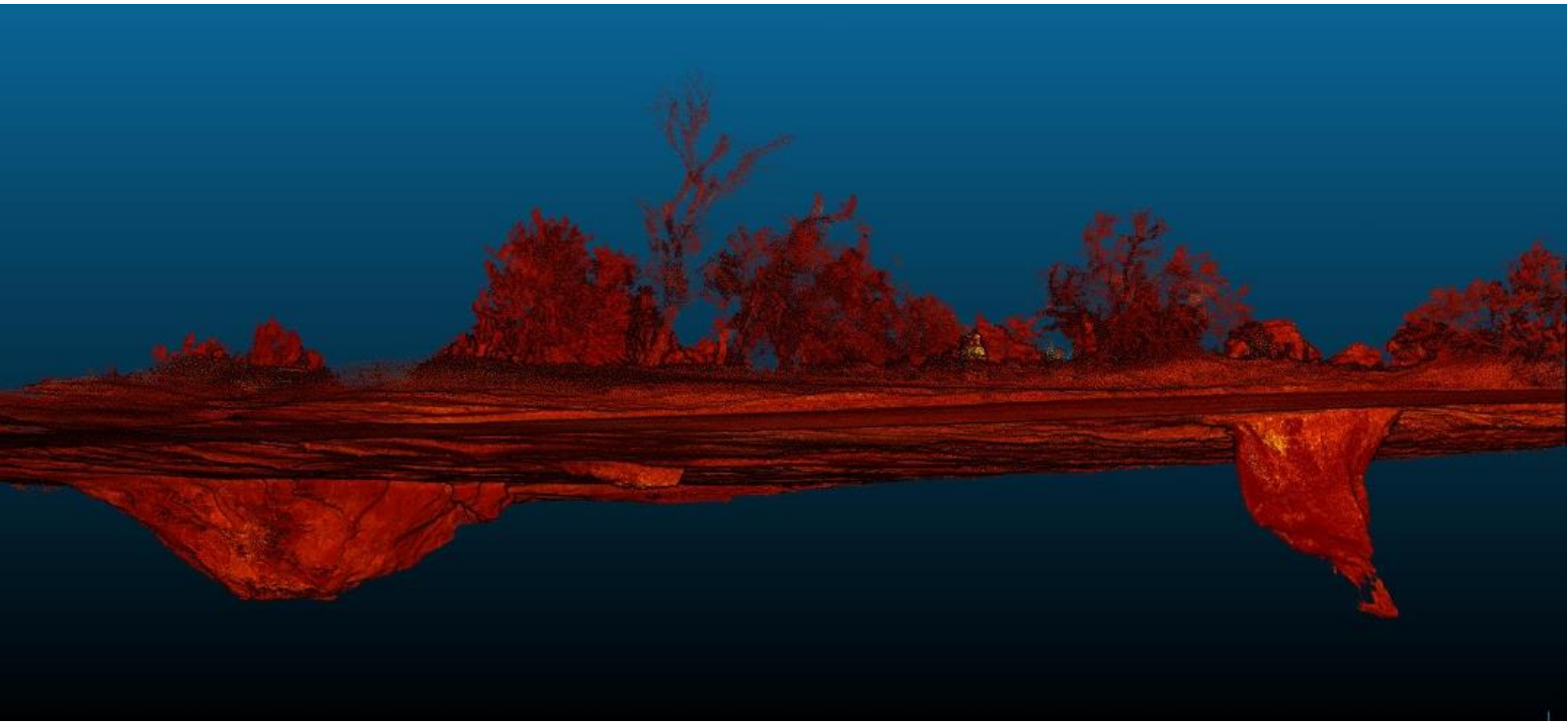

Department of Mines, Industry Regulation and Safety

Wheal Ellen Mine Shafts and Open Pits Remediation
Remediation Methodology Report

October 2020

Table of contents

Table index

Appendices

1. Introduction

1.1 Overview

This report presents a methodology to remediate hazards associated with the abandoned Wheal Ellen lead mine located approximately 2 km south west of Northampton, located 465 km north of Perth, Western Australia.

The work was commissioned by the Department of Mines, Industry Regulation and Safety (DMIRS) as part of their Abandoned Mines Program (AMP).

The hazards to be remediated relate to surface features associated with mine shafts, pits and subsidence as well as potential for future subsidence. Hazards associated with other aspects such as contamination are not addressed in this remediation methodology.

The hazards of concern are documented in a separate “Geotechnical Report” (GHD 2020) which should be read in conjunction with this report. The Geotechnical Report also includes information on topography, geology, surface water, groundwater and stockpiles that form the basis for the remediation methodologies presented herein.

In the following sections, the remediation objectives are discussed followed by a summary of requirements and challenges. An appraisal of options is then provided followed by details of the preferred remediation option together with a preliminary cost estimate. Details of a fauna desktop review and night survey undertaken by GHD is presented in Appendix A.

1.2 Limitations

This report has been prepared by GHD for Department of Mines, Industry Regulation and Safety and may only be used and relied on by Department of Mines, Industry Regulation and Safety for the purpose agreed between GHD and the Department of Mines, Industry Regulation and Safety as set out this report.

GHD otherwise disclaims responsibility to any person other than Department of Mines, Industry Regulation and Safety arising in connection with this report. GHD also excludes implied warranties and conditions, to the extent legally permissible.

The services undertaken by GHD in connection with preparing this report were limited to those specifically detailed in the report and are subject to the scope limitations set out in the report.

The opinions, conclusions and any recommendations in this report are based on conditions encountered and information reviewed at the date of preparation of the report. GHD has no responsibility or obligation to update this report to account for events or changes occurring subsequent to the date that the report was prepared.

GHD has prepared this report on the basis of information provided by Department of Mines, Industry Regulation and Safety and others who provided information to GHD (including Government authorities), which GHD has not independently verified or checked beyond the agreed scope of work. GHD does not accept liability in connection with such unverified information, including errors and omissions in the report which were caused by errors or omissions in that information.

GHD has prepared the preliminary cost estimate set out in Section 5.10 of this report (“Preliminary Cost Estimate”) using information reasonably available to the GHD employee(s) who prepared this report; and based on assumptions and judgments made by GHD and our sub-contractor Buru Centrals Rehabilitation.

The Cost Estimate has been prepared for the purpose of providing an indicative guide to assist DMIRS with project budgeting and must not be used for any other purpose.

The Cost Estimate is a preliminary estimate only. Actual prices, costs and other variables may be different to those used to prepare the Cost Estimate and may change. Unless as otherwise specified in this report, no detailed quotation has been obtained for actions identified in this report. GHD does not represent, warrant or guarantee that the works can or will be undertaken at a cost which is the same or less than the Cost Estimate.

2. Remediation objectives and land use

With respect to Wheal Ellen, the DMIRS stated project objectives are to:

- Provide a long-term solution to mitigate safety risks, to a standard where the site could be opened to the public.
- Minimise risk to personnel during construction.
- Be technically feasible and cost-effective.
- Minimise disturbance to the surrounding area.
- Require minimal ongoing monitoring or maintenance for the first 10 years, require no ongoing monitoring or maintenance post 10 years.

Opportunities and constraints (or challenges) to achieving the above are presented in Section 2. The following remarks are provided for context and general background.

With respect to achieving long term remediation outcomes, expectations need to be realistic and remediation effort balanced with cost. While is it possible to remediate the site so that there is no residual risk by filling all sub-surface voids with cementitious grout, the cost would be very high and would reduce the capacity to remediate other sites.

However, while sub-surface voids remain, the possibility of pre-existing and new features opening to the surface remains. The mechanism that causes this is usually related to water. Specifically, surface water infiltrating the ground and causing soil to move deeper into underground voids thus creating a sinkhole.

While good design and execution will have longevity, the remediation of shafts and subsidence features needs to consider the consequences of failure of the solution. That is, in the absence of complete void filling by grouting, the post remediation (residual) risk is not nil and so should be considered. In this context, the post remediation land use needs to be considered. In particular, the future number of people accessing the site, the time spent on site and the nature of the activities being undertaken all influence the residual risk and hence level of treatment.

For the Wheal Ellen site, the future land use that has been considered in the remediation methodology is rural with no dwellings or significant public infrastructure such as a road, railway or pipeline. While potentially open to the public, it is envisaged that large numbers visiting the site for recreation would not be encouraged.

Should land use change from the above significantly, for example a subdivision or other development, the proposed remediation methodology is unlikely to remain appropriate and additional mitigation measures would probably be required.

3. Requirements and challenges

3.1 Introduction

This section summarises key requirements of the remediation that have been taken into consideration and also some of the anticipated challenges or constraints.

3.2 Safety during remediation

The GHD Geotechnical Report includes a section titled: “Hazards from past mining” which documents existing hazards that present dangers to people accessing the site which should be communicated to those people and managed until remediation is complete.

The hazards considered and documented are limited to:

- Subsidence / collapse of the ground above mine workings.
- Instability around the crest of existing shafts, pits or subsidence features.
- Existing features observed by GHD in August 2020.
- Potential subsidence events occurring after August 2020 that we have been able to identify by the assessment presented herein.

3.3 Practicality and availability of resources

Ideally, the remediation treatments would be achievable with locally available materials and contractors. Where this is not possible, the volume and transport distance of imported material should be limited as far as is practicable.

3.4 Mineral sterilisation

Mineral sterilisation has been considered in the context of future open cut mining through the mined ore body. In this scenario the remedial measures would be removed by future mining and would not impede them.

3.5 Noxious and flammable gases

The mine workings are now largely filled with water and much of the workings above the groundwater are sufficiently open to be naturally ventilated.

Above the groundwater, small pockets of stale (low oxygen) air are likely to exist in underground voids. This is more likely in the Northern Workings area where the depth to the groundwater table is several metres lower due to the higher elevation in that area. During remediation, some of this air may be displaced and come to the surface. However, the volume would be insignificant and quickly diluted in the open air.

3.6 Groundwater

As discussed in the GHD Geotechnical Report, shallow groundwater is anticipated in the central and southern portions of the site.

Water in features will be displaced by backfilling and may overflow if the rate of water displacement during filling exceeds the rate that water can infiltrate into the ground or be pumped out. This is particularly possible during filling of the Main Shaft.

In addition to preventing uncontrolled surface water flows, removal of water from some features may be required following wet weather periods to avoid the situation of placing earth fill into water or just above saturated rock fill.

Management of water during backfilling by the contractor is likely to be required in some locations. This is expected to involve either waiting for water to dissipate within a particular feature or moving water from one feature to another. For example: water pumped into the Main Shaft is likely to infiltrate into the workings rapidly due to its depth and anticipated connection to the workings.

Further guidance on water management is included in Section 5.

3.7 Surface water

Watercourses based on the site topography at the time of survey (August 2020) are presented in the GHD Geotechnical Report and also shown on the figures included in Appendix B.

Modification to surface water flow pathways is needed to direct water into proposed drains while crossing over the area of mining.

Given other remediation activities are planned on the site in the coming 9 to 12 month, resulting in changes to drainage patterns and site disturbance, the design and construction of new drains should be incorporated into a whole of site surface water management plan. However, for management of site safety during remediation, the backfilling of features should be a priority. As such, the feature remediation work it expected to require two phases. Backfilling features and then surface water management.

3.8 Fauna impacts

The fauna assessment presented in Appendix A found that the likelihood of adverse impacts to fauna of conservation significance from the remediation work is very low.

3.9 Vegetation removal

Parts of the site, particularly the southern and northern portions are vegetated with grasses and scattered trees. Many of these trees are in or around features to be remediated. More broadly, areas or ground to be filled to improve surface water drainage and areas of drainage works would require clearing and stripping.

Consideration of flora impacts specifically were beyond the scope of the assessment but have been taken into consideration broadly with respect to mature trees.

3.10 Debris

A number of the shafts and open pits are partially filled with debris such as cars, sheet metal and wire. Potential Asbestos Containing Material (ACM) in the form of cemented sheeting was observed at two locations. Observations are detailed in the GHD Geotechnical Report.

The remediation treatments will require removal of debris that impacts backfilling. The following debris characteristics are problematic and such debris should be removed prior to filling where it is assessed to be sufficiently safe to do so.

- Debris extending into the earth fill zone of backfill.
- Car / truck bodies and sheet metal / corrugated iron.
- Vessels or containers over about 0.1 m^3 volume (e.g. tanks, troughs, bath tubs, gas cylinders).

- Explosive or combustible material.
- Organics or other material that could decompose rapidly and/or generate methane (e.g. trees, woodchips / mulch, branches, timber, putrescible waste).
- Other large objects that restrict backfilling / compaction and could lead to large (greater than 0.1 m^3) voids within rock fill.

3.11 Stockpiles and fill resources

Ten stockpiles were identified and are labelled on Figure 2 in Appendix B. Details are provided in the Geotechnical Report, including approximate volumes for each.

As advised by DMIRS, only “non-contaminated” material will be approved for use within remediation works. The contamination status and hence suitability for reuse of these stockpiles is yet to be confirmed and further assessment by Department of Planning, Lands and Heritage (DPLH) is understood to be occurring.

Assuming all 10 stockpiles are “non-contaminated”, all stockpile material would be considered suitable for reuse in remediation as earth fill. This represents approximately 5,670 m^3 of material. However, none would be suitable for filling the base of voids as rock fill and only about 2,460 m^3 of potential topsoil material appears to be available.

The volume to fill specific features and depressions is estimated to be approximately 3,300 m^3. In addition to this, 1,000 m^3 of earth fill is estimated to be required for general drainage improvement regrading (filling).

Proposed borrow pits from the adjacent lot to the northwest of the site are expected to generate additional earth fill but not rock fill.

4. Review of alternate remediation and management options

4.1 Overview

Alternate remediation and management methods considered are briefly discussed under the below sub-headings. These are not mutually exclusive and in practice could be applied in conjunction with other methods and/or to target particular areas.

4.2 Full sub-surface void filling

Filling of all sub-surface voids is the only practical way of removing the possibility of future sinkhole / subsidence occurrence. If development over the mined area was planned, for example: residential sub-division, a road or landfill facility, this would be the preferred remediation methodology.

As the aim would be to fill all sub-surface voids, there would be no need for surface regrade or drainage improvement work, at least not for subsidence remediation purposes.

The filling would either be with sand and / or bottom ash, sluiced into the workings with water or a fly-ash cement blend batched on-site and pumped into the workings as a slurry. In both cases, water extracted from the workings could be used rather than importing water. This would have the advantage of managing sediment / cement laden water being displaced and otherwise overflowing during the filling. The filling would be via the surface features (until they become blocked) and also through lines of boreholes drilled into the workings.

The method or remediation was not preferred for the following reasons:

- A specialist contractor and equipment is needed.
- All fill material (other than water) would need to be imported and a local supply of sand, bottom ash or fly-ash was not identified.
- The cost of remediation is expected to be higher and with greater uncertainty of the volume required.
- The need for certainty with respect to no future subsidence was not considered sufficient to warrant the additional cost anticipated.
- Surface regrade and drainage improvement works are expected to be required any way for general site remediation purposes.

4.3 Stabilised backfill

Filling the surface features with cement stabilised sand or no-fines concrete would both fill the features and block the pathway to sub-surface voids at these locations, effectively preventing future subsidence locally.

The stabilised backfill would be trucked to site from a local concrete batch plant or batched on site using imported materials. The process would be to fill the features and then rehabilitate the surface with earth fill and topsoil to revegetate. Surface regrade and drainage improvement work would also be required. Filling would likely need to start with smaller volume in the base of features with this allowed to set before bulk filling. This is to prevent the mobile backfill from being pushed into the sub-surface voids.

The method or remediation was not preferred for the following reasons:

- The majority of fill material would need to be imported.
- The lower permeability and erosion resistant backfill can have the tendency to concentrate water flows (both surface and sub-surface) resulting in greater likelihood of sinkholes and erosion around the perimeter of the backfilled area.
- The cost of remediation is expected to be higher.

4.4 Earth backfill

Backfilling the features with earth fill as opposed to cement stabilised sand or rock fill could be achieved with the existing stockpiled material available on-site (assume these are deemed to be non-contaminated). No imported material would be needed although surface regrade and drainage improvement work would be recommended. This method would be the cheapest of those considered and would remove the immediate (short term) hazard of falling into a feature.

The method or remediation was not preferred as the likelihood of future subsidence / sinkholes occurring was expected to be too high to meet DMIRS objectives.

4.5 Geogrids and geotextiles

Geogrid and/or geotextile layers could be incorporated with earth or rock backfilling of features to reduce migration of fines through the fill into sub-surface voids and, in the case of geogrid, to also span over small (less than about 1 m diameter) sub-surface voids that form beneath the grid. The use of a suitable geogrid to span over voids would inhibit the migration of a void to the surface and could also act as a warning system whereby a surface depression forms before a steep sided sinkhole occurs. This warning relies on an observer being present who also understands the significance of the developing depression.

Surface regrade and drainage improvement work would also be required.

To place the layers, either access into the features would be required or excavators / cranes used to handle and place the layers. Given the anticipated difficulty with such handling, it is likely the only practical method would be to place the layers no deeper than about 2 m from the feature crest and batter the sides above this to stable angles.

While adding cost, the use of geogrid and/or geotextile layers would reduce the likelihood of future subsidence and could also reduce the consequence of a sinkhole by providing warning.

This method or remediation was not preferred for the following reasons:

- Access to place layers would require excavation around features with additional removal of vegetation.
- An observer who understands the significance of the developing depression would need to be present for the warning to be realised.
- The cost of remediation is expected to be higher.

4.6 Abandonment bunds

Placing earth mounds around features to act as a warning would be effective in the short term while the site is controlled, inductions are required and workplace health and safety legislation is in effect. Once the site is uncontrolled and open to the public, the bunds would not provide a physical barrier and could even attract people to the features.

4.7 Layback excavation

Flattening the sides of features would remove the fall hazard that currently exists in some places. However, such flattening would provide easier access to the base of the features where openings (subsidence holes) into subsurface voids could occur.

This treatment method would also increase the area of disturbance requiring additional clearing and revegetation.

4.8 Shaft capping and covers

Engineered structures such as reinforced concrete slabs or steel grates can be used to make shafts and subsidence features safe. However, the continued reliability of such structures requires inspection, maintenance and eventual replacement. Without a suitable future custodian, such ongoing management is not considered likely to occur.

4.9 Fencing and signage

While fencing and signage is effective in preventing access and providing warning, ongoing maintenance is required to repair holes cut in fences and replace signs. To be completed effectively, maintenance would be needed several times per year. As for engineered structures, such ongoing management in not considered likely to occur without a suitable future custodian of the site.

5. Recommended remediation methodology

5.1 Overview

The recommended remediation treatments aim to create a surficial layer of stable ground through the following strategies.

- Reduce infiltration of surface water into the mined ground by:
  - Regrading (filling) low lying areas to move surface water flows toward formalised drains and reduce ponding.
  - Conveying surface water flows along formalised drains and through culverts that are designed to resist erosion.
- Halt or slow the formation of sinkholes reoccurring at existing features by:
  - Blocking / bridge over sub-surface voids in the base of features using large rock fill.
  - Reducing the migration of fines (clay and silt) into sub-surface voids by using graded backfill over rock fill.
  - Filling the Main Shaft with gravel and plugging both it and the Old Main Shaft with cemented material.
- Halt or slow the formation of sinkholes occurring at other locations by improving surface drainage as described above.
- Reduce the risk to Access Road users of sinkhole formation during remediation by managing vehicle types and speeds and conducting inspections.

Despite the above measures, it is likely that at times, small sinkholes will occur along the lode sub-crop. These are expected to be similar to observed features “Sinkhole 1” and “Sinkhole 2” and are more likely where shallow depressions have been filled with earth fill or topsoil rather than firstly graded rock fill at the base. The rock fill is intended to halt the migration of fines underground. However, where this process is occurring and the opportunity to introduce rock fill is not available (such as at shallow depressions), the process is likely to continue, albeit slowed by the surface drainage improvements.

This assumes that occasional occurrence of small sinkholes along the lode sub-crop is a tolerable hazard. That is, the associated risk (likelihood x consequence) is tolerable to those exposed to the hazard.

The preferred remediation treatments have been grouped into four types as A through D as well as drainage and regrade work. These are explained under the below sub-headings with reference to the figures in Appendix B. Following these sub-headings, Section 5.8 provides definitions for the materials used and Table 5-1 provides a summary including volume estimates for the various materials. These are approximate only and should not be relied upon. Contractors should make their own assessment based on data provided and make appropriate contingency allowances.

A minimum tracked excavator size of 20 tonnes is assumed for all treatments. The remediation contractor should confirm adequate reach for their selected plant.

Compaction of the rock fill and earth fill is discussed under the treatment sub-headings below. Various compaction techniques are given with selection of the technique up to the contractor based on safety considerations, equipment availability and compaction effectiveness. In general, use of a vibrating plate compactor mounted on an excavator arm is preferred for rockfill and either use of excavator tracks or an excavator mounted compaction wheel for earth fill.

Over time, backfill material will consolidate resulting in settlement of the ground surface. The amount of settlement will be most where the depth of fill is greatest. This settlement will tend to cause surface water to pond. To combat this, mounding of the final backfilled surface is recommended as set out in the below treatments.

Plant and equipment should generally be positioned on the east or southeast side of features where the ground is expected to be more stable. Broader access around features will be required and reference should be made to Section 7 of the GHD Geotechnical Report for guidance on sinkhole hazards and controls.

5.2 Treatment A – excavate and backfill

Applicable features: *S0113114, S0113111, S0113163, S0113143, Pass No. 1 North, Old Workings Pass, Old Workings Shaft*

Figure reference: *Figure 4 – Appendix B*

These features are likely to have been filled in the past and subsequently subsided as fines migrate into subsurface voids. Placing additional fill into the depression is less likely to prevent future subsidence than excavating the feature to allow a thicker backfill or engineered layers.

Treatment A is as follows:

1. If water is within the feature, remove or lower it by excavator bucket or submersible pump. Noting that for S0113143, Old Workings Pass and Old Workings Shaft only partial and temporary lowering may be achievable.
2. Remove problematic debris (as defined in Section 3.10) using a tracked excavator and dispose of or stockpile onsite as per DMIRS requirements.
3. Strip vegetation and topsoil and keep separate for reuse.
4. Excavate to the depth indicated in Table 5-1 across the full extent of the feature as defined by the crest. The excavated material can be reused as earth fill but may require drying out before doing so. Refer to Section 5.8.3 for guidance on moisture content for fill placement.
5. Inspection Hold Point (Refer to Section 5.10): Using the excavator bucket, assess the competence of the base by repeatedly trying to push the bucket down using the partial weight of the excavator (taking the weight off the front of the tracks).
6. Across the base of the excavation, place 1 m thickness of coarse rock fill and compact with either:
    (a) The back of the excavator bucket, using the partial weight of the excavator.
    (b) An excavator mounted vibrating plate compactor.
    (c) The excavator tracks (if safe to access the feature to do so).
7. Over the coarse rock fill, place a minimum of 0.3 m thickness of fine rock fill and compact as for the coarse rock fill.
8. Over the fine rock fill, place general earth fill in lifts of no greater than 0.3 m thickness up to the feature crest and compact with either:
    (a) At least three passes of the excavator tracks.
    (b) At least three passes of an excavator mounted compaction wheel.
9. Mound earth fill over the feature extent such that the central portion of the mound is at least 0.5 m higher than the natural surface level and compact as for earth fill.
10. Topsoil and revegetate as per DMIRS requirements.

Where water inflow (rising from the base) cannot be met by pumped outflow, excavation below water will be needed. In this scenario, it is acceptable to stop pumping and undertake the excavation, inspection hold point and rock fill placement below water. This is to reduce the volume of muddy water that would otherwise need to be managed.

The full extent of Pass No. 1 North is not observable and the feature will need to be excavated to allow the DMIRS representative to confirm the depth and extent of treatment.

5.3 Treatment B – backfill

Applicable features: *S0113122, S0113103, S0113151, S0113097, S0113149, S0113130, S0113141*

Figure reference: *Figure 5, Figure 6, Figure 7 – Appendix B*

These deeper features do not require excavation prior to backfilling although some battering may be required depending on the excavator reach and feature size to position the excavator in a stable location whist operating. For larger features, progressive filling could be used to allow the excavator to position on an already backfilled section while filling and compacting other areas of the feature.

Treatment B is as follows:

1. If water is within the feature, remove or lower it by excavator bucket or submersible pump. Noting that for S0113097, S0113130 and S0113141 only partial and temporary lowering may be achievable.
2. Remove problematic debris (as defined in Section 3.10) and vegetation (trees) using a tracked excavator and dispose of or stockpile onsite as per DMIRS requirements.
3. Remove soft / saturated soils (sediment in the base) where present and as directed by DMIRS and dispose of on site as per DMIRS requirements or allow to dry out to enable reuse as earth fill. Refer to Section 5.8.3 for guidance on moisture content for fill placement.
4. Inspection Hold Point (Refer to Section 5.10).
5. Across the base of the excavation, place 1 m thickness of coarse rock fill and compact with either:
    (a) The back of the excavator bucket, using the partial weight of the excavator.
    (b) An excavator mounted vibrating plate compactor.
6. Over the coarse rock fill, place a minimum of 0.3 m thickness of fine rock fill and compact as for the coarse rock fill.
7. Over the fine rock fill, place general earth fill in lifts of no greater than 0.3 m thickness up to the feature crest and compact with either:
    (a) At least three passes of the excavator tracks.
    (b) At least three passes of an excavator mounted compaction wheel.
8. For features S0113151, S0113097 and S0113141, mound earth fill over the feature extent such that the central portion of the mound is at least 0.8 m higher than at the natural surface level and compact as for earth fill. For other features, mound the central portion at least 0.5 m higher than the natural surface level.
9. Topsoil and revegetate as per DMIRS requirements.

Where water inflow (rising from the base) cannot be met by pumped outflow, excavation below water will be needed to remove sediment and 'test' the excavation base with the excavator bucket. In this scenario, it is acceptable to stop pumping and undertake the excavation, inspection hold point and rock fill placement below water. This is to reduce the volume of muddy water that would otherwise need to be managed.

5.4 Treatment C – deeper excavation and backfill

Applicable features: *S0113147*

Figure reference: *Figure 8 – Appendix B*

Treatment C is as for Treatment B except that:

- Drainage improvement work adjacent to this feature should ideally be completed before remediation to avoid erosion of topsoil and earth fill, necessitating repair.
- Removal of water by pumping from the sinkhole (prior to excavation of fines) is considered too dangerous and should not be attempted.
- Prior to filling, the fines (soil) that has filled the feature should be excavated as directed by DMIRS and be disposed of on site as per DMIRS requirements or allowed to dry out to enable reuse as earth fill. Refer to Section 5.8.3 for guidance on moisture content for fill placement.
- Mounded earth fill over the feature extent should be such that the central portion of the mound is at least 0.8 m higher than the natural surface level (about RL 115 m AHD).

The depth and hence volume of fines to be removed is unknown. The depth of the feature prior to being infilled with fines is speculated to be similar to feature S0113097 to the north at 6.7 m, whereas it is currently about 2 to 3 m deep. The batter slopes visible in the 2000 photograph in the GHD Geotechnical Report also provide an indication. A volume of fines of 160 to 200 m^3 is considered a reasonable estimate.

5.5 Treatment D – shaft fill and plug

5.5.1 General

Applicable features: *S0113158, S0113145*

Figure reference: *Figure 9, Figure 10, Figure 11 – Appendix B*

These shafts require a different remediation approach due to their depth. While the Old Main Shaft (S0113145) is backfilled to 3.2 m depth, this backfill may not be stable. The Main Shaft (S0113158) is open to at least 60.5 m depth.

5.5.2 Main Shaft (S0113158)

As shown on Figure 11, the Main Shaft is adjacent to piles of waste rock which may be removed by others as part of contamination remediation or this material would be available as earth fill. The post remediation ground surface is expected to be about 116 m AHD. That is, just below the Main Shaft collar as shown on Figure 10. As such, filling of the shaft can occur before or after removal of the waste rock piles.

Treatment D for the Main Shaft (S0113158) is as follows:

1. Inspection Hold Point (Refer to Section 5.10): Dip the three shaft chambers with a weighted tape (of at least 100 m length) and report the depths to the DMIRS representative.

2. Remove the old water pump, pipework and metal frame from the central chamber. Photograph the feature from all four sides.
3. Without dewatering the shaft, fill the shaft with fine rock fill by slowly pouring the rock into each of the three shaft chambers such that the level in one chamber does not become more than 1 m different than the level in the adjacent chamber. The method of filling is not specified but is expected to using an excavator bucket, kibble bucket or hopper/conveyor.
4. Inspection Hold Point (Refer to Section 5.10): For every 20 m^3 of placed rock fill, dip the three shaft chambers with a weighted tape and report the depths and cumulative placed volume to the DMIRS representative.
5. Continue filling until the depth in each chamber is 5 m from the final post rehabilitation ground surface (116 m AHD).
6. Form the base of a plug by filling 1 m of the shaft with either sand and cement or fly-ash cement blend. Measure the depths in the three chambers immediately following placement of the above 1 m of plug and report them to the DMIRS representative.
7. Inspection Hold Point (Refer to Section 5.10): At least 48 hours later and prior to placing additional plug material, re-measure the depths in the three chambers and report them to the DMIRS representative.
8. Form the remainder of the plug by filling to the post rehabilitation ground surface (116 m AHD) with either sand and cement or fly-ash cement blend. Measure the depths in the three chambers immediately following placement of the sand/cement and report them to the DMIRS representative.
9. Inspection Hold Point (Refer to Section 5.10): At least 48 hours later, re-measure the depths in the three chambers and report them to the DMIRS representative.
10. If required, top up with additional sand and cement or fly-ash cement blend and repeat the above measurements and filling until the fill remains at or above 116 m AHD after 48 hours.

5.5.3 Old Main Shaft (S0113145)

As shown on Figure 9, the Old Main Shaft is surrounded by waste rock which may be removed by others as part of contamination remediation or would be available as earth fill. The post remediation ground surface is expected to be about 112.5 m AHD. Filling of the shaft can occur before or after removal of the waste rock.

Treatment D for the Old Main Shaft (S0113145) is as follows:

1. Inspection Hold Point (Refer to Section 5.10): Measure the shaft vertical depth and report the depth to the DMIRS representative.
2. Remove the majority of timber from the shaft using the excavator bucket or other attachment and excavate the existing backfill within the shaft to 110 m AHD.
3. Pump water into the shaft to about 112.5 m AHD and allow to sit for at least 48 hours. This is to encourage existing backfill to consolidate and to test that the backfill is sufficiently competent to begin forming the plug. If after 48 hours water remains, remove it before commencing to form the plug. Dip the shaft with a weighted tape and report the depth to the DMIRS representative. If the backfill has subsided, additional cement stabilised fill and/or rock fill will be required as directed by the DMIRS representative.
4. If needed, remove fallen material by excavation to 110 m AHD.

5. Inspection Hold Point (Refer to Section 5.10): Using the excavator bucket, assess the competence of the base by repeatedly trying to push the bucket down using the partial weight of the excavator (taking the weight off the front of the tracks). If the floor collapses, additional cement stabilised fill and/or rock fill will be required as directed by the DMIRS representative.
6. Form the base of a plug by filling 1 m of the shaft with either sand and cement or fly-ash cement blend. Measure the depth immediately following placement of the above 1 m of plug and report this to the DMIRS representative.
7. Inspection Hold Point (Refer to Section 5.10): At least 48 hours later and prior to placing additional plug material, re-measure the depth and report to the DMIRS representative.
8. Form the remainder of the plug by filling with either sand and cement or fly-ash cement blend to at least 112.5 m AHD. Measure the depth immediately following placement and report to the DMIRS representative.
9. Inspection Hold Point (Refer to Section 5.10): At least 48 hours later, re-measure the depth and report to the DMIRS representative.
10. If required, top up with additional sand and cement or fly-ash cement blend and repeat the above measurements and filling until the fill remains at or above 112.5 m AHD after 48 hours.

5.6 Drainage and regrade work

Figure reference: *Figure 3 – Appendix B*

Treatment of individual features will not address possible future subsidence along the lode sub-crop between features. While full grouting of sub-surface voids would be needed to prevent such subsidence, improvements to surface drainage will reduce the frequency of occurrence as surface water infiltration into the ground is a key mechanism for weathering and transportation of fines into voids. The objectives of drainage improvement works are therefore to reduce infiltration along the lode sub-crop by:

- Reducing ponding/retention of surface water along the lode sub-crop.
- Reducing erosion by formalising watercourses over the lode sub-crop.
- Reducing localised flooding by ensuring culverts or causeways immediately downstream of the lode sub-crop are adequately sized and practically maintainable.

Where the groundwater table rises close to, or sometimes above, the ground surface such as in the south of the site at the Old Workings area, there is less opportunity or benefit from improving surface drainage generally. The fluctuations in groundwater level will continue regardless, driving the process of weathering and migration of fines independent of surface drainage conditions. More benefit in drainage improvements are anticipated where the groundwater table is deeper, where there are signs of existing erosion and where there is existing ponding. These areas are generally north of the Main Shaft (S0113158) and Pass No. 1 North.

A hydrological assessment of site drainage has not been undertaken to allow sizing of open drains and culverts for design flows. Furthermore, site topography and drainage patterns are likely to change significantly as the site is rehabilitated for non-mine subsidence objectives. However, an assessment of what drainage improvement works are needed for mine subsidence remediation purposes has been made using the August 2020 survey and observations. These remediation measures are shown on Figure 3 and 3a in Appendix A and comprise the following.

1. Regrade area around features S0113127, S0113128, “Sinkhole 1” and several unnamed passes. To shed surface water flow away from and prevent ponding in this area. Not including the specific feature fill volumes, this is estimated to be an area of 1,430 m² with a fill volume of approximately 1,000 m³, assuming an average fill depth of 0.7 m.

2. Construct a shallow open drain, “D1” (spoon drain or trapezoidal drain) near the northern entrance gate as shown to intercept water from upslope of the sub-crop and transfer it to the other side of the access road.
3. Construct a culvert or causeway across the access road, “C1” associated with drain D1.
4. If required, clean out the culvert at “C2” to prevent localised flooding on the eastern (upstream) side of the access road.
5. Construct a culvert or causeway at “C3” and associated shallow open drain “D2”(spoon drain or trapezoidal drain) downstream of the culvert / causeway.
6. If required, increase the capacity of the culvert at “C4” or convert to a causeway and construct an associated shallow open drain “D3” (spoon drain or trapezoidal drain) downstream and upstream of the culvert / causeway.
7. Construct shallow open drains “D4” and “D5” (spoon drain or trapezoidal drains) west of the containment cell in the Old Workings area.

The cross-sectional profile and need for lining of open drains will depend on the design flow and grade. Guidance on shallow open drain design and construction is available from the AUS-SPEC C224/1121 specification *Open Drains* and Department of Primary Industry and Regional Development website page: “Shallow relief drains in Western Australia”.

Rigid lining such as concrete, grout filled mattresses or stone pitching should be avoided as such structures are susceptible to cracking and dislocation from subsidence, often resulting in more severe erosion from concentrated water flows. If lining is deemed necessary, gabion (e.g. Reno) mattresses or simple rock lined channels are preferred.

5.7 Access road risk mitigation

Where the access road crosses the lode sub-crop, there would be increased likelihood of encountering sinkhole hazards due to the increased traffic. Offsetting this is the anticipated reduced vulnerability of a vehicle occupant as opposed to a person on foot and also the improved ability for a hazard to be seen and hence avoided. The later assumes there is adequate line of sight for the vehicle stopping distance and this is influenced by vehicle speed and driver alertness.

The size of a sinkhole is expected to be less than 1 m and so large enough to result in vehicle damage or an accident, depending on speed, but not large enough to engulf a vehicle or cause it to halt immediately.

Taking the above into consideration and in the absence of a formalised risk assessment, some risk mitigation along the access road where it crosses the lode sub-crop is considered prudent while remediation work is being completed.

The recommended risk mitigations comprises the following.

1. Over the area indicated on Figure 3 in Appendix B, restrict access to enclosed vehicles. That is, prevent bicycles, motorcycles or pedestrian access.
2. Restrict vehicle speed through this section of road to 40 km/hr.
3. Undertake daily inspections of the area on days that work is being undertaken on the site this could simply be achieved by slowly driving the section of road and looking for signs of cracking, depressions or holes.

The above mitigations could be achieved through a combination of signage, site induction and task specific risk assessments, safe work method statements and daily pre-start meetings.

5.8 Material definitions

The following terms are defined for backfill materials as referenced in the below treatments.

5.8.1 Coarse rock fill

Coarse rock fill should be durable crushed rock, ideally from a known and established hard rock quarry. A well graded material is preferred with nominal particle sizes ranging from 100 mm to 500 mm and at least 50% of the material by dry weight being greater than 300 mm.

The Contractor should submit details of the proposed material to DMIRS for approval. As a minimum, this should include details of source, rock type, durability and particle size distribution laboratory test reports. Durability could be demonstrated through reported field performance of the materials on other sites and projects and ideally would be supported with laboratory test results such as slake durability.

5.8.2 Fine rock fill

Fine rock fill should be durable crushed rock, ideally from a known and established hard rock quarry. A well graded material is preferred with particle sizes ranging from 5 mm to 100 mm and at least 50% of the material by dry weight being less than 50 mm.

The Contractor should submit details of the proposed material to DMIRS for approval. As a minimum, this should include details of source, rock type, durability (as per coarse rock fill) and particle size distribution laboratory test reports.

5.8.3 Earth fill

Earth fill should be homogenous and predominately clay and should not include organics such as tree roots and stumps, contaminants, putrescible or combustible materials or rock boulders greater than 0.2 m diameter.

Subject to approval from DMIRS with respect to contamination aspects as discussed in the GHD Geotechnical Report, material from stockpiles on site are expected to be suitable as earth fill. However, some removal of oversize or organics may be required.

Earth fill containing more than about 35% sand or gravel should be placed into deeper features such that at least the upper 1 m thickness is predominantly clay with:

- At least 20% of material smaller than 0.075 mm (clay and silt).
- 100% of material smaller than 200 mm.

If the excavated material has been allowed to dry, water should be sprayed while placing the material to improve compaction efficiency. The amount of water should be limited so as to avoid heaving or spreading under the force of the compaction wheel / tracks. Alternatively, the excavated material could be blended with dryer earth fill material.

Typically, the optimum moisture content (OMC) for compaction of clays will be within a percent or two of the materials equilibrium moisture content. That is, the moisture content of the in-situ buried soil not affected by seasonal drying or wetting. The OMC for the excavated material can be measured by undertaking a Standard Compaction test (AS1289 5.1.1).

5.8.4 Sand and cement (stabilised sand)

The sand and cement blend (stabilised sand) should be a homogenous blend comprised of washed uniform sand (with less than 5% finer than 75 µm) with either general purpose Portland cement or general purpose blended cement. Other constituents such as crusher dust (scalps), bottom ash, fly ash and aggregate could be included to reduce cost, subject to DMIRS review and approval.

Cement used for stabilisation should conform to AS 3972, 'Portland and Blended Cements'.

The material should have a 48 hour uniaxial compressive strength of at least 1 MPa and 28 day uniaxial compressive strength of at least 2 MPa.

Proposed alternative to the above sand and cement blend (such a flyash / cement grout) may be suitable and should be submitted to DMIRS for consideration.

5.9 Summary table of features and treatments

Table 5-1 below provide a summary of features including volume estimates for various material types. These estimates are approximate only and should not be relied upon. Contractors should make their own assessment based on data provided and make appropriate contingency allowances.

Table 5-1 Summary of mine features and treatments

Feature	Type / Name	Water conditions	Debris present [2]	Treatment type	Approximate fill volume (m^3) [1]				
					Total	Coarse rock fill	Fine rock fill	Earth fill [3]	Sand / cement
S0113**128**	Stope subsidence	Not expected	none	Drainage	17	0	0	17	0
S0113**127**	Stope subsidence	Not expected	none	Drainage	41	0	0	41	0
S0113**114**	Shaft ?	Not expected	minor	A: to 3 m	32	9	3	20	0
S0113**122**	Pass ?	Not expected	none	B	277	74	22	181	0
S0113**111**	Stope subsidence	Not expected	minor	A: to 3 m	75	24	7	44	0
-	Unnamed Pass 3	Not expected	none	Drainage	5	0	0	5	0
-	Sinkhole 1	Not expected	unknown	Drainage	1	0	0	1	0
-	Sinkhole 2	Not expected	unknown	Drainage	5	0	0	5	0
-	Other depressions	Not expected	unknown	Drainage	158	0	0	158	0
S0113**103**	Pass No. 5 North / stope	Not expected	major	B	50	10	3	37	0
S0113**163**	Pass No. 4 North	Base wet following rain	none	A: to 3 m	96	30	9	57	0
S0113**151**	Open Cut / Pass No. 3 North and unnamed pass	Base wet following rain	major	B	623	85	26	512	0
S0113**097**	Open Cut / Unnamed Passes x 2	Groundwater table in base	major	B	625	73	22	530	0
S0113**149**	Unnamed Pass	Base wet following rain	none	B	18	4	1	13	0
S0113**147**	Pass No. 2 North	Base wet following rain	unknown	C	448	100	30	318	0
-	Pass No. 1 North	Unknown – likely wet	unknown	A: to 3 m [4]	100 [4]	30 [4]	10 [4]	60 [4]	0
S0113**158**	Main Shaft	Groundwater table in base	minor	D	254	0	236	0	18
S0113**130**	Pass No. 1 South	Groundwater table in base	minor	B	39	5	2	32	0
S0113**141**	Open Cut / Unnamed Pass	Groundwater table in base	minor	B	323	35	11	277	0
S0113**143**	Open Cut	Groundwater table in base	none	A: to 3 m	122	36	11	75	0
S0113**145**	Old Main Shaft	Groundwater table in base	minor	D	26	0	0	0	26
Old Workings Pass	Pass	Groundwater table in base	none	A: to 2 m	30	13	4	13	0
Old Workings Shaft	Shaft	Groundwater table in base	minor	A: to 2 m	45	20	6	19	0
[1] These are approximate only. Contractors should make their own assessment based on data provided and make appropriate contingency allowances. [2] Refer to GHD Geotechnical Report for details.		[3] Includes an estimate for the volume of earth fill won from Treatment type A excavation. Regrade volumes not included. [4] Feature extent is not visible and will require excavation to confirm. Volumes are estimates only for contingency allowance and are subject to confirmation following excavation.		**Sum =**	**3410**	**548**	**403**	**2415**	**44**

5.10 Construction support and hold points

As not all aspects of the remediation work can be rigorously documented due to the uncertainty of ground conditions, the remediation contractor will need to request clarifications and be able to make adjustments during the work, subject to approval by DMIRS.

In addition to unplanned adjustments, quality assurance (QA) and hold point measures are recommended during remediation, both to check the work and document progress. These measures and the roles and responsibilities of people referenced, should be incorporated into a contract specification.

We anticipated that the following would be required as a minimum:

- Contractor QA representative – responsible for project QA.
- Contractor quantity surveyor – responsible for quantity estimates.
- DMIRS superintendent - representing DMIRS, witnessing hold points and directing Requests for Information (RFIs).
- DMIRS appointed geotechnical consultant – responding to RFIs as requested by DMIRS.

Recommended minimum hold points are included in the Treatment descriptions in Section 5. Additional inspections may be required to respond to unforeseen conditions or events and to address controls as an outcome of risk assessments. For example, to provide professional opinion on the stability of an area or make adjustments to sinkhole hazard zones.

5.11 Post remediation inspection and maintenance

Post remediation inspection and maintenance is likely to include DMIRS inspections and potentially supplementary treatment work. We assume the inspections would be undertaken by DMIRS at a frequency they determine appropriate. As a guide, we recommend the following inspection frequency:

- Immediately following major rainfall events (as a guide greater than 60 mm in 24 hours events occur at Northampton weather station every 3.8 years on average over the past 50 years) or in their absence:
- 1 year following remediation.
- 3 years following remediation.
- 6 years following remediation.
- 10 years following remediation.

Inspections are envisaged to be visual and undertaken by people familiar with the terrain and experienced in the identification and mapping of subsidence features. Differential GPS should be used to determine the coordinates of features to within 3 m horizontally and a database of features and their attributes maintained. Preferable on a GIS platform such as ArcGIS.

In order to prepare a preliminary cost estimate that includes an allowance for such activities, we have assumed the following:

- The cost of DMIRS inspections are not included in the preliminary cost estimate.
- No additional geotechnical or other consultant studies / assessments are required.
- On two separate occasions in the 10 years following remediation, there is a need for a Contractor to attend the site and undertake Treatment A to two sinkholes (four separate sinkholes in total) which are similar in size to “Sinkhole 1” and “Sinkhole 2”.

6. References

Armstrong, K. N. (2011). The current status of bats in Western Australia. In: 'The biology and conservation of Australasian bats.' Geraldton Sandplain Bioregion (Eds B. Law, P. Eby, D. Lunney and L. Lumsden.) pp. 257–269. (Royal Zoological Society of New South Wales: Mosman)

Atlas of Living Australia (ALA) - Commonwealth Atlas of Living Australia (ALA) (managed by CSIRO)

GHD (2020). Wheal Ellen Mine Shafts and Open Pit Geotechnical Assessment and Remediation Methodology (DMIRS750620) – Geotechnical Report. September 2020.

Department of Agriculture Water and Environment (DAWE) Protected Matter Search Tool

Department of Biodiversity, Conservation and Attractions (DBCA) NatureMap database

MWH (2017). Wheal Ellen: Flora and Fauna Reconnaissance Survey. Rev 2.0, 11 May 2017.

Appendices

Appendix A – Fauna survey

Fauna survey

Approach

To assess the potential impacts on fauna from the remediation, a desktop review and limited survey was undertaken as described below. The primary purpose was to determine if bat species were occupying Main Shaft (S0113158) and Old Main Shaft (S0113145).

These shafts were selected following review of photographs and information on depth, width and structure. The review concluded that the potential for bat species roosting in the features was likely to be limited to these two shafts. On visiting the site and viewing the features, Pass No. 5 North (S0113103) was added to the list of features potential hosting bats.

Methodology

Desktop review

The purpose of the desktop review was to collate a list of bat species and other fauna that may occur within the shafts. The desktop assessment included a review of:

- Armstrong, K. N. (2011). The current status of bats in Western Australia.
- Department of Agriculture Water and Environment (DAWE 2020) Protected Matter Search Tool to identify bat species listed under the EPBC Act potentially occurring within the area
- The Department of Biodiversity, Conservation and Attractions (DBCA) NatureMap database for bat species known from or potentially occurring within the area (100 km search area)
- Atlas of Living Australia (ALA) - Commonwealth Atlas of Living Australia (ALA) to capture additional records not included in the NatureMap database (100 km search area).
- MWH Australia Pty Ltd (2017). The report incorporated a 15 km area for desktop review
- Aerial photography, geology/soils, land systems and hydrology information to provide background information on the variability of the environment and likely habitat types present
- GHD (2020). Wheal Ellen Geotechnical Report. September 2020.

Field survey

To assess the presence or absence of bat species and other fauna at S0113158 and S0113145, the following survey was undertaken from the 20 to 22 August 2020:

- Ultrasonic bat detector (Songmeter Full Spectrum (SM4 bat) Wildlife Acoustics) was placed at the entrance of features Main Shaft (S0113158) and Old Main Shaft (S0113145) with the microphone positioned to record the calls of bats during the night. On the second night the detector from S0113145 was repositioned to Pass No. 5 North (S0113103). Plate 1 displays the location of the detector at each mine shaft. The detectors were installed during the day and set to turn on at least 30 minutes before sunset and off 30 minutes after sunrise. The data recorded was downloaded to computer for analysis.
- An in situ passive infrared cameras (Reconyx Hyperfire models) was installed at feature S0113158 and S0113145 to record the movements of animals exiting or entering the mine shaft. On the second night the camera set at S0113145 was repositioned to S0113103. Plate 1 displays the location of the camera at each mine shaft. The cameras operated from late afternoon through early morning recording still pictures. The data recorded by the cameras was downloaded to computer for analysis.

Table C-1 Summary of field survey effort

Method	S0113158	S0113145	S0113103
Bat detector	On: 20/8/2020 4:10 pm Off: 21/8/2020 7:45 am On: 21/8/2020 3:35 pm Off: 22/8/2020 8:00 am = 2 detector nights	On: 20/8/2020 4:20 pm Off: 21/8/2020 7:50 am = 1 detector night	On: 21/8/2020 4:36 pm Off: 22/8/2020 8:17 am = 1 detector night
Camera	On: 20/8/2020 4:10 pm Off: 21/8/2020 7:45 am On: 21/8/2020 3:37 pm Off: 22/8/2020 8:00 am = 2 camera nights	On: 20/8/2020 4:20 pm Off: 21/8/2020 7:50 am = 1 camera night	On: 21/8/2020 4:40 pm Off: 22/8/2020 8:17 am = 1 camera night

Plate 1 Bat detector and camera set ups

Bat call analysis

Call identification was assisted by consulting distribution information for potential species (Armstrong 2011) and records from NatureMap. No reference calls were collected.

Data was processed and analysed using a combination of manual review and automated processes using Kaleidoscope Pro (Wildlife Acoustic, version 5.3.6).

Files were downloaded from the units and saved to a laptop hard drive (back up copy) for processing and analysis. For each night, data was manually reviewed using Kaleidoscope Pro viewer. During the manual process, calls were analysed by visually comparing the time-frequency graph and call characteristics (e.g. peak frequency, characteristic frequency and call shape) with species call descriptions from published guidelines.

A call (pass) was defined as a sequence of three or more consecutive pulses of similar frequency and shape. Calls with less than three defined consecutive pulses of similar frequency and shape were not attributed to a species.

Summary of results

Desktop review results

The MWH desktop study identified a total of 285 species of vertebrate fauna, which have been recorded and/or have the potential to occur within the study area (MWH 2017). This total comprises 12 native mammal, 4 introduced mammal, 224 native bird, one introduced bird, 35 reptiles and 9 amphibian species. Of the 12 native mammals only one bat (*Austronomus australis*) was recorded for the study area. A summary of the bat species that may occur within the study area is provided in Table C-2.

Table C-2 Bats species known from the study area (desktop review)

Species name	Armstrong (2011)	NatureMap (DBCA 2020)	MWH (2017)	Conservation status
Austronomus australis	Y	Y	Y	
Chaerephon jobensis	-	Y	-	
Chalinolobus gouldii	Y	Y	-	
Chalinolobus morio	Y	Y	-	
Macroderma gigas		Y	-	Vulnerable EPBC Act and BC Act
Nyctophilus geoffroyi	Y	Y	-	
Ozimops kitcheneri (Mormopterus sp. 4)	Y	Y	-	
Ozimops lumsdenae (Mormopterus beaccarii)	-	Y	-	
Ozimops petersi (Mormopterus sp. 3)	Y	-	-	
Scotorepens balstoni	Y	Y	-	
Scotorepens greyii	-	Y	-	
Taphozous georgianus	-	Y	-	
Taphozous hilli	-	Y	-	
Vespadelus baverstocki	-	Y	-	
Vespadelus caurinus	-	Y	-	
Vespadelus finlaysoni	Y	Y	-	
Vespadelus regulus	-	Y	-	

Conservation status notes: EPBC Act – *Environment Protection and Biodiversity Conservation Act 1999* and/or BC Act - *Biodiversity Conservation Act 2016.*

Field survey results - camera analysis

Two species of fauna were recorded at S0113158 including Western Grey Kangaroo, *Macropus fuliginosus* and Common Brushtail Possum, *Trichosurus vulpecula* (see Plate 2 and 3). The Common Brushtail Possum is known to occupy artificial structures and it is possible that the mother and young use ledges / cross-braces in the shaft for daytime refuge.

Plate 2 Reconyx camera at S0113158 displaying two Western Grey Kangaroo

Plate 3 Reconyx camera at S0113158 displaying a female Common Brushtail Possum carrying young

Field survey results – bat call analysis

Approximately 222 full spectrum WAV files were analysed (all sites and all nights combined) of which approximately 57% (n = 127) contained a bat call of some description. Five species were positively identified of the 16 or so species that are known to occur in the area. Two other species may also have been recorded, but poor data quality and/or interspecific call similarities precluded reliable identification. Table C-3 provides a list of species recorded for each night. Table C-4 provides a summary of the first and last calls recorded for each night of the detector survey at each site.

No threatened species listed under the *Biodiversity Conservation Act 2016* and *Environment Protection and Biodiversity Conservation Act 1999* were recorded as a result of call analysis.

Table C-3 Summary of species recorded at each site using bat detectors

Species name	SM4 6 S0113158	SM4 5 S0113145	SM4 5 S0113130	Roost habitat preference
Austronomus australis	Yes	Yes	Yes	Hollow-bearing trees. Unlikely to use mine shafts
Chalinolobus gouldii	Yes	Yes	Yes	Hollow-bearing trees. Known to use human structures, although no evidence found regarding use of mine shafts
Chalinolobus morio	Yes	Yes	Yes	Hollow-bearing trees. Unlikely to use mine shafts
Nyctophilus geoffroyi	-	Yes	Probable	Hollow-bearing trees. Unlikely to use mine shafts
Ozimops species kitcheneri/ lumsdenae/petersi	Probable	Probable	Probable	Hollow-bearing trees. Some ozimops species known to use human structures, although no evidence found regarding use of mine shafts
Saccolaimus flaviventris	-	-	Probable	Hollow-bearing trees. Known to use human structures, although no evidence found regarding use of mine shafts
Vespadelus species	Probable	Probable	Probable	Hollow-bearing trees. Some Vespadelus species known to use human structures, although no evidence found regarding use of mine shafts
Vespadelus regulus	Yes	Yes	Yes	Hollow-bearing trees. Known to use human structures, although no evidence found regarding use of mine shafts

Table notes:

Roost habitat preference taken from Churchill, S (2008). Australian Bats, Allen and Unwin, Australia and species profiles from Wikipedia.

Yes = species identification not in doubt.

Probable = Call most likely to represent a particular species, but there exists a low probability of confusion with species of similar call type or call lacks sufficient detail.

Table C-4 Summary of first and last call times and number of calls near sunset and sunrise

Site / date	Species	Time of first call	Sunset time	Time of last call	Sunrise time	Bat call pattern notes
S0113158 20/8 – 21/8	V. regulus	6:23 pm	6:01 pm	6:07 am	6:48 am	Few calls (< 5) recorded within 30 mins of sunset and none within 30 mins sunrise
S0113158 21/8 – 22/8	A. australis/ C. gouldii and A australis/ C. gouldii	6:26 pm	6:01 pm	5:15 am	6:48 am	Few calls (< 5) recorded within 30 mins of sunset and none within 30 mins sunrise
S0113145 20/8 – 21/8	A. australis and Vespadelus sp.	6:28 pm	6:01 pm	5:56 am	6:48 am	Few calls (< 10) recorded within 30 mins of sunset and none within 30 mins sunrise
S0113103 21/8 – 22/8	A. australis/ V. regulus and A. australis	6:30 pm	6:01 pm	5:57 am	6:48 am	Few calls (< 5) recorded within 30 mins of sunset and none within 30 mins sunrise

Table notes: Sunset and sunrise times from:
https://www.timeanddate.com/sun/australia/geraldton?month=8&year=2020

Fauna survey discussion

The purpose of the fauna survey was to determine if fauna, particularly bat species were occupying the Main Shaft (S0113158) and Old Main Shaft (S0113145) during the time of the survey. Following a review of the survey results, site photographs and the geotechnical report (GHD 2020) the following conclusions apply:

- It is unlikely that any of the three shafts were used as a day time roost by any microbat species during the survey. Whilst it cannot be ruled out that one or two individuals may have occupied the shafts, it is highly unlikely that a colony (e.g. large number of bats of one or more species) was occupying any of the shafts during the survey. The timing and low frequency of calls near the sunset and sunrise periods (e.g. few calls were recorded near sunset or sunrise) suggest that few if any bats exited the shafts during the typical emergence and re-entry period. Furthermore the bat species recorded using the bat detectors have a preference for cavities/hollows within trees and not caves or cave like structures (e.g. mine shafts). However, some of these species are known to use human structures and there is a small possibility that a few individuals could occasionally use shafts.
- The Main Shaft S0113158 is vertical and greater than 60.5 m deep, however water depth in the shaft was at 5.9 m. Given the water depth there is little area available for roosting bats and other fauna. The vertical structure and sheer sided walls also limits or prevents the ability of other fauna species occupying the shaft. A camera recorded a Common Brushtail Possum near this shaft and it is possible that it may use small cavities within the wall of the shaft for daytime refuge. Some other fauna species (e.g. reptiles) may reside in the timbers and soil pile at the surface of the shaft.

- The Old Main Shaft S0113145 is vertical and mostly backfilled / collapsed to 3.2 m depth, and a water depth of 3.1 m. Given the water depth and partially collapsed structure there is little area available for roosting bats and other fauna. Some fauna (e.g. reptiles) may reside in the soil pile at the surface around the shaft.
- Feature S0113103 is a pass and not a vertical shaft. Although reported to be 30 m deep with the possibility of deeper voids, it has collapsed or been filled to a depth not exceeding 4.5 m from the surface. The opening appears to be less than 1 m x 1 m which limits access for fauna including bats. Given the partially collapsed nature and small opening there is little area available for roosting bats and other fauna.

The above features were considered the most likely roosting locations for threatened bat species. As such, bats roosting in other features is not anticipated.

Appendix B – Figures

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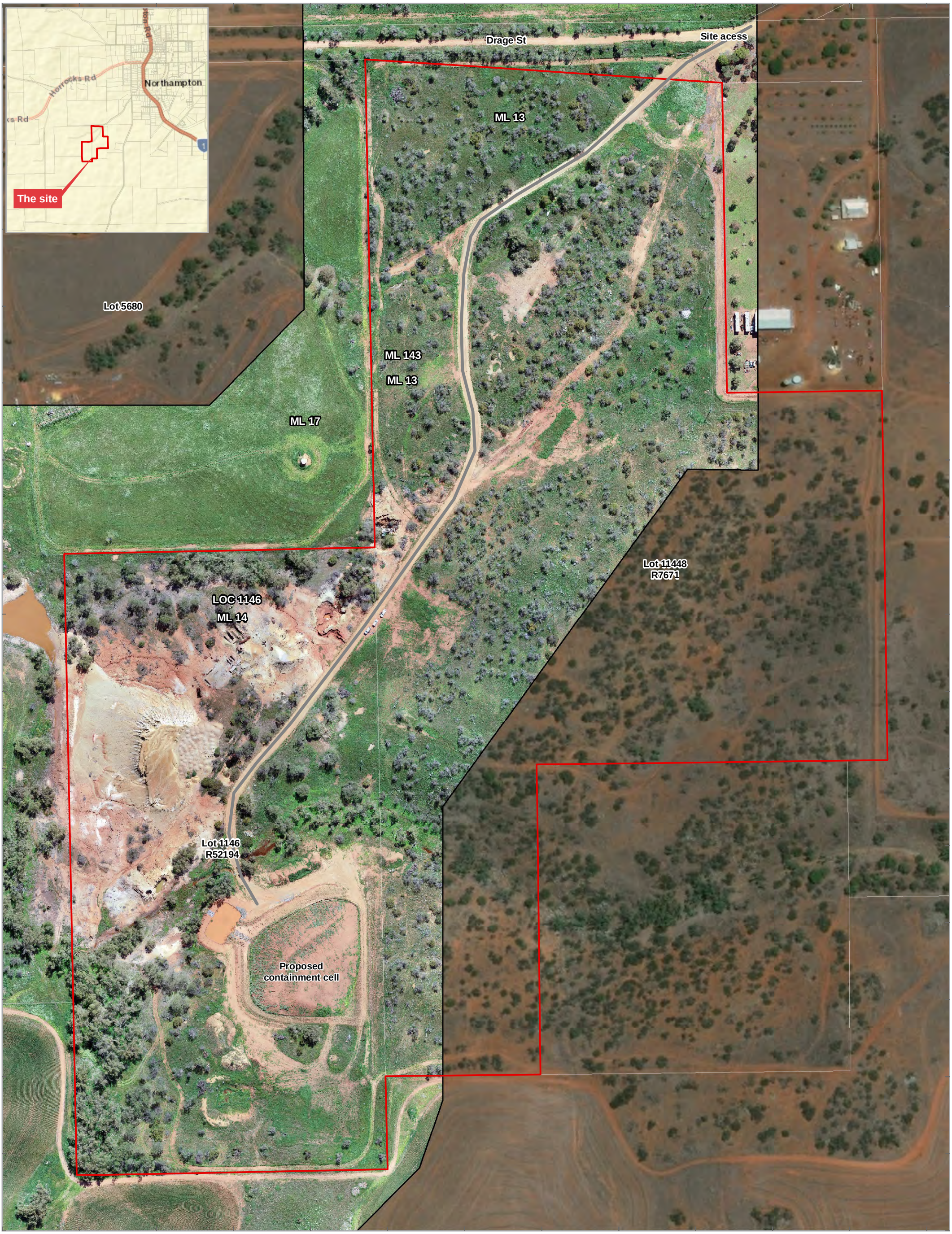

Legend

- Site boundary
- Cadastre
- Main access track
- MineLiDAR imagery capture extent (Aug 2020); Outside areas are old imagery (Oct 2019)
- Indicative mining lease areas are labelled

Paper Size ISO A3

50 100

Meters

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 50

N

GHD

DMIRS
Wheal Ellen Mine Shafts
and Open Pits Remediation

Site Location

Project No. 12535209
Revision No.
Date 24/09/2020

FIGURE 1

N:\AU\Newcastle\Projects\22\12535209\GIS\Maps\Deliverables\Remediation\12535209_Z007_SiteLocationPlan.mxd
Print date: 24 Sep 2020 - 12:02

Data source: Site boundary, GHD 2020; Mining Leases, DMIRS 2020; Cadastre, LANDGATE 2020; Aerial imagery - MineLiDAR 2020; Basemap Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User Community. Created by: lmanasan

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Site access
Sinkhole1
S0113127
S0113128
S0113114
S0113122
Depression1
S0113111
Sinkhole2
Depression2
Unnamed pass3
S0113103
S0113163
S0113151
S0113149
Unnamed pass4
S0113097
Stockpile 10
S0113147
S0113158
Pass 1 North
Stockpile 9
S0113130
Waste tailings "dump"
S0113141
Wheal Ellen Creek South
Wheal Ellen Creek East
Stockpile 6
Stockpile 1
Stockpile 7
Stockpile 2
Stockpile 8
S0113143
S0113145
Containment cell
Old Workings Pass
Old Workings Shaft
Stockpile 5
Stockpile 4
Stockpile 3

Notes

Mine feature locations adjusted from DMIRS database based on desktop review and MineLiDAR survey. Mine Photogrammetry basemap provided by MineLiDAR.

Legend

- Site boundary
- Surface extent
- Stockpile locations
- Main access track
- Watercourse
- MineLiDAR imagery capture extent (2020); Outside areas are old imagery (Oct 2019)

Paper Size ISO A3

0 50 100

Meters

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 50

N

GHD

DMIRS
Wheal Ellen Mine Shafts
and Open Pits Remediation

Feature Locations,
Stockpiles, and Watercourses

Project No. 12535209
Revision No.
Date 24/09/2020

FIGURE 2

N:\AU\Newcastle\Projects\22\12535209\GIS\Maps\Deliverables\Remediation\12535209_Z008_StockpileLocations.mxd
Print date: 24 Sep 2020 - 16:41

Data source: Site boundary, main access track, stockpile, watercourse - GHD 2020; Aerial imagery - MineLiDAR 2020; Basemap Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community. Created by: lmanasan

266396 266496 266596 266696 266796 266896 266996

6860180
6860080
6859980
6859880
6859780
6859680
6859580
6859480

C1 D1 C2 C3 D2 D3 C4 D4 D5

Wheal Ellen Creek South

Wheal Ellen Creek East

Notes

Mine Photogrammetry basemap provided by MineLiDAR.

Legend

- Site boundary
- Regrade fill area
- Access road risk mitigation area
- Culvert/causeway upgrade/construction
- Shallow open drain
- Main access track
- Watercourse
- MineLiDAR imagery capture extent (2020); Outside areas are old imagery (Oct 2019)

Paper Size ISO A3

0 50 100

Meters

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 50

N

GHD

DMIRS
Wheal Ellen Mine Shafts
and Open Pits Remediation

Recommended regrade areas
and drainage improvements

Project No. 12535209
Revision No.
Date 13/10/2020

FIGURE 3

N:\AU\Newcastle\Projects\22\12535209\GIS\Maps\Deliverables\Remediation\12535209_Z009_DrainageandRegrade.mxd
Print date: 13 Oct 2020 - 09:33

Data source: Site boundary, main access track, regrade, drainage, culvert, road access, watercourse - GHD 2020; Aerial imagery - MineLiDAR 2020; Basemap Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community. Created by: Imanasan

Legend

- Regrade fill area
- Surface extent
- Contour - 1m interval
- Contour - 0.25m interval
- Watercourse

Paper Size ISO A3

0 5 10

Meters

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 50

N

DMIRS
Wheal Ellen Mine Shafts
and Open Pits Remediation

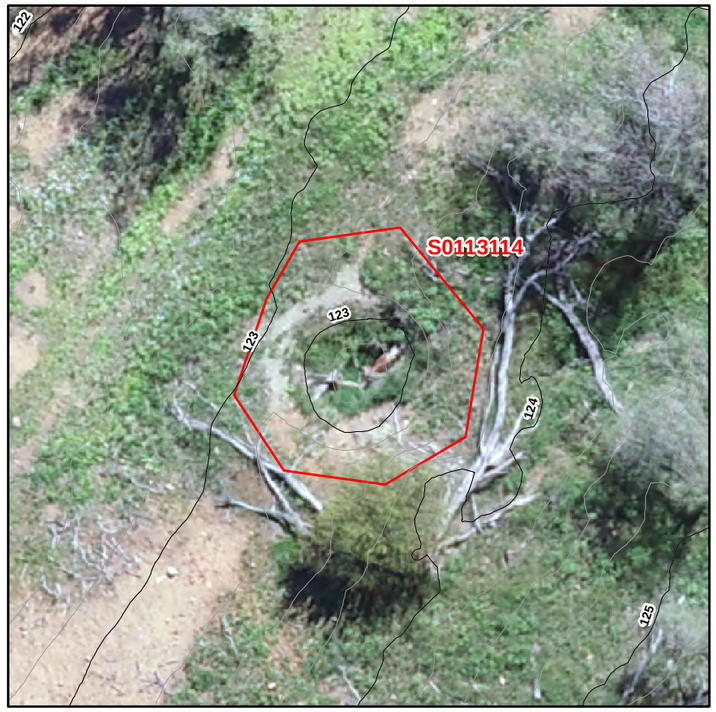
Regrade area inset

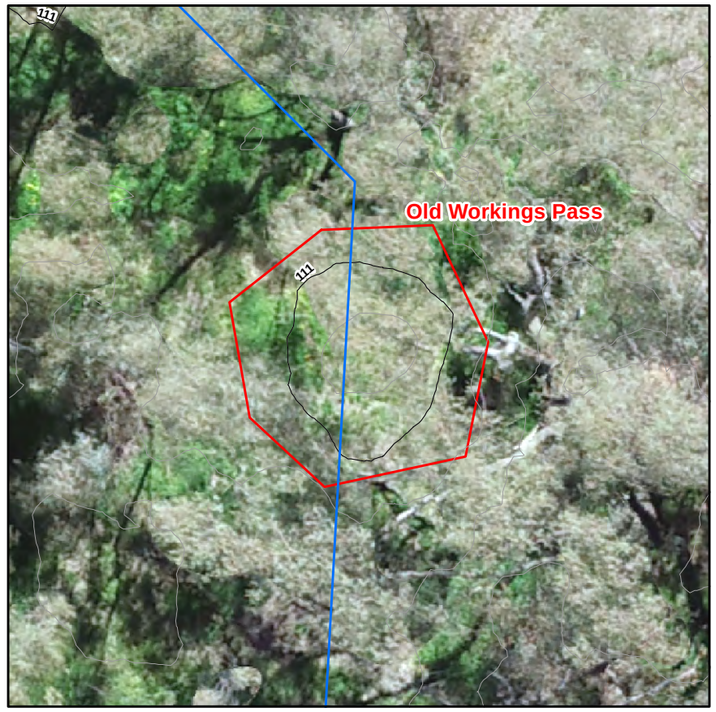
Project No. 12535209
Revision No.
Date 13/10/2020

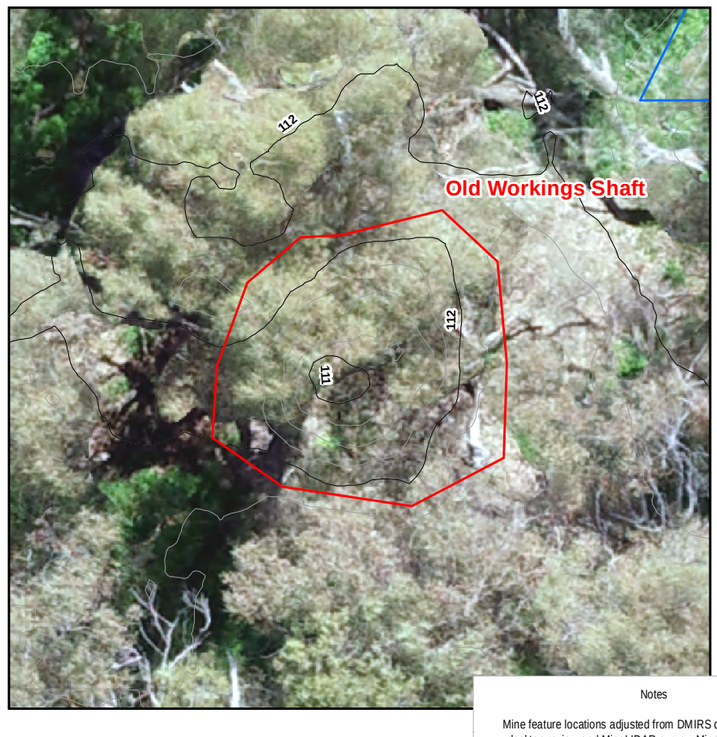
FIGURE 3a

N:\AU\Newcastle\Projects\22\12535209\GIS\Maps\Deliverables\Remediation\12535209_Z009A_RegradeArea.mxd
Print date: 13 Oct 2020 - 10:00

Data source: Main access track, regrade area, watercourse, contour - GHD 2020; Aerial imagery - MineLiDAR 2020; Basemap . Created by: lmanasan







Notes

Mine feature locations adjusted from DMIRS database based on desktop review and MineLiDAR survey. Mine Photogrammetry basemap provided by MineLiDAR.

Legend

- Surface extent
- Contour - 1m interval
- Contour - 0.25m interval
- Watercourse

Paper Size ISO A3

0 2 4

Meters

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 50

N

GHD

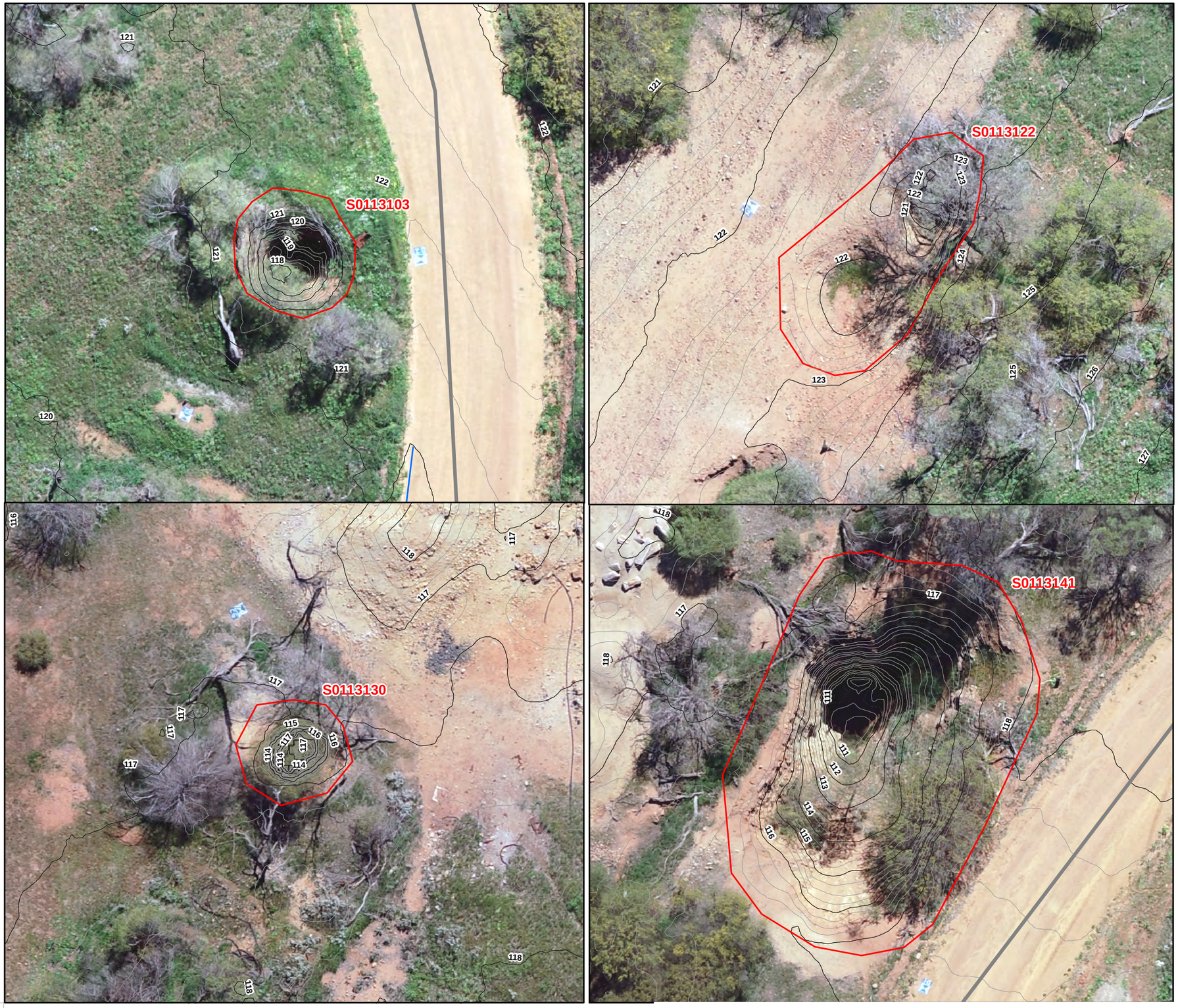
DMIRS
Wheal Ellen Mine Shafts and Open Pits Remediation
Treatment A: S0113114, S0113163 S0113111, S0113143, Old Workings Pass, and Old Workings Shaft

Project No. 12535209
Revision No.
Date 24/09/2020

FIGURE 4

N:\AU\Newcastle\Projects\22\12535209\GIS\Maps\Deliverables\Remediation\12535209_Z010_SurfaceFeatures.mxd
Print date: 24 Sep 2020 - 15:01

Data source: Surface extent, main access track, watercourse, contour - GHD 2020; Aerial imagery - MineLiDAR 2020; Basemap . Created by: Imanasan



Legend

- Surface extent
- Contour - 1m interval
- Contour - 0.25m interval
- Main access track
- Watercourse

Notes

Mine feature locations adjusted from DMIRS database based on desktop review and MineLiDAR survey. Mine Photogrammetry basemap provided by MineLiDAR.

Paper Size ISO A3

0 2 4

Meters

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 50

N

DMIRS
Wheal Ellen Mine Shafts
and Open Pits Remediation

Treatment B: S0113122,
S0113103, S0113130, S0113141

Project No. 12535209
Revision No.
Date 24/09/2020

FIGURE 5

N:\AU\Newcastle\Projects\22\12535209\GIS\Maps\Deliverables\Remediation\12535209_Z011_SurfaceFeatures2.mxd
Print date: 24 Sep 2020 - 14:41

Data source: Surface extent, main access track, watercourse, contour - GHD 2020; Aerial imagery - MineLiDAR 2020; Basemap . Created by: lmanasan

Paper Size ISO A3

0 2 4

Meters

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 50

N

DMIRS
Wheal Ellen Mine Shafts
and Open Pits Remediation

Treatment B: S0113151

Project No. 12535209
Revision No.
Date 24/09/2020

FIGURE 6

N:\AU\Newcastle\Projects\22\12535209\GIS\Maps\Deliverables\Remediation\12535209_2012_SurfaceFeatures3.mxd
Print date: 24 Sep 2020 - 14:22

Data source: Surface extent, main access track, watercourse, contour - GHD 2020; Aerial imagery - MineLiDAR 2020; . Created by: lmanasan

Legend

- Surface extent
- Contour - 1m interval
- Contour - 0.25m interval
- Main access track
- Watercourse

S0113097

S0113149

Unnamed pass4

Notes

Mine feature locations adjusted from DMIRS database based on desktop review and MineLiDAR survey. Mine Photogrammetry basemap provided by MineLiDAR.

Paper Size ISO A3

0 2 4

Meters

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 50

N

GHD

DMIRS
Wheal Ellen Mine Shafts
and Open Pits Remediation

Treatment B: S0113097, S0113149

Project No. 12535209
Revision No.
Date 24/09/2020

FIGURE 7

N:\AU\Newcastle\Projects\22\12535209\GIS\Maps\Deliverables\Remediation\12535209_Z013_SurfaceFeatures4.mxd
Print date: 24 Sep 2020 - 14:21

Data source: Surface extent, main access track, watercourse, contour - GHD 2020; Aerial imagery - MineLiDAR 2020; . Created by: lmanasan

Paper Size ISO A3

0 2 4

Meters

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 50

N

GHD

DMIRS
Wheal Ellen Mine Shafts
and Open Pits Remediation

Treatment C: S0113147

Project No. 12535209
Revision No.
Date 24/09/2020

FIGURE 8

N:\AU\Newcastle\Projects\22\12535209\GIS\Maps\Deliverables\Remediation\12535209_2014_SurfaceFeatures5.mxd
Print date: 24 Sep 2020 - 14:11

Data source: Surface extent, main access track, watercourse, contour - GHD 2020; Aerial imagery - MineLiDAR 2020; . Created by: lmanasan

Legend
- Surface extent
- Contour - 1m interval
- Contour - 0.25m interval
- Watercourse
- Profile A-A'

S0113145

A

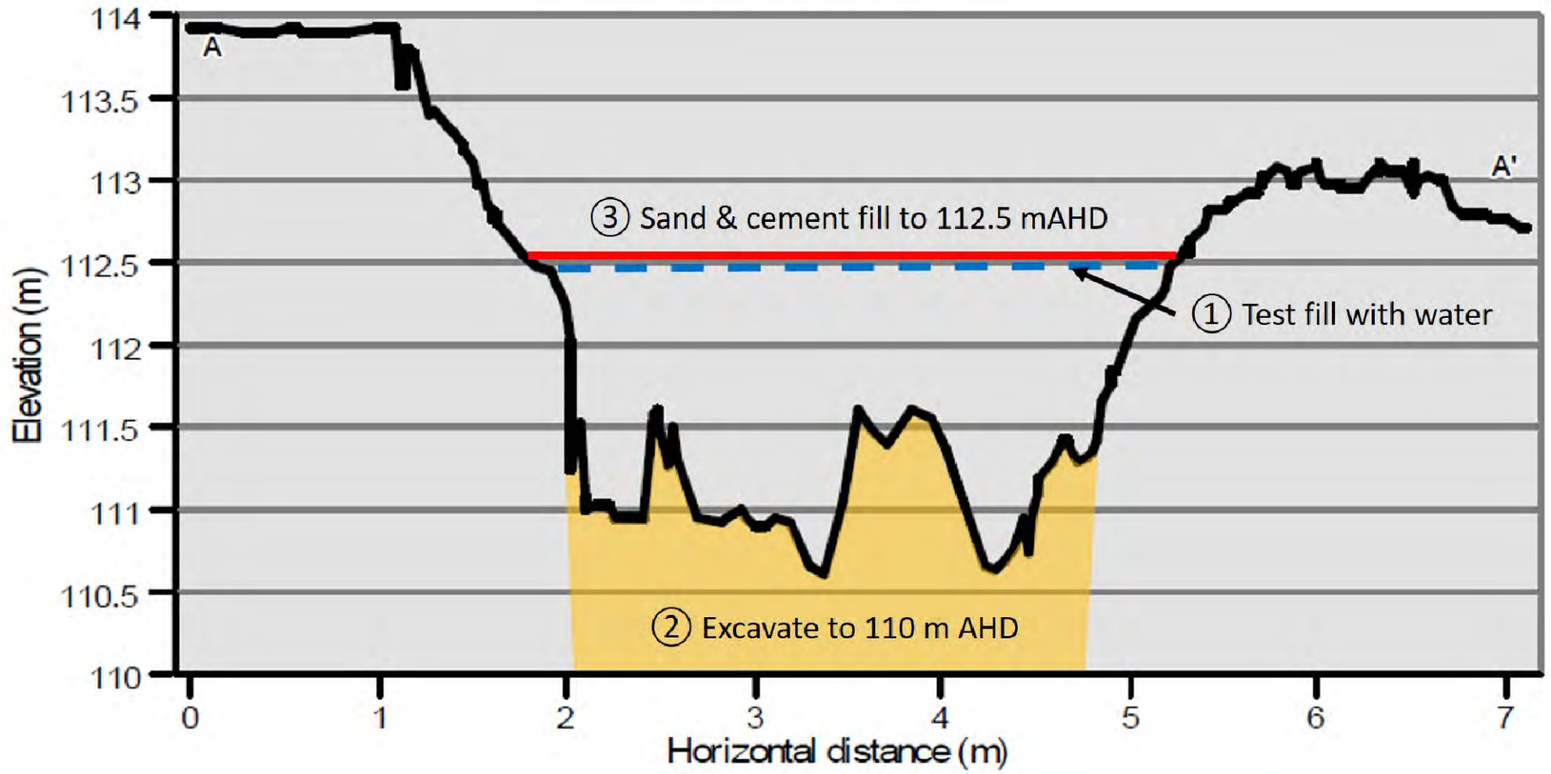
A'

112

111

113

NOTE HORIZONTAL EXAGGERATION



Notes

Mine feature locations adjusted from DMIRS database based on desktop review and MineLiDAR survey. Mine Photogrammetry basemap provided by MineLiDAR.

Paper Size ISO A3

0 0.5 1

Meters

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 50

N

GHD

DMIRS
Wheal Ellen Mine Shafts
and Open Pits Remediation

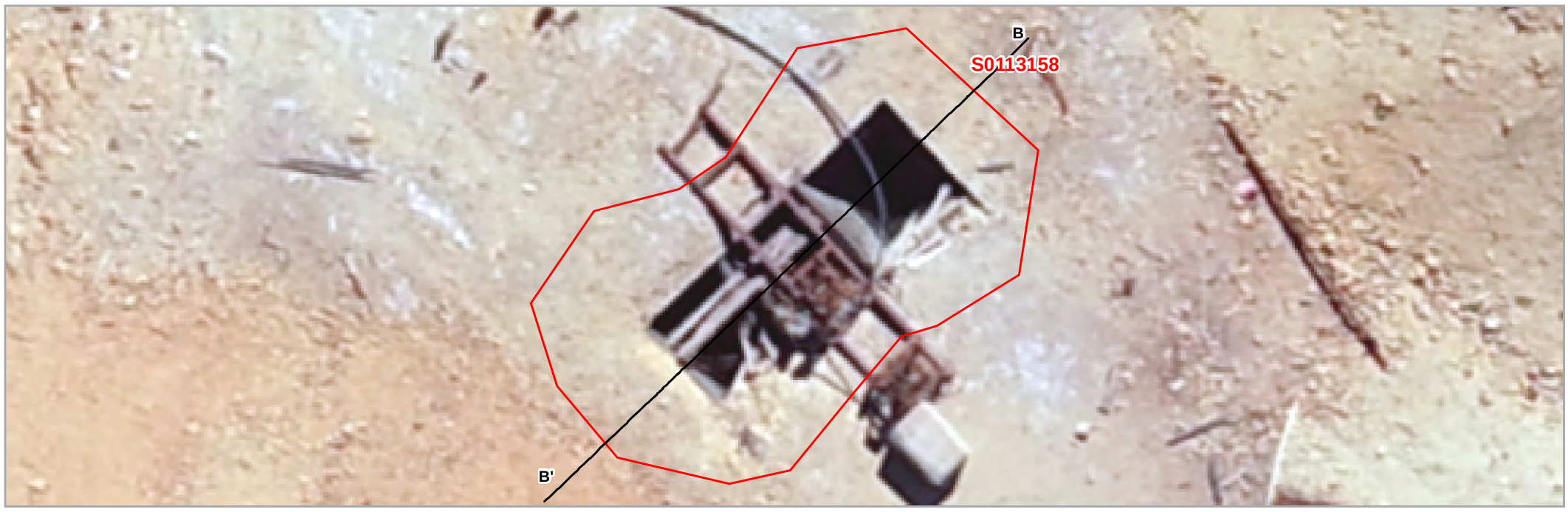
Treatment D: S0113145

Project No. 12535209
Revision No.
Date 25/09/2020

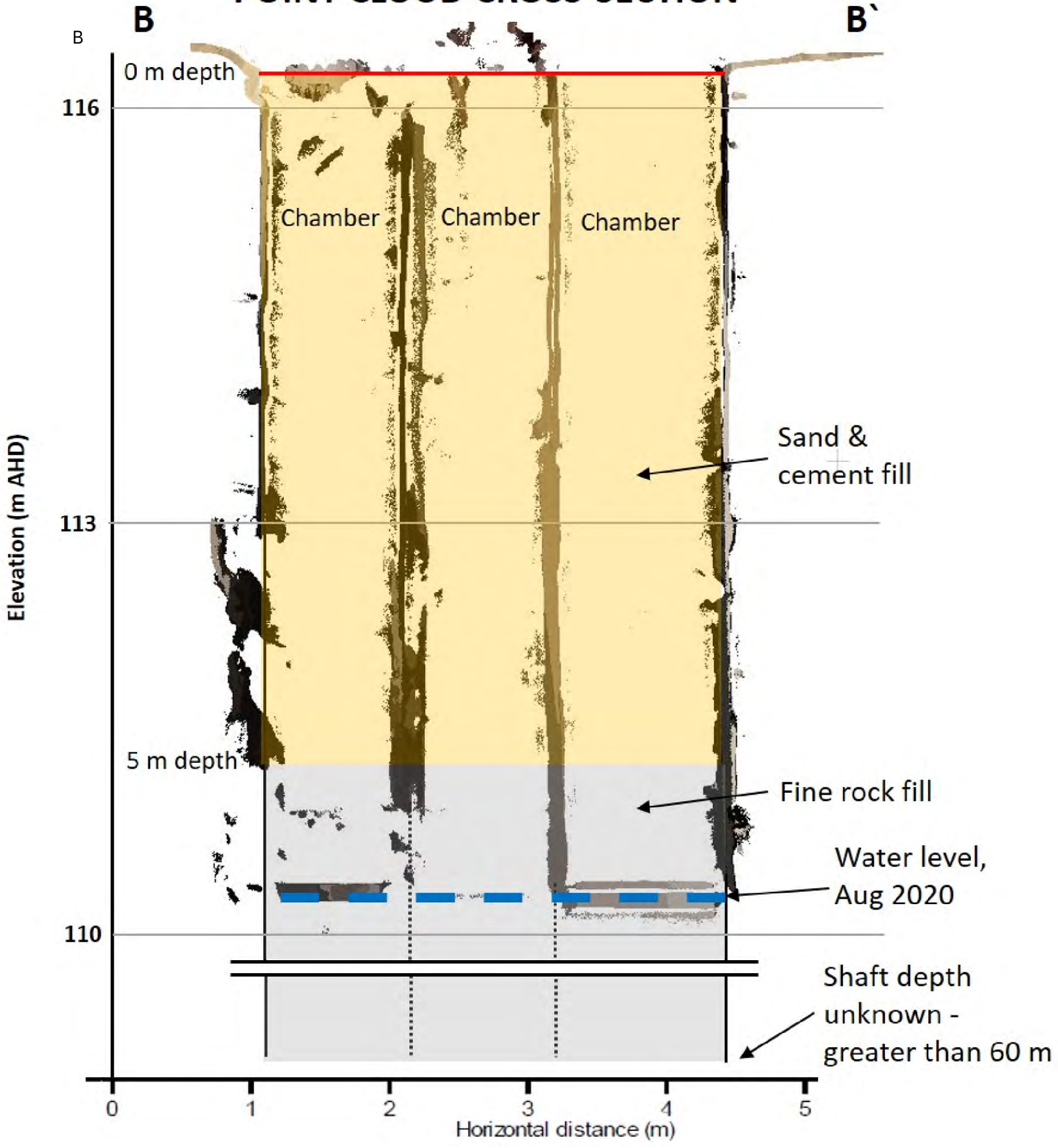
FIGURE 9

N:\AU\Newcastle\Projects\22\12535209\GIS\Maps\Deliverables\Remediation\12535209_Z015_SurfaceFeatures6.mxd
Print date: 25 Sep 2020 - 16:30

Data source: Surface extent, watercourse, contour - GHD 2020; Aerial imagery - MineLiDAR 2020; . Created by: lmanasan



POINT CLOUD CROSS-SECTION



Legend

- Surface extent
- Profile B-B'

Notes

Mine feature locations adjusted from DMIRS database based on desktop review and MineLIDAR survey. Mine Photogrammetry basemap provided by MineLiDAR.

Paper Size ISO A3

0 0.5 1

Meters

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 50

N

DMIRS
Wheal Ellen Mine Shafts
and Open Pits Remediation

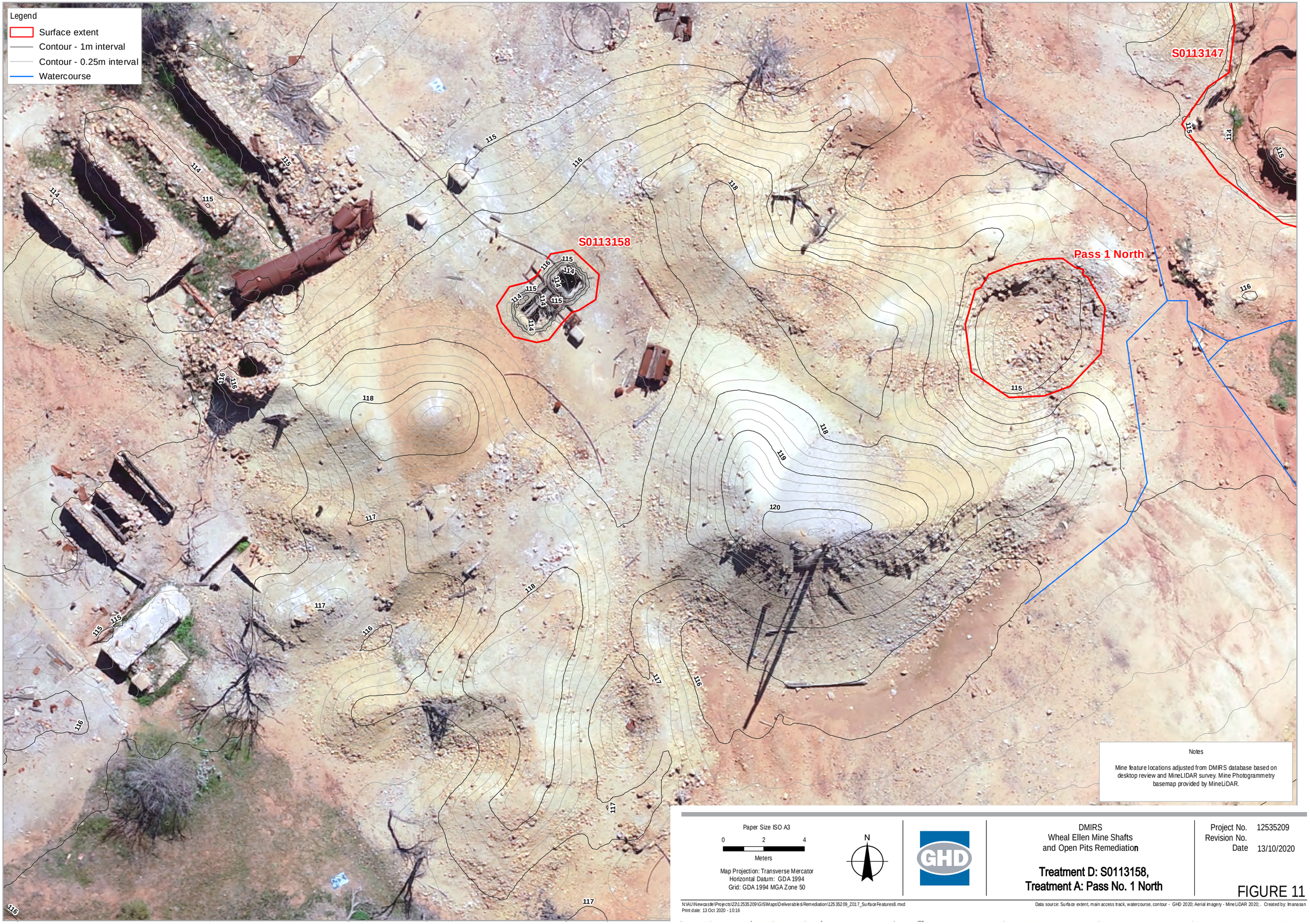
Treatment D: S0113158

Project No. 12535209
Revision No.
Date 25/09/2020

FIGURE 10

N:\AU\Newcastle\Projects\22\12535209\GIS\Maps\Deliverables\Remediation\12535209_Z016_SurfaceFeatures7.mxd
Print date: 25 Sep 2020 - 16:29

Data source: Surface extent, GHD 2020; Aerial imagery - MineLiDAR 2020; . Created by: Imanasan



Paper Size ISO A3

0 2 4

Meters

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 50

N

DMIRS
Wheal Ellen Mine Shafts
and Open Pits Remediation

Treatment D: S0113158,
Treatment A: Pass No. 1 North

Project No. 12535209
Revision No.
Date 13/10/2020

FIGURE 11

N:\AU\Newcastle\Projects\22\12535209\GIS\Maps\Deliverables\Remediation\12535209_2017_SurfaceFeatures8.mxd
Print date: 13 Oct 2020 - 10:16

Data source: Surface extent, main access track, watercourse, contour - GHD 2020; Aerial imagery - MineLiDAR 2020; . Created by: lmanasan

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12535209-81785-32/https://projectsportal.ghd.com/sites/pp01_01/whealellenmineshafts/ProjectDocs/12535209_REP-Wheal Ellen Remediation Report.docx

Document Status

Revision	Author	Reviewer		Approved for Issue		
		Name	Signature	Name	Signature	Date
0	S.Mackenzie	A Jennings		A Jennings		27/10/2020

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