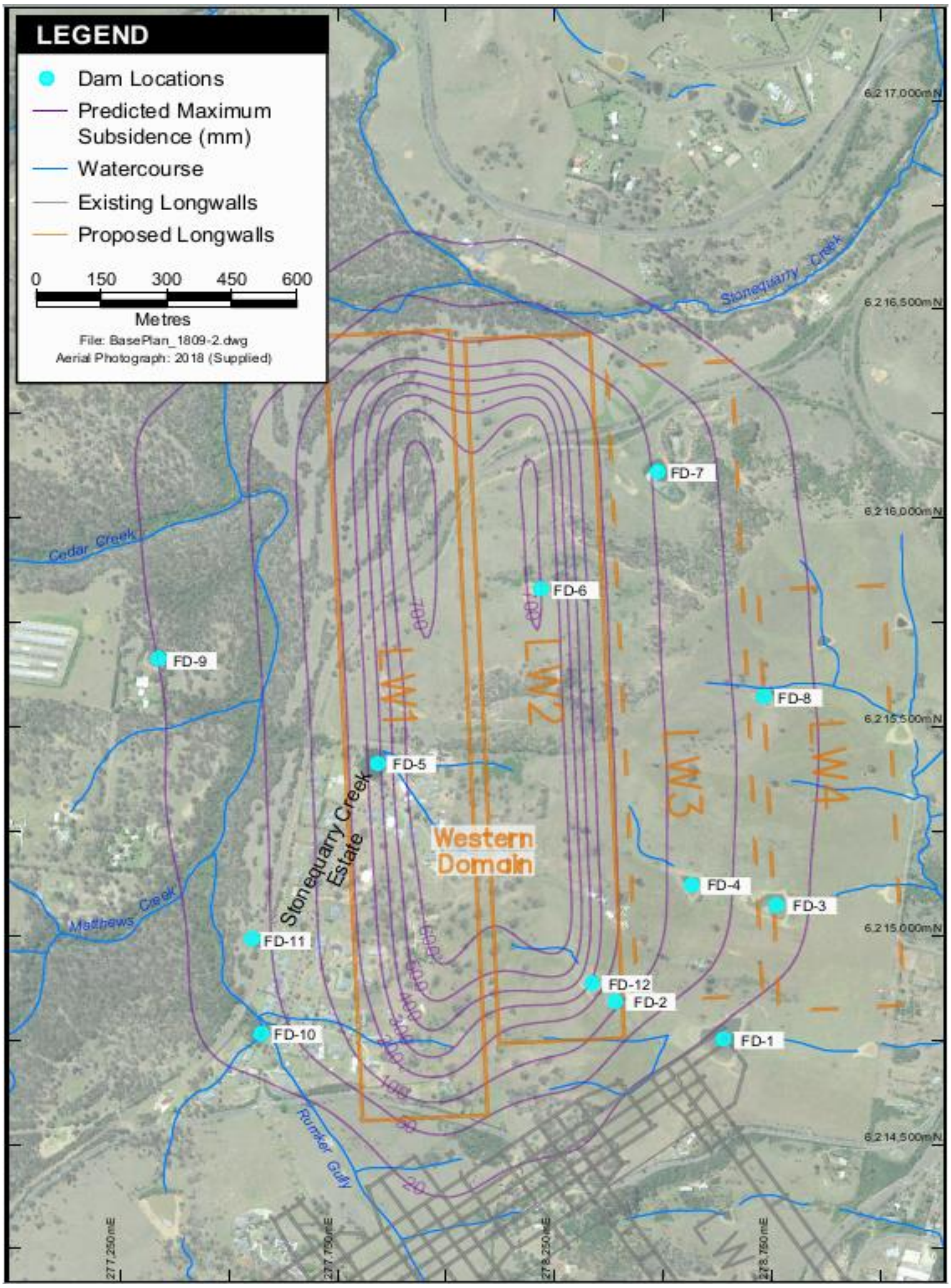

Figure 8: Location of farm dams in the study area

Australian National Committee on Large Dams (ANCOLD) Guidelines on the Consequence Categories for Dams (2012) defines the consequences of dam failure as ‘the outcome or result of a dam failure in terms of loss of life and damage to property and/or services, as well as environmental damage'. In this study, a consequence screening tool was used to arrive at the impact of subsidence on the farm dams. The tool is broadly consistent with the Initial Consequence Assessment level of ANCOLD (2012). The screening tool identifies the consequence of a dam breakage and provides a preliminary basis for determining dam safety management requirements. It covers the aspects such as surveillance and monitoring; emergency preparedness and response; operational procedures, requirement of additional investigation and dam safety improvement works.

The key inputs for assessment of farm dams are listed as following:

- Dam volume;
- Downstream topography;
- Extent of downstream impact;
- Population at Risk (PAR); and
- Location of PAR.

The PAR includes all people who would be directly exposed to flood waters assuming they took no action to evacuate. The PAR should be assessed using demographic data including dwelling occupancy rates, school populations, work sites and other places where people assemble (eg industrial, hospital, commercial and retail areas). The PAR may vary according to time of day, day of week and season. The framework of screening of ANCOLD Consequence Categories for small dams is made as per following steps:

1. Assess the inundation area by estimating downstream extent of dam break impact and PAR within the downstream extent;
2. Initial screening based on PAR and assessing the proximity of PAR to the dam; and
3. Establishing consequence category for each dam under very low to low; significant or above.

In the present study, farm dams having capacity of 1 ML or more have been considered for analysis based on the volume that could have a significant impact (Table 19). There are private residential structures in close proximity to the farm dams. The locations of these structures with reference to the dams are presented in Figures 9 to 11. The farm dams FD-2, FD-5 and FD-6 lie directly above the longwall panels where the predicted subsidence varies between 450 mm to 750 mm after the extraction of LW W1 and W2. Similarly, the farm dams FD-1, FD-3, FD-8 and FD-9 may experience subsidence of up to 20 mm to 50 mm. The farm dams are land locked, ie the dams are located in the valley. It is considered that there is no possibility of development of a flood wave due to topographical features. Cracking of the top surface may cause breaching of the dam and eventually loss of water pondage. However, there is only a low chance of water flooding the nearby houses due to dam breach as the houses are situated at a higher elevation than the farm dams. The structures in the vicinity are located on the upstream of the dams (except FD-5), hence the possibility of inundation due to dam break is minimal. As per the ANCOLD Consequence Categories for small dams, the consequence of farm dam break can be categorised as Very Low for all the dams except for FD-5 (Table 20). The structures around FD-5 are potentially at risk as there is very little difference in elevation levels. However, the topography is gentle, and PAR was estimated as 1 to 10.

Farm dams are constructed with clay material which can absorb conventional cracking. Localised cracking and deformations may occur which may require remediation. The three farm dams, FD-2, FD-

5 and FD-6, could potentially experience cracking due to mining induced subsidence, which may cause loss in the water storage capacity. The stored water volume in these dams should be reduced during the mining subsidence period.

Remediation may be required to restore any affected dam to its pre-mining condition. The dams may require periodic surveillance with regards to water level and visual inspection for crack development.

The dams should be inspected by a geotechnical engineer when site access is available prior to mining to allow re-assessment of the advice in this report.

Table 19: Distance of farm dams from the structures

General Reference	Dam ID	Volume (ML)	Distance from the closest structure (m)	Dam elevation (RL m)	Structure elevation (m)
PSC_019_d01	FD-5	7.34	34	224	226
PSC_080_d01	FD-6	2.75	-	208	-
PSC_090_d01	FD-7	11.34	37	196	206
PSR_010_d03	FD-8	2.96	-	234	-
PTH_031_d01	FD-2	6.27	128	234	258
PTH_055_d01	FD-4	7.67	123	228	258
PTH_080_d01	FD-1	30.08	115	226	252
PTH_105_d01	FD-3	14.56	148	224	252
TAD_005_d01	FD-9	3.79	34	222	224

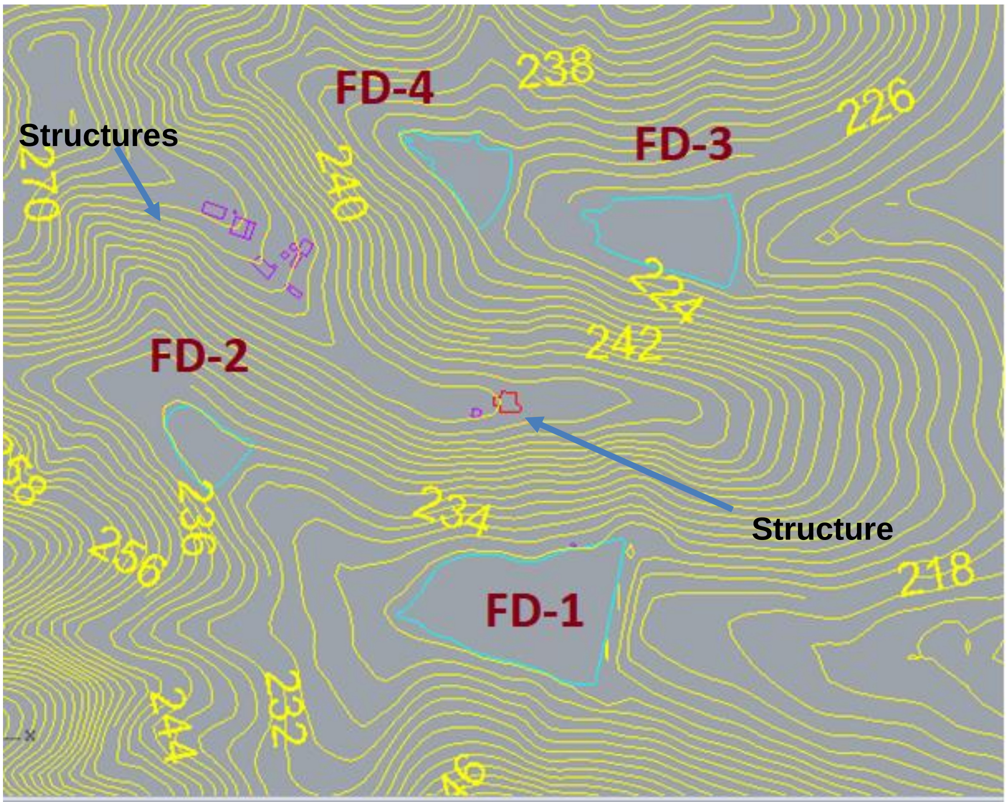

Figure 9: Location of Farm Dams, FD-1, FD-2, FD-3 and FD-4 with respect to the closest structures

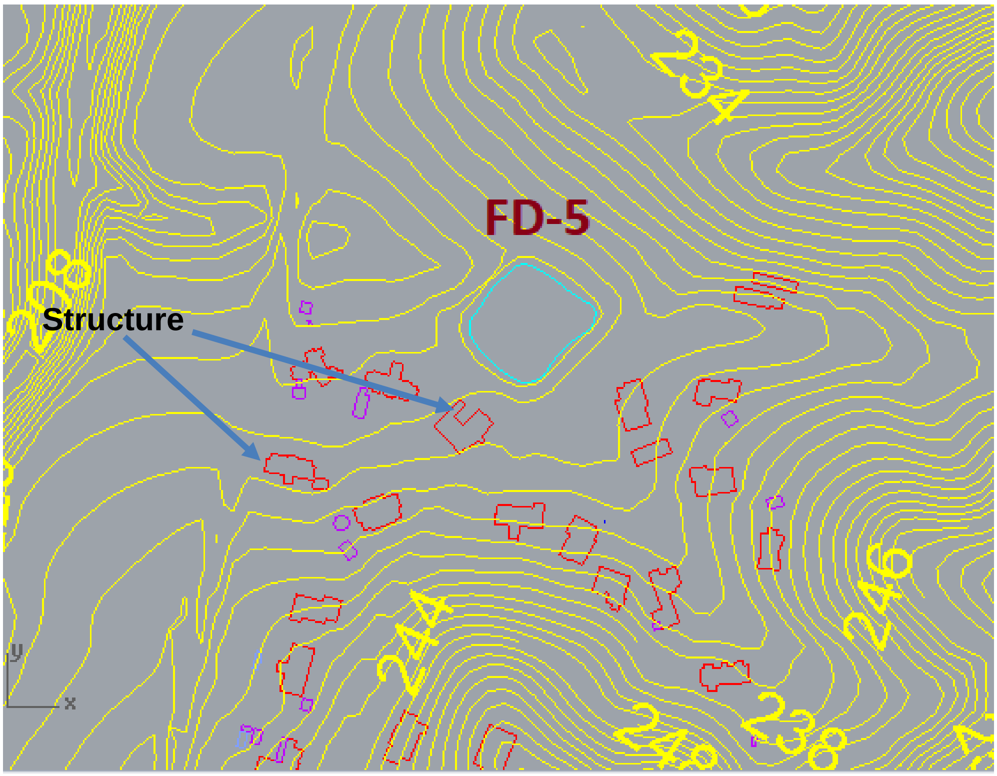

Figure 10: Location of Farm Dams (FD-5) with respect to the closest structures

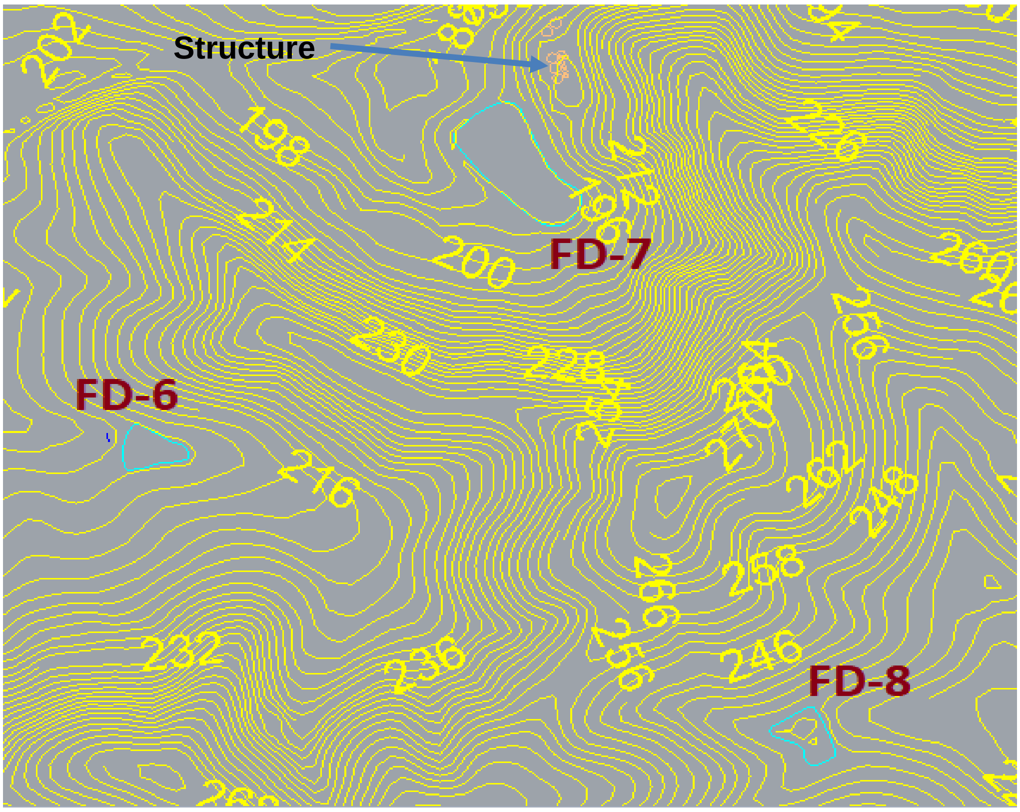

Figure 11: Location of Farm Dams (FD-6, FD-7 AND FD-8) with respect to the closest structures

Table 20: Assessment of farm dams

General Reference	Dam ID	Volume (ML)	Downstream Topography	Population at risk	Consequence
PSC_019_d01	FD-5	7.34	Gentle slope	≥1 to 10	Significant
PSC_080_d01	FD-6	2.75	Gentle slope	< 1	Very Low
PSC_090_d01	FD-7	11.34	Gentle slope	< 1	Very Low
PSR_010_d03	FD-8	2.96	Gentle slope	< 1	Very Low
PTH_031_d01	FD-2	6.27	Gentle slope	< 1	Very Low
PTH_055_d01	FD-4	7.67	Gentle slope	< 1	Very Low
PTH_080_d01	FD-1	30.08	Gentle slope	< 1	Very Low
PTH_105_d01	FD-3	14.56	Gentle slope	< 1	Very Low
TAD_005_d01	FD-9	3.79	Gentle slope	< 1	Very Low

6. Monitoring Plan

The Monitoring Plan outlined within Table 21 has been developed to assess the subsidence impacts on geotechnical features that can occur due to extraction of LW W1 and W2. The monitoring plan includes the following components:

- Cliff face monitoring;
- Steep slope monitoring; and
- Farm dam monitoring.

6.1 Trigger Action Response Plan

A contingency plan has been developed in the form of a Trigger Action Response Plan, as outlined on Table 21. The measures developed within the TARP are to address any potential significant subsidence related impacts and include cliff lines, steep slopes, surface cracking and farm dams.

Table 20: Monitoring Program for Geotechnical Features

Feature	Monitoring Component / Location	Monitoring		
		Prior to Mining	During Mining	Post Mining
Cliffs	Identified rock outcrops along cliff lines within the Study Area.	Visual Inspection baseline 1 month before active subsidence period by geotechnical engineer.	Monthly visual inspection during active subsidence period by geotechnical engineer.	Quarterly visual inspection for 12 month following active subsidence period by geotechnical engineer.
Steep Slopes	Identified steep slopes within the Study Area.	Visual Inspection baseline 1 month before active subsidence period by geotechnical engineer.	Monthly visual inspection during active subsidence period by geotechnical engineer.	Quarterly visual inspection for 12 month following active subsidence period by geotechnical engineer.
Farm Dams	Identified farm dams within the Study Area.	Dam embankment integrity and water level observation every month for at least two months immediately prior to undermining using fixed location photo points.	Dam embankment integrity and water level observation every week during active subsidence period using fixed location photo points.	Dam embankment integrity and water level observation 3-monthly for minimum of 12 months post mining using fixed location photo points.

Table 21 Trigger Action Response Plan for Landscape Features

Feature	Management	
	Trigger	Action
Cliff Line Damage or Instability	Normal	
	Surface cracking < 5 cm wide on top of cliff line, minor visible cracking on cliff face, or rock fall of isolated blocks	Monthly monitoring by geotechnical engineer during active subsidence period
	Within Prediction	
	Surface cracking 5 – 10 cm wide on top of cliff line, substantial visible cracking on rock face, , or rock fall of isolated blocks	Monthly monitoring by geotechnical engineer during active subsidence period Erect warning signs and danger tape in immediate area. Geotechnical engineer inspection to determine need for further action/investigation
	Exceeds Prediction	
	Surface cracking > 10cm wide, major damage to cliff face or rock fall of > 100m^3	Weekly monitoring by geotechnical engineer during active subsidence period

		Erect warning signs and danger tape in immediate area. Geotechnical engineer inspection to determine need for further action/investigation Notify Regulator and other stakeholders
Steep Slope Damage or Instability	Normal	
	Surface cracking < 5 cm wide on slope, or rock fall of isolated blocks	Monthly monitoring by geotechnical engineer during active subsidence period
	Within Prediction	
	Surface cracking 5 – 10 cm wide on slope, small rock fall	Monthly monitoring by geotechnical engineer during active subsidence period Repair cracks at the completion of the active subsidence period. Erect warning signs and danger tape where necessary
	Exceeds Prediction	
	Surface cracking > 10 cm wide, substantial rock fall, tree fall	Weekly monitoring by geotechnical engineer during active subsidence period Repair cracks at the completion of the active subsidence period. Erect warning signs and danger tape where necessary Geotechnical engineer inspection to determine need for further action/investigation Notify Regulator and other stakeholders
Surface cracking	Normal	
	Surface cracking < 5 cm	Monthly monitoring by geotechnical engineer during active subsidence period Repair cracks at the completion of the active subsidence period.
	Within Prediction	
	Surface cracking 5 – 10 cm	Monthly monitoring by geotechnical engineer during active subsidence period Repair cracks at the completion of the active subsidence period. Erect warning signs where necessary
	Exceeds Prediction	
	Surface cracking > 10 cm	Weekly monitoring by geotechnical engineer during active subsidence period

		Repair cracks at the completion of the active subsidence period. Erect warning signs where necessary Geotechnical engineer inspection to determine need for further action/investigation Notify Regulator and other stakeholders Repair cracks > 10 cm in width with excavation, grouting and re-compaction where practical
Farm dams	Normal	
	No cracks developed within dam wall.	Monthly monitoring by geotechnical engineer during active subsidence period Repair cracks at the completion of the active subsidence period.
	Within Prediction	
	Small isolated cracks developed within dam wall (cracks <5 cm).	Monthly monitoring by geotechnical engineer during active subsidence period
	Exceeds Prediction	
	Development of cracking within dam wall > 5 cm and non-isolated in nature	Weekly monitoring by geotechnical engineer during active subsidence period Erect warning signs where necessary Reduce dam water level by at least half dam volume. Notify Regulator and other stakeholders Repair cracks at the completion of the active subsidence period with excavation, grouting and re-compaction where practical

7. Comments

A high-level Geotechnical Assessment was conducted on the land features within the study area of LW W1 and W2. The Geotechnical Assessment included risk based assessments of cliffs, steep slopes and farm dams. A monitoring plan and TARP have been developed. The Geotechnical Assessment was based on the mine inputs received from Tahmoor Coal and the subsidence prediction report by MSEC. Walk-throughs along the Matthews, Cedar and Stonequarry Creeks were conducted for identifying the critical cliffs and outcrops. Similarly, walk-throughs were conducted adjacent to steep slopes and farm dams along Stonequarry Road and other areas. Site inspection of houses were not conducted as there was no permission for this from the private landowners.

The risk assessment of the cliffs was conducted using the procedure presented in ACARP C9067 (Subsidence Impacts on River Valleys, cliffs, Gorges and River System). Steep slopes were evaluated by the procedure recommended by Australian Geomechanics Society publication “Practice Note Guidelines for Landslide Risk Management 2007” (AGS 2007). The Small Dam Consequence Screening Tool (DEPI, 2014) was used to analyse farm dams.

The study revealed that the impact of subsidence on the identified cliffs can be classified as insignificant with a probability that less than 3% of cliff lines will be influenced by the extraction of LW W1 and W2. This can be attributed to the fact that the cliffs are not directly above the proposed extraction panels as well as that the access to these creeks and cliffs is difficult and restricted. There is a possibility of dislodgement, toppling and rolling of failed rocks due to weathering and tilting, but no harm to any property or human is foreseen. Toppling of cliffs and valley closure due to destressing is possible along the stretch of Cedar Creek close to northwest corner of LW W1.

The risk assessment of steep slopes indicated that landsliding is unlikely in identified Regions 2, 3, 4 and 5 and the impact of landslide in these regions was categorised as Low. However, the subsidence in Region 1 was reported to be between 425 mm to 750 mm, which is expected to influence the landform with possible local cracking and soil mass slides. Region 1 is categorised as having a Moderate risk to property from landsliding.

The consequence of farm dam failure on property or human lives were found to be Low in all the farm dams. Most of the farm dams were classified as being Low risk except for FD-5, which lies directly above the LW W1. This farm dam is located in close to structures. There could be cracking of some farm dams leading to loss of water and pondage. Remedial measures can be carried out to address these dams.

It is recommended that a monitoring program be undertaken to monitor movements which may indicate any rock/soil mass movements. The monitoring program as part of the TARP has been presented in the report. Periodic inspections and visual observations are key identify signs of distress. In the event that monitoring indicates the measured parameters are exceeding predicted values, the TARP measures need to be implemented. Remediation of cracks and unstable slopes can prevent cascading effects on the structures. The subsidence control measures and crack filling works may be required to minimise the potential for long term instability of steep slopes and cliffs.

8. References

1. ACARP, 2002. Impacts of Mine Subsidence on the Strata and Hydrology of River Valleys and Management Guidelines for Undermining Cliffs, Gorges and River System. ACARP Project C9067, Waddington & Associates Pty Ltd.

2. AGS, 2007. Guidelines for Landslide Risk Management. Australian Geomechanics Society, Journal Vol 42 No. 1.

3. Anon, 2014. Consequence Screening Tool for Small Dams. The State of Victoria Department of Environment and Primary Industries, Melbourne.

4. Ferguson, H. F. and Hamel, J. V., 1981. Valley Stress Relief in Flat-Lying Sedimentary Rocks. in Proceedings Weak rock: soft, fractured and weathered rock, A.A Balkema, 1235- 1240.

5. Hutchinson, J.N., 1987. Mechanisms producing large displacements in landslides on pre-existing shears. Mem. Geol. Soc. China, No 9, 175-200.

9. Limitations

Douglas Partners (DP) has prepared this report for this project at LW W1 and W2, Picton in accordance with DP's proposal WOL190014.P.003.Rev0 dated 11 June 2019 and acceptance received from Tahmoor Coal Pty Ltd dated 16 May 2019. The work was carried out under DP's Conditions of Engagement. This report is provided for the exclusive use of Tahmoor Coal Pty Ltd for this project only and for the purposes as described in the report. It should not be used by or be relied upon for other projects or purposes on the same or another site or by a third party. Any party so relying upon this report beyond its exclusive use and purpose as stated above, and without the express written consent of DP, does so entirely at its own risk and without recourse to DP for any loss or damage. In preparing this report DP has necessarily relied upon information provided by the client and/or their agents.

DP's advice is based upon the conditions encountered during this assessment. The accuracy of the advice provided by DP in this report may be affected by undetected variations in ground conditions across the site. Sub-surface conditions can change abruptly due to variable geological processes and also as a result of human influences. Such changes may occur after DP's inspections were completed.

This report must be read in conjunction with all of the attached and should be kept in its entirety without separation of individual pages or sections. DP cannot be held responsible for interpretations or conclusions made by others unless they are supported by an expressed statement, interpretation, outcome or conclusion stated in this report.

This report, or sections from this report, should not be used as part of a specification for a project, without review and agreement by DP. This is because this report has been written as advice and opinion rather than instructions for construction.

The contents of this report do not constitute formal design components such as are required, by Health and Safety Legislation and Regulations, to be included in a Safety Report specifying the hazards likely to be encountered during construction of all works (not just geotechnical components) and the controls required to mitigate risk. This report does, however, identify hazards associated with the geotechnical aspects of development and presents the results of risk assessment associated with the management of these hazards. It is suggested that the developer's principal design company may wish to include the geotechnical hazards and risk assessment information contained in this report, in their own Safety Report. If the principal design company, in the preparation of its project Design Report, wishes to undertake such inclusion by use of specific extracts from this subject DP report, rather than by appending the complete report, then such inclusion of extracts should only be undertaken with DP's express agreement, following DP's review of how any such extracts are to be utilised in the context of the project Safety Report. Any such review shall be undertaken either as an extension to contract for the works associated with this subject DP report or under additional conditions of engagement, with either option subject to agreement between DP and the payee.

Douglas Partners Pty Ltd

Appendix A

About This Report

Introduction

These notes have been provided to amplify DP's report in regard to classification methods, field procedures and the comments section. Not all are necessarily relevant to all reports.

DP's reports are based on information gained from limited subsurface excavations and sampling, supplemented by knowledge of local geology and experience. For this reason, they must be regarded as interpretive rather than factual documents, limited to some extent by the scope of information on which they rely.

Copyright

This report is the property of Douglas Partners Pty Ltd. The report may only be used for the purpose for which it was commissioned and in accordance with the Conditions of Engagement for the commission supplied at the time of proposal. Unauthorised use of this report in any form whatsoever is prohibited.

Borehole and Test Pit Logs

The borehole and test pit logs presented in this report are an engineering and/or geological interpretation of the subsurface conditions, and their reliability will depend to some extent on frequency of sampling and the method of drilling or excavation. Ideally, continuous undisturbed sampling or core drilling will provide the most reliable assessment, but this is not always practicable or possible to justify on economic grounds. In any case the boreholes and test pits represent only a very small sample of the total subsurface profile.

Interpretation of the information and its application to design and construction should therefore take into account the spacing of boreholes or pits, the frequency of sampling, and the possibility of other than 'straight line' variations between the test locations.

Groundwater

Where groundwater levels are measured in boreholes there are several potential problems, namely:

- In low permeability soils groundwater may enter the hole very slowly or perhaps not at all during the time the hole is left open;
- A localised, perched water table may lead to an erroneous indication of the true water table;
- Water table levels will vary from time to time with seasons or recent weather changes. They may not be the same at the time of construction as are indicated in the report; and
- The use of water or mud as a drilling fluid will mask any groundwater inflow. Water has to be blown out of the hole and drilling mud must first be washed out of the hole if water measurements are to be made.

More reliable measurements can be made by installing standpipes which are read at intervals over several days, or perhaps weeks for low permeability soils. Piezometers, sealed in a particular stratum, may be advisable in low permeability soils or where there may be interference from a perched water table.

Reports

The report has been prepared by qualified personnel, is based on the information obtained from field and laboratory testing, and has been undertaken to current engineering standards of interpretation and analysis. Where the report has been prepared for a specific design proposal, the information and interpretation may not be relevant if the design proposal is changed. If this happens, DP will be pleased to review the report and the sufficiency of the investigation work.

Every care is taken with the report as it relates to interpretation of subsurface conditions, discussion of geotechnical and environmental aspects, and recommendations or suggestions for design and construction. However, DP cannot always anticipate or assume responsibility for:

- Unexpected variations in ground conditions. The potential for this will depend partly on borehole or pit spacing and sampling frequency;
- Changes in policy or interpretations of policy by statutory authorities; or
- The actions of contractors responding to commercial pressures.

If these occur, DP will be pleased to assist with investigations or advice to resolve the matter.

About this Report

Site Anomalies
In the event that conditions encountered on site during construction appear to vary from those which were expected from the information contained in the report, DP requests that it be immediately notified. Most problems are much more readily resolved when conditions are exposed rather than at some later stage, well after the event.

Information for Contractual Purposes
Where information obtained from this report is provided for tendering purposes, it is recommended that all information, including the written report and discussion, be made available. In circumstances where the discussion or comments section is not relevant to the contractual situation, it may be appropriate to prepare a specially edited document. DP would be pleased to assist in this regard and/or to make additional report copies available for contract purposes at a nominal charge.

Site Inspection
The company will always be pleased to provide engineering inspection services for geotechnical and environmental aspects of work to which this report is related. This could range from a site visit to confirm that conditions exposed are as expected, to full time engineering presence on site.

Appendix B

Site Photographs

Photo 1

Photo 2

Douglas Partners Geotechnics / Environment / Groundwater	**Site Photographs**	PROJECT:	89541.00
	Cliffs at Matthew Creek	PLATE No:	1
	LW W1 – 2, Tahmoor North	REV:	A
	CLIENT: Tahmoor Coal Pty Ltd	DATE:	26-Jun-19

Photo 3

Photo 4

Site Photographs	PROJECT:	89541.00
Cliffs at Matthew Creek	PLATE No:	2
LW W1 – 2, Tahmoor North	REV:	A
CLIENT: Tahmoor Coal Pty Ltd	DATE:	26-Jun-19

Douglas Partners
Geotechnics / Environment / Groundwater

Photo 5

Photo 6

Douglas Partners Geotechnics / Environment / Groundwater	**Site Photographs** **Cliffs at Matthew Creek** **LW W1 – 2, Tahmoor North**	PROJECT: 89541.00 PLATE No: 3 REV: A
	CLIENT: Tahmoor Coal Pty Ltd	DATE: 26-Jun-19

Photo 7

Photo 8

	Site Photographs	PROJECT:	89541.00
Douglas Partners Geotechnics / Environment / Groundwater	Cliffs at Matthew Creek	PLATE No:	4
	LW W1 – 2, Tahmoor North	REV:	A
	CLIENT: Tahmoor Coal Pty Ltd	DATE:	26-Jun-19

Photo 9

Photo 10

Douglas Partners Geotechnics / Environment / Groundwater	**Site Photographs**	PROJECT:	89541.00
	Cliffs at Matthew Creek	PLATE No:	5
	LW W1 – 2, Tahmoor North	REV:	A
	CLIENT: Tahmoor Coal Pty Ltd	DATE:	26-Jun-19

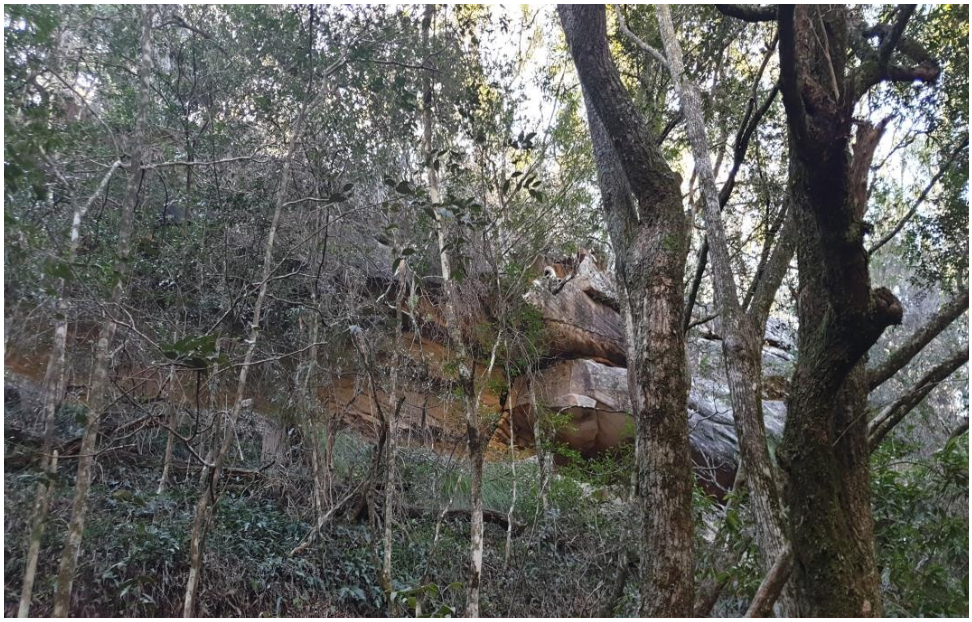

Photo 11

Photo 12

Douglas Partners Geotechnics / Environment / Groundwater	**Site Photographs**	PROJECT:	89541.00
	Cliffs at Matthew Creek	PLATE No:	6
	LW W1 – 2, Tahmoor North	REV:	A
	CLIENT: Tahmoor Coal Pty Ltd	DATE:	26-Jun-19

Photo 13

Photo 14

Douglas Partners Geotechnics / Environment / Groundwater	**Site Photographs**	PROJECT:	89541.00
	Cliffs at Matthew Creek	PLATE No:	7
	LW W1 – 2, Tahmoor North	REV:	A
	CLIENT: Tahmoor Coal Pty Ltd	DATE:	26-Jun-19

Photo 15

Photo 16

Douglas Partners Geotechnics / Environment / Groundwater	**Site Photographs**	PROJECT:	89541.00
	Cliffs at Stonequarry and Cedar Creek	PLATE No:	8
	LW W1 – 2, Tahmoor North	REV:	A
	CLIENT: Tahmoor Coal Pty Ltd	DATE:	26-Jun-19

Photo 17

Photo 18

Douglas Partners Geotechnics / Environment / Groundwater	**Site Photographs**	PROJECT:	89541.00
	Cliffs at Stonequarry and Cedar Creek	PLATE No:	9
	LW W1 – 2, Tahmoor North	REV:	A
	CLIENT: Tahmoor Coal Pty Ltd	DATE:	26-Jun-19

Photo 19

Photo 20

Douglas Partners Geotechnics / Environment / Groundwater	**Site Photographs**	PROJECT:	89541.00
	Cliffs at Cliffs at Stonequarry and Cedar Creek	PLATE No:	10
	LW W1 – 2, Tahmoor North	REV:	A
	CLIENT: Tahmoor Coal Pty Ltd	DATE:	26-Jun-19

Photo 21

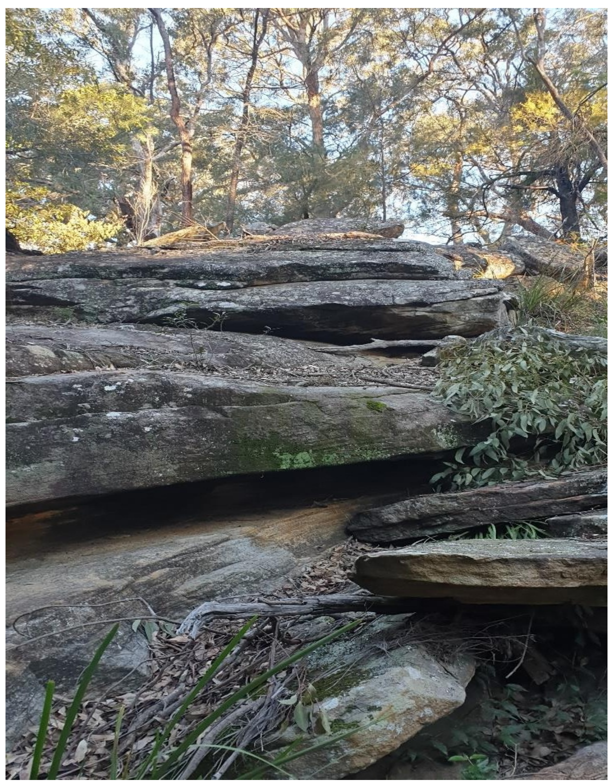

Photo 22

Douglas Partners Geotechnics / Environment / Groundwater	**Site Photographs**	PROJECT:	89541.00
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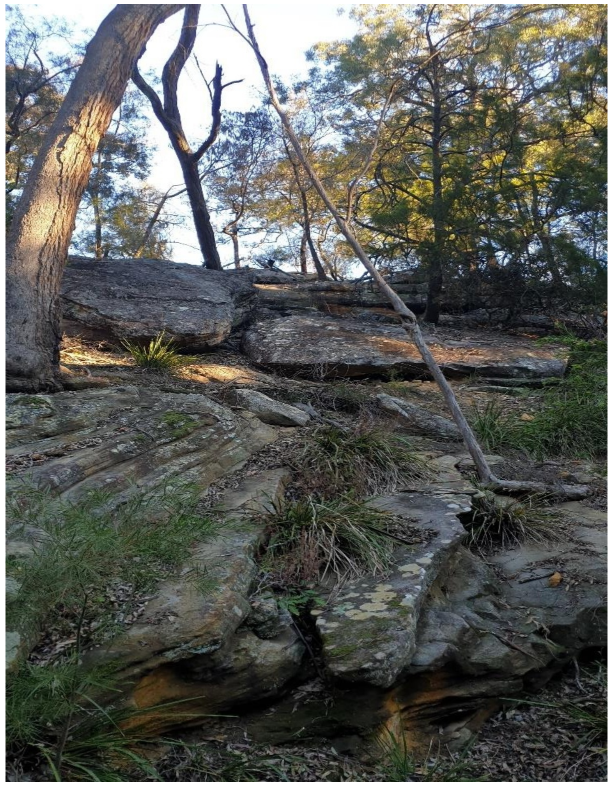

Photo 23

Photo 24

Douglas Partners Geotechnics / Environment / Groundwater	**Site Photographs**	PROJECT:	89541.00
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Photo 25

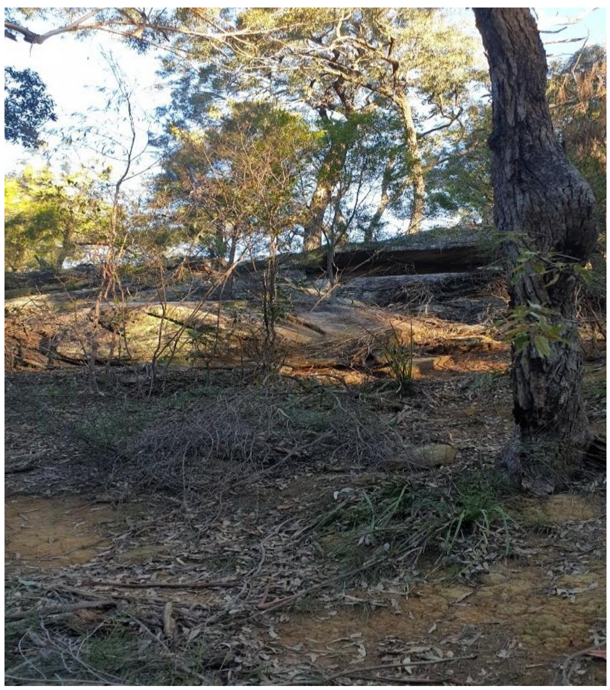

Photo 26

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	LW W1 – 2, Tahmoor North	REV:	A
	CLIENT: Tahmoor Coal Pty Ltd	DATE:	26-Jun-19

Photo 27

Photo 28

Douglas Partners Geotechnics / Environment / Groundwater	**Site Photographs**	PROJECT:	89541.00
	Cliffs at Cliffs at Stonequarry and Cedar Creek	PLATE No:	14
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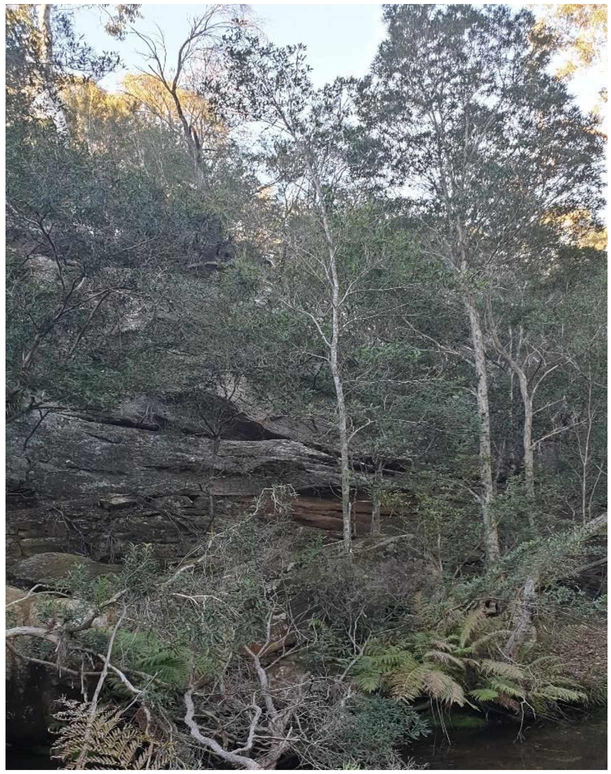

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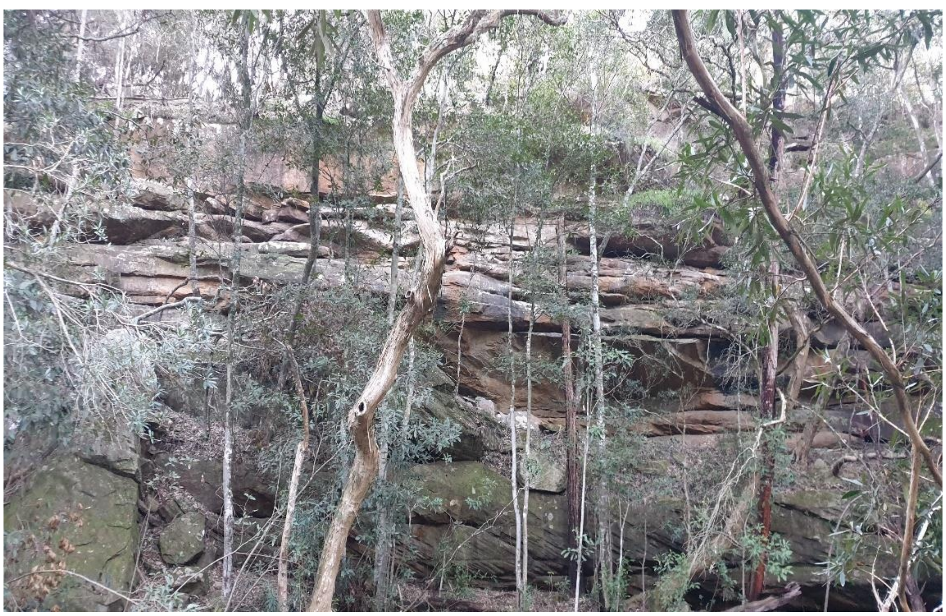

Photo 30

Douglas Partners Geotechnics / Environment / Groundwater	**Site Photographs**	PROJECT:	89541.00
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	LW W1 – 2, Tahmoor North	REV:	A
	CLIENT: Tahmoor Coal Pty Ltd	DATE:	26-Jun-19

Photo 31

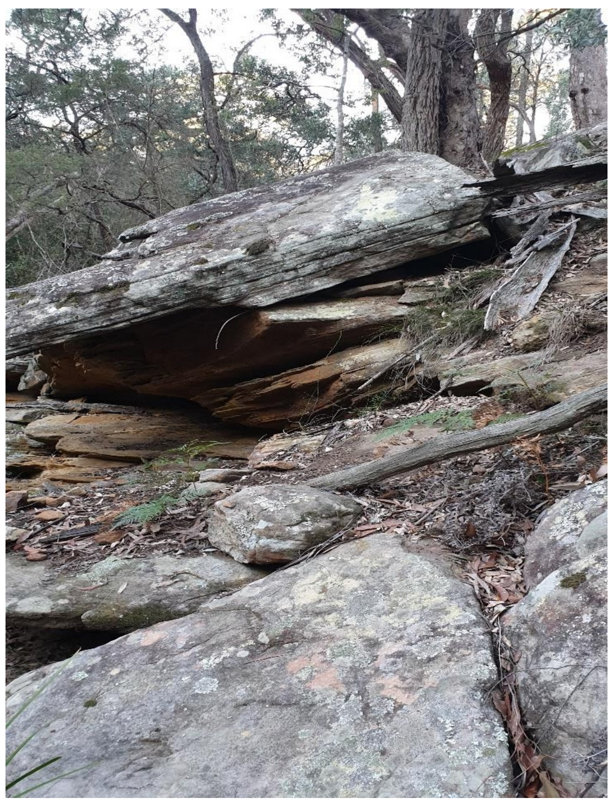

Photo 32

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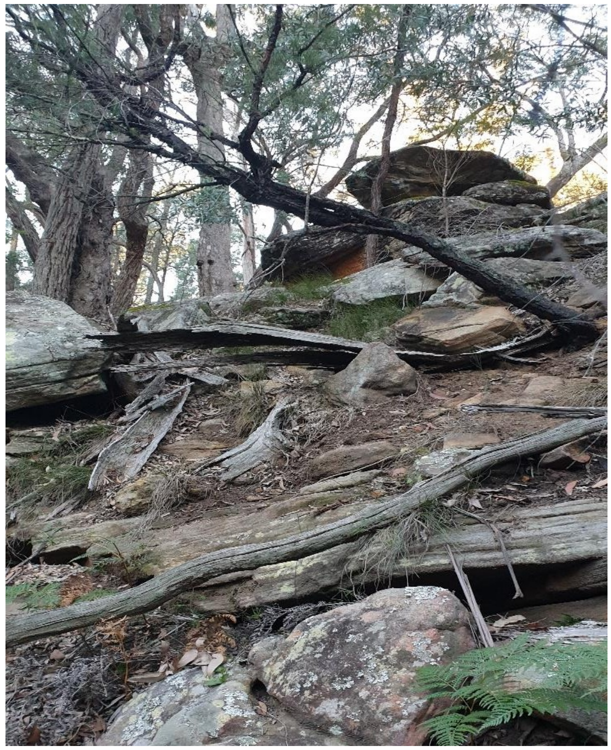
Photo 33

Photo 34

Douglas Partners Geotechnics / Environment / Groundwater	**Site Photographs** **Cliffs at Cliffs at Stonequarry and Cedar Creek** **LW W1 – 2, Tahmoor North**	PROJECT:	89541.00
		PLATE No:	17
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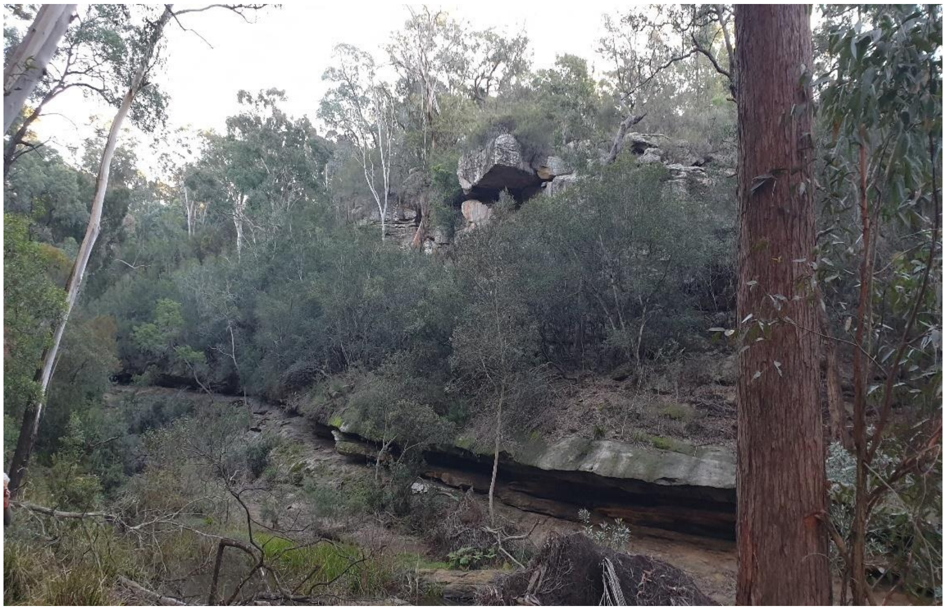


Photo 35

Douglas Partners Geotechnics / Environment / Groundwater	**Site Photographs**	PROJECT:	89541.00
	Cliffs at Cliffs at Stonequarry and Cedar Creek	PLATE No:	18
	LW W1 – 2, Tahmoor North	REV:	A
	CLIENT: Tahmoor Coal Pty Ltd	DATE:	26-Jun-19

Appendix C

Excerpts of ACARP 9037

10. The Assessment of Mining Impacts on Clifflines

This section presents methods that can be used for the assessment of mining impacts on clifflines and for predicting the likelihood of rockfalls.

10.1. Introduction

The method described in the final report on Stage 1 of this research project, for assessing the impacts of mining on clifflines, involved classifying the cliffs under four separate categories, namely:

1. Overall size and noticeable characteristics of the cliff.
2. Aesthetic quality and degree of public exposure.
3. Natural instability of the cliff formation.
4. Extent of the mining-induced ground movements.

The method covered a wide range of alternatives, but was essentially based on cliffs in the Southern Coalfield with heights up to 100 metres. All other cliffs above this height were included in a single group for the purposes of assessing the impacts.

An alternative, but similar, method of assessment was described by Radloff and Mills, Ref. 7.7, 2001, which classified the cliffs under four separate assessment categories, namely:

1. Physical characteristics.
2. Geological and mining characteristics.
3. Association with environmental features.
4. Human use aesthetics.

The method described by the authors included ratings for cliffs greater than 150 metres in height, which made the method more applicable to the Western Coalfield, where some very high cliffs exist. Since the two methods had many features in common, it was decided to integrate them, and, in that way, arrive at a single method that could have more universal application.

10.2. Development of the Method of Assessment

There was a certain amount of overlap between the first three categories and the method has, therefore, been amended and simplified, by the removal of Category 1, to avoid duplication of factors like cliff height, face length, face angle etc., which appeared in both Category 1 and Category 3. Other factors in Category 1, under the heading notable characteristics, were related to the appearance, and hence the aesthetic qualities, of the cliffs and these factors have been transferred to Category 2. The remainder of the factors, which could affect cliff stability, have been transferred to Category 3.

At the same time, the categories have been extended to include a wider range of values for each of the factors, extending the range of application of the method to include some of the higher cliffs that exist in the Western Coalfield.

The method therefore now employs only three classification categories and these are shown in Tables 10.1 to 10.3 below. Table 10.1 covers various factors that affect the extent of the mining-induced ground movements. Table 10.2 covers various factors that affect the aesthetic quality and degree of public exposure of the clifflines. Table 10.3 covers various factors that affect the natural instability of the cliff formation.

Table 10.1. Extent of the Mining-Induced Ground Movements

Score for each factor	0	1	2	4	6	Weighting
Mining induced vertical subsidence at the cliff	< 50 mm	< 100 mm	100 to 200 mm	200 to 500 mm	> 500 mm	**5**
Mining induced horizontal movement at the cliff	< 50 mm	50 to 100 mm	100 to 200 mm	200 to 300 mm	> 300 mm	**5**
Mining induced tilt at the cliff	< 1 mm/m	< 4 mm/m	< 7 mm/m	< 10 mm/m	> 10 mm/m	**5**
Mining induced strain at the cliff	< 1 mm/m	< 2 mm/m	< 5 mm/m	< 10 mm/m	> 10 mm/m	**5**
Depth of cover at the base of the cliff	> 400 m	300 to 400 m	200 to 300 m	100 to 200 m	< 100 m	**10**

Table 10.2. Aesthetic Quality and Degree of Public Exposure

Score for each factor	0	1	2	4	6	Weighting
Overall aesthetics of cliff formation	common	pleasant	distinctive	superb	spectacular	**20**
Ease of public viewing	very hard to view	hard to `view	easy to view from gravel roads	easy to view from sealed roads	tourist location	**10**
Overall height of cliff	<50m	50m to 75m	75m to 100m	> 100m	> 150m	**10**
Cliff type	rounded rock face with large talus slope	rounded rock face with minimal talus	sheer rock face with large talus	sheer rock face with minimal talus	sheer rock face with no talus	**5**
Shape of cliff face	rounded rock face	sheer rock face	sheer rock face with pagodas	sheer rock face with slender spires	Large overhangs notches or recesses	**5**
Location of cliff relative to others	Single feature	1 or 2 features	3 to 5 features	Major cliff line	Part of escarpment	**5**
Presence of archaeological sites	not related	related to a possible habitation site/s	related to a known habitation site/s	related to a prominent archaeological site/s	prominent shelter site/s with significant art	**10**
Ease of public walking access to cliff base areas exposed to rock falls	limited access, walk > 10km, no public walkways	access by walking >3km, no public walkways	access by walking >500 m, no public walkways	access by walking <500m, no public walkways	access by walking <500m, public walkways	**2**
Ease of public walking access to potentially unstable cliff top areas	limited access, walk > 10km, no public walkways	access by walking >3km, no public walkways	access by walking >500 m, no public walkways	access by walking <500m, no public walkways	access by walking <500m, public walkways	**2**
Ease of public vehicular access to cliff base areas exposed to rock falls	road access greater than 500m	road access less than 500m	4WD road access under cliff	unsealed road access under cliff	sealed road access under cliff	**5**
Ease of public vehicular access to potentially unstable cliff top areas	road access greater than 500m	road access within 500m	4WD road access to clifftop	unsealed road access to clifftop	sealed road access to clifftop	**5**
Buildings/structures above cliff face	within 10 km	within 5 km	within 1 km	within 100m	within 20m	**2**
Buildings/structures below cliff face	within 10 km	within 5 km	within 1 km	within 100m	within 20m	**5**
Dwellings above cliff face	within 10 km	within 5 km	within 1 km	within 100m	within 20m	**10**
Dwellings below cliff face	within 10 km	within 5 km	within 1 km	within 100m	within 20m	**20**

Table 10.3 Natural Instability of the Cliff Formation

Score for each factor	0	1	2	4	6	Weighting
Overall height of talus, cliff face, and crest slope.	< 50m	50m to 75m	75m to 100m	> 100m	> 150m	**2**
Cliff face height	< 20m	20m to 50m	50m to 75m	75m to 100m	> 100m	**5**
Talus slope height	< 20m	20m to 50m	50m to 75m	75m	> 100m	**1**
Cliff face length, or width	< cliff height	> cliff height	> 2 x cliff height	> 5 x cliff height	> 10 x cliff height	**4**
Cliff face angle	< 70o	> 70o	> 80o	> 90o	> 100o	**4**
Talus slope angle of repose	< 15o 1 in 3.73	> 15o 1 in 3.73	> 30o 1 in 1.73	> 40o 1 in 1.2	> 45o 1 in 1	**1**
Vegetation cover on cliff areas	dense vegetation and trees on talus and cliff	dense vegetation on talus and sparse vegetation on cliff	dense vegetation and trees on talus, none on cliff	sparse vegetation and trees on talus, none on cliff	no vegetation or trees on talus or cliffs	**2**
Degree of undercutting or weathering	clean sheer rock face	sheer rock face with small overhangs up to 1m	face with honeycomb weathering and small overhangs up to 2m	delicate honeycomb face or large overhangs i.e. 2m to 4m	delicate honeycomb face or large overhangs > 4m	**5**
Extent of horizontal jointing on cliff face	clean rock face no joints	minimal jointing > 20m	moderately jointed 10m to 20m	heavily jointed < 10m	Severely jointed < 5m	**5**
Extent of vertical jointing on cliff face	no continuous joints	joints continuing over several strata layers	continuously jointed over full height of cliff	several continuous joint systems	continuous open joints or fissures	**3**
In situ horizontal stress at seam level	< 10 MPa	10 to 20 MPa	20 to 30 MPa	30 to 40 MPa	> 40 MPa	**5**
Type of rock strata – rock strength	UCS >100 MPa	UCS > 75 < 100 MPa	UCS > 50 < 75 MPa	UCS > 30 < 50 MPa	UCS < 30 MPa	**5**
Location of cliff in relation to watercourses and valleys	not related	related to small creeks and minor tributaries	related to bluffs lining small valleys	part of major cliff lines lining valleys with talus	part of major cliff lines in gorges or escarpments	**2**
Location of cliff in relation to geological anomalies	not related	related to small faults & dykes < 500 mm	related to continuous vertical jointing	related to major faults & dykes > 500 mm	related to major thrust faults > 500 mm	**2**
Degree of exposure to ongoing weathering agents	not exposed to winds or creeks or streams	partly sheltered from winds and creeks or streams	exposed to winds and to small creeks or streams	exposed to wind action and next to major river	exposed to strong wind action and next to major river	**2**
Presence of water flows at base of slope	no stream or creek	stream or creek with gradient of less than 1 in 100	stream or creek with gradient of more than 1 in 100	river or creek with gradient of more than 1 in 75	river or creek with gradient > 1 in 50	**3**
Presence of loose & unstable blocks on cliff	few unlikely to fall	few could possibly fall	many could possibly fall	few likely to fall	many likely to fall	**5**
Loose and unstable blocks on talus	few unlikely to fall	few could possibly fall	many could possibly fall	few likely to fall	many likely to fall	**2**
Presence of natural cracks in cliff crest	none	one	two or three	several	many	**5**
Orientation of natural cracks relative to cliff line	no cracks or 90o to 60o	60o to 40o	40o to 20o	10o to 20o	< 10o	**5**

10.3. Application of the Method of Assessment to each Category

These tables allow the impact to be assessed under each category, using a point scoring system in which each factor is given a score and a weighting. The scores for each factor are then multiplied by the weighting and the resultant numbers for each factor are added to give a total score for each category. The scores are then expressed as a proportion of the highest possible score for the category, which is obtained by adding all of the weightings and multiplying the total by 6, i.e. the highest possible score for each factor. The proportions are then used to determine the impact classifications under each category using Table 10.4.

Table 10.4. Impact Classifications

Proportion of maximum score	Ranking	Classification
0 - 0.1	**1**	**insignificant**
0.1 - 0.2	**2**	**very low**
0.2 - 0.3	**3**	**low**
0.3 - 0.4	**4**	**moderate**
0.4 - 0.5	**5**	**high**
0.5 - 0.6	**6**	**very high**
> 0.6	**7**	**extremely high**

The maximum score for Table 10.1 is 180. The maximum score for Table 10.2 is 696 and the maximum score for Table 10.3 is 408. If the score for a particular cliffline is an exact decimal proportion that puts it at the top of one classification or the bottom of the next classification, then, the higher classification should be used. Factors relating to the position of the cliffline relative to the longwall and the widths of panels and pillars are reflected in the levels of ground movement given in Table 10.1 and have not been included separately.

10.4. Preparation of an Overall Impact Assessment

The classifications under each category can be combined to give an overall impact assessment for each cliffline using Tables 10.5 to 10.11. These tables have been compiled based upon the observation that if the extent of mining is extremely high, then, no matter what the classifications are within the other categories, the overall impact can not be insignificant. Similarly even if the extent of mining is insignificant, the overall impact can be as high as moderate if the classifications under the other categories are either very high or extremely high.

Tables 10.5 to 10.11 represent each of the mining classifications from an extremely high mining impact to an insignificant mining impact. The overall impact can be determined by selecting the table for the appropriate level of mining impact and then using the x and y axes to represent the impact classifications for the other two characteristics. For example, assume the classifications are:

- Aesthetic quality and degree of public exposure — very high
- Natural instability of the cliff formation — high
- The extent of mining induced ground movement — moderate

Then, the overall impact assessment can be obtained by selecting Table 10.8 for the moderate mining impact and by looking up the classification in the square where the very high column meets the high row. In this example, the overall impact would be extremely high.

It should be noted that the overall impact assessment is not a measure of the likelihood of rock falls. This is a function of the extent of the mining-induced ground movements and the natural instability of the cliffline, which is discussed further in Section 10.5, below.

Cliff Impact Assessment Tables for Different Levels of Mining Impact

Table 10.5 - Extremely High Mining impact

EH	EH	VH	H	M	L	VL	I
EH	EH	EH	EH	EH	EH	EH	M
VH	EH	EH	EH	EH	EH	EH	M
H	EH	EH	EH	EH	EH	VH	M
M	EH	EH	EH	EH	EH	H	L
L	EH	EH	EH	EH	H	M	L
VL	EH	EH	VH	H	M	L	VL
I	M	M	M	L	L	VL	VL

Table 10.6 - Very High Mining Impact

VH	EH	VH	H	M	L	VL	I
EH	EH	EH	EH	EH	EH	EH	M
VH	EH	EH	EH	EH	EH	VH	M
H	EH	EH	EH	EH	EH	H	L
M	EH	EH	EH	EH	VH	M	L
L	EH	EH	EH	VH	H	M	VL
VL	EH	VH	H	M	M	L	VL
I	M	M	L	L	VL	VL	VL

Table 10.7 - High Mining Impact

H	EH	VH	H	M	L	VL	I
EH	EH	EH	EH	EH	EH	VH	M
VH	EH	EH	EH	EH	EH	H	L
H	EH	EH	EH	EH	VH	H	L
M	EH	EH	EH	VH	H	M	L
L	EH	EH	VH	H	M	L	VL
VL	VH	H	H	M	L	L	VL
I	M	L	L	L	VL	VL	VL

Table 10.8 - Moderate Mining Impact

M	EH	VH	H	M	L	VL	I
EH	EH	EH	EH	EH	EH	H	L
VH	EH	EH	EH	EH	VH	M	L
H	EH	EH	EH	EH	H	M	L
M	EH	EH	EH	H	M	L	VL
L	EH	VH	H	M	L	L	VL
VL	H	M	M	L	L	VL	VL
I	L	L	L	VL	VL	VL	I

Table 10.9 - Low Mining Impact

L	EH	VH	H	M	L	VL	I
EH	EH	EH	EH	EH	H	M	L
VH	EH	EH	EH	VH	H	M	VL
H	EH	EH	VH	H	M	L	VL
M	EH	VH	H	M	M	L	VL
L	H	H	M	M	L	VL	VL
VL	M	M	L	L	VL	VL	VL
I	L	VL	VL	VL	VL	VL	I

Table 10.10 - Very Low Mining Impact

VL	EH	VH	H	M	L	VL	I
EH	EH	EH	VH	H	M	L	VL
VH	EH	VH	H	M	M	L	VL
H	VH	H	H	M	L	L	VL
M	H	M	M	L	L	VL	VL
L	M	M	L	L	VL	VL	VL
VL	L	L	L	VL	VL	VL	I
I	VL	VL	VL	VL	VL	I	I

Table 10.11 - Insignificant Mining Impact

I	EH	VH	H	M	L	VL	I
EH	M	M	M	L	L	VL	VL
VH	M	M	L	L	VL	VL	VL
H	M	L	L	L	VL	VL	VL
M	L	L	L	VL	VL	VL	I
L	L	VL	VL	VL	VL	VL	I
VL	VL	VL	VL	VL	VL	I	I
I	VL	VL	VL	I	I	I	I

The impact assessments are to a certain extent subjective, but the factors used in each category have been quantified, to reduce the subjectivity as far as possible. The method has been designed to provide an overall assessment of the impacts taking into account the extent of the mining-induced ground movements, the aesthetic quality and degree of public exposure of the clifflines and the natural instability of the clifflines.

It is therefore possible that the overall impact could be assessed as moderate, if the quality of the cliffline and the cliff instability were relatively low, even though the likelihood of significant rock falls was very high,. Alternatively, it is possible that the overall impact could be assessed as very high, if the cliffs had a high aesthetic value and a high instability rating, even though the likelihood of rock falls was very low,.

The method has been tested over a wide range of cases and appears to give reasonable results, but it has been designed in such a way that the scores and weightings in the assessment tables can be changed to fine-tune the method in the light of local experience. The levels of impact that are obtained using the method are not intended to be prescriptive in terms of what is, or is not, acceptable in every case and each case must be considered on its merits. What might be acceptable in one mining area might not be acceptable in another. In many cases the acceptability of the impact might rest on the likely extent of damage due to rock falls. In others, the issue of public safety might be the overriding factor.

10.5. The likelihood of Rock Falls

The likelihood of a particular cliff collapse or rock fall is impossible to predict since the stability of the cliff can not be fully determined from the appearance of the rock face. In many cases the apparently unstable rocks will remain standing, whilst the apparently stable rocks will fall. It is clear, however, that rock falls are more likely to occur as the extent of the mining impact increases, particularly where the natural instability of the cliffline is high. It is, therefore, possible to predict the likely extent of rock falls from a statistical perspective.

In the graph shown in Fig. 10.1, the percentages of the lengths of clifflines that experienced rock falls have been plotted against the natural cliff instability classification for a number of recorded cases. It should be noted that there was only one case where 100% of a cliffline experienced falls. All other cases were less than 33%. It can be seen that the percentage of clifflines that experienced rock falls increased as the mining impact increased and as the cliff instability increased. This graph can be used to predict the upper-bound % damage to clifflines based upon the scores from Tables 10.1 and 10.3. For example, if the proportion of mining-induced ground movement, assessed from Table 10.1, was 0.4 and the natural instability of the cliffline was low, then, up to 21% of the cliffline could experience rockfalls.

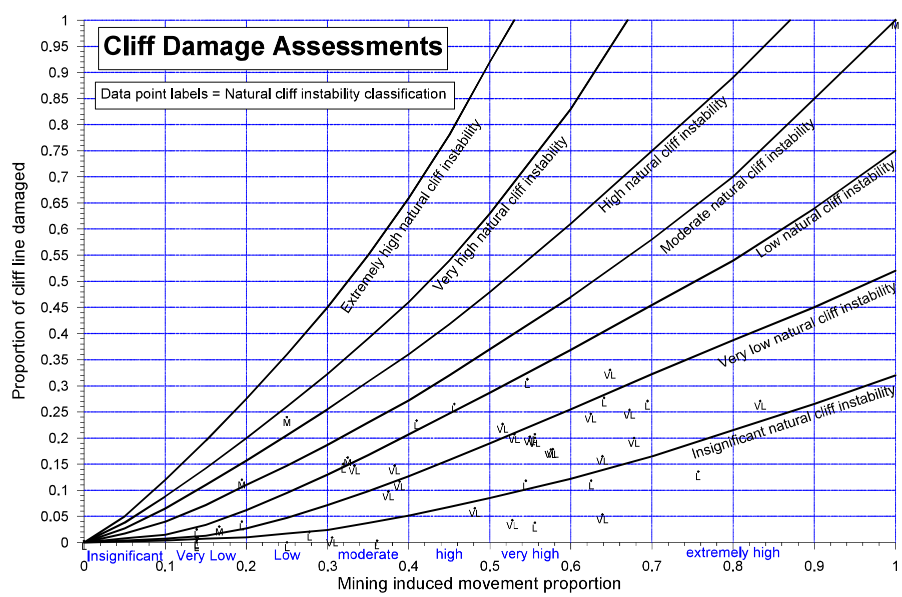


Fig. 10.1 Graph showing the likely incidence of rock falls for different levels of mining impact and different levels of cliffline instability.

It should be noted that the data used in developing the graph shown in Fig 10.1 were from the Southern and Western Coalfields and may not be representative of clifflines elsewhere. It should also be noted that the curves in this graph are upper-bound curves and in many cases the percentage of damage to clifflines could be significantly less than the maximum indicated by the graph. Similar graphs could advantageously be developed for specific mining areas where sufficient local data are available.

10.6. Testing of the method of assessment for subsidence impacts on clifflines

The method of assessment described above has been used to assess the subsidence impacts on a wide variety of clifflines including the following locations:

1. The Cataract and Nepean Gorges over Longwalls 15 to 17 at Tower Colliery.
2. The Bargo River Valley over Longwalls 14 to 19 at Tahmoor Colliery.
3. The Burragorang Valley over pillar extractions at Nattai North Colliery.
4. The clifflines of a tributary of Bullen Creek over Longwall 6 at Baal Bone Colliery.
5. The clifflines of the escarpment over Longwalls 1 to 7 at Angus Place Colliery.
6. The clifflines of the escarpment over Longwalls 8 to 11 at Angus Place Colliery.

The results of some of these analyses are shown in Table 10.12, below.

Photographs of typical cliffs at Tower Colliery, Tahmoor Colliery, Nattai North Colliery, Baal Bone Colliery and Angus Place Colliery are shown in Figs. 10.2 to 10.6, below.

Table 10.12 Some Examples of Cliff Assessment Results

	Tower Colliery Longwall 15	Tahmoor Colliery Longwall 17	Nattai North Pillar Extraction	Baal Bone Colliery Longwall 6	Angus Place Colliery Longwall 7	Angus Place Colliery Longwall 9
Aesthetic Quality	Very Low	Very Low	High	Very low	Low	Low
Natural Instability	Low	Low	Moderate	Very Low	Very Low	Low
Mining Impact	Very Low	Low	Extremely high	Extremely High	Moderate	Very High
Mining Impact Proportion	0.14	0.25	1.00	0.83	0.33	0.56
Overall Assessment	Very Low	Low	Extremely high	Low	Low	High
%Rock Falls	<2.5%	Nil	100%	27%	15%	21%

The cliffs at Baal Bone Colliery were rated as distinctive in terms of the overall aesthetics of the cliff formation, but had a very low total rating for the aesthetic quality and public exposure because of its remote location and relative inaccessibility. Similarly the cliffs at Angus Place Colliery were rated as pleasant in terms of the overall aesthetics of the cliff formation, but had a low total rating for the aesthetic quality and public exposure because of its remote location and relative inaccessibility.

In contrast, the cliffs at Nattai North Colliery were rated as spectacular in terms of the overall aesthetics of the cliff formation and had a high total rating for the aesthetic quality and public exposure because the cliffs can be easily viewed from a public road.

The cliffs at Tower Colliery and Tahmoor Colliery were generally rated as common or pleasant in terms of the overall aesthetics of the cliff formation, but had an insignificant to low total rating for the aesthetic quality and public exposure because the cliffs are not readily accessible to the public.

It can be seen that the greatest amount of damage occurred at the Nattai North Colliery even though the mining impact was also assessed to be extremely high at Baal Bone Colliery over Longwall 6. The reason for this is that the cliffs at Nattai North Colliery had a higher natural instability due to the massive scale of the cliffline, its exposure to ongoing weathering agents and the fact that the base of the cliff was directly undermined.

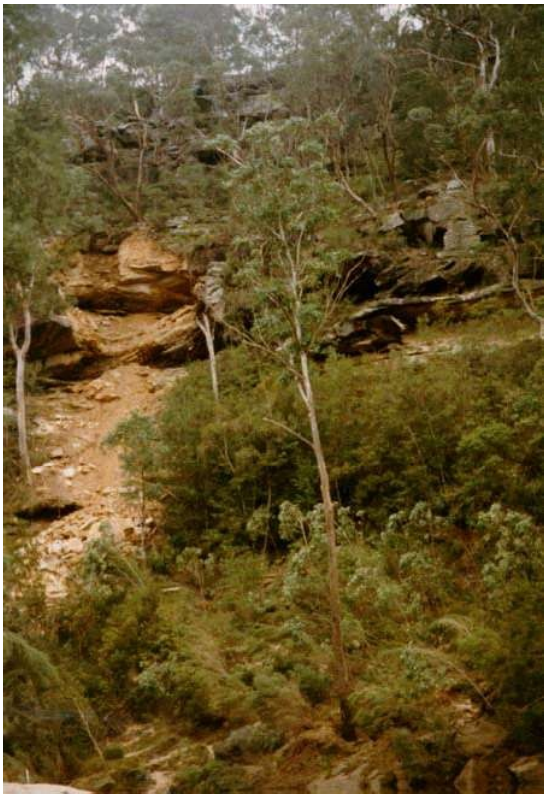


Fig. 10.2 Cliffs in the Cataract Gorge over Longwall 15 at Tower Colliery.

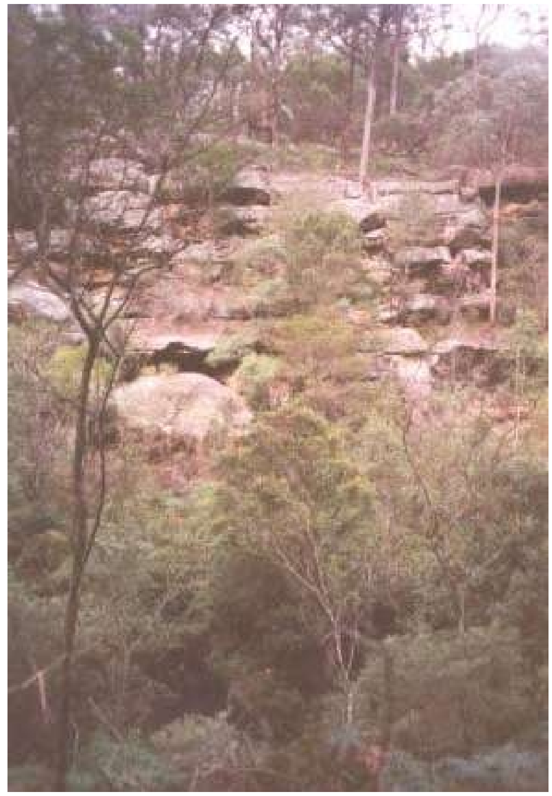


Fig. 10.3 Cliffs in the Bargo River Valley over Longwall 17 at Tahmoor colliery

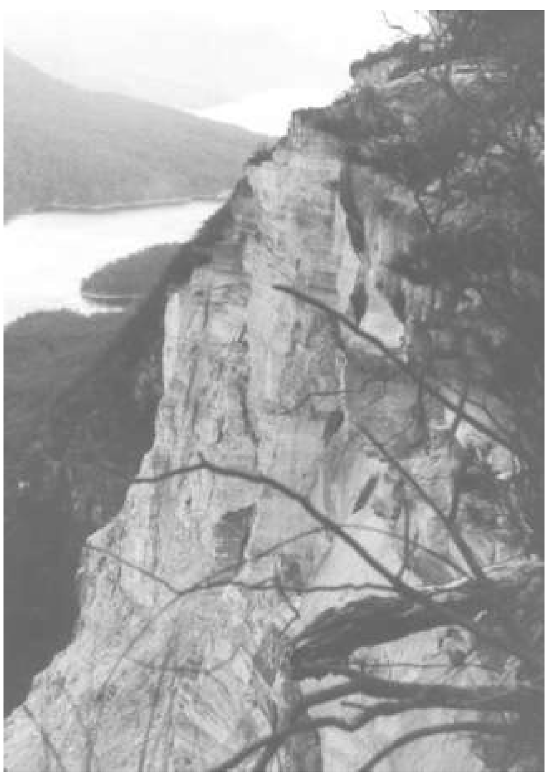


Fig. 10.4 Cliffs in the Burragorang Valley over Pillar Extractions at Nattai Colliery

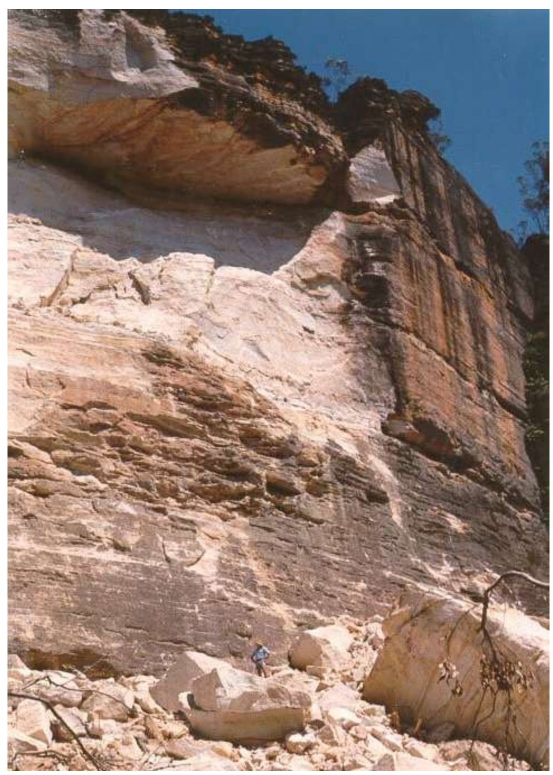


Fig. 10.5 Cliffs in a Tributary of Bullen Creek over Longwall 6 at Baal Bone colliery

Fig. 10.6 Cliffs over Longwall 2 at Angus Place Colliery

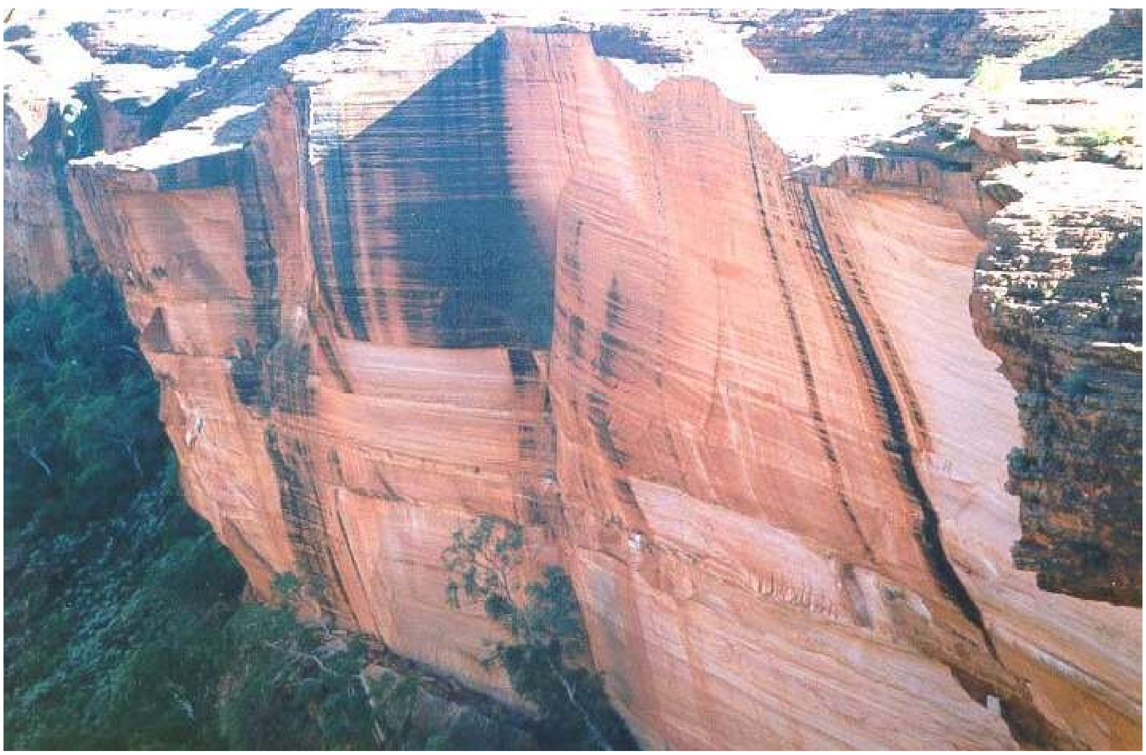


Fig. 10.7 Natural Rock Fall at Kings Canyon in Central Australia

The photographs in Figs. 10.1 and 10.4 to 10.6 show typical examples of rock falls that have occurred due to mining and indicate the immediate scarring of the landscape that occurs. Fig. 10.6, however, shows the natural regrowth that occurred on the talus slope within a period of ten years following the rock fall at Angus Place Colliery and it can be seen that nature quickly heals the scars.

For comparison, Fig. 10.7 shows a natural rock fall which occurred several years ago at Kings Canyon in Central Australia, as part of the normal process of erosion in the wall of the canyon. The canyon is a popular tourist attraction and its appeal to visitors has not been adversely affected by the fresh appearance of the rock face.

11 Methods used for the Prediction of Subsidence

This section of the report addresses the methods that can be used for the prediction of subsidence parameters and describes the Incremental Profile Method that has been used in the analysis of data for this research project.

11.1 Methods used for the Prediction of Subsidence Parameters

Several alternative methods have been used in the past to predict subsidence parameters, including:

- Graphical Methods, such as the National Coal Board Method used in the U.K.
- Profile Function Methods.
- Influence Function Methods.
- Numerical Modelling Methods.
- Empirical Methods.

Further information on alternative methods of prediction can be found in Kratzsch, Ref. 7.5, (1983) and Whittaker and Reddish, Ref. 7.9, (1989). Numerical modelling techniques have been developed in recent years using finite element and discrete element methods such as FLAC, UDEC and FLOMEC. These methods are particularly useful tools for investigating strata mechanisms and hydrological impacts, but, even with powerful computers, tend to be very time consuming, some analyses taking weeks of computer time.

Profile function methods, which seek to define the shape of the subsidence profile using a single mathematical formula, are generally only applicable to single panels, since they assume the profiles to be symmetrical and fail to recognise the way in which the shapes of subsidence profiles are modified over adjacent and previously mined goaf areas.

Whenever a large database of measured subsidence movements is available, empirical methods can be developed for the prediction of subsidence parameters and these methods can be advantageously employed over a wide range of mining geometries, taking into account local variations in strata lithology. Other modelling methods can also be beneficial where sufficient local data is available for calibration of the models. All methods of prediction, if they are to be successful, have to be checked against measured data and have to be calibrated to reflect local geology.

The empirical approach has generally been adopted in the coalfields of New South Wales and this has been expanded in recent years by the development of the Incremental Profile Method. This empirical method allows the prediction of subsidence profiles to be made over a series of longwalls for a wide range of mining geometries and can be calibrated to suit local strata lithology. The Empirical Method and the Incremental Profile Method are further described in the following sections.

11.2 The Empirical Method

The maximum subsidence of the surface, at collieries in New South Wales, has generally been predicted using empirical methods. In the past, subsidence predictions were based upon the method outlined in the Subsidence Engineers Handbook, first published by the National Coal Board, of the United Kingdom, in 1965 and revised in 1975, Ref. 7.6. This involved the use of a series of graphs, based upon numerous field observations in British mines, which allowed the shapes of the subsidence, tilt and strain profiles to be predicted.

The method gave good results when applied to British mining situations, but when the method was adopted in Australia, it became clear that the field observations differed considerably from predicted values and were generally much less than theory would suggest. This is because the strata that overlie the coal seams in British coalfields differ from those that occur in the coalfields of Australia. The rocks in Britain are generally less competent and less able to bridge the extracted voids and, therefore, for a given seam thickness, the maximum subsidence is greater than it would normally be for the same mining geometry in Australian conditions.

An intensive program of research was therefore undertaken by the New South Wales Department of Mineral Resources to arrive at a predictive model that was more appropriate for Australian conditions. It was noted that the subsidence behaviour varied significantly between the Southern Coalfield, the Newcastle Coalfield and the Western Coalfield of New South Wales. The subsidence data from collieries in New South Wales were, therefore, studied separately for each coalfield.

Appendix D

Excerpts of AGS 2007

Australian
Geomechanics
Society

Extract from

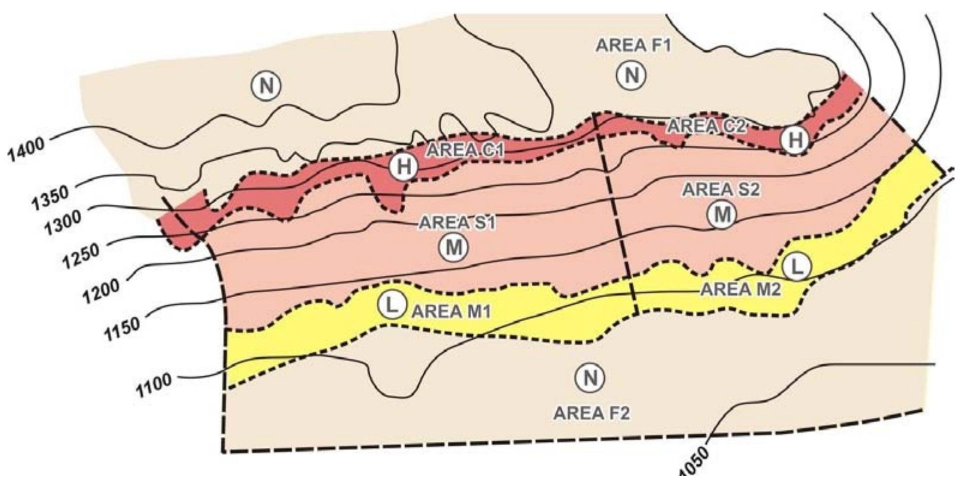
Australian Geomechanics

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

Extract containing:

"Guideline for Landslide Susceptibility, Hazard and Risk Zoning for Land Use Planning"

Ref: AGS (2007a)



Landslide Risk Management

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GUIDELINE FOR LANDSLIDE SUSCEPTIBILITY, HAZARD AND RISK ZONING FOR LAND USE PLANNING

Australian Geomechanics Society Landslide Zoning Working Group

TABLE OF CONTENTS

1 INTRODUCTION

There are a number of natural hazards which are relevant to urban, residential, rural and undeveloped property throughout Australia. These include flooding, bush fire, coastal processes and landslides. This guideline addresses landslide susceptibility, hazard and risk zoning for land use planning.

In 1998, following the Thredbo landslide in which 18 persons were killed, the Institution of Engineers Australia and the Australian Geomechanics Society (AGS) formed a Taskforce on the Review of Landslides and Hillside Construction Standards. The Taskforce after reviewing the Australian Standards and relevant codes on landslides and hillside construction concluded that they were inadequate and recommended the production of four guidelines:

- Landslide hazard zoning for urban areas, roads and railways
- Slope management
- Site investigations, design, construction and maintenance
- Landslide risk assessment

The Australian Geomechanics Society "*Landslide Risk Management Concepts and Guidelines*", already under preparation at the time of the Thredbo landslide, was published in 2000 (AGS 2000, 2002). This document touched on all four areas but mainly addressed the fourth. It is used extensively throughout Australia.

In 2005 the Australian Geomechanics Society in collaboration with the Sydney Coastal Councils Group, was successful in obtaining funding under the Australian governments' National Disaster Mitigation Program (NDMP) to further the development of the guidelines which had been recommended by the Taskforce. Work to prepare these guidelines has progressed in 2005 and 2006 and has involved extensive consultation with those involved in landslide mapping for land use planning and the application of such mapping for planning in local government.

This Guideline for Landslide Susceptibility, Hazard and Risk Zoning for Land Use Planning provides:

- Definitions and terminology.
- Description of the types and levels of landslide zoning.
- Guidance on where landslide zoning and land use planning is necessary to account for landslides.
- Definitions of levels of zoning and suggested scales for zoning maps taking into account the needs and objectives of land-use planners and regulators and the purpose of the zoning.
- Guidance on the information required for different levels of zoning taking account the types of landslides.
- Guidance on the reliability, validity and limitations of the investigation methods.
- Advice on the required qualifications of the persons carrying out landslide zoning and advice on the preparation of a brief for consultants to conduct landslide zoning for land use planning.

The guideline considers landslides occurring in natural slopes and from failure of constructed slopes including cuts, fills and retaining walls and the impact of the landslides on the area to be zoned. It is intended for use by local, state and national government officials, geotechnical professionals, land use planners and project managers.

This guideline has been developed at the same time as similar guidelines prepared by the JTC-1 *The Joint International Committee on Landslides and Engineered Slopes* and there has been an interchange of concepts and detailed inputs between the two guidelines.

Through the NDMP, Australian governments (at Commonwealth, State and Local Government levels) are also funding the development of a Practice Note Guideline (AGS 2007c) to supersede the Landslide Risk Management Guideline (AGS 2000, AGS 2002), and a series of GeoGuides on Slope Management and Maintenance (AGS 2007e).

2 DEFINITIONS AND TERMINOLOGY

2.1 DEFINITIONS

Definitions for terms used in landslide zoning and risk management are given in Appendix A. These definitions are based on IUGS (1997), with some amendments in matters of detail based on internationally adopted definitions prepared by The International Society of Soil Mechanics and Geotechnical Engineering (ISSMGE) Technical Committee 32. These definitions should be used for all zoning, reports and land use planning documents. It is recommended that the definitions are attached to these documents so there is no misunderstanding of the terms.

Definitions of the main terms are:

- **Landslide.** The movement of a mass of rock, debris, or earth (soil) down a slope**.**
- **Landslide Inventory.** An inventory of the location, classification, volume, activity and date of occurrence of individual landslides in an area.
- **Landslide Susceptibility.** A quantitative or qualitative assessment of the classification, volume (or area) and spatial distribution of landslides which exist or potentially may occur in an area. Susceptibility may also include a description of the velocity and intensity of the existing or potential landsliding.
- **Hazard.** A condition with the potential for causing an undesirable consequence. The description of landslide hazard should include the location, volume (or area), classification and velocity of the potential landslides and any resultant detached material and the probability of their occurrence within a given period of time.
  Landslide hazard includes landslides which have their source in the area or may have their source outside the area but may travel on to or regress into the area.
- **Risk**. A measure of the probability and severity of an adverse effect to health, property or the environment. Risk is often estimated by the product of probability and consequences. However, a more general interpretation of risk involves a comparison of the probability and consequences in a non-product form.
  For these guidelines risk is further defined as:
  (a) *For life loss*, the annual probability that the person most at risk will lose his or her life taking account of the landslide hazard and the temporal spatial probability and vulnerability of the person.
  (b) *For property loss*, the annual probability of the consequence or the annualised loss taking account of the elements at risk, their temporal spatial probability and vulnerability.
- **Elements at Risk.** The population, buildings and engineering works, economic activities, public services utilities, infrastructure and environmental features in the area potentially affected by the landslide hazard.

- **Vulnerability.** The degree of loss to a given element or set of elements within the area affected by the landslide hazard. It is expressed on a scale of 0 (no loss) to 1 (total loss). For property, the loss will be the value of the damage relative to the value of the property; for persons, it will be the probability that a particular life (the element at risk) will be lost, given the person(s) is (are) affected by the landslide.
- **Zoning.** The division of land into homogeneous areas or domains and their ranking according to degrees of actual or potential landslide susceptibility, hazard or risk.

In this guideline use of the word 'landslide' implies both existing (or known landslides) and potential landslides which a practitioner might reasonably predict based on the relevant geology, geometry and slope forming processes. Such potential landslides may be of varying likelihood of occurrence.

The term landslip is sometimes used to describe landslides but is not the recommended term.

It is noted that the term "zoning" has particular application by planners in Australia. This document uses the term as it best describes the process and is used internationally. To avoid confusion, those preparing landslide zoning using this document should always refer to " landslide susceptibility zoning", "landslide hazard zoning" and "landslide risk zoning".

2.2 LANDSLIDE CLASSIFICATION AND TERMINOLOGY

It is important that those carrying out landslide mapping use consistent terminology to classify and describe the landslides. It is recommended that the classifications of Cruden and Varnes (1996), Varnes (1978) or Hutchinson (1988) and terminology described in IAEG (1990) be used. These are reproduced in AGS (2007c).

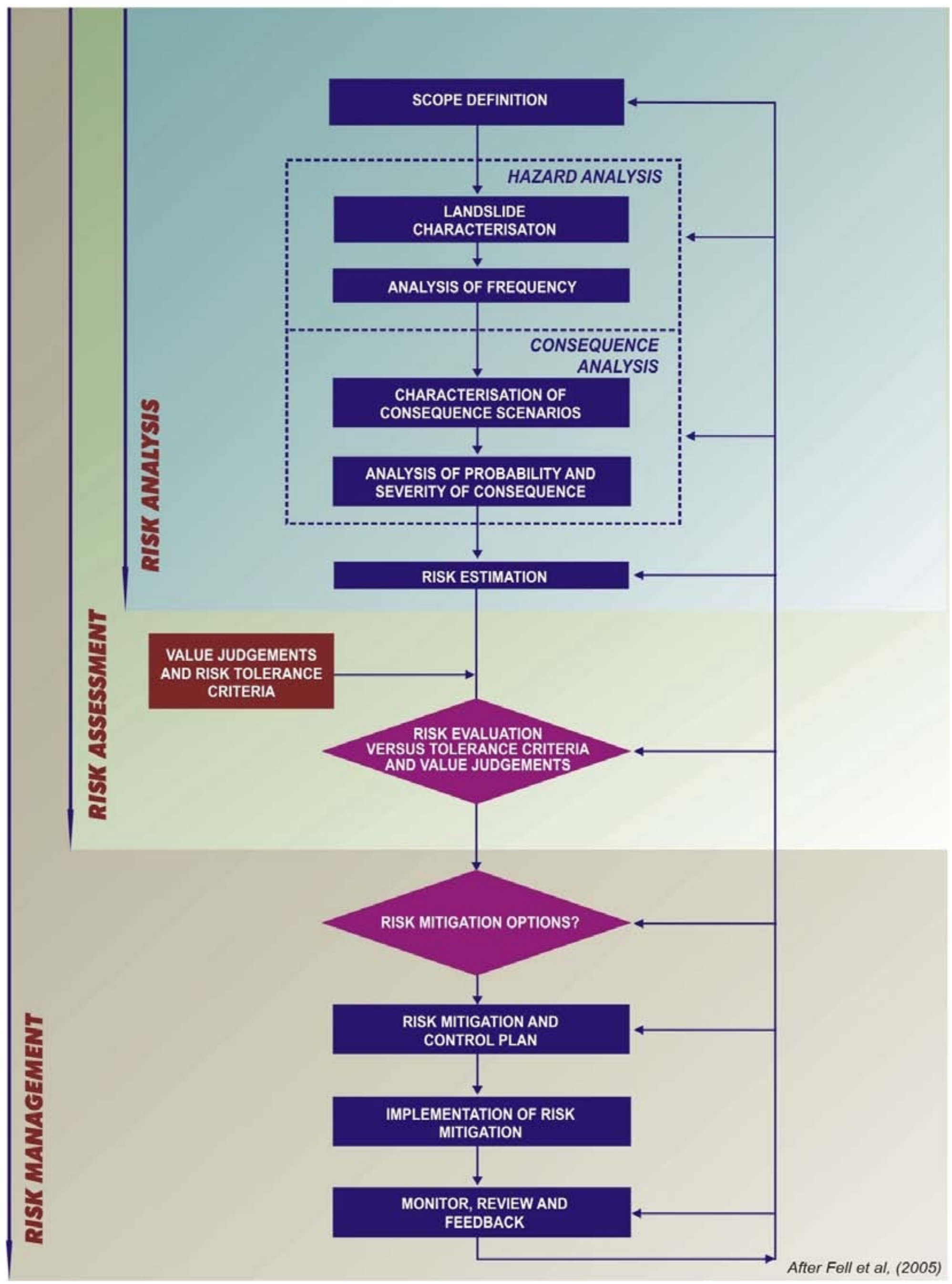
3 LANDSLIDE RISK MANAGEMENT FRAMEWORK

Since the publication of AGS (2000), many local government authorities have required a quantitative risk assessment approach for assessment of life loss risk for individual building developments. They have generally accepted qualitative or semi-quantitative assessment of property risk. These assessments are carried out using the risk based framework described in AGS (2000) and AGS (2002).

Figure 1 summarizes the framework for landslide risk management. This is taken from Fell *et al.* (2005) and represents a framework widely used internationally. It was the basis for the State of the Art papers and invited papers at the International Conference on Landslide Risk Management held on Vancouver in May 2005 and is consistent with AGS (2000), AGS (2002)and AGS (2007c).

It is recommended that this general framework be used for landslide susceptibility, hazard and risk zoning whether a quantitative or qualitative approach is being taken.

Figure 1. FRAMEWORK FOR LANDSLIDE RISK MANAGEMENT



4 DESCRIPTION OF LANDSLIDE SUSCEPTIBILITY, HAZARD AND RISK ZONING FOR LAND USE PLANNING

4.1 TYPES OF LANDSLIDE ZONING

Landslide Susceptibility Zoning involves the classification, volume (or area) and spatial distribution of existing and potential landslides in the study area. It may also include a description of the travel distance, velocity and intensity of the existing or potential landsliding. Landslide susceptibility zoning usually involves developing an inventory of landslides which have occurred in the past together with an assessment of the areas with a potential to experience landsliding in the future, but with no assessment of the frequency (annual probability) of the occurrence of landslides. In some situations susceptibility zoning will need to be extended outside the study area being zoned for hazard and risk to cover areas from which landslides may travel on to or regress into the area being zoned. It will generally be necessary to prepare separate susceptibility zoning maps to show landslide sources and areas onto which landslides from the source landslides may travel or regress.

Landslide Hazard Zoning takes the outcomes of landslide susceptibility mapping, and assigns an estimated frequency (annual probability) to the potential landslides. It should consider all landsliding which can affect the study area including landslides which are above the study area but may travel onto it and landslides below the study area which may retrogressively fail up-slope into it. The hazard may be expressed as the frequency of a particular type of landslide of a certain volume or landslides of a particular type, volume and velocity (which may vary with distance from the landslide source) or, in some cases, as the frequency of landslides with a particular intensity where intensity may be measures in kinetic energy terms. Intensity measures are most useful for rock falls.

Landslide Risk Zoning takes the outcomes of hazard mapping and assesses the potential damage to persons (annual probability the person most at risk loses his or her life) and to property (annual value of property loss) for the elements at risk, accounting for temporal and spatial probability and vulnerability.

It will often be necessary to produce separate susceptibility, hazard and risk zoning maps for the different types of landslides affecting the area; e.g. for rock falls, small shallow landslides and deep-seated larger landslides. It may be necessary to produce separate maps for landslides from natural slopes and constructed slopes. If these are combined on to one map the boundaries may be confusing.

Appendix A in the Commentary has examples of landslide susceptibility, hazard and risk zoning for slopes which may experience rock falls, small landslides and large landslides.

5 GUIDANCE ON WHERE LANDSLIDE ZONING IS USEFUL FOR LAND USE PLANNING

5.1 GENERAL PRINCIPLES

Landslide zoning for land use planning is most commonly required at the local government level for planning urban development, but may be required by state or federal governments for regional land use planning or disaster management planning. It may also be required by land developers, those managing recreational areas or those developing major infrastructure such as highways and railways. The following are some examples of situations that are more susceptible to landslide occurrence. Their identification through landslide zoning would facilitate development planning and landslide risk management. It is the combination of having an area which is potentially subject to landsliding and the scale and type of development of the area that will determine whether landslide zoning is needed for land use planning. The type of zoning required is discussed in Section 6.

5.2 TOPOGRAPHICAL, GEOLOGICAL AND DEVELOPMENT SITUATIONS WHERE LANDSLIDING IS POTENTIALLY AN ISSUE

The following are examples where landsliding is potentially an issue in land use planning:

(a) Where there is a history of landsliding e.g:
- Deep-seated sliding on natural slopes.
- Widespread shallow slides on steep natural slopes.
- Rock falls from steep slopes and cliffs.
- Rock falls from coastal cliffs.
- Landslides in cuts, fills and retaining walls on roads, railways and associated with urban development.
- Large currently inactive landslides subject to undercutting by active erosion of the toe or subject to reactivation by development.
- Debris flows and earth slides from previously failed slopes.
- Widespread shallow creep type landslides in slopes of any inclination.

(b) Where there is no history of sliding but the topography dictates sliding may occur. e.g:
- Cliffs (coastal and inland).
- Natural slopes steeper than 35^{o} (landslide travel is likely to be rapid).
- Natural slopes between 20^{o} and 35^{o} (rapid landslide travel is possible).
- Steep, high road or rail cuttings.
- Steep slopes degraded by recent forest logging, forest fires and/or construction of roads.

- Large currently inactive landslides subject to rising groundwater regimes; e.g. by forestry and agricultural operations.

(c) When there is no history of sliding but geological and geomorphologic conditions are such that sliding is possible e.g:

- Weathered basalt overlying other more competent rocks (sliding often occurs on the boundaries).
- Weathered granitic and volcanic rocks.
- Weathered interbedded rocks (such as claystone, shale and siltstone) and sandstone or limestone.
- Sand dunes.
- River banks in soil subject to floods and/or active erosion.
- Steep natural slopes in regions affected by large earthquakes.
- Slopes in highly sensitive weak clays (e.g. quick clays).
- Where there is active undercutting of slopes by rivers or the sea.
- In seismically active regions slopes in loose saturated soil which are susceptible to liquefaction.

(d) Where there are constructed features which, should they fail, may travel rapidly e.g:

- Loose silty sandy fills (residual/extremely weathered granite; ripped sandstone etc).
- Other side cast fills on steep slopes.
- Large retaining walls.
- Mine overburden spoil and mine waste dumps, particularly those sited on hillsides.
- Tailings dams constructed using upstream construction methods.

(e) Forestry works and agricultural land clearing where landsliding may lead to damage to the environment by degrading streams and other receiving water bodies.

It should be noted that rapid sliding is important because of the potential for life loss. However slow and very slow moving landslides are also of importance because they may also lead to property damage.

5.3 TYPES OF DEVELOPMENT WHERE LANDSLIDE ZONING FOR LAND USE PLANNING WILL BE BENEFICIAL

The following are examples of where landslide zoning for land use planning will be beneficial:

(a) Residential land development

- New urban areas.
- Subdivision of rural land.
- Subdivision of urban land where a number of allotments will be formed. It is envisaged that an area of at least 2 hectares or 20 house allotments would be involved. For smaller areas the procedures for individual risk assessments can be followed.
- Redevelopment of urban areas.

(b) Residential development controls in existing urban areas potentially affected by landsliding.

- Within part or all of a local government area.
- City wide.

(c) Development of important infrastructure.

- Hospitals, schools, fire brigades and other emergency services.
- Critical communications infrastructure.
- Major lifelines such as transport, water, gas pipelines and electricity power lines

(d) Recreational areas.

- Alpine resorts.
- Other resorts e.g. islands.
- State and national parks (coastal and others).
- Sports facilities.
- Coastal walkways.

(e) Development of new or redevelopment of existing highways, roads and railways.

- Rural.
- Urban main roads.
- Urban subdivision roads.

(f) Public land where landsliding may travel on to or retrogress into adjacent developments.

- State forests.
- State and National parks.
- Municipal parks.

(g) River valleys in which dams are to be constructed, including the slopes adjoining the reservoir and river valleys upstream where there is potential for blockage of rivers by landslides and breach of the landslide dam with subsequent outburst floods, and/or the creation of large waves which may overtop the dam if a large rapidly moving landslide travels into the reservoir.

It should be recognized that if the land under consideration for land use planning falls into any of the categories in Section 5.2, there will be potential land management benefits in carrying out landslide zoning.

The categories listed are not meant to be a complete list. Nether is it meant that if one or more of these categories are present that landslide zoning is essential. Those involved should assess whether zoning is necessary taking account of the factors detailed above, the development proposed and the applicable regulatory requirements.

6 SELECTION OF THE TYPE AND LEVEL OF LANDSLIDE ZONING

6.1 SOME GENERAL PRINCIPLES

Landslide zoning is carried out for regional, local and site specific planning. The outputs are usually in the form of one or more of the following: landslide inventory, susceptibility, hazard and risk zoning maps and associated reports.

The type and level of detail of the zoning and the scale of the maps depends on the purpose to which the landslide zoning is to be applied and a number of other factors:

- *The stage of development of the land use zoning plan or engineering project.* Susceptibility and hazard zoning are more likely to be used in preliminary stages of development with hazard and risk zoning for more detailed stages. However the choice depends mostly on the intended purpose of the zoning in land use management.
- *The type of development*. Risk zoning is more likely to be used for existing urban developments where the elements at risk are defined or for existing and planned road and railway developments where the elements at risk (the road or rail users) are readily predicted. However, the elements at risk often vary with time so risk zoning needs to be up-dated regularly.
- *The classification, activity, volume or intensity of landsliding*. Risk zoning is more likely to be required where the landslides are likely to travel rapidly and or have a high intensity as measured by the combination of volume and velocity (e.g. rock fall, debris flows, rock avalanches). For these situations life loss is more likely so it is useful to use risk zoning as this allows land use zoning to be determined using life loss risk criteria.
- *Funds available.* While the purpose should determine the level of zoning and the scale of the maps, the funding available may be a practical constraint. Landslide susceptibility zoning is lower cost than hazard zoning, and hazard zoning is somewhat lower cost than risk zoning, so land use planners may opt for a lesser type and level of mapping at least in a staged introduction of landslide land use planning.
- *The amount and quality of available information.* Only susceptibility zoning is performed where data on frequency of landslides either do not exist or are so uncertain as to not be relied on.
- *History of land use.* The history of the area being zoned and its evolution in terms of land use must be carefully taken into account as human activities may modify the slope instability environment and modify the susceptibility to and likelihood of landsliding and hence the hazard.
- *Degree of quantification.* Qualitative methods are often used for susceptibility zoning and sometimes for hazard zoning. It is better to use quantitative methods for both susceptibility and hazard zoning. Risk zoning should be quantified. More effort is required to quantify the hazard and risk but there is not necessarily a great increase in cost compared to qualitative zoning.
- *The required accuracy of the zoning boundaries*. Where statutory land use planning constraints are proposed large scale maps with appropriate levels of inputs should be used. In this regard it should be noted that State and Local governments may have different requirements. The largest scale required will determine the level and scale of landslide zoning.
- *Linkage to the proposed planning controls*. The use of complementary or linking processes such as planning schedules and development control plans whereby the landslide zoning initiates a more detailed assessment at site scale. In this case, the use of landslide susceptibility mapping which defines a planning control area may be sufficient to identify where a more detailed landslide risk assessment is needed.

Table 1: Recommended types and levels of zoning and zoning map scales related to landslide zoning purpose.

Purpose	Type of Zoning				Zoning Level			Applicable Zoning Map Scales
	Inventory	Susceptibility	Hazard	Risk	Preliminary	Intermediate	Advanced	
Regional Zoning								
Information	X	X			X			1:25,000
Advisory	X	X	(X)		X	(X)		to
Statutory	NOT RECOMMENDED							1:250,000
Local Zoning								
Information	X	X	X	(X)	X	(X)		1:5,000
Advisory	(X)	X	X	X	X	X	X	to
Statutory		(X)	X	(X)		X	X	1:25,000
Site Specific Zoning								
Information	NOT RECOMMENDED							>1:5000,
Advisory	NOT COMMONLY USED							typically
Statutory		(X)	X	X		X	X	1:5,000
Design		(X)	(X)	X		(X)	X	to 1:1,000

Notes: X= applicable; (X) = may be applicable

6.2 RECOMMENDED TYPES AND LEVELS OF ZONING AND MAP SCALES

Table 1 shows the recommended types of zoning, zoning levels and mapping scales that depend on the purpose of the zoning. The table is applicable to land use planning for urban development. The table is broadly applicable to other uses such as managing landslide hazard and risks for new and existing roads and railways.

It will usually be appropriate to carry out landslide susceptibility zoning as a first stage in the development of landslide hazard or risk zoning for planning purposes. Staging will allow better control of the process and may reduce the costs of the zoning by limiting the more detailed zoning only to areas where it is necessary.

It should be noted that it will seldom be necessary to carry out landslide zoning at an advanced level because the costs will potentially be so much larger than the costs for intermediate level zoning and this will potentially outweigh the benefits.

The levels of zoning and descriptors of susceptibility, hazard and risk are given in the following sections. It is recommended that these descriptors be used by all involved in landslide risk management.

6.3 DEFINITION OF THE LEVELS OF ZONING

Table 2 defines the levels of landslide inventory, susceptibility, hazard and risk zoning in terms of geotechnical and other input data. The definitions of the levels of the input data are given in Section 8. It is important to match the level of the zoning to the required usage, the scale of mapping and in turn match these to the level of the input data. It is not possible, for example, to produce a satisfactory advanced level hazard zoning without at least intermediate level assessment of frequency of landsliding. If only a basic level assessment of frequency can be made then the result will be no better than preliminary level and there is no point spending large resources getting the other inputs to a intermediate or, in particular, to a sophisticated level. On the other hand, if a preliminary level hazard zoning is required then the inputs may be at the basic level.

Table 2: Levels of activity required for susceptibility, hazard and risk zoning levels.

Type of Zoning	**Risk Zoning**						
	Hazard Zoning						
	Susceptibility Zoning						
	Inventory Mapping						
Zoning Level	**Inventory of existing landslides**	**Characteriz-ation of potential landslides**	**Travel distance and velocity**	**Frequency assessment**	**Temporal spatial probability**	**Elements at risk**	**Vulnerability**
Preliminary	Basic (1) (2)	Basic (1) (2)	Basic (1) Intermediate (2)	Basic (1,2)	Basic (1,2)	Basic (1,2)	Basic (1,2)
Intermediate	Intermediate	Intermediate	Intermediate	Intermediate	Intermediate	Intermediate	Intermediate to Basic
Advanced	Sophisticated	Sophisticated to Intermediate	Intermediate to Sophisticated	Intermediate to Sophisticated	Sophisticated	Sophisticated	Intermediate to Sophisticated

Notes:

(1) For qualitative zoning
(2) For quantitative zoning
(3) See Section 8 for description of the levels of input information. viz basic, intermediate, sophisticated.

6.4 LANDSLIDE ZONING REPORTS

Landslide zoning reports should include:

- A landslide inventory map and associated information on landslides in the inventory such as classification, location, time of sliding (if known), volume and a description of validation and limitations of the inventory.

- Susceptibility zoning map(s) with related information on how susceptibility was determined and a description of validation and limitations of the zoning.
- Where hazard zoning is required a hazard zoning map(s) at an appropriate scale with related information on how frequency of landsliding was assessed and a description of validation and limitations of the zoning. The report should also include the landslide inventory and susceptibility zoning.

Where risk zoning is required a risk zoning map(s) at an appropriate scale with related information on how frequency of landsliding was assessed and detail the assumed elements at risk, temporal spatial probabilities and vulnerabilities and how these were determined and a description of validation and limitations of the zoning. The report should also include the landslide inventory and susceptibility and hazard zoning.

7 LANDSLIDE ZONING MAP SCALES AND DESCRIPTORS FOR SUSCEPTIBILITY, HAZARD AND RISK ZONING

7.1 SCALES FOR LANDSLIDE ZONING MAPS AND THEIR APPLICATION

Table 3 summarizes map scales and the landslide inventory, susceptibility, hazard and risk mapping to which they are usually applied. Landslide zoning maps should be prepared at a scale appropriate for displaying the information needed at a particular zoning level.

Table 3: Landslide zoning mapping scales and their application.

Scale Description	Indicative Range of Scales	Examples of Zoning Application	Typical Area of Zoning
Small	< 1:100,000	Landslide inventory and susceptibility to inform policy makers and the general public	>10,000 square kilometres
Medium	1:100,000 to 1:25,000	Landslide inventory and susceptibility zoning for regional and local development or very large scale engineering projects. Preliminary level hazard mapping for local areas	1000 – 10,000 square kilometres
Large	1:25,000 to 1:5,000	Landslide inventory, susceptibility and hazard zoning for local areas Preliminary level risk zoning for local areas and the advanced stages of planning for large engineering structures, roads and railways	10-1000 square kilometres
Detailed	> 5,000	Intermediate and advanced level hazard and risk zoning for local and site specific areas and for the design phase of large engineering structures, roads and railways	Several hectares to tens of square kilometres

In practical terms the scale of mapping may be controlled by the scale of the available topographic maps.

7.2 DESCRIPTORS OF THE DEGREE OF SUSCEPTIBILITY, HAZARD AND RISK FOR USE IN LANDSLIDE ZONING

7.2.1 General

There will be considerable benefits if those carrying out landslide zoning use common descriptors to describe the degree of landslide susceptibility, hazard and risk. It will allow geotechnical professionals doing the zoning to relate to each other and allow legislators and those developing building controls to refer to these descriptors in the knowledge that they have a uniform meaning. This Section defines susceptibility, hazard and risk descriptors.

7.2.2 Examples of landslide susceptibility descriptors

It is difficult to standardise descriptions of landslide susceptibility because:

- Whether the geological, topographical, geotechnical and climatic conditions are judged to be conducive to landsliding is often subjective and not readily quantified.
- Different descriptors are required for the different types of landslides, e.g. the proportion of the area which may be affected by the landsliding for small scale landslides; the number of landslides/ square km for small landslides; the number of rock falls per kilometre length of cliff etc.

- The difficulty of assessing whether if landsliding occurs, it will travel on to slopes below or retrogress up-slope and the likelihood that a particular area will be affected by the landslide.
- The time frame in which landslides have occurred is not included (it is in hazard)

In some situations it may be sufficient to simply use two susceptibility descriptors; "susceptible" and "not susceptible". In general however there will be value in conveying to users of the maps the degrees of susceptibility either in quantified or relative terms.

Table 4 gives examples of landslide susceptibility mapping descriptors for some more common scenarios.

Table 4: Examples of landslide susceptibility mapping descriptors.

Susceptibility Descriptors	**Rock Falls**	**Small Landslides on Natural Slopes**	**Large Landslides on Natural Slopes**

(a) Quantified susceptibility descriptors

	Probability rock falls will reach the area given rock falls occur from a cliff (1)	Proportion of area in which small landslides may occur (2)	Proportion of area in which large landslides may occur (2) (3)
High susceptibility	>0.5	>0.5	>0.5
Moderate Susceptibility	>0.25 to 0.5	>0.25 to 0.5	>0.25 to 0.5
Low susceptibility	>0.01 to 0.25	>0.01 to 0.25	>0.01 to 0.25
Very low susceptibility	0 to 0.01	0 to 0.01	0 to 0.01

(b) Relative susceptibility descriptors

Susceptibility Descriptors	**Rock Falls**	**Small Landslides on Natural Slopes**	**Large Landslides on Natural Slopes**
	The proportion of the total landslide population in the study area.	The proportion of the total landslide population in the study area.	The proportion of the total landslide population in the study area.
High susceptibility	>0.5	>0.5	>0.5
Moderate Susceptibility	>0.1 to 0.5	>0.1 to 0.5	>0.1 to 0.5
Low susceptibility	>0.01 to 0.1	>0.01 to 0.1	>0.01 to 0.1
Very low susceptibility	0 to 0.01	0 to 0.01	0 to 0.01

Notes

(1) Spatial probability determined from historic, relative stability indexes, data or analysis taking consideration of the uncertainty in travel distance.
(2) Based on landslide inventory, geology, topography and geomorphology.
(3) Usually this is active, dormant and potentially reactivated slides, not first time slides.
(4) By "small" landslides is meant here landslides which are less than about 1000 m^3 volume.

Rock fall susceptibility may also be described in terms of the density of scars on a rock slope from which falls have occurred or the number of rocks which have fallen from a slope. For small shallow landslides the susceptibility may also be expressed as the number of slides per square kilometre.

There are advantages in using the quantified susceptibility descriptors in that the susceptibility of different areas being zoned can be compared. Relative susceptibility applies only within the study area and may represent quite different absolute susceptibilities in different areas being zoned.

For the relative susceptibility descriptors the objective usually is to include the largest number of landslides in the higher susceptibility classes whilst trying to achieve the minimum spatial area for these classes. So the higher susceptibility classes should have the greatest density of landslides, even though the density is not assessed.

It is important to note that landslide susceptibility mapping does not quantify the number of rock falls or small landslides which may occur in a given time period, nor for large landslides the annual probability that landsliding will occur. That is done in hazard mapping.

7.2.3 Recommended landslide hazard zoning descriptors

The manner in which landslide hazard is described depends on the type of landslide. For small slides and rock falls the hazard is described in terms of the number of slides per length of source area/annum, or the number of landslides per square kilometre of source area/annum. For large landslides hazard is described in terms of the annual probability of active sliding, or for active slides the annual probability movement will exceed a defined distance or the annual probability that cracking within a slide exceeds a defined length. Table 5 presents recommended descriptors for the most common landslide and rock fall situations.

Table 5: Recommended descriptors for hazard zoning.

Hazard Descriptor	**Rock Falls from Natural Cliffs or Rock Cut Slope**	**Slides of Cuts and Fills on Roads or Railways**	**Small Landslides on Natural Slopes**	**Individual Landslides on Natural Slopes**
	Number/annum/km of cliff or rock cut slope	Number/annum/km of cut or fill	Number/square km/annum	Annual probability of active sliding
Very High	>10	>10	>10	10^{-1}
High	1 to 10	1 to 10	1 to 10	10^{-2}
Moderate	0.1 to 1	0.1 to 1	0.1 to 1	10^{-3} to 10^{-4}
Low	0.01 to 0.1	0.01 to 0.1	0.01 to 0.1	10^{-5}
Very Low	< 0.01	<0.01	< 0.01	$< 10^{-6}$

The description of the hazard should include the classification and volume (or area) of the landslides.

7.2.4 Recommended landslide risk zoning descriptors

Table 6 gives recommended descriptors for landslide risk zoning using life loss criteria. These are based on annual individual risk for the person most at risk.

If there is a potential for a large number of persons to be killed in one landslide event there should be an assessment of societal risk as described in AGS (2007c) and Leroi *et al.* (2005).

For property loss risks the risk matrix and terms in AGS (2007c) should be used. This is reproduced in Table 7.

It should be recognised that risk zones are dependent on the hazard, the elements at risk and risk control factors. If any of these alter the risk zoning will need to be revised.

Table 6: Recommended descriptors for risk zoning using life loss criteria.

Annual Probability of Death of the Person Most at Risk in the Zone	**Risk Zoning Descriptors**
$>10^{-3}$ /annum	Very High
10^{-4} to 10^{-3} /annum	High
10^{-5} to 10^{-4} /annum	Moderate
10^{-6} to 10^{-5} /annum	Low
$< 10^{-6}$ /annum	Very Low

Table 7: Recommended descriptors for risk zoning using property loss criteria (AGS 2007c).

Likelihood		**Consequences to property (With indicative approximate cost of damage)** (1)				
	Indicative Value of Approximate Annual Probability	**1: CATASTROPHIC 200%**	**2: MAJOR 60%**	**3: MEDIUM 20%**	**4: MINOR 5%**	**5: INSIGNIFICANT 0.5%**
A ALMOST CERTAIN	10^{-1}	VH	VH	VH	H	M or **L** (2)
B LIKELY	10^{-2}	VH	VH	H	M	**L**
C -POSSIBLE	10^{-3}	VH	H	M	M	**VL**
D UNLIKELY	10^{-4}	H	M	**L**	**L**	**VL**
E RARE	10^{-5}	M	**L**	**L**	**VL**	**VL**
F BARELY CREDIBLE	10^{-6}	**L**	**VL**	**VL**	**VL**	**VL**

Notes: (1) As a percentage of the value of the property.
(2) For Cell A5, may be subdivided such that a consequence of less than 0.1% is Low Risk.
(3) L low, M medium, H high, VL very low, VH very high.

7.2.5 Recommended approach

It is recommended that Table 6 be used universally for life loss risk zoning. It is suggested that Table 7 be used for property loss so far as is practicable but it is recognized that project specific terms may be developed.

It is suggested that so far as possible Tables 4 and 5 be used to describe susceptibility and hazard zoning, but it is recognised that there will be cases where site specific descriptors will be preferred. Whatever descriptors are used it is important that the definitions should be attached to the report and so far as practical shown on zoning maps. Landslide zoning will generally be done for conditions as they are at the time of the study. There may be situations where a second zoning may be presented to allow for hazard and risk management measures which may be proposed as part of a land development.

8 METHODS FOR LANDSLIDE ZONING FOR LAND USE PLANNING

8.1 THE PURPOSE OF THIS SECTION

This Section discusses the methods for landslide zoning for land use planning. It is based on Table 1 which lists the levels of susceptibility, hazard and risk zoning, how these are related to the methods used to assess the inputs to the zoning and whether the inputs are determined using basic, intermediate or sophisticated methods. The methods involve "activities" which are presented so there is a common understanding of what is involved in the zoning process.

8.2 THE IMPORTANCE OF UNDERSTANDING SLOPE PROCESSES AND THE GEOTECHNICAL CHARACTERISTICS OF THE LANDSLIDING

It is essential for all levels of landslide inventories and susceptibility, hazard and risk zoning that those carrying out the study have a detailed knowledge of slope processes which lead to landslides. This includes knowledge of geology, geomorphology, and hydrogeology and the soil and rock mechanics of landsliding. It is also essential that there is sufficient geotechnical information about the slopes to allow an understanding of the soil and rock mechanics of slope failure. Zoning done in the absence of this knowledge is almost certain to be misleading.

8.3 APPLICATION OF GIS-BASED TECHNIQUES TO LANDSLIDE ZONING

It is strongly recommended that landslide zoning be carried out in a GIS-based system so that the zoning can be readily be applied for land use planning and can be up-dated as more information becomes available.

A Geographic Information System (GIS) is a computer-based system which facilitates the acquisition, storage, management, analysis and display of geographic data. GIS typically includes relational database functionality incorporating spatial data attributes, but also includes the ability to spatially manipulate and present the data with elaborate mapping capabilities and powerful spatial analyses.

The essential feature of all GIS platforms is that they recognize the spatial attributes of the data presented allowing natural features to be treated as part of a spatial system, rather than an isolated object. This capability enables the spatial system, (i.e., the environment of any given region) to be built within the computer project environment using often disparate data sets. The data used in this process can come from a variety of sources, often the project itself (geological and engineering geological mapping, landslide mapping, traditional surveys, GPS surveys, drilling of boreholes, test pits etc) and other outside sources including government organizations and authorities, private companies and other spatial organizations (i.e., digital elevation models, cadastre, contours, aerial photography, land usage, vegetation etc).

One of the most important capabilities of GIS is the ability of the software to manage spatial data, from data collection and generation through to archiving and documentation of data. An important point is that once data is in the GIS, it remains available for editing and updating, for reproduction in the form of maps or on-screen review, manipulation and querying and for GIS-based development and modelling of susceptibility, hazard and risk.

8.4 LANDSLIDE INVENTORY

Preparation of a landslide inventory is an essential part of any landslide zoning. It involves the location, classification, volume, travel distance and state of activity and date of occurrence of landsliding in an area. Table 8 lists the activities which will typically be required at the basic, intermediate and sophisticated level.

Table 8: Activities required to preparing a landslide inventory.

Characterisation Method	Activities
Basic	Prepare an inventory of landslides in the area from aerial photographs and /or satellite imagery, and by mapping and from historic records. The inventory includes the location, classification, volume (or area) and so far as practicable the date of occurrence of landsliding.
	Identify the relationship to topography, geology and geomorphology.
	Show this information on inventory maps along with topographic information including contours, property boundaries, mapping grid, roads and other important features such as streams and water-courses.
Intermediate	**The same activities as Basic plus**
	Distinguish different parts of the landslides.
	Map landslide features and boundaries.
	Collect and assess historical information on the activity of landsliding.
	Analyse the past evolution of the land use to know whether human activities have had an influence on the incidence of landslides.
	Increased time and resources in the research phase of the inventory compilation resulting in more rigorous and extended coverage
Sophisticated	**The same activities as Intermediate plus**
	Prepare an inventory of geotechnical data.
	Implement investigations to better define geotechnical conditions.
	Geotechnical analysis to understand slope instability processes.
	Advanced temporal cataloguing of periodic reactivations of the same hazard and temporal windowing of specific triggering events to provide periodic inventory data sets which can then be used in advanced validation approaches.

8.5 LANDSLIDE SUSCEPTIBILITY ZONING

8.5.1 Landslide characterization and travel distance and velocity

Landslide susceptibility zoning involves the classification, volume (or area) and spatial distribution of existing and potential landslides in the study area. It may also include a description of the travel distance, velocity and intensity of the existing or potential landsliding.

Table 9: Landslide susceptibility zoning-activities required to characterise, determine the spatial distribution of potential landslides and their relationship to topography, geology and geomorphology.

Characterisation Method	Activities
Basic	Prepare a geomorphologic map. (1)
	Prepare a landslide inventory as described in Table 8, (1)
	Prepare calculations of the % of the total landslide count for each susceptibility class, the % of the area affected by landslides for each class and the % of each class in comparison to the total study area and classify according to Table 4.
	Correlate the incidence of landsliding with the geology and slope to delineate areas susceptible to landsliding.
	For regional zoning correlate the incidence of landsliding with annual rainfall or snowmelt, and/or seismic loading.
	Prepare the landslide susceptibility zoning map superimposed on the topography with a suitable legend.
	Implement the data and the maps in a GIS (recommended).
Intermediate	**The same activities as basic plus**
	Obtain basic soil classifications and depths in the study area.
	Classify more complex terrain units. Qualitative rating of the landslide susceptible areas based on overlapping techniques.
	Develop quantitative ratings (often relative rating) of landslide susceptible areas based on data treatment techniques.
	Implement the data and the maps in a GIS (recommended).
Sophisticated	**The same activities as Intermediate plus**
	Detailed mapping and geotechnical investigations to develop an understanding of the mechanics of landsliding, hydrogeology and stability analyses.
	Perform data treatment analysis (discriminate; neural networks; fuzzy logic; logistic regression; etc) and develop quantitative ratings to obtain susceptibility classes.
	Perform stability analyses.
	Implement the data and the maps in a GIS (recommended).

Note. (1) The landslide inventory and geomorphologic mapping should be carried out at intermediate and sophisticated levels for intermediate and sophisticated level susceptibility zoning.

Table 9 lists the activities required to characterise the potential landslides, their spatial distribution in the area to be zoned and their relationship to topography, geology and geomorphology. It should be noted that there is a direct relationship between the scale of zoning maps and the level of landslide characterisation, with larger scale zoning maps being required at the intermediate and sophisticated levels. Table 10 lists the activities required to assess the travel distance and velocity of potential landslides. This table is based on the assumption that the activities in Tables 8 and 9 have been carried out.

Table 10: Activities required for assessing the travel distance and velocity of potential landslides.

Travel Distance and Velocity Analysis method	Activities
Basic	Collect and assess historical information on travel distances and velocity.
	Assess limiting travel distances from geomorphologic data and old landslide deposits.
	Assess the likely travel distance and velocity from consideration of the classification of the potential landslides, geology and topography and empirical methods.
	Based on this information assess the limit (greatest) likely travel distance for each classification of potential landslide.
Intermediate	**The same activities as Basic plus**
	Assess likely landslide mechanisms and classification of soils in the landslides.
	Use empirical methods based on travel distance angle or shadow angle to assess travel distance accounting for the uncertainty in the empirical methods and data inputs.
	Assess velocity from potential energy and travel distance using simple sliding block models.
Sophisticated	**The same activities as Intermediate plus**
	Investigate geotechnical properties of the sliding materials as required by numerical models.
	Use numerical models to model travel distance and velocity.

8.5.2 Preparation of landslide susceptibility map

Preparation of a landslide susceptibility map is usually based on two assumptions:

- That the past is a guide to the future, so that areas which have experienced landsliding in the past are likely to experience landsliding in the future.
- Areas with similar topography, geology and geomorphology as the areas which have experienced landsliding in the past are also likely to experience landsliding in the future.

These assumptions are often reasonable but it should be noted there are exceptions such as when the source of the landslides is exhausted by earlier landsliding.

Landslide susceptibility zoning maps should include:

- A map or a series of maps showing the inventory of historic landslides, showing the location and area (or number of slides, e.g. for rock falls) of the source landslides; where appropriate the travel paths after sliding; or for larger slides the activity or velocity of sliding.
- Maps at the same scale showing the instability conditioning terrain factors: i.e. the topography and topographic units (slope, watershed areas), the geology (lithological units); superficial formations; vegetation cover; land use; etc.
- In areas having potential for shallow landslides and debris flows, it is highly recommended that a map is prepared of the superficial formations (colluvium, till, alluvium, residual soils, etc.) because these types of failures usually take place in these formations. However it must be taken into account that usually these formations are of limited extent so such a map can only be prepared at a large scale.
- Where appropriate prepare a map showing the travel distance limits either as a maximum value or quantified as suggested in Table 10.
- A map showing the interpreted susceptibility zoning classification areas. This map should show the topography and cadastral information as well as the susceptibility zoning classifications for the area being mapped.

In some cases these may be superimposed on the same zoning map to limit the number of maps but often this will be confusing and it will be necessary to produce separate maps at the same scale for each classification of landslides such as rock falls and small shallow landslides.

8.6 LANDSLIDE HAZARD ZONING

8.6.1 Frequency Assessment

Tables 11 and 12 list the activities required to assess the frequency of rock falls, slides from cuts, fills and retaining walls, small landslides; and large landslides.

Table 11: Activities required for assessing the frequency of rock falls, slides from cuts, fills and retaining walls and small landslides on natural slopes.

Frequency Assessment Method	Activities
Basic	Frequency established based on the relative freshness of the morphological features of the scars and landside deposits taking into account the presence of active geomorphic events (e.g. slope undermining by either river or sea erosion).
	Frequency established based on interpretation of numbers of landslides from aerial photographs taken at known time intervals.
	Assess the historic frequency of rock falls, slides from cuts, fills and retaining walls, or small landslides on natural slopes from basic landslide inventories.
	As above and relate to the basic level of frequency of triggering events such as daily rainfall or seismic events.
Intermediate	**The same activities as Basic plus**
	Relate to slope characteristics such as topography (slope angle, elevation, aspect), geology, geomorphology using multi-variate analyses.
	Assess the historic frequency of rock falls, slides from cuts, fills and retaining walls, or small landslides on natural slopes from landslide inventories. Where appropriate, develop and use frequency volume curves.
	Use proxy data such as silent witnesses (e.g. damage to trees and dendrochronology).
	More detailed analysis of rainfall including the effects of antecedent rainfall, rainfall intensity and duration on the incidence of individual landslides (the threshold) or large numbers of landslides.
	For seismically induced landsliding, relate the incidence of sliding to seismic loading including the peak ground acceleration and magnitude of the earthquake using empirical methods.
Sophisticated	**The same activities as Intermediate plus**
	Assess geotechnical parameters of the soils. Model slope factors of safety from geotechnical parameters and rainfall frequency or piezometric data.
	For seismically-induced landslides, analyse displacements using 'Newmark' type analyses and for liquefiable soils, the likelihood of liquefaction and flow sliding.

Table 12: Activities required for assessing the frequency of landsliding for large landslides on natural slopes.

Frequency Assessment Method	Activities
Basic	Assess the historic frequency of landsliding from the landslide inventoy including activity indicators such as cracked buildings, displaced fences, bent and tilted trees.
	Assess frequency from geomorphology evidence such as the freshness of slide scarps and other surface features associated with landslide movement using subjective assessment.
Intermediate	**The same activities as Basic plus**
	As above, and use of proxy data such as carbon 14 dating, lichenometry dating, of vegetation buried by sliding, or in raised alluvial terraces in valleys which may have been blocked by landsliding.
	Relate history of landsliding to rainfall intensity and duration and antecedent rainfall or to snow melt.
	Assess the likelihood of seismically-induced sliding from consideration of the mechanics of the landslide. Use empirical and simplified methods to assess likely displacements during earthquakes.
	As an alternative to estimating from historic data, assess frequency by subjective assessment, e.g. by assessing the probability of landsliding given a rainfall or seismic load.
Sophisticated	**The same activities as Intermediate plus**
	As above and relating the history of landsliding or factor of safety to rainfall, slope geometry, piezometric levels (where available), geotechnical properties and factors of safety.
	For seismically-induced landsliding analyse displacements using 'Newmark' type analyses and for liquefiable soils, the likelihood of liquefaction and flow sliding.

8.6.2 Intensity assessment

Landslide intensity may be assessed either as the spatial distribution of:

- The velocity of sliding coupled with slide volume or
- The kinetic energy of the landslide; e.g. rock falls, rock avalanches or
- Total displacement or
- Differential displacement or
- Peak discharge per unit width (m^3/m/second), e.g. for debris flows.

The assessment of velocity is discussed in Section 8.5.1. For basic and intermediate level assessments of intensity only velocity and volume might be assessed. For advanced assessments of rock fall and debris flow hazard the energy might be assessed. Whether landslide intensity is required as part of a hazard zoning should be determined on a case-by-case basis. It is likely to be required for rock fall hazard zoning.

8.6.3 Preparation of Landslide hazard zoning map

Landslide hazard zoning maps are developed from the susceptibility zoning maps with the areas classified according to the frequency (annual probability) of landsliding. The way the frequency is expressed will depend on the classification and volume of the potential landslides. For example:

- For rock falls the hazard may be expressed as the number of rock falls/annum which will reach the area being mapped per kilometre length along a cliff.
- For slides from cuts, fills and retaining walls the hazard may be expressed as the number of landslides of a certain volume and classification/annum per kilometre of road or per building allotment or per square kilometre.
- For small landslides on natural slopes the hazard may be expressed as the number of landslides of a certain volume, velocity and classification per square km/annum for the area being mapped
- For large landslides on natural slopes the hazard may be expressed as the annual probability that there will be landsliding in the area being mapped. To this should be added the likely velocity or total displacement of sliding should it occur.

The hazard zoning map should be at the same scale as the susceptibility zoning map and show the topography and cadastral information as well as the hazard zoning classifications for the area being mapped.

8.7 LANDSLIDE RISK ZONING

8.7.1 Elements at risk

For risk to be determined and hence for landslide risk zoning to be implemented the elements at risk have to be assessed. Table 13 lists the activities required to do this.

The elements at risk include the persons and property potentially affected by landsliding on, below and up-slope of the potential landslides. They may include indirect impacts such as reduced economic activity resulting from the landslide, e.g. due to loss of a road, and environmental impacts.

Table 13: Activities required for assessing the elements at risk.

Method for Assessing Elements at Risk	Activity
Basic	Make an assessment of the population who live, work and travel through the area; property such as houses, buildings, roads, railways and services which are permanently in the area and of property such as vehicles which travel through the area. For existing development base this on the current and proposed land use. For new development estimate from proposed land use and occupancy. Where applicable assess environmental values which may be affected by landsliding.
	Generic classifications based on the main land uses, namely urban, industrial, infrastructure, or agricultural.
Intermediate	As above in greater degree of detail. Economic consequences may be included.
Detailed	As above in detail. Economic consequences will be estimated such as the implications of loss of a road providing access to a town until repairs are carried out.

8.7.2 Temporal spatial probability and vulnerability

Table 14 lists the activities required to assess the temporal spatial probability of the elements at risk.

Table 14: Activities required for assessing the temporal spatial probability of the elements at risk.

Method for assessing Temporal Spatial Probability	Activity
Basic	*Life Loss Risks* For persons at risk in residential areas assume the temporal-spatial probability is 1.0. For other type of developments such as factories and schools, make an approximate assessment of temporal-spatial probability from the likely pattern of use of the buildings. For roads and railways and other situations with transient populations at risk; make an approximate assessment of temporal spatial probability from the traffic volumes and velocities. *Property loss risks* For buildings the temporal spatial probability is 1.0. For vehicles, make an approximate assessment of temporal-spatial probability from the traffic volumes and velocities.
Intermediate	*Life Loss Risks* For all situations estimate temporal-spatial probability taking account of the nature of development, living and work pattern, existence of protected places (e.g. reinforced shelters), traffic (where relevant) and the intensity of landsliding. *Property loss risks* As for basic assessment although in more detail (e.g. allowing for the variability of trajectories of rock falls).
Sophisticated	As above, with greater detail in the assessment, particularly the temporal/spatial distribution of the elements at risk.

Vulnerability is generally assessed empirically for persons and property using published information (e.g. AGS 2007a). More sophisticated methods are not as yet available.

8.7.3 Preparation of landslide risk zoning maps

Landslide risk zoning maps are prepared using the hazard zoning maps and allowing for the elements at risk, the spatial-temporal probability and vulnerability. Separate zoning maps will be required for life loss risk and property loss risk. The risk zoning maps should be at the same scale as the susceptibility and hazard zoning maps. They should also show the topography and cadastral information as well as the risk zoning classification of the area.

For life loss, the risk should be expressed as individual risk (annual probability of the person losing his/her life). For property loss, the map may show annualised loss ($/year) but the report should also list the pairs of loss value and annual probability of the loss (e.g. 0.001 annual probability of $10 million loss).

For new development there will have to be an assessment made regarding the proposed development and the elements at risk. The risk will be unique to this proposed development.

If there are several landslide hazards (e.g. rock fall and shallow landslides) the risks are summed to give the total risk. However, it may be useful to present maps showing the risk from each type of landslide, as well as the total risk.

8.8 THE NEED FOR DOCUMENTATION OF THE LANDSLIDE ZONING PROCESS

It is essential that the landslide zoning process be well documented in a report. The report should include

- Zoning maps and legends.
- The definitions of the susceptibility, hazard and risk zones.
- The basis upon which the zoning has been carried out including data sources, zoning methodology, the time period covered by the landslide inventory if one has been used to assess landslide frequency.
- A description of any limitations of the zoning including accuracy of zone boundaries.
- Other information to explain the use of the landslide zoning as required for the particular project.

This informs those who are using the landslide zoning and facilitates peer review.

9 RELIABILITY OF LANDSLIDE ZONING FOR LAND USE PLANNING

9.1 POTENTIAL SOURCES OF ERROR

9.1.1 Description

There are a number of potential sources of error in the zoning process. These include:

- Limitations in the landslide inventory upon which the susceptibility and hazard zoning maps are based.
- Limitations in the stability of temporal series. For example the relationship between the triggering factor (e.g. rainfall) and the frequency of landslides may change if the area is deforested.
- Limitations in the level of detail available of topography, geology, geomorphology, rainfall and other input data.
- Model uncertainty, meaning the limitations of the methods used to relate the inventory, topography, geology, geomorphology and triggering events such as rainfall to predicting landslide susceptibility, hazard and risk.
- Limitations in the skill of the persons carrying out the zoning.

It must be recognised that landslide zoning is not a precise science and the results are only a prediction of performance of the slopes based on the available data. In general, intermediate or advanced level zoning will be less subject to error than preliminary level zoning with each done at a suitable zoning map scale.

9.1.2 Landslide inventories

Cascini *et al.* (2005) conclude that the greatest source of error is limitations in the inventory. They give examples showing gross mismatch of inventory maps for landsliding from the same area of natural slopes prepared by two groups. They point out that the greatest errors occur when inventories rely on air photo interpretation, particularly of small scale photography. These errors are in part due to the subjective nature of aerial photo interpretation but also to vegetation covering the areas to be mapped. Aerial photographic mapping should be supported by surface mapping of selected areas to calibrate the mapping.

Inventories of landsliding of cuts, fills and retaining walls on roads, railways and urban development will seldom be complete. To get a reasonable estimate of the number of slides the zoning will have to make a judgement about the proportion of the slides which have been recorded.

9.1.3 Topographic maps

Good topographic maps are most important input to zoning at intermediate and advanced levels. Topographic maps facilitate the modelling and mapping of landslide zoning boundaries with an appropriate accuracy. For large scale zoning, contours at 2 metre or at most 5 metre intervals will be required. Even then, zoning boundaries should be checked on the ground because the implications for land owners of errors in boundaries can be significant.

9.1.4 Model uncertainty

Model uncertainty is a fact of landslide zoning and none of the methods are particularly accurate. In general terms hazard and risk zoning based on statistical analyses of the input data using intermediate level inputs will give the best accuracy.

Sophisticated methods for assessing the inputs rely on carrying out calculations (for example of the factor of safety of a slope) which have a theoretical attraction and the appearance of being able to produce better accuracy. In reality the parameter uncertainty is large due to limitations in the knowledge of the input data (such as shear strength and pore pressures) and these make it very difficult to achieve any greater accuracy than other modelling methods.

9.2 VALIDATION OF MAPPING

9.2.1 Peer review

For most zoning studies for land use planning there should be a peer reviewer appointed to provide independent assessment of the susceptibility, hazard and risk zoning. The peer reviewer should have a high level of the skills and experience listed in Section 11.2.The peer reviewer should meet with those carrying out the study at the beginning of the study and, depending on the scale of the projects, perhaps after initial mapping and then as the zoning is being finalised. This process is a basic form of quality control and a form of validation if the peer reviewer has appropriate wide experience.

9.2.2 Formal validation

For more important advanced level mapping projects there can be a process of validation within the study. To do this the landslide inventory is randomly split in two groups: one for analysis and one for validation. The analysis is carried out in part of the study area (model) and tested in another part with different landslides. An alternative approach for advanced mapping projects is for an analysis to be carried out with landslides that have occurred in a certain period whilst validation is performed upon landslides that have occurred in a different period. Validation can also be carried out by this process after the mapping and land use planning scheme has been in place for some time. This is really only practical for high frequency landsliding because of the time frame required to gather performance data.

9.3 POTENTIAL EFFECTS OF CLIMATE CHANGE

There is a developing knowledge of climate change and the effects of this on rainfall and snowfall. It could be anticipated that for example a decreased frequency of high intensity rainfall might reduce the frequency of shallow landslides on steep hill slopes. However the science of prediction of the effects of climate change and the prediction of the frequency of landslides from rainfall is not sufficiently advanced at this time to warrant consideration of climate change when carrying out zoning studies.

Those involved in landslide zoning studies should keep informed of developments which might alter this conclusion.

10 APPLICATION OF LANDSLIDE ZONING FOR LAND USE PLANNING

10.1 GENERAL PRINCIPLES

These guidelines are for landslide susceptibility, hazard and risk zoning. Those who are considering the introduction of land use management controls for landsliding need to decide the type and level of zoning which they require based on the purpose of the zoning. This is detailed in Section 6. They may choose to stage the zoning and implementation of land use controls.

It should be recognised that it is not possible to delineate zoning boundaries accurately with regional and local zoning using small and medium scale zoning maps. This can only be done using local or site-specific zoning and large to detailed scale maps.

It is critical that the local governmental authority or other organization requiring the zoning, clearly and fully define the purpose and nature of any zoning study, understand the existing availability of potential input data, assess the implications for acquisition of new data and then define realistic goals for the zoning study taking into account, timeframes, budgets and resource limitations.

It should be noted that mapping will usually result in lines on a map delineating for example the landslide hazard zones based on contours and geomorphologic boundaries. However, for land use planning and zoning purposes the zone boundaries are often re-drawn to coincide with allotment boundaries for administrative reasons. This may lead to adoption of conservative boundaries and should be avoided where practical.

10.2 TYPICAL DEVELOPMENT CONTROLS APPLIED TO LANDSLIDE ZONING

Examples of the types of development controls which are applied to landslide zoning are:

- If zoning is by susceptibility the controls usually require geotechnical assessment of hazard and risk of the proposed development for zones determined as susceptible to landsliding whilst only minimal requirements (such as adherence to good hillside practice) in areas determined as very low susceptibility or not susceptible.
- If zoning is by hazard and the study has been done at an intermediate or advanced level it should be possible to delineate land use zones where: (a) Hazard is so low that no development controls are necessary; (b) Where some prescriptive controls such as limits to the heights of cuts and fills are necessary; (c) Where detailed geotechnical assessment of the hazard and risk is required before development can be approved and (d) Where the hazard is so high no development is possible.
- Where zoning is by life loss risk and the study has been done at an intermediate or advanced level, it should be possible to delineate land use zones where (a) Life loss risk is so low no development controls are necessary; (b) Where site specific assessment of the risk is required prior to approval of development and (c) Where the risk is so high that no development is possible.

In practice those considering landslide zoning for land use management would be well advised to seek advice from a Geotechnical Professional who is familiar with landslide zoning and risk management to provide advice in planning the landslide zoning study and applying the outcomes to land use planning.

10.3 NEED TO REVIEW AND UP-DATE LANDSLIDE ZONING

It should be recognised that there should be periodic reviews of landslide zoning because:

- The susceptibility, hazard and risk may be altered by development and land-use changes subsequent to the study.
- The state of knowledge of landsliding in the area will be improved with more detailed investigations carried out as part of the development.
- The elements at risk may change with time so landslide risk zoning should be reviewed to allow for this.
- Methods of landslide zoning are evolving so in combination with the factors listed above, improved zoning will be possible.

It is recommended that reviews be carried out at intervals no greater than about 10 years. In some cases more frequent reviews will be necessary.

11 HOW TO BRIEF AND SELECT A GEOTECHNICAL PROFESSIONAL TO UNDERTAKE A ZONING STUDY

11.1 PREPARING A BRIEF

The following are some matters which should be considered in preparing a brief for a landslide zoning study.

- Define the purpose of the zoning and how it will be used.
- Define the area to be zoned.
- Define what type of zoning is required: landslide susceptibility, hazard or risk.
- Define the level of zoning required and whether it will be staged.
- Identify the various stake holders and their interests.
- Describe what, if any, public consultation process will be required.
- State relevant legal and regulatory controls.
- Set out the documentation required for the results of the zoning, including details of what maps are required, map scales, and electronic formats and the supporting report describing the zoning processes, methods used, validation and limitations.
- Set a program for the study.
- Set a budget consistent with the scope and expectations of the study.
- Describe the peer review process which will apply.
- List the available data and the format it is in.
- Detail the expected method for the study.
- Define the terminology to be used to describe susceptibility, hazard and risk.

In so far as possible, this is best done in consultation with prospective consultants so there is a clear understanding of what is required.

11.2 SELECTING A CONSULTANT FOR THE ZONING

Landslide susceptibility, hazard and risk zoning is a science that should be done by well qualified geotechnical professionals who are experienced in mapping and who understand slope processes, risk assessment and geotechnical slope engineering. This will usually mean that a team of professionals will be needed including an engineering geologist, geomorphologist (for zoning of natural slopes where geomorphology mapping is required) and a geotechnical engineer. It should be noted that only a few engineering geologists and geotechnical engineers are experienced in geomorphologic mapping. It is essential that geotechnical engineers who understand the soil and rock mechanics of slope processes pre and post-failure are involved in the landslide susceptibility, hazard and risk assessments.

Consultants proposing to carry out landslide zoning should demonstrate they have personnel who will work on the project with the relevant skills and experience. It is not sufficient that a geotechnical company has done such studies because it is the personnel directly involved that are important.

One means of demonstrating competence is through registration upon the National Professional Engineering Register (NPER) under the specific area of practice for Landslide Risk Management (LRM).

11.3 PROVIDE ALL RELEVANT DATA

It is essential that the consultant is provided with all the available data regarding the incidence of landsliding in the study area. There should be a thorough search of records from files and works reporting repairs that have been carried out.

Where there is limited data on the incidence of landslides in the area those responsible will greatly benefit by establishing and maintaining a landslide inventory.

12 ACKNOWLEDGEMENTS

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The Australian Geomechanics Society established a Working Group within a Landslide Taskforce to develop the guidelines. The development of the guidelines was managed by a Steering Committee. Membership of the Working Group, Taskforce and Steering Committee is listed in Appendix B.

Concurrent with the development of the AGS guidelines, JTC-1, the Joint International Societies Technical Committee on Landslides and Engineered Slopes has been developing International Guidelines on Landslide Susceptibility, Hazard and Risk Zoning. Those guidelines have been prepared under the technical direction of a Scientific Committee. Membership of the JTC-1 Scientific Committee is attached in Appendix C.

Drafts of the AGS guideline have been subject to review by members of the AGS Landslide Taskforce, members of the geotechnical profession and local government.

Drafts of the International Guidelines have received extensive consideration and discussion and in a Workshop held in Barcelona from 18th to 20th September 2006. Later drafts of the guideline have been reviewed by attendees to the Barcelona Workshop and members of JTC-1. There has been an integrated approach between the groups developing the guidelines and they are similar except for details specific to AGS requirements.

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APPENDIX A - DEFINITION OF TERMS

Acceptable Risk – A risk which, for the purposes of life or work, society is prepared to accept as it is with no regard to its management. Society does not generally consider expenditure in further reducing such risks justifiable.

Annual Exceedance Probability (AEP) – The estimated probability that an event of specified magnitude will be exceeded in any year.

Consequence – The outcomes or potential outcomes arising from the occurrence of a landslide expressed qualitatively or quantitatively, in terms of loss, disadvantage or gain, damage, injury or loss of life.

Danger – The natural phenomenon that could lead to damage, described in terms of its geometry, mechanical and other characteristics. The danger can be an existing one (such as a creeping slope) or a potential one (such as a rock fall). The characterisation of a danger does not include any forecasting.

Elements at Risk – The population, buildings and engineering works, economic activities, public services utilities, infrastructure and environmental features in the area potentially affected by landslides.

Frequency – A measure of likelihood expressed as the number of occurrences of an event in a given time. See also Likelihood and Probability.

Hazard – A condition with the potential for causing an undesirable consequence.. The description of landslide hazard should include the location, volume (or area), classification and velocity of the potential landslides and any resultant detached material, and the probability of their occurrence within a given period of time.

Individual Risk to Life – The risk of fatality or injury to any identifiable (named) individual who lives within the zone impacted by the landslide or who follows a particular pattern of life that might subject him or her to the consequences of the landslide.

Landslide inventory –An inventory of the location, classification, volume, activity and date of occurrence of landsliding

Landslide activity –The stage of development of a landslide; *pre-failure* when the slope is strained throughout but is essentially intact; failure characterized by the formation of a continuous surface of rupture; *post-failure* which includes movement from just after failure to when it essentially stops and *reactivation* when the slope slides along one or several pre-existing surfaces of rupture. Reactivation may be occasional (e.g. seasonal) or continuous (in which case the slide is "active")

Landslide Intensity – A set of spatially distributed parameters related to the destructive power of a landslide. The parameters may be described quantitatively or qualitatively and may include maximum movement velocity, total displacement, differential displacement, depth of the moving mass, peak discharge per unit width, kinetic energy per unit area.

Landslide Susceptibility – A quantitative or qualitative assessment of the classification, volume (or area) and spatial distribution of landslides which exist or potentially may occur in an area. Susceptibility may also include a description of the velocity and intensity of the existing or potential landsliding.

Likelihood – Used as a qualitative description of probability or frequency.

Probability – A measure of the degree of certainty. This measure has a value between zero (impossibility) and 1.0 (certainty). It is an estimate of the likelihood of the magnitude of the uncertain quantity or the likelihood of the occurrence of the uncertain future event.

There are two main interpretations:

(i) Statistical – frequency or fraction – The outcome of a repetitive experiment of some kind like flipping coins. It includes also the idea of population variability. Such a number is called an "objective" or relative frequentist probability because it exists in the real world and is in principle measurable by doing the experiment.

(ii) Subjective probability (degree of belief) – Quantified measure of belief, judgement, or confidence in the likelihood of a outcome, obtained by considering all available information honestly, fairly and with a minimum of bias. Subjective probability is affected by the state of understanding of a process, judgement regarding an evaluation or the quality and quantity of information. It may change over time as the state of knowledge changes.

Qualitative Risk Analysis – An analysis which uses word form, descriptive or numeric rating scales to describe the magnitude of potential consequences and the likelihood that those consequences will occur.

Quantitative Risk Analysis – an analysis based on numerical values of the probability, vulnerability and consequences, and resulting in a numerical value of the risk.

Risk – A measure of the probability and severity of an adverse affect to health, property or the environment. Risk is often estimated by the product of probability x consequences. However, a more general interpretation of risk involves a comparison of the probability and consequences in a non-product form.

Risk Analysis – The use of available information to estimate the risk to individuals, population, property or the environment from hazards. Risk analyses generally contain the following steps: scope definition, hazard identification and risk estimation.

Risk Assessment – The process of risk analysis and risk evaluation.

Risk Control or Risk Treatment – The process of decision making for managing risk and the implementation or enforcement of risk mitigation measures and the re-evaluation of its effectiveness from time to time, using the results of risk assessment as one input.

Risk Estimation – The process used to produce a measure of the level of health, property or environmental risks being analysed. Risk estimation contains the following steps: frequency analysis, consequence analysis and their integration.

Risk Evaluation – The stage at which values and judgements enter the decision process, explicitly or implicitly, by including consideration of the importance of the estimated risks and the associated social, environmental and economic consequences, in order to identify a range of alternatives for managing the risks.

Risk Management – The complete process of risk assessment and risk control (*or risk treatment*).

Societal Risk – The risk of multiple fatalities or injuries in society as a whole: one where society would have to carry the burden of a landslide causing a number of deaths, injuries, financial, environmental and other losses.

Susceptibility – see Landslide Susceptibility

Temporal-Spatial Probability – The probability that the element at risk is in the affected area at the time of the landslide.

Tolerable Risk – A risk within a range that society can live with so as to secure certain net benefits. It is a range of risk regarded as non-negligible and needing to be kept under review and reduced further if possible.

Vulnerability – The degree of loss to a given element or set of elements within the area affected by the landslide hazard. It is expressed on a scale of 0 (no loss) to 1 (total loss). For property, the loss will be the value of the damage relative to the value of the property; for persons, it will be the probability that a particular life (the element at risk) will be lost, given the person(s) is affected by the landslide.

Zoning: The division of land into homogeneous areas or domains and their ranking according to degrees of actual or potential landslide susceptibility, hazard or risk.

APPENDIX B – TASKFORCE MEMBERS

AUSTRALIAN GEOMECHANICS SOCIETY

STEERING COMMITTEE

Andrew Leventhal, GHD Geotechnics, Sydney, Chair.
Robin Fell, School of Civil and Environmental Engineering, UNSW, Sydney, Convenor,Guidelines on Landslide Susceptibility, Hazard and Risk Working Group.
Tony Phillips, Consultant, Sydney, Convenor Slope Management and Maintenance Working Group.
Bruce Walker, Jeffery and Katauskas, Sydney, Convenor Practice Note Working Group.
Geoff Withycombe, Sydney Coastal Councils Group, Sydney

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Arthur Love, Coffey Geotechnics, Newcastle
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Garth Powell, Coffey Geotechnics, Brisbane
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Ian Stewart, NSW Roads and Traffic Authority, Sydney
Peter Tobin, Wollongong City Council, Wollongong
Graham Whitt, Shire of Yarra Ranges, Lillydale

APPENDIX C – JTC-1 MEMBERS

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Jordi Corominas, Technical University of Catalonia-UPC, Barcelona, Spain
Christophe Bonnard, École Polytechnique Féderale, Lausanne, Switzerland
Leonardo Cascini, University of Salerno, Italy
Eric Leroi, Urbater, France
Bill Savage, United States Geological Survey, Golden, Colorado, USA

Appendix E

Excerpts of Small dam consequence tool screening

Consequence Screening Tool for Small Dams

Water and Natural Resources

May 2014

Department of Environment and Primary Industries

State Government Victoria

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Accessibility

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Contents

This guideline and accompanying spreadsheet replace the original 'Screening Tool for Small Hazardous Dams, 2011'.

The Department of Environment and Primary Industries intends to review the screening tool spreadsheet and guideline periodically. Please forward any comments to Siraj Perera, Rural Water Programs Division, Water and Natural Resources Group, Department of Environment and Primary Industries, PO Box 500, East Melbourne VIC 3002 or email: siraj.perera@depi.vic.gov.au.

Acknowledgements

The Department of Environment and Primary Industries wishes to acknowledge the contribution of SKM Jacobs and Goulburn-Murray Water in the development of this Guideline.

1. Introduction to the Screening Tool

1.1. Purpose

The Screening Tool has been developed to provide a simplified method for assigning Consequence Categories to small dams and consists of this guideline and an accompanying spreadsheet. The tool is broadly consistent with the Initial Consequence Assessment level of the Australian National Committee on Large Dams (ANCOLD) *Guidelines on the Consequence Categories for Dams 2012*.

The Consequence Category obtained using the Screening Tool is intended to provide a basis for identifying the dam safety management requirements of small dams that require a licence under section 67 of the *Water Act 1989* but are of low hazard. Where the Screening Tool assesses that a dam may potentially pose a risk to downstream communities, the owner of the dam will be required to engage a suitably qualified engineer to undertake a more detailed Consequence Category assessment of the dam, and to assist with developing and implementing a dam safety management program.

While primarily developed for use by the five Victorian licensing authorities (Appendix A), the Screening Tool may also assist owners of small dams.

Throughout this document, a small dam refers to a dam that does not meet the ANCOLD definition of a large dam (Glossary) and has a volume of less than 500 ML.

1.2. Australian National Committee on Large Dams (ANCOLD) and Dam Safety

ANCOLD is an incorporated voluntary association of organisations and individual professionals with a common interest in encouraging improvements in the safety and operation of dams in Australia. Formed in 1937, it is a member of the international body ICOLD (International Commission on Large Dams). ICOLD's membership consists of 92 countries containing most of the world's significant dams. The Department of Environment and Primary Industries (DEPI) has actively participated as a member of ANCOLD for many years through the ANCOLD Regulators Forum. The forum includes representation from all states and meets annually.

ANCOLD has produced a series of guidelines (Appendix B) that are recognised by DEPI as representing the current industry position for dam safety management and are referenced by regulations in both Victoria and other jurisdictions across Australia.

The Consequence Category is used throughout the ANCOLD guidelines, such as in the *Guidelines on Dam Safety Management* (ANCOLD, 2003), in making recommendations about the appropriate level of dam safety practice for a particular dam.

1.3. Application of the Screening Tool

ANCOLD (2012) defines the consequences of dam failure as *'the outcome or result of a dam failure in terms of loss of life and damage to property and/or services, as well as environmental damage'*. The Screening Tool can be used to assign the following Consequence Categories (Table 1-1):

- Very Low or Low;
- Significant; and
- High C or above.

The Consequence Category provides a preliminary basis for determining dam safety management requirements. These cover aspects such as:

- Surveillance and monitoring;

- Emergency preparedness and response;
- Operational procedures;
- Skills and training of personnel involved in undertaking dam safety activities;
- Identification and prioritisation of further dam safety investigations and consequence assessment, particularly for dams with a Consequence Category of High C or above; and
- Dam safety improvement works.

However, irrespective of the Consequence Category assessed using the Screening Tool, dam owners who are required to have a licence under Section 67 of the *Water Act 1989*, must confirm their responsibilities with the relevant licensing authority (Appendix A) and comply with the conditions of their licences.

1.4. ANCOLD Consequence Categories

The ANCOLD *Guidelines on the Consequence Categories for Dams* (ANCOLD, 2012) provides a method to assess dams on the basis of the potential severity of damage and loss, in conjunction with the risk to human life which may result from a dam failure. The risk to human life can be expressed in terms of the Population at Risk (PAR) or the Potential Loss of Life (PLL). The Initial Consequence Assessment level described in the ANCOLD Guidelines recommends assessment using the Total PAR which is defined as 'the total population determined within the total flood zone'.

The risk associated with potential dam failure is expressed using seven Consequence Categories:

- Very low – where consequences from dam failure would be considered negligible;
- Low, Significant, High A, High B and High C; and
- Extreme – where consequences from dam failure would be considered severe.

Each category is defined by a severity of damage and loss and PAR threshold shown in Table 1-1. The guidelines also provide thresholds considering PLL, however the initial level primarily considers Total PAR.

In relation to the assignment of consequence categories, it is important to take note of this reference from the ANCOLD Consequence Guidelines – *"However the complexity of determining the various parameters that make up each Consequence Category means that only experienced dam engineering professionals should interpret and use these Guidelines when making these decisions that could impact on community safety, community cost and services, infrastructure, natural environment, heritage, and the owner's and other businesses."* In undertaking a consequence category assessment the information provided in the below tables should not be used without taking into account the full guidance provided in the Guidleines.

Table 1-1 ANCOLD Consequence Categories based on Population at Risk (PAR); Source: ANCOLD (2012)

Population at Risk (PAR)	Severity of damage and loss			
	Minor	Medium	Major	Catastrophic
<1	Very Low	Low	Significant	High C
≥1 to 10	Significant*	Significant*	High C	High B
>10 to 100	High C	High C	High B	High A
>100 to 1,000		High B	High A	Extreme
>1,000			Extreme	Extreme

*Change to "High C" where there is the potential of one or more lives being lost.

The ANCOLD guidelines provide guidance on the definition of the severity of damage and loss in relation to a number of assets. It is anticipated that damage and loss caused by the failure of a small dam will most likely fit the definition of Minor to Medium for most asset types as specified in Appendix B of the Consequence Category Guidelines (ANCOLD, 2012).

Thresholds of PAR for each category are similar for a Minor to Medium severity. These are summarised in Table 1-2 for the categories which are identified by the Screening Tool.

Table 1-2 Screening Tool Consequence Category definition for Severity of Damage and Loss

Consequence Category	Severity of Damage and Loss	Total PAR
Very Low to Low	Minor to Medium	<1
Significant*	Minor to Medium	≥1 to 10
High C or above	Minor to Medium	>10

*** Change to High C or above where there is the potential for one or more lives being lost**

Further details on the framework applied by the Screening Tool to assess the Consequence Category, is provided in Section 2 of this document.

1.5. Data Assembly and Key Inputs to the Screening Tool

The Screening Tool has been developed to perform an initial level assessment using information which can be readily obtained.

A summary of key inputs to the Screening Tool and potential sources of information are shown in Table 1-3. A complete list of information which can be entered and stored in the Screening Tool can be found in Appendix C.

Table 1-3 Summary of key inputs into the Screening Tool and possible sources of information

<table>
<tr><th>Key Screening Tool inputs</th><th>Examples of where information can be sourced</th></tr>
<tr><td>Dam volume</td><td rowspan="5">• Owner knowledge
• Site inspection
• Licence renewal pre-application questionnaire (for licensing authorities)
• Engineering reports
• Works plans
• Records
• Aerial photography
• Contour/Topographic maps</td></tr>
<tr><td>Downstream topography</td></tr>
<tr><td>Extent of downstream impact</td></tr>
<tr><td>Population at Risk (PAR)</td></tr>
<tr><td>Location of PAR</td></tr>
</table>

1.6. Screening Tool Limitations

It is the user's responsibility to ensure that the Screening Tool is applied correctly and that the results are reasonable. ANCOLD (2003) provides a description of the knowledge required for personnel involved in dam safety programs. As a minimum, users of the tool should have the level of dam safety knowledge and expertise of 'Inspector and Other Field Personnel' as described in the guidelines.

Application of the Screening Tool should be limited to dams that do not meet the ANCOLD definition of a large dam (Glossary), are up to 500 ML, and where the predicted severity of damage and loss is not expected to exceed medium as defined in ANCOLD (2012). If a dam does not meet the above criteria, then the Consequence Category assessment should be undertaken by a suitably qualified engineer (DSE, 2007) using the methods described in ANCOLD (2012). Furthermore, the Screening Tool is not intended for use in assessing the Consequence Category of tailings storage facilities.

Where there is uncertainty in the Consequence Category assessed using the tool, for example as to whether to assign a Significant or High C or above Consequence Category to a dam, the dam owner or licensing authority should seek further engineering confirmation.

The Screening Tool was developed using Microsoft Excel 2007 and may not be compatible with versions of Microsoft Excel pre Excel-97. Note that macros must be enabled for the Screening Tool to operate.

1.7. Structure of the Screening Tool Guideline

This document has been developed to assist in the operation of the Screening Tool spreadsheet and to provide background information to the concepts on which the Screening Tool initial level assessment method is based.

Section 2 of this document describes the concepts behind the framework which is applied by the Screening Tool.

Section 3 of this document provides instruction on the operation of the Screening Tool.

2. Screening Tool Framework

2.1. Framework Overview

The Screening Tool Framework (Figure 2-1) applies a decision process based on the Initial Consequence Assessment method for assigning a Consequence Category to a dam, as outlined in ANCOLD (2012). The Initial assessment is described as a conservative assessment used to '*identify Consequence Categories that are obvious from existing knowledge'* based on Total PAR.

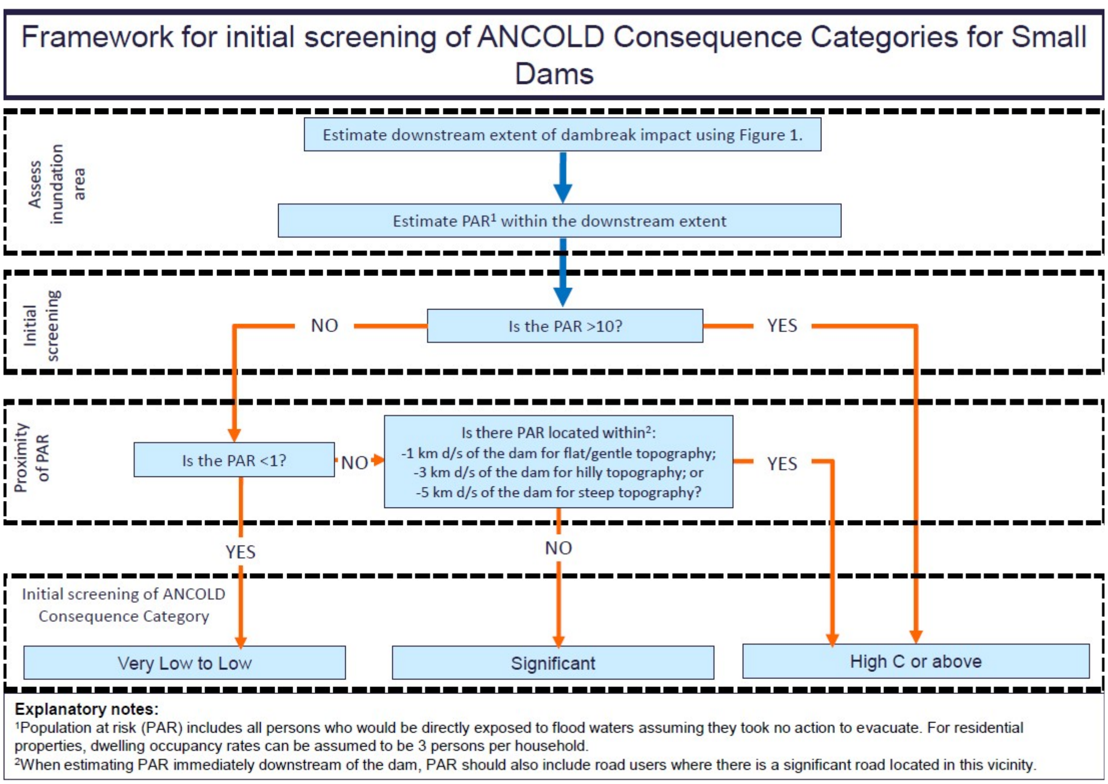
Assigning a Consequence Category using the Initial Consequence Assessment involves the estimation of the following parameters:

- Estimate of inundation area;
- Estimate of Total damage/loss; and
- Estimate of Total PAR.

The process which the Screening Tool framework uses to assign a Consequence Category incorporates the estimation of the above listed parameters and uses this information to categorise the dams based on the criteria summarised Table 1-2.

Each component of the framework is further described in the following sections.

Figure 2-1 Framework for initial screening of ANCOLD Consequence Categories for small dams as specified in the spreadsheet tool (larger version in Appendix D)



2.2. Estimate of Downstream Extent of Dambreak Impact

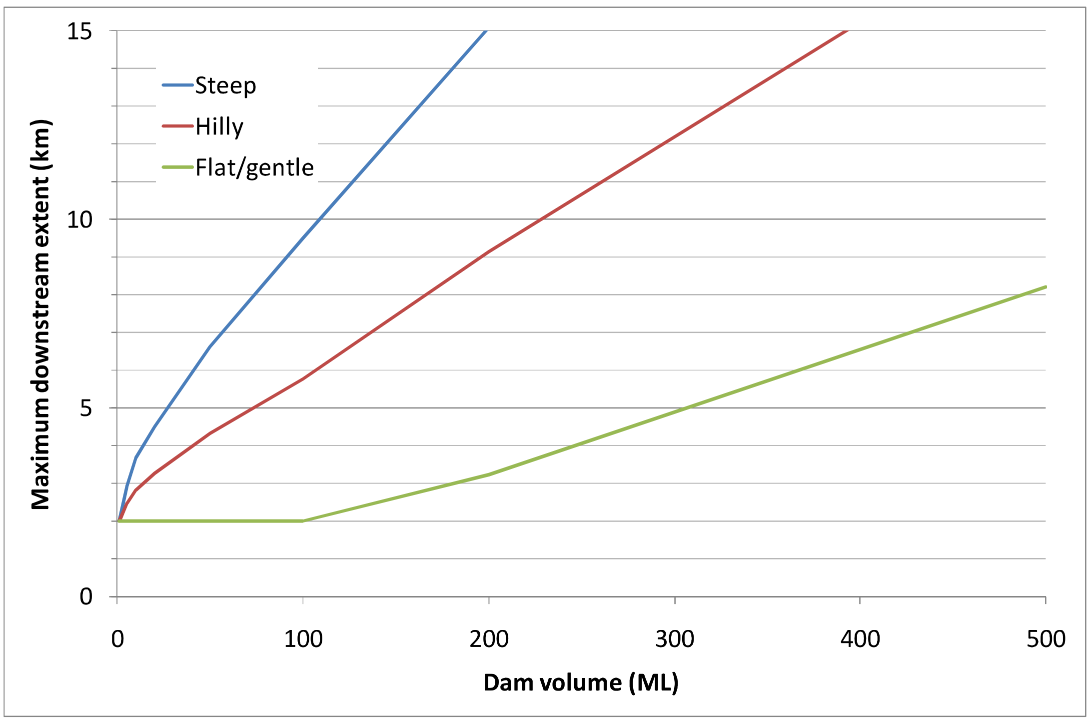
The downstream extent of dambreak impact referred to in Figure 2-1 relates to the estimation of inundation area in the Initial Consequence Assessment (ANCOLD, 2012). The inundation area which should be considered will depend on:

- The peak outflow from the dam breach;
- Routing and attenuation of the flood wave; and
- Depth and velocity at the location of the PAR.

The assessment should generally continue downstream until the dambreak flood would enter a river or downstream storage which has a sufficient storage volume to ensure that there are no further downstream impacts.

The maximum downstream extent is estimated by the Screening Tool using a series of indicative curves which provide guidance on the distance downstream where the flood wave could potentially result in significant consequences. The curves, shown in Figure 2-2 are employed by the Screening Tool to provide an estimate of downstream extent for a given dam volume and downstream terrain.

Figure 2-2 Indicative maximum downstream extent of dambreak impact



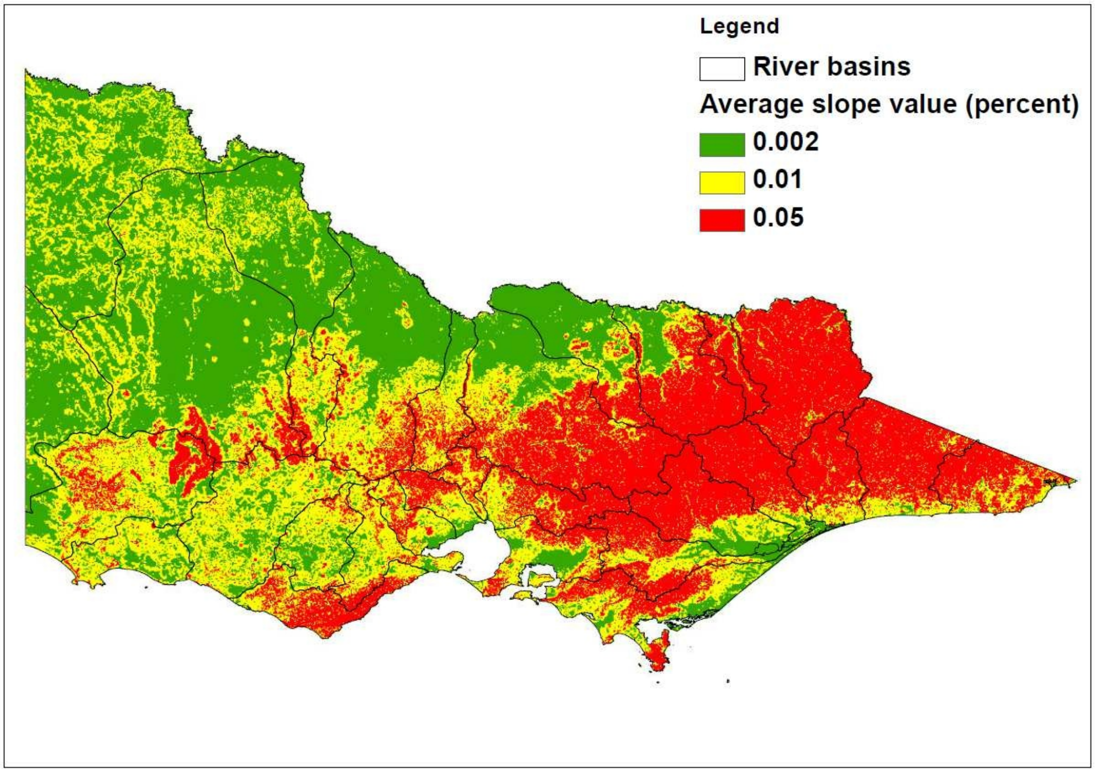
The maximum downstream extents in Figure 2-2 represent where the depth times velocity of the attenuated flood peak is no longer considered to provide a risk to human stability as defined by Cox (2010). The curves were derived using a combination of generalised methods for estimating peak flow from a dam failure (Froehlich, 1995) and generalised methods for estimating inundation areas (Schaefer, 1992). These curves are broadly consistent with the distances recommended in ANCOLD (2012) for the total distance downstream relative to dam volume which should be considered when developing a hydraulic model.

Three variations in terrain related to the slope of the downstream valley were considered in developing the extent curves: 'Steep', 'Hilly', 'Flat/gentle'. The curves were derived assuming slopes of up to 0.002% for the lower limiting 'Flat/gentle' curve and 0.02% for the upper limiting 'Steep' curve. To aid the selection of the appropriate slope category a map of Victoria is provided in Figure 2-3 showing average terrain slopes in different regions. Roughness of the downstream terrain was assumed to be similar to grass or pasture.

Figure 2-2 was derived assuming rural settings with minimal obstructions and can be considered conservative for dams located in more urbanised environments.

Use of topographic maps could also be used to determine the downstream extent which should be considered in the assessment.

Figure 2-3 Victoria statewide slope map



2.3. Estimate of PAR within the Downstream Extent

As noted in Section 1.4, the assigned Consequence Category is dependent on the Total PAR. An estimate of PAR located within the downstream extent, as identified from Figure 2-2 or from site-specific knowledge, should include all persons who may be caught in the path of the flood wave at the time of dam failure. The PAR assessment should consider all locations where people assemble including houses, schools, hospitals, commercial and retail areas, roads, and community and recreational facilities.

The user should also consider PAR within the downstream extent based on elevation. This can be informed by aerial photography, contour or topographic maps and site inspections. ANCOLD (2012) suggest considering a height above the stream bed of between one third (1/3) and one half (1/2) of the dam height when assessing flood level. As a rule of thumb, it can be assumed that the flood height would be about one half of the maximum downstream height of the dam wall immediately downstream of the dam, tapering to zero at the maximum downstream extent of the flood. This approach requires a degree of judgement in taking variations in local topography and terrain into account.

2.4. Assessment of Consequence Category

The initial screening portion of the framework assesses whether the PAR meets the criteria of a High C or above Consequence Category dam (PAR greater than 10 – described in Section 1.4). Dams which do not meet the criteria for this category are further assessed.

To assign a Consequence Category of Very Low or Low, a PAR of less than one must be satisfied. Where a dam does not meet the Very Low or Low criteria, the framework considers the proximity of the PAR to the location of the dam and topography in order to assess the potential for loss of life. Referring to Table 1-1, dams which fall into the Significant Category based on PAR may be upgraded to High C or above where there is the potential for loss of life. The "potential for loss of life" will depend upon the location and vulnerability of the PAR which will be influenced by the warning time, depth and velocity of floodwaters and associated understanding the PAR has of the impending flooding.

In lieu of detailed hydraulic modelling, proximity to the dam and downstream topography has been adopted within the Screening Tool as a surrogate for vulnerability of the PAR. Therefore, the potential for loss of life is assumed to be more likely where the PAR is located within:

- one kilometre downstream of the dam in flat/gentle topography; or
- three kilometres downstream of the dam for hilly topography; or
- five kilometres downstream of the dam for steep topography.

It is assumed that the PAR located in these areas will have little warning time available and the flood depth and velocity will also be most severe in such areas. Hence, if the PAR is between 1 and 10 and is located within the above areas, the Screening Tool classifies the dam as within the High C or above Consequence Category. If the PAR is between 1 and 10 and is located downstream of the above areas, the Screening Tool classifies the dam as within the Significant Consequence Category.

2.5. Consequence Category and Dam Safety Management Approach

As outlined in ANCOLD (2003) the level of dam safety practice should be consistent with the Consequence Category of the dam. The initial level Consequence Category obtained from the Screening Tool indicates whether a simplified approach to dam safety management can be used, or whether a failure of the dam could cause significant impacts to public safety and should be subject to a more detailed management approach and engineering input.

Table 2-4 outlines some typical dam safety requirements for small dams of different Consequence Categories. A Consequence Category of High C or above is a threshold for a higher level of dam safety practice including a safety review of the dam by a suitably qualified engineer (see Glossary). For a licensed dam, an owner must ensure compliance with the requirements set out in the 'Works Plan' and 'Works Licence' of the dam.

Where downstream development increases the potential impact of the dam may correspondingly increase. Owners are responsible for regularly reviewing the Consequence Category to ensure that they continue to manage their dams to a safe level.

Table 2-4 Typical dam safety requirements for owners of small dams based on Consequence Category

Initial Assessment Consequence Category using Screening Tool	Typical dam safety requirement for small dam owner
Low or Very Low	• Uses a simplified surveillance and monitoring plan (available from licensing authorities or DEPI) and dam safety emergency plan (e.g. template provided in DSE 2007). • Refers to guidance provided in the document 'Your Dam Your Responsibility'.
Significant	• If there is uncertainty about potential for loss of life, commissions a suitably qualified engineer to undertake Consequence Category Assessment as per ANCOLD (2012). • Uses a simplified surveillance and monitoring plan (available from licensing authorities or DEPI) and dam safety emergency plan (e.g. template provided in DSE 2007) endorsed by a suitably qualified engineer. • Refers to guidance provided in the document 'Your Dam Your Responsibility' and ANCOLD guidelines.
High C or above	• Commissions a suitably qualified engineer to undertake a full Consequence Category Assessment as per ANCOLD (2012). • Commissions a suitably qualified engineer to undertake a safety review and preparation of surveillance and monitoring plans and dam safety emergency plans. • Refers to and ensures compliance with ANCOLD dam safety guidelines. • Lodges the DSEP to the relevant municipal Council. • Where applicable, commissions a risk assessment.
All Consequence Categories	• Notifies the licensing authority or DEPI in an emergency or where a significant deficiency in a dam is detected. • Works to rectify a significant deficiency in a dam are devised by a suitably qualified engineer and completed as soon as practicable. • Notifies relevant emergency agencies (e.g. SES and Victoria Police), stakeholders and community in the event of an emergency. For a licensed dam, contact details should be set out in the DSEP. • Reviews Consequence Category every five years or sooner if significant downstream development occurs.

3. Using the Consequence Category Screening Tool

3.1. General Information

The Screening Tool is comprised of a series of sheets within a Microsoft Excel workbook. Sheets available for viewing are listed in Table 3-1. These are navigated to using the command buttons located at the top of each sheet. Note that command buttons vary depending on the sheet which is currently selected.

Table 3-1 Excel sheets within the Screening Tool workbook

Sheet	Description
Home	Introduction to the Screening Tool. Automatically loaded when the tool is opened.
Help	Provides a description of the functions available within the Screening Tool and a description of the input fields.
Add New Record	Input sheet for new dam assessments. White cells indicate where inputs can be entered.
Retrieve Record	Sheet on which records which have been previously stored in the database are retrieved and displayed. Previously stored assessments can be edited on this sheet. White cells indicate where inputs can be entered or edited.
View Record Database*	Sheet shows all information which has been stored within the Screening Tool.

***Only available on the 'Home' and 'Help' sheets**

Sheets which are used to add or edit assessment records also have additional command buttons located at the top of the sheet. These include command buttons for: save, delete, clear sheet and print.

3.2. Entering a New Dam for Assessment

A new dam can be entered into the Screening Tool for assessment using the ***'Add New Record'*** command.

The ***'Add New Record'*** input sheet is broken up into the following sections:

- General Information;
- Dam Information;
- Downstream extent of dambreak impact;
- Initial Screening and Proximity of PAR; and
- Assessment of Consequence Category.

White cells on the ***'Add New Record'*** sheet indicate where inputs can be entered. Grey cells are protected and cannot be altered.

The following sections provide descriptions of each input field available in the ***'Add New Record'*** sheet and some guidance in populating these fields.

A summary of all input fields available on the sheet are listed with a description of the data to be entered in Appendix C.

An example of an assessment sheet populated with dummy information is shown in Appendix E.

3.2.1. General information

Description of input fields

Section	Fields	Optional or Compulsory	Description
General Information	Dam No./Service ID	Compulsory	Dam identifier. Cannot be changed once saved into the Screening Tool. Only numerical values can be entered.
	Dam Name/Works ID	Compulsory	Secondary dam identifier. Cannot be changed once saved into the Screening Tool.

The 'Dam No. /Service ID' and 'Dam Name/Works ID' refer to unique identifiers for easy identification or reference of the dam. An entry into both fields is required to save the assessment. Both fields are also required to retrieve and edit any previously entered assessments.

Note:

- Only numeric values can be entered into the 'Dam No./Service ID' field; and
- Once the assessment is saved these two fields cannot be edited if the assessment is retrieved from the database.

3.2.2. Dam information

Description of input fields

Section	Fields	Optional or Compulsory	Description
Dam Information	Dam Volume	Compulsory	Storage capacity of the dam. Where there are multiple dams on a waterway the effects of cascade failure should be taken into account as described in Section 3.2.3, Cannot be changed once saved into the Screening Tool.

The dam volume entered is used in assessing the downstream extent of the dambreak impact.

Note:

- Once the assessment is saved, the dam volume cannot be edited if the assessment is retrieved from the database.

3.2.3. Cascade Dams

Where multiple dams are located on the same waterway there is a potential for cascade failure. This is where the failure of a dam on a waterway could result in the failure of dams located downstream. In this circumstance, ANCOLD (2012) recommends that '*the Consequence Category of the upstream dam should be based upon the combined effects of multiple dam breaks'*. In using the Screening Tool, this can be addressed by entering a volume for the upstream dam which is the combined volume of that dam and any downstream dams.

3.2.4. Downstream extent of dambreak impact

Description of input fields

Section	Fields	Optional or Compulsory	Description
Downstream extent of dambreak impact	Downstream topography	Optional	Topography downstream of the dam. Required to estimate the downstream extent of the dambreak impact. Three options are available: -Flat/gentle; -Hilly; and -Steep.
	Downstream extent of dambreak impact	Optional	Automatically calculated from Figure 2-2. This provides an estimate of the maximum distance downstream of the dam where the Population at Risk (PAR) should be considered in making an initial assessment of

Section	Fields	Optional or Compulsory	Description
			Consequence Category.
	Adopted extent	Optional	A downstream extent can be entered by the user to overwrite the downstream extent above where more specific information is known about where the flood wave from a dambreak event would travel. E.g. The user may enter a distance downstream of the dam in which to consider the PAR which is less than that which is estimated using Figure 2-2 as there is a creek located downstream of the dam which would capture the dambreak flood.
	Comments relating to dambreak extent	Optional	The user should record any comments relating to the estimate of the downstream extent of dambreak impact for future reference.

The downstream extent of dambreak impact provides guidance on the area in which the Total PAR should be considered downstream of a dam. To assess the downstream extent, the user is required to select a downstream topography from the drop down list.

The downstream extent is calculated by the Screening Tool as a function of the dam volume and the downstream topography from Figure 2-2.

The extents estimated from Figure 2-2 and reported in the Screening Tool are conservative and are intended to be used as a guide to the maximum distance downstream for which the PAR should be considered. These extents should be overwritten in the 'Adopted extent' field where further site-specific information is available.

A comments field is available in this section of the assessment form for the user to record any comments which may provide further understanding of downstream extent adopted when the record is retrieved in future.

It should be noted that the assessment can be saved into the database even if no fields in this section have been populated.

3.2.5. Initial Screening and Proximity of PAR

Description of input fields

Section	Fields	Optional or Compulsory	Description
Initial Screening and Proximity of PAR	Estimate of Total PAR within downstream extent	Compulsory	The estimate of the Total Population at Risk (PAR) located within the downstream extent described above. The PAR includes all persons who would be directly exposed to flood waters assuming they took no action to evacuate. For residential properties, dwelling occupancy rates can be assumed to be 3 persons per household. When estimating PAR immediately downstream of the dam, PAR should also include road users where there is a significant road located in this vicinity. The ANCOLD guidelines suggest considering a height above the stream bed of between one third (1/3) and one half (1/2) of the dam height when assessing flood level.
	PAR located within: 1 km d/s of the dam for flat/gentle topography, 3 km d/s for hilly topography or 5 km d/s for steep topography	Compulsory if PAR <=10	Identify if there is PAR located within: • 1 km d/s of the dam for flat/gentle topography; • 3 km d/s for hilly topography; or • 5 km d/s for steep topography. This input is only required if the Total PAR estimate is less than or equal to 10 and the permanent PAR is not less than one (refer figure 2-1).

Section	Fields	Optional or Compulsory	Description
	Source of estimate of Total PAR	Optional	The method/s for estimating the initial PAR can be selected from the check list. Six customisable check list labels are available. One check box labelled ‘Other’ is also available. If this option is selected the user should enter the other method into the adjacent comment box.
	Comments relating to PAR	Optional	The user should record any comments relating to the estimate of the PAR.

The estimate of PAR within the downstream extent entered in this section should consider all persons who may be caught in the path of the flood wave within a distance downstream of the dam informed by the downstream extent from the Screening Tool. This number should include any road users who are at risk. Some guidance for estimating PAR for residential dwellings is provided in the table above.

Information to assist in estimating the Total PAR can be obtained from a number of sources. The user should select the relevant sources of information using the check lists (see Figure 3-1). This data is stored for future reference.

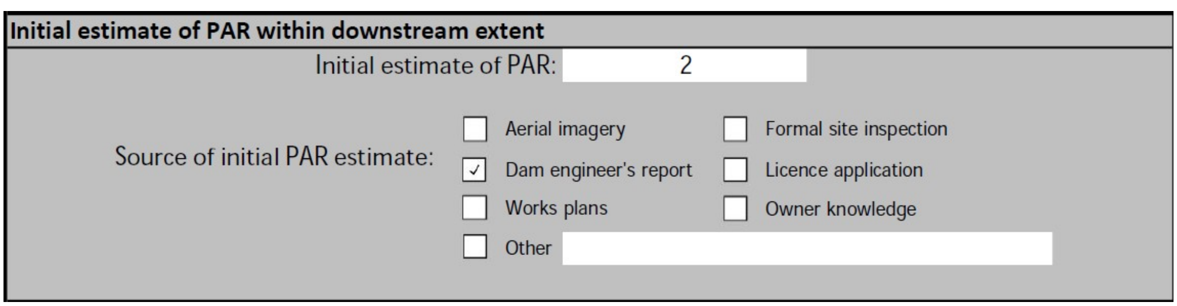
Depending on the estimated number of PAR, the user may be prompted to identify if PAR is located within:

- one kilometre downstream of the dam in flat/gentle topography; or
- three kilometres downstream of the dam for hilly topography; or
- five kilometres downstream of the dam for steep topography.

This question will only appear if the total PAR is less than or equal to 10.

A comments field is available in this section of the assessment form for the user to record any comments which may provide further understanding of the PAR adopted when the record is retrieved in future.

Figure 3-1 Initial Screening section of the assessment form


Initial estimate of PAR within downstream extent

Initial estimate of PAR: 2

Source of initial PAR estimate:

- [ ] Aerial imagery
- [ ] Formal site inspection
- [x] Dam engineer's report
- [ ] Licence application
- [ ] Works plans
- [ ] Owner knowledge
- [ ] Other

Note:

- Only numeric values can be entered into the estimate of PAR within downstream extent field.
- When the Screening Tool is opened on its first application, the check box labels will be generic (Option 1, Option 2, etc.). These labels should be customised before the Screening Tool’s first use with relevant options for estimating the PAR (see Figure 3-1). This can be done through the “Help” menu under ‘Source of estimate of Total PAR’ in the Description of Inputs table. Check box labels should NOT be changed following the first application as this may alter existing records.

3.2.6. Assessment of Consequence Category

Section	Fields	Description
Assessment of Consequence Category	Initial assessment of ANCOLD Consequence Category	Automatically calculated. The Consequence Category is estimated using the Framework for Initial Screening of ANCOLD Consequence Categories for Small Dams.

Following entry of the required data the populated assessment sheet will display the initial assessment of the ANCOLD Consequence Category as one of the following:

- Very Low or Low;
- Significant; or
- High C or above.

The Consequence Category is estimated using the framework described in Section 2.4 of this document.

3.2.7. Saving a new record

In order for the data entered into the assessment sheet to be saved to the Screening Tool database, the ***'Save New Record'*** command button (located at the top of the sheet) must be used. Selecting this command will write the assessment information into the database and save the whole workbook. **Selecting save from the Excel menu will not record the assessment details to the Screening Tool database.**

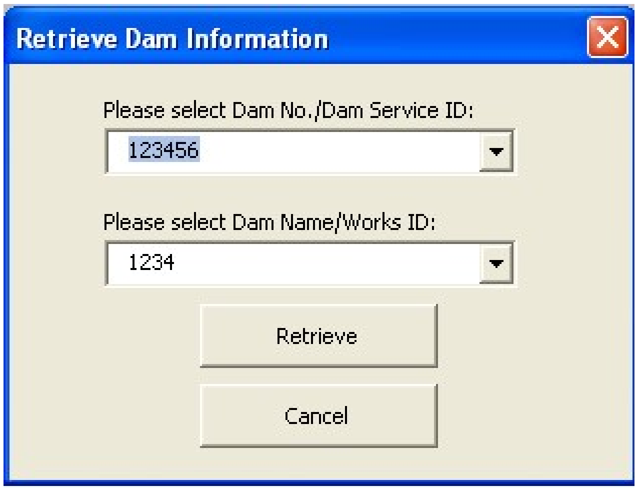
3.3. Retrieving/Editing an Existing Record

3.3.1. Retrieving a record

Records which have been previously entered and saved into the Screening Tool can be retrieved for viewing or editing by using the ***'Retrieve Record'*** command button. When selected, the user will be prompted for the 'Dam No. /Service ID' and 'Dam Name/Works ID' relating to the record to be retrieved. Dam details can be entered either by typing in the 'Dam No./Service ID' and 'Dam Name/Works ID' or selecting the two identifiers from the drop down list of the pop up user form (Figure 3-2). When using the drop down lists, the 'Dam No./Service ID' list will show all 'Dam No./Service IDs' stored in the database. When a 'Dam No/Service ID' has been selected, the 'Dam Name/Works ID' drop down list will show all 'Dam Name/Works IDs' stored in the database which have the selected 'Dam No./Service ID'. Once 'Retrieve' is selected from the pop up screen, the 'Retrieve Record' sheet will be populated with the data.

Note:
The same 'Dam No./Service ID' may appear more than once in the drop list, this means that there are a number of records with the same 'Dam No. Service ID'. However, there should only be one record with the same combination of 'Dam No./Service ID' and 'Dam Name/Works ID'.

Figure 3-2 'Retrieve Record' user prompt



3.3.2. Editing a record

When editing an existing record, the record must first be retrieved as described in Section 3.3.1. The retrieved record will appear in the same format as the 'Add New Record' assessment sheet. However, the following fields will be shaded in grey and locked from editing:

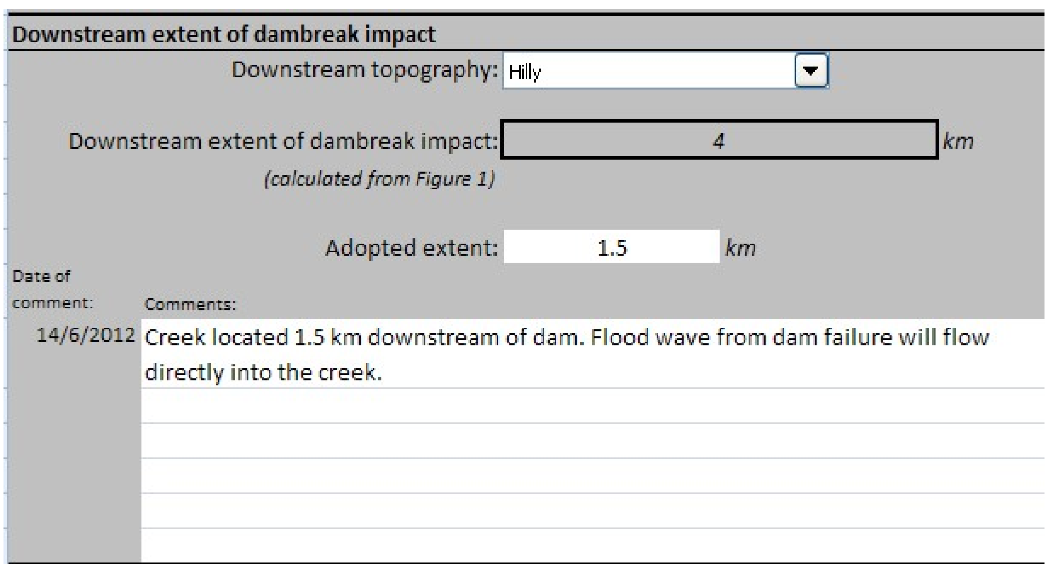
- Date of assessment – the date displayed will be the date on which the record was originally entered;
- User – the user displayed will be the user who originally entered the record;
- Dam No/Service ID;
- Dam Name/Works ID;
- Dam volume.

All other cells coloured in white are available for editing.

To maintain the integrity of the assessment record, it is suggested that any changes made to the assessment are recorded by the user in the available comment fields (see Figure 3-3) for an example). Six rows are available for comments under the 'Downstream extent of dambreak impact' and 'Confirm PAR location' sections. When a comment is entered, the date on which it was made is automatically recorded. Comments entered are saved into the database when the edited sheet is saved and will be shown when the record is retrieved in future.

Note:
There is no need to continue a single comment on the next row if the width of the text is wider than the width of the comment cell. The rows on which the comments are entered will adjust automatically in height to accommodate the text entered in the field.

Figure 3-3 Example of entering comments when editing a record



3.3.3. Saving an edited record

When saving a record which has been edited, the record which was previously saved for that particular dam will be overwritten with the edited data. The ***'Save Edits'*** command button must be used to register changes in the database.

3.3.4. Deleting an existing record

Records which have been previously entered and saved into the Screening Tool can be removed from the database by using the ***'Delete Record'*** command button (Figure 3-4). The user will be prompted to enter the 'Dam No. /Dam Service ID' and 'Dam Name/Dam Works ID' – both are required to continue.

Note:
Once a record has been deleted the data for that particular dam is removed permanently from the database and cannot be retrieved.

Figure 3-4'Delete Record' user prompt

3.4. Record Database

The record database can be displayed by selecting the ***'View Record Database'*** button. This option is only available on the "Home" and "Help" screens. The database stores all information which has been entered and saved into the Screening Tool.

Note:
Records cannot be added, edited or deleted in the database sheet. These functions can only be performed by using the respective command buttons.

3.5. Printing the Record

By using the ***'Print Current Sheet'*** command button the current assessment record is first saved to the database. The print area is automatically set to print the full area of the assessment sheet on a single A4 page and the print dialogue box will be displayed so the user can select the appropriate printer settings.

Note:
Selecting print from the Excel menu will not guarantee the print area settings. These settings should be checked prior to selecting print from the Excel menu.

4. References

Australian National Committee on Large Dams (ANCOLD, 2003). *Guidelines on Dam Safety Management* (www.ancold.org.au).

ANCOLD (2012). *Guidelines on the Consequence Categories for Dams*. (www.ancold.org.au).

Cox, R.J, T.D. Shand, M.J. Blacka (2010). *Australian Rainfall and Runoff Revision Projects, Project 10, Appropriate Safety Criteria for People, Stage 1 Report,* Institution of Engineers, Australia, Barton ACT, 2010.

Departments of Sustainability and Environment (DSE, 2007). *Your Dam Your Responsibility.* State Government of Victoria (www.water.vic.gov.au).

Froehlich, D.C. (1995). *Peak Outflow From Breached Embankment Dam*. Journal of Water Resources Planning and Management, vol. 121, no. 1, p. 90-97.

Schaefer, Melvin G. (1992). *'Dam Safety Guidelines – Technical Note 1: Dam Break Inundation Analysis and* Downstream *Hazard Classification'* Washington State Department of Ecology, July 1992 (Revised October 2007).

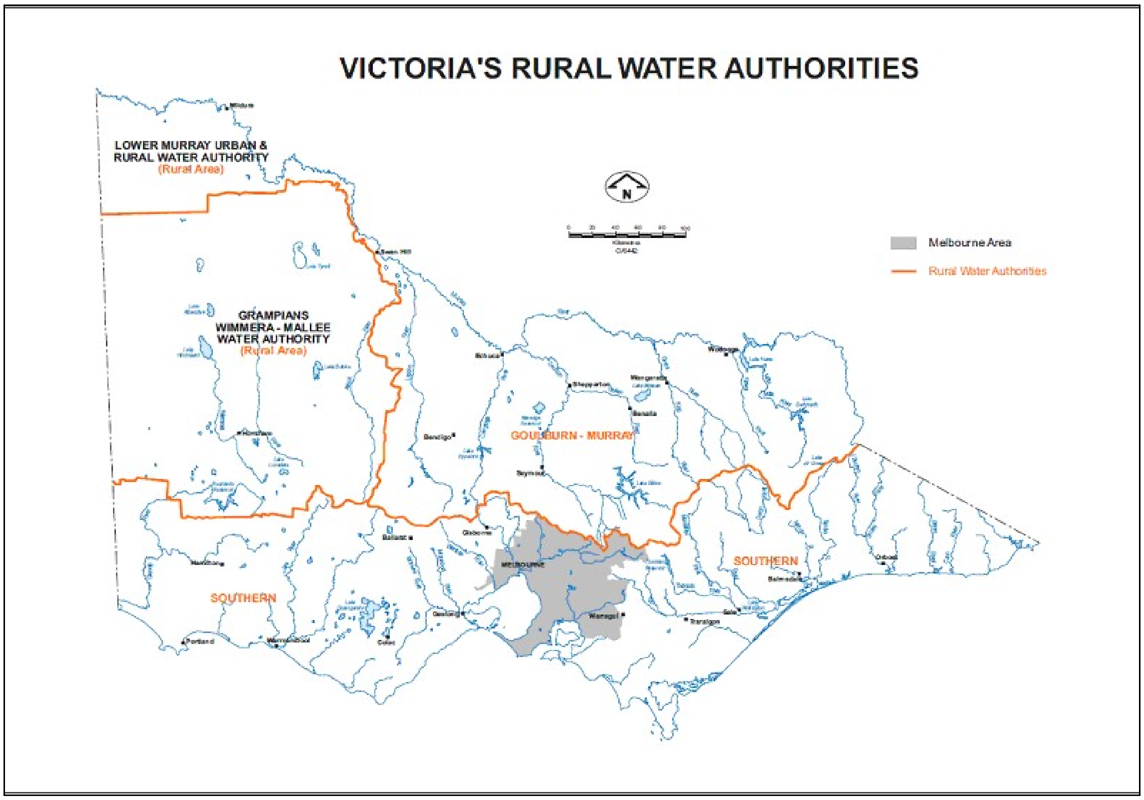
5. Glossary

TERM	DEFINITION
Large Dam (ANCOLD)	A large dam is defined as one which is: (a) more than 15 metres in height measured from the lowest point of the general foundations to the 'crest' of the dam; or (b) more than 10 metres in height measured as in (a) provided they comply with at least one of the following conditions: (i) the crest is not less than 500 metres in length; (ii) the capacity of the reservoir formed by the dam is not less than one million cubic metres; (iii) the maximum flood discharge dealt with by the dam is not less than 2000 cubic rnetres per second (approximately 170,000 ML/d); and (iv) the dam is of unusual design. No dam less than 10 metres in height is included.
Population at Risk (PAR)	The PAR includes all people who would be directly exposed to flood waters assuming they took no action to evacuate. The PAR should be assessed using demographic data including dwelling occupancy rates, school populations, work sites and other places where people assemble (eg. Industrial, hospital, commercial and retail areas). The PAR may vary according to time of day, day of week and season.
Potential Loss of Life (PLL)	The PLL is synonymous with the term Loss of Life (LOL) as described in the ANCOLD *Guidelines in Risk Assessment* (2003b). PLL may be used where: • a risk assessment has already been undertaken consistent with ANCOLD *Guidelines in Risk Assessment*; or • a loss of life assessment is undertaken in accordance with the recommendations of ANCOLD's *Guidleines on the Consequence Categories for Dams* (0ctober 2012). PLL estimates resulting from a potential dam failure can be influenced by factors including: • warning time for people exposed to the life threatening flood waters; • severity of the flod event and types of failure scenarios used in the evaluation; • time of failure, including day, night, season; and • inability to precisely determine the fatality rate.
Suitably Qualified Engineer (DSE, 2007)	A professional engineer who: a) has qualifications sufficient for eligibility for membership of Engineers Australia; b) is recognized by the engineering profession as experienced in the engineering of dams; c) is competent to undertake the investigation, design, construction supervision, repair and remedial work, operational, surveillance, maintenance and decommissioning activities associated with farm dams; and d) has an appropriate amount of professional indemnity insurance.

Appendix A: Licensing Authorities

The licensing authority function under the *Water Act 1989* is delegated to the following water corporations:

- Goulburn Murray Water;
- Grampians Wimmera Mallee Water;
- Lower Murray Water;
- Melbourne Water; and
- Southern Rural Water.



Appendix B: ANCOLD Guidelines

Guidelines for Design of Dams for Earthquake, 1998.

Guidelines on Selection of Acceptable Flood Capacity for Dams, 2000.

Guidelines on the Environmental Management of Dams, 2001.

Guidelines on Dam Safety Management, 2003(a).

Guidelines on Risk Assessment, 2003(b).

Guidelines on the Consequences Categories for Dams 2012.

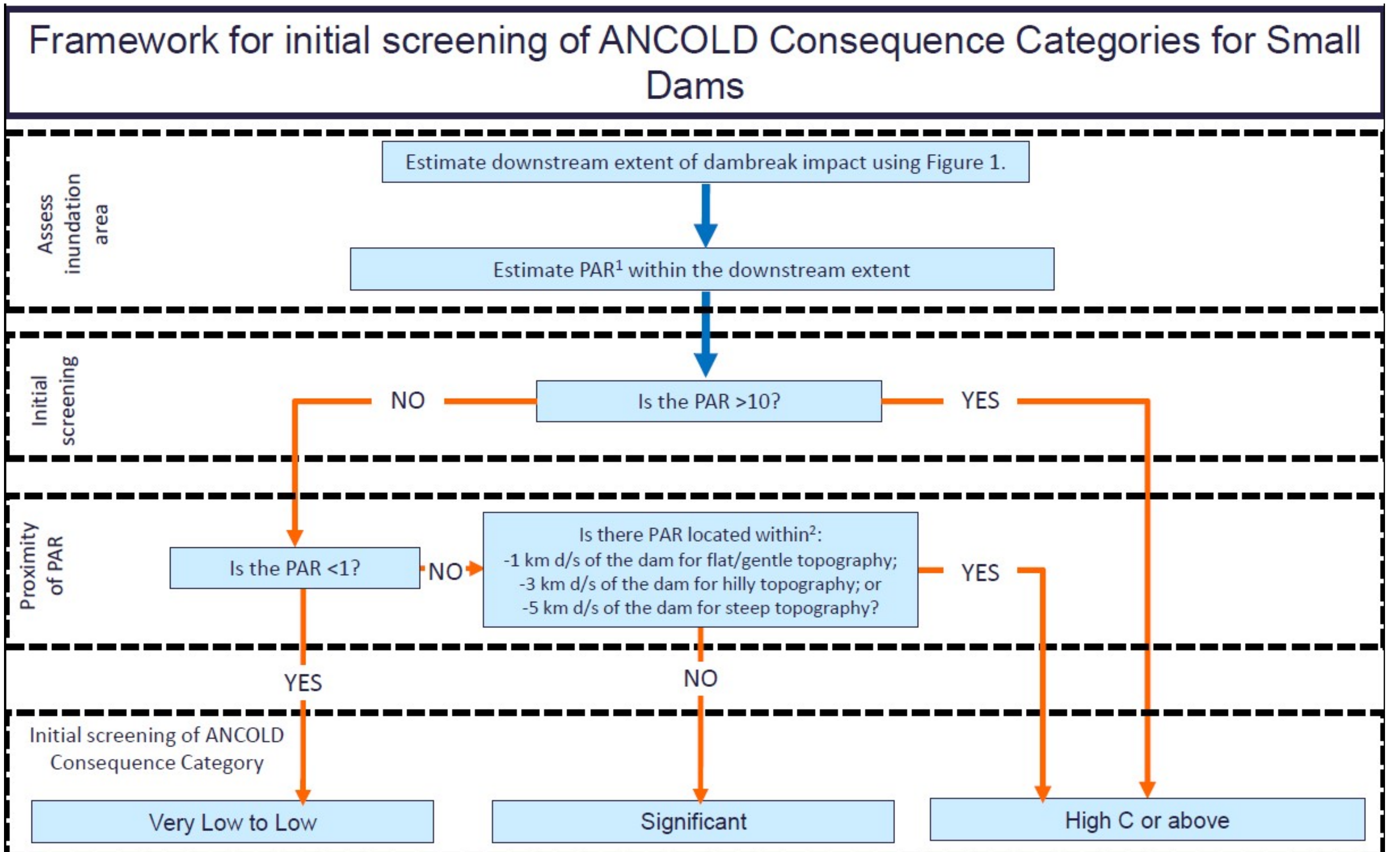
Appendix C: Screening Tool Input Fields

Table C-1 Input fields available when adding a new dam for assessment

Section	Fields	Optional or Compulsory	Description
	Date of assessment	Automatic	Date on which the dam was entered into the Screening Tool. Date is automatically generated.
	User	Optional	Identifier for the user whom entered the dam into the Screening Tool.
General Information	Dam No./Service ID	Compulsory	Dam identifier. Cannot be changed once saved into the Screening Tool.
	Dam Name/Works ID	Compulsory	Secondary dam identifier. Cannot be changed once saved into the Screening Tool.
Dam Information	Dam Volume	Compulsory	Storage capacity of the dam. Cannot be changed once saved into the Screening Tool.
Downstream extent of dambreak impact	Downstream topography	Optional	Topography downstream of the dam. Required to estimate the downstream extent of the dambreak impact. Three options are available: • Flat/gentle; • Hilly; or • Steep.
	Downstream extent of dambreak impact	Optional	Automatically calculated from Figure 2-2. This provides an estimate of the maximum distance downstream of the dam where the Population at Risk (PAR) should be considered in making an initial assessment of Consequence Category.
	Adopted extent	Optional	A downstream extent can be entered by the user to overwrite the downstream extent above where more detailed information is known about where the flood wave from a dambreak event would travel. E.g. The user may enter a distance downstream of the dam in which to consider the PAR which is less than that which is estimated using Figure 2-2 as there is a creek located downstream of the dam which would capture the dambreak flood.
	Comments relating to dambreak extent	Optional	The user should record any comments relating to the estimate of the downstream extent of dambreak impact for future reference.
Initial Screening and Proximity of PAR	Estimate of PAR within downstream extent	Compulsory	The initial estimate of the Population at Risk (PAR) located within the downstream extent described above. The PAR includes all persons who would be directly exposed to flood waters assuming they took no action to evacuate. For residential properties, dwelling occupancy rates can be assumed to be 3 persons per household. When estimating PAR immediately downstream of the dam, PAR should also include road users where there is a significant road located in this vicinity. The ANCOLD guidelines suggest considering a height above the stream bed of between one third (1/3) and one half (1/2) of the dam height when assessing flood level.

Section	Fields	Optional or Compulsory	Description
	PAR located within 1 km d/s of the dam for flat/gentle topography, 3 km d/s for hilly topography or 5 km d/s for steep topography?	Compulsory if PAR <=10	Identify if there is PAR located within: • 1 km d/s of the dam for flat/gentle topography; • 3 km d/s for hilly topography; or • 5 km d/s for steep topography. This input is only required if the Total PAR estimate is less than or equal to 10 and the permanent PAR is not less than one (refer figure 2-1).
	Source of estimate of Total PAR	Optional	The method/s for estimating the initial PAR can be selected from the check list. Six customisable check list labels are available. One check box labelled 'Other' is also available. If this option is selected the user should enter the other method into the adjacent comment box.
	Comments relating to PAR	Optional	The user should record any comments relating to the estimate of the PAR.
Assessment of Consequence Category	Initial assessment of ANCOLD Consequence Category	Automatic	Automatically calculated. The Consequence Category is estimated using the Framework for Initial Screening of ANCOLD Consequence Categories for Small Dams.

Appendix D: Framework for Screening of ANCOLD Consequence Categories for Small Dams as specified in the Screening Tool



Explanatory notes:

[1]Population at risk (PAR) includes all persons who would be directly exposed to flood waters assuming they took no action to evacuate. For residential properties, dwelling occupancy rates can be assumed to be 3 persons per household.

[2]When estimating PAR immediately downstream of the dam, PAR should also include road users where there is a significant road located in this vicinity.

Appendix E: Example of a Populated Assessment Sheet

Initial Assessment of ANCOLD Consequence Category for Small Dams		
Date of Assessment	9/11/2012	
User	A. Smith	
General Information		
Dam No./Service ID	12345	
Dam Name/Works ID	ABC Dam	
Dam Information		
Dam Volume (ML)	325	
Downstream extent of dambreak impact		
Downstream topography:	Hilly	
Downstream extent of dambreak impact: *(calculated from Figure 1)*	*12*	*km*
Adopted extent:	5	*km*
Comments:	River located 5 km downstream of dam would capture dambreak flood.	
Initial estimate of PAR within downstream extent		
Initial estimate of PAR:	2	
Source of initial PAR estimate:	☐ Aerial imagery ☑ Dam engineer's report ☐ Works plans ☐ Other	☐ Formal site inspection ☐ Licence application ☐ Owner knowledge
Confirm PAR Estimate and Proximity of PAR		
Confirmed estimate of PAR:	2	
Is there PAR located within: -1 km d/s of the dam for flat/gentle topography; -3 km d/s of the dam for hilly topography; or -5 km d/s of the dam for steep topography?	○ Yes	◉ No
Source of confirmed PAR estimate:	☐ Aerial imagery ☑ Dam engineer's report ☐ Works plans ☐ Other	☐ Formal site inspection ☐ Licence application ☐ Owner knowledge
Comments:	1 residential property located 3 km downstream of dam may become inundated. 2 residents estimated at property.	
Assessment of Consequence Category		
Initial assessment of ANCOLD Consequence Category	**Significant**	

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