Douglas Partners
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Integrated Practical Solutions

Report on
Geotechnical Investigation

Donnybrook Mine Shaft Condition
Lot F27 Goodwood Road, Upper Capel

Prepared for
Department of Mines, Industry Regulation & Safety

Project 96721.00
June 2021

Douglas Partners
Geotechnics / Environment / Groundwater

## Document History

Document details

| | | | |
|---|---|---|---|
| Project No. | 96721.00 | Document No. | R.002.Rev1 |
| Document title | Report on Geotechnical Investigation<br>Donnybrook Mine Shaft Condition | | |
| Site address | Lot F27 Goodwood Road, Upper Capel | | |
| Report prepared for | Department of Mines, Industry Regulation & Safety | | |
| File name | 96721.00.R.002.Rev1.Donnybrook Shaft Condition Assessment | | |

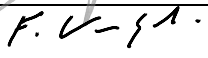
Document status and review

| Status | Prepared by | Reviewed by | Date issued |
|---|---|---|---|
| Revision 0 | Damian Jagoe-Banks | Fred Verheyde | 30 April 2021 |
| Revision 1 | Damian Jagoe-Banks | Fred Verheyde | 14 June 2021 |
| | | | |
| | | | |

Distribution of copies

| Status | Electronic | Issued to |
|---|---|---|
| Revision 0 | 1 | Kate Hryczyszyn , Department of Mines, Industry Regulation & Safety |
| Revision 1 | 1 | Kate Hryczyszyn , Department of Mines, Industry Regulation & Safety |

The undersigned, on behalf of Douglas Partners Pty Ltd, confirm that this document and all attached drawings, logs and test results have been checked and reviewed for errors, omissions and inaccuracies.

| | Signature | Date |
|---|---|---|
| Author |  | 14 June 2021 |
| Reviewer |  | 14 June 2021 |

bsi. ISO 9001 Quality Management
FS 604853

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# Report on Geotechnical Investigation
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## 1. Introduction

This report presents the results of a geotechnical investigation undertaken for the Donnybrook Mine Shaft Remediation Methodology project. The purpose of this report is to detail the site conditions and discuss the results and findings of the investigation.

The investigation was commissioned in a letter dated 14 September 2020 from the Department of Mines, Industry Regulation & Safety (DMIRS) and was undertaken in accordance with Douglas Partners' proposal PER200261 dated 7 August 2020.

It is understood that it is proposed to remediate mine features, identified by DMIRS as high risk to persons within the forest (either for recreational or professional reasons).

Two reports have been produced:

- Shaft assessment report (this report) – detailing the findings of the shaft assessment; and
- Shaft remediation report – providing recommendations on suitable remediation options and budget estimates.

The aim of the investigation was to undertake a desktop study and field work to assess the condition of ten mine features identified by DMIRS as high priority for remediation and provide an assessment of:

- Relevant desktop and historical information;
- Local geology and groundwater conditions;
- Mine feature geometry, including lateral workings, if encountered and potential for underground connectivity between features;
- Condition of the base of each feature and the presence of material/obstructions within the features;
- Stability of the features;
- Presence of fauna within the features; and
- Potential for noxious and/or flammable gases within the features.

The field investigation was undertaken in two phases, as summarised below:

*Phase 1:*

- Assessment of the general condition and stability of the features using a backhoe with an extendable boom.
- Scanning of all features using LiDAR to obtain spatial measurements.

- Photo and video of the features from ground surface and using equipment attached to an extendable pole.
- Gas monitoring for noxious and flammable gases.

*Phase 2:*

- Drilling from the surface to intercept horizontal workings identified during Phase 1 of the field work.
- Additional assessment of selected features using hand tools.

The details of the investigation are presented in this report, together with comments and recommendations on the items listed above.

## 2. Site Description and Desktop Study

The site comprises ten mine features selected by DMIRS for assessment due to risk to persons within the forest. The ten identified features are located within ten metres of an access track into the forest area and are a risk to firefighting personnel and equipment and recreation users and prospectors. The site is located within the Argyle Forest Block, approximately 2.6 km south of Donnybrook townsite. It is emphasised that the surrounding forest contains at least 42 recorded features possibly related to past mining activities. The site location and ten study features are detail on Drawing 1, Appendix B.

The 1:250,000 scale Collie Geological Sheet (SI 50-6, 1983) indicates that the site is underlain by Donnybrook Sandstone (Kn) comprising feldspathic sandstone and grit, with minor ripple marked shale and conglomerate. An area of gneiss is shown on the mapping to outcrop to the east of the sandstone beyond the site boundary.

Surface levels across the site rise from approximate RL 125 m AHD near Feature 1 to 142 m AHD at Feature 10.

Review of various historical documents available, including a report ("*Donnybrook Project, Annual Report 1988*") prepared by West Coast Holdings who undertook some exploration drilling across the site in the 1980s, indicates that the ground conditions generally comprises 6 m of sand with clay (weathered sandstone) overlying the Donnybrook sandstone (mostly weathered arenite, some wacke and mudrock) to a depth of about 30 m, overlying mudrocks and wackes to depths of about 75 m, in turn overlying archaen bedrock.

Historical information indicates that the ten studied features located within the historical "Queen of the South" mine. At least two shafts for the Queen of the South mine (designated Shafts 1 and 2) are interpreted to be located within the general vicinity of the ten study features, and are understood to be constructed to a depth of about 30 m (100 feet). Plans indicate that the Queen of the South mine had at least five levels of workings down to about 70 m depth (linked by various internal shafts), following a lode "Jackson's Reef" that intersects another lode "New Reef", both in an approximate north-south direction.

Information throughout articles from the West Australian (provided by DMIRS) written between 1899 and 1900 indicate that the ore within this goldfield was contained within reefs, within sandstone and

granite. The reefs were generally between 2.5 and 5 feet wide (0.75 m to 1.5 m wide) and were typically encountered at depths as shallow as 9 m. Shaft depths in the area were typically around 15 m deep.

The Jackson's Reef, located within the Queen of the South mining tenement (where all 10 mine features of this investigation are located) was reported on March 1900 to have a total length of 31 m, with a well-defined face within sandstone.

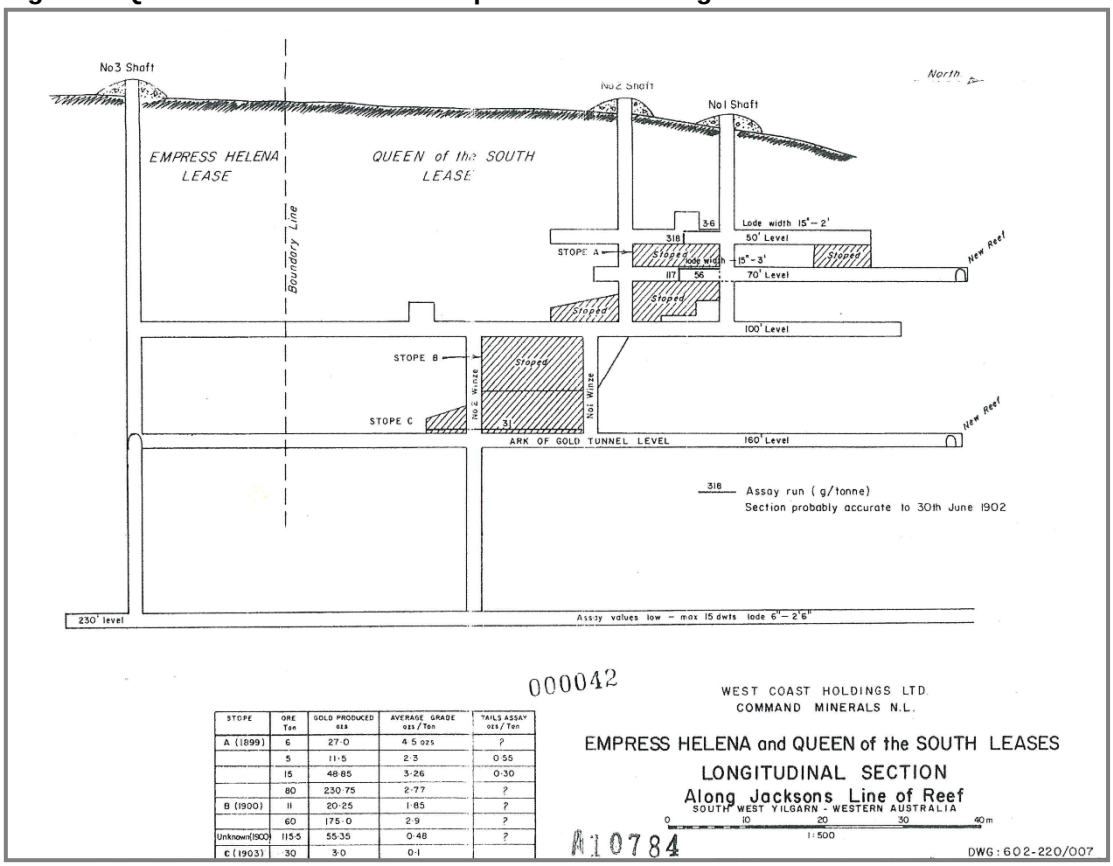
The neighbouring tenement to the south, The Empress Helena, was reported in 1900 to have water "working its way into the bottom of the shaft" when the shaft depth was at 57 m.

Additional information within 1899 notes from the Government's Assistant Geologist (Torrington Blatchford) indicates that generally, the reefs at the Donnybrook goldfields had a strike "a little west of north and east of south with a prevailing dip to the east at a very high angle".

A Mining Monthly 1982 publication indicates that "most of the major shafts in the area have collapsed or have been used as rubbish dumps". The afore mentioned quotes would refer to the larger area, which contain numerous other shafts and mine related features.

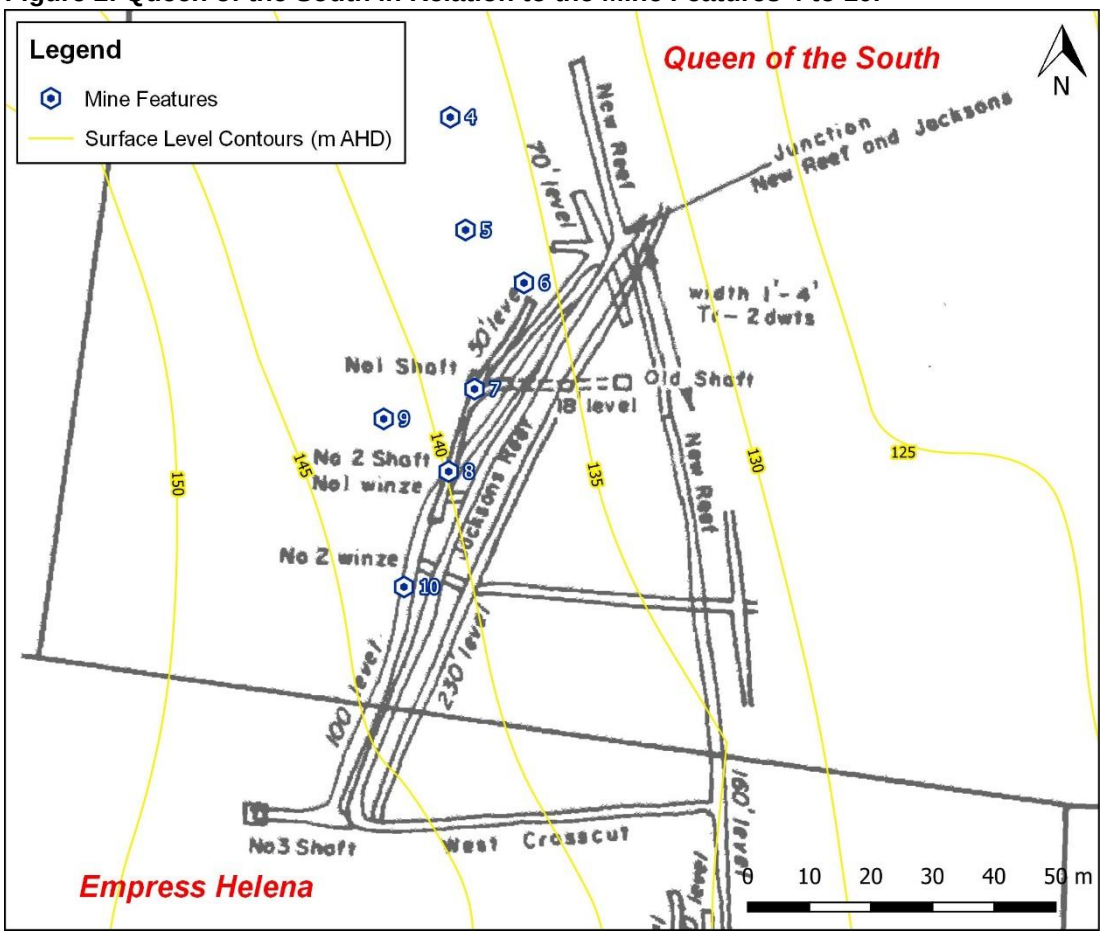
Georeferencing a plan of the Queen of the South with records of mining tenement boundaries sourced from DMIRS online data and the database of abandoned mine features suggests that some of the features chosen for assessment as part of this study (Feature 7 and 8) may be associated with the main shafts of the mine targeting Jackson's Reef, as shown in Figures 1 and 2 below.

**Figure 1: Queen of the South and Empress Helena Longitudinal Cross Section**




| STOPE | ORE Ton | GOLD PRODUCED ozs | AVERAGE GRADE ozs/Ton | TAILS ASSAY ozs/Ton |
|---|---|---|---|---|
| A (1899) | 6 | 27·0 | 4·5 ozs | ? |
| | 5 | 11·5 | 2·3 | 0·55 |
| | 15 | 48·85 | 3·26 | 0·30 |
| | 80 | 230·75 | 2·77 | ? |
| B (1900) | 11 | 20·25 | 1·85 | ? |
| | 60 | 175·0 | 2·9 | ? |
| Unknown(1900) | 115·5 | 55·35 | 0·48 | ? |
| C (1903) | 30 | 3·0 | 0·1 | |

**Figure 2: Queen of the South in Relation to the Mine Features 4 to 10.**




Various information indicates that groundwater is anticipated to be greater than 20 m depth, although some seasonally perched groundwater is considered possible at shallower depth on low permeability soils such within the abovementioned surficial sand with clay, such as water ponding at the base of Feature 3 in a photo of the feature provided by DMIRS (taken 22 September 2020).

In summary, it is considered that information of value for the purpose of this assessment can be summarised in the following points:

- Ground conditions comprise weathered sandstone, likely to increase in strength with depth.
- Ore targeted by mining began from relatively shallow depths, such as 9 m.
- Typical depths of shafts in the area was approximately 15 m however nearby mines were worked to 60 m.
- The reefs targeted by mining activities were relatively narrow, generally not greater than 1.5 m in width, indicating that large underground stopes would be unlikely. Information within Figure 1 indicates widths up to 0.9 m within areas in the vicinity of the ten features for investigation, Furthermore, no historical documents provide any indication of large open workings below ground.
- Figure 1 suggests mining activities in the vicinity of the ten features began from 50 feet (15 m) deep.

# 3. Field Work Methods

The field work was carried out in two phases under an Environmental and Safety Management Plan which incorporated measures to manage safety when working around the features, bush fire risk and limiting impact on the surrounding forest.

Both phases incorporated dieback management generally comprising work undertaken within dry weather, the use of rubber wheeled machinery where possible, removal of soil from excavation equipment prior to moving test locations and when tracked machinery was required, thorough brushing of soil prior to moving locations and at the boundary between zones mapped as dieback infested and non-infested.

## 3.1 Phase 1

Phase 1 of the field work was undertaken on 25 and 26 February 2021 and comprised:

- Inspection of the features from ground surface, by an experienced Geotechnical Engineer and a Principal Geotechnical Engineer from Douglas Partners;
- Minor excavation and tamping of the base, within the features (where possible), using a backhoe equipped with an extendable boom, under supervision by a Geotechnical Engineer;
- Photos of the features and where possible horizontal workings within approximately 5 m of the ground surface were visible, and video footage within the feature;
- LiDAR scanning of the features and their surrounds; and
- Monitoring for noxious or flammable gases within features.

The primary purpose of the backhoe was to assess the condition of the base of the features to provide information on whether the visible base was natural or comprising collapsed material or potentially a deeper shaft, plugged with fallen debris. At most locations where possible, the bases of the features were tamped using the backhoe bucket to provide an indication on the strength and capacity of the soils forming the base of the feature to support backfill soils as possible remediation measure. Where the unfavourable dimensions of features or waste prevented tamping the base of the excavation (i.e. Features 2 and 6), an extendable steel rod was manually pushed into the base soils until stiff material was identified during Phase 2 of the investigation (see next Section).

The LiDAR scanning was undertaken using the Hovermap Platform, utilised Simultaneous Localisation and Mapping (SLAM) based LiDAR technology. Data collected using a combination of hand-held and winch mounted scanning methods was stitched together into a single, spatially correct model in order to provide accurate data on the spatial relationship between the features as well as dimensions and volumes of each feature. Douglas Partners engaged the services of specialist contractors, MineLiDAR to undertake this work.

The gas monitoring was undertaken using a Ventis MX4 portable multi gas monitor with pump attachment capable of detecting carbon monoxide, hydrogen sulphide and oxygen concentrations and the lower explosives limit (LEL). The site engineer received suitable training about the use of the equipment by Douglas Partners' environmental scientists prior to the field work. The unit was lowered into the features and air was sampled directly into the unit from the base of the feature for features shallower than 5 m or at a depth of approximately 5 m where the feature was greater than 5 m deep (i.e.

Features 1, 5 and 8). The use of tubing to sample air at greater depth at Feature 8 was attempted due to the depth of the feature, but led to inconsistent readings produced once the unit was sampling air through a 20 m length of tubing.

### 3.2 Phase 2

Phase 2 of the field work was undertaken on 18 and 19 March 2021 and comprised:

- Drilling from the access track to intercept horizontal mine workings passing beneath the track or otherwise provide further information to assist in the assessment of the risk they may pose;
- Further investigation of Features 2 and 6 using hand tools to supplement observations made at these two features during Phase 1; and
- Walk over survey of access tracks to the south of the ten features.

Drilling was undertaken using a EP-26 sonic drill rig and 3 inch (76 mm) diameter hollow flight augers to depths of between 5 m and 10 m, adjacent to three features: 5, 7 and 8. These features were selected because results of Phase 1 of the field work (see Section 4.1 for further detail) indicated evidence of horizontal openings.

Where voids were intercepted (adjacent to Features 7 and 8), directionality of the underground openings were assessed by using a camera mounted at a fixed orientation on a rigid pole, aligned to bearing/direction markings at the surface (marked up using a compass), and lowered into the opening via the borehole.

Owing to the base of Feature 2 being out of reach of the excavator, a 5 m length of rods with a dynamic cone penetrometer (DCP) tip was used to probe the base of the feature for an indication on the strength of the material at the base. A similar method was used at Feature 6, where an extended DCP rod was pushed down through suspected asbestos contaminated fill to provide further information on the possible base of Feature 6, without disturbing the debris within the feature.

The walk-over survey of access tracks to the south of the features was undertaken to assess the condition of the access tracks and suitability for earthmoving equipment access, and to subsequently aid the development of suitable remediation methods, to be reported on in a separate report.

## 4. Field Work Results

### 4.1 Phase 1

Comments on the observations made following the assessment of the features with the backhoe are provided in the table below. Photographs of the features at the time of the investigation are included in Appendix B.

**Table 1: Mine Feature Observations**

| Feature | Comments |
|---|---|
| 1 | Tamping the base of the feature indicates competent ground/sandstone at the base however owing to the shape of this feature and the site constraints, excavation of material from the base was not possible. The base opens out (balloon-like shape), with no evidence of horizontal workings on video recorded from the base. The volume of stockpile around the feature is similar to the volume of the open feature, and therefore consistent with no horizontal continuation of this feature. |
| 2 | This feature was too deep for the excavator, however visually, the base appears natural and free from excessive collapsed material or waste. The side walls are near vertical and show no obvious signs of collapse. Prodding the base with hand tools in Phase 2 suggests the base consists of competent, natural material (rather than say a loose plug). |
| 3 | A small hole with competent, natural material at the base. |
| 4 | A trench excavation, approximately 7 m long with two depths: 1.5 m deep in the shallow western half and increasing to 3.3 m at the eastern extremity of the feature. A short horizontal continuation approximately 0.3 m to 0.5 m in length extends from the base of the 3.3 m deep section towards the track (to the east). Water was observed ponding in this continuation during a previous site inspection, suggesting no further continuation. The base appears natural and can support the weight of the 8 tonne excavator when bearing down on its bucket placed at the base of the feature. The side walls are near vertical and show no evidence of collapse. |
| 5 | A relatively square vertical shaft extending to 3.6 m depth. From the base of the shaft, an opening angles downwards in an easterly direction (bearing 110°). LiDAR captured data up to 4.6 m inside the angled opening, to a depth of approximately 10 m below ground surface. The lateral opening is on average 1 m wide. LiDAR data indicated a separation of approximately 7.5 m between the roof of the opening and the ground surface beneath the track. The side walls are near vertical and show no evidence of collapse. |
| 6 | A roughly circular excavation with waste fill visible at a depth of 1.6 m. Placement of the excavator bucket on the fill compacted the material 0.3 m, indicating very loose backfill. A single bucket was excavated at this location due to the potentially asbestos containing material (PACM) encountered within the spoil excavated from Feature 6. Further assessment was abandoned during phase 1 for OH&S reasons. Phase 2 included pushing a 16 mm diameter steel rod ended with a 20 mm diameter cone (rod from a dynamic cone penetrometer) until refusal on what felt solid at a depth of 3.9 m, indicating that depth of this feature is possibly approximately 4 m, with a low level of confidence, although this depth would be consistent with several adjacent features. No horizontal openings were identified to the maximum depth of inspection (2.3 m). |
| 7 | This feature aligns with "*No 1 Shaft*" on the historical plan of the Queen of the South mine. It is a large depression that is potentially the pothole from a collapsed main shaft. It can similarly be hypothesised that this feature is a more recent excavation, using a large excavator for instance. During the investigation, excavation of the material from the base of the feature indicated some evidence of a filled/collapsed vertical shaft, of similar plan dimensions as Feature 8, within the southern part of the feature. Following further excavation in this part of the feature to about 4 m depth, tamping the base of the feature using the excavator bucket suggested competent ground. This further excavation also revealed a horizontal opening from near the base of the excavated feature on the southwestern side of the feature. The direction of the horizontal opening was difficult to assess from what could be exposed with the backhoe from the surface. The horizontal opening |

| Feature | Comments |
|---|---|
| | was estimated to be approximately 1 m wide and have 3 m of clearance between its roof and the ground surface at the crest of the feature. |
| 8 | The feature aligns with "*No. 2 Shaft*" on the historical plan of the Queen of the South mine. It is a roughly square shaft with vertical sides extending to a depth of approximately 16 m. Horizontal openings, heading in three directions, are visible from the surface, at a depth of approximately 6 m. LiDAR data indicates that horizontal openings are heading in four directions with bearings of 20°/200° and 95°/280°and are present at three levels at depths of approximately 6 m, 9 m and 16 m. A horizontal opening heads directly towards Feature 7, however no interconnectivity was observed. LiDAR data indicated that a horizontal opening passing below the adjacent access track has a separation of approximately 6.1 m from the roof of the opening to the surface. |
| 9 | A roughly circular hole, 2.1 m deep. Following removal of forest debris collected at the base, natural material was observed at the base. The base could support the weight of the 8 tonne excavator when bearing on its bucket. No horizontal openings were identified. |
| 10 | A hole approximately 3.7 m in diameter and 1.6 m deep. Following excavation of approximately 0.6 m of collapsed material from the base of the hole, approximately 0.3 m of natural material was exposed. The base could support the weight of the 8 tonne excavator when bearing on its bucket. |

The evidence of horizontal openings from Features 5 and 8 passing under the access track and the potential for a openings from Feature 7 to pass below the track triggered Phase 2 field work, where drilling was undertake from the track to intercept the horizontal openings to allow for the assessment of the condition of the voids below the track.

No carbon monoxide, hydrogen sulphide or flammable gases were detected by the gas monitor lowered to the base of the feature, or 5 m in the case of Features 5 and 8. Oxygen levels were consistently 20.8% to 20.9%.

Drawing 3 in Appendix B provides an orthogonal view of the complete digital model created with the LiDAR scanning. Drawing 4 in Appendix B provides a view of Features 5 to 10 from below ground, to highlight those features where lateral workings were detected and provide a spatial representation of the recorded size and directionality of the lateral workings.

Digital mesh models of Features 1, 2, 4, 5, 7, 8 and 10 were produced by MineLIDAR and are included in Appendix C. Models of Features, 3, 6 and 9 were not created due to their small size (<5 $m^3$).

## 4.2 Phase 2

Feature 7, Feature 8 and Feature 5, in this order of priority, were further assessed during Phase 2. The priority order resulted from a preliminary assessment of the risk that the horizontal openings (or potential openings) identified during Phase 1 as potentially extending beneath the track, would cause to the public or members of emergency services using the track.

The location of the boreholes drilled in Phase 2 can be seen on Drawing 2 in Appendix B.

**Table 2: Comments/Observations from Phase 2 Drilling.**

| Feature | Comments |
|---|---|
| 7 | Four boreholes were drilled along the access track at this location. Initially three boreholes were drilled to depths of between 5.0 m and 5.3 m. The fourth borehole encountered a void from 3.2 m depth to 3.95 m depth (0.75 m high). Hard ground conditions, including 0.5 m to 1 m of caprock overlying inferred low strength weathered sandstone with zones of very dense sand with clay, were encountered above the void. Video recording undertaken within the void indicates that the width of the opening is approximately 1 m and the alignment is relatively straight, at an approximately bearing of 70° (ie towards the horizontal opening exposed during the field work in Feature 7) and between bearings of 240° and 260° (in the approximate direction of Feature 9).<br><br>Video suggests that collapse of a small amount of material within the void has occurred. |
| 8 | A single borehole was drilled and encountered a void from 5.8 m to 6.4 m (0.6 m high). Video recording undertaken within the void indicates that the width of the opening is approximately 1 m and the alignment is relatively straight, at a bearing of approximate 245°. The LiDAR data indicated that the width of the horizontal opening coming from Feature 8 is approximately 0.5 m and a possible narrow connection into the void is visible on the video recording, therefore suggesting that the borehole intercepted the void at a point where it widens from 0.5 m to 1 m.<br><br>Video suggests that collapse of a small amount of material within the void has occurred. |
| 5 | A single borehole was drilled to 10.3 m depth and no void was encountered at the test location. Hard clayey soils and low to medium strength rock was encountered with several bands of possibly medium to high strength material (notable drill rig grinding and slow drill rate) were encountered between depths of 1.5 m and 4.3 m. |

## 4.3 Field Work Results Summary

The observations and findings of field work Phases 1 and 2 are summarised in the table on the following page.

**Table 3: Summarised Results of the Field Work**

| Feature | Approximate Dimensions[1] (LxWxD) (m) | Volume ($m^3$)[5] | Lateral/Horizontal Opening/s Detected? | Estimated Dimensions of Lateral Opening Below Access Track | | Depth below track (m)[6] | Direction of the Lateral Opening (bearing in plan view) | Comment | Harmful Gas Detected? | Fauna Detected? |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Height (m) | Width (m) | | | | | |
| 1 | 6.4 x 5.8 x 5.0 | 51 | No | - | - | - | - | Base of feature assessed to be competent. | No | No[4] |
| 2 | 2.3 x 1.7 x 4.6 | 12 | No | - | - | - | - | | | |
| 3 | 1.7 x 1.2 x 1.0 | <5 | No | - | - | - | - | | | |
| 4 | 7.2 x 1.0 x 3.3 | 13 | No | - | - | - | - | | | |
| 5 | 2.0 x 1.8 x 3.6 | 18 | Yes | ~1.5 | 1.0-1.5 | 7.5[7] | 110° | Base of feature assessed to be competent. Lateral opening appears stable. No notable signs of collapse from the roof or walls. | | |
| 6 | 1.6 x 1.4 x 3.9[2] | <5[3]/~10 | No | - | - | - | - | Feature backfilled with PACM. Condition at base of feature not assessed. | | |

| Feature | Approximate Dimensions[1] (LxWxD) (m) | Volume ($m^3$)[5] | Horizontal Opening/s Detected? | Estimated Dimensions of Lateral Opening Below Access Track | | Depth below track (m)[6] | Lateral Opening Direction Bearing (in plan view) | Comment | Harmful Gas Detected? | Fauna Detected? |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Height (m) | Width (m) | | | | | |
| 7 | 7.4 x 4.5 x 4.0 | 72 | Yes | 0.75 | 1.0 | 3.2[8] | Between 240° and 260° | Base of feature assessed to be competent. Horizontal opening appears stable. Minor collapse observed from roof. | No | No |
| 8 | 4.3 x 3.2 x 17.0 | 84 | Yes | 0.6 | 1.0 | 5.8[8] | 245° | | | |
| 9 | 2.6 x 1.9 x 2.1 | <5 | No | - | - | - | - | Base of feature assessed to be competent. | | |
| 10 | 3.7 dia x 2.5 | 25 | No | - | - | - | - | | | |

Notes [1]: Length and width dimensions taken at ground surface.

[2]: Depth of Feature 6 estimated to be 3.9 m during Phase 2 field work.

[3]: Volume of feature to the top of the contaminated backfill, approximately 1.9 m below the surface. Volume of feature following removal of debris possible approximately 10 $m^3$

[4]: Based on visual assessment of photos and video of the features and ground surface observations during the field work.

[5]: Based on recorded LiDAR data and include total volume including horizontal workings, if applicable.

[6] Depth to the roof of the opening beneath the track.

[7]: Derived from LiDAR data

[8]: Measured within borehole intercepting void.

## 5. Discussion

Some discussions in this section use the terminology regarding likelihood, consequence and risk proposed by the Australian Geomechanics Society (AGS, 2007). This terminology, albeit originally derived for landslide risk management, is considered suitable to assist with the description of risks of collapse at this site. A relevant extract of AGS (2007) is included in Appendix D.

The ten mine features assessed are generally in good condition and overall stable.

It is considered that the risk of collapse of either the vertical features (1 to 10) or their lateral extensions below the track adjacent to Features 5, 7 and 8 is very low. This risk allocation considers the generally hard ground conditions observed within the features and encountered during drilling, the overall stability of the features noting that they are more than 100 years old, the relatively small size of the lateral openings, and the depth below ground surface to the openings relative to their size.

More specifically for the lateral openings extending beneath the track, the allocated 'very low' risk results from:

- a likelihood of collapse that is conceivable but only under exceptional circumstances over say a 100 year period from today, and
- an insignificant to minor consequence at ground surface in the event of the collapse of a horizontal opening. It is considered that following a hypothetical full collapse at depth of a void of the size such as encountered, the resulting void progressing toward the ground surface would likely stabilise prior to reaching the surface (from arching of its roof, owing to hard ground conditions encountered), or would result under a worst case scenario in a minor surface depression of no more than 0.5 m depth, and likely shallower, and therefore is unlikely to cause any significant hazard to public or personnel from the emergency services, or significant damage to equipment such as a fire truck.

It is considered likely that most of the features assessed are exploratory or prospecting holes, terminating at depths not greater than 5 m and with no significant horizontal workings.

Feature 8 is possibly No. 2 Shaft of the Queen of the South mine, however historical data suggests that the historical No. 2 Shaft extends to 30 m depth, whereas the measured depth of Feature 8 was 16 m (which generally agrees with the 50 foot (15 m) deep mine level shown in Figure 1, page 3). Imagery produced by the LiDAR scanning and video footage indicate that the base of Feature 8 is unlikely to be a plug created from material collapse from above and appears the be the base of a shaft providing access to the horizontal level at 15 m depth.

The location of Feature 7 suggests the potential for this feature to be associated with the No. 1 Shaft of the Queen of the South mine, however the investigation could not confidently ascertain that this is the case. Some evidence of a backfilled shaft was observed while excavating within the feature and at least one horizontal opening at a depth of approximately 3 m was identified. No evidence of shaft could be identified below the level of the horizontal opening, however, such evidence could have been masked during the investigation owing to disturbed soils by the investigation at the base of the feature and the maximum reach of the excavator limiting suitable exposure of the base. Assessment using the weight of the backhoe on its bucket pushed into the base at the potential shaft location indicated competent ground leading to the conclusion that this shaft might have ended at that depth or backfilled to approximately 4 m below the surface (i.e. the base of the Feature 7). Although speculation only but consistent field observations, the source of backfill was possibly the natural surficial soils immediately

adjacent to the shaft; effectively, pushing the adjacent soil, north of the shaft, into the shaft, creating a wide and relatively shallow hole at the surface (the current Feature 7).

The condition of the base of Feature 6 is not known due to the PACM encountered within the hole, however based on the historical data and nature of the surrounding features, it is considered a reasonable assumption that this feature is an exploratory hole, similar to Feature 2.

No evidence of fauna was detected in either phase of field work.

Gas monitoring did not detect any harmful gases within the features. It is worth noting that harmful gasses can be heavier than air and reliable readings of the air quality at the base of Features 5 and 8 (greater than 5 m) was not achievable.

## 6. References

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The Donnybrook Gold-Field. (1899, May 6). *The West Australian*, p. 10.

## 7. Limitations

Douglas Partners (DP) has prepared this report for this project at Lot F27 Goodwood Road, Upper Capel in accordance with DP's proposal dated 7 August 2020 and acceptance received from the Department of Mines, Industry Regulation and Safety (DMIRS) dated 14 September 2020. The work was carried out under DMIRS General Conditions of Contract dated August 2019.This report is provided for the exclusive use of Department of Mines, Industry Regulation & Safety for this project only and for the purposes as described in the report. It should not be used by or relied upon for other projects or purposes on the same or other 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.

The results provided in the report are indicative of the sub-surface conditions on the site only at the specific sampling and/or testing locations, and then only to the depths investigated and at the time the work was carried out. 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 field testing has been completed.

DP's advice is based upon the conditions encountered during this investigation. The accuracy of the advice provided by DP in this report may be affected by undetected variations in ground conditions across the site between and beyond the sampling and/or testing locations. The advice may also be limited by budget constraints imposed by others or by site accessibility.

The assessment of atypical safety hazards arising from this advice is restricted to the (geotechnical / environmental / groundwater) components set out in this report and based on known project conditions and stated design advice and assumptions. While some recommendations for safe controls may be provided, detailed 'safety in design' assessment is outside the current scope of this report and requires additional project data and assessment.

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.

**Douglas Partners Pty Ltd**

# Appendix A

About This Report

# About this Report

Douglas Partners

## 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



## 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

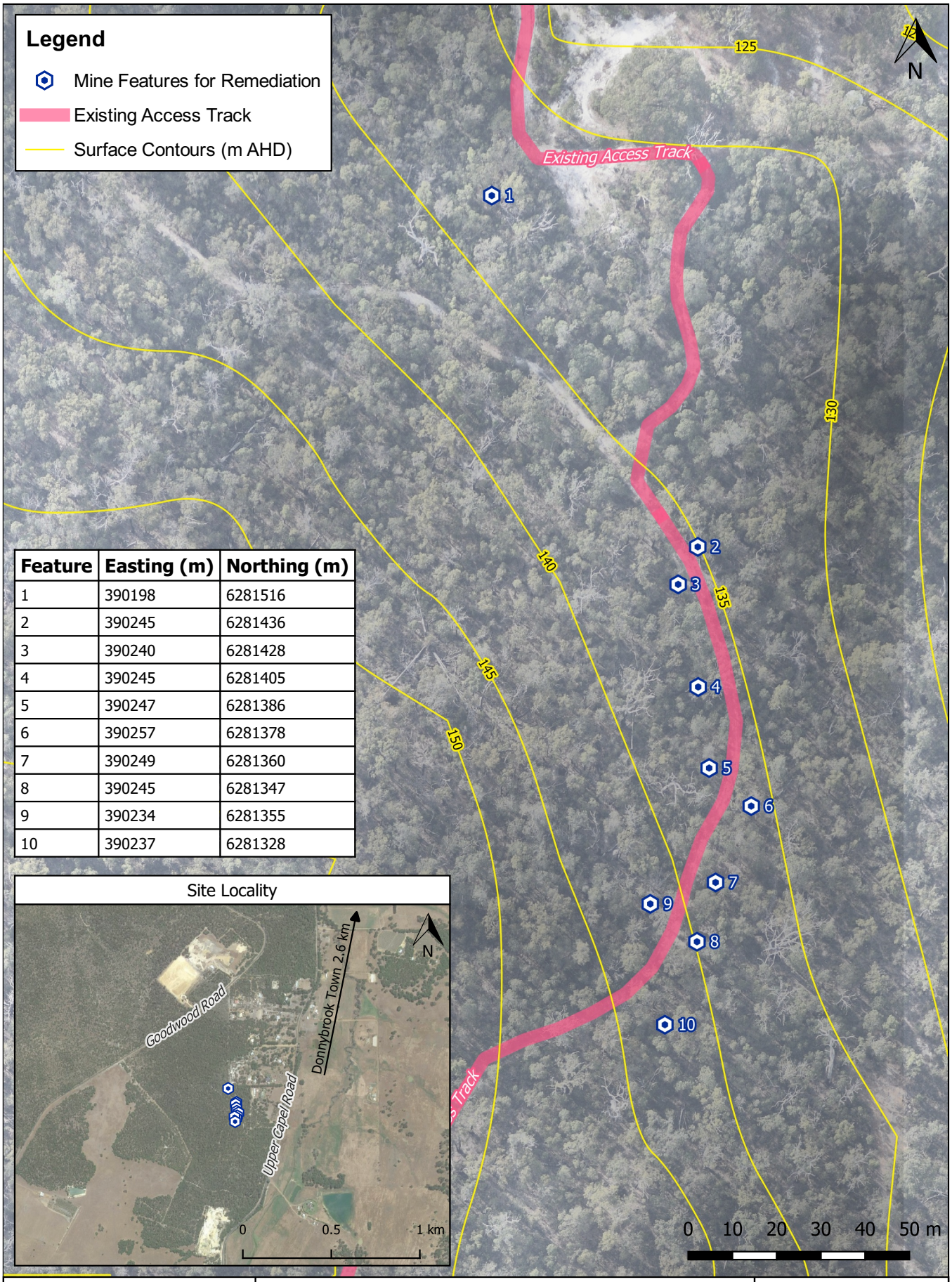
Where information obtained from this report is provided for tendering purposes, it is recommended that all information, including the written report and discussion, be made available. In circumstances where the discussion or comments section is not relevant to the contractual situation, it may be appropriate 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

Drawing 1 - Mine Features and Access Track
Drawing 2 - Borehole Targeting Horizontal Workings and LiDAR Data
Drawing 3 - Orthogonal View of Complete LiDAR Model
Drawing 4 - LiDAR Data – Features 5 to 10
Feature and Void Photos




| Feature | Easting (m) | Northing (m) |
|---|---|---|
| 1 | 390198 | 6281516 |
| 2 | 390245 | 6281436 |
| 3 | 390240 | 6281428 |
| 4 | 390245 | 6281405 |
| 5 | 390247 | 6281386 |
| 6 | 390257 | 6281378 |
| 7 | 390249 | 6281360 |
| 8 | 390245 | 6281347 |
| 9 | 390234 | 6281355 |
| 10 | 390237 | 6281328 |

Site Locality




**Douglas Partners**
Geotechnics / Environment / Groundwater

**Mine Features and Access Track**
**Donnybrook Shaft Remediation**
**Argyle Forest Block, Donnybrook, WA**

CLIENT: Department of Mines, Industry Regulation and Safety

PROJECT: 96721.00
Drawing No: 1
REV: 0
DATE: 29/4/2021

## Legend

- Mine Features
- Borehole
- Alignment of Horizontal Workings and Approximate Width

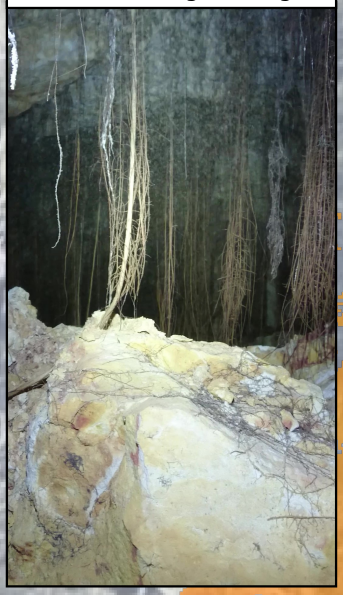
*Note: LiDAR data overlay is displaying a representation of the lowest elevation (z) data point recorded for each given easting (x) and northing (y).*

N

5
F5-1
Existing Access Track
7
F7-4
F7-1
F7-2
F7-3
9
Existing Access Track
F8-1
8

Feature 5
Photo bearing 110 deg

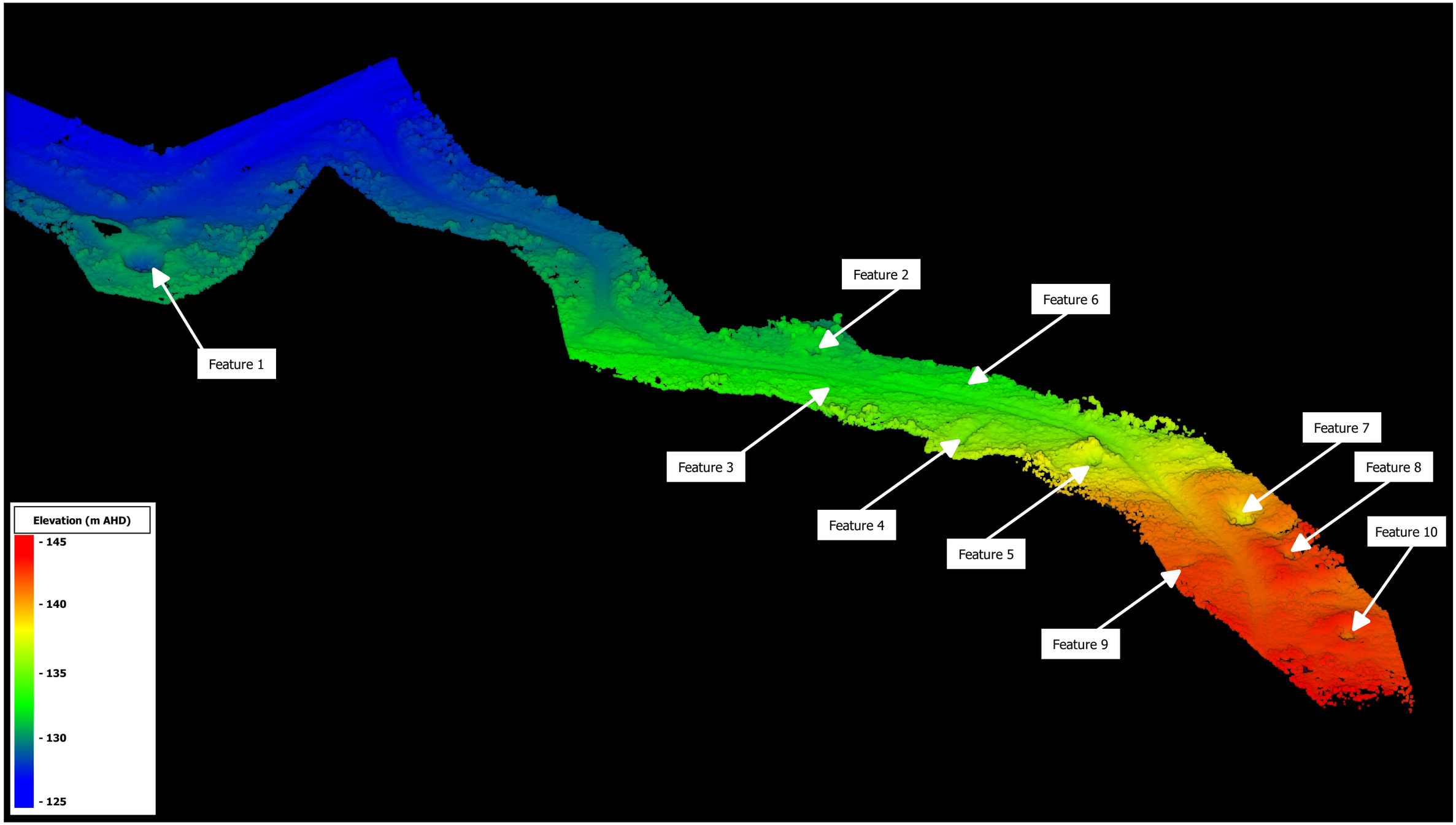
Borehole F7-4
Photo bearing 250 deg



Borehole F8-1
Photo bearing 245 deg

0 2 4 6 8 10 m

| | | |
|---|---|---|
| Douglas Partners<br>Geotechnics / Environment / Groundwater | **Boreholes Targeting Horizontal Workings & LiDAR data**<br>**Donnybrook Shaft Remediation**<br>**Argyle Forest Block, Donnybrook, WA** | PROJECT: 96721.00<br>Drawing No: 2<br>REV: 0 |
| | CLIENT: Department of Mines, Industry Regulation and Safety | DATE: 29/4/2021 |

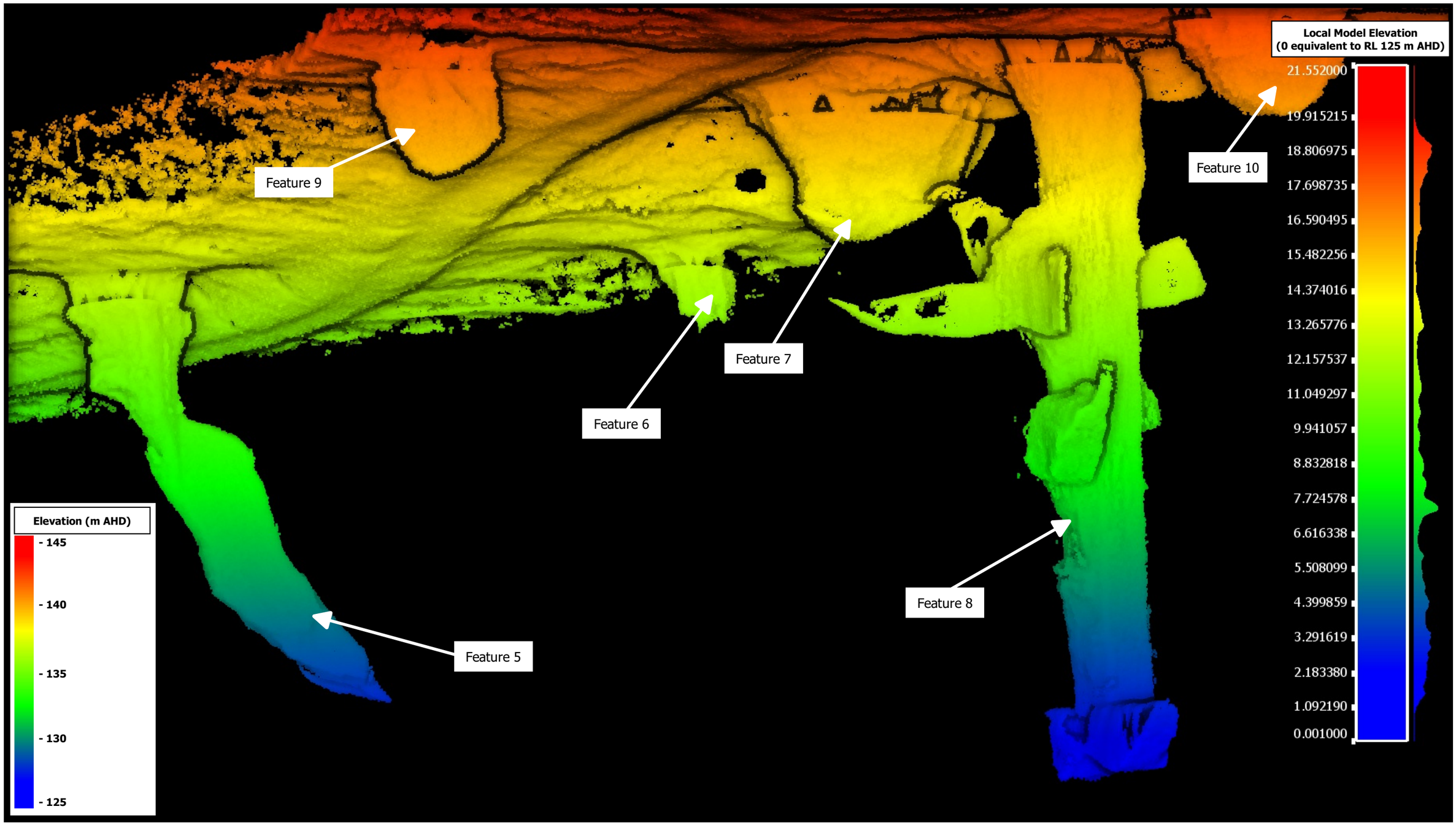



Douglas Partners
Geotechnics / Environment / Groundwater

**Complete LiDAR Model**
**Donnybrook Shaft Remediation**
**Argyle Forest Block, Donnybrook, WA**

CLIENT: Department of Mines, Industry Regulation and Safety

| | |
|---|---|
| PROJECT: | 96721.00 |
| Drawing No: | 3 |
| REV: | 0 |
| DATE: | 30/4/2021 |




| | | |
|---|---|---|
| Douglas Partners<br>Geotechnics / Environment / Groundwater | **LiDAR Data - Features 5 to 10**<br>**Donnybrook Shaft Remediation**<br>**Argyle Forest Block, Donnybrook, WA** | PROJECT: 96721.00<br>Drawing No: 4<br>REV: 1 |
| | CLIENT: Department of Mines, Industry Regulation and Safety | DATE: 10/6/2021 |

**Photograph 1**: Feature 1

**Photograph 2**: Feature 1 - base

| | | | |
|---|---|---|---|
| Douglas Partners<br>Geotechnics / Environment / Groundwater | **Photographs - Feature 1**<br>Donnybrook Mine Shaft Condition<br>Lot F27, Argyle Forest Block, Upper Capel | Project No.: | 96721.00 |
| | | Photo Plate No.: | 1 |
| | | Revision: | 0 |
| | CLIENT: Department of Mines, Industry Regulation and Safety | Date: | Apr-21 |

**Photograph 3**: Feature 2

**Photograph 4**: Feature 2 - base

| | | | |
|---|---|---|---|
| Douglas Partners Geotechnics / Environment / Groundwater | **Photographs - Feature 2** | Project No.: | 96721.00 |
| | Donnybrook Mine Shaft Condition | Photo Plate No.: | 2 |
| | Lot F27, Argyle Forest Block, Upper Capel | Revision: | 0 |
| | CLIENT: Department of Mines, Industry Regulation and Safety | Date: | Apr-21 |

**Photograph 5**: Feature 3

**Photograph 6**: Feature 3 - base

| | | | |
|---|---|---|---|
| Douglas Partners<br>Geotechnics / Environment / Groundwater | **Photographs - Feature 3** | Project No.: | 96721.00 |
| | Donnybrook Mine Shaft Condition | Photo Plate No.: | 3 |
| | Lot F27, Argyle Forest Block, Upper Capel | Revision: | 0 |
| | CLIENT: Department of Mines, Industry Regulation and Safety | Date: | Apr-21 |

**Photograph 7**: Feature 4

**Photograph 8**: Feature 4 - eastern face (deeper section of trench)

| | | | |
|---|---|---|---|
| Douglas Partners Geotechnics / Environment / Groundwater | **Photographs - Feature 4** | Project No.: | 96721.00 |
| | Donnybrook Mine Shaft Condition | Photo Plate No.: | 4 |
| | Lot F27, Argyle Forest Block, Upper Capel | Revision: | 0 |
| | CLIENT: Department of Mines, Industry Regulation and Safety | Date: | Apr-21 |

**Photograph 9**: Feature 5 - eastern face with visible lateral opening at base

**Photograph 10**: Feature 5 - lateral opening

| | | | |
|---|---|---|---|
| Douglas Partners Geotechnics / Environment / Groundwater | **Photographs - Feature 5** | Project No.: | 96721.00 |
| | Donnybrook Mine Shaft Condition | Photo Plate No.: | 5 |
| | Lot F27, Argyle Forest Block, Upper Capel | Revision: | 0 |
| | CLIENT: Department of Mines, Industry Regulation and Safety | Date: | Apr-21 |

**Photograph 11**: Feature 6

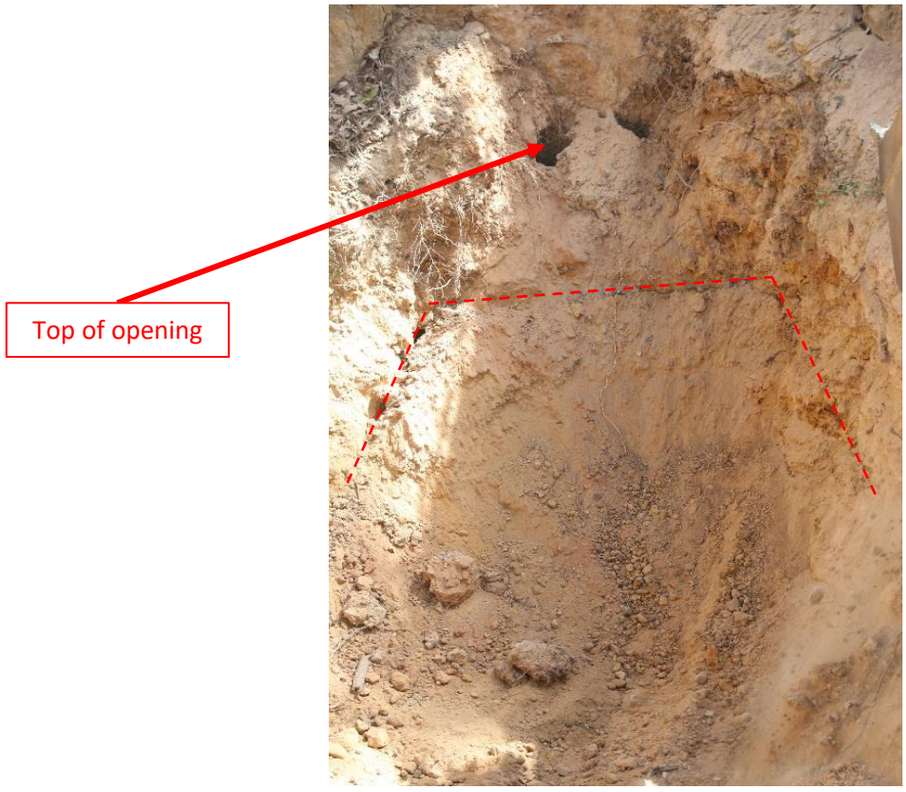

**Photograph 12**: Feature 6 - potentially asbestos containing material in spoil

| | | | |
|---|---|---|---|
| Douglas Partners<br>Geotechnics / Environment / Groundwater | **Photographs - Feature 6** | Project No.: | 96721.00 |
| | Donnybrook Mine Shaft Condition | Photo Plate No.: | 6 |
| | Lot F27, Argyle Forest Block, Upper Capel | Revision: | 0 |
| | CLIENT: Department of Mines, Industry Regulation and Safety | Date: | Apr-21 |

**Photograph 13**: Feature 7

**Photograph 14**: Feature 7 - excavation of southern part

| | | | |
|---|---|---|---|
| Douglas Partners<br>Geotechnics / Environment / Groundwater | **Photographs - Feature 7** | Project No.: | 96721.00 |
| | Donnybrook Mine Shaft Condition | Photo Plate No.: | 7 |
| | Lot F27, Argyle Forest Block, Upper Capel | Revision: | 0 |
| | CLIENT: Department of Mines, Industry Regulation and Safety | Date: | Apr-21 |




**Photograph 15**: Feature 7 - possible evidence of backfilled shaft (red dotted line interpreted interface between backfill and natural ground)

**Photograph 16**: Feature 7 - opening exposed following excavation

| | | | |
|---|---|---|---|
| Douglas Partners Geotechnics / Environment / Groundwater | **Photographs - Feature 7** | Project No.: | 96721.00 |
| | Donnybrook Mine Shaft Condition | Photo Plate No.: | 8 |
| | Lot F27, Argyle Forest Block, Upper Capel | Revision: | 0 |
| | CLIENT: Department of Mines, Industry Regulation and Safety | Date: | Apr-21 |

**Photograph 17**: Feature 8 - northern face

**Photograph 18**: Feature 8 - opening on western face approximately 6 m depth

| | | | |
|---|---|---|---|
| Douglas Partners Geotechnics / Environment / Groundwater | **Photographs - Feature 8** | Project No.: | 96721.00 |
| | Donnybrook Mine Shaft Condition | Photo Plate No.: | 9 |
| | Lot F27, Argyle Forest Block, Upper Capel | Revision: | 0 |
| | CLIENT: Department of Mines, Industry Regulation and Safety | Date: | Apr-21 |

**Photograph 19**: Feature 9

**Photograph 20**: Feature 9

| | | | |
|---|---|---|---|
| Douglas Partners<br>Geotechnics / Environment / Groundwater | **Photographs - Feature 9** | Project No.: | 96721.00 |
| | Donnybrook Mine Shaft Condition | Photo Plate No.: | 10 |
| | Lot F27, Argyle Forest Block, Upper Capel | Revision: | 0 |
| | CLIENT: Department of Mines, Industry Regulation and Safety | Date: | Apr-21 |

**Photograph 21**: Feature 10

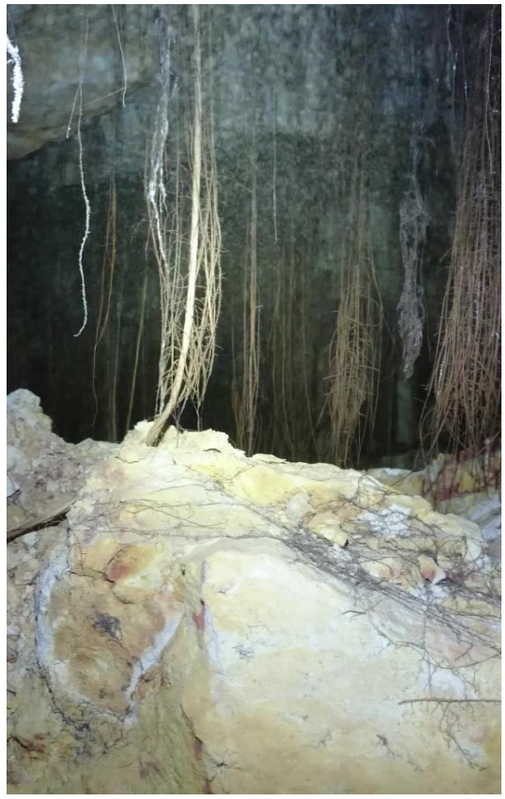
**Photograph 22**: Feature 10 - after excavation

| | | | |
|---|---|---|---|
| Douglas Partners<br>Geotechnics / Environment / Groundwater | **Photographs - Feature 10**<br>Donnybrook Mine Shaft Condition<br>Lot F27, Argyle Forest Block, Upper Capel<br>CLIENT: Department of Mines, Industry Regulation and Safety | Project No.:<br>Photo Plate No.:<br>Revision:<br>Date: | 96721.00<br>11<br>0<br>Apr-21 |

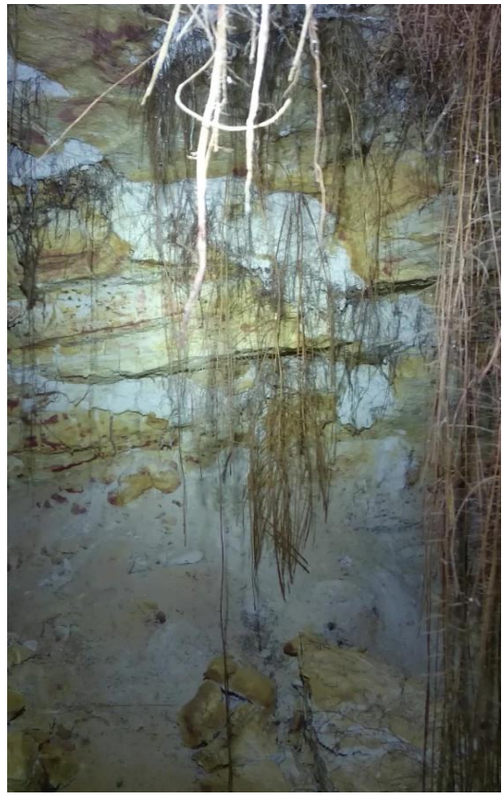
**Photograph 23**: Feature 5 lateral working - approximate bearing 110°

**Photograph 24**: Within borehole F7-4 - approximate bearing 20°

| | | | |
|---|---|---|---|
| Douglas Partners Geotechnics / Environment / Groundwater | **Photographs - Underground Voids** | Project No.: | 96721.00 |
| | Donnybrook Mine Shaft Condition | Photo Plate No.: | 12 |
| | Lot F27, Argyle Forest Block, Upper Capel | Revision: | 0 |
| | CLIENT: Department of Mines, Industry Regulation and Safety | Date: | Apr-21 |



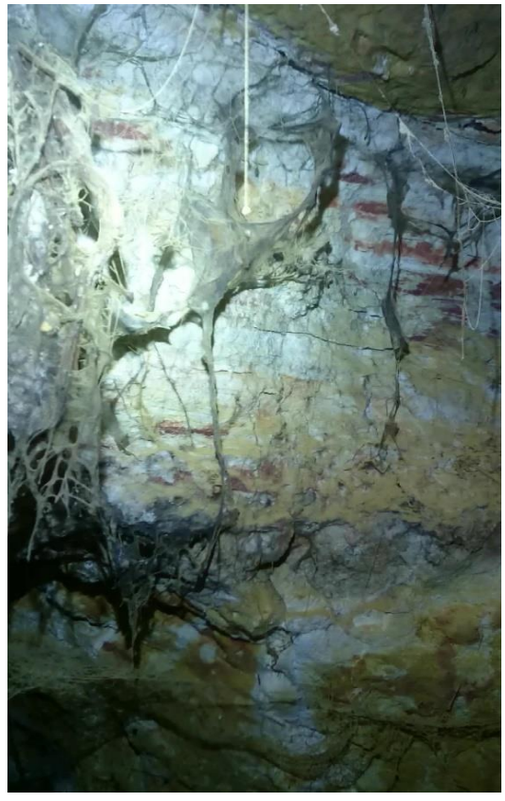
**Photograph 25**: Within borehole F7-4 - approximate bearing 250°



**Photograph 26**: Within borehole F7-4 - northern wall

| | | | |
|---|---|---|---|
| Douglas Partners Geotechnics / Environment / Groundwater | **Photographs - Underground Voids** | Project No.: | 96721.00 |
| | Donnybrook Mine Shaft Condition | Photo Plate No.: | 13 |
| | Lot F27, Argyle Forest Block, Upper Capel | Revision: | 0 |
| | CLIENT: Department of Mines, Industry Regulation and Safety | Date: | Apr-21 |

**Photograph 27**: Within borehole F8-1 - approximate bearing 245°

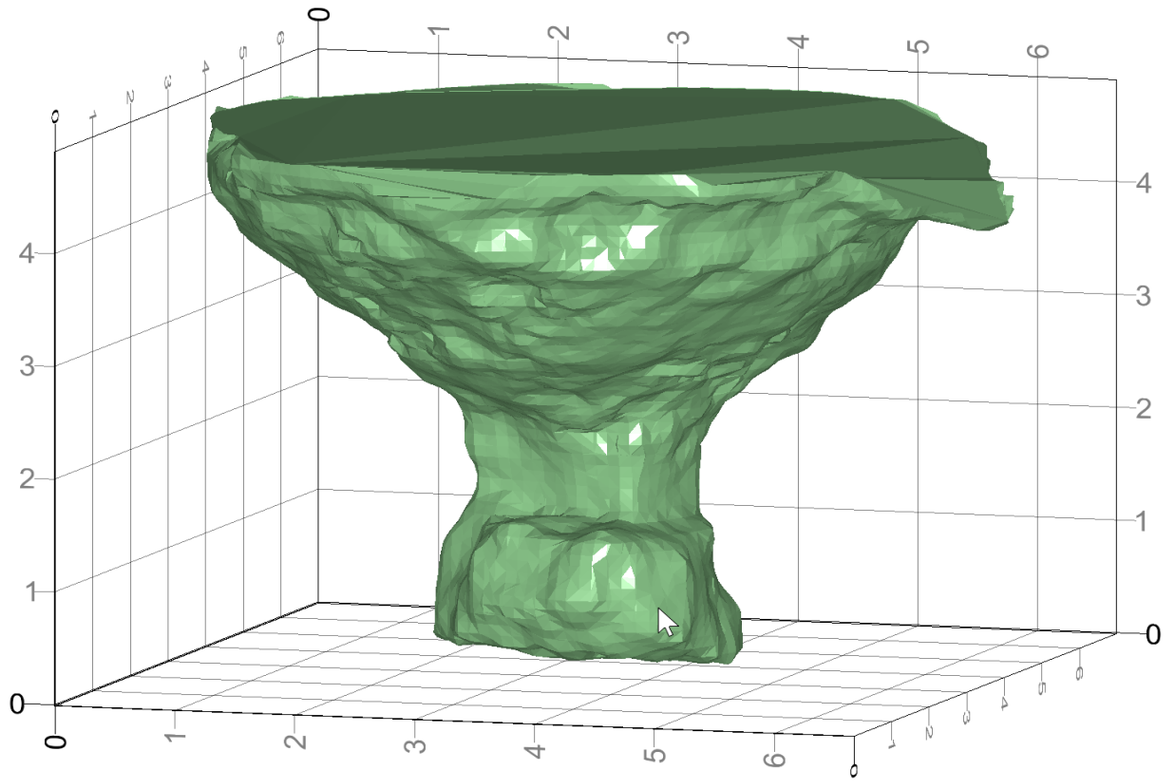


**Photograph 28**: Within borehole F8-1 - northern wall

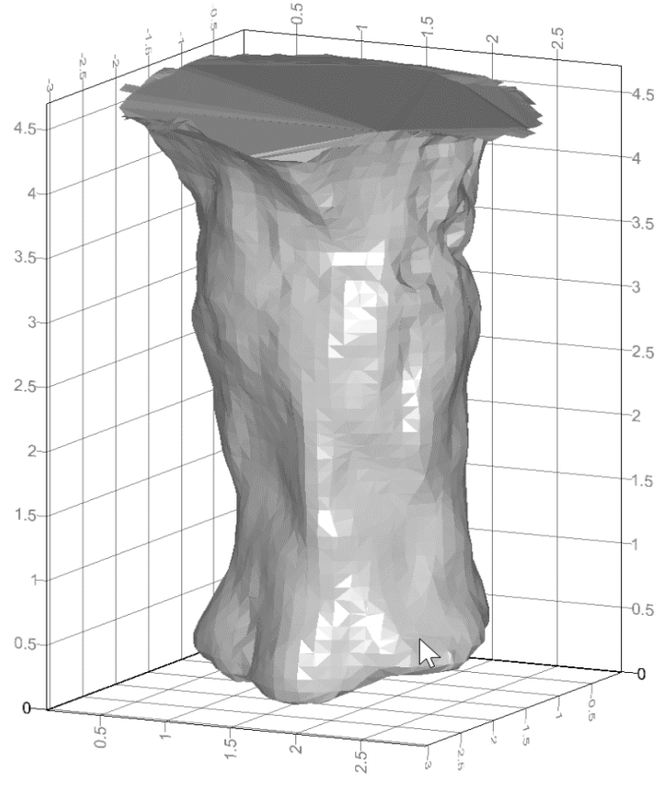
| | | | |
|---|---|---|---|
| Douglas Partners Geotechnics / Environment / Groundwater | **Photographs - Underground Voids** | Project No.: | 96721.00 |
| | Donnybrook Mine Shaft Condition | Photo Plate No.: | 14 |
| | Lot F27, Argyle Forest Block, Upper Capel | Revision: | 0 |
| | CLIENT: Department of Mines, Industry Regulation and Safety | Date: | Apr-21 |

# Appendix C

Mesh Models of Features

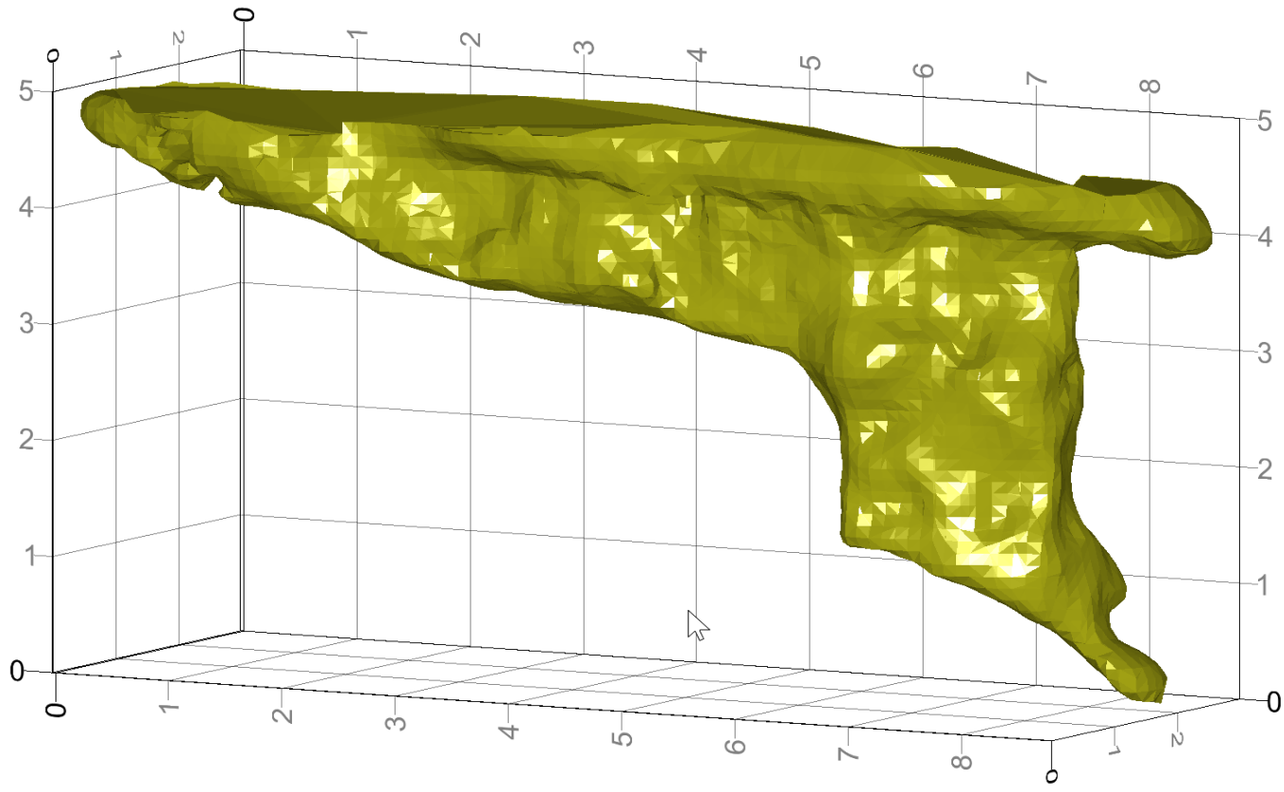


**Mesh 1**: Feature 1

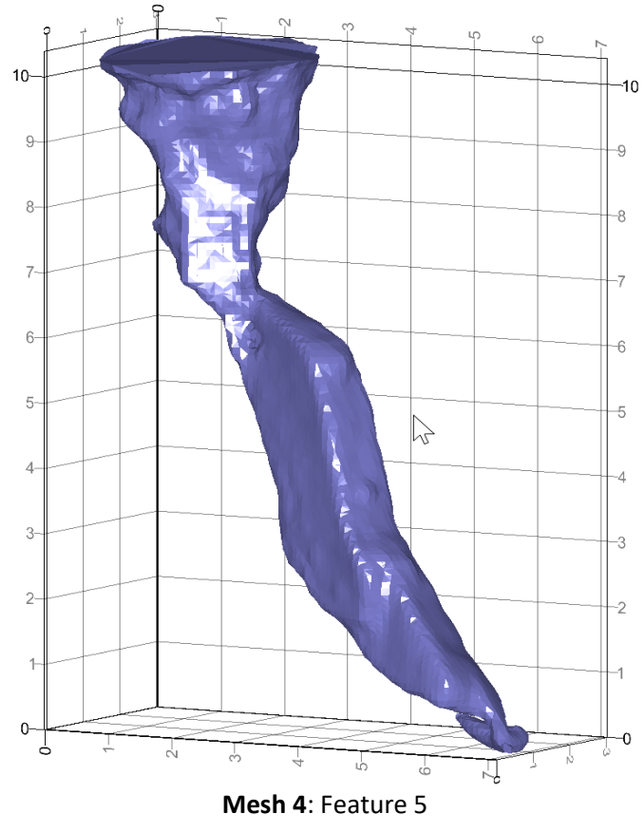


**Mesh 2**: Feature 2

| | | | |
|---|---|---|---|
| Douglas Partners<br>Geotechnics / Environment / Groundwater | **LiDAR Data Meshes - Features 1 and 2**<br>Donnybrook Mine Shaft Condition<br>Lot F27, Argyle Forest Block, Upper Capel<br>CLIENT: Department of Mines, Industry Regulation and Safety | Project No.: | 96721.00 |
| | | Photo Plate No.: | 1 |
| | | Revision: | 0 |
| | | Date: | Apr-21 |

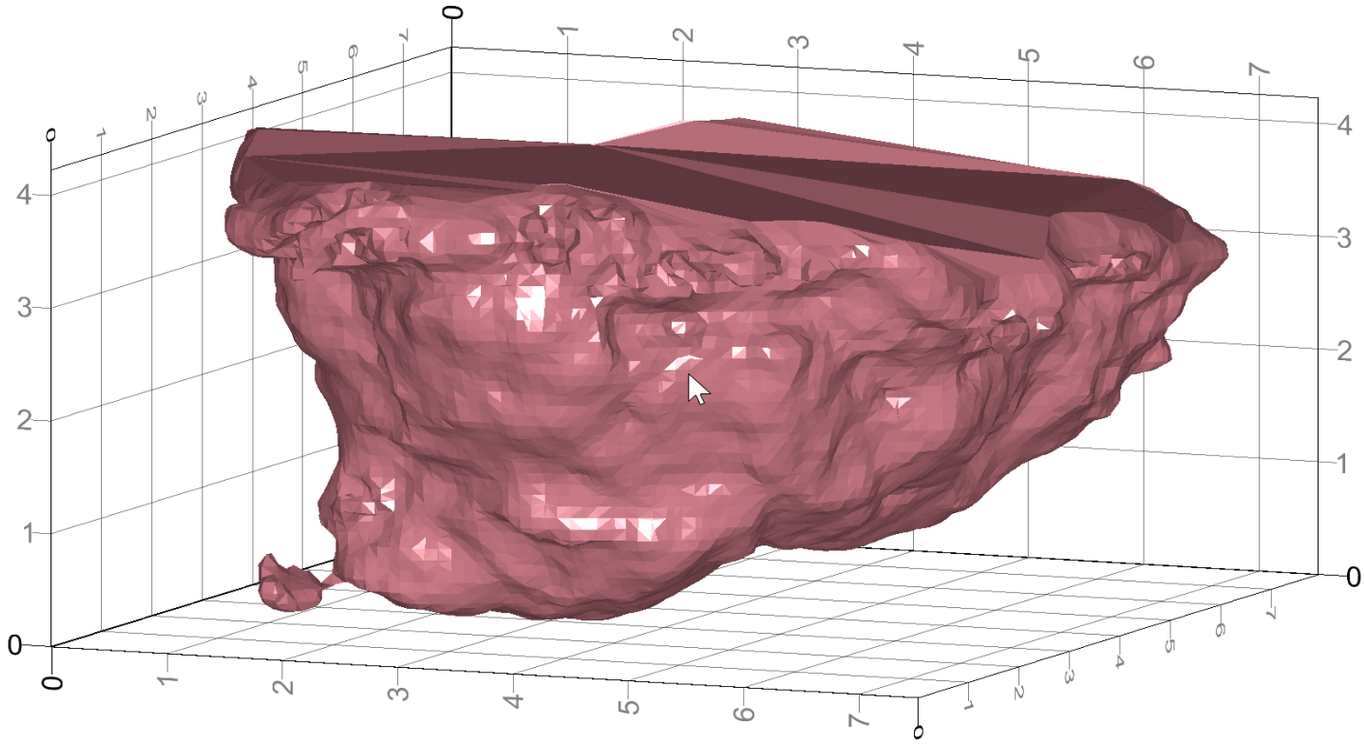


**Mesh 3**: Feature 4

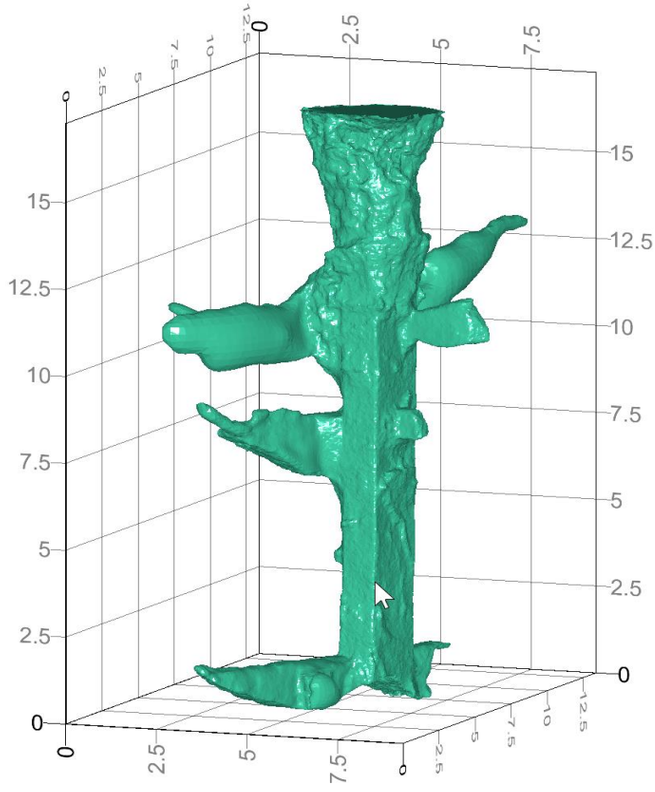


**Mesh 4**: Feature 5

| | | | |
|---|---|---|---|
| Douglas Partners<br>Geotechnics / Environment / Groundwater | **LiDAR Data Meshes - Features 4 and 5**<br>Donnybrook Mine Shaft Condition<br>Lot F27, Argyle Forest Block, Upper Capel<br>CLIENT: Department of Mines, Industry Regulation and Safety | Project No.:<br>Photo Plate No.:<br>Revision:<br>Date: | 96721.00<br>2<br>0<br>Apr-21 |

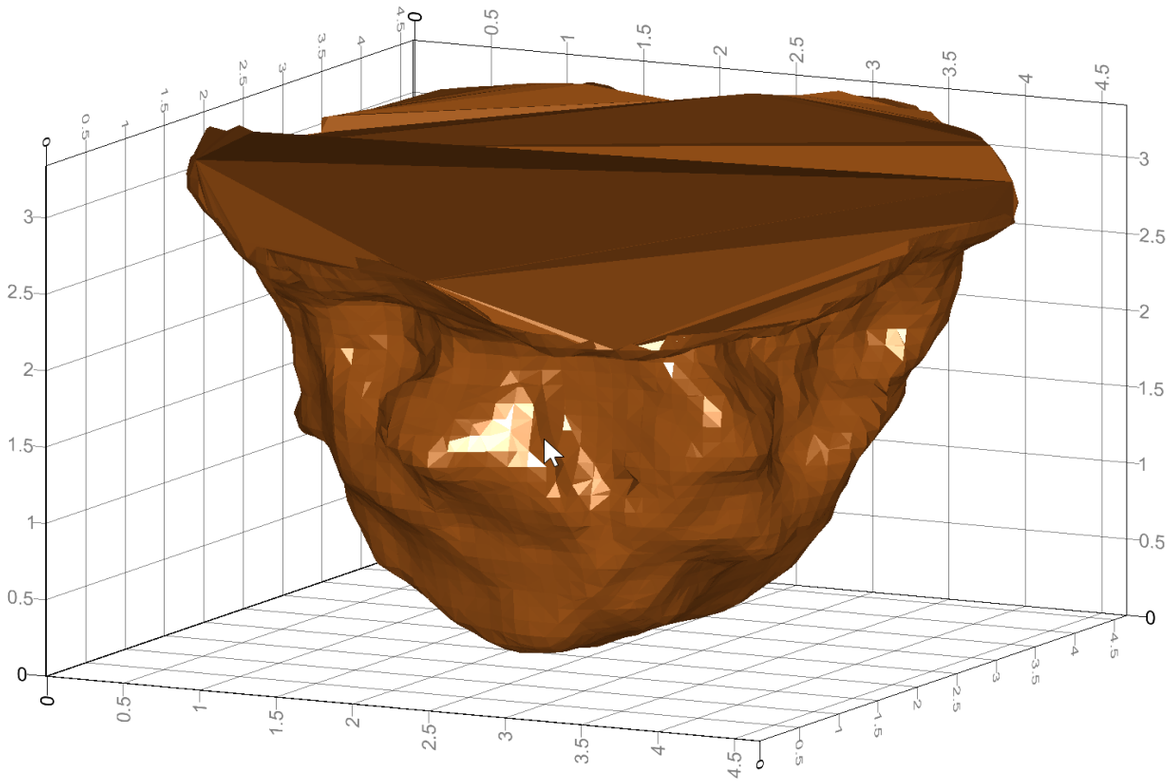


**Mesh 5**: Feature 7



**Mesh 6**: Feature 8

| | | | |
|---|---|---|---|
| Douglas Partners<br>Geotechnics / Environment / Groundwater | **LiDAR Data Meshes - Features 7 and 8** | Project No.: | 96721.00 |
| | Donnybrook Mine Shaft Condition | Photo Plate No.: | 3 |
| | Lot F27, Argyle Forest Block, Upper Capel | Revision: | 0 |
| | CLIENT: Department of Mines, Industry Regulation and Safety | Date: | Apr-21 |




**Mesh 7**: Feature 10

| | | | |
|---|---|---|---|
| Douglas Partners<br>Geotechnics / Environment / Groundwater | **LiDAR Data Meshes - Feature 10** | Project No.: | 96721.00 |
| | Donnybrook Mine Shaft Condition | Photo Plate No.: | 4 |
| | Lot F27, Argyle Forest Block, Upper Capel | Revision: | 0 |
| | CLIENT: Department of Mines, Industry Regulation and Safety | Date: | Apr-21 |

# Appendix D

Practice Note Guidelines for Landslide Risk Management (2007)

# PRACTICE NOTE GUIDELINES FOR LANDSLIDE RISK MANAGEMENT 2007

## APPENDIX C: LANDSLIDE RISK ASSESSMENT

## QUALITATIVE TERMINOLOGY FOR USE IN ASSESSING RISK TO PROPERTY

### *QUALITATIVE MEASURES OF LIKELIHOOD*

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

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

### *QUALITATIVE MEASURES OF CONSEQUENCES TO PROPERTY*

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

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

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

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

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

### *QUALITATIVE RISK ANALYSIS MATRIX – LEVEL OF RISK TO PROPERTY*

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

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

### *RISK LEVEL IMPLICATIONS*

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

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

# AUSTRALIAN GEOGUIDE LR7 (LANDSLIDE RISK)

## LANDSLIDE RISK

### Concept of Risk

Risk is a familiar term, but what does it really mean? It can be defined as *"a measure of the probability and severity of an adverse effect to health, property, or the environment."* This definition may seem a bit complicated. In relation to landslides, geotechnical practitioners (GeoGuide LR1) are required to assess risk in terms of the likelihood that a particular landslide will occur and the possible consequences. This is called landslide risk assessment. The consequences of a landslide are many and varied, but our concerns normally focus on loss of, or damage to, property and loss of life.

### Landslide Risk Assessment

Some local councils in Australia are aware of the potential for landslides within their jurisdiction and have responded by designating specific "landslide hazard zones". Development in these areas is often covered by special regulations. If you are contemplating building, or buying an existing house, particularly in a hilly area, or near cliffs, go first for information to your local council.

**Landslide risk assessment must be undertaken by a geotechnical practitioner**. It may involve visual inspection, geological mapping, geotechnical investigation and monitoring to identify:

- potential landslides (there may be more than one that could impact on your site)
- the likelihood that they will occur
- the damage that could result
- the cost of disruption and repairs and
- the extent to which lives could be lost.

Risk assessment is a predictive exercise, but since the ground and the processes involved are complex, prediction tends to lack precision. If you commission a landslide risk assessment for a particular site you should expect to receive a report prepared in accordance with current professional guidelines and in a form that is acceptable to your local council, or planning authority.

### Risk to Property

Table 1 indicates the terms used to describe risk to property. Each risk level depends on an assessment of how likely a landslide is to occur and its consequences in dollar terms. "Likelihood" is the chance of it happening in any one year, as indicated in Table 2. "Consequences" are related to the cost of repairs and temporary loss of use if a landslide occurs. These two factors are combined by the geotechnical practitioner to determine the Qualitative Risk.

**TABLE 2: LIKELIHOOD**

| Likelihood | Annual Probability |
|---|---|
| Almost Certain | 1:10 |
| Likely | 1:100 |
| Possible | 1:1,000 |
| Unlikely | 1:10,000 |
| Rare | 1:100,000 |
| Barely credible | 1:1,000,000 |

The terms "unacceptable", "may be tolerated", etc. in Table 1 indicate how most people react to an assessed risk level. However, some people will always be more prepared, or better able, to tolerate a higher risk level than others.

Some local councils and planning authorities stipulate a maximum tolerable level of risk to property for developments within their jurisdictions. In these situations the risk must be assessed by a geotechnical practitioner. If stabilisation works are needed to meet the stipulated requirements these will normally have to be carried out as part of the development, or consent will be withheld.

**TABLE 1: RISK TO PROPERTY**

| Qualitative Risk | | Significance - Geotechnical engineering requirements |
|---|---|---|
| Very high | VH | **Unacceptable** without treatment. Extensive detailed investigation and research, planning and implementation of treatment options essential to reduce risk to Low. May be too expensive and not practical. Work likely to cost more than the value of the property. |
| High | H | **Unacceptable** without treatment. Detailed investigation, planning and implementation of treatment options required to reduce risk to acceptable level. Work would cost a substantial sum in relation to the value of the property. |
| Moderate | M | **May be tolerated** in certain circumstances (subject to regulator's approval) but requires investigation, planning and implementation of treatment options to reduce the risk to Low. Treatment options to reduce to Low risk should be implemented as soon as possible. |
| Low | L | **Usually acceptable** to regulators. Where treatment has been needed to reduce the risk to this level, ongoing maintenance is required. |
| Very Low | VL | **Acceptable**. Manage by normal slope maintenance procedures. |

# AUSTRALIAN GEOGUIDE LR7 (LANDSLIDE RISK)

**Risk to Life**

Most of us have some difficulty grappling with the concept of risk and deciding whether, or not, we are prepared to accept it. However, without doing any sort of analysis, or commissioning a report from an "expert", we all take risks every day. One of them is the risk of being killed in an accident. This is worth thinking about, because it tells us a lot about ourselves and can help to put an assessed risk into a meaningful context. By identifying activities that we either are, or are not, prepared to engage in we can get some indication of the maximum level of risk that we are prepared to take. This knowledge can help us to decide whether we really are able to accept a particular risk, or to tolerate a particular likelihood of loss, or damage, to our property (Table 2).

In Table 3, data from NSW for the years 1998 to 2002, and other sources, is presented. A risk of 1 in 100,000 means that, in any one year, 1 person is killed for every 100,000 people undertaking that particular activity. The NSW data assumes that the whole population undertakes the activity. That is, we are all at risk of being killed in a fire, or of choking on our food, but it is reasonable to assume that only people who go deep sea fishing run a risk of being killed while doing it.

It can be seen that the risks of dying as a result of falling, using a motor vehicle, or engaging in water-related activities (including bathing) are all greater than 1:100,000 and yet few people actively avoid situations where these risks are present. Some people are averse to flying and yet it represents a lower risk than choking to death on food. Importantly, the data also indicate that, even when the risk of dying as a consequence of a particular event is very small, it could still happen to any one of us any day. If this were not so, no one would ever be struck by lightning.

Most local councils and planning authorities that stipulate a tolerable risk to property also stipulate a tolerable risk to life. The AGS Practice Note Guideline recommends that 1:100,000 is tolerable in newly developed areas, where works can be carried out as part of the development to limit risk. The tolerable level is raised to 1:10,000 in established areas, where specific landslide hazards may have existed for many years. The distinction is deliberate and intended to prevent the concept of landslide risk management, for its own sake, becoming an unreasonable financial burden on existing communities. Acceptable risk is usually taken to be one tenth of the tolerable risk (1:1,000,000 for new developments and 1:100,000 for established areas) and efforts should be made to attain these where it is practicable and financially realistic to do so.

**TABLE 3: RISK TO LIFE**

| **Risk** (deaths per participant per year) | **Activity/Event Leading to Death** (NSW data unless noted) |
|---|---|
| 1:1,000 | Deep sea fishing (UK) |
| 1:1,000 to 1:10,000 | Motor cycling, horse riding , ultra-light flying (Canada) |
| 1:23,000 | Motor vehicle use |
| 1:30,000 | Fall |
| 1:70,000 | Drowning |
| 1:180,000 | Fire/burn |
| 1:660,000 | Choking on food |
| 1:1,000,000 | Scheduled airlines (Canada) |
| 1:2,300,000 | Train travel |
| 1:32,000,000 | Lightning strike |

**More information relevant to your particular situation may be found in other AUSTRALIAN GEOGUIDES:**

- GeoGuide LR1 - Introduction
- GeoGuide LR2 - Landslides
- GeoGuide LR3 - Landslides in Soil
- GeoGuide LR4 - Landslides in Rock
- GeoGuide LR5 - Water & Drainage
- GeoGuide LR6 - Retaining Walls
- GeoGuide LR8 - Hillside Construction
- GeoGuide LR9 - Effluent & Surface Water Disposal
- GeoGuide LR10 - Coastal Landslides
- GeoGuide LR11 - Record Keeping

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The Australian GeoGuides (LR series) are a set of publications intended for property owners; local councils; planning authorities; developers; insurers; lawyers and, in fact, anyone who lives with, or has an interest in, a natural or engineered slope, a cutting, or an excavation. They are intended to help you understand why slopes and retaining structures can be a hazard and what can be done with appropriate professional advice and local council approval (if required) to remove, reduce, or minimise the risk they represent. The GeoGuides have been prepared by the Australian Geomechanics Society, a specialist technical society within Engineers Australia, the national peak body for all engineering disciplines in Australia, whose members are professional geotechnical engineers and engineering geologists with a particular interest in ground engineering. The GeoGuides have been funded under the Australian governments' National Disaster Mitigation Program.