Design of the Days Creek Domain

Stage 1 of the progressive remediation of the Brukunga Mine Site

November 2015
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Brukunga Technical Advisory Group

Government of South Australia
Department of State Development

Detailed design of the Days Creek domain – Stage 1 of the progressive remediation of the Brukunga Mine Site

Report prepared by the
Brukunga Mine Remediation Program –
Technical Advisory Group (TAG) for
South Australian Department of
State Development (DSD)

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CONTENTS

TABLES

FIGURES

ABBREVIATIONS

AMD	Acid and metalliferous drainage
AHD	Australian Height Datum
bgl	below ground level
DSD	Department of State Development South Australia
DMITRE	Department of Manufacturing, Innovation, Treade, Resources and Energy
TAG	Technical Advisory Group
TSF	Tailings storage facility
WRD (N,S)	Waste rock dump (North, South)
WTP	Water treatment plant

FOREWORD

This report was commissioned by the Department of State Development and written by the Brukunga Mine Remediation Program – Technical Advisory Group (TAG).

The purpose of the report is to set out the basis and design of the first stage of the progressive remediation of the Brukunga Mine Site, known as the Days Creek domain. The remediation design was developed in the preceeding TAG reports - *Development and Assessment of Remediation Options for the Brukunga Remediation Project 31 October 2008 (Phase 1)* and *Validating the Technical Feasibility of a Saturated Waste Remediation Option (Phase 2).*

EXECUTIVE SUMMARY

This report sets out the basis and designs for the first stage of the progressive remediation of the Brukunga Mine Site. The first stage comprises remediation of Days Creek domain. This report has been prepared by the Brukunga Mine site Technical Advisory Group (TAG) for the South Australian Department of State Development (DSD).

Brukunga Mine site and background to report

The Brukunga mine site is located 40 km east of Adelaide in the Mt Lofty Ranges. Iron sulphide minerals (pyrite and pyrrhotite) were mined by open pit methods at Brukunga between 1955 and 1972. Waste rock produced during the operation of the mine was stockpiled in waste rock dumps (WRDs) and tailings were placed in a tailings storage facility (TSF) on site. Oxidation of sulfidic material in the waste rock dumps, the TSF and the mine bench and highwall left after mining has resulted in acidic drainage (pH <3) in the form of seepage and runoff. The acidic drainage contains elevated concentrations of sulfate and dissolved metals. This phenomenon is commonly referred to in the mining industry as acid and metalliferous drainage (AMD).

The South Australian (SA) Government took responsibility for the site in 1977. A low density sludge, lime-based water treatment plant (WTP) was commissioned in September 1980 to treat the acidic drainage and improve water quality in Dawesley Creek, which runs through the mine site. The site has been managed by Primary Industries and Resources, South Australia (PIRSA) (subsequently DMITRE and DSD) since 1998, after taking over from SA Water.

Objectives for the remediation of the Brukunga Mine site have been developed by the TAG in association with departmental representatives and with consideration of the Environment Act (1993). The agreed objectives for the remediation of the site are to:

- substantially limit or avoid the need for indefinite interception and treatment of AMD;
- provide water quality in Dawesley Creek downstream of the Brukunga Mine site that is suitable for domestic (excluding human consumption), stock and primary production purposes, and which complies with the EPA Water Quality Policy;
- return all or part of the site to productive use or for environmental ecosystem values; and
- apply leading practice to site management and the remediation options and solutions.

Through investigations undertaken to date, the TAG identified that the co-disposal of sulfidic waste rock and tailings maintained under saturated conditions behind a series of three impoundment walls within three catchments at the site could fulfil these objectives. It was estimated that the application of this approach to the full remediation of the site would cost an estimated $120 million.

The cost of the full project implementation and the innovative nature of the proposed remediation strategy led to the development of a staged remediation program for the site. The TAG identified that the installation of one impoundment in the upper catchment, the Days Creek catchment (known as the Days Creek domain), would permit partial remediation of the site and would provide a definitive assessment of the performance of the proposed saturated co-disposal technique. The Department accepted the proposal and agreed to proceed with a detailed evaluation and costing for remediation of the Days Creek domain of the Brukunga Remediation Project. This report sets out the approach to and outcomes from that detailed evaluation, design and costing.

Days Creek domain

A set of objectives was developed by the TAG in association with departmental staff, for the Days Creek project. It is proposed that remediation of Days Creek domain will:

- commence the progressive remediation of waste rock and tailings at the Brukunga Mine site by co-disposal of about 800,000 m^3 of AMD generating materials;
- demonstrate the feasibility of the saturated co-disposal strategy so that it can be implemented with confidence over the entire site;

- generate improvements in the water quality of Days Creek downstream of the mine pits;
- preserve water quality from upstream in Days Creek through clean water diversion, and thereby:
  - increase clean water flows to and downstream of the Dawesley Creek diversion, and
  - decrease the hydraulic load on the acidic water storage-pump back system, and water treatment plant; and
- create a self-sustaining landscape with manageable human health and safety, and environmental risks over the remediated lands.

The Days Creek Domain remediation provides for the saturated co-disposal of sulfidic waste material with limestone in an impoundment within the disused mine pits. The sulfidic material includes both waste rock from the adjoining waste rock dumps and tailings from the TSF. The impoundment within which the co-disposed material will be placed will be created through the construction of low permeability embankments across the Days Creek valley and around the perimeter of the co-disposed wastes. Realignment of Days Creek will enable the embankment construction and will protect the cover system overlying the co-disposed material from stream-related erosion. Material won from the diversion works will be used in the construction of the proposed embankment.

It is proposed that the impoundment have:
- a robust, high infiltration cover to maximise the inflow of rainfall into the co-disposed material, and
- seepage control to limit the loss of water from the co-disposed material.

Both the high infiltration cover and the seepage control are aimed at maintaining saturation of the co-disposed material. A lateral overflow zone will be provided between the cover and the co-disposed material to drain surplus clean infiltrated water into the realigned Days Creek and to ensure that water contained in the co-disposed material does not come into contact with the revegetation or ponded clean water on the cover system. Some grouting of the bedrock underlying the embankments and the impoundment will be required. The grouting will serve to limit the seepage of water from the co-disposed material to local groundwater. The extent of the final grouting will be determined during the construction phase and will depend on the competency of the bedrock locally. All waste rock from the area of the Northern Waste Rock Dump, where runoff currently discharges to Days Creek, will be disposed into the impoundment. This will enable a return of the land surface as far as practicable to the natural surface elevations, and improvement of the water quality of Days Creek. All disturbed and remediated lands, including the waste rock dumps, the cover for the impoundment, the embankment and the TSF will be rehabilitated and revegetated using appropriate native vegetation.

The proposed construction works include the containment and management of surface runoff and appropriate dust and noise control. An ongoing management and monitoring program is proposed for the site to provide the best chance of success and to assess the outcomes from the works, informing the progressive remediation of the site.

Project benefits and key facts

The benefits of the Days Creek Domain remediation include the effective and progressive remediation of the site and the demonstration of the saturated co-disposal technique.

The project provides for the diversion of Days Creek away from its current course and its associated contamination from stockpiled waste rock. The project will not only improve water quality in Days Creek but will also provide for the discharge of this clean water into the diverted alignment of Dawesley Creek. As a consequence, Days Creek flows will no longer be passed through the existing water treatment plant. This design will result in both:

- increased hydraulic capacity of the treatment plant to treat peak flow events from the site, resulting in less contaminated water bypassing the treatment plant, and
- increased dilution of treated runoff from the site with clean water from the Days Creek catchment.

Improvements in downstream water quality would be expected as a result of the increased capacity of the existing treatment plant to treat contaminated water from the site and the dilution of discharges from the treatment plant.

The integration of the diversion and embankment construction would provide a cost-effective solution to the long-term storage of the co-disposed material. The size of the impoundment and extent of work have been optimised to provide a cost-effective solution within the constraints of anticipated project budgets.

Key project details are set out below.

Days Creek Domain project cost	$35,000,000 approx.
Total volume of Brukunga waste rock treated	455,000 m^3 approx.
Proportion of total Brukunga waste rock treated	10 to 15%
Total volume of Brukunga tailings treated	360,000 m^3 approx.
Proportion of total Brukunga tailings treated	10 to 15%
Area remediated	35 ha approx.
Proportion of area remediated	25 to 30%
Expected decrease in hydraulic load on treatment plant	35 to 40%
Expected decrease in pollution load to treatment plant	10 to 15%
Volume of clean Days Creek water diverted to Dawesley Creek	40 to 50 ML/annum

1. INTRODUCTION

1.1 BACKGROUND

The Brukunga Mine site is located 4 km north of Nairne, and 40 km east of Adelaide in the Mount Lofty Ranges of South Australia. The location of the site is shown in Figure 1.

Geology

The Geological Survey of South Australia (1962) 1:250,000 Mount Barker map sheet (Sheet 1 54-13) indicates that the Brukunga Mine site is underlain predominantly by the Cambrian Brukunga Formation, which comprises inter-bedded micaceous and feldspathic meta-sediments containing lenticular sulfidic and calc-silicate lenses. This formation has been subjected to two significant phases of regional deformation, and has been regionally metamorphosed. The western boundary of the pit (highwall) coincides with the contact with the underlying Backstairs Passage Formation, and the eastern pit boundary lies along the overlying Tapanappa Formation. The key fabric observed in the highwall is bedding.

The macroscopic structure observed in the Mine indicates a position on the E-limb of a SE plunging anticline. A geological structural map is presented in Attachment J. Some N-S, E-W and NW trending faults are observed in the northern end of the bench area but none in the south. These faults feature kaolinite infill and are of limited extent (Jacobs 2015 *Structural geological mapping of Days Creek domain*).

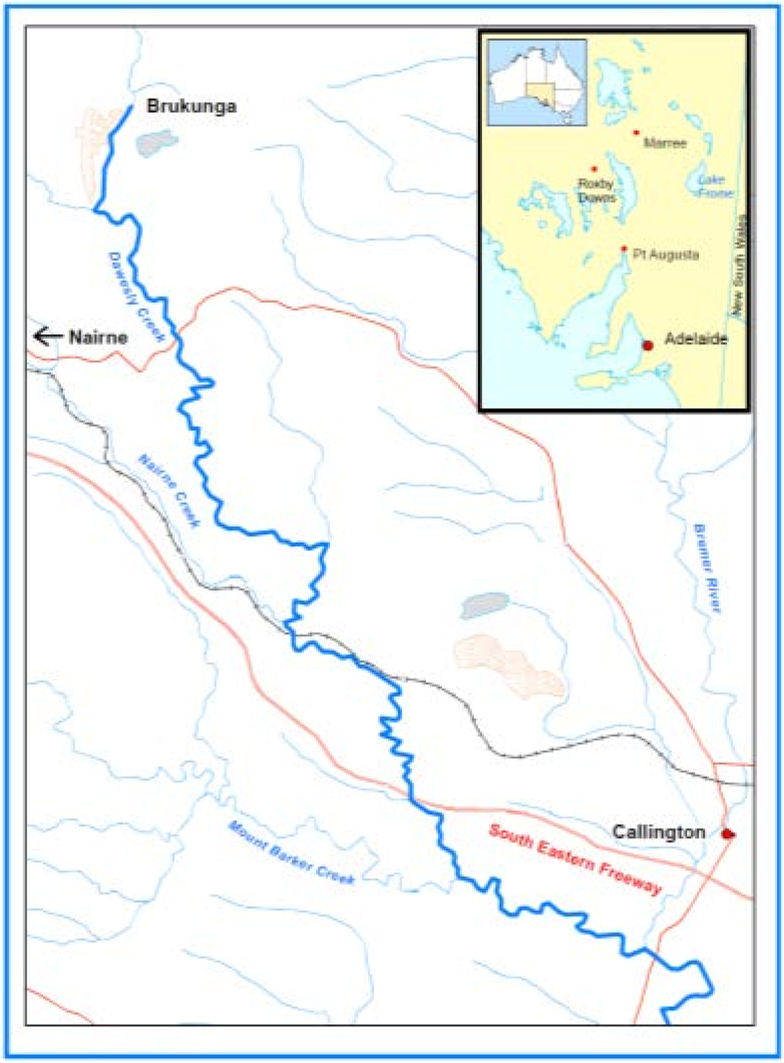

Figure 1. Site location.

Hydrogeology
Groundwater occurs in the fractured bedrock and alluvial sediments in the Brukunga Area, typically declining towards Dawesley Creek. Groundwater elevations at the site generally mimic topography, declining towards Dawesley Creek. Groundwater elevations beneath the waste rock dumps and TSF are also likely to be elevated.

A small amount of groundwater seepage occurs from the highwall. This, combined with the high hydraulic gradient across the highwall suggests low bedrock permeability in the east-west direction. The high water table in the vicinity of the mine pits also indicates a relatively tight rock mass and inherent low permeability. This is consistent with the geology of the region.

Groundwater recharge occurs across the area, including through the waste rock dumps and TSF. Groundwater discharge occurs to Dawesley Creek and its underlying sediments, leading to visibly impacted and acidic surface water in the original Dawesley Creek channel. Groundwater also discharges into specific parts of the the base and sides of the mined out pits, and downgradient of the TSF.

Climate
The area around the Brukunga Mine site experiences cool, moderately wet winters and warm to hot, mostly dry summers. Average annual rainfall at the site over the last 33 years was 575 mm, most of which falls between April and October, inclusive. The annual pan evaporation averages 1100 to 1400 mm (EGi 1995), and the estimated potential evaporation is 900 to 1100 mm/year (based on a pan factor of 0.8).

Land use
The Brukunga Mine lies immediately adjacent to the Brukunga Township and covers an area of some 136 ha. The township itself consists of 72 houses and was built by the Government Housing Trust in 1952 as accommodation for Mine employees. Currently, almost all houses are privately owned and the town has a population of approximately 220.

The Mine site is closed to the public and is primarily used to collect and treat AMD. Two dedicated staff manage the operation of the treatment plant as well as the maintenance of the property. On site management activities include maintenance of the treatment plant and a number of acid water pumps on site; the pipe network; roads; sludge disposal; fences; weeds; feral animals; groundwater monitoring network; surface water monitoring and sampling; stormwater drains; landscaping and tree planting; and fire management.

Third party users of the site include the South Australian Country Fire Service, training providers, and film crews, and the mine hosts two drilling research hubs (the Deep Exploratation Technology CRC and Boart Longyear).

Mining history
The Brukunga Mine was encouraged and sponsored by both the State and Commonwealth Governments in the 1950s to ensure that Australia was self-sufficient in supplies of sulphur for superphosphate fertiliser production. Pyritic minerals (i.e. iron sulphides) were quarried from the hillside at Brukunga and concentrated as a source of sulphur for the production of sulphuric acid, which was then used to manufacture fertiliser.

Iron sulphide was quarried from the side of two steep hills using a power shovel and trucks. The Mine concentrate was trucked to a rail siding at Nairne and then railed to Snowdens Beach, Port Adelaide, where it was converted to sulphuric acid (H_2SO_4). Imported phosphate rock was treated with the acid to produce superphosphate fertiliser to sustain South Australian agriculture.

During mining operations, two waste rock dumps (WRDs) were generated from approximately 8 million tonnes of sulfidic overburden material (2 wt.% S), and a valley-fill TSF adjacent to the Mine was filled with 3.5 million tonnes of sulfidic sand-tailings (1.7 wt.% S). The North and South

WRDs are located on the western side of Dawesley Creek with surface areas of about 11 ha and about 14.7 ha, respectively.

Key features of the existing site are shown in Figure 2.

In the late 1960s cheaper sources of sulphur became available, mainly due to Canada's refining of "sour natural gas".

The Commonwealth Government withdrew the pyrite subsidy on 31 May 1972 and the Mine ceased mining operations on the same day. During its 17-year operation, the Brukunga Mine produced 5.5 Mt of iron sulphide (pyrite and pyrrhotite) ore at an annual production rate of about 380,000 tpa. The ore had an average grade of 11% sulphur and was crushed and processed on site to produce a 40% sulphur concentrate.

Although the Mine closed in 1972, contamination of Dawesley Creek with AMD continued. Following a request from the mining company for assistance, the State Government accepted responsibility for the site in August 1977.

The Environmental Impact of Mining

The main environmental concern at Brukunga is caused by the natural oxidation of pyrite minerals in air and water to form acid, known as Acid and Metalliferous Drainage (AMD). The ongoing oxidation of pyrite remaining in the waste rock dumps and the TSF causes AMD to seep out at the base of the dumps and TSF. The acidic drainage dissolves small amounts of other metals from the wastes.

Dawesley Creek flows north to south through the Mine site and picks up contaminants, carrying them downstream into Mount Barker Creek, Bremer River and into Lake Alexandrina. Soon after the mine opened, and up to the construction of a diversion of the creek in 2003, the water from the Mine was contaminated with sulphate and heavy metals such as aluminium, iron, cadmium, and manganese. The water was unsuitable for livestock and irrigation use up to 55 km downstream of the Mine site.

The geological formation hosting the pyrite is not specific to Brukunga, extending approximately 40 km north and south of the Mine, and it also continues steeply into the ground beneath the current quarry floor. The blasting and crushing activity of mining increased the surface area of the pyrite exposed to the air and water, significantly increasing the amount of oxidation occurring. This is estimated to be an order of magnitude greater than was occurring naturally when the minerals were in the ground.

In 1993-94, the Australian Nuclear Scientific and Technology Organisation (ANSTO) was engaged to provide an estimate of how long the oxidation would continue above previous background levels. Temperature and oxygen levels were monitored in a series of boreholes drilled into the tailings and waste rock dumps and the results were used in calculations that indicated the reactions are likely to continue for at least 240 years and up to 750 years. Subsequent analysis by the TAG indicates that oxidation could potentially continue for in excess of 1,000 years.

Government History at Brukunga

The South Australian (SA) Government took responsibility for the site commencing in 1977. A low density sludge lime-based water treatment plant (WTP) was commissioned in September 1980 to treat the acid and metalliferous drainage generated by the mine site and to improve water quality in Dawesley Creek, which runs through the mine site. The site has been managed by PIRSA, now DSD, since 1998, after taking over from SA Water. PIRSA staff noted that while the WTP was effective in lowering pollution loads to Dawesley Creek, the large catchment above the mine and the limited acidic water storage capacity on site meant that uncontrolled discharges of AMD into Dawesley Creek were not uncommon during high rainfall events.

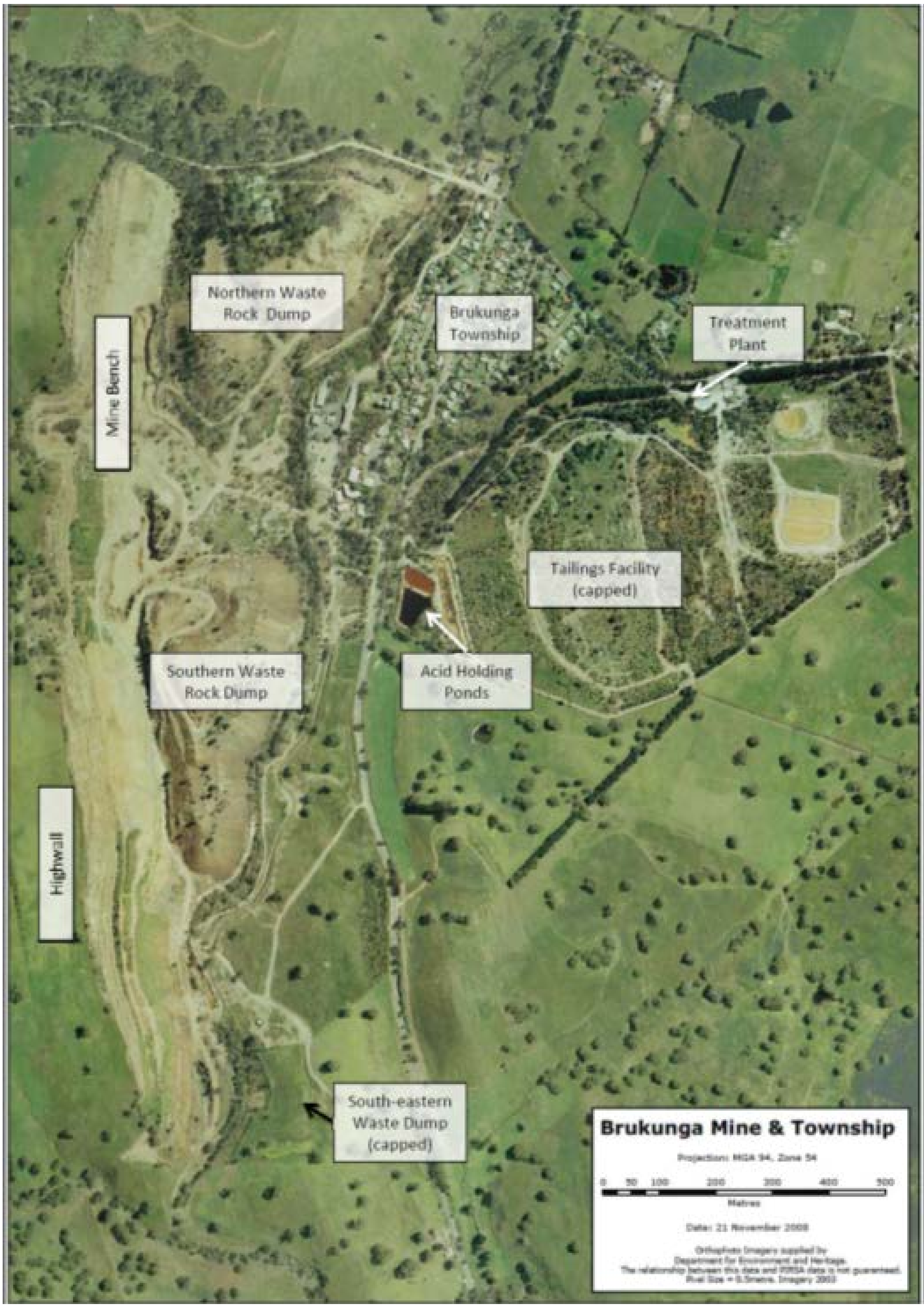

Figure 2. Site features.

With the aim of improving water quality outcomes in Dawesley Creek downstream of the mine, PIRSA staff devised in 2001 a three-stage remediation program (hereinafter referred to as the "original option") involving:

Stage 1: Diverting upper Dawesley Creek around the mine and away from the acid generating material in an attempt to lower the volume of acid-impacted water, increasing the proportion of pollution captured on site and directed to the WTP, and therefore decreasing the number and volume of uncontrolled offsite discharges of AMD;

Stage 2: Increasing the peak hydraulic capacity of the WTP to deal with improved capture of AMD on site;

Stage 3: Decreasing the generation of acidic seepage from the South Waste Rock Dump (SWRD) and North Waste Rock Dump (NWRD) by relocating and blending them with 1-2 wt.% limestone.

A channel was constructed in June 2003 to divert Dawesley Creek around the mine to maximise the separation of clean and polluted water and reduce unnecessary hydraulic load on the WTP (Stage 1). Having achieved this outcome, WTP modifications were commissioned in 2005 (Stage 2) to deal with the increased treatment volumes resulting from improvements in the collection and containment of AMD from the site. The hydraulic capacity of the WTP was more than doubled and its operation was upgraded to a high-density sludge process. The Stage 2 work program had the effect of:

- improving the efficiency of reagent use;
- improving discharge water quality and sludge management; and
- lowering overall treatment costs.

Prior to the commencement of Stage 3 works, there was considerable discussion and debate about the likely success of preventing or substantially lowering residual AMD associated with the "original option" involving moving the waste rock and blending it with 1 to 2 wt.% limestone. PIRSA decided to suspend the Stage 3 work program and seek specialist advice on the optimum remediation strategy. The Brukunga Remediation Project Technical Advisory Group (TAG) was convened to assist PIRSA in this process. The TAG's initial brief was to examine the potential to formulate a more comprehensive and full-scale remediation strategy that would permit the government to "walk away" from the site. At that time, the South Australian Government's definition of "walk-away" was:

"Remediation allowing return of the land to a land use suitable for release of the land from Government ownership such that the site requires no further intervention by, ongoing responsibility for, or cost to the Government and/or the community."

1.2 WHOLE-OF-SITE REMEDIATION

Objectives

Key objectives of the whole of site "walk-away" remediation strategy for the Brukunga Mine are to:

- avoid the need to intercept and treat AMD indefinitely;
- ensure that the water quality in Dawesley Creek downstream of the Brukunga Mine site would be suitable for domestic (excluding human consumption), stock and primary production purposes, and comply with the EPA Water Quality Policy;
- return all or part of the site to productive use(s) or for environmental ecosystem value(s); and
- apply leading practice to site management and the remediation option(s) and solution(s).

In order to meet these objectives, the TAG has completed three phases of work to date, which are outlined in the following sections. The work has focussed on attainment of the objects of the Environment Act (1993) and, in particular, the development of a sustainable long-term strategy for the site.

Phase 1: Option investigation 2007-08

Fifteen remediation options for Brukunga were developed and assessed by the TAG. It was agreed that the previous option (waste rock relocation and limestone blending) would not provide a sustainable remediation solution. The TAG identified that the co-disposal of sulfidic waste rock and tailings maintained saturated behind a series of three impoundment walls within the Days

Creek, Dawesley Creek and Taylors Creek catchments could fulfil the requirement of a "walk-away" remediation strategy. In addition, the TAG concluded that this strategy would require significant additional investigation and would ultimately require considerable capital expenditure (TAG 2008).

Phase 2: Strategy definition 2008-2011

The Phase 2 work program was directed at confirming the technical viability of the selected strategy by clarifying important aspects of the logistics, engineering, geochemistry and hydrology. Phase 2 technical projects included: waste material and void volume surveys, geotechnical, geochemical and hydrogeological investigations, water balance modelling, waste rock and tailings co-disposal trials, feasibility design, logistics planning, and preliminary costing and scheduling. Results of the Phase 2 work program validated the technical feasibility of the recommended remediation strategy involving the co-disposal of waste rock and tailings maintained under saturated conditions (TAG, 2009).

Phase 3 (this report): Detailed investigation and design (Days Creek domain) 2012-2015

The estimated high cost of project implementation and the innovative nature of the proposed remediation strategy led to a re-assessment by the South Australian Government of expenditure priorities. PIRSA (subsequently DMITRE and DSD) asked the TAG to identify the potential for implementing a component or domain of the "whole-of-site" project in a manner that would provide a partial solution to the remediation as well as demonstrating the viability of the strategy.

The TAG concluded that the installation of one impoundment in the Days Creek catchment would permit partial remediation and provide an opportunity to assess the performance of the saturated co-disposal technique. PIRSA accepted the proposal to proceed with detailed evaluation and costing for remediation of the mine-impacted portion of the catchment of Days Creek – here after referred to as the "Days Creek Domain" of the Brukunga Remediation Project.

The Days Creek domain encompasses the northern end of the mined area characterised by the western highwall and an elongated bench within which are two deeper pits as shown in Figure 3.

The Days Creek domain includes AMD sources from:

- Part of the north WRD
- Part of the TSF
- Mine pits and northern main bench
- Part of the northern highwall.

The outcomes of Phase 3 are the subject of this report.

Key features of the existing site are shown in Figure 3.

Figure 3. Aerial photo of current site with remediation works area.

2. TEAM MEMBERS, OBJECTIVES AND SCOPE OF WORK

2.1 TEAM MEMBERS

The assessment and development of a site-wide remediation strategy for the Brukunga Mine, including the detailed design for remediation of Days Creek, have involved a multi-disciplinary team comprising the TAG, DSD officers and the project consulting engineers and scientists. The project team is set out in Table 1.

Table 1. Project team and roles.

Organisation/team	Role
Brukunga team, Department of State Development (DSD)	Project Client and Sponsor, Overall Project Direction, Procurement & Project Management of Contractors and Consultants, Project Funding
Technical Advisory Group (TAG)	Technical Lead and Independent Technical Advice, Project “Champions” for individual projects and some TAG members conducted projects. Writing of Phase 3 Summary report
Jacobs Group (Australia) – formally Sinclair Knight Merz (SKM or Jacobs)	Lead consultant for Project BR01-06 Detailed Investigation and Design (see Phase 3 project tasks for detail)
Golder Associates (Golder)	Consultant for Project BR04-04 3D Hydrological Modelling and associated groundwater well installation
URS Australia (URS)	Consultant for Project BR12-05 Brukunga Phase 2 Contaminated Land Investigation (non-AMD contamination)
Environmental Earth Sciences (Phil Mulvey/Auditor)	Auditor for Project 12-02 Site Contamination Audit: Remediation Process, Brukunga Mine Remediation Program

This report has been written by selected members of the TAG, which currently comprises:

- **David Brett**
  Principal Engineer, Mine Waste & Water Management, GHD
- **Ross Hardie**
  Chairman – Alluvium Consulting Australia
- **Mike O’Kane**
  President and CEO, O’Kane Consultants
- **Peter Scott**
  Director, General Manager Australia, Principal Geochemist, O'Kane Consultants
- **Dr Jeff Taylor**
  Director - Senior Principal Environmental Geochemist, Earth Systems
- **Dr Tamie Weaver**
  Technical Director – Hydrogeology, Environmental Resources Management (ERM)
- **Professor David J Williams**
  Director, Geotechnical Engineering Centre, The University of Queensland

The TAG has been involved in three phases of technical investigations relating to remediation of the Brukunga Mine site. These are detailed in Section 1.4.

2.2 OBJECTIVES

The remediation of Days Creek represents the first stage of the progressive remediation of the Brukunga Mine site. Objectives for the remediation of Days Creek domain were developed by the TAG in association with DSD officers. These objectives are consistent with those sought for the entire site, reflecting the inevitable limitations of partial remediation, and are to:

- commence the progressive remediation of waste rock and tailings at the Brukunga Mine site by co-disposal of AMD generating materials;
- demonstrate the feasibility of saturated co-disposal strategy in order that it can be implemented with confidence over the entire site;
- generate improvements in the water quality in Dawesley Creek downstream of the mine site;
- enhance the clean water diversion capacity of the site, and thereby decrease the hydraulic load on the available acid water storage-pump back system, and water treatment plant; and
- create a self-sustaining landscape with manageable human health and safety, and environmental risks over the remediated lands.

This report has been produced to support the development of a business case for investment in the site and builds upon previous work by the TAG in the formulation of conceptual strategies for the full remediation of the site.

2.3 SCOPE OF WORK

The Phase 3 work program focussed on taking conceptual remediation designs for the Days Creek domain, and refining them into fully costed detailed designs (± 15% accuracy), ready for construction. The TAG's involvement in this included:

- Identifying, specifying and documenting the outstanding work program (developed as an output from Phase 2) as required to permit detailed design of the remediation program for the Days Creek domain. Key project tasks in the work program included:
    - Task 1B, 1C — Site Characterisation
    - Task 1D — Groundwater Hydrology
    - Task 2A — Conceptual Landform Design
    - Task 2B — Cover System Design
    - Task 2D(1), 2D(2) — Landform Evolution Modelling
    - Task 2E — Embankment Design
    - Task 2F — Dilution Modelling
    - Task 6 — Engineering Feasibility Design
    - Task 8 — Detailed Design
- Conducting a Failure Modes and Effects Analysis (FEMA) to identify and mitigate potential risks associated with the design. The FMEA was undertaken to identify all means by which the proposed design could fail to meet expectations, to identify the risks associated with the each failure mode, and to identify approaches to reduce the risks associated with each failure mechanism. In several cases, the remediation design was modified to address these potential risks. Further discussion on the FMEA is provided in Attachment C.
- Peer reviewing outputs from engineering design consultants (SKM/Jacobs) and groundwater flow and solute transport modellers (Golder Associates) in order evaluate and approve detailed designs for the Days Creek Domain remediation work program.

All substantive outputs from the Phase 3 work program are provided as Appendices to this report. These outputs are summarised in Table 2.

Table 2. Project outputs and authors.

Output	Author(s)
Design of the Days Creek domain – The first stage of the progressive remediation of the Brukunga Mine site (this report)	Brukunga TAG
Failure modes analysis (FMEA)	Brukunga TAG
Brukunga Mine Remediation Porgram BR01-06 – Days Creek domain • Geotechnical Materials Investigation • Geotechnical Assessment – Impoundment Area • High Wall and Pit Hydrogeology • Conceptual Landform Design • Cover System Design • Catchment Hydrological Modeling • Landform Evolution Modeling – Erosion • Landform Evolution Modeling – Sediment • Embankment Design • Dilution Modeling • Feasibility Design – Combined • Detailed Design	Jacobs Group (Australia) – formally Sinclair Knight Merz (SKM)
Hydrogeological Modeling – Flow Modeling Hydrogeological Modeling – Solute Transport	Golder Associates (Golder)
Brukunga Phase 2 Contaminated Land Investigation	URS Australia (URS)
Site Contamination Audit: Remediation Process, Brukunga Mine Remediation Program	Environmental Earth Sciences (Phil Mulvey)

2.4 INTENDED AUDIENCE

This report summarises the detailed design and justifies the need for the remediation of Days Creek within the Brukunga Mine site. The intended audience is the DSD, as the client and owner of the mine site. Other State Government departments will be involved in the approval and consultation process, including (as a minimum) the Environmental Protection Authority (EPA), the Department of Planning, Transport and Infrastructure (DPTI), the South Australian Health Department (SA Health), the Department of Environment, Water and Natural Resources (DEWNR) and the South Australian Treasury.

This report is also intended for other stakeholders, including the Environmental Auditor (appointed under the *Environmental Protection Act 1993*), the District Council of Mount Barker, local community groups (such as Landcare) and the members of the local Brukunga community.

3. LOCAL DRAINAGE AND WATER QUALITY

Ongoing water quality issues arising from the Brukunga Mine site impact on the downstream receiving environment and have necessitated the ongoing operation and maintenance of the Brukunga Water Treatment Plant (WTP). Despite the operation of the WTP, the water quality discharged from the site fails to meet regulatory requirements and community expectations. This is primarily due to significant inflows of relatively clean water from Days Creek, which mixes with AMD on site and subsequently requires collection and pumpback to the WTP. During peak flows, there is insufficient storage and pump back capacity to ensure that all site runoff (including Days Creek inflows) is fully captured and diverted to the WTP.

This chapter provides an overview of surface water upstream and downstream of the mine, mine site surface water and groundwater quality in the vicinity and down hydraulic gradient of the site. Further details on site water quality can be found in Attachment I

3.1 SURFACE WATER UPSTREAM OF THE MINE

Dawesley Creek
Dawesley Creek has a total catchment area of approximately 56 km^2, with a catchment area of approximately 20 km^2 upstream of the mine site. The creek is ephemeral and receives contributions from the Bird in Hand Wastewater Treatment Plant (WWTP) and runoff from agricultural land upstream of the mine site.

Results for the background chemistry of surface water sampled from Dawesley Creek upstream of the mine are summarised in Attachment I. Key results of the water quality analyses include:

- Dawesley Creek water upstream of the mine is slightly alkaline, with a pH of 8.1.
- The water contains relatively high alkalinity levels at 190 mg/L $CaCO_3$, probably at least partially derived from the nearby "Bird in the Hand" sewage treatment plant.
- Mg and K concentrations are slightly elevated at 26 and 27 mg/L, respectively.
- Acidity values are below the detection limit.

Dawesley Creek water quality upstream of the mine site is relatively good in comparison with site water quality (refer to Section 3.2), but is mildly affected by the Bird in Hand WWTP and agricultural runoff.

Days Creek
Days Creek is a tributary of Dawesley Creek and has a catchment area of approximately 1.2 km^2 upstream of the mine site. The creek is ephemeral, with flows only evident after significant rainfall (e.g. 2 to 3 months of the year). Most of the Days Creek flow entering the mine site is captured and pumped to the WTP. However, during peak flow events some of the creek flow bypasses the WTP.

Very little water quality data are available for Days Creek upstream of the mine. Since upper Days Creek is believed to crosscut the sulfide loads, it is important to understand whether this ephemeral surface flow is impacted by natural oxidation processes. Indicative baseline water chemistry from Days Creek is summarised in Attachment I - Water quality monitoring results. Key results of the water quality analyses include:

- pH values range between 5.8 and 7.14 with low Electrical Conductivity (EC).
- The creek water is slightly alkaline with alkalinity values ranging between 2 mg/L and 26 mg/L as $CaCO_3$.
- The concentrations of dissolved Al, Mn and Zn are occasionally slightly elevated at 0.62 mg/L, 0.218 mg/L and 0.159 mg/L, respectively, but these are very small and correspond to natural background contributions to acidity.

The limited available data indicate that Days Creek water quality upstream of the mine site is relatively good in comparison with site water quality (refer to Section 3.2) despite some influence of naturally slightly elevated metal concentrations relating to natural AMD release from exposed pyrite lodes upstream of the mine.

The proposed Days Creek remediation strategy is expected to lead to substantial long term improvements in Days Creek water quality, as described in Section 4.

3.2 MINE SITE SURFACE WATER

Seepage and runoff from mine landforms including the pits and highwall, the north and south WRDs and the TSF is significantly impacted by AMD including highly elevated acidity, sulfate, and dissolved metals such as iron, manganese, aluminium, zinc, cadmium, cobalt, copper, chromium and nickel and is therefore unsuitable for direct discharge to the receiving environment.

Key sources of contamination to surface water at the site include:

- oxidation of pyrite and pyrrhotite and dissolution of secondary acid generating minerals associated with weathering and recharge from exposed mineralisation on the highwall, bench, pit walls and pit floor;
- oxidation of pyrite and pyrrhotite and dissolution of secondary acid generating minerals associated with seepage and runoff to surface water from the NWRD and SWRD; and
- seepage to surface water from the base of the TSF.

The key measure of the scale of AMD issues on site is the “acidity load”. Annual acidity loads in surface water on site are estimated at 684 tonnes of H_2SO_4 equivalent per year (from July 2013 to June 2014).

This has necessitated the diversion of clean Dawesley Creek water from entering and mixing with mine impacted catchment water and the need to capture and treat all water from the mine impacted portion of the Dawesley Creek catchment (as outlined in Section 1.2). The captured AMD-affected water is treated to a standard acceptable for discharge, and the resultant treatment sludge disposed on site, but at significant ongoing cost to the DSD.

Table 3. Volume and mass of acid load acidity water treated by financial year .

Time Period	Volume Treated (ML)	Acidity treated (t)*
2014-13	166.1	1,128.1
2013-12	137.5	853.7
2012-11	112.1	851.0
2011-10	166.2	1,150,1
2010-09	157.5	1,110.4
2009-08	96.3	702.2

* Calculated tonne of acidity from tonne of sulphate

AMD from the mine site is collected in a series of pump sumps and directed to two acid water collection ponds at the toe of the TSF. These ponds provide surge storage capacity for the WTP during the winter months, providing a uniform AMD feed chemistry to the plant. Table 4 provides a summary of the chemistry of typical average raw AMD from the collection ponds, as well as fully treated water discharged from the WTP. Table 4 also provides values for the ANZECC/ARMCAMZ (2000) water quality guidelines for the protection of 95% of aquatic species, and the South Australian EPA (2003) guidelines for waterways which are provided for the purpose of comparison. The proportional changes in water quality parameters following treatment are included, and demonstrate the marked improvement in water quality associated with the current treatment.

The proposed Days Creek remediation strategy is expected to lead to further long-term improvements in the WTP performance, by decreasing the hydraulic load to the plant, as described in Section 4.

Table 4. Comparison of average raw AMD from the acid water collection ponds and fully treated water discharged from the WTP in January 2004.

Parameter	Units	EPA Guideline	ANZECC/ARMCANZ Guideline (95%)	Average Raw AMD	Treatment Plant Discharge	% Increase (↑) or Decrease (↓) in Treated Water
pH		6.5-9.0	6.5-9.0	2.7	9.3	n/a
EC	μS/cm	no value	100-5000	10 350	3830	↓ 63.0%
ORP	mV	no value	no value	434	-22	n/a
Ca	mg/L	no value	1000 livestock	418	733	↑ 75.4%
Mg	mg/L	no value	no value	762	45	↓ 94.1%
Na	mg/L	no value	no value	221	203	↓ 8.0%
K	mg/L	no value	no value	21	17	↓ 20.5%
Acidity	mg/L $CaCO_3$	no value	no value	10 377	6	↓ 99.9%
Alkalinity	mg/L $CaCO_3$	no value	no value	0	17	n/a
Sulfate	mg/L	1000 livestock	1000 livestock	11 360	1673	↓ 85.3%
Chloride	mg/L	no value	no value	458	346	↓ 24.5%
Al (diss.)	mg/L	0.1	0.055	898	0.5	↓ 99.9%
Al (total)	mg/L			1094	0.7	↓ 99.9%
As (diss.)	mg/L	0.05	0.024 (As III) 0.013 (As V)	0.01	0.001	↓ 91.3%
As (total)	mg/L			0.01	0.001	↓ 92.0%
Cd (diss.)	mg/L	0.002	0.0002	0.20	0.0001	↓ 100.0%
Cd (total)	mg/L			0.22	0.0001	↓ 100.0%
Cr (diss.)	mg/L	1 (irrigation)	no value	0.12	0.001	↓ 99.2%
Cr (total)	mg/L			0.13	0.021	↓ 83.6%
Cu (diss.)	mg/L	0.01	0.0014	0.71	0.002	↓ 99.7%
Cu (total)	mg/L			0.74	0.024	↓ 96.8%
Fe (diss.)	mg/L	1.0	0.2 (irrigation)	925	1.4	↓ 99.8%
Fe (total)	mg/L			1390	7.7	↓ 99.4%
Mn (diss.)	mg/L	2 (irrigation)	1.9	97	0.6	↓ 99.4%
Mn (total)	mg/L			98	0.6	↓ 99.4%
Ni (diss.)	mg/L	0.15	0.011	2.43	<0.001	↓ 100.0%
Ni (total)	mg/L			2.51	0.15	↓ 94.0%
Pb (diss.)	mg/L	0.005	0.0034	<0.001	<0.001	n/a
Pb (total)	mg/L			<0.001	<0.001	n/a
Zn (diss.)	mg/L	0.05	0.008	49	<0.1	↓ 100.0%
Zn (total)	mg/L			60	6.2	↓ 89.7%

Values exceeding either or both EPA (2003) or ANZECC/ARMCANZ (2000) guidelines (for the protection of aquatic ecosystems) are shaded.

3.3 SURFACE WATER DOWNSTREAM OF THE MINE

Dawesley Creek downstream of the mine site comprises inflows from the catchment upstream of the mine (via the Dawesley Creek diversion channel) as well as treated water from the mine WTP.

In the late 1990's and early 2000's, the mine site clearly had a significant effect on downstream water quality in Dawesley Creek, with pH, salinity (sulfate) and metal concentrations commonly exceeding one or more irrigation and/or livestock drinking water quality guidelines.

Despite the improved water quality in Dawesley Creek attributed to the diversion channel and WTP installation over recent years, there have still been some exceedences of irrigation and/or livestock water quality guidelines since 2006 downstream of the mine site, for pH, EC, sulfate and metal concentrations.

A key reason for such exceedances is the limited capacity for storage and pumping of AMD-affected mine water to the WTP.

Overall, Dawesley Creek water quality downstream of the mine site is relatively good in comparison with site water quality (refer to Section 3.2) but occasionally influenced to some extent by uncontrolled site drainage, for example during peak flow events.

Table 5. Average annual water quality data immediately downstream mine (site ref. 3158).

Year	pH	Aluminium	Iron	Manganese	Zinc
2002*	5.5	57	8.7	6.4	3.8
2004	6.1	12	1.9	2.0	1.1
2006	7.2	6	4.9	2.4	0.5
2008	7.0	3	1.8	0.7	0.2
2010	6.2	12	6.3	2.2	0.6
2012	6.7	3	2.0	1.6	0.2
2013	6.4	27	5	1.7	1.4

* pre-diversion water quality

The proposed Days Creek remediation strategy is expected to lead to further long-term improvements in Dawesley Creek water quality, as described in Section 4.

3.4 GROUNDWATER

Regional groundwater in areas away from the north-south strike of the mineralised zone appears to be relatively unimpacted and is characterised by low TDS and sulfate concentrations, and near-neutral pH values. These areas include the area to the west of the highwall, potentially to the north of the mine, and the area to the south of the TSF.

Results of long-term monitoring of groundwater levels and quality in the vicinity and down hydraulic gradient of the Brukunga Mine site are summarised in ERM (2013), which indicates that groundwater in the vicinity of the mine pits, the TSF, and waste rock dumps (WRDs) is impacted by AMD based on elevated acidity, sulfate, and dissolved metals, including iron, manganese, aluminium, zinc, cadmium, cobalt, copper, and nickel.

Groundwater from beneath the TSF, WRDs and bench area discharges to the base of the mined pits and into the base of Dawesley Creek (ERM, 2013).

Leakage and recharge to groundwater from the site have led to the current groundwater condition and through groundwater discharge have contributed to degraded surface water conditions. Key sources of contamination to groundwater at the site include:

- naturally occurring oxidation of pyrite and pyrrhotite outside of the mine area;
- oxidation of pyrite and pyrrhotite and dissolution of secondary acid generating minerals associated with weathering and recharge from exposed mineralisation on the highwall, bench, pit walls and pit floor;
- oxidation of pyrite and pyrrhotite and dissolution of secondary acid generating minerals associated with infiltration to groundwater from the NWRD and SWRD; and
- leakage to groundwater from the base of the TSF and from associated ponds.

Groundwater sampled from wells on site range from values that are likely to represent background conditions to those that indicate significant impact by AMD from the mined area, waste rock dumps, and tailings.

The most impacted groundwater is characterised by pH values of approximately 2.5 to 4. Elevated sulfate concentrations have led to TDS values that exceed 10,000 mg/L in impacted groundwater. Elevated concentrations of metals derived from are also common. Across the site, total dissolved solids (TDS) (arising as a result of increased sulfate), sulfate, metals concentrations (particularly iron, manganese, aluminium and zinc) and pH are primary indicators of impact. Of these, sulfate and zinc are likely to behave relatively conservatively once they enter the groundwater system.

Mine-impacted groundwater will ultimately discharge into the base of Dawesley Creek. Some of this groundwater will therefore be captured on site and pumped to the WTP, whereas other groundwater has the potential to bypass the site water collection and pump back system. Acidity loads from groundwater are assumed to be minor relative to surface water contributions.

The proposed Days Creek remediation strategy is expected to decrease acidity loads to groundwater over time, as described in Section 4.

4. DAYS CREEK REMEDIATION STRATEGY

As noted in Chapter 1, the "Days Creek domain" includes sources from:

- Part of the north WRD
- Part of the TSF
- Mine pits and northern main bench
- Part of the northern highwall.

Acidity load reductions likely to be achieved by remediation of Days Creek Domain are estimated to be approximately 10 to 15% of the total site acidity load. This equates to roughly 70 to 110 t of H_2SO_4 acidity per year.

The proposed remediation of Days Creek Domain will involve:

- diverting the clean Days Creek upstream water into the Dawesley Creek diversion channel, and thus reducing the volume of seepage and runoff water from Days Creek Domain that needs to be captured and treated on site.
- construction of embankments at three locations to permit saturated co-disposal of sulfidic and jarositic waste material with limestone in an impoundment within the disused mine pit.
- installation of coarse-textured drainage layer and engineered cover system above the co-disposed materials.
- installation of a highwall drainage control system.

Key details of the proposed Days Creek remediation strategy are set out below:

Days Creek domain project cost	$35,000,000 approx
Total volume of Brukunga waste rock treated	455,000 m^3 approx
Proportion of total Brukunga waste rock treated	10 to 15%
Total volume of Brukunga tailings treated	360,000 m^3 approx
Proportion of total Brukunga tailings treated	10 to 15%
Area remediated	35 ha approx
Proportion of area remediated	25 to 30%
Expected decrease in hydraulic load on treatment plant	35 to 40%
Expected decrease in pollution load to treatment plant	10 to 15%
Volume of Days Creek clean water diverted to Dawesley Creek	40 to 50 ML/annum

4.1 REMEDIATION CONCEPT FOR DAYS CREEK DOMAIN

The Days Creek domain remediation project provides for the saturated co-disposal of sulfidic and jarositic waste material with limestone in an impoundment within the disused mine pit. The purpose of permanently saturating the co-disposed wastes is to isolate sulfidic material from atmospheric oxygen to prevent ongoing acidity generation. The purpose of the limestone addition is to deal with the acidity released from jarosite (the product of the past oxidation of sulfidic material) when it is submerged.

The sulfidic material comprises both waste rock from the waste rock dumps and tailings from the TSF. It is proposed that the impoundment be created through the construction of a low permeability containment structure across the Days Creek valley and around the storage perimeter. This structure includes replacement of permeable weathered rock by trenching and replacing with clay and also allowance for cement grouting of fractured rock zones. It is proposed that Days Creek be realigned to protect the cover system and co-disposed material from stream-related erosion. It is also proposed that geochemically inert material excavated from the realignment of Days Creek be used in the construction of the embankment.

The impoundment will have a robust, high infiltration cover to maximise the inflow of surface water to the co-disposed material, and seepage control to limit the loss of water from the co-disposed material. Both the high infiltration cover and the seepage control are aimed at ensuring that the co-disposed material remains saturated. A lateral drainage layer zone will be provided between the cover system and the co-disposed material to allow for the overflow of surplus infiltration into the realigned Days Creek. The components of the Days Creek Domain impoundment are:

- Main (East) embankment
- South embankment
- North embankment
- Impoundment comprising co-disposed materials (tailings, waste rock and limestone)
- High infiltration cover including soakaways and connecting channel way
- Highwall drain
- Days Creek diversion channel (to Dawesley Creek diversion channel).

A schematic of the proposed remediation concept design showing these components is illustrated in plan (Figure 4) and as 3D perspectives (Figures 5 to 8).

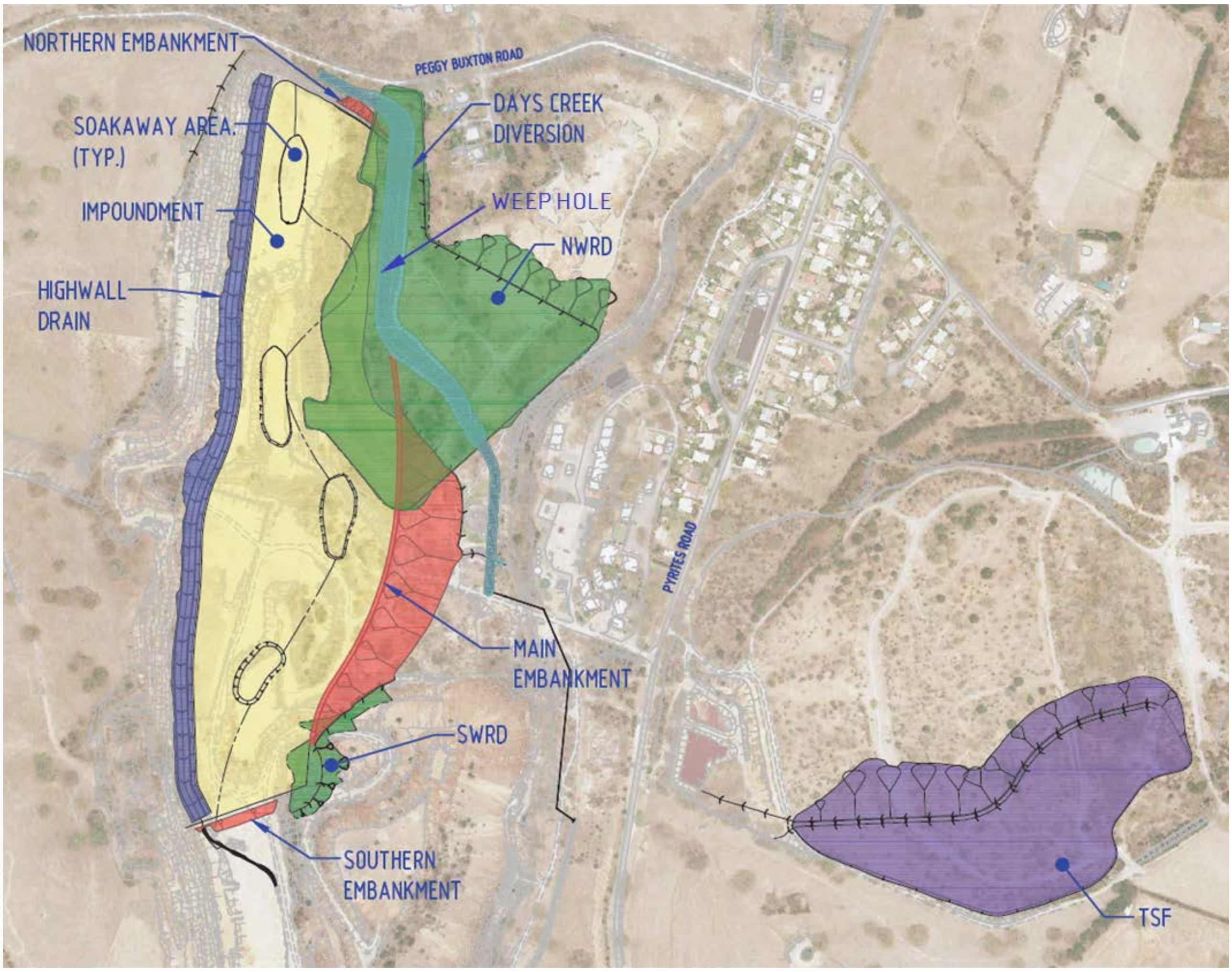

Figure 4. Schematic layout of proposed remediation designs.

Yellow: Cover system, Green: Waste Rock Dump borrow area, Red: Embankments, Blue: Highwall drain, Purple: TSF borrow area. Also shown: Days Creek diversion (light blue) and connection to Dawesley Creek diversion channel (black line)

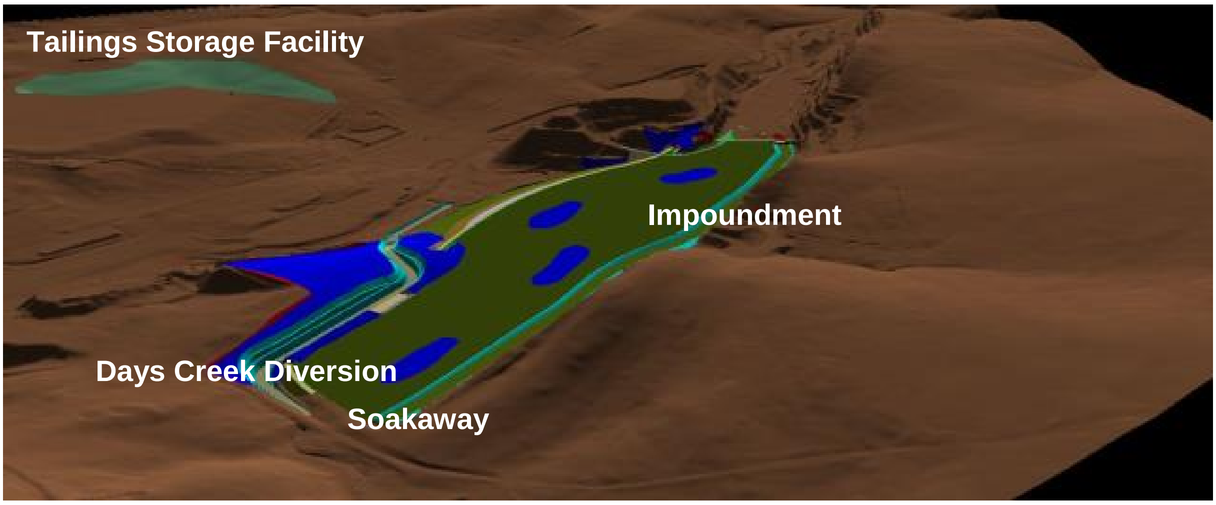

Figure 5. Looking south-east over the impoundment with the remnant Tailings Storage Facility in the background.

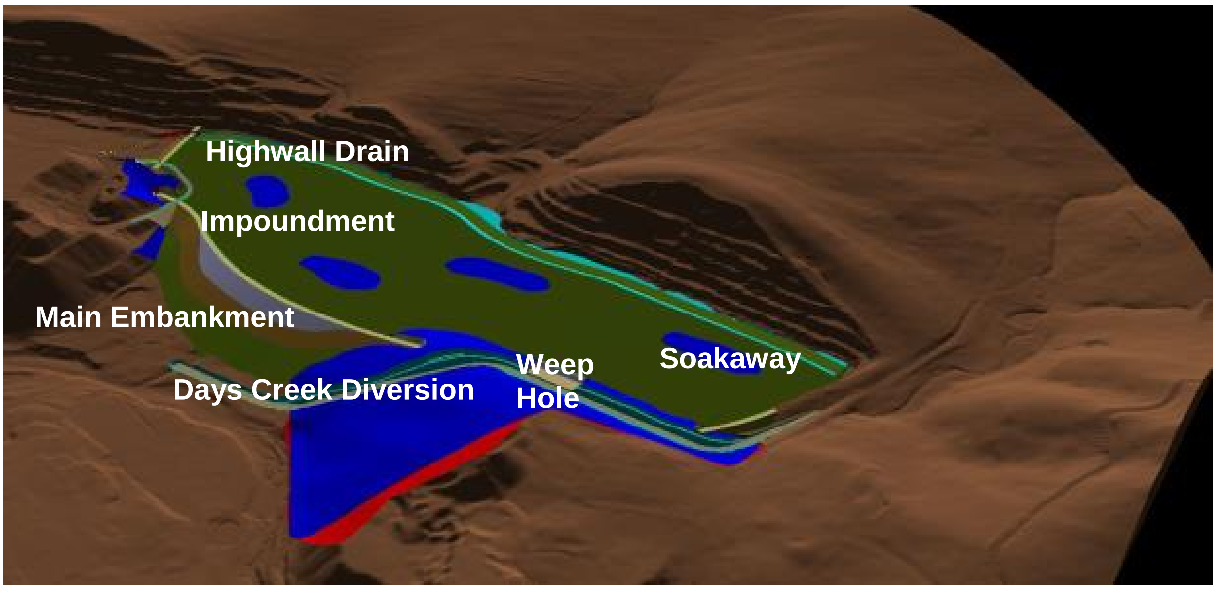

Figure 6. Looking west over the impoundment.

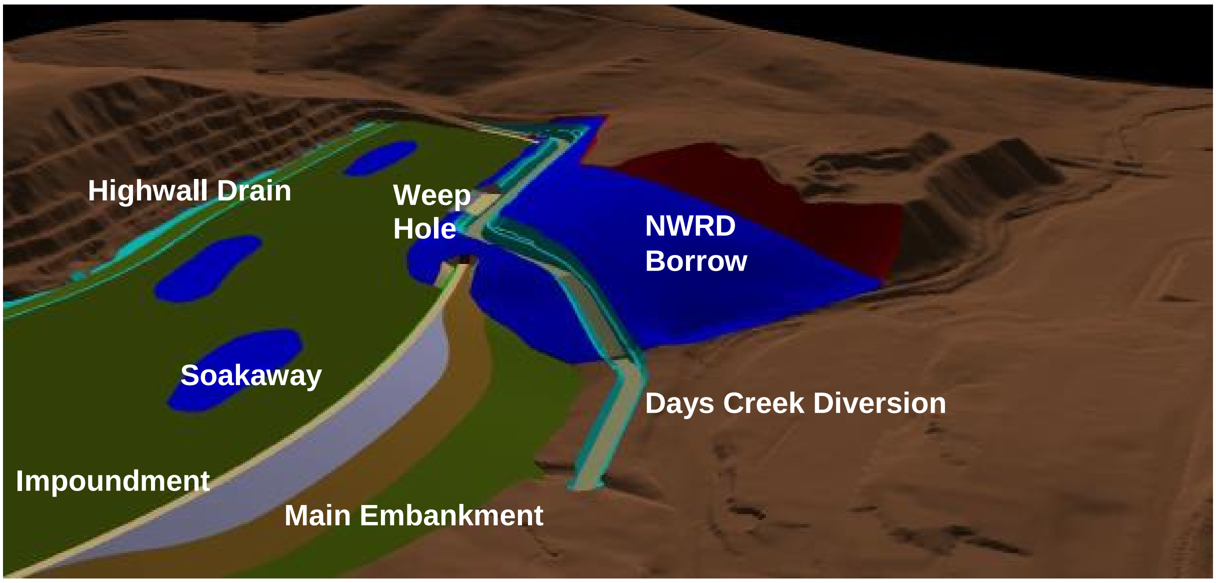

Figure 7. Looking north-west over the northern section of the impoundment with the embankment in the foreground.

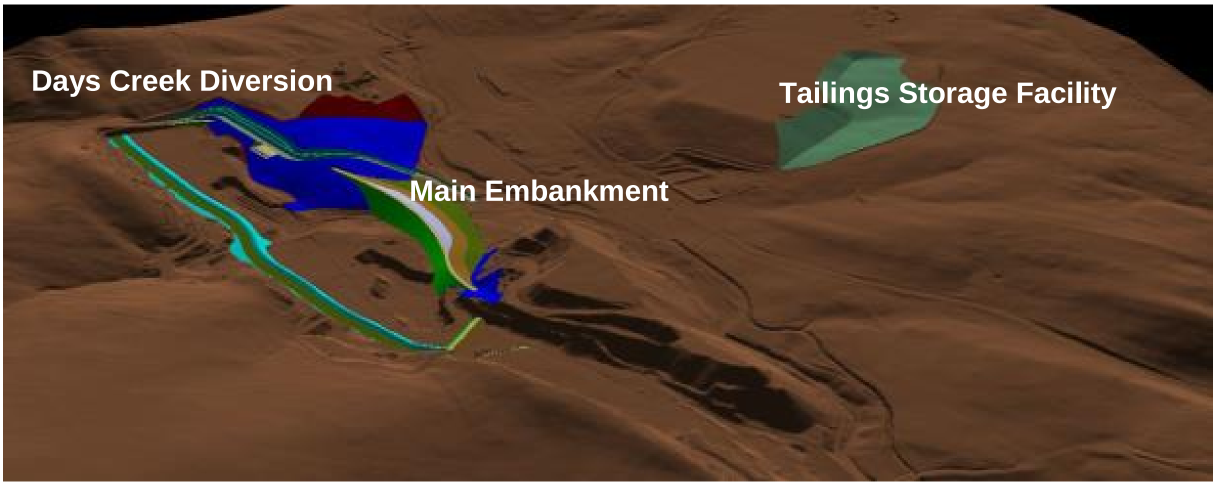

Figure 8. Looking north-east with the SWRD in the foreground (co-disposed wastes omitted).

4.2 PROJECT COMPONENTS

Many project components make up the final designs for the site, as set out below, together with criteria developed to assist with their design and to meet the project objectives.

Table 6. Design component and criteria.

Design component	Design criteria
The disused mine pits	Remove and appropriately dispose of or store unsuitable materials from the pits, including domestic rubbish and built-up deposits of precipitated jarosite.
Benches and highwall	Maximise cover of exposed sulfides and provide sealing of foundation areas around the perimeter of the impoundment area. Allow for potential long-term sloughing of weathered rock materials from the highwall and separation between acidic runoff/seepage derived from the highwall and the impoundment.
Embankment	Provide a low permeability containment structure for the co-disposed wastes that is geotechnically stable over the long term. The embankment is to comply with ANCOLD/ICOLD guidelines[12] for the operation and closure of mine waste facilities. In the foundation design, allow for the removal of permeable weathered rock layers and cement grouting of fractured bedrock to achieve the target maximum saturated permeability (hydraulic conductivity) of 10^{-8} m/s in the embankment core and foundation cut-off.
Grouting and permeability control	The entire perimeter of the waste impoundment is to be free of permeable zones that could lead to significant leakage from the impoundment. This requires removal of permeable materials, including fractured rock, to an approriate practical excavation depth and grouting of remaining fractured bedrock to achieve the target maximum saturated permeability of 10^{-8} m/s.
Co-disposed wastes/limestone	Waste rock from the NWRD and sulfidic tailings from the TSF are to be combined and co-disposed as backfill into the mine pits and onto the main bench. The optimum ratio for recombination is: Tailings: 35.5%, Waste Rock: 60.5%, Calcium carbonate ($CaCO_3$): 4.0 wt.% $CaCO_3$ containing limestone is to be added to neutralise existing secondary acid salts (e.g. jarosite) that will release acid upon saturation. The co-disposed wastes will be capped with a cover system designed to maintain permanent saturation and retard oxygen entry (see below). The maximum elevation of the finished co-disposed wastes cover system will be limited to 370 m AHD.
Day Creek realignment	The Days Creek diversion channel design must meet the following criteria: • contain annual recurrence interval (ARI) 1,000-year critical flows without overtopping onto the cover system; • be robust against erosion processes and not subject to elevated rates of aggradation (sedimentation); and • maintain separation between clean and acid-impacted runoff.
Drainage layer, saturation and oxygen diffusion control	The co-disposed wastes are to be capped with a 300 mm layer of non-sulfidic (fully oxidised) tailings and covered by the lower filter and coarse-textured drainage layer of the cover system. These oxidised tailings will be mixed with limestone containing 6 wt.% $CaCO_3$ to neutralise water soluble acid salts. This layer is designed to remain saturated and to retard the diffusion of oxygen into the underlying sulfidic co-disposed wastes. The coarse-textured layer will be 600 mm thick and comprise materials that range in size from 1 to 25 mm, and has been designed to enhance infiltration and maintain saturated conditions within the layer. During extended wet periods, excess water entering the coarse-textured layer will be diverted to the Days Creek diversion via a linear overflow weep hole.

Design component	Design criteria
Cover system, infiltration and surface drainage	The cover system materials comprise the following: • Growth medium: well-graded sandy loam of nominal thickness 300mm. • Filter layer: fine uniformly-graded sand layers 200mm thick above and below the coarse drainage layer with max 5% passing 75m • Coarse material: a coarse uniformly-graded gravel drainage layer 600 thick with max particle size 20mm and max 5% passing 4.75mm The function and integrity of the proposed waste impoundment cover system require to be maintained for the nominal 1,000-year design life.
Final Landform, land use and stability	The intended land use for the remediated Days Creek domain has not yet been conclusively decided, however: • remediated land will remain owned and controlled by the Government of South Australia; • leasing of remediated land to non-government parties will not be permitted; • public access to the remediated land will not be permitted; • only activities necessary for maintenance of the remediated land will be permitted (all for Days Creek domain only); and • the assumed level of maintenance required for the remediated land will be of a level not substantially greater than what would be reasonably expected for an area of similar land use.

[1]Bulletin 153 E-F Sustainable Design and Post-Closure Performance Of Tailings Dams, ICOLD, 2011
[2]Guidelines on Planning, Design, Construction, Operation and Closure of Tailings Dams, ANCOLD, 2012

The designs for these project components have required the design of various elements including:

- preparation of foundations and construction of embankments;
- control of seepage to bedrock and beneath the embankments;
- realignment of Days Creek and recovery of rock for construction of the embankment;
- preparation and excavation of material from the TSF;
- mix and placement procedure for tailings, waste rock and limestone;
- non-sulfidic tailings capping over co-disposed wastes;
- drainage layer over non-sulfidic tailings layer and drainage discharge system;
- cover system with enhanced infiltration zones;
- drainage contours in cover system;
- revegetation of cover;
- highwall drain; and
- Shepherds Creek drainage diversion.

4.3 PREDICTED CHANGES TO LOCAL HYDROLOGY AND HYDROGEOLOGY

Local Hydrology

The new diversion channel will permit Days Creek to flow directly into the existing Dawesley Creek diversion channel, effectively bypassing the mine site. As a consequence, Days Creek flows will no longer be collected on site and pumped to the existing WTP, with the exception of a small proportion during significant flood events.

Incident rainfall across the surface of the new impoundment will contribute to maintaining saturated conditions in the co-disposed materials, and any excess will seep laterally, via the coarse-textured drainage layer, into the new Days Creek diversion channel.

Drainage from the highwall will be diverted around the impoundment. The highwall drainage, as well as any seepage from the new embankments of the impoundment, will be collected on site and pumped to the WTP.

Local Hydrogeology

The estimated typical seepage via groundwater from the Days Creek domain is 37.4 m^3/day, compared to infiltration to the landform from rainfall and runoff of 35.1 m^3/day (Golder, 2015). Groundwater inflow to the codisposed waste totals 5.6 m^3/day. The potential for water from the co-disposed wastes to discharge via the drainage layer and weep hole would be limited to extended and persistent wet periods (see Section 5.6 5.6 Coarse-textured drainage layer, cover system and surface drainage) and in the model represents an average discharge of 3.3 m^3/day from the weep hole under steady state conditions.

4.4 PREDICTED WATER QUALITY IMPROVEMENTS

Fundamental to the design of the Days Creek remediation system is the attainment of water quality improvement in the downstream receiving environment. This will be achieved through the control of acid generation and release from the co-disposed wastes through:

- maintaining saturation of the sulfidic components of the co-disposed wastes; and
- incorporating sufficient calcium carbonate into the co-disposed wastes to neutralise any acid generated from jarosite dissolution.

Rainfall infiltration through the coarse-textured layer is designed to maintain saturation of the co-disposed wastes, but there is expected to diffusional exchange between pore water within the co-disposed wastes and the pore water within the coarse-textured layer. This exchange is predicted to impact on the quality of the seepage water discharging from the coarse-textured layer into the Days Creek diversion. A water quality dilution model (Hydrogeological Modeling – Solute Transport) was developed to estimate the likely net water quality in Days Creek downstream of the finished Day Creek domain.

Pore Water Quality in Days Creek Impoundment

Water quality results for the leachate from column leach tests containing the proposed ratio of waste rock, tailings and limestone (Table 7; refer to Appendix F) provide the best available indication of pore water quality in the co-disposed wastes that will potentially seep to groundwater or discharge to the surface through the embankments. The water quality analyses summarised in Table 7 indicate that the column leachate water was characterised by:

- pH values that are near-neutral (pH: 6.5);
- moderate electrical conductivity (approximately 4,000 µS/cm) values associated with elevated sulfate concentrations (approximately 1,400 mg/L);
- elevated acidity values (approximately 700 mg/L $CaCO_3$) and elevated alkalinity concentrations (approximately 650 to 700 mg/L $CaCO_3$); and
- dissolved Fe, Mn and Zn concentrations of approximately 3.0 mg/L, 3.0 mg/L and 0.3 mg/L, respectively

Table 7. Indicative pore water quality from the co-disposed wastes materials based on column leach testwork.

Parameter	Units	Co-Disposed Wastes Pore Water
pH		6.54
EC	µS/cm	4010
Acidity	mg/L $CaCO_3$	708
Acidity - calculated	mg/L $CaCO_3$	13
Alkalinity	mg/L $CaCO_3$	685
Residual alkalinity	mg/L $CaCO_3$	0
Ca	mg/L	702
K	mg/L	12
Mg	mg/L	60
Na	mg/L	216
Sulphate	mg/L	1390
Chloride		
Fluoride	mg/L	0.1

Parameter	Units	Co-Disposed Wastes Pore Water
Dissolved Metals		
Al	mg/L	<0.01
As	mg/L	0.002
Cd	mg/L	0.0002
Cr	mg/L	<0.001
Cu	mg/L	0.004
Fe	mg/L	2.93
Mn	mg/L	2.54
Ni	mg/L	0.111
Pb	mg/L	0.001
Zn	mg/L	0.277
pH		6.54

The diffusional exchange between the co-disposed wastes pore water and the infiltrating rainwater in the coarse-textured layer is expected to have a small impact on the final Days Creek water quality when seepage of excess infiltration water discharges sideways into the Days Creek diversion.

Receiving Surface Water Quality

Following construction, the Days Creek Domain remediation is expected to lead to:

- improvements in Days Creek water quality, by preventing the mixing of Days Creek with mine-impacted water;
- improvements in Dawesley Creek water quality, due to:
  - increased dilution of treated runoff from the site with clean water from the Days Creek catchment;
  - reductions in the hydraulic load to the WTP (increasing the capacity of the WTP to treat peak flow events, resulting in less contaminated water bypassing the WTP); and
- reductions in acidity load to the WTP, due to:
  - relocation and geochemical stabilisation of a portion of sulfidic waste from the NWRD, SWRD and TSF;
  - incorporation of limestone to neutralise acidity relating to jarosite dissolution within the co-disposed wastes.

As previously noted, highwall drainage and seepage from the embankments will be contained on site and pumped to the WTP. Therefore, the key controls on surface water quality in the remediated Days Creek, at the confluence with the Dawesley Creek diversion, will be:

- Days Creek water quality upstream of the mine site (refer to Attachment I); and
- seepage water quality from the coarse-textured drainage layer overlying the co-disposed wastes.

A dilution model was developed to investigate whether the water quality in Days Creek would be suitable for direct discharge to the Dawesley Creek diversion. The dilution model enabled prediction of seepage water quality resulting from diffusional mixing of clean rainwater infiltrating through the impoundment cover system and the pore water within the co-disposed wastes (refer to Table 7) on a daily basis.

The dilution modelling for a preliminary remediation design configuration indicated that during particularly low rainfall conditions an additional water retention layer would be required to lower the potential for oxidation of the co-disposed sulfidic wastes. This additional layer, comprising a 300 mm thickness of non-sulfidic tailings and 6 wt% $CaCO_3$ (to neutralise any jarosite from the tailings) was subsequently incorporated into the detailed remediation design.

Based on revised dilution modelling conducted for the currently proposed remediation design, Days Creek water quality is expected to be characterised by near-neutral pH, with elevated sulfate and iron at times, but considerably improved water quality relative to the pore water within the co-disposed wastes (Table 7), due to dilution. Thus, Dawesley Creek is not expected to be adversely affected by inflows from the remediated Days Creek Domain.

Groundwater

Excavation to competent bedrock and grouting, where needed, around the perimeter of the proposed Days Creek impoundment will limit seepage from the co-disposed wastes to groundwater. When combined with the predicted improvement in pore water quality within the co-disposed wastes, this will reduce long-term contributions of acid and heavy metals to the groundwater.

While improvement in downstream surface water quality can be expected eventually, water quality in surface water receptors over a time frame of <10 years may decline as impacted groundwater is discharged into surface water (e.g. Pump Site 1; Golder, 2015). Measureable improvements in local groundwater quality are unlikely to be achieved in the short-term as a result of this first stage of the mine site remediation as long as the SWRD, part of the NWRD, and the bulk of the TSF remain in place, AMD impacted recharge and leakage from these areas will continue to degrade groundwater quality which will, in turn, discharge to the original Dawesley Creek channel (from where it is pumped to the WTP). Desired improvements in groundwater quality will be achieved in the longer-term following remediation of the entire Brukunga Mine site.

Remediation of Days Creek Domain may have some impacts on local groundwater levels due to the placement of significant tonnages of co-disposed wastes in the former mine pits. Under these conditions, groundwater levels may increase locally, and increased discharge of impacted groundwater that currently is underneath the mine pits to the original Dawesley Creek channel is likely to occur. This represents discharge of the current impacted groundwater quality in the area and will be characterised by high acidity, and elevated sulfate and metals concentrations, consistent with current discharge of groundwater to surface water. Eventually, seepage from the Days Creek impoundment will enter the groundwater system, improving groundwater quality (Golder, 2015). As described above, this seepage will be characterised by elevated sulfate and iron concentrations (due to jarosite dissolution in the co-disposed wastes), but its pH will be near-neutral. Consequently, the concentrations of other metals and the acidity load associated with seepage derived from the remediated Days Creek Domain will be substantially lower than those in the existing AMD-impacted groundwater.

5. DAYS CREEK DOMAIN REMEDIATION COMPONENTS, ISSUES AND DESIGN SOLUTIONS

This chapter sets out the details of the Days Creek Domain remediation components, issues and design solutions.

5.1 EXISTING MINE SURFACES IN THE DAYS CREEK DOMAIN

Oxidation of pyrite and pyrrhotite in the waste rock, tailings, mine benches and highwalls has led to the development of , its seepage to groundwater and discharge to surface water. Another feature of the mine workings, particularly in the pits, is the presence of jarosite precipitates associated with evaporation of acidic groundwater that discharges at the surface. Jarosite precipitates are of concern due to the potential acidity that can be released during future jarosite dissolution. Consequently, it needs to be removed from the pit floors and disposed of safely.

In addition, there are domestic and industrial waste materials in several areas of the pits and in the Shepherds Creek Gully, stockpiles of sludge from the WTP along the base of the highwall, and several mounds of waste rock material from previous trials on the mine bench.

The design solutions for this component of the Days Creek remediation project include:

- removal and off-site disposal of rubbish and non-mine waste materials;
- removal of jarosite from the pits and treatment elsewhere on the Brukunga mine site;
- stripping of WTP sludge to the southern end of the mine bench;
- removal of vegetation;
- construction of the highwall drain to accommodate potential future sloughing of rock slabs from the highwall;
- excavation of fractured, weathered rock in a cut-off trench around the perimeter of the impoundment;
- dental concrete slope corrections to the floor of the trench; and
- cement grouting to a pattern and intensity sufficient to lower the saturated permeability of the remaining foundations to the target maximum of 10^{-8} m/s.

5.2 HIGHWALL DRAIN

The highwall to the west of the Days Creek domain is intended to remain in its current state as part of the total Brukunga Mine site remediation. Accordingly, this part of the site will be left intact during the proposed Days Creek works.

Additional trenching to extend the length of the existing highwall drain, and construction of a rock-armoured clay bund along the eastern side of existing highwall drain, will be required to divert potentially acidic runoff from the highwall. The proposed highwall drain cross-section is presented in Figure 9. The width of the drain allows for long-term sloughing of rock from the highwall as it weathers.

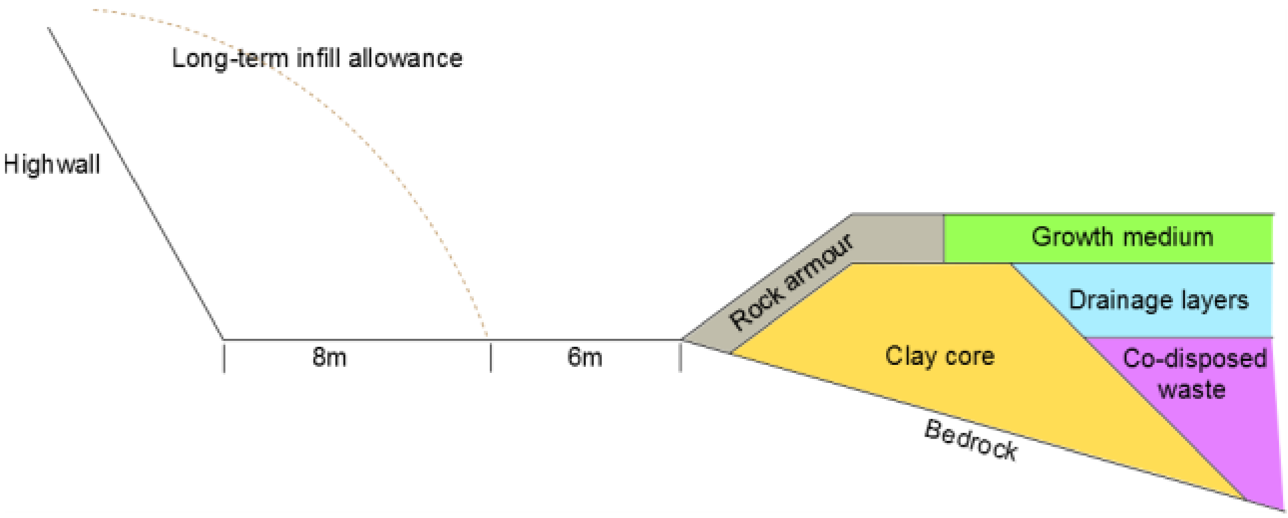

Figure 4. Highwall drain cross-sectional design.

5.3 EMBANKMENTS

A low permeability embankment is proposed around the perimeter of the proposed impoundment containing the co-disposed wastes. Embankments, as shown on Figure 10, are required:

- above the foundation level along the eastern side south of the proposed Days Creek diversion;
- along the south end of the mine bench; and
- along the western edge abutting the highwall drain.

A similar cross-section has been adopted for each of the embankments, with the main design criterion being to achieve a barrier with a maximum saturated permeability of 10^{-8} m/s extending from the crest of the impoundment to the sound low-permeability bedrock. It is proposed that the embankments be constructed as far as practical from materials that can be won on site. These materials include clean NAF clay from local quarries and clean rock fill sourced from the construction of the Days Creek diversion. A typical cross section of the eastern embankment is presented in Figure 11.

The main features of the embankment design are:

- a 3 m wide clean NAF compacted clay “core” inclined in the downstream direction. This is the prime seepage control but is inclined to reduce the volume of clean fill materials (NAF) in the downstream shell and maximise the use of low permeability waste (LPW) in the upstream shell;
- a 1 m thick filter to prevent piping through the clay core;
- foundation preparation requiring excavation of permeable, fractured weathered rock under the LPW;
- a grout curtain to seal permeable fractures in the remaining foundation rock; and
- a concave profile to the outer face to mimic natural landforms.

Figure 5. Location of proposed embankments (hatched brown).

The compacted NAF clay core design is based on maintaining the phreatic surface within this zone to maintain permanent saturation of all materials in the impoundment, thus preventing the formation of acidic drainage from the co-disposed wastes.

- The LPW will have a target maximum saturated permeability of 10-8 m/s and is expected to be derived from:fines won from screening waste rock;
- finegrained tailings; and
- blended fines won from screening waste rock and tailings.

Review of sonic boreholes in the NWRD (Jacobs, 2015) indicates that the proportion of fine materials (sand, silt and clay) in the NWRD varies from approximately 30 to 50%. This suggests that adequate fine-grained material will be available to achieve similar results to the original Stage 2 trial embankment as opposed to the coarser-grained material used in the Phase 3 trials.

The target grading for the crushed waste rock fines will be limited by practical screening limitations, with the current recommendation (Jacobs, 2015) of a screen aperture size of 10 mm considered the minimum practical to prevent screen clogging. It could possibly be larger depending on the results of pre-construction trials. Jacobs (2015) indicate that the saturated permeability of compacted, screened, fine-grained waste rock will achieve the target maximum of $1x10^{-8}$ m/s.

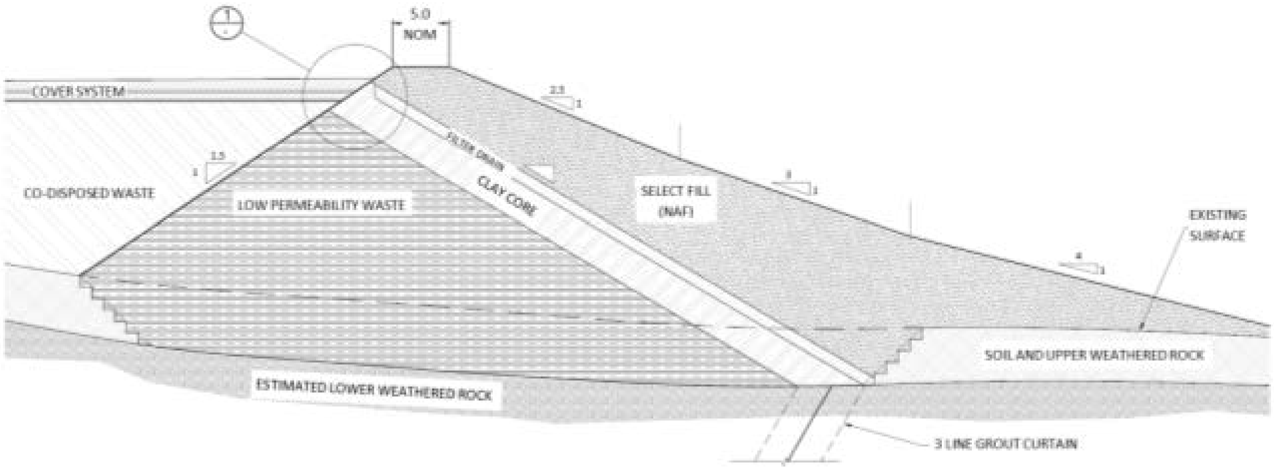

Figure 6. Typical embankment cross-section.

The main embankment will form the most prominent visual element of the Days Creek domain remediation design and will be appropriately revegetated, as will the other embankments around the perimeter of the impoundment.

5.4 DAYS CREEK DIVERSION CHANNEL

Days Creek is currently located within the alignment of the proposed eastern embankment. It is proposed that Days Creek be diverted from its current alignment to:

- enable construction of the eastern embankment;
- provide a source of clean rock for the embankment construction; and
- separate this source of clean water from acid producing material including the co-disposed material.

It is proposed that Days Creek be re-aligned tight against the natural surface that will be exposed beneath the existing NWRD to maximise the space available for co-disposed material on the existing mine bench. Geological investigations undertaken to date suggest that the proposed alignment is free of acid generating materials. It is proposed that the diversion:

- not be subject to erosion;
- not be subject to accelerated aggradation; and
- not overtop and inundate the cover over the co-disposed material.

The proposed design meets these criteria. The analysis and design has included:

- analysis and review of sediment generation from the catchment;
- estimation of velocity of flows in flood events; and
- analysis and design of the diversion designs.

The catchment investigations revealed that the Days Creek catchment supplies and delivers very low levels of coarse-grained sediment to the Days Creek domain. Most of the limited coarse-grained material that is supplied to and transported in Days Creek is deposited upstream from the site in the backwater created by Peggy Buxton Road.

It is proposed that the Days Creek diversion be excavated through bedrock. The bedrock will be resistant to the velocities of 1.1 m/s expected in major flood events. The proposed diversion has a capacity of 10.8 m^3/s, capable of handling up to the 1 in 1000 year average recurrence interval (ARI) event. Flood events up to this level are not expected to overtop the diversion banks and inundate the proposed cover system; however, larger floods can. Modelling has shown that flow velocities in even the largest probable flood should not lead to any erosion of the cover system over the co-disposed wastes.

A low bed grade has been adopted for much of the diversion across the bench, adjacent to the NWRD. However, a steep, 1 in 3 grade is proposed to discharge flows from the bench down 30 m to the Dawesley Creek floodplain. An energy dissipation pond has been allowed for in the design at the bottom of this steep section.

The Days Creek diversion terminates at a pipe connection that allows delivery of clean water to the Dawesley Creek diversion. Due to economic factors, the size of this pipe is limited and there will be some overflow of contaminated water during storm events that exceed the 2-year ARI event.

A longitudinal profile and a typical cross-section of the proposed Days Creek diversion are shown in Figure 12 and Figure 13, respectively.

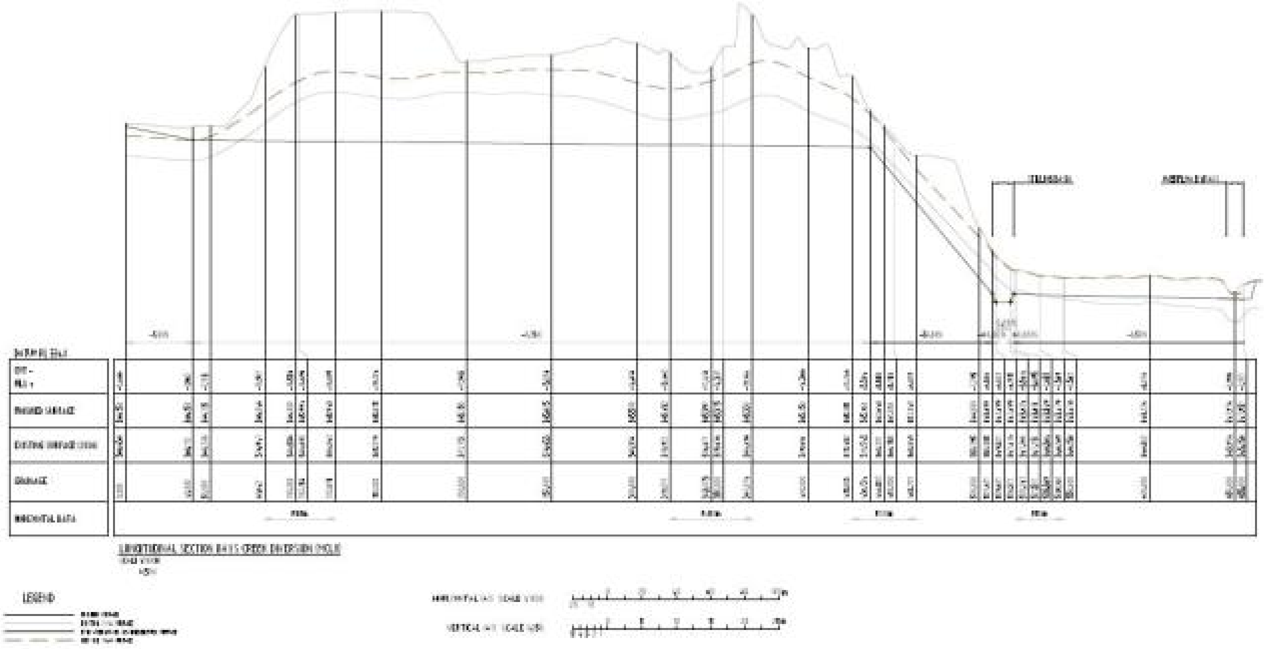

Figure 7. Days Creek longitudinal bed profile.

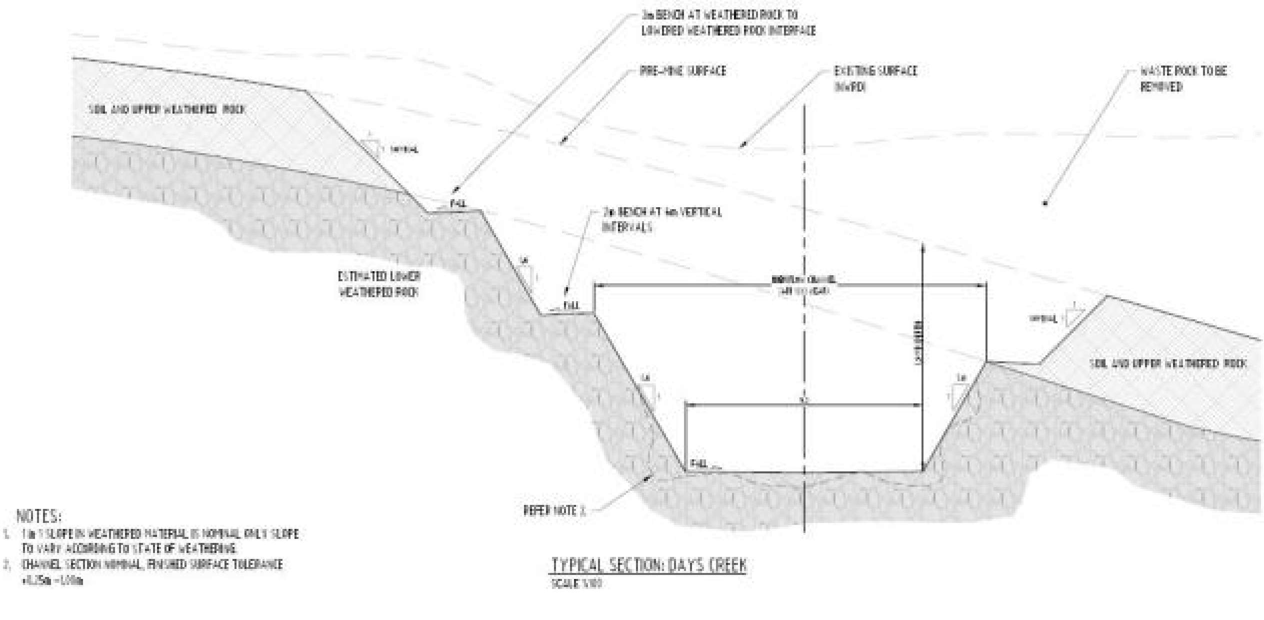

Figure 8. Days Creek typical cross-section.

5.5 CO-DISPOSED WASTES

Early investigations revealed that the proportions of wastes present in the WRDs and TSF were close to that necessary for the optimum co-disposal of the coarse and fine-grained wastes. Detailed column leach testing on saturated co-disposed samples to identify the optimum mixtures (61 wt.% waste rock: 39 wt.% tailings) identified that the presence of secondary acid salts (e.g. jarosite) had the capacity to generate substantial soluble acidity even in the absence of oxygen. Jarosite and similar acid-storing sulfate minerals are generated at Brukunga by the interaction of sulfuric acid (from sulfide oxidation) with minerals such as biotite, muscovite and feldspars. While jarosite formation involves at least partial acid neutralisation, the mineral temporarily stores acidity, which is readily released on dissolution. The process of sub-aqueous disposal would exacerbate jarosite dissolution and acidity release.

While sulfide oxidation can be controlled via sub-aqueous disposal, acidity release from jarosite dissolution can be controlled by limestone addition. Calculations were conducted to identify the minimum limestone addition necessary to prevent acidification following the proposed sub-aqueous disposal. The calculations were based on the static geochemical characteristics of about 30 representative samples of waste rock and tailings. The addition of 4 wt.% limestone was identified as being optimal. Additional column leach tests were conducted on co-disposed wastes with limestone concentrations varying from 0 to 6 wt.%. After several months of monitoring the column leach testwork, the mixture containing 60 wt.% waste rock, 36 wt.% tailings and 4 wt.% $CaCO_3$ was confirmed as the most appropriate for safe disposal of jarositic mine wastes. The addition of 4 wt.% $CaCO_3$ was considered the minimum safe proportion of limestone to permit complete jarosite acidity neutralisation and to prevent significant acidity contributions to surface water and groundwater. The 4 wt.% $CaCO_3$ refers to the effective $CaCO_3$ content in the limestone amendment, not the wt.% of limestone.

Table 8. Proposed composition of co-disposed material.

Material	Mixing Ratio
Waste Rock	60%
Tailings	36%
$CaCO_3$ (in Limestone)	4%

5.6 COARSE-TEXTURED DRAINAGE LAYER, COVER SYSTEM AND SURFACE DRAINAGE

The co-disposed wastes are to be capped by a cover system whereby the water table is decoupled from the atmosphere (i.e. not linked to the atmosphere by water in the unsaturated zone). To support this remediation option, the cover system needs to be designed to achieve the following objectives:

- to control net percolation by providing sufficient opportunity for downward water flux at a level that maintains the water table elevation above the top of the co-disposed wastes, while also limiting upward flux and losses of water through evaporation and evapotranspiration;
- to provide sufficient lateral drainage to minimise the potential for water logging of the growth medium due to water table rise during periods of excess water; and
- to minimise the potential for erosion of the cover.

The following design criteria were developed to achieve these objectives:

- the probability of the water table exceeding the top of the co-disposed wastes should be 95% or greater in any given year;
- the probability of co-disposed wastes being greater than 85% saturated should be 99% or greater in any given year;
- the probability of the water table remaining below the atmospheric decoupling point should be 90% or greater in any given year; and

- the probability that the water table remains below the root zone should be 95% or greater in any given year.

The cover system design was closely linked to the embankment design and hydrogeological flow modelling, since the designs derived from these complementary studies determine the rate at which water leaves the Days Creek impoundment and thus define the net percolation requirements of the cover system. The performance of the design in terms of meeting these objectives was tested through modelling on a transient basis under a variety of climatic conditions (e.g. prolonged drought and extended wet periods) and was evaluated probabilistically.

The approach adopted for analysis of the cover system and coarse-textured drainage layer are set out in Attachment H and documented in Jacobs 2014 Detailed Design report.

The initial concept proposed by the TAG (2009) for the cover design consisted of three layers:

- a growth medium suitable for supporting vegetation;
- a filter layer; and
- a coarse drainage layer to decouple the atmosphere and to facilitate drainage of excess water into Days Creek.

Analytical and numerical modelling undertaken and reported in Jacobs (2014) and Golder (2015) largely supported this concept and provided further constraints on material parameters. Based on these analyses, it is proposed that soakaways be included in the design as a means of improving infiltration, particularly during drier than average conditions. It is proposed that soakaways be used as the primary means of delivering percolation to the co-disposed wastes, with no reliance on the growth medium to achieve this. The basis for this proposal is:

- the texture contrast between a growth medium and a coarse, underlying drainage layer is not conducive to percolation, with the growth medium options evaluated displaying poor performance (negligible percolation) during dry conditions;
- by contrast, soakaways are effective in allowing regular percolation to occur, even in response to minor rainfall;
- the cover system can be designed with a focus on dry periods rather than average conditions. If regular percolation can be delivered by soakaways during dry periods at a level that meets the performance criteria, then the cover need not be over-designed such that excessive percolation leads to waterlogging during wet years;
- the remaining area of the cover system (i.e. adjacent to the soakaways) can still be comprised of a growth medium to support vegetation; and
- material used for the growth medium will have to be imported from off site or manufactured on site by combining or crushing clean materials. If the growth medium is not being relied upon to deliver a certain amount of percolation then its specification can be relaxed, providing some cost savings.

Consequently, a final design was developed that incorporated zones of coarse-grained, rocky material (soakaways) within the cover system to facilitate higher net percolation rates to the co-disposed wastes. A cross-section for the proposed cover system, including the soakaways, is provided in Figure 14.

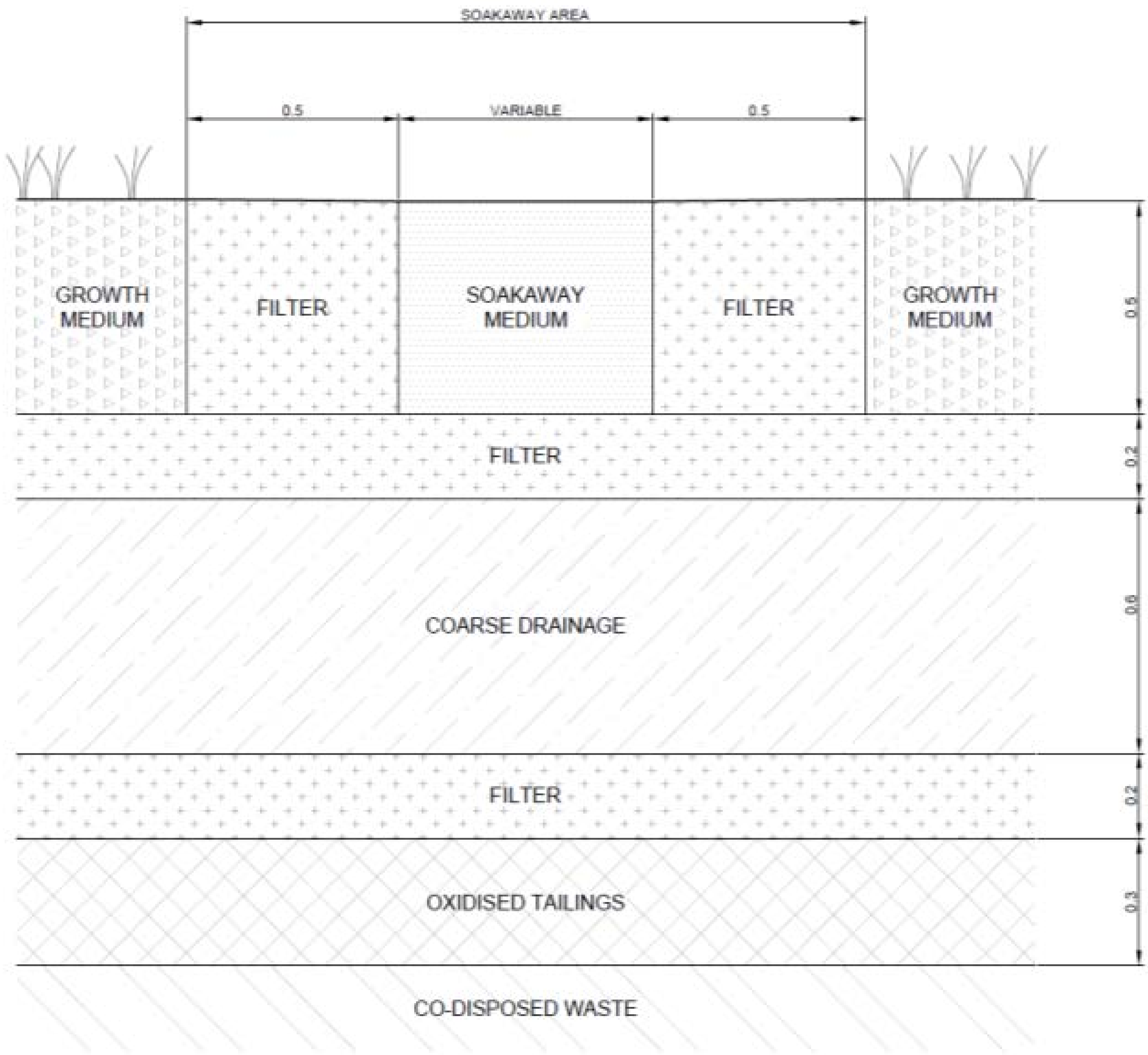

Figure 9. Cover system cross section.

The cover system materials comprise the following:

- Growth medium: well-graded sandy loam of nominal thickness 300 mm.
- Filter layer: fine uniformly-graded sand layers 200 mm thick above and below the coarse drainage layer with max 5% passing 75 m.
- Coarse material: a coarse uniformly-graded gravel drainage layer 600 thick with max particle size 20 mm and max 5% passing 4.75 mm.

Particle size distribution curves for the coarse material and filter layer is provided in Figure 15.

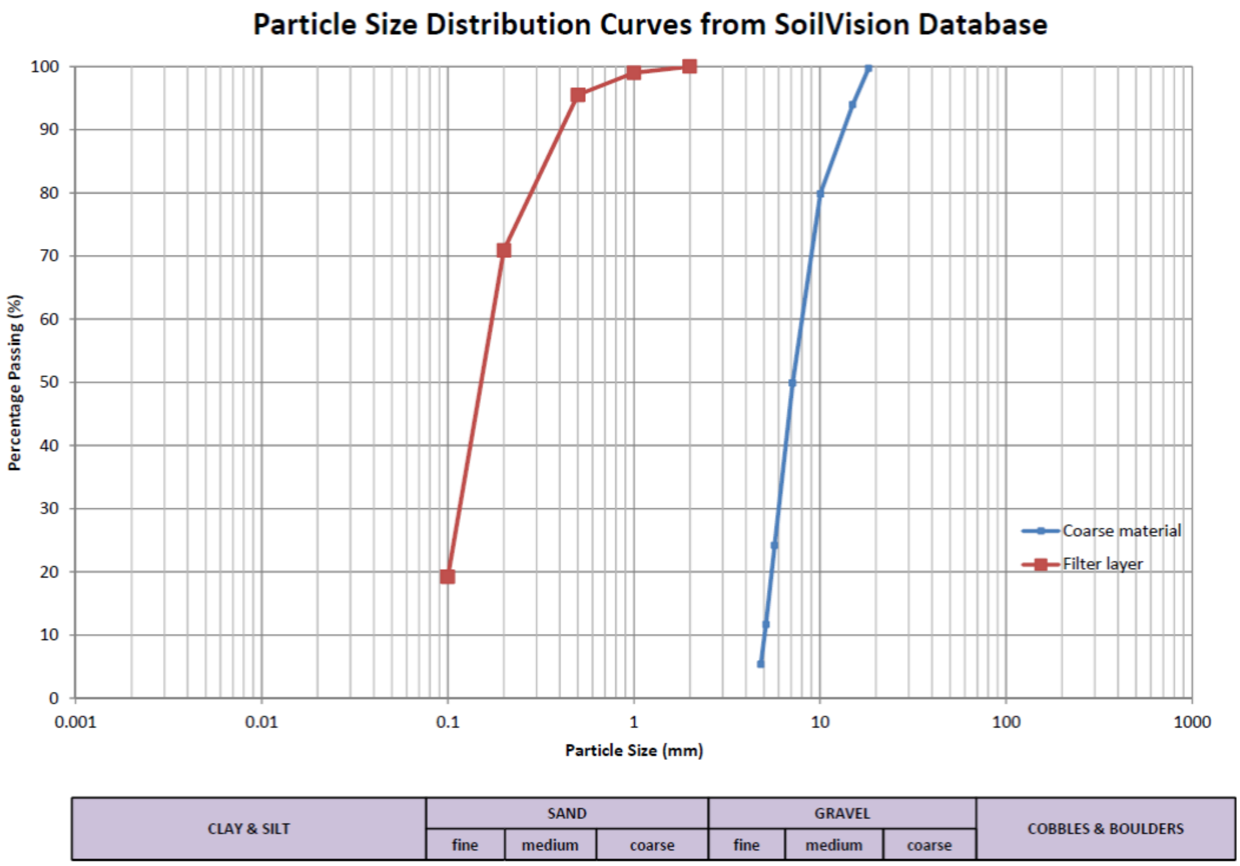

Figure 10. Particle size distribution curves for coarse material and filter layers.

Oxidised tailings layer

Hydrogeological modelling (Case 12.4T; Golder, 2015) applying rainfall from a 10-year 'dry' climate period indicated that, although typically maintained at or above 0.2 m within the coarse-textured drainage layer, water levels would drop to approximately 0.2 m below the top of the codisposed material for short periods. Water levels, and saturated conditions would recover quickly; however, during these periods, the potential for oxidation of the co-disposed sulfidic wastes increases. To reduce the risk of sulfide oxidation, it is proposed that the co-disposed sulfidic waste be capped with a 300 mm layer of non-sulfidic (fully-oxidised) tailings from the surficial portion of the TSF. This layer provides a further 300 mm of very fine-grained, saturated, non-sulfidic material to substantially limit oxygen penetration into the co-disposed wastes, even during extended dry periods.

Fully-oxidised tailings contain elevated concentrations of acidity-generating jarosite. To avoid acidity release from the sub-aqueous disposal of jarosite-bearing tailings, the 300 mm layer is to be mixed with 6 wt.% limestone. This quantity of limestone is calculated to be sufficient to neutralise the jarosite acidity.

Coarse-textured drainage layer

The coarse-textured drainage layer consists of poorly-graded (uniformly-sized) medium gravel. This material has to be coarse-grained in order to maximise its lateral drainage capacity and to minimise capillary action. Selecting a material that is poorly-graded and has a low packing density due to its uniform size enhances these characteristics.

The coarse-textured drainage layer needs to be sufficiently thick and permeable to facilitate the drainage of excess water via the proposed weep drain to Days Creek, which has been designed to be of sufficient capacity to meet this requirement. The results of 2D and 3D numerical modelling provided design constraints on the hydraulic conductivity and thickness of the coarse-textured drainage layer and on the required lateral connectivity with Days Creek, to allow sufficient drainage during wet periods. Filter layers above and below the drainage layer will be required to protect the it from clogging with overlying growth material or underlying wastes.

Based on the analyses, the drainage layer should comprise a uniformly-graded gravel of predominantly 5 to 15 mm particle size, with a saturated permeability of 10^{-2} m/s.

Soakaways

Numerical modelling revealed that in the absence of percolation, the water table drops at a rate of approximately 70 mm/year, resulting in partial desaturation of the co-disposed wastes after a period of approximately 7 years. According to the design criteria, the probability of partial desaturation occurring must be less than 5% in any given year. Therefore, the percolation rate must not be less than the steady-state saturation requirement as defined by the 3D modelling (about 5 mm/yr) for 7 consecutive years nor any more than five times a century (Golders 2015). The probability that this requirement is met in any given year is equivalent to the 67th percentile of the percolation record (0.67 to the power of 7 is approximately equal to 5%). Therefore, the cover system as a whole must deliver at least 5 mm/year in 33 out of 100 years, and the long-term average percolation should exceed 5 mm/year. Based on the percolation data for the soakaways, this would require that at least 1.25% of the cover system area be comprised of soakaways.

Soakaways should be distributed in a manner to aid percolation across the cover system during dry periods and to assist with lateral drainage during wet periods. Placement of soakaways to promote percolation in the area up-gradient of the eastern embankment, which the 3D modelling identified as the area most prone to the potential development of unsaturated conditions in the upper co-disposed wastes, would also be beneficial. Connecting the soakaways and promoting drainage to the south-east of the impoundment would further enhance these functions.

Soakaways should consist of coarse highly permeable material extending from the drainage layer to the surface, to provide a direct, highly permeable conduit to the water table. Based on the results of the modelling, the soakaways should comprise uniformly-graded coarse gravel of approximately 50 mm in size.

The soakaways have been designed to mitigate the risk of clogging from siltation or the accumulation of organic matter that could adversely affect their infiltration performance. Using large-sized material lowers the probability of blockages occurring. Filters have been incorporated into the design to restrict the migration of fines from the adjacent growth medium and to protect the underlying drainage layer.

A factor of safety of four has been applied to the area of soakaways, requiring that 5% of the cover system area comprise soakaways.

Some limited ongoing maintenance of the soakaways will likely be required through time (e.g. clearing vegetation that may encroach over time, or flushing the material to remove blockages).

Growth medium and vegetation

The growth medium should be at least 500 mm thick to provide a level of protection to the underlying drainage layer. The growth medium should be composed of a material with a fines content (particle size < 20 μm) of at least 10%, ensuring that it can retain enough moisture and nutrients for vegetation. The bulk density of the material should ideally be less than 1.80 g/cm^3 to allow for root growth and sufficient aeration.

The establishment of trees and deep-rooted perennials should be discouraged from the surface of the growth medium, as these may penetrate into the drainage layer and draw water from the water table. An annual pasture mix (e.g. annual ryegrass and sub clover species) is common in the region and can be used to support grazing practices, which would also be of benefit to discouraging tree growth. Alternatively, a low maintenance native grass cover could also be established over the cover.

Filter layers

Soil particles from the growth medium have the potential to clog the drainage layer and soakaways. Filter layers are proposed to prevent this from occurring. Filter layer materials were selected in accordance with the criteria developed by Terzaghi (1948) as outlined in Lambe and Whitman (1979), which are based on the particle size distribution curves of the overlying and underlying layers. Filters will also be required between the drainage layer and the fully-oxidised tailings layer.

5.7 FINAL LANDFORM DESIGN

Overview

A robust final landform is proposed for Days Creek remediation program. A design life of up to 1000 years has been adopted for the final landform reflecting the desire for a robust, low maintenance outcome. Components that make up the final landform include:

- the highwall and the highwall drain;
- the Days Creek diversion;
- The residual part of the NWRD;
- The majority of the SWRD;
- the cover system;
- the eastern embankment within the Days Creek valley;
- the northern embankment; and
- The majority of the TSF.

In addition, some temporary components are required as interim measures pending the completion of the entire site remediation. These temporary designs include:

- the southern embankment on the existing bench; and
- a temporary diversion of Days Creek over the contaminated on-site reach of Dawesley Creek.

It is proposed that the final landform associated with the remediation of Days Creek be consistent and compatible with that proposed for the remediation of the broader site.

While a “walkaway” solution was desired, the final landform will require some level of ongoing management and maintenance. However, the level of management and maintenance associated with the proposed works and landform can be expected to be orders of magnitude less than that required for the current site. Significant areas of ongoing monitoring and management will be associated with the management of the major embankment and impoundment under the requirements of ANCOLD (2012), in addition to site safety management, particularly associated with the remaining highwall and Days Creek diversion, and stock management over the remediated land, in particular over the co-disposed material cover system.

Highwall and highwall drain

The proposed design for the highwall and highwall drain result in a robust, low maintenance landform. While some ongoing collapse of the weathered elements of the highwall will occur, much of the weathered material will collect on existing benches on the highwall. Some material is expected to fall, from the benches and areas of the highwall below the benches, into the proposed highwall drain. However, the highwall drain has been sized to accommodate such rock falls without impacting the performance of the drain or the adjoining cover system.

Days Creek diversion and NWRD

The Days Creek diversion will be constructed in competent rock and is not expected to undergo any significant erosion. The reach of the diversion has low sediment supply and is not likely to be subject to gross sediment accumulation. Rock falls from the adjoining NWRD are unlikely as all waste rock in the Days Creek catchment of the NWRD will be removed and that part of the NWRD will be returned as far as practicable to natural surface elevations. It is proposed that the land underlying the NWRD be revegetated with native vegetation.

Cover systems

It is proposed that the co-disposed wastes be protected with a robust cover system that will be resistant to wind and rain through the selection of material and through appropriate vegetation establishment. The infiltration zones, within the cover system, necessary for the permanent saturation of the co-disposed wastes have been over-sized, making provision for potential blockage through a build-up of vegetation. The Days Creek diversion and the highwall drain have been designed to ensure that flood events would rarely (if ever) inundate the cover system. Days Creek has been designed to contain the 1,000-year ARI event. A review of the velocity of flow over the cover system during the probable maximum flood reveals a low velocity that is unlikely to mobilise the material and its vegetative cover.

Eastern Embankment

The proposed eastern embankment has been designed to contain the co disposed wastes for in excess of 1,000 years. The design has included assessment of potential failure modes, including scour and seismic loading. It is proposed that the surface of the embankment be covered with a low maintenance ground cover. Ongoing maintenance will be required to prevent establishment of shrubs and trees on the embankment.

Tailings storage facility

The Days Creek remediation includes the removal of some tailings from the TSF. It is proposed that, where possible, the tailings be removed to natural surface levels and that a temporary embankment be installed to retain the remaining tailings. Land returned to natural surface will be revegetated with appropriate low maintenance native vegetation.

6. CONSTRUCTION METHOD AND SCHEDULE

6.1 DESIGN DRAWINGS AND PROJECT DOCUMENTATION

Detailed design drawings for the proposed Days Creek remediation works are provided in Jacobs 2015 Feasibility Design – Combined and Detailed Design reports.

The design drawings show details of earthworks and associated infrastructure required to achieve the design objectives and strategy as outlined in this report. They are backed-up by reports on the design basis design development and technical specification These documents are provided under a separate cover to this report.

The construction would be expected to be undertaken by an experienced civil/mining contractor and the construction drawings and specifications have been developed with this expectation in mind. The nature of the work is not straightforward and requires a number of decisions to be made during construction in order to achieve the design intent in an economical and technically feasible manner. Accordingly, many of the construction activities are covered by Schedule of Rates items to give the construction team the ability to vary materials and construction methods to achieve the required outcome. This is appropriate given the extent of the site that is currently buried in waste rock or tailings and the variable nature of the ground conditions. As a consequence, the project team must include suitably-skilled and experienced personnel, acting on behalf of the DSD, supervising the works.

6.2 SUGGESTED CONSTRUCTION TEAM

Project contract documents have not been prepared and these will depend on the nature of the contract envisaged by DSD. However, the TAG recommend that the construction team have a defined and robust technical QA/QC system that includes regular input from the designer and TAG support and a reporting, sign-off and certification component to ensure that the design intent is met. An example of a structure that could be appropriate is presented in Figure 16.

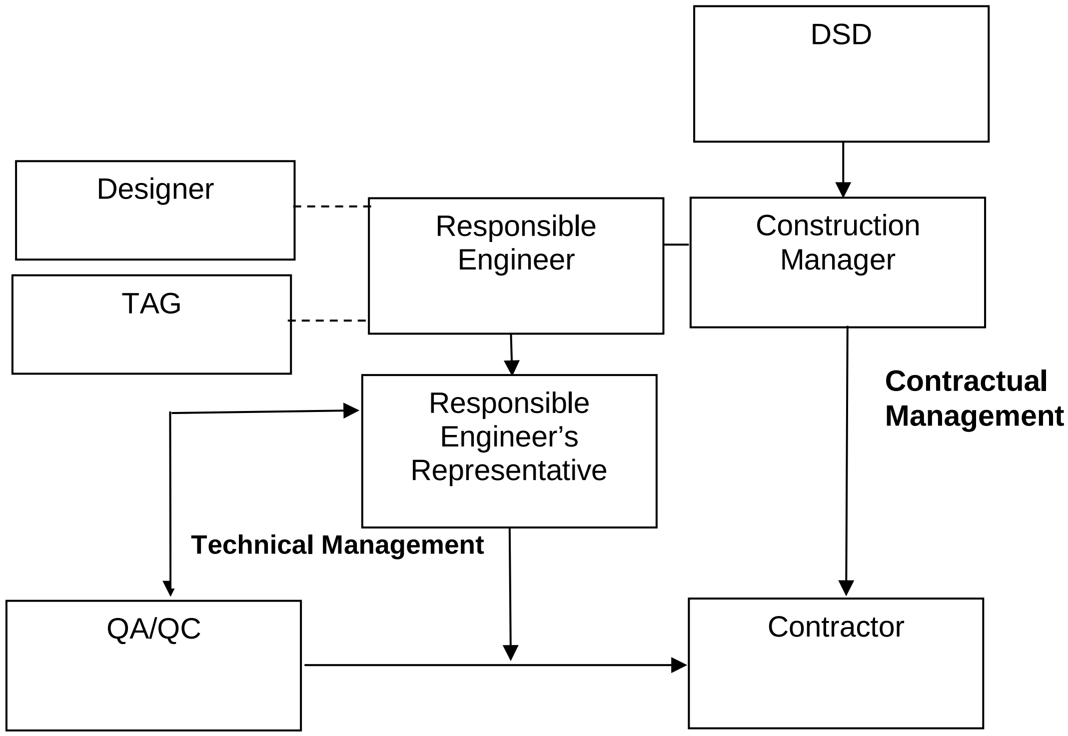

Figure 11. Possible construction team structure.

6.3 CONSTRUCTION ISSUES

Preparatory works

A range of preparatory works are required prior to placement of wastes in the impoundment area, including the following.

Removal of jarosite sludge from the mine voids – Jarosite sludge has been formed by the oxidation of pyrite and precipitated in drains and shallow ponds at the base of the north and south mine voids. Jarosite poses a risk to the co-disposed wastes as it can break down and release sulfuric acid when exposed to water. For this reason, it is proposed to remove the jarosite sludge from the Days Creek domain. Removal of an estimated 500 m^3 of jarosite sludge has been allowed for. Stockpiling within an impoundment containing an appropriate quantity of intimately mixed, ultra-fine grained limestone will permit *in situ* neutralisation. Regular water addition to the impoundment may be required, and regular monitoring will permit the neutralisation progress to be monitored. The fully treated materials will comprise gypsum, ferrihydrite and soluble potassium sulfate. The fully-treated jarosite sludge is likely to be suitable as a soil amendment and could potentially be used around the grassed areas of the mine site.

Removal of gypsum sludge – An estimated 8000 m^3 of gypsum sludge from the Brukunga Water Treatment Plant has been stockpiled on the mine bench. Gypsum is soluble in acidic conditions and has the potential to release contaminants if included in the co-disposed wastes. This material is to be removed and stockpiled in the southern mine bench area. The long-term plan for this material is for encapsulation in a cell within the wider Brukunga site.

Removal of organic materials – Various organic materials, including vegetation, and organic domestic and industrial wastes, are located within the mine voids, in Shepherds Creek and over areas to be excavated. Organic material is undesirable in the waste impoundment for various reasons, including its impact on the geochemistry of the wastes and also in view of potential long-term settlement impacts. Accordingly, all organic material is to be removed and disposed offsite.

Reworking of previous trial waste materials – Early waste rock amendment trials, the Phase 2 trial embankment and the Phase 3 trial embankment materials are to be removed and reworked as necessary to comply with the current specification for waste placement.

Perimeter cut-off trench and grout curtain

A key feature of the design of the co-disposed wastes, as determined by seepage analyses, is the provision of a perimeter cut-off with a maximum saturated permeability of 10^{-8} m/s. This can be achieved by a combination of excavation of fractured and weathered rock, where practical, supplemented by cement grouting. Drilling of cored holes and permeability testing has determined that the site is characterised by an upper weathered rock layer and a lower weathered rock layer over an essentially tight bedrock. The upper weathered layer is typically 3 to 6 m below natural surface level and has a saturated permeability in the order of 10^{-4} m/s. The lower weathered rock zone has a saturated permeability of approximately 10^{-8} m/s, controlled primarily by joints and fractures. In reality, a range of conditions is expected. Over the mine bench much of the upper weathered rock zone has been removed, other than in the vicinity of Shepherds Creek, and will be substantially removed along the Days Creek diversion. This means that the highest permeability foundation is likely to be beneath the eastern embankment foundation.

The construction methodology for the preparation of foundations will comprise:

- excavation of the upper weathered rock zone around the perimeter of the impoundment using heavy earthmoving equipment with rippers and narrow rock buckets. The intention is to remove the more permeable rock features, including soft, highly-fractured rock and soil over a minimum width of 6 m. Over much of the perimeter the trench will be shallow, but around Shepherds Creek and the Eastern Embankment a trench is likely to be typically 5 m deep, with locally deeper sections;

- excavation will extend to either refusal for the heavy equipment, or to a suitable tight rock surface, to facilitate effective grouting. It is not proposed to allow blasting, due to the potential for fracturing of the rock formation, but limited mechanical rock-breaking may be required for local batter correction;
- where the exposed foundation is judged by the Responsible Engineer to be unusually permeable, the width of the cut-off trench should be widened to either remove the permeable feature or to allow capping with a low permeability blanket;
- the floor of the trench is likely to be uneven and may contain permeable features such as fractured zones or clay-filled joints. These will need to be thoroughly mapped by a geologist and then addressed by local excavation and slope correction with “dental concrete”, as required and directed by the Responsible Engineer. The resulting trench floor should be relatively even and trafficable by grouting equipment;
- an assessment of the need for and detail of grouting will be made by the Responsible Engineer, following review of the trench mapping. This will be followed by the setting out of primary holes in the areas to be grouted. The angle and target depth of the holes will be determined on site. Due to the steep easterly dip of the bedding in the project area, it is anticipated that grout holes will be angled to the west in order to intercept the maximum number of rock features. However, other angles may be necessary if suspected permeable features run across the bedding direction. Primary holes should typically be drilled to a depth approximately equal to the potential height of the embankment above the trench floor and will range from approximately 20 m to a nominal 5 m. Allowance must be made for the angle of the hole;
- in areas were intense grouting is expected, primary holes should be at 6 m centres. In areas where grouting is expected to be limited, the spacing could be increased to 12 m or even 24 m, with constant head (at low pressure) or rising head (pump-out) permeability testing being carried out prior to grouting to determine the local permeability;
- grouting of primary holes should then be undertaken in stages of approximately 5 m using either upstage or downstage grouting methodology;
- a decision on the need for secondary grout holes will need to be made by the Responsible Engineer based on the outcomes of the primary hole grouting;
- similarly, decisions on subsequent grouting of tertiary or further holes will depend on records from earlier holes in the area as assessed by the Responsible Engineer;
- final permeability checking in highly-grouted areas should be undertaken by drilling a centrally placed hole and carrying out constant head (at low pressure) or rising head (pump-out) permeability testing; and
- following grouting the floor of the trench should be cleaned up to remove any loose or potentially permeable material and the surface “slush” grouted with a thin slurry of cement grout placed immediately prior to placing clay core or LPW.

Backfill of cut-off trench

In most areas, the cut-off trench will be backfilled with clay or LPW. A minimum width of clean compacted clay (with a maximum saturated permeability of 10^{-8} m/s) of 5.9 m measured horizontally (translates to a thickness perpendicular to the face of 3 m) is required. This is supplemented by a width of LPW to make up the total width of low permeability material equal to the total embankment height at the section. The target maximum saturated permeability for LPW is also 10^{-8} m/s.

A sand filter downstream of the clay core is required at the eastern and southern embankments.

Embankments

The perimeter embankments vary in height around the perimeter and in some areas, such as the Days Creek diversion, are not required. The embankments feature a limited clay core supplemented by an upstream LPW shell. On the downstream side a sand filter is required where the embankment is higher than 2 m above the final surface of the downstream side. The downstream shell comprises selected NAF rock, likely to be well-graded and relatively fine-grained. Coarse rock pitching is required on the sections of batter subject to water flow, such as the western Highwall Drain and Days Creek diversion.
The intention of the design is to maximise the use of site-won materials for construction to avoid the need for the importation of materials. The required excavation of Days Creek diversion is expected to provide some clay and a significant volume of NAF rock. There could be some localised pyrite seams within the required excavations and these will need to be identified and removed separately for incorporation into the impoundment.

The construction of the containing embankments should be staged to suit the exposure of materials during the removal of waste rock and do not need to be constructed in advance. It would be possible to place most of the co-disposed wastes in advance of the final containing embankments if appropriate controls on erosion and stormwater management are implemented.

Co-disposed wastes

BLENDING OF TAILINGS AND LIMESTONE

The tailings borrow area is located on the southern side of the TSF and is designed to access a range of tailings weathering and moisture conditions. The borrow excavation is intended to expose a significant area of natural ground to be rehabilitated. The remaining tailings batter will be left at a stable slope of 3(H):1(V) and revegetated.

The process for mixing tailings and limestone will be similar to the process successfully used during the Phase 3 10,000 tonne trial, where an appropriate thickness of limestone was spread evenly over a prepared area of tailings then a layer of appropriate thickness excavated and loaded into trucks for transport . The layer thicknesses can be developed to suit the site equipment, provided that adequate mixing is achieved. For the Phase 3 trial, the contractor (Lucas Earthmoving) elected to excavate a nominal 550 mm combined layer of tailings (500 mm) and limestone (47 mm). No active mixing took place at the TSF, although the action of excavating and transporting the materials to the trial area provided nominal mixing.

PREPARATION OF WASTE ROCK

As discussed in Appendix G the Phase 3 trial embankment highlighted problems with achieving compaction of the mixed wastes due to oversize rock, although this was possibly exacerbated by placing the materials too wet. Nevertheless, it has been determined that for the actual project works it will be necessary to remove and crush larger rock pieces to achieve a better, more consistent compaction result. From the Phase 3 trial, a maximum size of 400 mm is proposed. In addition, there is a need to produce 165,000 m^3 of LPW, which is proposed as selected clayey waste rock screened to achieve the required permeability. Jacobs propose screening to 10 mm maximum size, however the TAG have reservations that this will be achievable and also that it could limit the availability of suitable material. A maximum particle size of 75 mm might be more practical. This will need to be confirmed on site, with input from the construction contractor.

The waste rock preparation will thus comprise:

a. majority of general mix:
    - pre-screening with a 400 mm grizzly,
    - primary crushing oversize to nominal 300 mm minus,
    - re-blending, and
    - transfer to disposal area for tailings/limestone blending;

b. LPW:
   - pre-screening with a finer grizzly or screen (size to be confirmed),
   - blend screened fines with limestone as use as LPW, and
   - mix oversize back to general mix preparation.

BLENDING AND PLACING OF TAILINGS/LIMESTONE WITH WASTE ROCK

For the Phase 3 trial (Appendix G), targeting a 1 m deep compacted layer, the loose mix was initially placed at a nominal 1.2 m thickness, comprising approximately 0.7 m of waste rock, 0.5 m of tailings and 0.05 m of limestone. The mixing of the tailings/limestone blend with waste rock should follow a similar process to that successfully used in the Phase 3 trial embankment. This will involve:

- moisture-conditioning the prepared waste rock to wet of optimum moisture content;
- spreading a layer of moisture-conditioned waste rock of appropriate thickness targeting a final mixed and compacted layer thickness of 1 m;
- placing a layer of mixed tailings/limestone of appropriate thickness;
- mixing, using excavator, bulldozer or other method; and
- checking and calibration to ensure adequate mixing and moisture levels.

The mix was compacted using a High Energy Impact Compactor (HEIC). The HEIC used in the Phase 3 trial is shown in Figure 17. This equipment featured on-board telemetry systems to capture the response of the ground to the passes by the machine, which are referred to as the Continuous Impact Response (CIR) and Continuous Induced Settlement (CIS) measurement systems. The CIR is a technique for monitoring the ground response to the loads delivered by the twin drum HEIC with fully integrated GPS for accurate positioning, producing an indication of the ground strength/stiffness across an entire layer during the compaction process. The CIS employs a differential GPS, which allows for levels to be accurately recorded during the compaction process. Neither system directly measures the degree of compaction; the data obtained have to be correlated with *in situ* data.

Figure 12. Impact Roller at Phase 3 trial embankment.

Cover layer

The cover layer would be prepared by shaping the compacted waste material to the required lines and levels being an effectively horizontal surface. This will be overlain by a series of layers comprising:

- 300 mm selected oxidised tailings;
- 200 mm lower filter;
- 600 mm coarse drainage layer;
- 200 mm upper filter; and
- minimum 500 mm growth medium or soakaway medium.

It is proposed that the growth medium will be NAF soil or weathered rock with at least 10% fines and able to support vegetation. The soakaway medium comprises uniformly-graded gravel with a maximum particle size of 50 mm. These layers will be placed and spread to the required levels and compacted.

The design is based on sufficient water being delivered by the soakaways to maintain a permanent water level within the coarse drainage layer, with inflows at least equal to seepage from the facility, thus maintaining the saturation of the co-disposed wastes.

The maximum water level in the drainage layer is controlled by a “weep drain” along the western Days Creek bank. This allows discharge of excess water to Days Creek.

Days Creek diversion

Days Creek currently runs through the eastern edge of the proposed impoundment area and needs to be diverted through the eastern ridgeline over the northern end of the site. This requires excavation through the natural rock with the expected generation of substantial construction materials for embankments and the cover system. The current design details the minimum excavation, and can be adjusted to suit the requirement for materials in conjunction with the type of material exposed in the excavation.

The northern extent of the diversion is relatively flat-graded, which will result in low flow velocities and limited risk of erosion. However, the southern end drops steeply across the ridge and will feature higher flow velocity. It is expected that the channel floor will be in the lower weathered rock, which should be competent and resist erosion. In addition, flow will be generally perpendicular to the rock bedding, which will mean that harder bands noted in field mapping will control the erosion. Some concrete has been allowed for in the design to strengthen weaker areas.

Excavation could require blasting. This will need to be carefully controlled to reduce risk of vibration and fly-rock damage, and to minimise blast damage tio otherwise tight rock.

Highwall drain

The highwall drain is designed to collect acidic runoff from the highwall and direct it to the south of the waste impoundment. Construction of the drain will require minor excavation, but mainly filling of the invert in order maintain sufficient fall to allow drainage.

6.4 SCHEDULE OF CONSTRUCTION

Jacobs have developed a construction program that allows for the progressive implementation of the works and results in completion within a period of 11 months, assuming a start in January 2016 and based on a single-shift, 5-day week operation. This short time frame has been assumed to minimise the time of the works to reduce overheads and mobilisation/demobilisation costs. However TAG believe this time frame is a stretch target and, given the range of different operations and materials involved, will require a substantial fleet of equipment and a high degree of management. The major items of excavating, crushing, mixing and placing of just over 1.3 Mm^3 of earth and rock extending over a period of approximately 200 days would require an average placement rate of approximately 6,700 m^3/day. An alternative approach would be to stretch the project over a number of years using a smaller core fleet of equipment with staging of specialist projects such as grouting and crushing being programmed appropriately. A construction period of 5-6 years would be feasible with additional overheads being relatively minor. The selection of a construction timeframe is relatively flexible and can be adjusted to suit budget limitations.

A slower construction timeframe is likely to have the advantage of allowing ongoing assessment of the performance of the system against modelled and design expectations and for progressive implementation of revegetation. An evaluation period of up to 5 years is expected following final construction works being completed, resulting in an overall project time frame in the order of 10 years.

7. REMEDIAL ACTION PLAN- MANAGING AND MONITORING FOR SUCCESS

7.1 INTRODUCTION

A draft remediation action plan had been developed for the site. The draft remediation action plan is provided in Attachment A to this report and has been developed in recognition that the success of the project is reliant on the ongoing management, monitoring, evaluation, reporting and improvement of environmental conditions at the site.

7.2 OBJECTIVES

The TAG has set the objective to develop a "walk away" remediation solution for the Brukunga Mine site, measured against the "do-nothing" and ongoing water treatment options. This remediation solution should aim to ensure that water quality in Dawesley Creek emanating from the Brukunga Mine site is suitable for domestic (excluding human consumption), stock and primary production purposes.

Key objectives of the "walk-away" remediation strategy for the Brukunga Mine site included:

- avoiding the need to intercept and treat AMD indefinitely;
- ensuring that water quality in Dawesley Creek downstream of the Brukunga Mine site would be suitable for domestic (excluding human consumption), stock and primary production purposes, and comply with the EPA Water Quality Policy;
- returning all or part of the site back to productive use(s) or for environmental ecosystem value(s); and
- applying leading practice to site management and the remediation option(s) and solution(s).

The Days Creek remediation project comprises the first stage in the remediation of the Brukunga Mine site. Objectives for this stage include:

- commencing the progressive remediation of waste rock and tailings at the Brukunga Mine site by co-disposal of of AMDgenerating materials;
- demonstrating the feasibility of the saturated co-disposal strategy so that it can be implemented with confidence over the entire site;
- generating improvements in the water quality of Days Creek downstream of the mine pits;
- preserving water quality from upstream in Days Creek through clean water diversion, and thereby:
  - increase clean water flows to and downstream of the Dawesley Creek diversion, and
  - decrease the hydraulic load on the acid water storage-pump back system, and water treatment plant; and
- creating a self-sustaining landscape with manageable human health and safety, and environmental risks over the remediated lands.

Success of the Days Creek remediation project comprises the attainment of these objectives.

7.3 MANAGEMENT AND MONITORING TO ENSURE SUCCESS

- Management and monitoring of the site is proposed to meet both regulatory requirements and the specific objectives of the Days Creek remediation project. To this end, management and monitoring of the site is required before, during and after the construction phase. Elements of the management and monitoring program within these phases include:site water management and monitoring
  - surface water quality and flows entering and leaving the site,
  - groundwater quality and elevations within and adjoining the site, and

  - WTP loads and by-pass;
- site environmental management and monitoring
  - saturation of the co-disposed material,
  - dust,
  - noise,
  - vegetation, and
  - landform stability;
- site safety management and monitoring:
  - highwall stability,
  - embankment stability,
  - Days Creek stability and flows, and
  - WTP operation.

An evaluation program will be implemented to assess the outcome from the monitoring and management program.

7.4 LICENSES AND APPROVALS REQUIRED

The legal and regulatory procedures and approvals that are required for the commencement of the rehabilitation of the Brukunga Mine site, including the project approvals and permits and/or licences required for specific activities have been outlined by DSD (PIRSA, 2009). DSD has identified the relevant statutory authorities that are involved in the approval process, the timeframes required to gain regulatory approval and what actions are required, i.e. stakeholder consultations, detailed planning and design.

The major parts of the proposed remediation that require statutory approval are:

- Development Approval for the whole of the remediation project through the Development Assessment;
- Commission (DAC) as either a Crown Development or declared a Major Development or Project. The relevant legislation is the Development Act 1993; and
- Environmental approval(s) through the Environmental Protection Authority (EPA) either through the provisions of the Environmental Audit process or through specific licensing to the site. The relevant legislation is the Environment Protection Act 1993.

Being located within the District Council of Mount Barker, Brukunga Mine will be assessed against the council-wide and specific objectives of the Mount Barker Development Plan. The Development Regulations 2008 list Brukunga as a site of major environmental significance, and all development approvals relating to the site are required to go through the Development Assessment Commission (DAC).

The Brukunga Mine Rehabilitation Project is expected to be assessed either as a Crown Development, or Major Development or Projects development. DAC will determine the assessment criteria that best facilitate the approval process during the pre-lodgement negotiations. DAC will refer the development application to (as a minimum):

- the Environmental Protection Authority;
- the Natural Resources Management Board;
- Mount Barker Council;
- Department of Environment, Water and Natural Resources; and
- the Minister for Water and the River Murray.

DSD will refer the proposed development to DAC, who will identify key social, environmental and economic issues relevant to the assessment of the development. Following consultation with State agencies DAC will set the assessment level and guidelines for the development. Given the extensive data base for the site the likely assessment level is a Public Environmental Report (PER).

The DAC will publically release a Guidelines document to DSD as to what level of assessment is required and what issues that assessment should address. DSD will then prepare the PER and arrange a public meeting (if required), respond to any public or agency comments and amend the PER as deemed appropriate.

The relevant Minister will prepare an Assessment Report on the proposed development and the development proposals will be refined in response to the Assessment Report. A decision on the final proposal may attach conditions if approval is given.

The environmental impacts of the project will be assessed by the Environmental Protection Authority during the planning approval process. An Environmental Management Plan (EMP) will be prepared by DSD to ensure that the measures identified and commitments made in the environmental assessment process are delivered in the construction and operational phases of the project. The scope and content of the EMP is a function of the potential impact and environmental significance of the project. The EMP provides the basis for the construction contractor to develop and document how the environmental management requirements should be implemented during construction. The contractor’s final (EMP) will include inspection and monitoring for compliance with the environmental outcomes.

7.5 AUDITING/THIRD PARTY REVIEW

A third part auditor was appointed during Phase 2 of the project. The auditor is currently Mr Phillip Mulvey of Environmental Earth Sciences. The audit was undertaken with consideration of SA regulatory requirements including SA EPA’s Remediation to the Extent Necessary (RTEN) process. Phase 2 of the project has been audited and the RTEN report for that phase has been issued.

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ATTACHMENT A
DRAFT REMEDIAL ACTION PLAN – DAYS CREEK DOMAIN

Introduction

A draft remediation action plan had been developed for the site. The draft remediation action plan has been developed in recognition that the success of the project is reliant on the ongoing management, monitoring, evaluation, reporting and improvement of environmental conditions at the site.

The impacts of acidic drainage on downstream water quality at Brukunga triggered:

- the inclusion of the Brukunga mine site and the acid neutralisation plant in the Environmental Protection Act 1993;
- the requirement for the owner/manager of the site to hold a licence under that Act; and
- the requirement to undertake an extensive surface water quality monitoring program to assess the impacts of the site.

The Brukunga mine site and infrastructure is as follows:

SITE LOCATION	The site is located west and southwest of the township of Brukunga, lying between Pyrites Rd to the east and farmland to the west. It is noted that an additional portion of the former mine, located to the east of Pyrites Rd is beyond the scope of this investigation.
PROPERTY DESCRIPTION AND CERTIFICATE OF TITLE	Allotment 28 Filed Plan 9068, CT Volume 5841 Folio 589; Allotment 1 Deposited Plan 45003, CT Volume 5378 Folio 425; Allotment 80 Filed Plan 157515, CT Volume 5597 Folio 441; Allotment 30 Filed Plan 9068, CT Volume 5486 Folio 440; and Allotment 100 Deposited Plan 24651, CT Volume 5555 Folio 603.
SIZE OF INVESTIGATION AREA	Approximately 138 hectares (estimated from Certificates of Titles)
LOCAL GOVERNMENT AUTHORITY	District Council of Mount Barker
ZONING	See Section 2.3
CURRENT OWNERSHIP	Minister for State Development
CURRENT LAND USE	Former Mine Site and Acid Water Neutralisation Plant
PROPOSED LAND USE	See Section 2.3

Principles underpinning the approach to remediation and management

The impacts of AMD on downstream water quality at Brukunga triggered:

- the inclusion of the Brukunga mine site and the acid neutralisation plant in the Environmental Protection Act 1993;
- the requirement for the owner/manager of the site to hold a licence under that Act; and
- the requirement to undertake an extensive surface water and groundwater quality monitoring program to assess the impacts of the site on the surrounding environment.

The objectives of South Australia's (SA) *Environment Protection Act 1993* contain and describe the principles underpinning the approach to remediation and management of site contamination in SA as follows.

The objects of the act are:

a) to promote the following principles (principles of ecologically sustainable development):

(i) that the use, development and protection of the environment should be managed in a way,

and at a rate, that will enable people and communities to provide for their economic, social and physical wellbeing and for their health and safety while:
(a) sustaining the potential of natural and physical resources to meet the reasonably foreseeable needs of future generations;
(b) safeguarding the life-supporting capacity of air, water, land and ecosystems; and
(c) avoiding, remedying or mitigating any adverse effects of activities on the environment.
(ii) that proper weight should be given to both long and short term economic, environmental, social and equity considerations in deciding all matters relating to environmental protection, restoration and enhancement.

b) to ensure that all reasonable and practicable measures are taken to protect, restore and enhance the quality of the environment having regard to the principles of ecologically sustainable development, and
(i) to prevent, reduce, minimise and, where practicable, eliminate harm to the environment:
(a) by programmes to encourage and assist action by industry, public authorities and the community aimed at pollution prevention, clean production and technologies, reduction, reuse and recycling of material and natural resources, and waste minimisation;
(b) by regulating, in an integrated, systematic and cost-effective manner:
- *activities, products, substances and services that, through pollution or production of waste, cause environmental harm; and*
- *the generation, storage, transportation, treatment and disposal of waste;*

(ii) to establish processes for carrying out assessments of known or suspected site contamination and, if appropriate, remediation of the sites
(iii) to co-ordinate activities, policies and programmes necessary to prevent, reduce, minimise or eliminate environmental harm and ensure effective environmental protection, restoration and enhancement
(iv) to facilitate the adoption and implementation of environment protection measures agreed on by the State under intergovernmental designs for greater uniformity and effectiveness in environment protection
(v) to apply a precautionary approach to the assessment of risk of environmental harm and ensure that all aspects of environmental quality affected by pollution and waste (including ecosystem sustainability and valued environmental attributes) are considered in decisions relating to the environment
(vi) to require persons engaged in polluting activities to progressively make environmental improvements (including reduction of pollution and waste at source) as such improvements become practicable through technological and economic developments
(vii) to allocate the costs of environment protection and restoration equitably and in a manner that encourages responsible use of, and reduced harm to, the environment with polluters bearing an appropriate share of the costs that arise from their activities, products, substances and services
(viii) to provide for monitoring and reporting on environmental quality on a regular basis to ensure compliance with statutory requirements and the maintenance of a record of trends in environmental quality
(ix) to provide for reporting on the state of the environment on a periodic basis
(x) to promote:
(a) industry and community education and involvement in decisions about the protection, restoration and enhancement of the environment and
(b) disclosure of, and public access to, information about significant environmental incidents and hazards.

The regulatory basis for the remediation and management of the site contamination
The regulatory basis for remediation falls under the guidance of the following Acts and Regulations:

- Environment Protection Act 1993
- Environment Protection Regulations 2009
- Development Act 1993
- Planning Advisory Notice 20

- Mining Act 1971
- Mining Regulations 2011

Responsibility for regulating and/or administering processes
In South Australia, the EPA is the lead agency for the management of contaminated sites with support from local government and the police.

Remediation and management planning, implementation and validation
Remedial action plan
The preparation of a RAP is required for all remediation projects. The RAP includes the following components.

Objectives
The TAG has defined that the objective is to develop a "walk away" remediation solution for the Brukunga Mine site, measured against the "do nothing" and ongoing water treatment options. This remediation solution should aim to ensure that water quality in Dawesley Creek emanating from the Brukunga Mine site is suitable for domestic (excluding human consumption), stock and primary production purposes.

Key objectives of the "walk-away" remediation strategy for the Brukunga Mine site included:
- substantially limiting or avoiding the need to intercept and treat acidic drainage indefinitely;
- ensuring that water quality in Dawesley Creek downstream of the Brukunga Mine site would be suitable for domestic (excluding human consumption), stock and primary production purposes, and comply with the EPA Water Quality Policy.
- returning all or part of the site back to productive use(s) or for environmental ecosystem value(s); and
- applying leading practice to site management and the remediation option(s) and solution(s).

Extent of remediation necessary – description of site
The Days Creek remediation provides for the saturated co-disposal of sulfidic waste material with limestone in an impoundment within the disused mine pit. The size of the impoundment has been optimised to provide a cost effective solution within the constraints of anticipated project budgets.

The sulfidic material comprises both waste rock from the northern waste rock dump (NWRD) and tailings from the TSF. It is proposed that the impoundment be created through the construction of low permeability embankment across the Days Creek valley. It is proposed that Days Creek be realigned to protect the cover system and co-disposed material from stream related erosion. It is proposed that material excavated from the realignment of Days Creek be used in the construction of the embankment.

The impoundment will have a robust, high infiltration cover to maximise the inflow of surface water to the co-disposed material, and seepage control to limit the loss of water from the co-disposed material. Both the high infiltration cover and the seepage control are aimed at ensuring the co-disposed material remains saturated. A lateral drainage layer zone will be provided between the cover and the co-disposed material to allow the overflow of surplus infiltration into a realigned Days Creek.

Procedures and plan to reduce human and environmental risk
Fundamental to the design of the Days Creek remediation system is the control of acid generation and subsequent enhanced dissolution of metals in the co-disposed wastes through:
- maintaining saturation of the co-disposed wastes; and
- incorporating sufficient calcium carbonate into the co-disposed wastes to neutralise acid generated from jarosite dissolution.

As a result of this design, the pH of the pore water in the co-disposed wastes will be near neutral, resulting in lower concentrations of dissolved metals such as aluminium and zinc in seepage and drainage from the impoundment.

Excavation to competent bedrock and grouting, where needed, around the perimeter of the impoundment will limit seepage from the co-disposed wastes to groundwater, thereby reducing long-term contributions of acid and heavy metals to groundwater. The cover of the impoundment is designed so that discharge through the drainage layer to the realigned Days Creek primarily comprises recharge through non-acid forming (NAF) materials. The potential for water from the co-disposed wastes to discharge via the drainage layer and weep drain would be limited to extended and persistent wet periods.

The recent extension to the Dawesley Creek diversion has reduced the volume of impacted water requiring treatment at the WWTP. Following construction, the Days Creek remediation, will lead to immediate:

- improvements in Days Creek water quality; and
- reductions in acidity load to the WWTP.

However, measureable improvements in groundwater quality are unlikely to be achieved as a result of this first stage of the mine site remediation. While the Southern Waste Rock Dump (SWRD), much of the Northern Waste Rock Dump (NWRD), and the bulk of the TSF remain in place, acid-impacted recharge and leakage from these areas will continue to degrade groundwater quality which will, in turn discharge to the original Dawesley Creek channel. Desired improvements in groundwater quality will be achieved in the longer term following completion of the entire Brukunga Mine site.

The construction of the Days Creek remediation may have some impacts on groundwater levels through loading due to the placement of co-disposed wastes in the former mine pits. Under these conditions, groundwater levels may increase locally, and increased discharge of impacted groundwater that currently is underneath the mine pits to the original Dawesley Creek channel is likely to occur. This discharge will be consistent with the current impacted groundwater quality in the area, namely characterised by high acidity, and elevated sulfate and metals concentrations. Eventually, the limited seepage from the Days Creek impoundment will enter the groundwater system and will be characterised by high sulfate and iron concentrations (due to jarosite dissolution in the co-disposed wastes) but, since its pH will be near-neutral, the concentrations of other metals will be lower than those in the existing acid-impacted groundwater.

Environmental safeguards to be implemented

During construction all clean water runoff, essentially Days Creek upstream water, will be diverted and prevented wherever possible to mix with mine-affected water (AMD water).

All runoff and seepage derived from mine affected areas that will be disturbed by the Days Creek remediation will be collected and pumped back to the treatment plant for treatment to an approved discharge water quality standard. This includes:

- earthworks associated with shaping the Days Creek waste storage precinct including the northern mine cut, mine bench and highwall;
- Days Creek within the mine precinct;
- the NWRD;
- the TSF; and
- access tracks through the mine precinct.

Dust suppression will be used for all active and exposed earthwork areas to limit fugitive dust in compliance with agreed air quality limits as set jointly by DSD and EPA.

Guidelines and policy for managing dust emissions include: Protection of health and the environment and compliance with the National Environment (Ambient Air Quality) Protection Measure 1998 (Air Quality NEPM). Codes of Practices include: Schedule B(2) Guideline on Protection of Health and the Environment during the Assessment of Site Contamination, Amended National Environment Protection (Assessment of Site Contamination) Measure 1999 (NEPC, 2013); and Guideline For Stockpile Management Waste and Waste Derived Products for Recycling and Reuse. South Australia EPA, September 2010.

It is noted that management of asbestos waste and asbestiform waste will managed under the RAP for non-AMD materials.

To ensure that construction activities do not result in air quality impacts that cause environmental nuisance or harm:

- burning of waste or litter is prohibited;
- works will be staged where possible, minimising disturbance;
- long-term stockpiles will be stabilised and/or covered where required;
- all vehicles hauling materials will be adequately covered, where there are visible dust emissions;
- existing vegetation will be retained wherever possible to assist in limiting dust levels;
- dust generating activities to be avoided or minimised during dry and windy conditions;
- where required, haul roads and site roads will be watered to minimise the generation of dust by traffic;
- mobile plant exhausts will not be directed downwards as this may cause dust to rise. Where activities are generating significant volumes of dust, dust collection or suppression devices will be considered to mitigate and control dust emissions;
- plant and equipment on site will be regularly serviced and maintained in accordance with the manufacturer's recommendations; and
- mud and dirt will not be carried on to the road from the site. Road construction activities will not be carried out in times of heavy rainfall.

There are no national air quality guideline values for the nuisance dust effect that can be used to assess the impact of dust on the receiving environment. However, there is a number of criteria commonly used by regulatory agencies in Australia. Generally, the criteria have been derived from subjective observations and investigation of dust levels and nuisance effects. A dust deposition limit of 120 milligrams per square metre per day, averaged over 1 month, when monitored in accordance with "AS3580.10.1 Methods for sampling and analysis of ambient air – Determination of Particulates – Deposited Matter – Gravimetric method, 1991", is frequently used in Queensland.

In some areas there may already be relatively high background levels of dust. If dust is a potential concern, deposition gauges should be used near sensitive receptors and the proposed construction site. The dust deposition data collected from the site will be analysed and the results compared against the above standards.

The Environment Protection (EP) Act 1993, the Environment Protection (Noise) Policy 2007 (Noise Policy) and the Occupational Health, Safety and Welfare Regulations 2012 provide guidance on noise levels that may be deemed excessive under the EP Act. It should be noted that the Act requires site-specific issues be taken into account when determining noise levels that may be excessive. Codes of Practice relevant to noise and vibration include: SA EPA Information Sheet – SA EPA Guidelines for the use of the Environment Protection (Noise) Policy 2007 (2009); Environmental Noise (May 2013), EPA Information Sheet 424/13; Construction Noise (April 2014), EPA Information Sheet 425/14; and Handbook for Pollution Avoidance on Building Sites (2nd ed. June 2004), EPA.

It is important to ensure that all practicable steps are taken to minimise the adverse effect that noise emissions may have on the amenity value of an area. This responsibility includes not only the noise emitted from the plant and equipment but also associated noise sources, such as radios, loudspeakers and alarms.

Most of the local earthworks involving excavation and co-disposal of tailings and waste rock will be shielded from the Brukunga town site that will assist with mitigating noise. Hours of operation will be confined daylight hours as specified by EPA.

Mitigation measures to be implemented during construction include the following:

- Plant and equipment will have noise suppression equipment and will be regularly maintained to ensure efficient performance and minimum noise emissions;
- Screening will be erected where required;
- Notification of nearby sensitive receptors will be undertaken a minimum of 7 days prior to construction works commencing;
- All site personnel will be informed during a site specific induction in relation to:
    - limiting use of audible signals;
    - unnecessary revving of engines; and
    - unnecessary engine braking.
- Where works have the potential to generate noise that may be audible at sensitive receptors, construction work shall not commence prior to 6.30am and shall be restricted to daylight hours, Monday to Friday. No works shall be carried out outside these hours without written approval from the Client; and
- Engines will be turned off when not in use.

Licenses and approvals required

The legal and regulatory procedures and approvals that are required for the commencement of the rehabilitation of the Brukunga Mine site, including the whole of project approvals and permits and/or licences required for specific activities have been outlined by DSD (PIRSA, 2009). DSD has identified the relevant statutory authorities that are involved in the approval process, the timeframes required to gain regulatory approval and what actions are required, i.e. stakeholder consultations, detailed planning and design.

The major parts of the proposed remediation that require statutory approval are:

- Development Approval for the whole of the remediation project through the Development Assessment;
- Commission (DAC) as either a Crown Development or declared a Major Development or Project. The relevant legislation is the Development Act 1993; and
- Environmental approval(s) through the Environmental Protection Authority (EPA) either through the provisions of the Environmental Audit process or through specific licensing to the site. The relevant legislation is the Environment Protection Act 1993.

Brukunga Mine is located within the District Council of Mount Barker and will be assessed against the council wide and specific objectives of the Mount Barker Development Plan. The Development Regulations 2008 list Brukunga as a site of major environmental significance, and all development approvals relating to the site are required to go through the Development Assessment Commission (DAC).

The Brukunga remediation project is expected to be assessed either as a Crown Development, or Major Development or Projects development. DAC will determine the assessment criteria that best facilitates the approval process during the pre-lodgement negotiations. DAC will refer the development application to (as a minimum):

- the Environmental Protection Authority;

- the Natural Resources Management Board;
- Mount Barker Council;
- Department of Environment, Water and Natural Resources; and
- the Minister for Water and the River Murray.

DSD will refer the proposed development to DAC, who will identify key social, environmental and economic issues relevant to the assessment of the development. Following consultation with State agencies DAC will set the assessment level and guidelines for the development. Given the extensive data base for the site the likely assessment level is a Public Environmental Report (PER).

The DAC will publically release a Guidelines document to DSD as to what level of assessment is required and what issues that assessment should address. DSD will then prepare the PER and arrange a public meeting (if required), respond to any public or agency comments and amend the PER as deemed appropriate.

The relevant Minister will prepare an Assessment Report on the proposed development and the development proposals will be refined in response to the Assessment Report. A decision on the final proposal may attach conditions if approval is given.

The environmental impacts of the project will be assessed by the Environmental Protection Authority during the planning approval process. It is envisaged that an Environmental Management Plan (EMP) and Remediation Management Plan (RMP) will be prepared by DSD to ensure that the measures identified and commitments made in the environmental assessment process are delivered in the construction and operational phases of the project. The scope and content of the EMP is a function of the potential impact and environmental significance of the project. The EMP provides the basis for the construction contractor to develop and document how the environmental management requirements should be implemented during construction. The contractor's final EMP will include inspection and monitoring for compliance with the environmental outcomes.

Technology to be used

Co-disposed wastes

The co-disposed wastes is a mixture of waste rock, tailings and imported limestone. The total volume of each co-disposed material, defined by the total disposal size and the materials ratio, forms a key input into the design of the borrow pits from where the materials will be sourced.

In accordance with the mixing ratios adopted in the field mixing and compaction trial (SKM, 2014), the following co-disposal wt% materials ratios have been adopted for general co-disposal materials volume calculations:

- Tailings: 35.5%
- Waste Rock: 60.5%
- $CaCO_3$: 4.0%.

Additionally, based on the results of oxygen consumption testing (Earth Systems, 2014), the following further direction on mixing ratios was received by Jacobs:

- There shall be a 300 mm oxidised tailings layer above the co-disposed material.
- There shall be 6 wt% $CaCO_3$ blending in the oxidised tailings and 6 wt% $CaCO_3$ blending in the top 1.5 to 2 m of the co-disposed wastes.

The adopted limestone proportions assume a pure material with high calcium carbonate content. In the case where a less pure limestone source is used, the mixing ratios will require adjustment according to the altered calcium carbonate content.

Compaction trials will be undertaken as part of the construction contract to confirm that the maximum material dimension and layer thickness are appropriate for the plant selected.

Mixing and placement of co-disposed wastes

The limestone tailings mix and the waste rock material will be blended through the use of a large bulldozer, rather than using an excavator as per the 10,000 t trial. Based on experience from the 10,000 t trial, the excavator option proved adequate for the task, but is considered to be a crude method for mixing. A large bulldozer will “blade mix” the material in a similar way to how a grader may be employed to mix materials on a road construction project. The advantages of the bulldozer are that it can handle large quantities of materials, can handle varying material types and sizes, and is able to mix 500 mm deep layers quite quickly.

The mixing area would be set up by placing the correct mix of limestone tailings and waste rock in windrows adjacent to each other, which could be done by truck weight or truck count of each material. The dozer will flatten the top of the stockpiles to a uniform depth and then tilt the blade and commence running along the prepared area perpendicular to the tipped loads, pushing and reeling the material together. Water carts will operate in conjunction with the dozer, flooding the area and getting moisture into the mixed materials. After repeated passes back and forth the material will become a well-mixed blend of the different materials.

Due to the sizing of the processed waste rock materials (200 mm down), a 500 mm thick compacted layer thickness has been assumed with compaction effected using heavy vibrating rollers or High Energy Impact Rollers.

Discharges and outputs

Raw acidic drainage

The following Table 1 is a compilation of water quality data referred to as raw which is based on acid and metalliferous drainage derived from all sources of runoff and seepage within the Brukunga mine precinct (NWRD, SWRD, mine cuts and benches, highwalls, haul roads, sludge stockpile, Days Creek, Dawesley Creek, ponded areas, TSF, etc.) that is captured and pumped back to the Water Treatment Plant for treatment. It is derived from the monitoring of feed water to the Treatment Plant and is provided as an Average Raw A.

Table 1. Raw AMD water quality.

Parameter	Units	Average Raw AMD
pH		2.7
EC	µS/cm	10,350
Ca	mg/L	418
Mg	mg/L	762
Na	mg/L	221
K	mg/L	21
Acidity	mg/L $CaCO_3$	10,377
Alkalinity	mg/L $CaCO_3$	0
Sulfate	mg/L	11,360
Cl	mg/L	458
Dissolved Metals		
Al	mg/L	898
As	mg/L	0.01
Cd	mg/L	0.2
Cr	mg/L	0.12
Cu	mg/L	0.71
Fe	mg/L	925
Mn	mg/L	97
Ni	mg/L	2.43
Pb	mg/L	<0.001
Zn	mg/L	49
Total Metals		
Al	mg/L	1094
As	mg/L	0.01
Cd	mg/L	0.22
Cr	mg/L	0.13
Cu	mg/L	0.74
Fe	mg/L	1,390
Mn	mg/L	98
Ni	mg/L	2.51
Pb	mg/L	<0.001
Zn	mg/L	60

Dilution Model

The dilution model utilises statistically generated historic daily rainfall and pan evaporation data for input hydrological parameters. This dataset includes daily data from 01/01/1908 to 31/12/2007. Any time interval inclusive of these dates can be entered as the Model Run Time. It is recommended that the model be run for no more than 10 year intervals to maintain efficient calculation speeds.

The "clean" Days Creak Catchment is defined as the Days Creek Catchment area, less the Co-Disposed Wastes Impoundment surface area.

For the "Clean" Days Creek Catchment, only a Surface Water Runoff Coefficient needs to be assigned as Net Percolation is not accounted for in this catchment area.

Evaporation of rainfall at the ground surface is calculated by applying an "Evaporation Coefficient" (from 0 to 1) which is multiplied by the daily, statistically generated Pan Evaporation values. Evaporation is only applied to days with rainfall.

Evapotranspiration losses apply to the Cover Layer and the Coarse-Textured NAF Layer units on a daily time step. Evapotranspiration losses occur daily regardless of rainfall and the depth below which evapotranspiration is assumed to be zero can be assigned in the model inputs.

For the Co-Disposed Wastes Impoundment Catchment, Net Percolation is calculated as the incident daily Rainfall, less Evaporation of Surface Water, less Evapotranspiration from the Cover Layer and Coarse-Textured NAF Layer, and less Surface Water Runoff. Therefore, Net Percolation into the Co-Disposed Wastes Catchment can be modified by adjusting both the percentage of Surface Water Runoff and the Evaporation/Evapotranspiration Coefficients.

Chemical diffusion of solute concentrations between the Co-Disposed Wastes pore water and water in the Coarse-Textured NAF Layer is applied on a daily time step. Species concentrations in the Coarse-Textured NAF Layer are determined by applying a near linear concentration gradient between the Co-Disposed Wastes pore water and the water in the Coarse Texture NAF Layer.

The Days Creek Assessment Point is located just upstream of the confluence between Days Creek and Dawesley Creek.

Co-Disposed Wastes pore water losses through groundwater are constant values applied each daily time step. Therefore, the minimum daily combined discharge at the Days Creek Assessment point is always greater than zero due to seepage into Days Creek.

Chemical concentrations are calculated only from dilution and evaporative concentration. Precipitation and dissolution of chemical species are not accounted for in this model. The inputs and outputs of the Dilution Model are summarised in Table 2.

Table 2. Dilution Model Input chemistry and output chemistry for days 8 and 4014.

Parameter	Units	Precipitation	Coarse-Textured NAF Layer	Diffusion Coefficients (m^2 day^{-1})	Output The model inputs and outputs are summarised in Tab	
Day					8	4014
Rainfall	mm				0.83	0.67
Water Level in CTNAF Layer above co-disposed wastes	mm				456.93	249.91
Discharge	m^3 day^{-1}				53.72	43.48
pH		---	---	---		
Electrical Conductivity	µS/cm	---	3,520	---		
Acidity	mg/L $CaCO_3$	---	4,995	---		
Alkalinity	mg/L $CaCO_3$	7	133	0.000079747	19.37	22.21
Sulfate	mg/L	3.63	4,805	0.000092016	453.57	559.55
Calcium	mg/L	3.32	230	0.000068429	24.66	29.69
Potassium	mg/L	0.57	318	0.000169085	30.33	37.34
Magnesium	mg/L	1.27	184	0.000060998	18.40	22.43
Sodium	mg/L	9.54	331	0.000115258	40.05	47.24
Aluminium	mg/L	0.01	0.005	0.000046742	0.010	0.010
Arsenic	mg/L	0.001	0.001	6.21216E-05	0.001	0.001
Cadmium	mg/L	0.0001	0.00005	0.000062122	0.00010	0.00010
Chromium	mg/L	0.001	0.001	0.000051408	0.001	0.001
Copper	mg/L	0.001	0.002	0.000061690	0.001	0.001
Iron	mg/L	0.001	1,855	0.000062122	174	215
Lead	mg/L	0.001	0.001	0.000081648	0.0010	0.0010
Manganese	mg/L	0.001	7.6	0.000061517	0.71289	0.88056
Zinc	mg/L	0.005	0.041	0.000060739	0.0086	0.0094

Timeframe of activity

The estimated timeframe for completion of the Days Creek remediation from commencement of construction to completion is 24 months. This will comprise 12 months for construction, 1 month for start-up, 1 month for completion and hand-over and 10 months for detailed works and vegetation establishment.

Expected endpoints and outcomes
The remediation of the Days Creek at the Brukunga Mine site seeks to:
- commence the progressive neutralisation of acid waste rock and tailings from the Brukunga mine site;
- demonstrate the feasibility of saturated co-disposal strategy in order that it can be implemented with confidence over the entire site;
- generate at least minor improvements in the water quality in Dawesley Creek downstream of the mine site;
- enhance the clean water diversion capacity of the site, and thereby decrease the hydraulic load on the available acid water storage-pump back system, and water treatment plant; and
- create a self-sustaining landscape with manageable human health and safety, and environmental risks over the remediated lands.

A fundamental output of the design of the Days Creek remediation is the control of acid generation and subsequent enhanced dissolution of metals in the co-disposed wastes through:
- maintaining saturation of the co-disposed wastes;
- incorporating sufficient calcium carbonate into the co-disposed wastes to neutralise acid generated from jarosite dissolution;
- reduction in the contaminated load being discharged to the WTP for treatment; and
- increase in the clean water flows discharged to Dawesley Creek.

Results of trials
10,000 t mixing and compaction trial
The objectives field mixing and compaction trial were to determine and demonstrate the optimal methodology for mixing, placement and compaction of waste rock, tailings and limestone (co-disposed material) at full-scale and establish an appropriate quality assurance/quality control (QA/QC) method for the main construction phase of Days Creek remediation. In addition, the trial was to assess the chemical composition of boulders within the WRD, for potential re-use within the main remediation. This objective was later removed from the trial upon guidance form the TAG via DMITRE (DSD).

The methodology and specification for the trial are presented in the following documents:
- 1957-SD-2013-Brukunga Mine Rehabilitation Field Mixing Trial Addition – Methodology Document.
- 5399-E-2013-Brukunga Mine Rehabilitation Field Mixing Trial Addition – Earthworks Specification.

Lucas Total Contract Solutions (LUCAS) was appointed to carry out the trial works.

General description of the trial
The trial consisted of the following general sequence of construction:
- At the TSF:
- The tailings area was stripped to provide an approximately level surface, to allow the imported limestone to be spread evenly across the surface.
- Limestone was imported to site (TSF) with a maximum particle size of 2 mm from the Penrice Quarry, Angaston.
- The limestone was spread over the tailings in a nominally 50 mm thick layer.
- The limestone and tailings was excavated as a single layer nominally 550 mm thick.
- The combined limestone and tailings was excavated and hauled from the TSF to the trial area.

- On completion of the excavation within the TSF waste rock from the Northern Waste Rock Dump (NWRD) was used to back fill the tailings borrow area.

At the northern waste rock dump:
- Waste rock from the NWRD was excavated and transported to the trial area, for mixing with the combined tailings and limestone in the trial.
- Waste rock from the NWRD was transport to the tailings borrow area, to reinstate the tailing borrow area excavation on completion of the works.
- At the end of the excavation works within the NWRD borrow area two trial pits were excavated to identify the pre-mine ground level and bedrock level below the NWRD.

At the trial area:
- The trial area was prepared by compacting waste rock into a depression along the eastern side of the trial area.
- Prior to the placement of the co-disposed material a layer of limestone nominally 25 to 30 mm thick was spread over the base of the trial area.
- A layer of waste rock was placed within the trial area and overlain with tailings and limestone in the required quantities. The combined layer was excavated and the material was side-cast to the required position within the trial area.
- The mixed materials were compacted in layers to form the trial earthwork. The compaction of the earthwork was undertaken using both a smooth drum vibratory roller and a High Energy Impact Compactor (HEIC).
- In situ density testing (Nuclear Density Measurements) was undertaken between the placement and compaction of subsequent layers.
- Representative bulk samples were taken of the co-disposed material throughout the trial. Additional samples were also taken from the NWRD, tailings and limestone stockpile, trial pits within the NWRD and of the rock face adjacent the trial.
- A selection of geotechnical and geochemical tests were scheduled for the recovered sample.
- Monitoring equipment was installed at various locations during the trial. These included soil moisture sensors and oxygen probes.
- On completion of the compaction trial three (3) soak-away tests were undertaken within the trial earthwork.

Project overview
The field mixing and compaction trial was developed to assess the optimal methodology for mixing, placement and compaction of co-disposed material at full scale and establish an appropriate QA/QC method for the main construction phase of Days Creek remediation.

Mixing of the co-disposed material
The mixing of the co-disposed material was achieved by placing the constituent materials and at a range of practical layer thicknesses and excavating through the layer with a 20 tonne excavator. This was a relatively crude mixing method, but due to the percentage of oversize material within the waste rock it was considered the only viable method, without screening the material to control the oversize content percentage.

Visual inspection of the mixed material appeared to show that the material was relatively well mixed and this was backed up by the particle size distribution test data for the co-disposed material. The particle size distribution testing of the co-disposed material showed a relatively uniform envelop for the samples tested, ranging from clay up to cobbles (>63 mm).

The geochemical test results for the co-disposed material also indicated that the mixing of the material was successful.

Compaction of the co-disposed material
The *in situ* density ratio results indicate that the compaction was generally ineffective for the particular layer thickness tested and method used, only four (4) of the results provided *in situ* density ratios of greater than 95% and approximately 50% of the results had an *in situ* ratio of less than 90%.

It is considered that the compaction of the co-disposed material was ineffective for the following reasons:

- The layer thicknesses were found to be too thick for the materials particularly and plant utilised.
- The maximum particle size reduced the effectiveness of the compaction.

Consideration should be given to the fact that the *in situ* density results were partially affected by the preparation of the test areas. The test areas were prepared by excavating through the compacted layer to approximately the mid-point. This preparation caused some disturbance to the material being tested; when a boulder was encountered in the test area the disturbance was more significant.

It is understood that the grading and crushing of the waste rock would be costly and time consuming for the main remedial works. Exclusion of large particles above say 300 mm in diameter would in itself raise a volume cut/fill balance dilemma. It is likely that grading and crushing will be required. DMITRE will need to assess the costs of the grading and crushing against the implications of having a poorly compacted co-disposed material.

Implementation/ construction plan
Survey and level control
Wherever possible GPS guided machinery for excavation and trimming works will be used. It has been assumed that all graders, dozers, excavators and scrapers that require level control will be fitted with GPS machine guidance equipment. In addition, a dedicated surveyor will be utilised to input electronic survey models in 3D format into GPS controlled machinery. From these survey control points, construction activities will be controlled and maintained against design. The GPS equipment can be used for stripping activities through to final formation levels to ensure that design standards are maintained.

Clear and grub
Clearing and grubbing activities will be undertaken using a Caterpillar D7R bulldozer fitted with a special purpose stick rake, or by a 30 t excavator with grab attachment. The dozer and stick rake would have the ability to grub out light vegetation to full depth, while larger trees would involve the use of excavators and grabs to remove stumps. In either methodology, the vegetation will be cleared and grubbed from the proposed working areas after the relevant permits and approvals are obtained and the vegetation stockpiled for subsequent processing to produce mulch and wood chips for re-use in the remediation works.

In the event that the stockpile location is too far to be pushed by a bulldozer, articulated dump trucks and an excavator with grab attachment will be used to transport the vegetation to stockpile.

Cleared vegetation could be made available to local residents for firewood as an act of community engagement and to maintain positive relationships during the works.

Borrow areas
Tailings Storage Facility
Based on direction received from the TAG, the adopted borrow design primarily removes materials from the southern side of the TSF. The design allows for adequate drainage of the remaining materials while also allowing for a substantial area of natural ground below the TSF to be exposed. Oxidised tailings material is readily identified by its pale yellow colour; however, it is not possible to confirm the presence of fully oxidised (or non-sulfidic) tailings visually. Field based static geochemical tests, to maximum depths of around 2 m, will be carried out at approximately 10

locations across the TSF to confirm the depth of the fully oxidised tailings. The fully oxidised tailings will be excavated and stockpiled separately for reuse as a (300 mm thick) cover layer placed on top of the co-disposed wastes.

The average thickness of the oxidised tailings layer is estimated to be 0.65 m (SKM 2008, 2009 & 2013c). The anticipated volume of oxidised tailings from the proposed TSF cut is approximately 47,000 m^3. Field testing will be required to identify the depths of fully oxidised tailings across the TSF. Any excess excavated fully oxidised tailings material is to be placed and compacted at the eastern end of the TSF cut such that the resulting landform is free draining.

As per the NWRD, the design of the TSF borrow is governed by the volume of tailings (oxidised and unoxidised) materials required in the waste co-disposal mix (refer to Detailed Design Development Report (Jacobs, 2015b). The stability of temporary batter slopes (1V:3H) has been assessed and the factor of safety against shallow failure is greater than 1.5. The temporary batter slopes will be faced with erosion control matting, topsoil and seeded to promote rapid vegetation growth, improve shallow stability and minimise the potential for suspended sediment discharge.

Clean and dirty surface water flows in the TSF borrow area will be segregated to reduce the quantity of AMD impacted water requiring treatment. An open channel along the toe of the TSF batter will segregate AMD impacted water which will be direct to the existing AMD ponds located to the west of the TSF borrow.

Topsoil stripping
Topsoil and sub-soil at the TSF will be stripped to a nominal depth of approximately 500 mm in proposed working areas after the clearing and grubbing activities with Caterpillar 623 elevating scrapers, or similar to stockpile locations within the TSF footprint. Work fronts and scraper haul roads will be maintained with a grader and water cart. It has been assumed that stockpile locations are located within approximately 1 km of the stripped area.

Spreading limestone to prepared tailings surface
The limestone material will be procured from an off-site source as a minus 2 mm pure $CaCO_3$ material and transported to site stockpile through the use of prime movers and trailer combinations. The material will be crushed in advance and the delivery arranged to match the production rates required for the project.

The limestone material will be tipped directly onto the prepared tailings surface and spread to the required nominal thickness using a grader fitted with GPS equipment to ensure that a uniform depth of material to achieve Detailed Design specification. This methodology was adopted during the field mixing and compaction trial (SKM, 2014) and proved successful. Alternative mixing methods have been considered, including mixing the 2 mm pure $CaCO_3$ limestone with the in situ tailings using tractors and disc ploughs or a Bomag soil stabilising machine.

Excavation and haulage of limestone and tailings mix
The excavation of the limestone and tailings mix will be undertaken with excavators and 40 tonne articulated trucks and the material hauled to the placement site along the established roadways. The cost estimate is based on achieving approximately 30 to 35 loads/day with four trucks carting and an average volume per truck of 17 m^3. The excavations will be undertaken in approximately 500 mm deep benches and the level will be controlled through either GPS or laser levelling to ensure the correct depth of excavation for the amount of limestone added to the surface.

Following haulage to the mine site, the material will be placed in rows ready for adjacent waste rock to be placed so that it can be mixed together.

Respreading of topsoil
Allowance has been made for replacing the stripped topsoil from the TSF concurrently during excavation with scrapers moving material back to the stripped areas once excavation has been completed. These areas will be made available progressively as required for vegetation by others.

North Waste Rock Dump (NWRD)
The material in the waste rock dumps will be crushed using a Nordberg Metso 3054 Jaw Crusher, or similar and stockpiled from the belt using a stacker. The material will be fed into the crushing plant using a 47 t excavator and the crusher will be opened to the maximum jaw setting of 200 mm to produce a 200 mm minus waste rock product. The crusher is able to handle feed material nominally less than 600 mm. The crusher will incorporate a screen to allow fine-grained material (termed LPW) to be segregated for use in embankment cores and the highwall drain. Allowance has been made for the provision of a 35 t excavator with a rock breaker attachment at 50% usage to break material greater than 600 mm maximum dimension prior to it being fed into the crushing plant.

The crushed material will be carted to the mine site using temporary haul roads benched into the existing waste rock dumps. The haul trucks will be loaded using a Caterpillar 988 wheel loader from the stockpile and the material carted to the mixing location using articulated 40 t haul trucks. The waste rock will be placed alongside the limestone/tailings mixture for future blending.

Other borrow areas
Suitable materials won from the excavation of the Days Creek diversion (in soil and rock) will be used as a source of select fill for embankments, the coarse drainage layer and the highwall drain..

The sandstone unit located at the south-east corner of the waste impoundment area, identified by structural geology mapping (Geostructures, 2014), could potentially be used to provide an additional source of site-won materials. Excavation and re-profiling of some areas of the SWRD will be required to allow this material to be quarried. However, it is envisaged that increasing the extent of the Days Creek diversion cut at the inside radius at Ch 350 towards the NWRD, will provide a more readily winnable source of material to balance any material shortfall (refer Section 5.1).

Co-disposed wastes
The adopted limestone proportions assume a pure material with high calcium carbonate content. In the case where a less pure limestone source is used, the mixing ratios would require adjustment according to the reduced calcium carbonate content.

Compaction trials will be undertaken as part of the construction contract to confirm that the maximum particle size and layer thickness are appropriate for the plant selected.

Mixing and placement of co-disposed wastes
The limestone tailings mix and the waste rock material will be blended using a large bulldozer, which will “blade mix” the material in a similar way to a grader employed to mix materials on a road construction project.

The mixing area would be set up by placing the correct mix of waste rock, tailings and limestone in windrows adjacent to each other, which could be done by truck weight or truck count of each material. The dozer would flatten the tops of the stockpiles to a uniform depth and then tilt the blade and commence running along the prepared area perpendicular to the tipped loads, pushing and mixing the materials. Water carts would operate in conjunction with the dozer, wetting the area and getting moisture into the mixed materials. After repeated passes the material would become a well-mixed blend of the different materials.

Due to the sizing of the processed waste rock (200 mm minus), a 500 mm thick compacted layer thickness has been assumed with compaction effected using a Caterpillar 825 machine and 12 to 18 tonne pad foot rollers.

Site clearance
Site clearance will involve the removal and/or management of the following waste streams that currently occupy the site:

- trial co-disposal waste pyramids (7 no.) and trial stockpile materials located on the north bench and adjacent to the highwall, respectively (approximately 3,600 m^3);
- co-disposed wastes, waste rock and tailings (approximately 3,200 m^3) from the Field Mixing;
- Compaction Trial (SKM, 2014b);
- waste rock and construction/demolition waste (approximately 15,000 m^3) including chipboard, plastic bags and metal in the southern mine pit (Waste Dump A in URS 2013); and
- waste rock and construction/demolition waste (approximately 20,000 m^3) including PVC pipe, plastic and metal in Shephards Creek North (Waste Dump B in URS 2013).

The trial co-disposal waste pyramid and trial stockpile materials will be mixed with tailings and limestone and placed and compacted as co-disposed wastes.

The co-disposed wastes from the Field Mixing and Compaction Trial contains oversize material that will be crushed to the maximum particle size established during the compaction trials. The processed material will then be mixed with tailings and limestone prior to placement and compaction as co-disposed wastes

If initial excavation of the materials in Waste Dumps A and B indicate that they contain a significant and reclaimable amount of waste rock, it should be segregated and incorporated in the co-disposed wastes. Waste Dump A and B materials should be classified in accordance with Environmental Protection Authority (South Australia) criteria in order to determine whether or not off-site disposal is an option.

DSD is currently progressing the removal and/or management of the following two waste streams that occupy the Days Creek domain, in advance of the remediation works:

- Jarosite sludge (approximately 500 m^3) located in the base of the northern and southern mine pits will be excavated, stockpiled on the south mine bench and neutralised with limestone.
- Gypsum sludge (from the Brukunga Water Treatment Plant) located on the north mine bench (approximately 8,000 m^3). DSD is currently separating the sludge from other wastes and relocating them to the existing gypsum sludge stockpile on the south mine bench. The location and characterisation of Waste Dumps A and B and the gypsum sludge are described in the Brukunga Phase 2 Contaminated Land Investigation Report (URS, 2013).

Embankments

Following excavation of soil material beneath embankment foundations, it has been assumed that ripping would be carried out using a Caterpillar D9T to near design level. Finishing off to design level will be carried out using an excavator and rock breaker to minimise disturbance to the formation level.

Following completion of rock excavation to design level, loose rock and overhangs will be removed and rock surfaces will be cleaned and dewatered. Dental concrete and slush grout will be used to fill in irregularities and to provide a suitable surface to accept the co-disposed wastes.

Where possible site won fine material (wet of optimum moisture content) will be pushed into irregular surfaces and compacted.

Highwall drain

Construction of the highwall drain will involve minor cut (up to approximately 2 m) and minor fill (up to approximately 1.5 m). Rock excavation will be carried out by bucket digging and ripping with a Caterpillar D9T or similar, to near design level. Finishing off to design level will be carried out using an excavator and rock breaker to minimise disturbance to the formation level. Dental concrete and slush grouting will be used to fill in surface irregularities, where fill placement is impractical. Where fill is required to be placed and compacted to achieve the required invert level, a well graded NAF fill material with sufficient fines to encourage run-off will be sourced from site won material.

Days Creek diversion

Following excavation of soil material beneath embankment foundations, it has been assumed that ripping would be carried out using a Caterpillar D9T, or similar, to near design level. Finishing off to design level will be carried out using an excavator and rock breaker to minimise disturbance to the formation level.

Following completion of rock excavation to design level, loose rock and overhangs will be removed and rock surfaces will be cleaned. Dental concrete and slush grout will be used to fill in irregularities. If blasting is required, a similar methodology would be used where the sub-drill of the blast holes would not be drilled beneath the design formation level and any material left on the floor and side slopes would be excavated using an excavator and rock breaker.

Excavated soil and NAF rock material from the Days Creek diversion cut will be stockpiled separately for re-use as select fill in embankments and the highwall drain. PAF materials will be identified on site using field geochemical testing and visual assessment and segregated from the NAF materials. The NAF rock materials won from Days Creek will be processed by crushing and screening on site to provide material for the coarse drainage layer and rock armour for the highwall drain and weep hole, subject to satisfactory laboratory tests to determine material suitability/durability.

Temporary diversion of Days Creek

Construction of the Days Creek diversion cut will entail the temporary diversion of flows from Days Creek during the remediation works. For the purposes of the Detailed Design and cost estimate, it has been assumed that by judicious sequencing: excavation of NWRD, Days Creek diversion cut and construction of the co-disposed impoundment, and programming of the works in the dry season, the flows can be managed by staged temporary minor diversions within the mine site. Ideally, the works commencement date and program will allow Days Creek diversion to be completed before winter.

Alternatively, the flows from Days Creek could be diverted in a temporary pipe along Peggy Buxton Road (approximately 600 m) to discharge into Dawesley Creek. A temporary balancing storage pond is likely to be required to the north of Peggy Buxton Road to allow peak flows to be discharged. The capacity of Dawesley Creek to accept flows from Days Creek during the construction period will need to be reviewed.

Monitoring and validation

Monitoring during construction

Water Quality Objectives

The remediation of Days Creek will still require all water to be captured and pumped back to the treatment plant before discharge to Dawesley Creek Downstream. The Water Quality Objectives (WQO) for water impacted by the Days Creek remediation as measured at gauging station A4260659 is based on Water Treatment Plant discharge water quality summarised in Table 3.

Table 3. Water quality of WTP discharge.

Parameter	Units	Treatment Plant Discharge
pH		9.3
EC	µS/cm	3,830
Ca	mg/L	733
Mg	mg/L	45
Na	mg/L	203
K	mg/L	17
Acidity	mg/L $CaCO_3$	6

Parameter	Units	Treatment Plant Discharge
Alkalinity	mg/L $CaCO_3$	17
Sulfate	mg/L	1,673
Cl	mg/L	346
Dissolved Metals		
Al	mg/L	0.5
As	mg/L	0.001
Cd	mg/L	0.0001
Cr	mg/L	0.001
Cu	mg/L	0.002
Fe	mg/L	1.4
Mn	mg/L	0.6
Ni	mg/L	<0.001
Pb	mg/L	<0.001
Zn	mg/L	<0.1
Total Metals		
Al	mg/L	0.7
As	mg/L	0.001
Cd	mg/L	0.0001
Cr	mg/L	0.021
Cu	mg/L	0.024
Fe	mg/L	7.7
Mn	mg/L	0.6
Ni	mg/L	0.15
Pb	mg/L	<0.001
Zn	mg/L	6.2

Surface water

A surface water quality monitoring program has been in place at the site since 1996. The water quality monitoring program was established to:

- Determine annual and seasonal loads of heavy metals entering the Dawesley Creek from the site, by measuring stream flow and metal concentration upstream and downstream of the Mine (composite sampling).
- Determine the temporal and spatial variations of pH and heavy metals concentrations within the zone of impact by undertaking a monthly sampling program (grab sampling).
- Determine the extent of impact of the Mine (i.e. the zone of impact) on Dawesley Creek and the Bremer River by undertaking biological (macroinvertebrate) monitoring on a quarterly basis.

A Monitoring Plan for the Brukunga Remediation Program was developed as part of an Environment Improvement Program established by negotiation between the South Australian Environmental Protection Authority (EPA) and SA Water (which previously managed the site) in August 1996 and approved by the EPA in the same year.

The first stage of the progressive remediation of the Brukunga Mine site - the Days Creek domain will adopt some of the established water quality monitoring locations within the mine precinct and in Dawesley Creek downstream of the mine station A4260359.

All runoff and seepage from the remediated Days Creek domain during construction will be collected and pumped back to the Treatment Plant for treatment prior to discharge. The monitoring point for discharge from water treatment plant is gauging station A4260659.

Groundwater

Construction has the potential to increase groundwater elevations due to loading and subsequently to lead to increased discharge to the original Dawesley Creek channel. During construction and operation, groundwater elevations should be monitored in the existing wells shown in Tables 4 and 5, which include elevation-based trigger levels that would lead to the implementation of contingency measures to manage water table increases. The groundwater monitoring program during construction should be finalised as part of the development of an environmental management plan for the site.

Table 4. Groundwater Elevation Monitoring Program during construction.

Groundwater Monitoring Program - during construction	Trigger	Proposed contingency
Groundwater gauging and sampling of all nominated wells prior to construction (see Table 13 - post construction monitoring for nominated wells). Quarterly groundwater gauging and inspection for groundwater seepage during construction (see Table 13 - during construction monitoring for nominated wells).	Water level rises in well to within 0.5 m of ground surface. Evidence of groundwater discharge, AMD, or salt build up on ground surface.	Assess ground condition, evaluate need for additional targeted excavation/grouting of weathered material to reduce surface permeability in vicinity of seepage.

Table 5. Groundwater Monitoring Program during construction

Wells to be gauged quarterly during construction	Field measurements/inspections
KAN23, KAN20 H01 (if remains), H02, H03, H04a, H04b, H06a, H06b GMW01 C03, C04, C05	Depth to water from top of casing (m bTOC) and calculation of groundwater elevation (mAHD). Stickup (height of casing above ground level, m). Inspection for groundwater seepage at ground surface. Inspection for well, cap and surface seal integrity.

Materials

Geotechnical/ stability/mixing

Co-disposed wastes

A significant QA/QC program will be required during the construction phase. This will need to be developed as a component of the project delivery. However, for the long-term success of the project, particular monitoring emphasis will be required for the co-disposed wastes.

The co-disposed wastes is a mixture of waste rock, tailings and imported limestone. The total volume of each co-disposed material, defined by the total disposal size and the materials ratio, forms a key input into the design of the borrow pits from where the materials will be sourced.

In accordance with the mixing ratios adopted in the field mixing and compaction trial, the following co-disposal wt% materials ratios have been adopted for general co-disposal materials volume calculations:

- Tailings: 35.5%
- Waste Rock: 60.5%
- $CaCO_3$: 4.0%

Additionally, based on the results of oxygen consumption testing undertaken by Earth Systems (Ref. 10), the following further direction on mixing ratios was received by Jacobs:

- there shall be a 300 mm oxidised tailings layer above the co-disposed material; and
- there shall be 6 wt% $CaCO_3$ blending in the oxidised tailings and 6 wt% $CaCO_3$ blending in the top 1.5 to 2 m of the co-disposed wastes.

The adopted limestone proportions assume a pure material with high calcium carbonate content. In the case where a less pure limestone source is used, the mixing ratios would require adjustment according to the reduced calcium carbonate content.

Compaction trials will be undertaken as part of the construction contract to confirm that the maximum material dimension and layer thickness are appropriate for the plant selected.

Dust

In some areas there may already be relatively high background levels of dust. If dust is a potential concern, deposition gauges should be used near sensitive receptors and the proposed construction site. The dust deposition data collected from the site will be analysed and the results compared against the following standards/criteria.

There are no national air quality guideline values for the nuisance dust effect that can be used to assess the impact of dust on the receiving environment. However, there are a number of criteria commonly used by regulatory agencies in Australia. Generally, the criteria have been derived from subjective observations and investigation of dust levels and nuisance effects. A dust deposition limit of 120 milligrams per square metre per day, averaged over 1 month, when monitored in accordance with "AS3580.10.1 Methods for sampling and analysis of ambient air – Determination of Particulates – Deposited Matter – Gravimetric method, 1991", is frequently used in Queensland.

Noise

The Environment Protection (Noise) Policy 2007 (Noise Policy) provides guidance on noise levels that may be deemed excessive under the EP Act. It should be noted that the Act requires site-specific issues be taken into account when determining noise levels that may be excessive.

All practicable steps will be taken to minimise the adverse effect that noise emissions may have on the amenity value of an area. This responsibility includes not only the noise emitted from the plant and equipment but also associated noise sources, such as radios, loudspeakers and alarms.

Most of the local earthworks involving excavation and co-disposal of tailings and waste rock will be shielded from the Brukunga town site that will assist with mitigating noise. Hours of operation will be confined daylight hours as specified by EPA.

Monitoring post construction

Water

Surface water

All runoff and seepage from the remediated Days Creek following construction will be collected and pumped back to the Treatment Plant for treatment prior to discharge. The monitoring point for discharge from water treatment plant is gauging station A4260659.

Groundwater

The Days Creek Remediation Program is focussed on providing improvements to surface water quality; measureable improvements in groundwater quality over the post-construction monitoring period (assumed to be 30 years) are considered unlikely to result as long as only the Days Creek domain is remediated. While the SWRD, much of the NWRD, and the bulk of the TSF remain in place, acid-impacted recharge and leakage from these areas will continue to degrade groundwater quality which will, in turn discharge to the original Dawesley Creek channel.

Following construction, groundwater elevations and groundwater quality would be monitored in the existing groundwater monitoring wells. This includes elevation-based trigger levels that would lead to the implementation of contingency measures to manage water table increases. The post-construction groundwater monitoring program will be finalised as part of the EMP development. Groundwater sampling of all nominated wells following construction of the Days Creek Remediation System will be undertaken for field and laboratory testing.

Wells will be tested in three successive campaigns as follows:

- Years 1-5: 6 monthly sampling
- Years 5-15: 3 yearly sampling
- Years 15 -30: 5 yearly sampling.

Nominated wells to be monitored include, but are not limited to:

- KAN23, KAN20, KAN28
- H01 (if it remains), H02, H03, H04a, H04b, H06a, H06b, H08, H09, H10, H13, H14a, H14b, H15
- GMW01
- C01, C03, C04, C05, C06.

Testing will include field and laboratory analysis. A non-filtered and filtered to minus 0.45 µm water sample will be collected for total and dissolved metal ion species respectively. The list of field and laboratory analytes is as follows:

Field Testing Analytes	Laboratory Testing Analytes (mg/L)
Depth to water from top of casing (m bTOC)	Total dissolved solids (TDS)
Stickup (height of casing above ground level, m)	Acidity (as $CaCO_3$)
Electrical conductivity (EC, uS/cm)	Chloride, sulfate
pH	Bicarbonate alkalinity and Carbonate alkalinity (as $CaCO_3$)
Dissolved oxygen (DO, mg/L) Redox (mV)	Calcium, magnesium, sodium, potassium
Temperature (°C)	Metals (total and filtered): iron, manganese, aluminium, arsenic, cadmium, cobalt, copper, lead, mercury, nickel, zinc.

Vegetation Performance and Completion Criteria Monitoring

Rehabilitation completion criteria set benchmarks for a suite of parameters that need to be met to demonstrate that rehabilitation has been successful, or is considered sustainable. These are documented in the EMP. Annual rehabilitation monitoring program will be undertaken that will include the following objectives:

- rehabilitation performance will be monitored to ensure vegetation is establishing and to determine the need for any maintenance and/or contingency measures;
- rehabilitation will be monitored in the interface between the remediated Days Creek domain and existing remnant vegetation, agricultural land, urban land;
- monitoring will be undertaken after the first year and at intervals thereafter depending on the type of rehabilitation in accordance with the Rehabilitation Monitoring SOP (refer to RMP); and
- results of monitoring will be reviewed to identify where improvements are required in design works, annual rehabilitation plans or where maintenance is required to existing rehabilitation.

Additional vegetative cover is essential to reduce erosion rates to levels that could be considered sustainable in the long term. However, although the data indicate that establishment of a vegetative cover will control erosion satisfactorily, it should be noted that high rates of erosion prior to establishment of cover can create incised rill lines that will continue to erode even after the bulk of the area is covered by vegetation. This indicates that rapid establishment of vegetation on this area will be essential, particularly because erosion hazard is highest early in the winter growing season. Heavy seeding rates of grasses and high levels of nitrogen fertiliser are strongly advised. If available, irrigation would be extremely helpful to establish vegetation early in the growing season.

Erosion potential in the steeper parts of the Days Creek domain is sufficiently high that reliance on vegetation for both initial and long-term stability would be questionable. The incorporation of rock in the rehabilitation methodology ensures not only immediate erosion mitigation, but also considerable resilience if the area is subject to disturbance and loss of surface vegetative cover due to grazing or fire in the future. These sites will need to be documented and monitored against completion criteria post construction.

Soil Management Monitoring
Topsoil
It should be noted that topsoil availability and quality will be a critical issue for the success of revegetation works. Therefore, any work programme developed for site earthworks, including re-shaping, quarrying, and waste co-disposal must also consider the stripping, stockpiling, and effective management of topsoil (or of materials that will be used as topsoil or "growth medium").

Effective management of topsoil stockpiles should aim to improve "soil" quality during the time it is stockpiled, by judicious application/mixing of amendments, fertilisers, and by establishment of appropriate vegetation on the stockpiles.

Some thought should also be given to the seed bank present in topsoils prior to stripping, as that may also be important for their subsequent placement. For example, the growth medium currently on the TSF will carry a high load of tree and shrub seed, and be relatively low in grasses. That material would be highly undesirable for placement on areas to be by design dominated by grasses and wetland sedges etc. (where trees are definitely not wanted), but may be a useful source of tree propagules if placed in areas where trees are required such as Days Creek domain.

The topsoil handling plan specifies topsoil sources (principally the tailings storage area), collecting depth, volumes and handling equipment needed, respreading depth, and any follow-up treatment (such as scarifying prior to seeding/planting, deep ripping). The subsurface horizons of the TSF area soils will possess undesirable characteristics such as high salinity, extreme acidity and associated aluminium toxicity, or calcium deficiencies for many plants. Generally, it is preferable to strip and replace the horizons separately (double-stripping) to ensure that the nutrient-containing, microbial-containing and (sometimes) seed containing horizon is returned to the surface.

Refer to soil management and monitoring section of the Remediation Management Plan.

Geotechnical
Post construction monitoring of the geotechnical components the Days Creek domain remediation are documented in the Remediation Management Plan. They include monitoring the covers system for moisture and matric suction and oxygen to ensure design saturation conditions are maintained and sulfide oxidation is detected. The embankment should be monitored for pore pressures as well as movement.

Contingency plans
All runoff and seepage from the Days Creek remediation activity will be captured in the Dawesley Creek collection system and pumped back to the WTP for treatment prior to discharge, during and post-construction.

Additional contingencies include:

- increasing the water holding capacity of Weir 2 by raising the Weir 2 height. Weir 2 is located at Surface water Gauging Station A4260659; and
- constructing a new weir on Dawesley Creek adjacent to the southern end of the SWRD. This will act as extra storage of seepage and runoff water from the existing mine landforms and the newly remediated Days Creek, which will require treatment through the WTP before discharge to downstream Dawesley Creek.

Auditing/third party review
A third part auditor was appointed during Phase 2 of the project. It is currently Mr Phillip Mulvey of Environmental Earth Sciences. The audit is undertaken in line with the RTEN process. Phase 2 of the project has been audited and the RTEN report has been issued.

ATTACHMENT B
NON-AMD REMEDIAL ACTION PLAN

Abbreviations

Abbreviation	Description
AMD	Acid and Metalliferous Drainage
ANZECC	Australia and New Zealand Environment and Conservation Council
ARMCANZ	Agriculture and Resource Management Council of Australia and
B(a)P	Benzo(a)pyrene
BGL	Below Ground Level
BTEX	Benzene, toluene, ethylbenzene and xylenes
COPC	Contaminants of Potential Concern
EIL	Ecological Investigation Level
EMP	Environmental Management Plan
EPA	Environment Protection Authority
EPP(WQ)	Environment Protection (Water Quality) Policy
EQL	Effective Qualitation Limit
ESA	Environmental Site Assessment
GAC	Groundwater Acceptance Criteria
GHCR	Glenside Health Campus Redevelopment
HIL	Health-based Investigation Level
HSEP	Health Safety and Environment Plan
KBR	Kellogg Brown & Root Pty Ltd
LCS	Laboratory control spike
LOR	Limit of Reporting
MS	Matrix Spike
µg/L	micrograms per litre
mg/kg	milligrams per kilogram
MW	Monitoring Well
NATA	National Association of Testing Authorities
NEPM	National Environment Protection Measure
NHMRC	National Health and Medical Research Council
NSW	New South Wales
OCP	Organochlorine Pesticide
OP	Organophosphate Pesticide
PAH	Polycyclic Aromatic Hydrocarbon
PCB	Polychlorinated Biphenyl
PFC	Perfluorinated compounds
PFOA	Perfluorooctanic acid
PFOS	Perfluorooctane sulfonate
PID	Photoionisation Detector
ppm	Parts per million
QA/QC	Quality Assurance/Quality Control
RAP	Remediation Action Plan
RPD	Relative Percent Difference
TCE	Trichloroethylene
TDS	Total Dissolved Solids
TPH	Total Petroleum Hydrocarbons
TSF	Tailings Storage Facility
UCL	Upper Confidence Limit
URS	URS Australia Pty Ltd
UST	Underground Fuel Storage Tank
VOC	Volatile Organic Compound
WQMP	Water Quality Management Plan
WRD	Waste Rock Dump

INTRODUCTION

COMMISSION

URS Australia Pty Ltd (URS) was commissioned by the Department of State Development (DSD, formerly known as the Department of Manufacturing, Innovation, Trade, Resources and Energy and formerly Primary Industries and Resources South Australia) to address Site Contamination Auditor (Auditor) comments on the Brukunga Phase 2 Land Investigation report (URS, 2013). The Phase 2 investigation was undertaken in October and November 2012 with the purpose of examining the contamination status of the site outside the perspective of acid rock drainage. Areas investigated by URS are shown on Figure 1.

The SA EPA Accredited Site Auditor provided comments to DSD on this report in a letter dated 3 March 2014 (Environmental Earth Sciences, 2014).

URS was engaged by DSD on the 26 May 2014 to implement the agreed, and Auditor reviewed, scope of works outlined in the URS proposal dated 6 May 2014.

The proposal outlined two main deliverables:

1. Addendum Report supplementing the original Brukunga Phase 2 investigation
2. Preliminary Remediation Action Plan (RAP).

This report presents the Preliminary RAP.

The Addendum Report has been provided as a separate document (URS, 2014).

OVERVIEW

The Addendum Report (URS, 2014) updated the findings of the Brukunga Phase 2 investigation in the context of additional works at the site and recently updated regulatory guidance that post-dates works undertaken by URS in 2012. Key data gaps remain and require addressing so that remediation of non-acid and metalliferous drainage (non-AMD) contamination issues is well targeted and appropriately prioritised.

Review of this report by the Auditor (letter dated 30 October 2014) highlighted the need for a Preliminary RAP to:

- provide advice on further works required to address data gaps and to identify assessment and clean-up requirements for non-AMD issues;
- outline requirements for a surface water and groundwater monitoring plan for the site; and
- provide a timeline and estimated timeframes for completion of work programs to address data gaps and to implement remedial actions.

The Preliminary RAP presents a staged approach to remediation and management of non-AMD issues that addresses the key data gaps and uses the outcomes of each stage to inform, target and prioritise subsequent stages of work.

The proposed timeframes for addressing data gaps, subsequent review and development of remedial actions are cognisant of other intrusive investigation programs and implementation of the staged AMD remediation program. The proposed timelines and suggested remedial actions may require revision as new information comes to light or if the regulatory requirements change, to this end, the Preliminary RAP is considered to be a “living document” which is subject to on-going appraisal.

AIM

The purpose of a Remedial Action Plan will be to detail remedial works proposed to appropriately address non-AMD contamination issues identified at the Brukunga site in the context of the proposed future site use.

The current status of investigation of these issues is detailed in the Addendum Report to the Brukunga Phase 2 Contaminated Land Investigation (URS, 2014); and it is noted that data gaps have been identified Until detailed site investigations (DSI) are completed and non-trivial contamination issues are delineated, this RAP document provides only preliminary guidance on the environmental management of on-site remediation.

In addition, this Preliminary RAP provides DSD with a planning tool to prioritise further DSI works and to guide contractors as to the remediation principles to be followed and the required clean-up criteria for water and soil.

The appraisal of appropriate site remediation technologies will be undertaken as part of a separate tender process and will be dependent upon the findings of the DSI.

Finalisation of the RAP may occur when data gaps have been addressed and contractors present remediation technologies appropriate and compatible with both AMD and non-AMD issues as deemed suitable by the Auditor.

SCOPE OF WORK

The Preliminary RAP was developed based on an updated understanding of site conditions presented in the Addendum Report (URS, 2014), advice from the Auditor and consideration of State and National regulatory guidance.

Auditor comments following the review of the draft Preliminary RAP are provided in **Appendix A**, along with URS responses.

The timeframes for recommended DSI works have been prioritised to address key data gaps with remedial actions scheduled to coincide with the broader timing of the Days Creek Domain remedial program.

In line with the understanding between the Auditor and DSD, this Preliminary RAP provides the following:

1. A process to address identified data gaps in advance of remediation (**Section 5**).
2. Broad remediation principles to be followed (**Section 3**).
3. Interim remediation criteria for water and soil (**Section 4**).
4. Timeframes for remediation activities in advance of the AMD remediation time line (**Section 6**).

URS notes the following with respect to the scope of work conducted in relation to preparation of this Preliminary RAP:

- No new intrusive work has been undertaken by URS at the site.
- URS has not provided any independent verification of information collected and presented by others.

BACKGROUND

SITE APPRECIATION

The Brukunga Mine site operated from 1955 until its closure in 1972 and the legacy issues, including impacts to Dawesley Creek and feeder creeks from acid and metalliferous drainage (AMD), have been well researched. The mine currently comprises two main areas bisected by Pyrites Road. The Tailings Storage Facility (TSF) and Water Treatment Plant (WTP) are located on the eastern portion of the site whilst remnant mining infrastructure and waste rock dumps (referred to as the North Waste Rock Dump and South Waste Rock Dump) are present on the western portion of the site.

On the western portion of the site the waste rock dumps are located at the base of the benched former mine face, and have not been capped. Uncontrolled water infiltrates these piles, and results in seepage of acid drainage generated within these piles. The natural drainage path of Dawesley Creek was historically through the site and impacts to the creek were evident.

In 2003, a surface water diversion system was implemented to improve water quality in the creek downstream of the mine site. The system involved construction of a 1.7 km creek diversion drain and coupled with the upgrade of the WTP in 2004, has tripled the capacity to treat AMD from the site (DMITRE, 2013).

Regular surface water monitoring has shown a marked improvement in downstream water quality compared with levels measured prior to 2003. However, the ultimate goal is to establish a longer term and more satisfactory remediation strategy. The preferred remediation strategy to decrease acid seepage is containment and saturation of mine wastes on-site. Overall, the aim is to implement a "walk away" remediation solution that would allow closure of the WTP.

In order to satisfactorily achieve this outcome an understanding of other potential contaminants on the site within the containment area not associated with AMD was required.

Late in 2012, URS conducted a Phase 2 Contaminated Land Investigation to examine the contamination status of the site outside the perspective of AMD which is the subject of other investigations.

The contamination assessment was conducted to allow the Auditor to provide a Remediation to the Extent Necessary (RTEN) opinion for areas of the site not previously investigated.

The scope of work was limited to investigation of generally inactive areas located within the western portion of the mine site (west of Pyrites Road) and included use of existing groundwater monitoring locations for assessment purposes.

Since that time additional groundwater and surface water information has been collected. In addition, further feasibility studies on the preferred remediation option for the Brukunga mine site have also been completed. Review of studies conducted since the URS 2012 works program has been included in the Addendum Report (URS, 2014) resulting in an updated Conceptual Site Model and identification of key data gaps.

This Preliminary RAP has been developed to address these data gaps and to provide a roadmap for remedial works associated with non-AMD issues on the western portion of the site.

SITE IDENTIFICATION

The site was identified in Table 2-1 of the Brukunga Phase 2 Contaminated Land Investigation report (URS, 2013), provided below. It is noted that the Current Ownership and Land Use details have been updated with information provided by DSD.

Table 2-1. Site Identification.

SITE LOCATION	The site is located west and southwest of the township of Brukunga, lying between Pyrites Rd to the east and farmland to the west. It is noted that an additional portion of the former mine, located to the east of Pyrites Rd is beyond the scope of this investigation.
PROPERTY DESCRIPTION AND CERTIFICATE OF TITLE	Allotment 28 Filed Plan 9068, CT Volume 5841 Folio 589; Allotment 1 Deposited Plan 45003, CT Volume 5378 Folio 425; Allotment 80 Filed Plan 157515, CT Volume 5597 Folio 441; Allotment 30 Filed Plan 9068, CT Volume 5486 Folio 440; and Allotment 100 Deposited Plan 24651, CT Volume 5555 Folio 603.
SIZE OF INVESTIGATION AREA	Approximately 138 hectares (estimated from Certificates of Titles)

LOCAL GOVERNMENT AUTHORITY	District Council of Mount Barker
ZONING	See Section 2.3
CURRENT OWNERSHIP	Minister for State Development
CURRENT LAND USE	Former Mine Site and Acid Water Neutralisation Plant
PROPOSED LAND USE	See Section 2.3

The Certificates of Title covered by the scope of work excluded Volume 5779 folio 133 and Volume 5788 folio 476. These Certificates of Title describe the portion of the former Brukunga mine site located to the east of Pyrites Road which was beyond the scope of the URS investigation.

It is understood that DSD excluded the portion of the mine site to the east of Pyrites road from the scope of URS' investigation on the basis of:

- continued operation of the Water Treatment Plant (WTP);
- initial remediation works focusing on the Days Creek Domain; and
- no known residual (non-AMD) contamination sources present at the TSF.

ADJACENT LAND USES, CURRENT ZONING AND PROPOSED FUTURE LAND USE

Figure 1 shows the current land zoning and identifies adjacent land uses being:

North: Farming land/Rural

East:

- Residential Properties (Township of Brukunga)
- Country Fire Service (CFS) training facility. It is noted the current helicopter landing pad for the CFS facility lies within the site as detailed in this investigation.
- Former Brukunga Mine Tailings Dam, currently used (in part) for treatment of contaminated mine run-off water.
- Farming land/Rural.

South: Farming land/Rural. It is noted the township of Nairne lies approximately 2.8 km to the south west.

West: Farming land/Rural.

As noted by the Auditor (Environmental Earth Sciences, 2014) zoning information presented in the URS report (2013) has been superseded by the new Mount Barker Council Development Plan (issued 24 October 2013).

The relevant sections from the updated Development Plan pertaining to the Brukunga mine site zoning are provided in the Addendum Report (URS, 2014). It is noted that the portion of the map identified as A6 pertains to the adjacent CFS facility and does not form part of the Brukunga mine site. The plan indicates that the site is located within a “Primary Production (Mount Lofty Ranges)” zone where permissible land uses include commercial forestry, farming and horticulture.

Information was provided by DSD on planned future land use of the site (email dated 11 June 2014). DSD plans not to release the land over to the public until the remediation of the entire Brukunga mine site has been completed and there is evidence for the acceptable performance of the remediation (structural stability and environmental outcomes). Following verification of remediation performance the land will be turned over to the public for an agreed beneficial use.

PLANNED AMD REMEDIATION

At the outset, fifteen remediation options were considered by the Technical Advisory Group (TAG). The TAG recommended that saturation of co-disposed acid generating wastes behind a downstream wall (Option 7a) offered the lowest risk, most cost-effective and most achievable strategy for a walk-away remediation solution for the Brukunga Mine Site, avoiding the need for ongoing active water treatment (TAG, 2008). This preferred remediation option takes advantage of the natural topography and water flow in the Dawesley Creek to co-dispose and saturate the mine wastes from the Northern Waste Rock Dumps (NWD), Tailings Storage Facility (TSF) and mine face (High Wall).

Implementation of the remediation program will be a staged process, the first of which is the Days Creek Domain. This initial stage serves to act as a demonstration project and focusses on the construction of an impoundment for co-disposed tailings and waste rock in the Days Creek and former mine pit area. During this first remediation stage, the northern mine bench (inclusive of the former rifle range area) will receive an approximately 2 m thick cover system as part of the overall remediation design (SKM, 2013). The success of the remediation approach will be critically reviewed and closely monitored prior to implementation of further stages including the Dawesley Creek and Taylors Creek impoundments. DSD has indicated that the presence of organic materials is incompatible with the AMD remediation strategy and therefore material impacted with organic chemicals will need to be removed as part of the site preparation works.

Prior to the commencement of on-ground remedial works at the Days Creek Domain, further installation of additional monitoring wells by Boart Longyear is planned with specific locations to be identified by Jacobs and the TAG in consultation with DSD. On this basis, it is anticipated that the impoundment construction is unlikely to start for another 2 to 3 years (say 2017). Monitoring and subsequent modelling of the Days Creek Domain remediation performance is anticipated to be concluded within 10 years (say 2025).

It has been assumed that implementation of the Days Creek Domain remediation strategy will require the development of a Remediation Action Plan covering aspects outlined in **Section 3**. It is anticipated that remediation options for non-AMD issues will be prioritised following review of baseline data (see **Section 5.2**) and therefore actions may then be incorporated into the existing RAP for the site.

The broader remediation implementation schedule for the mine site will help to prioritise areas previously investigated by URS for additional assessment and/or remediation.

FOCUS FOR NON-AMD REMEDIATION

The focus for the non-AMD remediation strategy is driven by the outcomes of the Addendum Report (URS, 2014) and broader timing of the Days Creek Domain remedial program as discussed above.

Overall, timing for the Preliminary RAP may be divided into the following:

- Short-term works program (<2 years) – detailed scope and timeframes for further DSI, focused on obtaining baseline data and incorporating new monitoring wells as appropriate. Interim remediation criteria will be finalised.
- Medium-term works program (<5 years) – broad scope and timeframes, focused on implementing and reviewing baseline information and updating the Days Creek Domain RAP to include non-AMD remediation scopes.
- Longer-term works program (>5 years) – broad scope and timeframes, some specific remediation actions outlined but require review of RAP updates.

The Addendum Report (URS, 2014) presented an updated Conceptual Site Model identifying key contaminants of potential concern (COPCs) and potential source areas.

Known areas where data gaps exist in the site conceptual model include:

- Lack of temporal and spatial groundwater and surface water data for COPCs not related to the broader acid mine drainage issues, including establishing background water quality.
- Lack of information on background soil concentrations of COPCs, soil pH, clay content and CEC in the near vicinity of the site in order to appropriately apply appropriate assessment criteria to help set future remedial goals.
- Status of the existing UST, surrounding soils and underlying groundwater condition.
- Insufficient characterisation of fill material at Waste Dumps A or B for disposal off site should this be one of the preferred remedial options.
- Insufficient characterisation of the nature and extent of COPC concentrations in fill material around buried infrastructure across the eastern portion of the former central mine operations area.
- Confirmation that fencing along the off-site, down-stream section of Dawesley Creek remains an impediment to access by humans and livestock such that the exposure pathway is shown to be incomplete.
- Interactions between shallow and deeper groundwater horizons in benched and void areas in the vicinity of the former rifle range and Waste Dump A.

The Preliminary RAP short-term works program is focused upon addressing these data gaps.

The resultant prioritisation of remedial actions as part of the medium-term works program will occur upon review of the additional data collected.

REMEDIATION APPROACH

OVERVIEW

On-ground remedial actions will need to be developed in accordance with the Work Health and Safety Act 2012 and Work Health and Safety Regulations 2012, National Environmental Protection Measure (NEPM) 1999 guidelines and the SA EPA guidelines for Environmental Management of On-site Remediation, reprinted November 2008 and SA EPA guidelines for Assessment and Remediation of Groundwater Contamination, dated February 2009.

The following table provides a summary of legislation, guidelines and standards relevant to the various elements of the remediation methodology. Table 1 provides a guide to legislation, guidelines and standards relevant to the design and implementation of remedial actions; however, confirmation should be sought from the regulatory authorities prior to works to check currency.

Table 2. Legislation and guidelines relevant to contamination remediation.

Element	Legislation/Regulations	Guidelines and Standards
Occupational Health, Safety & Welfare	Work Health and Safety Act 2012 Work Health and Safety Regulations 2012	Codes of Practice http://safework.sa.gov.au/show_page.jsp?id=5892
Noise and Vibration	Environment Protection (EP) Act 1993 Environment (Noise) Protection Policy 2007 Occupational Health, Safety and Welfare Regulations 2012.	SA EPA Information Sheet – SA EPA Guidelines for the use of the Environment Protection (Noise) Policy 2007 (2009). Environmental Noise (May 2013), EPA Information Sheet 424/13. Construction Noise (April 2014), EPA Information Sheet 425/14. Handbook for Pollution Avoidance on Building Sites (2nd ed. June 2004), EPA.

Element	Legislation/Regulations	Guidelines and Standards
Odour and Gaseous Emissions	Environment Protection Act 1993 Protection of health and the environment and compliance with the National Environment (Ambient Air Quality) Protection Measure 1998 (Air Quality NEPM). National Environment Protection (Air Toxics) Measure, April 2004.	Air quality impact assessment using design level pollutant concentrations, January 2006, EPA Guideline 386/06. Schedule B(2) Guideline on Protection of Health and the Environment during the Assessment of Site Contamination, Amended National Environment Protection (Assessment of Site Contamination) Measure 1999 (NEPC, 2013). EnHealth (2002), Environmental Health Risk Assessment—Guidelines for assessing human health risks from environmental hazards.
Dust	Protection of health and the environment and compliance with the National Environment (Ambient Air Quality) Protection Measure 1998 (Air Quality NEPM).	Wastes containing asbestos—removal, transport and disposal, December 2014 EPA Guideline 414/14. Code Of Practice for the Safe Removal of Asbestos (Second edition), National Occupational Health and Safety Council, 2005 [NOHSC:2002(2005)]. Management of asbestos in the non-occupational environment, enHealth Council, 2005 enHealth. Schedule B(2) Guideline on Protection of Health and the Environment during the Assessment of Site Contamination, Amended National Environment Protection (Assessment of Site Contamination) Measure 1999 (NEPC, 2013). Guideline For Stockpile Management Waste and Waste Derived Products for Recycling and Reuse. South Australia EPA, September 2010.
Soil and Groundwater Contamination Prevention	Environment Protection Act 1993 Pollution of Waters by Oils and Noxious Substances Act 1987 Environment Protection (Water Quality) Policy 2003	National Environment Protection Measure (NEPM) 1999 SA EPA Guideline for the Assessment and Remediation of Groundwater Contamination (2009) SA EPA Environmental Management of On-going Site Remediation (2008) Code of Practice—Industrial, Retail and Commercial Stormwater Management (in draft under development). Land and Water Biodiversity Committee 3rd Edition (2012) Minimum construction requirements for water bores in Australia.

Element	Legislation/Regulations	Guidelines and Standards
Waste Management and Dangerous Goods Management	Environment Protection Act 1993 Environment Protection (Used Packaging Materials) Policy 2001 Environment Protection (Waste Management) Policy 1994 SA Dangerous Substances Regulations 2002. Dangerous Substances Act 1979.	SA EPA Guidelines for Waste Tracking Form (EPA 416/02) SA EPA Guidelines for Waste Transport Certificate (EPA 415/02) SA EPA Waste Disposal Information Sheet – Current criteria for the classification of waste – including Industrial and Commercial Waste (List) and Waste Soil (EPA 889/10) Bunding and spill management, EPA Guideline 080/12. AS1940: The storage and handling of flammable and combustible liquids. AS1692: Tanks for flammable and combustible liquids. How to manage and control asbestos in the workplace (Safework SA Code of Practice) Code of Practice for the Management and Control of Asbestos in Workplaces [NOHSC:2018 (2005)] Wastes containing asbestos – removal, transport and disposal (EPA 414/14)
On-site Interim Storage of Soil and Groundwater	EPA Guideline for stockpile management: Waste and waste derived products for recycling and reuse, September 2010. EPA Guideline: Bunding and Spill Management (EPA 080/12), updated August 2012.	Suitability for reuse as construction material in the overall Days Creek Domain remediation plan (criteria yet to be finalised).
Off-site Disposal of Soil and Groundwater	Environment Protection Act 1993 (the Act), Regulations and Environment Protection Policies (EPPs). Environment Protection (Water Quality) Policy, 2003. Environment Protection (Waste to Resources) Policy, 2010.	EPA Guideline (EPA 415/10) October 2010 – Waste Transport Certificate. EPA Information sheet (EPA 889/10) March 2010. Standard for the production and use of Waste Derived Fill (updated October 2013).
Protection of Flora and Fauna with substantial environmental value	Development Act 1993 National Parks and Wildlife Act 1972 National Vegetation Act 1991 Federal legislation – Environment Protection and Biodiversity Conservation Act 1999	www.environment .sa.gov.au/biodiversity/threatened.html www.deh.au/epbc
Protection of areas of cultural or heritage significance	Development Act 1993; Heritage Places Act 1993 Federal legislation	Department for Aboriginal Affairs and Reconciliation (DAARE) www.deh.au
Timely and clear information to all stakeholders during all stages of the remediation process		National Environmental Protection (Assessment of Site Contamination) Measure 1999, Schedule B(8) Guideline on Community Consultation and Risk Communication Contaminated Site Management Series, Community Consultation, Department of Environment, Western Australia (June 2012)

Element	Legislation/Regulations	Guidelines and Standards
Protection of site structures during remediation		Environmental management of on-site remediation – Appendix K Structural Aspects (2008)

GUIDING PRINCIPLES

The SA EPA guidelines for environmental management of on-site remediation (EPA 623/06, reprinted in 2008) provides the overarching guidance for successful implementation of remedial strategies so as to minimise any potentially adverse effects.

The guideline describes the expectations for those undertaking remediation projects and outlines the key environmental aspects which should be considered and planned for prior to commencing work.

As stated in the guideline, remediation should start with the preparation of a remediation action plan (RAP) and an environmental management plan (EMP). The RAP should detail the methods, processes and controls of the remediation activities. The EMP should address all environmental management issues. These two plans may be combined to form a remediation management plan (RMP).

The most appropriate remediation strategy will be based on the findings of the DSI and on this basis the appraisal of remediation technologies needs to be undertaken following completion of the short-term baseline program. Completion of the baseline program will also result in finalisation of the remediation clean-up criteria.

It is anticipated that remedial strategies will be implemented at the site within the medium and longer-term timeframes, with the shorter-term works aimed at filling data gaps to better define remediation strategies.

Once remediation works have been prioritised an overall Remediation Action Plan for the site will be developed. In addition, an environmental management plan (EMP) to identify and address any likely environmental impacts that may arise should also be developed.

The EMP, as a minimum, will need to cover the aspects provided in Appendices C to L of the SA EPA guidelines for environmental management of on-site remediation (2008) which include the following:

- Chains of Command and Responsibility for the Site
- Noise and vibration controls, which will include aspects such as hours of operation, noise monitoring and assessment of significant noise generating activities and equipment
- Odour (volatiles compounds, dust and odour) monitoring and controls, which will include measures to minimise potential impacts, monitoring requirements (eg Lower Explosive Limit meter, Photoionisation Detector etc) and contingency measures (eg odour suppressants and dust control) , in accordance with SA EPA requirements
- Handling and disposal of contaminated materials (solids and fluids), in accordance with SA EPA requirements
- Working hours and vehicular movement / traffic controls
- Chemical and materials storage
- Site security
- Monitoring requirements of surrounding receptors and further defined trigger levels for action.

Addenda to the plan may be included at any time if significant site operations change or improved management options become available.

Given that the bulk of the remedial activities involving non-AMD issues will likely be focussed on soil impacts, either as a direct contact health risk issue or as a continuing source of impact to water, a generalised EMP for remediation of soil contamination is provided in **Appendix B**, together with supporting detail on each of the main components related to environmental management of soil contamination. It is noted that **Appendix B** does not include all required elements of an EMP compliant with the guideline (SA EPA, 2008) and reference to this guideline should be undertaken when preparing the site specific EMP.

Implementation for all environmental obligations outlined in the EMP shall, in the first instance, be the responsibility of DSD, unless specifically assigned to a contractor nominated by DSD.

This EMP example does not present procedures regarding management of health and safety aspects of the proposed work, nor does it include controls associated with all the required elements (Appendices H to L) In the first instance, reference should be made to DSD as to the available information collated for the AMD remediation strategy to determine whether it is directly applicable to preparation of the EMP for the non-AMD remedial actions.

INTERIM REMEDIATION CRITERIA

OVERVIEW

This section provides a discussion on the interim remediation criteria based on the currently planned public space end land-use of the site and the updated Conceptual Site Model (CSM) identifying exposure pathways and receptors. The CSM is presented in the separate Addendum Report (URS, 2014).

Further, the South Australian Environment Protection Agency (SA EPA) *Standard for the production and use of Waste Derived Fill* (updated October 2013) provides maximum concentrations of chemical substances to meet a range of waste classifications for potential off-site reuse of materials. Criteria for the classification of wastes for disposal to landfill are provided in the EPA 889/10 information sheet. Should on-site reuse be considered, the NEPM guidelines (Schedule B1) may be appropriate. These guidelines are applicable to the planned characterisation of materials placed at Waste Dumps A and B.

It is important to note that planned AMD remediation works have not yet defined site specific clean-up criteria. If and when these criteria are developed they may supersede the (likely) more conservative interim remediation criteria presented herein.

Finalisation of the remediation criteria will need to consider other relevant guidance such as enHealth (2012) *Environmental health risk assessment* and Australian exposure factor guide, as well as the relevant schedules of the ASC NEPM (2013) such as B1, B2, B4, B5a, B6 and B7, within the context of the findings of the baseline investigations.

The tender process for individual components of the remediation program should direct contractors to justify and specify relevant risk-based clean up criteria based on the outcomes of the baseline investigations. This approach will aim to capture updates in regulatory compliance,

For reference, the following sections provide information on the assessment criteria adopted for investigations to date and the proposed additional investigations.

It is proposed that these assessment criteria form the interim remediation criteria.

CHEMICALS OF POTENTIAL CONCERN

Identified COPCs in soil and groundwater that are not associated with AMD include nutrients, petroleum hydrocarbons and PFCs. There is also the potential for lead in soil in the former rifle range area to impact groundwater. Explosive residue in surface water and/or groundwater in the vicinity of the former magazine shed has not been assessed. Collection of baseline water quality data will include testing for explosive residues in surface water and groundwater samples to assess whether historical storage of materials at the site has resulted in impacts. Based on the presence and magnitude of explosives impacts in groundwater or surface water, further assessment and remediation may be warranted.

The available data set for these COPCs is limited, spatially and/or temporally.

Identification of these key COPCs above adopted guidelines and/or above inferred background soil, surface water or groundwater concentrations will identify the broad extent of site derived impacts. Remedial strategies may then be prioritised and targeted appropriately.

No field observations during the course of the URS investigation identified any substance that was considered to be potential Asbestos Containing Material (ACM); therefore no samples were submitted to the laboratory for asbestos analysis. It is noted however that recent information provided by DSD identified six asbestos pipes in the vicinity of Waste Dump A (HSE, 2013).

Visual assessment of the presence of suspected ACM should be included in any investigation or remediation activity undertaken at the site. In addition, appropriate dust control measures should also be administered as per the EMP (**Appendix B** and **Section 3.3.8**). Positive identification of ACM will require an immediate “stop work” and the engagement of a competent person or appropriately licensed contractor, depending on the volume and nature of material encountered (see **Section 3.3.1**). Further investigation of the extent of ACM impact should be conducted by an environmental consultant in a manner consistent with NEPM guidance (Schedule B1, referencing WA DOH Guidelines for Asbestos Contaminated Sites (May 2009)).

SOIL ASSESSMENT CRITERIA

In lieu of any current site specific criteria for soil quality, state and national assessment frameworks have been adopted. Review of the applicable assessment criteria should be made on a regular basis as updates to state and national guidance occur.

Based on the current zoning of the site, the surrounding land use and the presence of the identified potential receptors at and in the vicinity of the site, the following soil investigation levels are considered currently relevant for environmental site assessment.

Table 1 provides a comparison of applicable soil assessment criteria. As ambient background concentrations in soils at the site have not been established, specific ecological investigation levels have not been established and hence are identified as “to be determined” in **Table 1**.

NEPM Human Health Investigation Levels (HILs)

The National Environment Protection Measure 1999 (NEPM) provides risk-based health investigation levels (HILs) for selected organic and inorganic chemicals in soils. Different levels are provided for a variety of exposure settings including residential, open-space / parks / recreational and commercial / industrial land uses. The NEPM HILs have been developed to be protective of human health and do not take into account environmental concerns.

For assessment purposes (and preliminary remediation targets) the health investigation levels (HIL) C, as defined in the *National Environment Protection (Assessment of Site Contamination) Measure 1999, amended 2013* (NEPM, 1999) are deemed the most applicable to ensure the protection of human health from any contamination existing at the site. The HIL C criteria are defined in the updated NEPM 1999 as applicable for land use comprising:

“Public open space such as parks, playgrounds, playing fields (e.g. ovals), secondary schools and footpaths. This does not include undeveloped public open space where the potential for exposure is lower and where a site-specific assessment may be more appropriate.”

It is noted that a less stringent criteria may be more appropriate (in particular for remediation targets) taking into account that the land will likely be left in an undeveloped state, however, for human health considerations the NEPM HIL C thresholds should apply unless a site-specific assessment is completed.

NEPM Heath Screening Levels (HSLs)
As the NEPM Heath Screening Levels (HSLs) for petroleum hydrocarbon compounds are based on assessing and preventing potential risks to human health due to intrusion of hydrocarbon vapours from contaminated soil into overlying buildings their application is considered limited given the current and likely future conditions of the site which are likely to be mainly open space. It is understood that DSD plans not to release the land over to the public until the remediation of the entire Brukunga mine site has been completed and there is evidence for the acceptable performance of the remediation (structural stability and environmental outcomes). Following verification of remediation performance the land will be turned over to the public for an agreed beneficial use.

Where petroleum hydrocarbons are identified in soil or groundwater it is prudent to consider the application of the CRC CARE[1] 'Health screening levels for petroleum hydrocarbons in soil and groundwater' (Technical report no. 10) by completing the application checklist, http://www.crccare.com/publications/downloads /HSL-Application-Checklist.xls, to confirm their applicability and any limitations that may need to be applied.

As soil samples are typically collected from a range of depths within the saturated zone, the applicable HSL may vary from sample to sample. Consequently, HSLs are identified below for a range of depths. The soil HSLs adopted for this site are based on the site being turned over to the public for an agreed purpose assumed to be consistent with recreational / open space (HSL C) with sandy soil. As the extent of contamination has not been delineated and due to the sites proximity to the road the direct contact HSLs for intrusive maintenance worker has also been adopted. These HSLs may be relevant should hydrocarbon impacts to soil be identified, particularly during any planned excavation of the underground storage tank (UST) adjacent the former workshop area.

The relevant soil HSLs considerations applicable to the Brukunga mine site are presented below.

- Land use: open space / recreational (HSL C)
- Soil type: sand (selected to be conservative, although the soil has also been logged as clayey sand, and silty clay)
- Depth to source: variable.

NEPM Management Limits
Management limits for petroleum hydrocarbons have been developed to consider adverse effects related to the nature and properties of the chemicals; namely:

- The formation of observable light non-aqueous phase liquids (LNAPL)
- Fire and explosive hazards
- Effects on buried infrastructure.

Their applicability to industrial (including mine sites) is limited, however, their consideration for future land use as potentially public open space is warranted.

NEPM Ecological Investigation Levels (EILs) and Environmental Screening Levels (ESLs)
The NEPM (1999) also provides ecologically-based investigation levels (EILs) for selected organic and inorganic chemicals in soils. These values are developed on a regional basis and allow for the protection of flora, fauna, soils, climate etc.

[1] Cooperative Research Centre for Contamination Assessment and Remediation of the Environment

Ecological investigation levels (EILs) exist for the protection of terrestrial ecosystems under a model developed by the ASC NEPM (Schedule 5b) for As, Cu, CrIII, DDT, naphthalene, Ni, Pb and Zn. The EILs are land use dependent with three generic land use settings offering different levels of ecosystem protection. Consistent with the HIL C public open space end use, the urban residential/public open space land use setting offers 80% protection, whilst the commercial and industrial land use setting offer 60% protection.

Brukunga's climate has been described as essentially Mediterranean with cool wet winters and hot dry summers (Taylor and Cox, 2003). On this basis, the EILs for the site apply principally to contaminants in the top 2 m at the finished surface/ground level.

The EIL is derived by summing the added contaminant limit (ACL) which considers the bioavailability of element based on soil characteristics (pH, cation exchange capacity and clay content) and the Ambient Background Concentration (ABC).

The NEPM methodology assumes that the ecosystem has adapted to the ambient background concentration for the local area. The NEPM Schedule B1 notes that this approach is essential where there is a high naturally occurring background level such as will occur in mineralised areas.

Given the naturally occurring pyritic mineralisation of the area, it is likely that some ABCs of metals may exceed the NEPM HIL C guidelines.

Site specific EILs can be calculated for CrIII, Cu, Ni and Zn where soil physicochemical properties are known (Table 4, NEPM Schedule 1). A scope of work to collect appropriate soil samples representing background conditions at the western portion of the site and subsequent analysis of samples for appropriate analytes (including soil properties) is provided in **Section 5.2.3**.

In addition Environmental Screening Levels (ESLs) also exist for Benzene, Toluene, Ethylbenzene and Xylenes (BTEX), benzo(a)pyrene and F1 (C_6-C_{10}) and F2 (>C_{10}-C_{16}).

Waste Characterisation for Disposal
Waste has been deposited in two main areas at the site referred to as Waste Dump A and Waste Dump B.

A broad scope to adequately characterise waste fill material deposited at these locations is provided in **Section 6.1.4**. Application of the SA EPA Standard for the production and use of waste derived fill (SA EPA, 2013) maximum concentrations of chemical substances to meet waste classifications for Waste Fill (WF) and Intermediate Waste Soil (IWS) is considered relevant for future stockpile sampling of segregated material from Waste Dumps A and B. Should on-site reuse be considered, the NEPM guidelines outlined above are considered to be appropriate.

Other guidance
In lieu of a local guideline for PFOS (related to the use of Aqueous Film-Forming Foam), the US EPA Region 4 residential soil screening level of 6 mg/kg for PFOS[2] was previously adopted. It is noted that assessment of PFOS and associated compounds is currently the focus of much scientific study and screening levels may be subject to change.

GROUNDWATER AND SURFACE WATER ASSESSMENT CRITERIA

Protected environmental values applicable to aquifers beneath the site are prescribed by the Environmental Protection (Water Quality) Policy (EPA, 2003). An assessment of whether these protected environmental values are aligned with beneficial uses of groundwater at the site was conducted based on consideration of factors such as site and regional groundwater quality and yield, the current zoning of the site, surrounding land uses, known or suspected potential use of groundwater in the area and the presence of identified potential receptors at and in the vicinity of the site.

[2]http://www.epa.gov/fedfac/pdf/emerging_contaminants_pfos_pfoa.pdf

Table 2 presents the applicable protected environmental values for the site and an assessment of the applicable beneficial uses.

Table 2. Protected Environmental Values and Applicable Beneficial Uses.

Protected environmental value	Beneficial use at this site	Justification
Aquatic ecosystem (fresh waters)	Yes	Dawesley Creek runs intermittently in a southerly direction through the site, and eventually drains into the River Murray. There is the possibility of fresh water ecosystems being present within the creek system.
Recreation and aesthetics	No	The creek has limited access due to the vegetation surrounding the feature, and has limited flows, particularly in summer. No evidence of recreational use was identified during the site inspection conducted by URS in October 2012, nor in the review of previous investigations. It is noted that the presence of the fence between the southern site boundary and the intersection of Mt. Barker Creek (see below) limits access for recreational purposes.
Potable use	No	Groundwater salinity in groundwater wells sampled in August 2014 ranged from 2,680 mg/L (H16B) up to 10,900 mg/L (BH19) which is too high to be considered for potential future potable use (SA EPA, 2009). Historically (1998 to 2014), groundwater salinities in the inferred up and down hydraulic gradient direction of the site have been at levels that preclude realistic use for potable supply.
Agriculture (Irrigation and Livestock)	Yes	Potential for use of groundwater for irrigation and livestock on adjacent sites, potential for the use of water from Dawesley Creek downstream from the mine site. It is noted that DSD had restricted public access to Dawesley Creek following suspected adverse health effects in cattle downstream of the mine in the 1990's. Parts of Dawesley Creek have been initially fenced and sign posted with warnings from the site until reaching its intersection to Mt. Barker Creek to prevent access by people and livestock.
Industrial	Yes	There is the potential for industrial use of groundwater, however, it is noted that there is no industrial use of adjoining sites.

Based on the justification provided in Table 2, the relevant beneficial uses for the site are assessed to be:

- Freshwater aquatic ecosystems
- Agriculture – Irrigation
- Agriculture – Livestock watering.

State-based regulatory criteria:

- *South Australian Environment Protection (Water Quality) Policy 2003.*

Nationally applied risk-based screening criteria:

- ANZECC, ARMCANZ (2000) *Australian and New Zealand guidelines for fresh and marine water quality*. Australian and New Zealand Environment and Conservation Council, Agriculture and Resource Management Council of Australia and New Zealand.

For screening level assessment, it is considered reasonable to apply the groundwater assessment criteria to surface water samples.

Groundwater investigation levels (GILs) provided by in Schedule 1 of the NEPM (1999), based on the applicable beneficial uses of the groundwater and are less conservative than the already applied SA EPP (EPA, 2003) water quality guidelines based on the Protected Environmental Values (PEVs) outlined in Table 2.

In the absence of appropriate state or national screening criteria consideration was given to appropriate guidance on identifying trigger levels for further investigation of persistent organic pollutants Perfluorinated Compounds (PFCs) primarily as perfluorooctane sulfonate (PFOS) and perfluorooctanic acids (PFOA) in surface or groundwater.

PFOS and PFOA are now known to be persistent, toxic at relatively low concentrations and bioaccumulative. The screening criteria applied to the reported PFOS and PFOA surface water sample and groundwater concentrations include:

- US EPA Provisional Health Advisory – Drinking Water Short Term Exposures
  PFOS = 0.2 µg/L
  PFOA = 0.4 µg/L
- UK Environmental Agency – Surface Water – Fresh
  PFOS = 1 µg/L
- Environment Canada Ecological water quality
  PFOS = 6 µg/L.

Of these, the short term drinking water guidelines are the most conservative.

Table 2 provides a summary of the applicable screening guidelines for the identified chemicals of potential concern, including the primary guidance (EPP, 2003) and the ANZECC 2000 guidelines for freshwater ecosystems (95% protection).

Critical to determining whether actual or potential harm to water exists that is not trivial resulting from site contamination (EPA 839/08, 2008) is establishing background conditions.

Comparison of on-site water quality data with background concentrations (EPA 838/08, 2008) will determine if the observed chemical concentrations are due to on site activities or are representative of natural or ambient conditions. On this basis, collection of surface water and groundwater quality data in the up-stream and up hydraulic gradient direction of the site is critical in determining whether site contamination exists. It is noted however, that the EPA considers that the presence of anthropogenic chemicals (such as solvents or explosives) above the laboratory limit of reporting is considered to represent harm to water, regardless of background concentrations.

Data collected from wells sampled as part the URS investigation and regular sampling by DSD suggests that native groundwater may contain zinc concentrations above criteria relevant to the protection of aquatic ecosystems and irrigation beneficial uses. Other COPCs tested by URS including TRH, BTEX, Polycyclic Aromatic Hydrocarbons (PAHs), nutrients, Poly Chlorinated Biphenyls (PCBs), Organochloride and Organophosphorous Pesticides (OCPs) and cyanide were not identified at concentrations above the adopted investigation levels and typically not above the laboratory LORs in groundwater entering the site. On this basis, the laboratory LORs for the aforementioned COPCs represent the screening criteria when others are not available.

SHORT-TERM WORKS PROGRAM

INTRODUCTION

The short-term works program focuses on collecting baseline data to determine priorities for remedial actions.

The short-term timeframe for works has been nominally identified as being within the next 1 to 2 years.

ESTABLISHING BASELINE CONDITIONS

Timeframe: The recommended timeframe for establishing baseline conditions is by the end of 2015.
Duration: The duration of baseline investigations and reporting is considered to be 4 months from award date.

Groundwater monitoring

Aim	To provide an updated assessment of assess the distribution of non-AMD COPCs within groundwater beneath the site and surrounds.
Scope	For the initial groundwater monitoring event it is proposed to collect water quality information on a comprehensive selection of active groundwater wells on the western portion of the site. The aim would be to reduce the subsequent monitoring rounds to key wells for key analytes as detailed in the Water Quality Monitoring Plan for the site. Recommended wells include: **Background wells**: H08, KAN23, KAN26, KAN27 and KAN28 **On-site wells:** H-series: H01, H02, H03, H04a, H04b, H06a, H06b, H09, H12, H13, H14a, H14b, H17 (GAMW01), H18 (GAMW02) and H19 (GAMW03) KAN series: KAN11 (or KAN12), KAN13, KAN15, KAN16, KAN30 and KAN31 BH series: BH01 (or BH02 or BH03), BH08, BH10, BH14A, BH18, BH19, BH21 (or BH22), BH33 and BH34. Gauging the depth to water and total well depth at each location prior to purging and sample collection will be required. Analytical program to include: • Dissolved metals As, Cd, Cr, Cu, Ni, Pb, Zn, Hg, Al, Fe and Mn and • TRH(C_6-C_{40})/BTEX/PAH/Phenols/Pesticides/PCBs/Nutrients (NO_3, NO_2, NH_3, TKN, total phosphorous)/Total Cyanide, explosives and PFOS/PFOA. The field collected quality parameters (pH, redox potential, salinity and temperature) to be recorded during the groundwater sampling. Analytical program to allow for 36 primary samples and 6 quality assurance/quality control samples; specifically • 2 quality assurance/quality control intra-laboratory duplicate (split sample). • 2 quality assurance/quality control inter-laboratory duplicate (split sample) • 1 rinse blank/equipment blank • 1 trip blank.
Methodology	Sampling should be consistent with the EPA (2007) guidelines for Regulatory Monitoring and Testing: Groundwater sampling.
Deliverable	Baseline water quality report to be prepared. Includes assessment of groundwater flow direction. Review of accuracy and precision of data, background water quality, changes in water quality in comparison to adopted guidelines and historical context and exceedences of appropriate assessment criteria. Comparison with historical data sets and identification of key COPCs with respect to non-AMD sources should be undertaken. Include recommendations on revision or expansion of the groundwater monitoring as part of the Environmental Monitoring Plan (EMP) development.

Surface/Seepage water monitoring

Aim	To assess whether non-AMD COPCs have impacted surface water quality prior to being collected into the diversion drain targeting areas close to potential non-AMD source areas.
Scope	Collect surface/seepage water samples from the following locations: 1. Near TP18 or BH13 for most sources upstream of the Days Creek Domain 2. At the base of the southern void for potential impacts from Waste Dump A 3. Near R07/TP09 for potential impacts from Waste Dump B. Analytical program to include: • Dissolved metals As, Cd, Cr, Cu, Ni, Pb, Zn, Hg, Al, Fe and Mn; and • TRH(C_6-C_{40})/BTEX/PAH/Phenols/Pesticides/PCBs/Nutrients (NO_3, NO_2, NH_3, TKN, total phosphorous)/Total Cyanide, explosives and PFOS/PFOA. The field collected quality parameters (pH, redox potential, salinity and temperature) to be recorded during the surface water sampling. Analytical program to allow for 3 primary samples and 2 quality assurance/quality control samples; specifically • One quality assurance/quality control intra-laboratory duplicate (split sample) • One quality assurance/quality control inter-laboratory duplicate (split sample).
Methodology	DSD staff to collect grab samples in a manner consistent with the “The Monitoring Plan for the Brukunga Remediation Program” which was developed as part of an Environment Improvement Program established by negotiation between EPA and SA Water (which previously managed the site) in August 1996 and approved by EPA in the same year. Sampling should be consistent with the EPA (2007a) guidelines for Regulatory Monitoring and Testing: Water and wastewater sampling.
Deliverable	Baseline water quality report to be prepared. Includes assessment of accuracy and precision of data, background water quality, changes in water quality in comparison to adopted guidelines and historical context and exceedences of appropriate assessment criteria. Comparison with historical data sets and identification of key COPCs with respect to non-AMD sources should be undertaken. Include recommendations on revision or expansion of the seepage and/or surface water monitoring program as part of the Environmental Monitoring Plan (EMP) development.

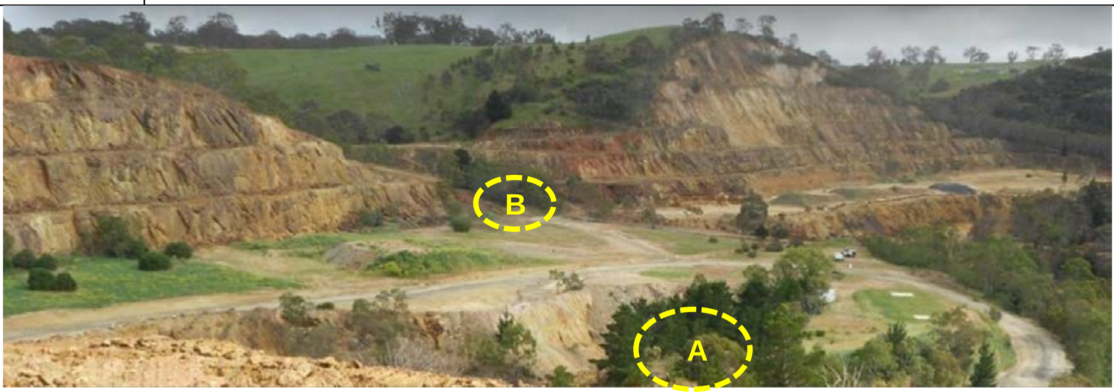

Figure 5-1 Approximate location of Waste Dump Areas A & B (photo from SKM, 2013)

Background soil sampling

Aim	To establish Ambient Background Concentrations (ABC) of COPCs in soil and to determine site specific Ecological Investigation Levels (EILs) where appropriate.
Scope	Conduct a site visit to ascertain potential background soil sample collection points cognisant of elevations representing future surface / completion elevations. Natural surficial soils within site boundaries but away from mining features should be assessed for suitability as representative for background conditions. Areas close to adjacent land uses should be considered to assess whether ambient contaminants have been contributed from off-site sources. Potential locations for background sampling are shown in **Figure 5-2** below. These areas are not exhaustive and additional locations should be considered cognisant of adjacent land-uses and access. Analytical program to include at least 10 and up to 30 primary samples for : • Soil pH and moisture content; • Metals As, Cd, Cr, Cu, Ni, Pb, Zn, Hg, Al, Fe and Mn; • Nutrients (NO_3, NO_2, NH_3, TKN, total phosphorous)/Total Cyanide and PFOS/PFOA; • Soil pH, particle size distribution (for clay content) and cation exchange capacity (CEC); and • An allowance for leachability testing of 2 primary samples reporting the highest concentrations of COPCs should be made. Leaching under neutral (pH 7 or rainwater equivalent) and acidic (pH 5) conditions should be considered.
Methodology	Collect soil samples using a decontaminated hand-trowel or shovel directly into a laboratory prepared glass jar. Collect samples from at least two depths (e.g. 0.0 - 0.2 m and 0.3 - 0.4 m) to account for the potential for wind-blown dust in the surficial material. Log material AS:1726 and assess whether variations in soil type exist across the site. Ensure that sufficient numbers of samples representative of differing soil types at both the surface and sub-surface have been collected to determine whether chemical variations across the site laterally and vertically in areas assess to be unimpacted by mining activities. Consistent with NEPM Schedule 5b, select sampling locations based on a similar unpolluted reference soil to the contaminated soil. Decontaminate sampling equipment between locations. To enable statistical evaluation of results using 95% Upper Confidence Level (UCL), analysis of a minimum of 10 primary samples is required. The exact number of samples analysed will need to be assessed on the lateral and vertical variation in soil encountered.
Deliverable	Factual letter report collating data, assessing data integrity and comparing results with the SAHT (1993) results for samples collected close to the Brukunga township. To include recommendations for risk based soil clean-up criteria for remedial work based on background soil quality, exposure pathways for workers (eg dermal contact or dust inhalation) and agreed end land-use.

Figure 5-2 Potential background soil sample locations

Inspection and maintenance program for the Dawesley Creek fence line

Aim	To provide evidence of a maintained barrier to access to Dawesley Creek downstream of the site.
Scope	On an annual basis conduct a site visit to ascertain the integrity of the fence line and status of the signage between the southern site boundary and the Mt. Barker Creek intersection). Currently, off-site exposure of animals and humans to Dawesley Creek is considered to be an incomplete exposure pathway given the integrity of the fence line downstream of the site remains intact.
Methodology	Visual inspection of the full length of the fence line on both sides of the creek is required. Documentation should include written and photographic records outlining: • Inspection date and personnel undertaking inspection. • Photographs of signage and fence line, representative if in good order, otherwise noting where repairs are required. • Any other observations (animals, health of vegetation). • Completion of follow up actions (repairs), dates/personnel/photographs.
Deliverable	Annual inspection records to be included in the Environmental Monitoring Plan annual review.

Water Quality Monitoring Plan

Timeframe: The recommended timeframe for developing a site specific Water Quality Monitoring Plan (WQMP) is immediately following the completion of baseline investigations (**Section 5.2**), nominally the by the end of 2015.

Duration: The duration of WQMP development is considered to be 2 months from award date.

The design of the WQMP will be based on baseline soil and water quality conditions, complete exposure pathways and agreed end land-use. The CSM should be updated as necessary as new information comes to light.

Aims

The development of a WQMP will aim to:

- Provide a uniform approach to sampling, clearly outlining appropriate sample collection methodologies and minimum field data requirements.
- Provide an overview of the hydrogeological setting.
- Identify which wells best represent water quality changes from different areas across the site and from which hydrogeological units.
- Identify site specific water quality assessment criteria which include consideration of the ambient groundwater quality in a mineralised geological setting.
- Identify which analytes are likely to describe changes in water quality that are likely to be attributable to site-derived impacts.
- Identify mechanisms for review of applicable assessment criteria, monitoring frequency, suitability of the selected monitoring network and adequacy of the analytical program.
- Identify sentinel wells that may trigger further investigations if water quality changes reach threshold levels (ie wells close to off-site receptors or deeper wells) indicative of contaminant migration.

Scope

The WQMP should be prepared in accordance with the following guidance:

- NEPM Schedule B2 Site Characterisation (NEPM, 1999);
- EPA Guidelines - Regulatory monitoring and testing: Groundwater Sampling (SA EPA, 2007); and
- EPA Guidelines - Regulatory Monitoring and Testing: Water and wastewater sampling (SA EPA, 2007a).

At a minimum monitoring program should be prepared with respect to the following considerations:

- Monitoring objective
- Conceptual Site Model
- Spatial extent of impacts
- Precision / accuracy required
- Logistical and OH&S issus
- Cost.

Key elements of the monitoring plan should include:

- Duration of sampling (campaign and on-going)
- Sampling points (location and number)
- Frequency and patterns of sampling
- Analytes and parameters
- Sampling methodology
- Responsible persons.

A statement on the data quality objectives (DQO) and the subsequent development of a sampling and analysis quality plan (SAQP) as per Section 5 of Schedule B2 (NEPM, 1999) should be included in the WQMP.

MEDIUM AND LONGER-TERM WORKS PROGRAM

Given the current understanding of non-AMD contamination issues, it is likely that remedial works will be required at the UST/workshop area and at the Waste Dump area in the medium term. As the underlying geology is comprised of weathered to fresh rock with predominantly low hydraulic conductivities the options for in-situ remedial technologies are limited and are unlikely to include in-situ chemical oxidation or soil vapour extraction. Where impacts above assessment criteria occur or organic compounds that are incompatible with planned AMD remediation are identified then remediation options will primarily focus on removal, characterisation and either off-site disposal or on-site reuse.

Longer term prioritisation of additional areas for remediation, such as the remnant toilet block infrastructure, former rifle range and biosludge areas will be conditional on whether impacts to groundwater have been identified and whether the planned Days Creek Domain remediation has been assessed as being successful.

It is understood that site preparation works for the Days Creek Domain will include clearing of unconsolidated material down to bedrock and hence surficial impacts within the former rifle range and nearby remnant toilet block infrastructure will be addressed by removal of this material.

Continued environmental monitoring

The WQMP will require annual review as a minimum. Variability in water quality results will determine appropriate sampling frequencies with more stable conditions requiring less monitoring events to capture changes. Consideration to the implementation schedule of the Days Creek Domain and associated monitoring requirements should be made to ensure no duplication occurs.

DEVELOPMENT OF A DETAILED RAP AND EMP

Develop a site by site Remediation Action Plan and Environmental Management Plan for remedial works to which subsequent remedial stages can be attached as addenda (see **Section 3.2**).

Consideration should be given to incorporating remediation of non-AMD remedial works into the RAP and EMP developed for the Days Creek Domain to ensure no duplication occurs.

Timeline: Development of detailed RAPs and EMPs for separate remedial areas should form part of the tender scope, nominally to be undertaken by early 2016. Information provided to tenderers by DSD will need to include baseline investigation outcomes, updated remediation criteria and consider limitations applied by the concurrent AMD remediation program. Justification for the proposed remedial approach should be included in the tender response and be based on the information provided.

Duration: Allow 1 month for tender specification, 1 month for tender response, 1 month for tender evaluation and award and 1 month for RAP and EMP preparation and provision to DSD.

UST AND WORKSHOP AREA

Duration: Allow 2 months from award date for investigation and validation completion. Allow a further 2 months for reinstatement and reporting.

The existing data set has not identified petroleum hydrocarbon impacts to soils in the vicinity of the UST and workshop area.

The SA EPA recommends removing all underground storage tanks (USTs) that are no longer being used for their originally intended purposes as soon as reasonably practical.

Removal of the existing UST and validation testing of the remaining soils is recommended to confirm that no source to groundwater exists. Additional groundwater and soil investigation may be required should impacts be identified during tank excavation.

The UST tank removal scope of work should be prepared in accordance with the following guidance:

- AS4482.1-2005 Guide to the sampling and investigation of potentially contaminated soil Part 1: Non-volatile and semi-volatile compounds.
- AS4482.2-2005 Guide to the sampling and investigation of potentially contaminated soil Part 2: Volatile substances.
- National Environment Protection (Assessment of Site Contamination) Measure 1999, Schedule B2 – Guideline on Site Characterisation, and
- EPA Guidelines - Assessment of Underground Storage Systems – EPA 580/05 (SA EPA, 2005).

Table 3 provides the recommended minimum sampling density for UST excavations based on guidance listed above.

Table 3. Recommended Minimum Sampling Density for UST Excavations.

Sample location	Sampling rate	Sample volume
UST pit floor	Min. 2 / tank	1 jar & 1 bag (PID) / sample
UST pit wall	Min. 2 / wall; or 1:25m^2 for large excavation (e.g. if two tanks present)	1 jar & 1 bag (PID) / sample
Fuel lines	1 / linear 5m	1 jar & 1 bag (PID) / sample
Beneath fuel dispenser	1 / dispenser	1 jar & 1 bag (PID) / sample

HISTORICAL USE OF THE SITE FOR WASTE FILL STORAGE (WASTE DUMP A AND WASTE DUMP B)

Duration: Allow 3 months from award date for excavation, segregation and classification. Allow a further 1 month for reporting.

The estimated volume of Waste Dump A is in the order of 15,000 m^3. The number of samples analysed from Waste Dump A was 17 primary samples; given the estimated volume of fill, this results in a sampling density of around 1 per 880 m^3.

The estimated volume of Waste Dump B, as the volume of fill between the high wall sections in the Aerometrex report (2009) is in the order of 20,000 m^3. The number of samples analysed from Waste Dump B was 6 primary samples; given the estimated volume of fill, this results in a sampling density of around 1 per 3,330 m^3.

The existing sampling density was not sufficient to classify waste for off-site disposal.

As noted in the URS report a review of the site history, and more importantly the aerial photographs, suggests multiple stages of landfilling. As such, characterisation of soils upon excavation of the material is recommended so that larger objects can be removed from the material and finer material segregated for potential on-site retainment or off-site disposal.

The sampling rate suitable for characterising materials for disposal off-site or on-site re-use is dependent on the heterogeneity of the material excavated. Segregation of materials of similar composition will be required. The resultant volume, physical description and chemical composition of each stockpile will need to be assessed prior to waste classification.

The preliminary work conducted by URS regarding the status of the waste dumps can be used to tailor an appropriately targeted analytical suite for materials segregated based on their physical description. The number of samples required to be collected will be based on the size and homogeneity of the segregated stockpiles. Inspection of the segregated stockpiles will be necessary prior to development of an appropriate sampling plan suitable for waste classification.

Development of an appropriate scope for the excavation, segregation and classification of waste materials will need to be based on the following guidance.

- AS4482.1-2005 Guide to the sampling and investigation of potentially contaminated soil Part 1: Non-volatile and semi-volatile compounds.
- AS4482.2-2005 Guide to the sampling and investigation of potentially contaminated soil Part 2: Volatile substances.
- EPA Victoria, 2009, Industrial Waste Resource Guidelines Sampling and Analysis of Waters, Wastewaters, Soils and Wastes.
- Current SA EPA "Standard for the production and use of Waste Derived Fill (updated October 2013); and
- National Environment Protection (Assessment of Site Contamination) Measure 1999, Schedule B2 – Guideline on Site Characterisation.

Based on current knowledge, the scope of work may include provision for the following:

- Supervision of excavation by a suitably qualified person to better segregate materials and to identify potential anthropogenic materials (e.g. asbestos, bitumen fragments etc).
- Minimum sampling rates of:
    - 1 sample per 250 m^3, with a minimum of 10 samples per segregated stockpile (say 60 samples for Waste Dump A and 80 samples for Waste Dump B; based on current volume estimates) for key analytes of TRH and metals.
    - 20% of samples collected for additional COPCs such as PAH (associated with bitumen fragments), PFOS/PFOA.
    - Minimum of 10 samples required for a full SA EPA Waste Classification suite and leachability testing. A rate of 10% can be adopted if stockpile sizes are large enough.
    - 10% of samples for leachability testing based on highest reported concentrations of COPCs. Leaching under neutral (pH 7 or rainwater equivalent) and acidic (pH 5) conditions should be considered.
- Specification of stockpile sample points on a plan as per NEPM Schedule B2. Samples collected from the exterior 300 mm of the stockpile should be avoided due to the higher risk of weathering and grain size grading errors. Samples for inorganic and non-volatile components should be taken at various depths towards the centre of the stockpile from 300 mm below the stockpile surface.
- Statistical evaluation of results using 95% Upper Confidence Level (UCL) based on a minimum data set of 10 samples per stockpile.
- Characterisation of materials and classification for off-site disposal and/or assessment for potential for on-site reuse (potentially as growth media for AMD remedial works).

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TABLES

Soil Assessment Criteria / Interim Remediation Criteria

	Recreational / Open Space Land use					
Criteria	**NEPM EILs**	**NEPM ESLs**	**NEPM HSL C**	**Current NEPM HIL C**	**NEPM Management Limits**	**Current SA EPA WDF**
Units mg/kg		assuming coarse grained	assuming sand 0-<1m		assuming coarse grained	
Metals/Metalloids						
Arsenic (total)	100			300		20
Barium						300
Beryllium				90		20
Cadmium				90		3
Cobalt				300		170
Chromium	TBD					400
Chromium VI				300		1
Copper	TBD			17,000		60
Lead	TBD			600		300
Manganese				19,000		500
Mercury (inorganic)				80		1
Methyl mercury				13		
Nickel	TBD			1,200		60
Selenium				700		
Tin						
Zinc	TBD			30,000		200
Organics						
Benzene		50.0	NL			1
Ethyl benzene		85	NL			3
Toluene		70	NL			1.4
Xylenes		105	NL			14
F1 (TRH C_6-C_{10} - BTEX)		180	NL		700	
F2 (TRH >C_{10}-C_{16} - naphthalene)		120	NL		1,000	
F3 (TRH >C_{16}-C_{34})		300			2,500	
F4 (TRH >C_{34}-C_{40})		2,800			10,000	
Petroleum hydrocarbons TPH C_6-C_9 (total)						65
Petroleum hydrocarbons TPH >C_9						1,000
TPH C_{16}-$C_{35\ Aromatics}$						
TPH C_{16}-$C_{35\ Aliphatics}$						
TPH >$C_{35\ Aliphatics}$						
TRH >C_{34}-C_{40}						
TPH C_{10}-C_{36}						
Aesthetics/volatiles						
Total PAHs				300		
Naphthalene	170		NL			
Benzo(a)pyrene		1			NA	
PAHs (total)				300		5
Carcinogenic PAHs (as BaP TEQ)				3		
Phenolic compounds (total)						0.5
Phenol (only)				40,000		
Pentachlorophenol				120		
Cresols				4,000		
PCBs (total)				1		2
Aldrin + Dieldrin				10		2
Chlordane				70		
DDT	180					2
DDT + DDD + DDE				400		
Heptachlor				10		
Other						
Boron				20,000		
Phosphorous						
Sulphate						
pH						
PFOS				6^		
Cyanide (free)				240		
Cyanide (total)						500

Assumes:
TBD = to be determined
^ Interim guideline based on USEPA Regional 4 residential land-use screening guideline
NA = Not Applicable NL = Non Limiting
All Chromium present as Cr (III), unlesss tested specifically for CrVI
Total cyanide is equivalent to complexed cyanide
Superseded NEPM HIL E - Parks, recreational open space and playing fields incl. secondary schools equivalent to NEPM HIL C
Current NEPM HSL C = recreational / open space
Carcinogenic PAHs based on 8 PAHs and their Toxicity Equivalent Factors (TEFs =potency relative to B(a)P) - see below for method.

World Health Organisation Toxic Equivalence Factors for PAHs as per NEPM Schedule B1, Table 1A.

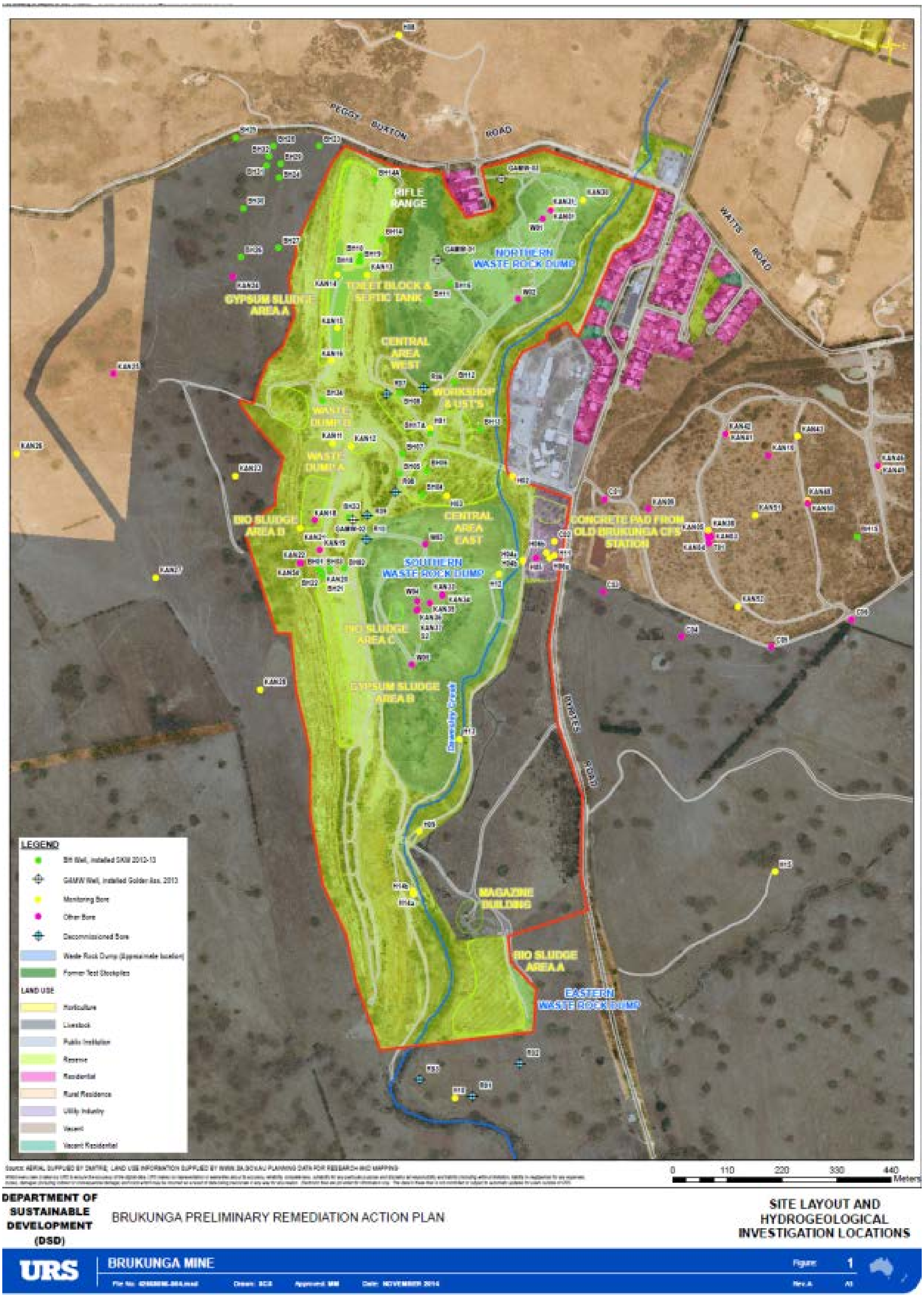
PAH	Toxic Equivalence Factor (TEF)
Benz(a)anthracene	0.1
Benzo(a)pyrene	1
Benzo(b+j)fluoranthene	0.1
Benzo(k)fluoranthene	0.1
Benzo(g,h,i)perylene	0.01
Chrysene	0.01
Dibenz(a,h)anthracene	1
Indeno(1,2,3,cd)pyrene	0.1

Table 2 Water Assessment Criteria / Interim Remediation Criteria

Method_Type	ChemName	output unit	LOR	State Regulatory Criteria: SA Water Quality, 2003, Ag, Irrigation	SA Water Quality, 2003, Ag, Livestock	SA Water Quality, 2003, Potable	SA Water Quality, 2003, Aquatic, Fresh	Adopted Most Stringent Regulatory Criteria	Risk Based Criteria: ANZECC 2000 for 90% Protection Level Aquatic ecosystems - fresh	ANZECC 2000 for 95% Protection Level Aquatic ecosystems - fresh	USEPA Provisional Health Advisory - Drinking Water Short Term Exposures	UK Environment Agency - Surface Water - Fresh	Environment Canada Ecological water Quality	Adopted Most Stringent Risk Based Criteria
PAH/Phenols (GC/MS - SIM)	Sum of polycyclic aromatic hydrocarbons	mg/L	0.0005											
TPH Volatiles/BTEX	C6-C9 fraction	µg/L	20											
TRH - Semivolatile Fraction	>C10-C16 fraction	µg/L	100											
	>C16-C34 fraction	µg/L	100											
	>C34-C40 fraction	µg/L	100											
	>C10-C40 fraction (sum)	µg/L	100											
TPH Volatiles/BTEX	C6-C10 fraction (F1 minus BTEX)	µg/L	20											
	C6-C10 fraction	µg/L	20											
	Benzene	µg/L	1			1	300	1	1300	950				950
	Toluene	µg/L	2			800	300	300						
	Ethylbenzene	µg/L	2			300								
	m&p-Xylene	µg/L	2											
	o-Xylene	µg/L	2											
	Total Xylenes	µg/L	2			600		600	720	550				550
	Naphthalene (VOC)	µg/L	5											
Perfluorinated Compounds	PFOS	µg/L	0.02								0.2	1	6	0.2
	PFOA	µg/L	0.02								0.4			0.4
	6:2 Fluorotelomer sulfonate (6:2 FtS)	µg/L	0.1											
	8:2 Fluorotelomer sulfonate	µg/L	0.1											
PAH/Phenols (GC/MS - SIM)	Naphthalene	µg/L	1						0.037	0.016				0.016
	Acenaphthylene	µg/L	1											
	Acenaphthene	µg/L	1											
	Anthracene	µg/L	1											
	Fluorene	µg/L	1											
	Phenanthrene	µg/L	1											
	Fluoranthene	µg/L	1											
	Benz(a)anthracene	µg/L	1											
	Benzo(b&j)fluoranthene	µg/L	1											
	Benzo(k)fluoranthene	µg/L	1											
	Benzo(a)pyrene	µg/L	0.5											
	Benzo(a)pyrene TEQ	µg/L	0.5											
	Chrysene	µg/L	1											
	Pyrene	µg/L	1											
	Benzo(g,h,i)perylene	µg/L	1											
	Dibenz(a,h)anthracene	µg/L	1											
	Indeno(1,2,3-cd)pyrene	µg/L	1											
	Phenols	µg/L	100											
	Phenol	µg/L	1				50	50	0.6	0.32				0.32
	2-Chlorophenol	µg/L	1						0.63	0.49				0.49
	2-Methylphenol (o-Cresol)	µg/L	1											
	3-&4-Methylphenol (m&p-Cresol)	µg/L	2											
	2-Nitrophenol	µg/L	1											
	2,4-Dichlorophenol	µg/L	1			0.3	0.2	0.2	0.2	0.16				0.16
	2,4-Dimethylphenol	µg/L	1											
	2,6-Dichlorophenol	µg/L	1											
	4-Chloro-3-methylphenol	µg/L	1											
	2,4,6-Trichlorophenol	µg/L	1						0.04	0.02				0.02
	2,4,5-Trichlorophenol	µg/L	1			2		2						
	Pentachlorophenol	µg/L	2			0.01	0.05	0.01						
Dissolved Mercury by FIMS	Mercury (Filtered)	mg/L	0.0001	0.002	0.002	0.001	0.0001	0.0001	0.0019	0.0006				0.0006
Dissolved Metals by ICP-MS - Suite A	Aluminium (Filtered)	mg/L	0.01	1	5		0.1	0.1	0.08	0.055				0.055
	Arsenic (Filtered)	mg/L	0.001	0.1	0.5	0.007	0.05	0.007	0.042	0.013				0.013
	Cadmium (Filtered)	mg/L	0.0001	0.01	0.01	0.002	0.002	0.002	0.004^	0.002^				0.002
	Chromium (Filtered)	mg/L	0.001	1	1			1						
	Copper (Filtered)	mg/L	0.001	0.2	0.5	2	0.01	0.01	0.0162^	0.0126^				0.0126
	Iron (Filtered)	mg/L	0.05	1			1	1						
	Lead (Filtered)	mg/L	0.001	0.2	0.1	0.01	0.005	0.005	0.150^	0.127^				0.127
	Manganese (Filtered)	mg/L	0.001	2		0.5		0.5						
	Nickel (Filtered)	mg/L	0.001	0.2	1	0.02	0.15	0.02	0.117^	0.099^				0.099
	Zinc (Filtered)	mg/L	0.005	2	20		0.05	0.05	0.135^	0.072^				0.072
Alkalinity by PC Titrator	Hydroxide Alkalinity as CaCO3	mg/L	1											
	Carbonate Alkalinity as CaCO3	mg/L	1											
	Bicarbonate Alkalinity as CaCO3	mg/L	1											
	Total Alkalinity as CaCO3	mg/L	1											
	Total Hardness as CaCO3	mg/L	20											
Total Dissolved Solids	Total Dissolved Solids	mg/l	1											
pH	pH	-	-	4.5-9		6.5-8.5	6.5-9	6.5-8.5	6.5-9					6-5-9.0
Sulphate (Turbidimetric) as SO4 2- by DA	Sulphate as SO4 2- - Turbidimetric	mg/L	1	1000		500		500						
Chloride Discrete Abalyser	Chloride	mg/L	1											
Fluoride by PC Titrator	Fluoride	mg/L	0.1			1.5		1.5						
Dissolved Major Cations	Calcium	mg/L	1											
	Magnesium	mg/L	1											
	Sodium	mg/L	1											
	Potassium	mg/L	1											
Ionic Balance	Total Anions	meq/L	0.01											
	Total Cations	meq/L	0.01											
	Ionic Balance	%	0.01											
Total Cyanide	Total Cyanide	mg/L	0.05			0.08		0.08	0.011					0.011
Ammonia as N by Discrete analyser	Ammonia as N	mg/L	0.01				0.5	0.5	1.43	0.9				0.9
Nitrate as N by Discrete Analyser	Nitrate (as N)	mg/L	0.01		30	10		10						
Nitrite and Nitrate as N (NOx) by Discrete Analyse	Nitrate & Nitrite (as N)	mg/L	0.01				0.5	0.5						
Nitrite as N by Discrete Analyser	Nitrite (as N)	mg/L	0.01		10	1		1						
Total Kjeldahl Nitrogen as N By Discrete Analyser	Total Kjeldahl Nitrogen	mg/L	0.1											
Total Nitrogen as N (TKN + Nox) By Discrete Analyser	Total Nitrogen as N	mg/L	0.1				5	5						
Total Phosphorus as P By Discrete Analyser	Total Phosphorus as P	mg/L	0.01				0.5	0.5						
Reactive Phosphorus as P by Discrete Analyser	Reactive Phosphorus as P	mg/L	0.01											
Polychlorinated Biphenyls (PCB)	Polychlorinated Biphenyls	µg/L	1											
Pesticides by GCMS	Aldrin	µg/L	0.5											
	Dieldrin	µg/L	0.5											
	Aldrin + Dieldrin	µg/L	0.5											
	a-BHC	µg/L	0.5											
	b-BHC	µg/L	0.5											
	d-BHC	µg/L	0.5											
	g-BHC (Lindane)	µg/L	0.5											
	cis-Chlordane	µg/L	0.5						0.014	0.08				0.08
	trans-Chlordane	µg/L	0.5											
	Chlordane	µg/L	0.5											
	DDD	µg/L	0.5											
	DDE	µg/L	0.5											
	DDT	µg/L	2						0.00002	0.00001				0.00001
	DDT+DDE+DDD	µg/L	0.5											
	Endosulfan 1	µg/L	0.5						0.0006	0.0002				0.0002
	Endosulfan 2	µg/L	0.5											
	Endosulfan sulfate	µg/L	0.5											
	Endrin	µg/L	0.5						0.00004	0.00002				0.00002
	Endrin aldehyde	µg/L	0.5											
	Endrin ketone	µg/L	0.5											
	Heptachlor	µg/L	0.5						0.00025	0.00009				0.00009
	Heptachlor epoxide	µg/L	0.5											
	Hexachlorobenzene (HCB)	µg/L	0.5				0.007	0.007						
	Methoxychlor	µg/L	2											
	Malathion	µg/L	0.5											
	Azinphos Methyl	µg/L	0.5											
	Bromophos-ethyl	µg/L	0.5											
	Carbophenothion	µg/L	0.5											
	Chlorfenvinphos	µg/L	0.5											
	Chlorpyrifos	µg/L	0.5											
	Chlorpyrifos-methyl	µg/L	0.5											
	Demeton-S-methyl	µg/L	0.5											
	Diazinon	µg/L	0.5											
	Dichlorvos	µg/L	0.5											
	Dimethoate	µg/L	0.5											
	Ethion	µg/L	0.5											
	Fenamiphos	µg/L	0.5											
	Fenthion	µg/L	0.5											
	Monocrotophos	µg/L	2											
	Parathion	µg/L	2											
	Parathion-methyl	µg/L	2											
	Pirimphos-ethyl	µg/L	0.5											
	Prothiofos	µg/L	0.5											

^ adjusted for hardness (based on 1,300 mg/L CaCO3, 400 mg/L used in calculation), DMITRE 2013

FIGURES


PEGGY BUXTON ROAD
WATTS ROAD
RIFLE RANGE
NORTHERN WASTE ROCK DUMP
TOILET BLOCK & SEPTIC TANK
GYPSUM SLUDGE AREA A
CENTRAL AREA WEST
WORKSHOP & UST'S
WASTE DUMP B
WASTE DUMP A
BIO SLUDGE AREA B
CENTRAL AREA EAST
CONCRETE PAD FROM OLD BRUKUNGA CFS STATION
SOUTHERN WASTE ROCK DUMP
BIO SLUDGE AREA C
GYPSUM SLUDGE AREA B
Dawesley Creek
MAGAZINE BUILDING
BIO SLUDGE AREA A
EASTERN WASTE ROCK DUMP
LEGEND
LAND USE
Horticulture
Livestock
Public Institution
Reserve
Residential
Rural Residence
Utility Industry
Vacant
Vacant Residential
0
110
220
330
440
Meters
DEPARTMENT OF SUSTAINABLE DEVELOPMENT (DSD)
BRUKUNGA PRELIMINARY REMEDIATION ACTION PLAN
SITE LAYOUT AND HYDROGEOLOGICAL INVESTIGATION LOCATIONS
URS
BRUKUNGA MINE
Figure:
1

APPENDIX A Auditor Comments

APPENDIX B Generic Environmental Management Plan

Waste Disposal

General wastes generated by the remedial activities are to be transferred from the site to a suitably licensed disposal (and/or treatment/recycling) facility. The site waste management system should be used for the disposal of any general wastes.

Should small amounts of suspected non-friable Asbestos Containing Material (ACM) during earthworks be encountered application of the commercial removal and transport of ACM and Asbestos Waste guidance provided by the EPA applies (EPA guidance EPA414/14).

Off-site Disposal of Soil

Waste soil generated during excavation works at the site will be managed to prevent cross-contamination of other nearby clean soils. Samples of any soils with visual or olfactory indications of contamination will be laboratory tested for contaminants of potential concern identified during previous environmental investigations.

Any soils deemed not suitable for storage/re-use at the site will be disposed of to an appropriately licensed facility.

Disposal will be in accordance with the Environment Protection Act (1993). Contaminated materials will be pre-classified in accordance with the current criteria for the classification of waste (EPA 889/10) March 2010. As required, waste assessment and classifications for contaminated materials will be provided to the civil contractor by the DSD appointed representative (typically an environmental consultant).

Waste soils will be transported in accordance with the EPA Guidelines (EPA415/10) October 2010. All transport and disposal records shall be kept and maintained for reporting purposes.

Approvals from the disposal facilities required for the off-site disposal of materials shall be the responsibility of DSD or their nominated representative.

Containers or truck bodies used in the transport of the contaminated materials shall be equipped with tautly tied tarps and with seals between doors such that no soil, dust or water can escape during transport. All vehicles utilised for the movement of contaminated materials shall be licensed by the EPA for the purpose.

Following loading and prior to leaving the site, the exterior of all vehicles shall be inspected for the presence of loose material that has the potential to fall onto the road during travel. Any such material shall be removed prior to the departure of the vehicle. Only vehicles which have clean exterior bodywork and which will not pollute the off-site transportation corridors shall be permitted to leave the site.

The civil contractor shall maintain records and documentation in accordance with regulatory requirements and these records shall be suitable for the purposes of tracking of the exported materials.

The civil contractor shall ensure that all drivers responsible for the transport of contaminated materials from the site are trained and appropriately licensed in the procedures to be implemented in the event of any incident involving the escape of contaminated materials from their vehicles.

The civil contractor shall take all necessary steps to ensure all vehicles leaving the site do not track contaminated soil, sand or mud and the like onto areas outside of the site boundary and/or public roadways. This may include leaving site pavements in place, regular sweeping or scraping of the loading area to remove loose soil and brushing down vehicle bodies and tyres prior to allowing vehicles to leave the site. In addition, the civil contractor will monitor the condition of roadways leading from the site and commission a street sweeper as and where required.

Surface and Storm Water Management

Surface water runoff may be generated from the site following periods of significant rainfall.

Wherever possible it is preferable to adopt the measures to prevent pollution of surface water to prevent the requirement for retainment and disposal. Potential mitigation measures may include:

- Use of temporary rainproof covers for stockpiles
- All stockpiles will be temporary bunded and located on waterproof surfaces
- Exposed soil surfaces will be minimised wherever possible.
- Temporary barriers (hay bales) will be placed around the work site boundary.

If oily water is encountered within an excavation, these waters would be removed by a licensed contractor for subsequent testing and disposal.

Sediment Control

Sediment management shall be undertaken with respect to the overall site and specifically with respect to stockpile management (discussed further in **Section B.7** below).

As required, erosion control through the use of temporary bunds around handling areas, erection of siltation barriers (hay bales) (or other site specific technique) shall be adopted to manage site erosion and reduce environmental impact through silt loading. Such controls shall be tailored to suit site conditions and level of protection (i.e. absent in areas of hardstand and continuous in areas of open excavation).

Importation of Soil or Liquids

It is not expected that liquid products will need to be imported to site. However, where materials required for the purposes of the works are imported, the following must be determined and potential risks to the environment identified and methods adopted for mitigation of identified risks:

- Supplier's data: The supplier's product data including sources and general properties; and

- Product warranties: The supplier's written statement certifying the product complies with the Specification and is suitable for the intended use (in the case of materials, such as backfill).

Imported Soils

The requirements for management of imported soils will typically depend on the nature and origin of the materials, but might include the following. Specific requirements should be established on the basis of the detail of the final RMP.

All soil material imported to the site must meet the background contaminant ranges and the waste fill criteria (SA EPA, 2010).

All imported materials should be visually inspected (at the source or upon delivery at the site) for foreign substances, suspicious staining and/or odours. In the event that the material is found to contain any of the aforementioned DSD or their nominated representative should be consulted to determine a course of action. This will likely involve a review of the materials source and whether any activities undertaken at the site may have potentially caused contamination.

The following is a list of materials whose presence may indicate potentially contaminated material:

- Marine mud, peat, vegetation, timber, organic, soluble or perishable materials;

- Dangerous or toxic material or material susceptible to combustion;
- Metal, rubber, plastic or synthetic material or other forms of general rubbish; and/or
- Construction debris.

DSD or their nominated contractor will undertake sampling of the imported material. Analytical sampling of the imported material will include the following analyte list:

- Inorganics (including arsenic, cadmium, chromium, copper, lead, zinc, nickel, mercury);
- Total petroleum hydrocarbons (TPH);
- Benzene, toluene, ethyl benzene, xylenes (BTEX) compounds;
- Polycyclic aromatic hydrocarbons (PAH);
- Polychlorinated biphenyls (PCB);
- Organochlorine and organophosphorous pesticides (OCPs/OPPs); and
- Any other analytes that may be specifically required depending on the source of the materials.

Volumes of imported material utilised for reinstatement shall be determined on the basis of the required specifications as determined by the civil contractor and DSD.

Stockpile Management

In the event that impacted soils are identified; DSD or their nominated representative should be contacted to provide advice on appropriate handling and storage options. Generally; the following guidelines should be followed:

- Stockpiles of impacted soils should be placed at locations that do not threaten cross-contamination of other materials;
- In the event that grossly contaminated materials are uncovered, stockpiles should be placed in a secure area and covered with black plastic where proposed to remain on site for an extended period of time.
- Stockpiles should be of a size that does not present a potential hazard of collapsing.
- Stockpiles should be kept away from the site boundary wherever possible.
- As appropriate, silt fences shall be constructed around the perimeter of each stockpile area.

Provision for the management of both dust and surface water run-off from the stockpiles will be made by the Civil Contractor so as to minimise the potential for environmental impact from these areas. These measures may include, but not be limited to, the construction of temporary bunds around the handling areas, excavation of drains, erection of siltation barriers and dust suppression by use of appropriate water spraying equipment.

Air Quality and Dust Management

The inhalation of dust particles during the excavation operation may present a potential hazard to on site workers and the surrounding community. In the event that contaminated soil is identified or dust/odours present a hazard due to weather conditions, the following mitigation measures can be used where deemed appropriate.

- The excavation should be kept moist for the prevention of dust generation through the periodic watering of exposed areas. A water tanker with sufficient hoses and spray capacity should be available at the site, and be utilised, as necessary, to maintain soil moisture during intrusive works. Saturation of soils should be avoided to minimise the potential for impacted runoff. Water conservation measures (restrictions) must be considered.
- Work should be avoided on days that are particularly windy, dry and hot, and if dust from the site is caused to move beyond the site boundary, excavation works should be halted and potential control measures assessed.
- If dusts are being generated on site then an appropriate dust mask or half face respirator fitted with a particulate filter should be worn on site. A supply of suitable dust masks should be maintained on site by DSD or their nominated representative.
- Keeping the worksite clean and minimising the exposed work area and any traffic over exposed areas.

- Rolling or compaction of any exposed soils at the site can help to reduce dust, particularly when moist.
- Continuous monitoring of conditions on site will be undertaken to address any concerns as quickly as possible.

Odour and Gaseous Emissions

The potential for odour and gaseous (volatile) emissions from exposure and handling of contaminated soils and/or contaminated waters may be present during the works and can create noxious or offensive odours creating nuisance to site workers, adjacent land-users and the local community. Potential sources of odour and volatile emissions at the site include petroleum hydrocarbons which can present various types and degrees of impact including explosive atmospheres and toxic environments that pose unacceptable health risks (both chronic and acute). In the event that odours/volatile emissions become a problem the site, the following measures may be used to help mitigate the associated hazards:

- Minimising the exposed surface area of odorous/noxious materials by using a staged excavation approach.
- Timing excavation activities to minimise off-site nuisance.
- Where possible, undertaking works in favourable weather conditions such as lower temperatures and favourable winds.
- Covering exposed surfaces overnight or during periods of low excavation activity. This can be done with either plastic sheeting or clean soil.
- Not stockpiling odorous materials unless covered.
- As soon as practicable, removing offensive odorous material offsite.
- Passive monitoring of volatile organic compounds in ambient air to allay potential concerns. It is proposed that monitoring (using a PID) be undertaken within breathing space of site workers and along all site boundaries.
- Constant monitoring of work areas for the presence of explosive atmospheres.
- Documentation and prompt investigation and response to community complaints (including initiation of any necessary corrective actions).

Based on results of groundwater sampling and analytical testing undertaken historically at the site it is not expected that significant concentrations of volatile compounds will be encountered. The lack of volatile compounds is expected to limit the potential for the generation of unpleasant odours beyond what would typically be expected at a petroleum facility. However, the presence of unpleasant odours will be monitored and work ceased where unexpected conditions are encountered and alternative techniques undertaken.

ATTACHMENT C
FMEA AND CONTROLS

FMEA Worksheet - Brukunga Technical Advisory Group (TAG) - DSD Brukunga Mine Remediation (01 April 2014) Rev9

Failure Mode ID	Failure Mode Description	Effects and Pathways	Likelihood	Consequences												Level of Confidence	Highest Risk Rating	2013 Mitigation / Comments
				Environmental Impact		Special Considerations		Legal and Other Obligations		Consequence Costs		Community / Media / Reputation		Human Health and Safety				
1a	Sulphide oxidation as a result of desaturation following drought, leading to acidic pore-water in co-disposed waste	Acidic pore-water released to Days Creek via lateral seepage	M	Mo	Mo-H	n/a	n/a	n/a	n/a	L	L	L	L	L	L	H	Mo-H	Maintain elevated water table through proper design. Ultimately it is controlling seepage out the base that is important for this one.
1b		Acidic pore-water released to Days Creek and Dawesley Creek via groundwater seepage downgradient of embankment	NL	Ma	Mo	n/a	n/a	n/a	n/a	Ma	Mo	Ma	Mo	L	L	M	Mo	Depends on whether a drought condition or wet climate conditions are occurring, and the prevalence of these conditions over the assessment period. Design and construction (proper QA/QC), add in contingencies as per Jeff's comments (changing limestone placement). Low level of confidence because there is lack understanding of the landuse, need to look at some mitigation measure for taking water from Days Creek, model the extremes for the initial design to understand the risk and what are the key design elements.
2a	Ineffective mixing of limestone, tailings and waste rock, leading to acidic pore-water in co-disposed waste	Acidic pore-water released to Days Creek via lateral seepage	L	Mo	Mo	n/a	n/a	n/a	n/a	C	Mo-H	L	L	L	L	L	Mo-H	Review after looking at outcomes of 10,000t trial
2b		Acidic pore-water released to Days Creek and Dawesley Creek via groundwater seepage downgradient of embankment	L	Mi	L	n/a	n/a	n/a	n/a	C	Mo-H	Mi	L	Mi	L	M	Mo-H	Review after looking at outcomes of 10,000t trial

3a	Poor quality limestone leading to insufficient neutralising capacity	Acidic pore-water released to Days Creek via lateral seepage	L	L	L	n/a	n/a	n/a	n/a	L	L	L	L	L	L	H	L	Design calls for 4% by weight $CaCO_3$; hence if limestone quality diminishes, the application rate will go up. Implies on-going monitoring of this design aspect.
3b		Acidic pore-water released to Days Creek and Dawesley Creek via groundwater seepage downgradient of embankment	L	L	L	n/a	n/a	n/a	n/a	L	L	L	L	L	L	H	L	Limestone quality analysis
4a	Failure to meet design specifications leading to insufficient limestone applied to co-disposed waste	Acidic pore-water released to Days Creek via lateral seepage	M	Mo	Mo-H	n/a	n/a	n/a	n/a	Mi	Mo	Mi	Mo	Mi	Mo	M	Mo-H	A construction issue, limestone isn't applied in the right manner, Review after looking at outcomes of 10,000t trial
4b		Acidic pore-water released to Days Creek and Dawesley Creek via groundwater seepage downgradient of embankment	L	Mo	Mo	n/a	n/a	n/a	n/a	Mi	L	Mi	L	Mi	L	M	Mo	Review after looking at outcomes of 10,000t trial
5a	Insufficient volume of limestone applied to co-disposed waste as a result of a design flaw	Acidic pore-water released to Days Creek via lateral seepage	L	Mi	L	n/a	n/a	n/a	n/a	Mi	L	Mi	L	Mi	L	L	L	Highlights importance of 3D GW and solute transport modelling; Investigate source and load, allow for acid input in limestone quantity; strategic placement of limestone material.
5b		Acidic pore-water released to Days Creek and Dawesley Creek via groundwater seepage downgradient of embankment	E	Ma	C	n/a	n/a	n/a	n/a	Mo	H	Mo	H	Mi	Mo-H	H	C	Determine if the amount of dissolved organic carbon observed / measured in the 100t trial is only restricted to the upper ~2m in the tailings (this organic is coming from historic irrigation of sludge on tailings).
6a	Insufficient volume of limestone applied to co-disposed waste as a result of acidic	Acidic pore-water released to Days Creek via lateral seepage	E	Ma	C	n/a	n/a	n/a	n/a	Mo	H	Mo	H	Mi	Mo-H	H	C	Determine if the amount of dissolved organic carbon observed / measured in the 100t trial is only restricted to the upper ~2m in the tailings (this organic is coming from historic irrigation of sludge on tailings).

6b	groundwater influx	Acidic pore-water released to Days Creek and Dawesley Creek via groundwater seepage downgradient of embankment	E	Ma	C	n/a	n/a	n/a	n/a	Mo	H	Mo	H	Mi	Mo-H	L	C	
7a	Dissolved organic carbon in co-disposed waste pore-water leading to dissolution of jarosite and generation of ferrous ion	Ferrous ions precipitating in coarse textured layer leading to blockage of lateral drainage to Days Creek	NL	L	L	n/a	n/a	n/a	n/a	L	L	L	L	L	L	L	L	Further investigation. As above. Also, if there is sufficient organic carbon then reduction of sulphate and precipitation of iron sulphides is likely to occur and limit ferrous ion mass load. My feeling is that organic carbon is likely to have an overall positive rather than negative effect in the completed co-disposal facility. TRW: it depends on rates/dilution. If a lot of ferrous iron, have potential for clogging of drainage layer as well as iron floc / acid release.
7b		Ferrous ions released to Days Creek and Dawesley Creek via groundwater seepage downgradient of embankment	NL	L	L	n/a	n/a	n/a	n/a	L	L	L	L	L	L	L	L	Clarify that this (and 7c) is "reductive dissolution" - i.e., above that dissolution accounted for in the design limestone calculations. 7a should now be the same as 7b since all items were evaluated in terms of downgradient impact.
7c		Acidic water generated from overflow from gravel drainage layer	M	Mo	Mo-H	n/a	n/a	n/a	n/a	Mo	Mo-H	Mo	Mo-H	L	L	H	Mo-H	The design will result in jarosite dissolution. Design needs to control flux of water (with ferrous iron) from co-disposed waste so that when the oxidation to ferric iron occurs (particularly on discharge to the surface), the impact is acceptable.
8	Anticipated dilution does not match actual dilution provided by Days Creek	Contaminated water (sulphate) within Days Creek in excess of water quality objectives	H	Mo	Mo-H	n/a	n/a	n/a	n/a	Mi	Mo	Mo	Mo-H	L	Mo	L	Mo-H	At periods of low flow, dilution will be limited. Explore design issues regarding stream rehabilitation upstream; We'll combine 9 and 10 into one, as 9 is one of the mechanisms within 10. Only 10 ranked. This is one of the key reasons we came up with the need for the dilution modelling.
9a	Insufficient depth of fractured bedrock material removed prior to embankment construction leading to higher seepage rates	Acidic pore-water released to Days Creek and Dawesley Creek via groundwater seepage downgradient of embankment	NL	Mi	L	n/a	n/a	n/a	n/a	L	L	Mi	L	Mi	L	L	L	Groundwater connection will be there. Modelling will inform leakage rates to/from co-disposed waste and discharge rates to surface. Impact will depend on these rates. Have left as Mi/L assuming no reductive jarosite dissolution and design is to control discharge.

9b	than anticipated, a drop of phreatic surface, leading to oxidation of co-disposed waste	Acidic pore-water released to Days Creek via lateral seepage	E	Mi	Mo-H	n/a	n/a	n/a	n/a	L	Mo	Mi	Mo-H	Mi	Mo-H	L	Mo-H	Review results of 2D and 3D modelling to evaluate need for additional grouting and/or removal of fractured bedrock.
10a	Embankment foundation permeability conditions greater than used in design leading to higher seepage rates than anticipated, a drop of phreatic surface, leading to oxidation of co-disposed waste	Acidic pore-water released to Days Creek and Dawesley Creek via groundwater seepage downgradient of embankment	E	Mi	Mo-H	n/a	n/a	n/a	n/a	L	Mo	Mi	Mo-H	L	Mo	H	Mo-H	12 is a subset of 13. 12 is one of the mechanisms.
10b		Acidic pore-water released to Days Creek via lateral seepage	L	L	L	n/a	n/a	n/a	n/a	L	L	L	L	L	L	H	L	
11a	Design error or inappropriate selection / use of PAF materials for construction of embankment on the downstream side (unsaturated areas)	Generation of acid drainage from embankment face leading to unacceptable effects on aquatic receiving environment	NL	Mi	L	n/a	n/a	n/a	n/a	Mo	L	Mo	L	L	L	H	L	SOP required for classification of material types.
11b	Embankment failure due to vegetation and root development into clay core	Higher seepage rates leading to lowering the phreatic surface and desaturation desaturation of co-disposed waste	L	C	Mo-H	n/a	n/a	n/a	n/a	C	Mo-H	C	Mo-H	C	Mo-H	M	Mo-H	Design and construction (proper QA/QC) so that maintenance of embankment is not required long term (e.g. keeping vegetation off).
12a	Embankment failure due to earthquake	Generation of acid drainage from embankment face leading to unacceptable effects on aquatic receiving environment	NL	C	Mo-H	n/a	n/a	n/a	n/a	C	Mo-H	C	Mo-H	C	Mo-H	L	Mo-H	Static and dynamic failure needs to be considered.
12b		Days Creek and Dawesley Creek contaminated by co-disposed waste following embankment failure	NL	C	Mo-H	n/a	n/a	n/a	n/a	C	Mo-H	C	Mo-H	C	Mo-H	L	Mo-H	Deformation of surface leading to erosion and exposure of waste, and/or a slop failure leading to exposure.

13a	Inappropriate selection / use of PAF materials and/or iron-rich weather rocks for construction of the capping layer	Potential blockage of the drainage layer leading to unacceptable effects on aqautic receiving environment	NL	L	L	n/a	n/a	n/a	n/a	L	L	L	L	L	L	L	L	SOP required for classification of material types.
13b		Dissolved metal and sulfate (salinity) release via sulfide oxidation and leaching of metals from non-sulfide bearing minerals	NL	Ma	Mo	n/a	n/a	n/a	n/a	Ma	Mo	Ma	Mo	L	L	H	Mo	SOP required for classification of material types.
14a	Desiccation cracking of cover material	Higher net percolation rates leading to higher phreatic surface, and therefore higher sulfate flushing rates	H	Ma	H	n/a	n/a	n/a	n/a	Ma	H	Ma	H	Mo	Mo-H	M	H	
14b		Reduced water holding capacity for plant use leading to reduced vegetation ground cover and potentially higher erosion rates than per design	H	Ma	H	n/a	n/a	n/a	n/a	Ma	H	Ma	H	Mo	Mo	M	H	
15	Disruption of the cover due to tree interference (roots, falling over etc.)	Higher net percolation rates leading to higher phreatic surface, and therefore higher sulfate flushing rates	H	Ma	H	n/a	n/a	n/a	n/a	Ma	H	Ma	H	Mi	Mo	M	H	
16	Failure of the cover system due to surface erosion (gross scouring) from Days Creek leading to exposure of the co-disposed waste	Contaminated water released to Days Creek	M	Mo	Mo-H	n/a	n/a	n/a	n/a	Ma	H	Ma	H	L	L	M	H	

17	Disruption of cover due to overtopping of Days Creek as a result of sediment deposition leading to exposure of co-disposed waste	Contaminated water released to Days Creek	M	Mo	Mo-H	n/a	n/a	n/a	n/a	Mo	Mo-H	Mo	Mo-H	L	L	L	Mo-H	Design to PMF?? Design to minimise sedimentation and maximise robustness of Days Creek/cover interface. Sediment removal maintenance.
18a	Cap failure due to surface erosion from Shepherds North and South Creeks overtopping their channels	Exposure of co-disposed waste to the atmosphere	NL	L	L	n/a	n/a	n/a	n/a	L	L	L	L	L	L	L	L	Maintenance; potential for routing Shepards Creek down the highwall drain, rather than taking it over top of the co-disposed waste.
18b		Creek contaminated by co-disposed waste	NL	L	L	n/a	n/a	n/a	n/a	L	L	L	L	L	L	L	L	
19a	Overtopping of Days Creek due to excessive flow from a high rainfall event	Exposure of co-disposed waste to the atmosphere	M	Mo	Mo-H	n/a	n/a	n/a	n/a	Mo	Mo-H	Mo	Mo-H	L	L	L	Mo-H	Design to PMF??
19b		Days Creek contaminated by co-disposed waste	M	Mo	Mo-H	n/a	n/a	n/a	n/a	Mo	Mo-H	Mo	Mo-H	L	L	L	Mo-H	
20a	Salt transport from PAF and/or saline material and accumulation in growth medium	Vegetation cover failure	L	Mo	Mo	n/a	n/a	n/a	n/a	Mo	Mo	Mo	Mo	L	L	L	Mo	Design - capillary break in cover. Environmental impacts downstream associated with long-term failure of cover by enhanced erosion.
20b		Cracking of cover, exposing waste to atmosphere	L	Mo	Mo	n/a	n/a	n/a	n/a	Mo	Mo	Mo	Mo	L	L	L	Mo	Design - capillary break in cover. Environmental impacts downstream associated with long-term failure of cover by enhanced erosion.
20c		Water clogging of growth medium due to clogging of the capillary break layer	L	Mo	Mo	n/a	n/a	n/a	n/a	Mo	Mo	Mi	L	L	L	L	Mo	Design - capillary break in cover. Environmental impacts downstream associated with long-term failure of cover by enhanced erosion.
21	Cover system failure due to surface water runoff	Excessive erosion of cover material	NL	L	L	n/a	n/a	n/a	n/a	L	L	L	L	L	L	L	L	Runoff from rainfall incident to the cover itself.
22a	Mass movement from highwall onto the landform	Disruption of cover and exposure of co-disposed waste to the atmosphere	L	Mi	L	n/a	n/a	n/a	n/a	L	L	L	L	L	L	L	L	

22b		Contaminated material within highwall drainage ditch leading to unacceptable effects on aquatic receiving environment	E	Mo	H	n/a	n/a	n/a	n/a	Mo	H	Mo	H	L	Mo	M	H	Design
22c		PAF rock falling onto cover surface potentially leading to poor surface water quality	NL	L	L	n/a	n/a	n/a	n/a	L	L	L	L	L	L	H	L	
22d		Potential for blockage of the highwall drain leading to overtopping and damage to the receiving environment	NL	L	L	n/a	n/a	n/a	n/a	Mo	L	L	L	L	L	H	L	
23	Embankment failure due to vegetation and root development	Disruption / bioturbation of downstream face leading to erosion	NL	L	L	n/a	n/a	n/a	n/a	L	L	L	L	L	L	L	L	
24a	Embankment failure due to flooding	Generation of acid drainage from embankment face leading to unacceptable effects on aquatic receiving environment	NL	L	L	n/a	n/a	n/a	n/a	L	L	L	L	L	L	L	L	
24b		Days Creek and Dawesley Creek contaminated by co-disposed waste following embankment failure	NL	L	L	n/a	n/a	n/a	n/a	L	L	L	L	L	L	L	L	
25	High water levels during flooding in Days creek (or blockage of diversion channel)	Backflooding of Days Creek and water flowing back into the drainage layer	NL	L	L	n/a	n/a	n/a	n/a	L	L	L	L	L	L	L	L	
26a	Fire leading to vegetation failure	Increased soil loss leading to unacceptable sedimentation of surface water receptors	E	L	Mo	n/a	n/a	n/a	n/a	L	Mo	L	Mo	L	Mo	M	Mo	Failure of vegetation is only an issue if required to stabilise the cover and control recharge to co-disposed waste.

26b		Excessive water plant water use during regeneration / regrowth	NL	Ma	Mo	n/a	n/a	n/a	n/a	L	L	L	L	L	L	M	Mo	Erosion control? Design to allow long-term performance of cap and cover (with minimal maintenance) and minimise veg growth. If cap and cover are disrupted, oxidation can occur leading to AMD discharge to groundwater and runoff.

ATTACHMENT D HYDROGEOLOGICAL MODELLING OUTPUTS SUPPORTING FINAL DESIGN

This attachment summarises the groundwater modelling conducted as part of the Brukunga Phase 3 project to support the development of the detailed engineering design of the Days Creek impoundment. The modelling was performed by Golder Associates with support from Aquanty and relied primarily on the groundwater modelling packages Feflow, HydroGeoSphere (HGS) and GoldSim. Information provided in this attachment is taken from the report "Three Dimensional Regional Groundwater Flow Modelling: Brukunga Mine Remediation Program" prepared by Golder and submitted in Draft to DSD in October 2015 (Golder, 2015).

The overarching objective of the groundwater modelling project was to assess further the extent to which co-disposed material in the impoundment consistent with the Phase 3 design would remain saturated under varying conditions. In contrast to earlier groundwater flow modelling conducted for the Phase 2 remediation design, the most recent modelling incorporated the Phase 3 design and site information, and modelled the Days Creek impoundment to evaluate the extent to which saturated conditions persist under seasonal and long-term variations in climate conditions. The Groundwater Modelling Report (2015) presents the groundwater modelling components conducted as part of Phase 3 and as such provides the basis for the information included in this attachment.

Several stages of modelling were conducted as part of the Phase 3 program, including:

- update of the conceptual hydrogeological model (CHM) underpinning the numerical model development;
- refinement of the Feflow groundwater flow model that was completed previously in 2009 as part of the Brukunga Phase 2 program, and calibration of the pre-remediation model to data including data collected as part of the Phase 3 works (Phase 1 Groundwater Modelling);
- predictive numerical steady state and transient groundwater flow modelling of the Days Creek remediation design under extended dry and wet conditions using HydroGeoSphere (Phase 2 Groundwater Flow and Solute Transport Modelling); and
- predictive modelling of solute transport associated with the implementation of the Days Creek remediation design using GoldSim (Phase 2 Groundwater Flow and Solute Transport Modelling).

The modelling approach and results (including sensitivity analyses) from these stages are described in detail in Golder (2015), and key aspects are summarised below. Throughout the Phase 3 modelling project, inputs to the groundwater flow and solute transport models were provided from results of the engineering investigations and engineering design. Outputs from the groundwater flow model were in turn provided to the impoundment design team and led to changes in the remediation design and placement of waste material.

UPDATE OF THE CHM

Groundwater at the site is hosted in the variably weathered and fractured bedrock underlying the former mine area and in alluvial sediments along drainage alignments. Recharge to groundwater occurs across the site, at the waste rock dumps (NWRD and SWRD) and at the TSF. Groundwater beneath and/or downgradient of the mine pits, waste rock dumps and TSF is impacted by sulfate, acid and metals and discharges locally to the former Dawesley Creek channel where it is captured by the pumping system (Pump Station 1) for treatment at the water treatment plant.

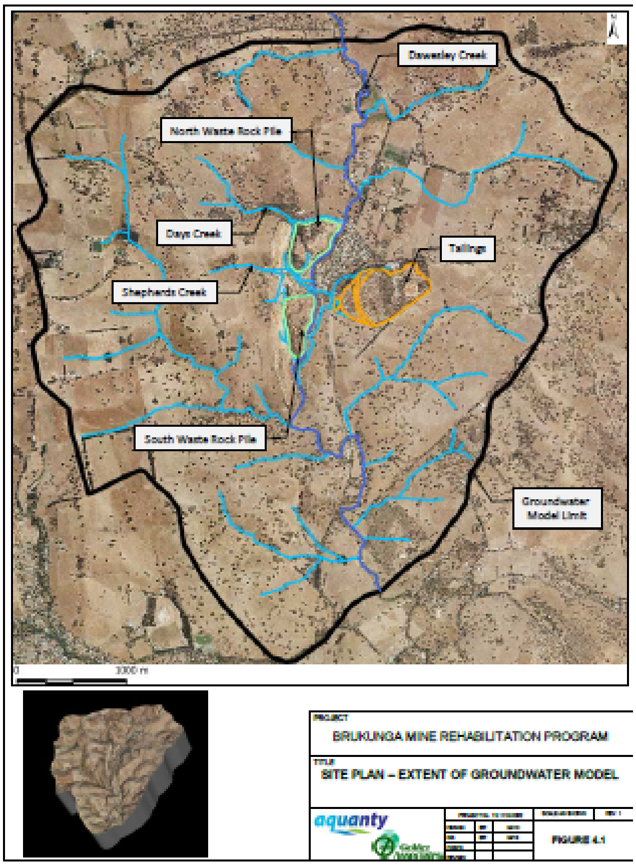
Locally, groundwater flow into pits appears to be associated with fractures, particularly in ore zone rocks. Field testing indicates that hydraulic conductivity values vary across the site, ranging from 3 x 10-9 m/s to 1 x 10-6 m/s and, based on limited data, less weathered bedrock (at and below approximately 12 metres below ground surface (mbgs)) may be characterized by lower hydraulic conductivity values than shallower bedrock. Based on groundwater elevation data and the presence of impacts to groundwater, it is considered likely that a preferential groundwater flow path may exist beneath the original Dawesley Creek channel.

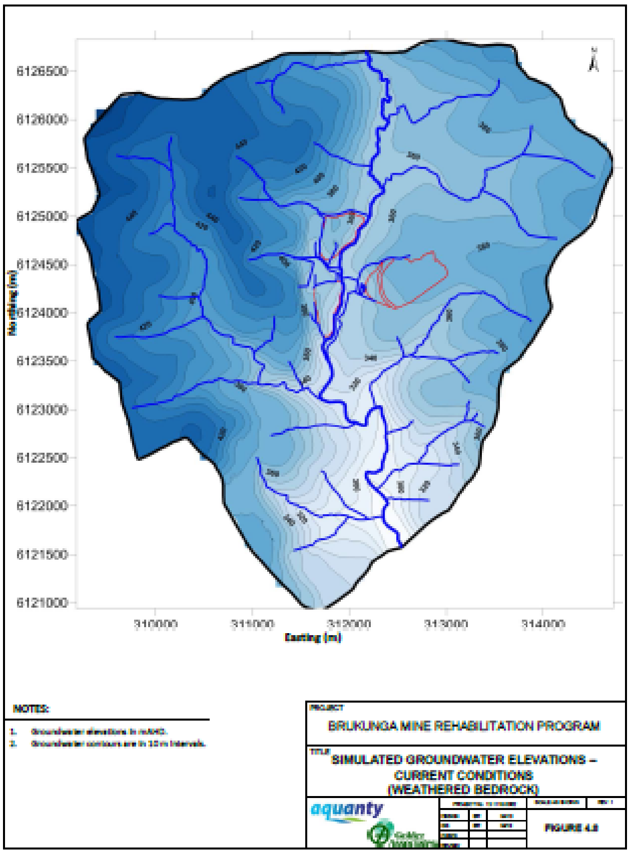
Areas of the CHM that remain uncertain following the Phase 3 works include:

- limited information is available on hydraulic conductivity values of rocks at depths greater than 20-25 mbgs;
- the extent of recovery of groundwater conditions following mining remains unclear due to the availability of only recent groundwater elevation data;
- groundwater elevations indicate that structures in the bedrock (e.g. potential faults beneath Dawesley Creek and other creek lines) may provide important local pathways for groundwater flow and seepage migration away from mining areas;
- long-term seepage rates and quality from the WRDs and TSF remain unclear and are not well understood. Consequently, comparison of predicted seepage rates and quality from the remediated impoundment with those from remaining waste forms cannot be assessed; and
- detailed relationships between groundwater and surface water, and the extent, locations and rates of groundwater discharge to surface water throughout the area remain uncertain.

PHASE 1 - GROUNDWATER MODELLING

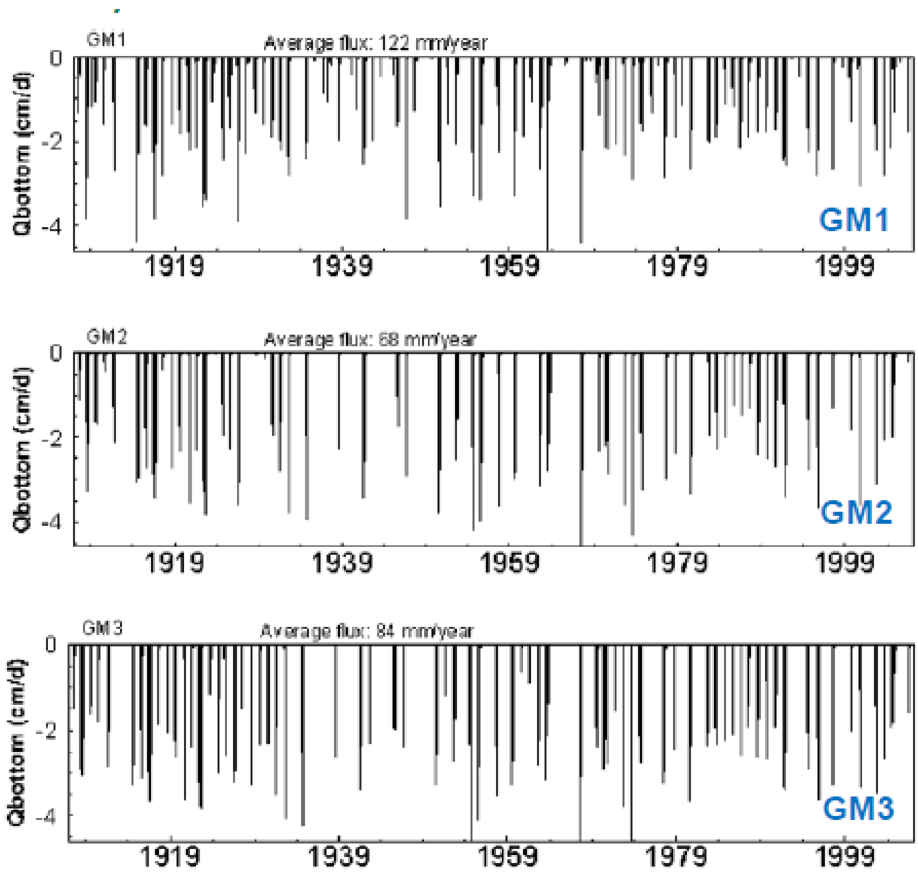
The previously developed 3D numerical groundwater flow model (Feflow) for the entire area was updated to be consistent with the revised CHM. This model covered the entire area as shown below and the steady state flow model was calibrated using recent groundwater elevation data.





Figures 4.1 and 4.8 from Golder (2015).

Subsequently an initial transient simulation using HGS and focused on the localized Days Creek footprint was completed applying parameters from calibration of the Feflow model. Predictive simulations were then completed on the smaller footprint, using HGS and incorporating the conceptual design for the Days Creek Impoundment and recharge to the co-disposed waste (based on modelling conducted by SKM - see figure below).

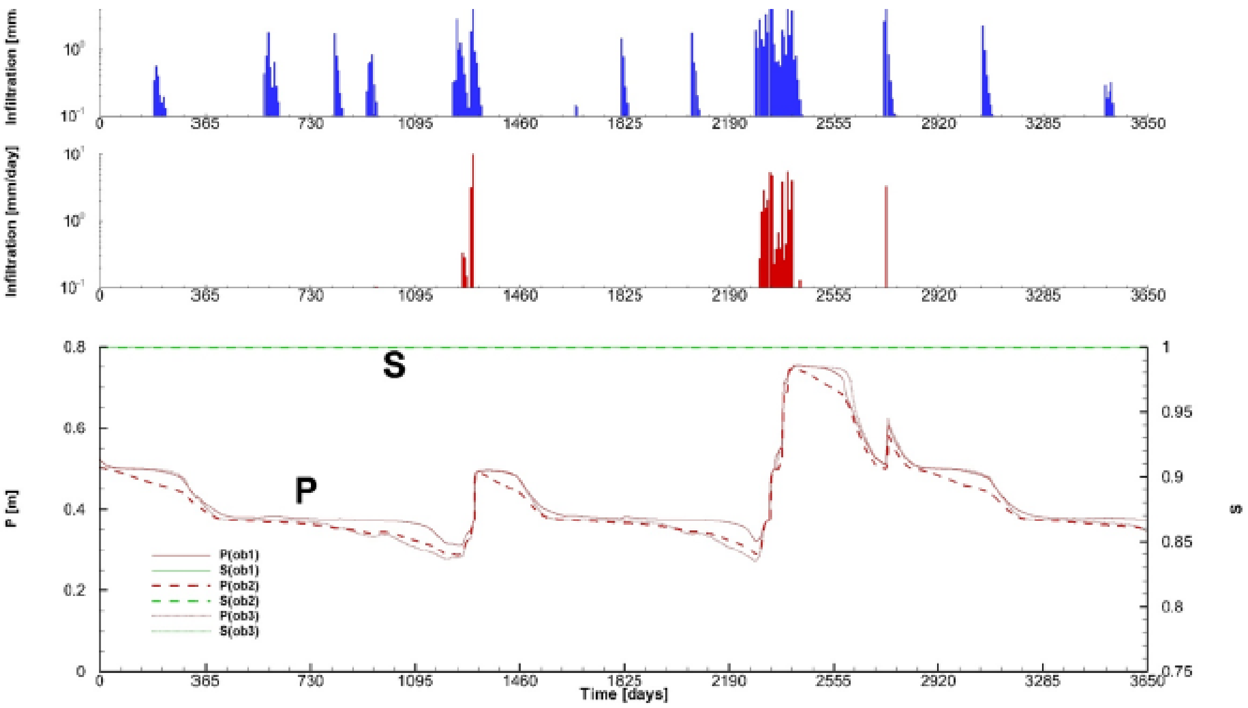


Page 12, Appendix I from Golder (2015): Simulated 100-year water flux at the base of the cover for growth medium (GM) 1, 2, and 3 (1-D cover model results provided by SKM).

In this phase of the project, over 30 model simulations were completed, assessing multiple engineering design cases and ranging from steady state conditions to transient conditions that included longer-term dry and wet periods. Key findings from these preliminary simulations were:

- when model parameters from the calibrated Feflow model were applied to the HGS model, some desaturation of the co-disposed material occurred under steady state conditions; and
- if the underlying bedrock was assigned a hydraulic conductivity of 1×10^{-8} m/s, saturated conditions were maintained and the drainage layer was sufficient thick and permeable to prevent flooding of the overlying growth media.

Subsequently, steady state flow simulations were carried out that tested different configurations of grouting in the bedrock surrounding the impoundment. In these simulations, the hydraulic conductivity of the grout varied from 1×10^{-8} to 1×10^{-7} m/s; the depth, width and extent of the grouted areas was also varied. Transient simulations were then completed using Case 17 (original engineering design with grouting to 15 mbgs around the perimeter of the impoundment - 1×10^{-8} m/s beneath east embankment and 1×10^{-7} m/s elsewhere - Page 27, Annex I, Golder 2015). The transient simulations tested performance over a period of 3 years without recharge and illustrated that, under these conditions, saturation of the co-disposed material was not maintained after 2 years of drought (i.e. no recharge). A further 10 year transient simulation of the 10-year “dry” climate cycle also indicated that saturation of the co-disposed material would not be maintained, particularly in the southern part of the impoundment. By reducing the hydraulic conductivity of the grout curtain around the entire perimeters of the impoundment to 1×10^{-8} m/s, saturation of the co-disposed material was maintained throughout the 10 year dry period (1936-1945) even with infiltration from GM3 (see figure below).



Page 33, Appendix I from Golder (2015). Case 18 (lower K grout curtain, GM3 infiltration (red). Saturation was maintained over the 10-year "dry" period simulation. GM1 infiltration is in blue.

In addition to the simulations to assess performance under extended dry conditions, the potential for interference between the water level in the drainage layer and the base of the cover material (i.e. breaching of the capillary break) was assessed by simulating an extended "wet" period (1920-1930 from the 100 year climate record). Under these conditions, the water level in the drainage layer intercepted the base of the growth medium after 3 years and the simulation was halted. A simple Modflow model was developed to assess the characteristics of the drainage layer and associated drain area (weep holes) required to prevent build up of water in the drainage layer during extended wet conditions. The results of this modelling indicated that the hydraulic conductivity of the drainage layer would need to be approximately $1x10^{-2}$ m/s or greater, either with more weep holes (to Days Creek channel) than in the original engineering design or with an increased drainage layer thickness.

Further sensitivity analyses were conducted using HGS to assess the effect of increasing the hydraulic conductivity of the grout by factors of 2 and 5 (model outcomes were sensitive to an increase of 5 fold) and increasing the hydraulic conductivity of the co-disposed material (the model was insensitive to this parameter).

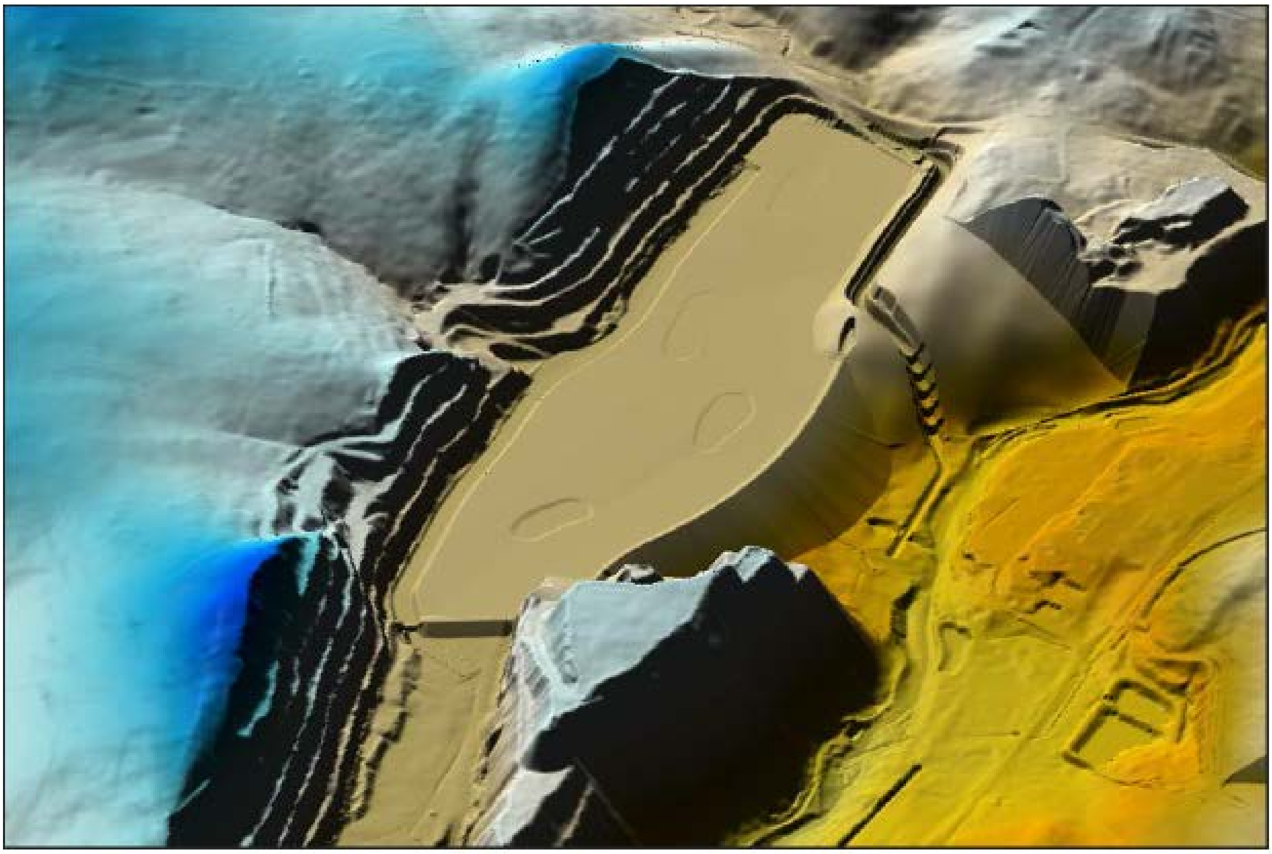
The Phase 1 modelling indicated that:
- without grouting to reduce the hydraulic conductivity of the weathered bedrock surrounding the impoundment, the co-disposed waste material did not remain saturated;
- the primary seepage pathway was in the weathered bedrock beneath the embankments; and
- developing a cover system that increased infiltration to the drainage layer may be effective in improving the long term performance of the Days Creek impoundment.

These findings led to modifications in the original engineering design, which were modelled as part of Phase 2.

PHASE 2 - GROUNDWATER FLOW AND SOLUTE TRANSPORT MODELLING
Groundwater Flow Modelling
This stage of the groundwater flow modelling assessed the effectiveness of new design elements including:

- changes to the growth medium, properties of the underlying drainage layer, and increased extent of the weep holes;
- incorporation of soakaway areas on the cover;
- addition of an embankment on the north side of the impoundment and changes to the layout of the other embankments; and
- integration of grout curtains surrounding the impoundment.

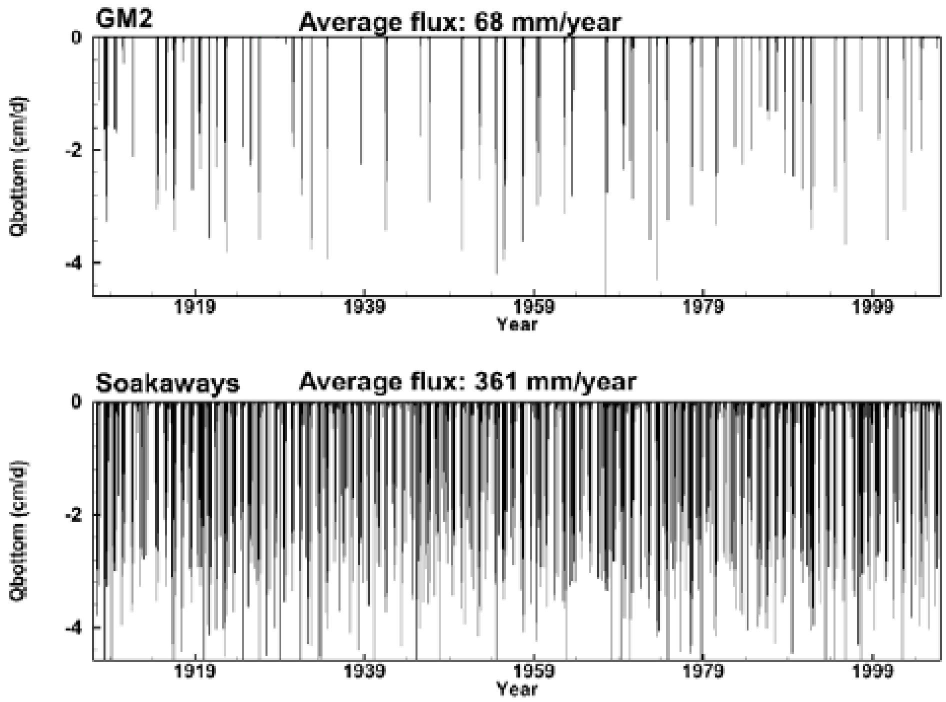
A 3D view of the final DEM of the modelled impoundment is shown below. Details of the Phase 2 groundwater flow modelling are provided in Appendix J of Golder (2015).



Oblique 3D view of the combined Digital Elevation model for the Phase 2 Layout

Page 3, Appendix J from Golder (2015).

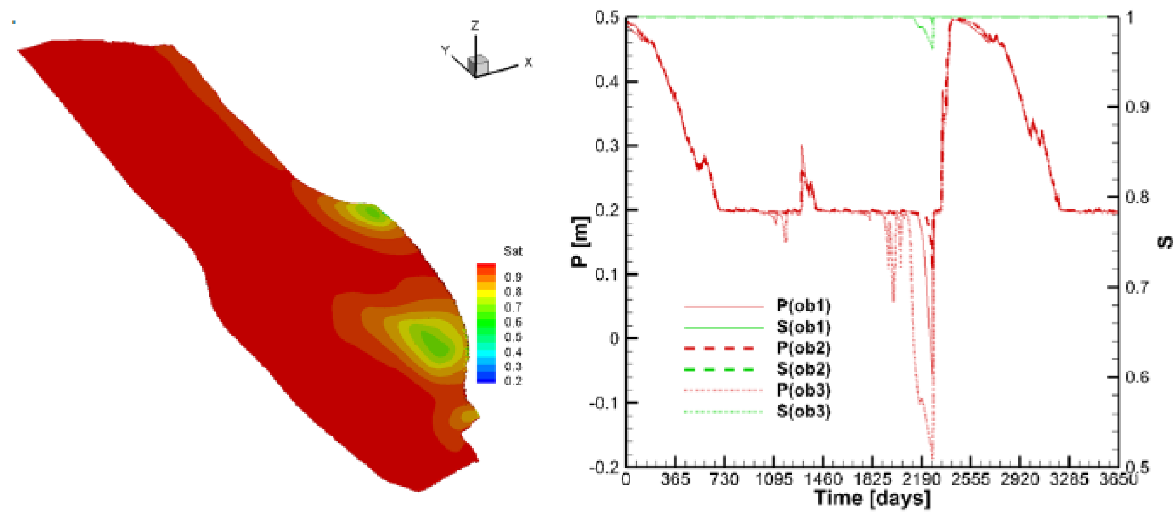
In this phase of the modelling the GM2 cover was used, with the incorporation of four soakaway areas to allow increased infiltration to the drainage layer. The modelled infiltration from these layers for the 100-year synthetic climate record (SKM) is show below.



Page 10, Appendix J from Golder (2015). Modelled cover infiltration for GM2 and soakaways (SKM).

Results of the Phase 2 groundwater flow modelling showed that, with grouting to 1x10^{-8} m/s around the impoundment, increased infiltration through soakaway areas and increased hydraulic conductivity of the drainage layer, saturation was maintained in the intial steady state flow simulations. Subsequent simulations were completed to assess model sensitivity, particularly to less stringent grouting criteria around the perimeter.

Following several steady state simulations of different grout configurations, a transient simulation of the 10 year "dry" period was conducted that maintained the most stringent grouting (1x10^{-8} m/s) beneath the east embankment but which reduced the hydraulic conductivity of the grouting to 5x10^{-8} m/s elsewhere on the perimeter. Under these conditions, head in the drainage layer fell to 0.2 m below the top of the co-disposed material for a limited period during dry conditions, however, the head recovered rapidly after rainfall.



Page 20, Appendix J from Golder (2015). Transient simulation of 10-year "dry" showing limited areas of drying of the upper co-disposed material, and rapid recovery of groundwater elevations following rainfall (P is head above the co-disposed material, S is saturation).

Further simulations were conducted to assess the sensitivity of the model to different groundwater flow conditions and to changes in grouting criteria away from the east embankment.

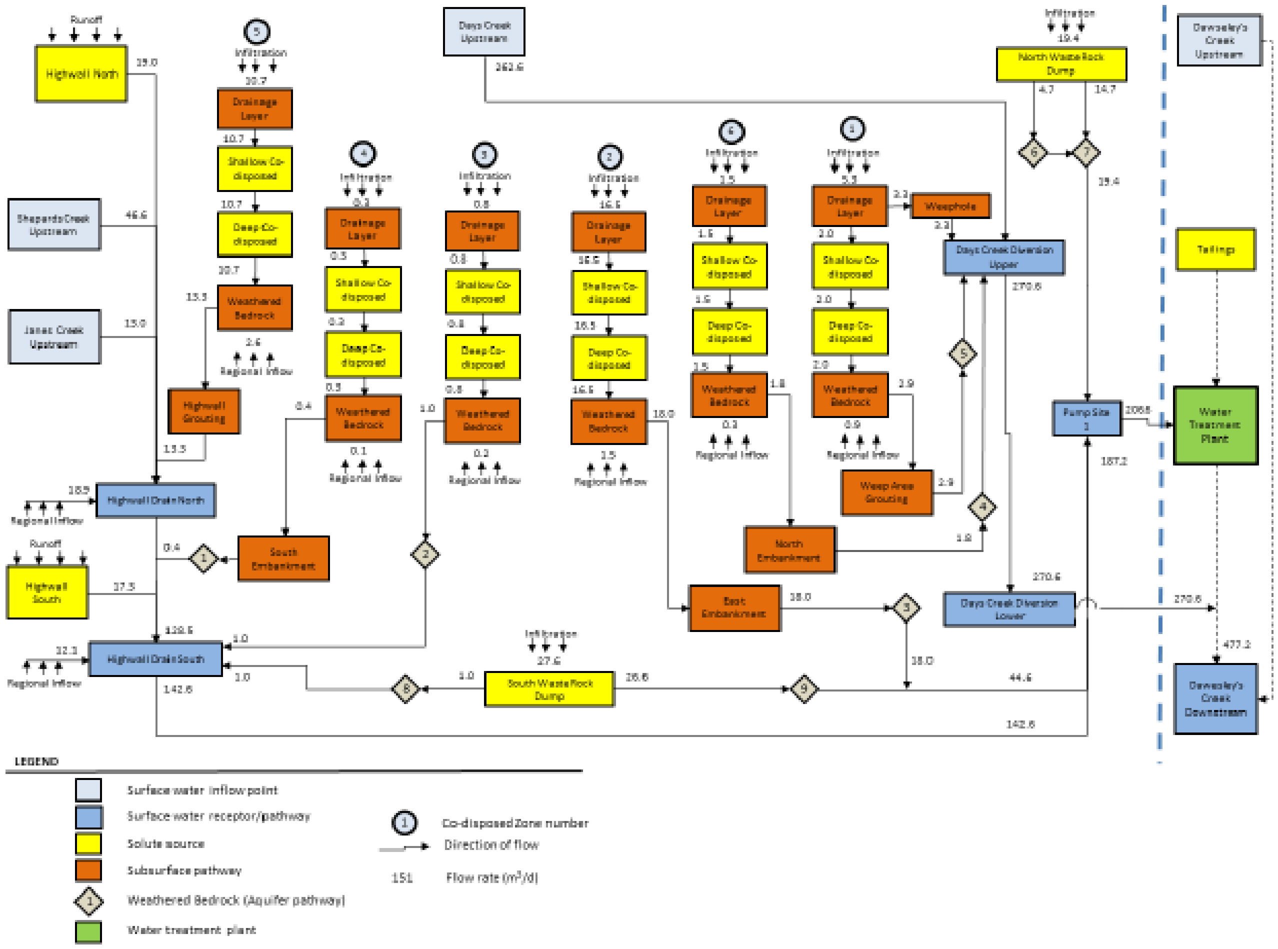
The Phase 2 modelling indicated that the revised Phase 2 Engineering Design largely met the assessment requirements with:

- grouting to 1×10^{-8} m/s beneath the east embankment impoundment and grouting to 5×10^{-8} m/s elsewhere around the perimeter;
- small zones of the co-disposed material near the east embankment dropped below full saturation for short periods during the 10 year "dry" simulations - grouting or infiltration could be adjusted to further mitigate this occurrence; and
- although a nominal grouting depth of 15 m and width of 6 m was applied in the model, these dimensions would vary depending on field conditions.

Based on the results of the Phase 2 modelling, which indicated success of the engineering design, outputs from the Phase 2 model were used as inputs to the solute transport modelling (GoldSim, Appendix K, Groundwater Modelling Report).

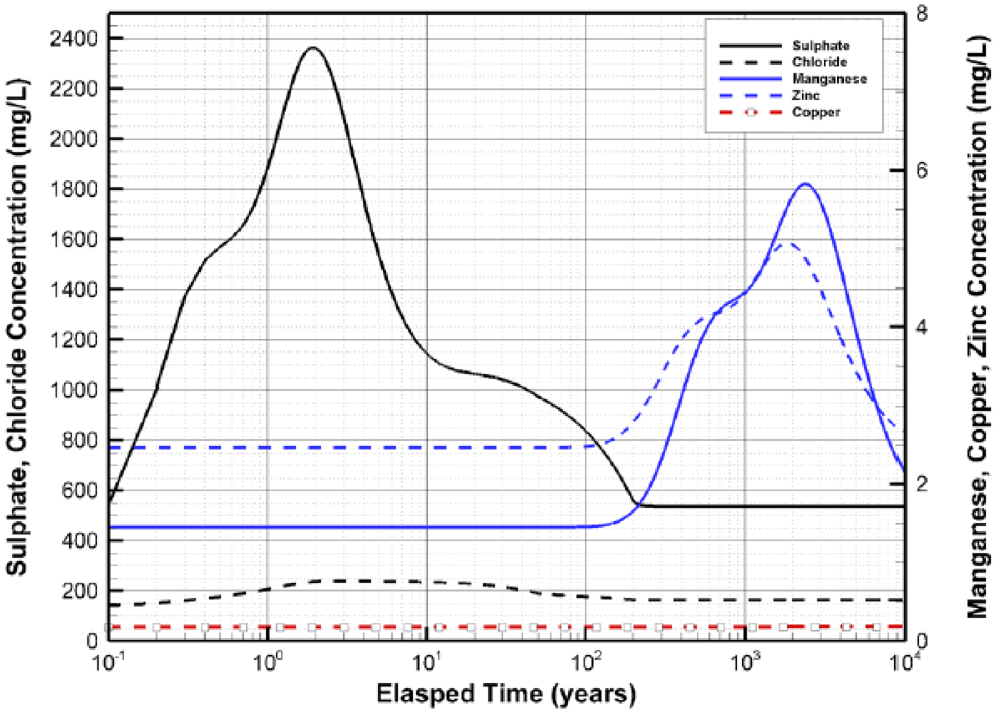
Solute Transport Modelling

As part of the Phase 2 modelling assessment, solute transport calculations were completed using seepage rates and directions from HGS, and source terms for sulfate, chloride, copper, zinc, and manganese in the co-disposed material, high wall runoff/seepage, and WRDs. Throughout the simulations, starting groundwater quality downstream of the site was not "preloaded" with impacts. Details of the Phase 2 solute transport modelling are provided in Appendix K of Golder (2015).



Page 6, Appendix K from Golder (2015). GoldSim model set-up using seepage outputs from HGS model simulation for Case 12.4.

The GoldSim modelling predicted indicative solute concentrations in the lower part of the Days Creek Diversion and in Pump Site 1, to the south of the SWRD. Concentrations of the modelled species at the water treatment plant (i.e. Pump Site 1) are shown below and illustrate the early discharge of sulfate relative to the discharge of manganese and zinc, which is delayed because of sorption. Early peaks (<10 years) represent the movement and discharge of the existing impacted groundwater beneath the impoundment and the longer term (10-200 year period) decline in concentrations (e.g. sulfate) represents the decay of the shallow co-disposed source term.



Page 8, Appendix K from Golder (2015). Model simulation results for concentrations vs time at the Water Treatment Plant (Pump Site 1).

SUMMARY

In summary, groundwater flow modelling was conducted in a phased approach to assess performance of the engineering design of the impoundment and to inform that design. Key aspects of the design that were modified as a result of the groundwater flow modelling included:

- lower hydraulic conductivity of the clay core of the embankments, reducing seepage through the embankments;
- incorporation of grouting to 1×10^{-8} m/s beneath the east embankment with perimeter grouting elsewhere, reducing seepage from the impoundment and particularly beneath the east embankment;
- incorporation of soakaway areas, increasing infiltration through the cover, thereby relaxing criteria for the growth medium in other areas of the cover; and
- increased hydraulic conductivity of the drainage layer and increased extent of the weep hole area, thereby reducing the potential for the growth medium to be wet from the drainage layer.

Solute transport modelling provided an indication of the decline in surface water quality that would occur as impacted groundwater beneath the impoundment was discharged, and the subsequent improvement in surface water quality as discharge of this groundwater was replaced with groundwater affected by seepage from the impoundment.

ATTACHMENT E
OXYGEN DIFFUSION TEST WORK AND MODELLING

EARTH SYSTEMS
Environment | Water | Sustainability
Australian Business Number 42 120 062 544

Oxidation of Co-disposed Material Below a Saturated Coarse-textured Cover Layer – Laboratory Investigation to Support the Days Creek Domain Remediation Design

Prepared for

DMITRE

May 2014

SUMMARY

A remediation strategy for the Days Creek Domain of the Brukunga mine site has been developed by the South Australian government in collaboration with the Brukunga Technical Advisory Group (TAG) and various consultants. Earth Systems previously conducted testwork that suggested that the minimum predicted water level of 300 mm within the coarse-textured layer of the remediation design may be insufficient to prevent acid and metalliferous drainage (AMD) generation from the co-disposed material. Additional oxygen consumption testwork was carried out under a range of saturated coarse textured layers ranging from 100 - 400mm thickness to quantify the potential for residual AMD generation.

The testwork found that the saturated oxidised tailings layer (beneath the coarse textured layer) is likely to play the key part in limiting oxygen transport to the reactive co-disposed material. The saturated coarse textured layer is likely to play a lesser role in limiting oxygen diffusion, hence the current design thickness for the coarse-textured drainage layer is acceptable from a geochemical perspective. The residual acidity generated from the oxidation of co-disposed material within the Days Creek Domain, below a saturated oxidised tailings layer (of 150 mm), is likely to be in the order of 2-3 tonnes H_2SO_4-equivalent per year. This is likely to decrease as the oxidation front moves downward and the diffusive pathway for oxygen ingress increases over time. Furthermore, the acid neutralising capacity (ANC) within the oxidised tailings material (~6 wt% $CaCO_3$) and additional ANC (~2 wt% $CaCO_3$ additional to the ~4 wt% $CaCO_3$ added for neutralisation of jarosite acidity) within the upper 1.5-2 m of the co-disposed material is likely to neutralise the residual acidity generated from sulfide oxidation for up to several hundred years.

Based on testwork results, it is recommended that the thickness of the oxidised tailings layer above the co-disposed material be maximised to significantly limit oxygen diffusion through the layer. A target of 300 mm thickness should be used, however this may be limited by the volume of non-sulfidic tailings available in the TSF.

Oxidation of Co-disposed Material Below a Saturated Coarse-textured Cover Layer – Laboratory Investigation to Support the Days Creek Domain Remediation Design
May 2014

INTRODUCTION

A remediation strategy for the Days Creek Domain of the Brukunga mine site has been developed by the South Australian government in collaboration with the Brukunga Technical Advisory Group (TAG) and various consultants.

Some of the features of the current design are:

- Amendment of ~4 wt% $CaCO_3$ to the co-disposed tailings and waste rock material to neutralise acidity generated from the dissolution of jarosite (an acid storing secondary mineral within the co-disposed material).
- Amendment of ~6 wt% $CaCO_3$ to the upper 1.5-2.0 m of co-disposed material to provide additional neutralising capacity within this zone.
- To minimise interaction between the co-disposed material and atmospheric oxygen, the co-disposed material will be covered with a layer of fine-grained oxidised (non-sulfidic) tailings (nominally 0.15 m thick and blended with ~6 wt% $CaCO_3$).
- A coarse-textured drainage layer (nominally 1 m thick) is proposed above the oxidised tailings layer, which is intended to act as a drainage layer and overflow into Days Creek when the water level within the layer is above 0.5 m above the oxidised tailings layer.

Recent hydrogeological modelling of the Days Creek Domain remediation design has indicated that a water depth within the coarse textured layer may reach as little as 300 mm during extended dry periods. Earth Systems previously conducted oxygen consumption testwork during the 10,000 t construction feasibility trial (Earth Systems, 2014) that identified that sulfide oxidation was potentially significant under water columns ranging from 50 - 150 mm depth. Such data indicated that AMD could potentially be generated from the co-disposed material under shallow water-only covers during extended dry periods.

Earth Systems proposed further testwork to investigate the potential for AMD generation under a saturated coarse textured layer, as proposed in the remediation design.

METHOD

Laboratory testwork

Four equivalent sub-samples of co-disposed material (~35.5 wt% sulfidic tailings, ~60.5 wt% sulfidic waste rock and ~4 wt% $CaCO_3$) were prepared and placed in sealed vessels with saturated coarse-textured media cover comprised of washed sand (1.0 - 3.0 mm screened material) to depths 100 mm, 150 mm, 250 mm and 400 mm. The cover depths were chosen to evaluate performance around the currently designed minimum depth for a water saturated coarse-textured layer of ~300 mm.

Oxygen and carbon dioxide concentrations were measured continuously in the headspace of each vessel for 53 days to quantify pyrite oxidation and carbonate mineral neutralisation / dissolution rates.

Oxygen consumption rates were adjusted to account for dilution by carbon dioxide gas generation. For each sample, the adjusted oxygen consumption rate was then assumed to be attributed solely to pyrite oxidation and hence directly proportional to the acidity generation rates (AGR) for that sample, based on the stoichiometry in Equation 1:

$$FeS_2 + 3.75\ O_2 + 3.5\ H_2O \rightarrow Fe(OH)_3 + 2\ H_2SO_4 \qquad (1)$$

To allow application of the data to the Day's Creek domain conceptual design, the AGR was normalised to the reactive sample area during the laboratory tests. The normalised AGR for each sample is expressed in units of kilograms of sulfuric acid equivalent generated from pyrite oxidation, per square meter of reactive co-disposed material per year (or kg $H_2SO_4/m^2/year$).

The normalised AGR's were applied to the Day's Creek domain by multiplying the AGR by the estimated reactive surface area of co-disposed material within the domain (assumed to be ~70,000 m^2, based on approximate dimensions of 700 m x 100 m).

Modelling

To assist with interpretation of experimental results, oxygen transport (via diffusive transport alone) was modelled based on Fick's Law, based on three scenarios:

- Oxygen diffusion through an ideal water column.
- Oxygen diffusion through a water saturated coarse sand, assuming an ideal column containing coarse sand (porosity 0.35), negligible tortuosity.
- Oxygen diffusion through a water saturated silt sized material (representing oxidised tailings), assuming an ideal column containing silt (porosity 0.35) and a tortuosity factor of 0.35 (obtained from literature).

The oxygen flux through the column was calculated based on the equation below:

$$J = D\tau\theta\frac{\partial C}{\partial z}$$

Where:

J = Oxygen flux (mol/m^2.sec)

D = Diffusion coefficient for oxygen in water at 25°C = 2.42 x 10^{-9} m^2/sec

T = Tortuosity factor

Θ = Volumetric water content for saturated media (equivalent to porosity in fully saturated media)

RESULTS

Testwork data for each sample are provided in Attachment A. Measured acidity generation rates (AGRs), normalised to sample surface, area are plotted in Figure 1, including previous testwork results, obtained using water-only covers ranging from 2-150 mm (Earth Systems, 2014). Figure 1 also shows modelled AGRs (limited by oxygen diffusion alone) for a water-only cover, water saturated coarse sand cover and water saturated tailings (silt sized) cover.

Key results are (refer to Figure 1):

- The saturated coarse textured material appears to be more effective than water alone, in lowering oxygen flux to reactive pyrite bearing material.
- Pyrite oxidation appears to be occurring at a similar rate for all samples tested with saturated coarse sand covers. Hence a coarse-textured layer thickness of 400 mm appears to offer the same benefit as a coarse-textured layer thickness of 100 mm.
- The measured AGRs for saturated coarse sand covers of 250–400 mm are similar to the modelled estimates. However, the measured AGRs saturated coarse sand covers of 100–150 mm do not follow the same trend and are significantly lower than the modelled estimates. A possible

explanation is that the pyrite oxidation rate is being controlled by the sample, somewhat independent of the cover material.

- Modelling also suggests that the proposed 150 mm layer of saturated tailings would become the oxygen flux-limiting component of the saturated cover above the co-disposed material. However, the theoretical AGR would be similar to that measured in these experiments for a saturated coarse sand cover of 150 mm.

Based on the results from this testwork, using a saturated coarse sand cover that limits the AGR to an average of 0.038 kg H_2SO_4/m^2/year (normalised to sample surface area), and assuming a reactive surface area of ~70,000 m^2 for the Day's Creek co-disposed material, then approximately 3 t H_2SO_4-eq acidity may be generated per year for the entire domain. Based on the modelled AGR for a 150 mm saturated oxidised tailings layer, and assuming that this layer controlled oxygen fluxes for the entire system, annual acidity generation for the Days Creek Domain may be lower, and is estimated at approximately 2 t H_2SO_4-eq/year.

If an amended oxidised tailings layer is used to cap the co-disposed material, as proposed, the ANC contained within this layer will amount to approximately 1,500 tonnes of $CaCO_3$. Hence, it is likely that sufficient ANC exists to neutralise contained jarosite acidity and any additional acidity generated from the upper layers (estimated at 2-3 t H_2SO_4-eq/year) of the co-disposed material, potentially for up to several hundred years.

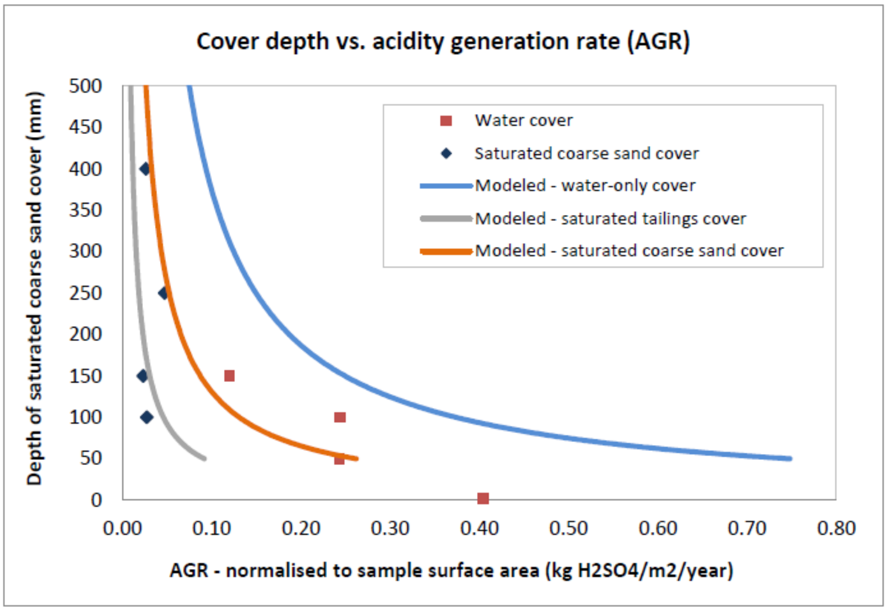


Figure 1: Depth of saturated coarse sand cover vs. acidity generation rate (AGR) normalised to sample surface area. Red squares indicate AGRs measured previously (Earth Systems, 2014) using water-only covers. Modelled acidity generation rate (AGR) limited by oxygen diffusive transport through the cover layer is shown for a water-only cover (blue dotted line), saturated coarse sand cover (orange line) and saturated tailings cover (grey dashed line).

CONCLUSIONS

Key interim conclusions are:

1. The saturated oxidised tailings layer is likely to play a key part in limiting oxygen transport to the reactive co-disposed material. The saturated coarse textured layer is likely to play a lesser role in limiting oxygen diffusion, hence the current design thickness for the coarse-textured drainage layer is less important from the perspective of oxygen diffusion.
2. The acidity generated from the oxidation of co-disposed material within the Days Creek Domain, below a saturated oxidised tailings layer, is likely to be in the order of 2-3 tonnes H_2SO_4-equivalent per year. This is expected to decrease as the oxidation front moves downward and the diffusive pathway for oxygen ingress increases over time.
3. The ANC within the oxidised tailings material (~6 wt% $CaCO_3$) and additional ANC (~2 wt% $CaCO_3$ additional to the ~4 wt% $CaCO_3$ added for neutralisation of jarosite acidity) within the upper 1.5-2 m of the co-disposed material is likely to neutralise the residual acidity generated from sulfide oxidation for up to several hundred years.

RECOMMENDATIONS

Key recommendations include:

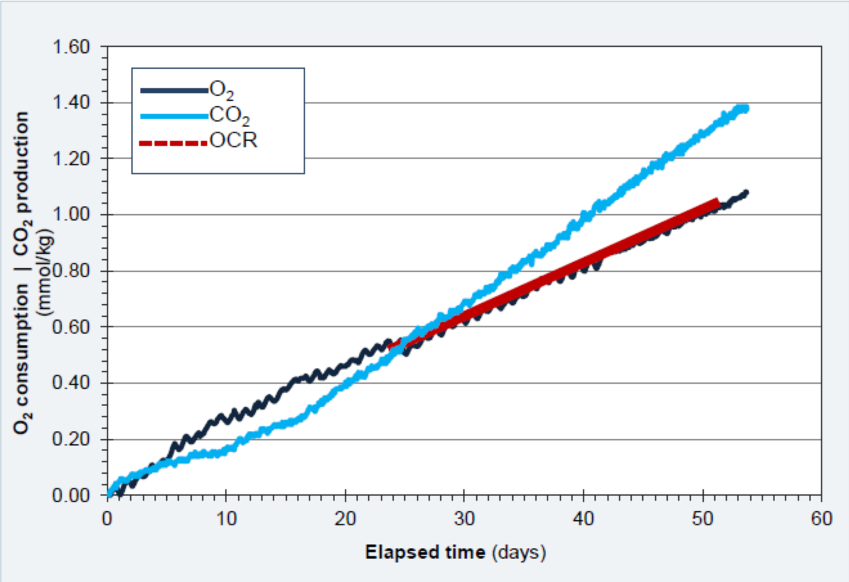
- Maximise the thickness of the oxidised tailings layer above the co-disposed material to significantly limit oxygen diffusion through the layer. A target of 300 mm thickness is recommended. Incorporate this detail into the final design.
- Conduct a desktop assessment to determine whether 300 mm of oxidised tailings is both available and can be safely recovered from the TSF during construction of the Days Creek Domain.
- Incorporate the additional limestone blending requirements in the oxidised tailings layer and upper 1.5-2.0 metres of co-disposed waste into the final design of the Days Creek Domain.

REFERENCES

Earth Systems. 2014. *Kinetic Geochemical Testwork to support the Brukunga Mine Site Remediation Strategy.* Prepared for SKM. February 2014.

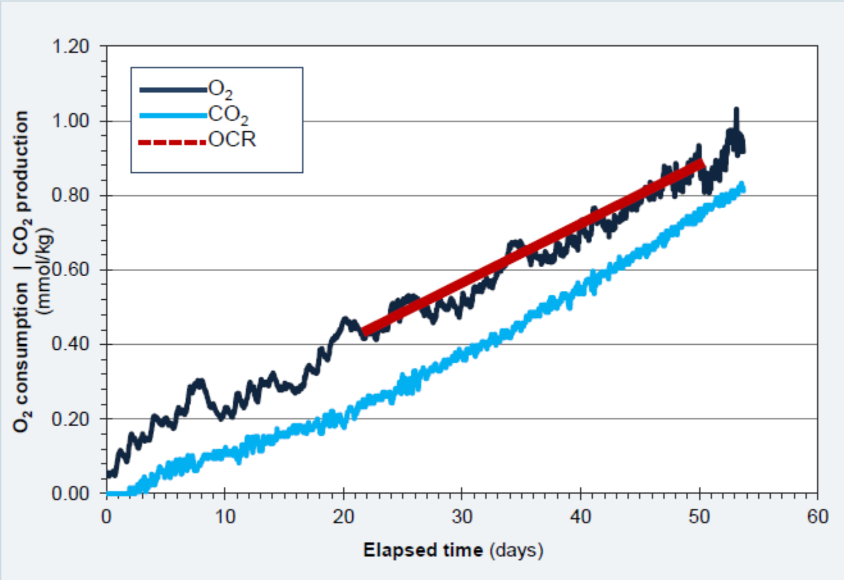
ATTACHMENT A – PRELIMINARY TESTWORK RESULTS

Sample 1 – 100 mm saturated coarse sand cover



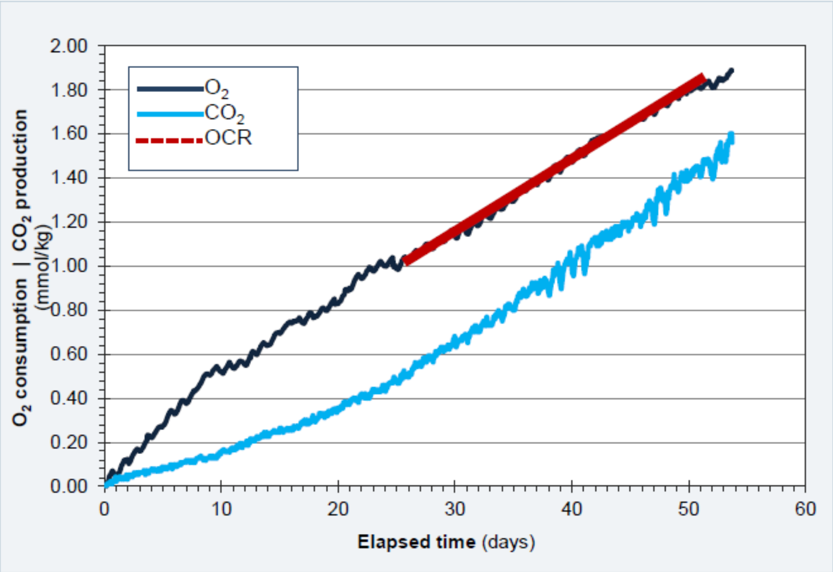
OxCon test results				
Acidity generation rate	0.36	kg/t/yr H_2SO_4	0.027	kg/m²/yr H_2SO_4
Oxygen consumption rate (OCR)	0.0191	mmol/kg/day O_2	0.046	mmol/m²/day O_2
Carbon dioxide production rate (CPR)	0.0307	mmol/kg/day CO_2		
Acid neutralisation efficiency (ANE_{carb})	303	%		
Pyrite oxidation rate (POR)	0.63	wt%/yr FeS_2		

Sample 2 – 150 mm *saturated coarse sand cover*



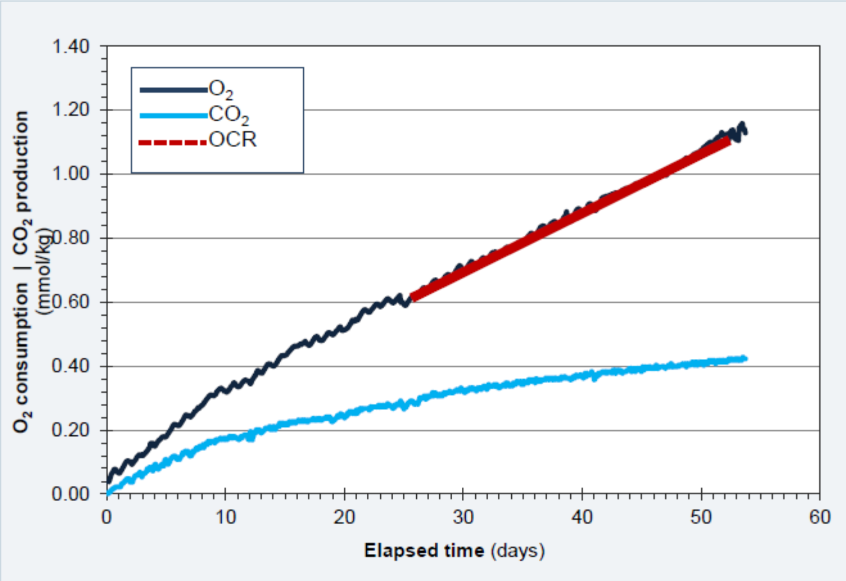
OxCon test results				
Acidity generation rate	0.30	kg/t/yr H_2SO_4	0.023	kg/m^2/yr H_2SO_4
Oxygen consumption rate (OCR)	0.0159	mmol/kg/day O_2	0.038	mmol/m^2/day O_2
Carbon dioxide production rate (CPR)	0.0195	mmol/kg/day CO_2		
Acid neutralisation efficiency (ANE_{carb})	231	%		
Pyrite oxidation rate (POR)	0.52	wt%/yr FeS_2		

Sample 3 – 250 mm saturated coarse sand cover



OxCon test results				
Acidity generation rate	0.63	kg/t/yr H_2SO_4	0.047	kg/m²/yr H_2SO_4
Oxygen consumption rate (OCR)	0.0329	mmol/kg/day O_2	0.079	mmol/m²/day O_2
Carbon dioxide production rate (CPR)	0.0382	mmol/kg/day CO_2		
Acid neutralisation efficiency (ANE_{carb})	219	%		
Pyrite oxidation rate (POR)	1.08	wt%/yr FeS_2		

Sample 4 – 400 mm saturated coarse sand cover



OxCon test results				
Acidity generation rate	0.35	kg/t/yr H_2SO_4	0.026	kg/m²/yr H_2SO_4
Oxygen consumption rate (OCR)	0.0185	mmol/kg/day O_2	0.045	mmol/m²/day O_2
Carbon dioxide production rate (CPR)	0.0040	mmol/kg/day CO_2		
Acid neutralisation efficiency (ANE_{carb})	41	%		
Pyrite oxidation rate (POR)	0.61	wt%/yr FeS_2		

ATTACHMENT F
GEOCHEMISTRY OF WASTE ROCK AND TAILINGS

Indicative static geochemical characteristics for the optimal co-disposed material (60 wt.% waste rock, 36 wt.% tailings and 4 wt.% $CaCO_3$) are provided in Table 1.

The Total S value is 1.89 wt.% S with a chromium reducible sulfur S_{Cr} (sulfide sulfur) value of 0.39 wt.% S. The sample contains appreciable ANC at 48 kg/t H_2SO_4 as a result of the limestone addition. The Net Acid Production Potential (NAPP) value is slightly positive at 10 kg/t H_2SO_4 if the total S value is used to calculate MPA (maximum potential acidity), but the Net Acid Generation (NAG) leachate (NAGpH) was near neutral at 7.92 and both NAG4.5 and NAG7.0 values were 0 kg/t H_2SO_4. These values indicate that the limestone addition rate is sufficient to deal with all jarosite acidity.

Table 1. Indicative static geochemical characterisation for co-disposed waste materials.

Material	Total S	S_{Cr}	S_{KCl}	S_{HCl}	S_{NAS}	ANC	MPA	NAPP	NAG_{pH}	$NAG_{4.5}$	$NAG_{7.0}$
	wt.% S					kg/t H_2SO_4			pH	kg/t H_2SO_4	
Waste rock and tails mix with 4 wt.% $CaCO_3$	1.89	0.39	0.60	0.71	0.11	48	58	10	7.92	0	0

The static geochemical properties of the individual waste materials (waste rock and tailings) and the limestone are provided below.

Waste Rock

Geochemical characterisation data for representative waste rock material (<25 mm fraction) is provided in Table 2.

The results indicate that the waste rock has a mean Total S content of 2.1 wt.% S, while the mean S_{Cr} content is much lower at 0.3 wt.% S. The mean NAG7.0 leachate value is 20.9 kg/t H_2SO_4. The waste rock material does not retain any acid neutralising capacity (ANC; -1.5 kg/t H_2SO_4).

Table 2. Physical and static geochemical characterisation results for Waste Rock (<25 mm) and Tailings.

Material	GMC	Total S	S_{Cr}	S_{KCl}	S_{HCl}	ANC		NAG_{pH}	$NAG_{4.5}$	$NAG_{7.0}$
	wt.% H_2O	wt.% S	wt.% S	wt.% S	wt.% S	kg/t H_2SO_4	wt.% $CaCO_3$	pH	kg/t H_2SO_4	
Waste rock	9.0	2.1	0.3	0.3	0.8	-1.5	-0.2	3.0	14.2	20.9
Tailings	6.1	1.3	0.9	0.1	0.2	4.5	0.5	3.0	16.7	24.4

Tailings

Static geochemical characterisation data for the composite tailings materials is provided in Table 2 above.

The mean Total Sulfur (Total S) content of the tailings material is 1.3 wt.%S, with a mean SCr content of 0.9 wt.% S. NAG testwork produced acidic leachate with a mean NAG7.0 value of 24.4 kg/t H_2SO_4. The tailings material exhibits a very small neutralising capacity which may be in the form of silicates rather than carbonates.

Limestone

Physical and static geochemical characterisation data for the agricultural limestone used in the co-disposal mixture trials are provided in Table 3. The $CaCO_3$ equivalent content of the limestone (i.e. purity) was determined using the C_{Total}, CaO, MgO and loss on ignition (LOI) values as purity indicators, based on the assumption that all C, Ca and Mg are in the form of mineral carbonates, and that LOI is equivalent to CO_2 loss on ignition. The limestone purity was calculated to be ~91-93 wt.% $CaCO_3$. For the purpose of the testwork and associated calculations, the purity was conservatively assumed to be 90 wt.% $CaCO_3$. The limestone addition rate of 4 wt.% $CaCO_3$ accounted for the 10 wt.% reduction in $CaCO_3$ content of the limestone.

Table 3. Physical and static geochemical characterisation for Agricultural Limestone.

Material	C_{Total}	C_{Org}	CaO	MgO	Al_2O_3	Fe_2O_3	SiO_2	K_2O	Na_2O	TiO_2	P_2O_5	MnO_2	LOI	ANC*	GMC
	wt.%													wt% $CaCO_3$	wt% H_2O
Limestone	10.90	<0.02	53.8	0.68	0.72	0.47	2.61	0.18	0.03	0.04	<0.05	0.05	41.04	90.0	0.5

**Denotes value calculated from the reported analytical data.*

ATTACHMENT G
KEY OUTCOMES OF 10,000 TONNE TRIAL

Compaction trials
It is proposed that waste rock, tailings and limestone be intimately blended to form a well graded material that can be compacted to a high density in order to result in a low permeability saturated material able to retain moisture and minimise the risk of oxygen ingress. This outcome has been tested in two trials:

- Phase 2: small co-disposal trial in the Brukunga Mine Remediation TAG Phase 2 Report (2009); and
- Phase 3: 10,000 tonne trial reported in Appendix J (DSD 2015 Manual of geochemical leaching trials 2010–2014)

Trial results
The selected blending ratio adopted for the Phase 2: small co-disposal trial was based on the available volumes of materials at the entire site, resulting in a "mixture" comprising waste rock and tailings, in the dry mass ratio 63:37, plus 1% crushed limestone by dry mass (now increased to 4 wt.% $CaCO_3$). The individual gradings and the mixed material grading used in the trial is presented in Figure 1. The mixture was found to have a better grading than the sampled waste rock, and a much better grading than the narrowly-graded tailings.

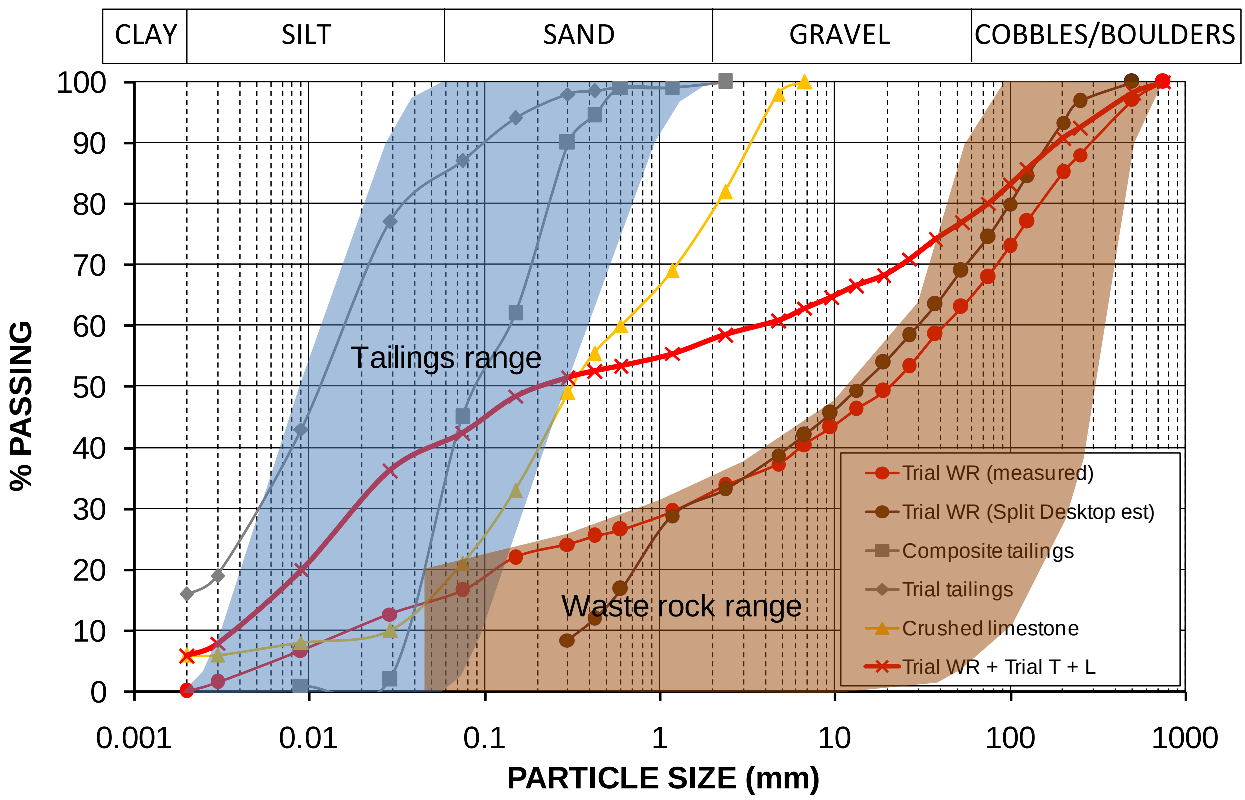


Figure 13. Summary of combined particle size distribution data

Figure 1 highlights the large variation in the particle size of the Brukunga waste rock, with the median D_{50} size ranging from about 10 to 300 mm. The waste rock used for the co-disposal trials was at the fine end of the range for the Brukunga waste rock as a whole.

This grading has been compared with the grading achieved in the 10,000 tonne trial undertaken during the Phase 3 Study (Figure 2). This shows that the latter trial used material significantly lower in the sand/silt size range with less than half of the <75micron portion.

The compaction and permeability results achieved for the 10,000 tonne trial, were lower than the Phase 2 trial and lower than that expected and desired. The gradings of waste rock used in the 10,000 t trial are shown in Figure 2 noting that the results do not include sizes above 150 mm, estimated to be typically greater than 20%. Figure 3 shows two distinct types of waste rock, a low fines material and a high fine s material closer to the grading of material used in the Stage 2 trial.

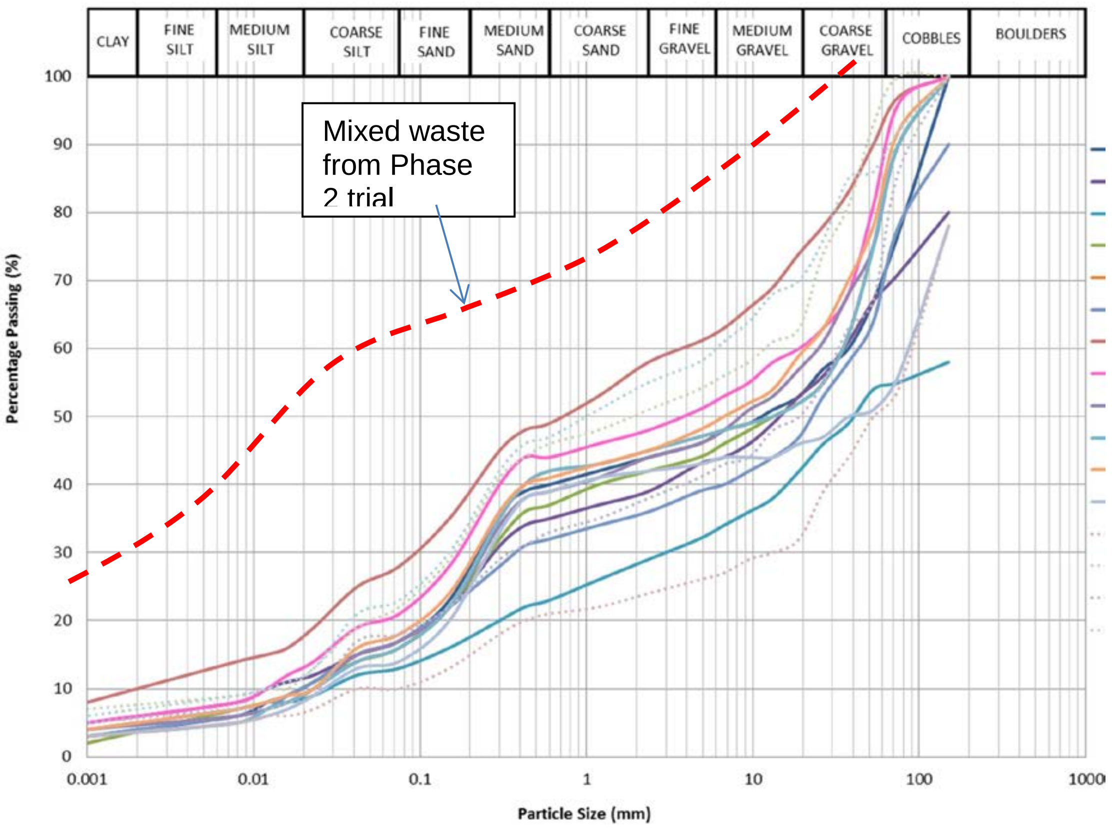


Figure 2. Grading for co-disposed materials in the 10,000 t trial

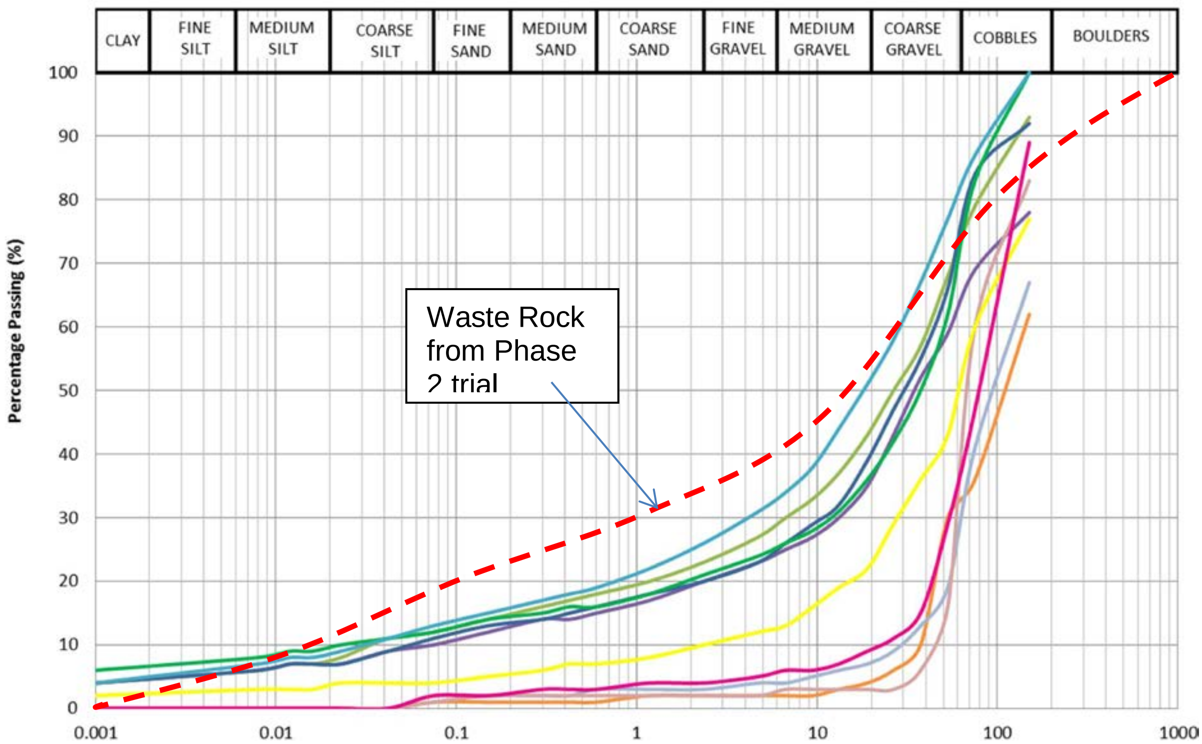


Figure 3. Gradings of waste rock for 10,000t trial

Laboratory Standard compaction testing from the Phase 2 trial are summarised in Figure 4. The results for the 10,000 t trial are superimposed on these figures showing very similar results for maximum dry density (MDD) and optimum moisture content (OMC).

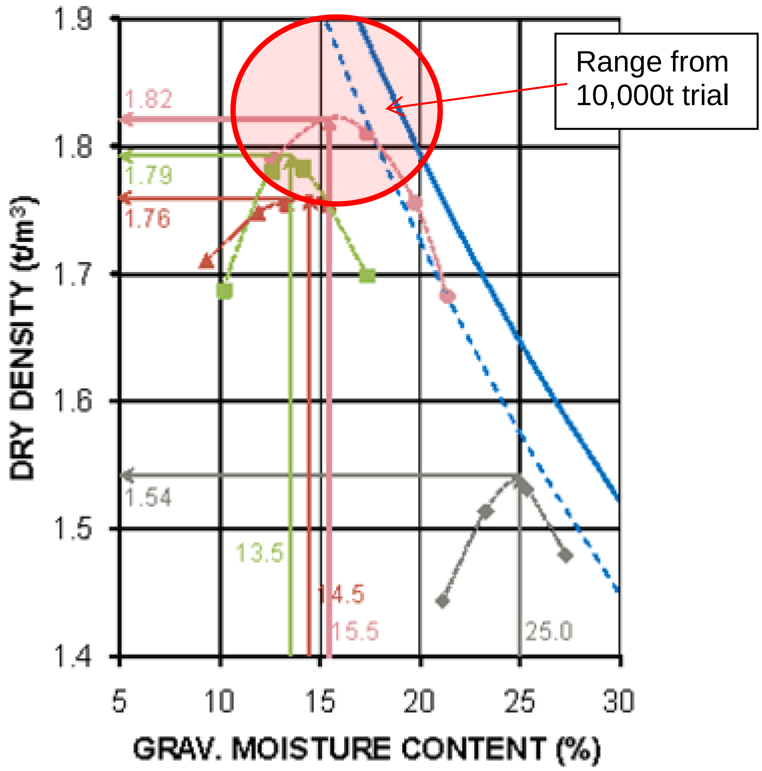


Figure 4. Laboratory Standard compaction curves for scalped trial waste rock, trial tailings and mixtures of waste rock and tailings showing estimated OMC and MDD

Compaction test results from the 10,000 t trial are shown in Figure 5.

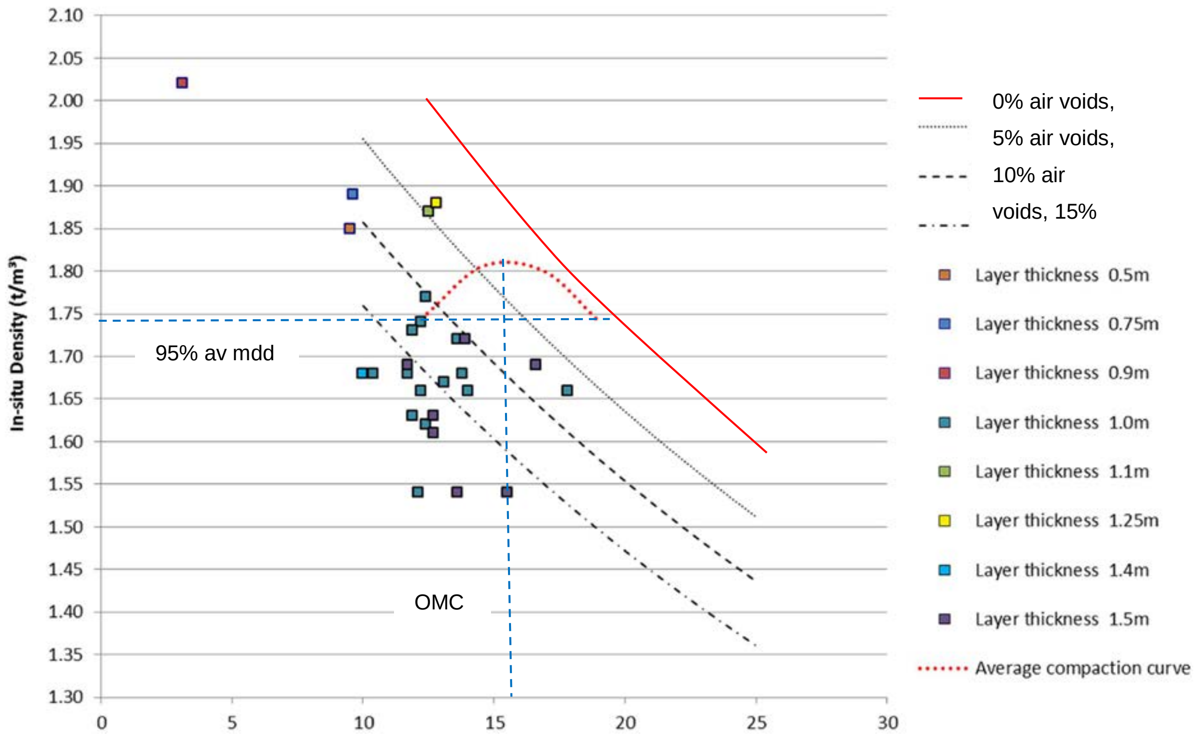


Figure 5. Compaction test results

The trials and the analysis of the materials show mixed results but a clear problem with achieving adequate moisture content during the trial with the majority of results being well below optimum moisture content and outside a likely specification for the actual works. This lower than required moisture content would have had a significant impact on compaction and the density achieved in the 10,000 t trial. Nevertheless reasonable density was achieved at layer thickness of around 1 m with the impact roller used.

As a result of the poor compaction and low moisture content the field permeability results of $1.5x10^{-5}$m/s and $3x10^{-5}$m/s achieved in the 10,000 t trial are considered unrepresentative of what can and should be achieved in the actual works. If a finer rockfill were selected for critical areas and compacted at appropriate moisture content was achieved, we would expect permeability results to be several orders of magnitude lower and similar to that found in the Phase 2 trials. The resulting moisture retention data from the trial work in Stage 2 are shown in Figure 6 with the data from the 10,000 t trial superimposed for -4.75mm material. This shows similar results to the original data for the mixed material with an Air-Entry Value (AEV) in the order of 6 kPa.

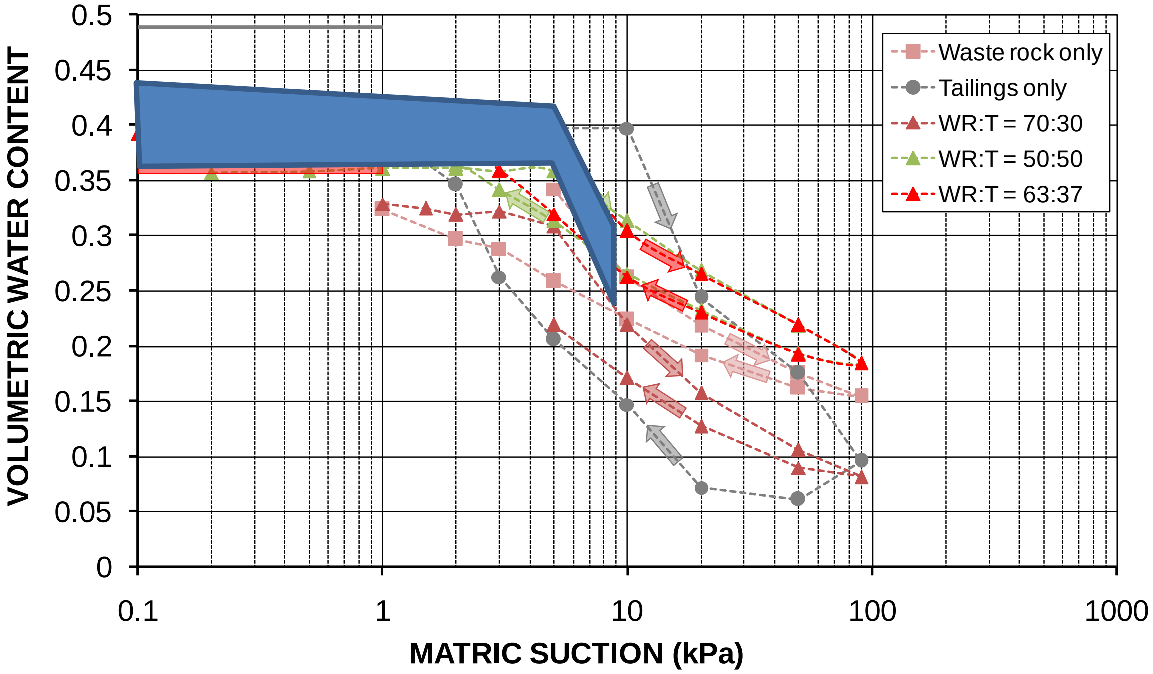


Figure 6. Moisture retention curves for scalped trial waste rock, trial tailings and mixtures of scalped waste rock and tailings

Conclusion from trials

The results of the two trial embankments have confirmed the feasibility of the mixing and placing methodology with some improvements required as highlighted by the Phase 3 10,000 t trial. In particular, the proportion of coarse rock caused problems with achieving the required level of compaction and permeability leading to a recommendation from Jacobs (REF) for primary crushing of the coarser waste rock.

This would come at a cost penalty which should be minimised by field assessment of the grades of waste rock being handled and segregation of the coarser materials with low fines content for crushing and potentially selective placement within the impoundment. Subject to this condition, the trials have demonstrated that compaction of co-disposed waste rock and tailings will achieve a high density and a high degree of saturation, with a low potential for further oxidation, which will be further enhanced by full saturation. The compaction is expected to be enhanced by better moisture conditioning of the mixed material to OMC or better. In addition, the compacted waste rock/tailings mixture will have a high capability to hold water and remain saturated between rainfall events.

The trials have also confirmed:

- The feasibility of mixing limestone with tailings using simple methods at the TSF;
- The feasibility of mixing the tailings/limestone mix with waste rock on site using excavators;
- The compaction of layers up to 1 m thick using impact rollers with a rider that the mix must be at or wetter than OMC.
- For a target layer thickness of 1 m the maximum desirable rock size is 400 mm. Rock over this size should be broken down ideally by crushing, with the intention of producing additional fines in the sand/silt range.

A proposed construction methodology has been developed that reflects the outcome from the trials.

ATTACHMENT H
COVER SYSTEM DESIGN

Preliminary cover system design
Introduction
The objective of this component of the project was to generate cover system designs and to refine these designs using 1D, 2D and 3D modelling tools. The output is a refined cover system design, including material specifications, which was used to progress the overall project design to a costing accuracy of +/- 15 %.

The Brukunga Mine cover system is based on the Brukunga Mine Remediation Option 7a, where an embankment is used to create an elevated water table that maintains saturation of co-disposed waste material. The co-disposed waste is to be capped by a cover system such that the water table is decoupled from the atmosphere (i.e. is not linked to the atmosphere by water in the unsaturated zone). To support this remediation option the cover system needs to be designed to achieve the following objectives:

- to control net percolation by providing sufficient opportunity for downward flux at a level that maintains the water table elevation above the top of the co-disposed material while also limiting upward flux and losses through evaporation and evapotranspiration;
- to provide for sufficient drainage laterally such that the potential of waterlogging to the growth medium due to water table rise in periods of excess water is minimised; and
- to minimise the potential for erosion of the cover.

The following design criteria in meeting these objectives were developed:
- the probability of the water table exceeding the top of the co-disposed waste should be 95 % or greater in any given year;
- the probability of co-disposed material being above 85 % saturation should be 99 % or greater in any given year;
- the probability of the water table remaining below the atmospheric decoupling point should be 90 % or greater in any given year; and
- the probability that the water table remains below the root zone should be 95 % or greater in any given year.

Throughout development, the Cover System Design was closely linked to the Embankment Design and Hydrogeological Flow Modelling as the designs derived from these complementary studies determine the rate at which water leaves the Days Creek impoundment area and thus define the net percolation requirements of the cover system. The performance of the design in terms of meeting these objectives was tested on a transient basis under a variety of climatic conditions (e.g. prolonged drought and extended wet periods) and evaluated probabilistically.

Methodology Overview
Existing conceptual design
A design concept of the cover system recommended for the remediated Brukunga site is outlined by the Brukunga Technical Advisory Group (TAG) in the Phase Two Report for the remediation program (TAG, 2009). The purpose of the cover system is to provide a stable medium to support vegetation and to enable sufficient downwards percolation to keep the co-disposed mine waste saturated. The conceptual design outlined by TAG (2009) is a flat surface directly overlying the co-disposed waste and is comprised of three layers as follows:
- A growth medium at the surface suitable to support vegetation growth (nominally 1 m thick);
- A filter layer to prevent the downward migration of colloids that might clog the underlying drainage layer; and

- A drainage layer consisting of crushed rock to act both as a capillary break (to limit evaporative losses) and as a conduit for the distribution of water to the co-disposed waste to maintain its saturation or to adjoining creeks if water is in excess. A key design objective of this layer is to ‘decouple’ the saturated co-disposed waste from the atmosphere.

Overview of modelling assessments
The suitability of this basic design concept was evaluated using several modelling tools as follows:

- An analytical model, the Kisch Solution (Kisch, 1979), was used to derive a minimum thickness for the drainage layer such that the co-disposed waste can be de-coupled from the atmosphere;
- A 1D numerical model of the soil-plant-atmosphere interface was used to generate net percolation rates for a variety of growth medium options (with different thicknesses and materials) under transient climatic conditions over a 100 year period;
- A 2D numerical model was used to model seepage losses though the embankment wall and to evaluate the performance of selected growth media in terms of their net percolation rates being able to maintain the water table elevation above the minimum level;
- The performance of cover system options in their maintenance of the water table was also evaluated using the 3D hydrogeological flow model Hydrogeosphere (HGS) and reported in Golder (2015).

The results from modelling assessments were used to inform the design of the cover system and identified that the inclusion of vegetation over the full extent of the cover system may result in insufficient percolation to maintain the water table elevation above the minimum level. Consequently, an alternative design was considered that incorporates zones of coarse-grained, rocky material (soakaways) within the cover system to facilitate higher net percolation rates to the co-disposed waste.

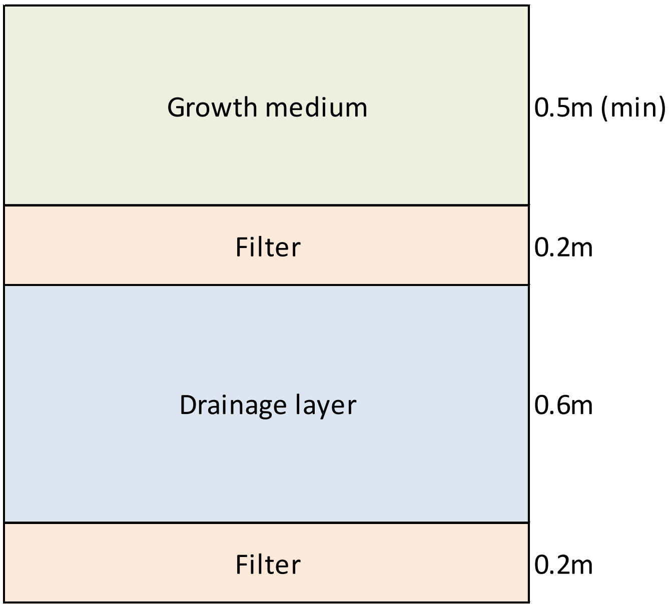


Figure 1. Cover system cross section

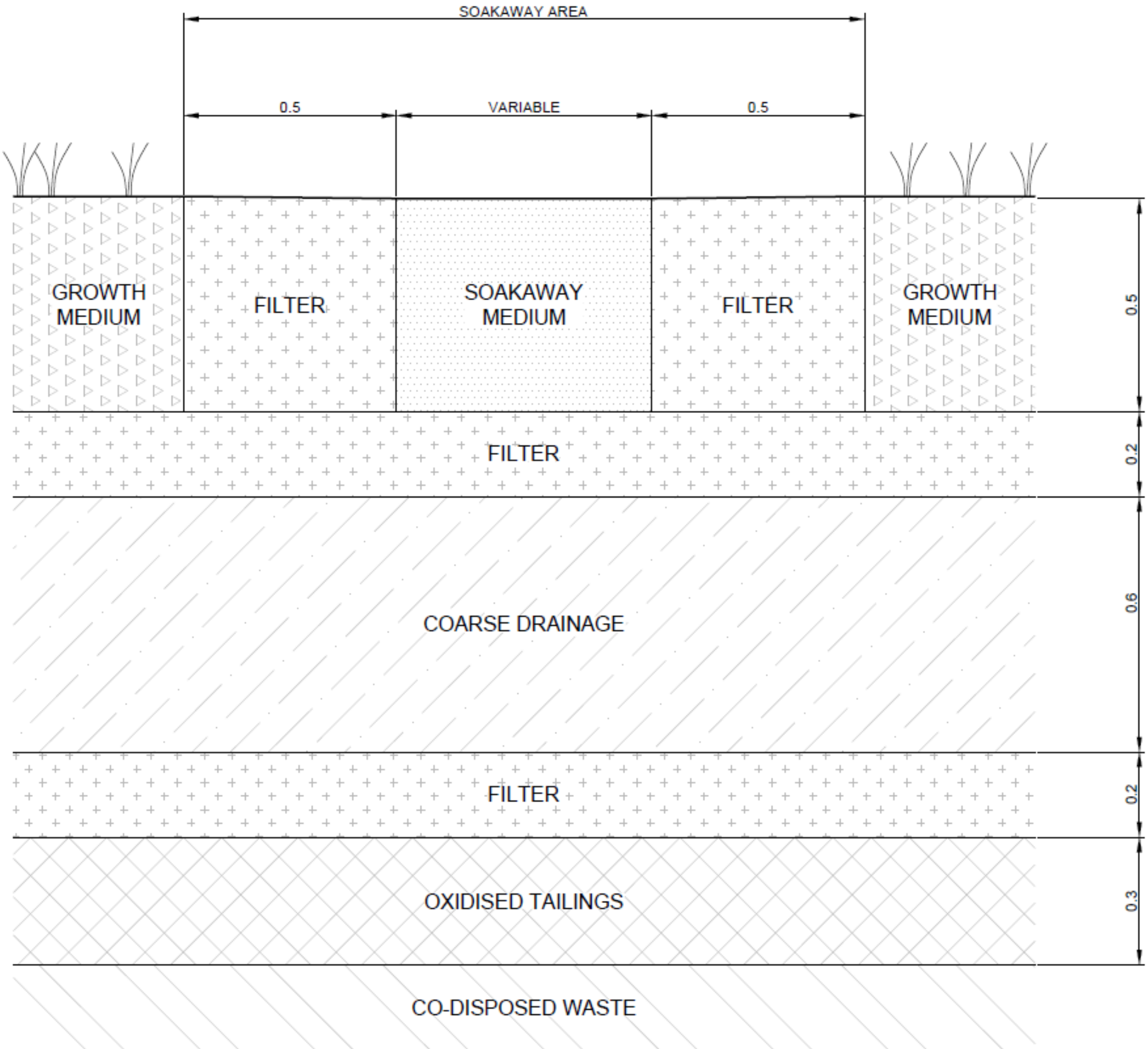


Figure 14. Soakaway cross section

Material selection

MATERIAL AVAILABILITY

There is limited material available on site that can be used, in its current state, to support the construction of the cover system. The material used to create the cover will have to be either imported or manufactured on site by combining and/or crushing clean materials. Much of the material that is available is not sufficiently clean for this purpose. There is potential to obtain some material for the cover through the excavation works performed for the Days Creek realignment. Initial testing (Sub-project 4b) has shown that this material is non-acid forming and could potentially be used as a component of the growth medium. However, it does not appear to be structurally durable so may not be suitable for the drainage layer.

For the purposes of this sub-project, all material properties that comprise the cover system are assumed with the aim of providing a specification that can be consistently achieved. The assumed materials all have hydraulic properties linked to detailed material specifications provided in the SoilVision Database (version 4, 2005). The materials considered for the cover system design all come from real-world examples and have measured hydraulic properties.

POTENTIAL COVER SYSTEM MATERIALS

Several materials have been selected as potential options for the cover system as part of this evaluation. The materials selected are part of four different design options that differ in the type of growth medium used and filter materials required to support the corresponding growth medium. The options are outlined in Table 16.

Table 17. Potential cover design options and composite materials

	Design Option			
Layer	*GM1*	*GM2*	*GM3*	*Soakaways*
Growth Medium	GM1	GM2	GM3	DL
Filter Layer	FL1	FL2	FL2	DL
Drainage Layer	DL	DL	DL	DL

The three different growth medium options (GM1, GM2, GM3) represent a range of materials for potential use. In recognition of the need to maximise net percolation in a Mediterranean climate in which drought periods are not uncommon, these materials are all relatively coarse. Their particle size distribution curves are shown in Figure 3. GM1 represents poorly-graded coarse sand. GM2 represents moderately-graded medium loamy sand. GM3 represents well-graded loamy sand.

The drainage layer (DL) is common to all options and consists of poorly-graded medium gravel. This material has to be coarse in order to maximise its lateral drainage capacity and to minimise capillarity. Selecting a material which is poorly-graded enhances these characteristics because packing density is reduced. Its particle size distribution is shown in Figure 3. For modelling purposes, soakaways are examined by assuming that, in the soakaway zones, this coarse layer extends to the surface.

Filter layers (FL1 and FL2) are required to keep soil particles from the growth medium from clogging the drainage layer and thus hampering its performance. FL1 and FL2 (Figure 3) were selected in accordance with the criteria developed by Terzaghi (1948), as outlined by Lambe and Whitman (1979), which are based on the particle size distribution curves of the overlying and underlying layers.

Figure 3. Particle size distribution curves for cover system materials

MATERIAL PROPERTIES

Table 17 lists the assumed properties for the materials considered as part of the cover system design. The hydraulic properties were derived from examples in the SoilVision database with minor adjustments made based on correspondence with the TAG. Thermal conductivity was estimated using the method developed by Johansen (1975), which suggested a common value of 170 kJ/d/m/°C could be assigned to each of the materials. Similarly, a common value for volumetric heat capacity (2850 kJ/m/°C) was assigned to all materials as informed by an estimation technique described in Hillel (1980).

Table 18. Assumed material properties for cover system

Attribute	GM 1	GM 2	GM 3	FL1	FL2	DL
SoilVision Counter ID	10706	11161	11515	11554	11550	12461
Dry density (g/cm^3)	1.61	1.58	1.43	1.85	1.91	1.7
Particle density	2.77	2.77	2.61	2.62	2.78	2.53
Sat. water content (cm^3/cm^3)*	0.42	0.43	0.45	0.30	0.31	0.33
Residual water content (cm^3/cm^3)*	0.06	0.06	0.06	0.00	0.02	0.00
alpha (1/kPa)*	0.84	0.43	1.40	35.00	0.84	29.01
n*	1.73	1.46	1.25	1.12	1.52	2.33
m*	0.42	0.32	0.20	0.11	0.34	0.57
Maulem Air-Entry Point (kPa)	0.5	1	0.3	0.02	0.5	0.02
Ks (m/s)	1.00E-05	5.00E-06	5.00E-05	1.00E-03	5.00E-05	1.00E-02
Thermal conductivity (kJ/d/m/°C)	170	170	170	170	170	170
Volumetric heat capacity (kJ/m/°C)	2850	2850	2850	2850	2850	2850

*van Genuchten (1980) parameter
Ks: hydraulic conductivity under saturated conditions

Water retention curves and hydraulic conductivity functions are shown in Figure 4 and Figure 5 respectively.

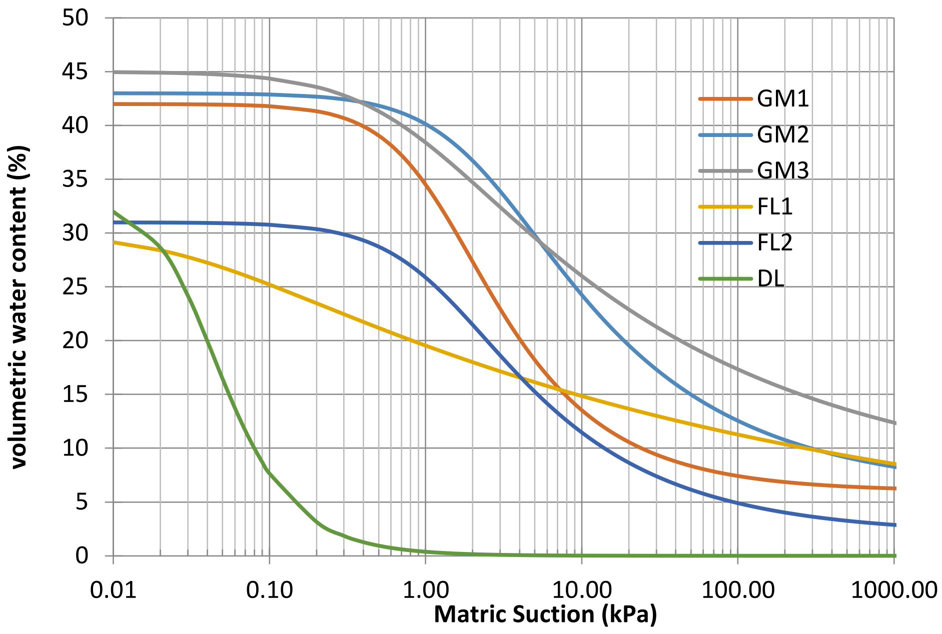


Figure 4. Water retention curves for materials considered in cover system design

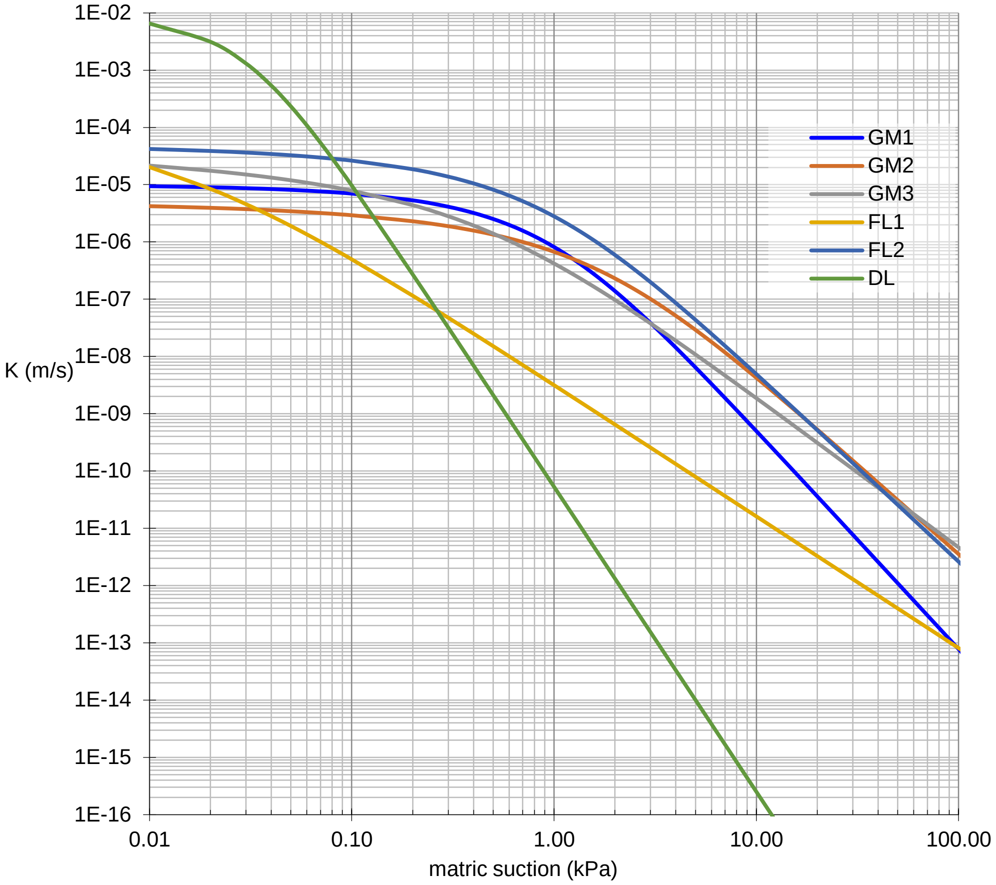


Figure 5. Hydraulic conductivity functions for materials considered in cover system design

Modelling

The documentation for the 1D, 2D and 3D modelling are contained in SKM/Jacobs (2014) and Golder (2015).

Cover System Design

CONCEPTUAL DESIGN

The materials properties assessment, 1D and 2D and 3D modelling undertaken to develop the preliminary cover system design is documented in Jacobs report: *Brukunga mine remediation program BR01-06, Technical note 4, Sub-project 2b, Rev4*, dated 6 May 2014 (Jacobs/SKM, 2014x).

The initial concept proposed for the cover design by TAG (2009) consisted of three layers:

- a growth medium suitable for supporting vegetation;
- a filter layer;
- a coarse drainage layer to decouple the atmosphere and to facilitate drainage of excess water into Days Creek.

Analytical and numerical modelling undertaken and reported in Jacobs/SKM (2014) and Golder (2015) largely supports this concept and provided further constraints on material properties. It is recommended that soakaways be included in the design as a means of improving infiltration, particularly during drier than average conditions. Indeed, it is recommended that soakaways be used as the primary means of delivering percolation to the co-disposed waste and having no reliance on the growth medium to achieve this. The basis for this recommendation is as follows:

- The texture contrast between a growth medium and a coarse, underlying drainage layer is not conducive to percolation, with the growth medium options evaluated displaying poor performance (negligible percolation) during dry conditions;
- By contrast, soakaways are effective in allowing regular percolation to occur, even in response to minor rainfall;
- The cover system should be designed with a focus on dry periods rather than average conditions. If regular percolation can be delivered by soakaways during dry periods at a level that meets the performance criteria, then it need not be overdesigned such that excessive percolation results in wet years leading to waterlogging;
- The remaining area of the cover system (i.e. adjacent to the soakaways) can still be comprised of a growth medium to support vegetation;
- Material used for the growth medium will have to be imported from off-site or manufactured on-site by combining or crushing clean materials. If the growth medium is not being relied upon to deliver a certain amount of percolation then its specification can be relaxed which allows for cost-savings.

The coarse drainage layer will need to be sufficiently thick and permeable to facilitate the drainage of excess water to Days Creek to meet the design criteria. The design of the weep hole to Days Creek must also be of sufficient capacity to meet this requirement. Results of 2D and 3D modelling provided design constraints on the hydraulic conductivity and thickness of the coarse drainage layer and on the lateral extent of connection required with Days Creek to allow sufficient drainage during wet periods. Filter layers above and below the drainage will be required to protect the drainage layer from clogging from the growth material above and the waste material beneath.

Specification

Soakaways

Modelling suggests that in the absence of percolation, the water table declines at a rate of approximately 7 cm per year resulting in partial desaturation of the co-disposed waste after a period of approximately 7 years. According to the design criteria, the probability of partial desaturation occurring must be less than 5% in any given year. Therefore the percolation rate must not be less than the steady-state saturation requirement as defined by the 3D modelling (~5 mm/year) for 7 consecutive years any more than 5 times a century. The probability that this requirement is met in any given year is equivalent to the 67th percentile of the percolation record (0.67 to the power of 7 is approximately equal to 5 %). Therefore, the cover system as a whole must deliver at least 5 mm/y in 33 years out of 100 years, and the long-term average percolation should exceed 5 mm/y. Based on the percolation data for soakaways, this would require that at least 1.25 % of the cover system area is comprised of soakaways.

Soakaways should be distributed in a manner to aid percolation across the cover system during dry periods and to assist with lateral drainage during wet periods. Placement of soakaways to promote percolation in the area upgradient of the eastern embankment, which the 3D modelling identified as the area most prone to the potential development of unsaturated conditions in the upper co-disposed waste, would also be beneficial. Connecting the soakaways an promoting drainage to the south-east of the impoundment would further enhance these functions. A dendritic pattern similar to a natural watercourse could add aesthetic appeal and will be considered during the detailed design.

Soakaways should consist of coarse highly permeable material extending from the drainage layer to the surface, to provide a direct, highly permeable conduit to the water table. Based on the results of the modelling, the soakaways should be composed of uniformly graded coarse gravel of approximately 50 mm in size.

The soakaways should be designed to mitigate the risk of clogging from siltation or the accumulation of organic matter adversely affecting their infiltration performance. Using large-sized material lowers the probability of blockages occurring. The use of filter media should be incorporated to restrict the migration of fines from the adjacent growth medium and to protect the underlying drainage layer. A factor of safety in terms of the area of soakaways has also been applied in the +/-15 % designusing 5 % of the area as soakaways. Other design features to lower the probability of siltation occurring will be considered during the detailed design – for instance the inclusion of upstream siltation control measures such as grass swales. Despite these control measures, some ongoing maintenance of the soakaways will likely be required (e.g. clearing vegetation that may encroach over time, or flushing the material to remove blockages).

Growth medium and vegetation

The growth medium should be at least 50 cm in thickness to provide a level of protection to the underlying drainage layer. It should be composed of a material with a fines content (particle size < 20 μm) of at least 10 % such that it can retain enough moisture and nutrition for vegetation. By this definition, GM1 is considered unsuitable. The bulk density of the material should ideally be less than 1.80 g/cm^3 to allow for root growth and sufficient aeration.

Consideration should be given to long-term land use of the site and the establishment of trees and deep-rooted perennials should be discouraged as these may penetrate into the drainage layer and draw water from the water table. An annual pasture mix (e.g. annual ryegrass and sub clover species) is common in the region and can be used to support grazing practices, which would also be of benefit to discouraging tree growth.

Filter layer

A filter layer should also be installed between the growth medium and the drainage layer, and between soakaways and adjacent growth medium as protection from siltation. Filters will also be required between the drainage layer and the co-disposed waste to provide an intermediate material between the highly permeable drainage layer and the less permeable co-disposed waste. The specification of the filter layer is dependent on the particle size distribution of the overlying and underlying layers in accordance with the criteria developed by Terzaghi (1943)[3]. Filters can comprise geologic material and/or geotextiles. Both of these options will be investigated during the detailed design phase with their inclusion in the design subject to meeting design-life requirements.

Drainage layer

The drainage layer must be sufficiently transmissive to meet the design criteria for lateral drainage specified in Section REF of Jacobs (2014). In the numerical modelling assessment, the drainage layer had a permeability of 10^{-2} m/s and a nominal thickness of 100 cm. The 3D modelling undertaken as part of the project indicated that these characteristics deliver drainage performance well in excess of the design criteria – the water table exceeded the atmospheric decoupling point only during the wettest year on record (i.e. the probability of meeting the criteria of 99 % compared to the required 90%) and did not reach the base of the growth medium.
The 3D modelling analyses indicated the requirement for a discharge area for the drainage layer. This was modelled as “weep holes” along a length of Days Creek and was subsequently modified in the design to be a continuous overflow zone (“weep drain”) to Days Creek (rather than individual weep holes).

The drainage layer used should comprise a uniformly graded gravel material of predominantly 5 mm -15 mm particle size, similar to the DL material listed in Figure 1, and achieve a permeability of 10^{-2} m/s. The modelling results and the inclusion of soakaways and an elongated overflow point to Days Creek indicate some optimisation of the drainage layer thickness can occur. As a starting point for the detailed design, it is suggested that the thickness of the coarse drainage layer be reduced to 60 cm and be buffered by filter layers above and below of 20 cm in thickness to provide a composite transmissive layer of 100 cm in total thickness. Further optimisation of the drainage layer will occur during detailed design when material availability and characteristics are investigated further.

[3] Terzaghi, K. 1943. Theoretical Soil Mechanics. John Wiley & Sons, New York, London.

ATTACHMENT I
WATER QUALITY MONITORING RESULTS

Ongoing degradation of water quality at and downstream of the Brukunga mine site is the major driver for remediation of the remaining mine features, particularly the waste rock and tailings.

Groundwater quality

Results of long-term monitoring of groundwater elevations and quality in the vicinity and down hydraulic gradient of the Brukunga Mine site (Figure 1 - Figure showing entire well network) are summarised in ERM (2013) and indicate that:

- groundwater in the vicinity of the mine pits, TSF, and WRDs is impacted by acidity, sulfate, and dissolved metals including iron, manganese, aluminium, zinc, cadmium, cobalt, copper, and nickel; and
- groundwater from beneath the TSF, WRDs and bench area discharges to the base of the mined pits and into the base of Dawesley Creek.

Leakage and recharge to groundwater from the site have led to the current groundwater condition and, through groundwater discharge, have contributed to degraded surface water conditions. The sources of contamination at the site include:

- naturally occurring oxidation of pyrite away from the mine area;
- oxidation of pyrite and dissolution of secondary acid generating minerals associated with weathering and subsequent recharge from exposed mineralisation on the highwall, bench, pit walls and pit floor;
- oxidation of pyrite and dissolution of secondary acid generating minerals associated with infiltration to groundwater from the NWRD and SWRD; and
- Leakage to groundwater from the base and toe of the tailings dam and from associated ponds.

Groundwater sampled from the wells on site ranges from values that are likely to represent background conditions to those that indicate significant impact by acid, metals, and sulfate associated with AMD from the mined area, WRDs, and TSF.

The most impacted groundwater at the site occurs in the immediate vicinity of the mine pits, the WRDs and the TSF. Much of this groundwater is characterised by pH values of approximately 2.5 to 4. Elevated sulfate concentrations have led to TDS values that exceed 10,000 mg/L in impacted groundwater. Elevated concentrations of metals derived from AMD are also common. Across the site, total dissolved solids (TDS) (arising as a result of increased sulfate), sulfate, pH, and metals concentrations (particularly iron, manganese, aluminium and zinc) are primary indicators of impact. Of these, sulfate and zinc are likely to behave relatively conservatively once they enter the groundwater system.

Regional groundwater in areas away from the north-south strike of the mineralised zone appears to be relatively unimpacted and characterised by low TDS and sulfate concentrations, and near neutral pH values. These areas include the area to the west of the highwall, potentially to the north of the mine, and in the area to the south of the TSF.

Water quality in Dawesley Creek upstream of the mine

Results for the background chemistry of surface water sampled from Dawesley Creek upstream of the mine are summarised in Table 1. Key results of the water quality analyses include:

- The creek water is slightly alkaline with a pH of 8.1.
- The water contains relatively high alkalinity levels at 190 mg/L $CaCO_3$, probably at least partially derived from the nearby “Bird in the Hand” sewage treatment plant.
- Mg and K concentrations are slightly elevated at 26 and 27 mg/L, respectively.
- Acidity values are below the detection limit.

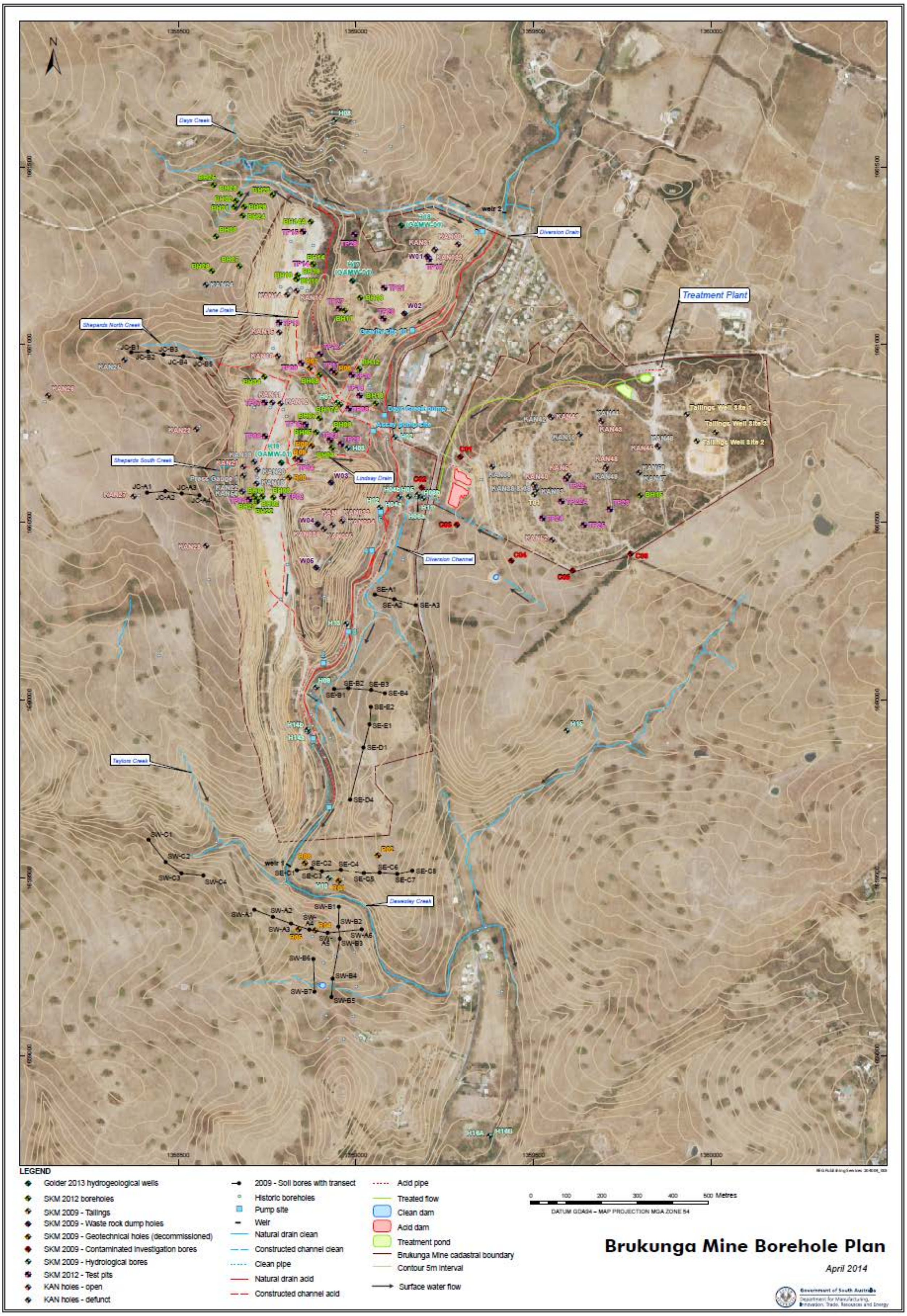


Figure1. Brukunga Mine Borehole Plan 2014

Table 1. Baseline water chemistry for Dawesley Creek water.

Parameter	Units	Value	Value
pH		8.1	7.9
EC	µS/cm	1300	
Acidity	mg/L $CaCO_3$	< 10	< 10
Acidity – calculated*	mg/L $CaCO_3$	0	0
Total Alkalinity	mg/L $CaCO_3$	190	
Residual alkalinity*	mg/L $CaCO_3$	190	
Ca	mg/L	37	22
K	mg/L	27	8
Mg	mg/L	26	23
Na	mg/L	190	122
Sulfate	mg/L	26	86
Dissolved Metals			
Al	mg/L	< 0.05	0.002
Cu	mg/L	0.009	0.001
Fe	mg/L	0.13	0.0024
Mn	mg/L	0.004	0.0002
Ni	mg/L	< 0.005	0.006

Trace metal values refer to soluble concentrations.

Water Quality in Days Creek upstream of the Mine

Very little water quality data are available for Days Creek upstream of the mine. Since upper Days Creek is believed to crosscut the sulfide loads, it is important to understand whether this ephemeral surface flow is impacted by natural oxidation processes. Indicative baseline water chemistry from Days Creek is summarised in Table 2. Key results of the water quality analyses include:

- pH values range between 5.8 and 7.14 with low EC.
- The creek water is slightly alkaline with alkalinity values ranging between 2 and 26 mg/L as $CaCO_3$.
- The concentrations of dissolved Al, Mn and Zn are occasionally slightly elevated at 0.62, 0.218 and 0.159 mg/L, respectively, but these very small contributions to acidity are apparently rare and most commonly offset by the background alkalinity in the stream flows.

Water Quality entering and leaving the WTP

AMD from the mine site is collected in a series of pump sumps and directed to two acid water collection ponds at the toe of the TSF. These ponds provide surge sstorage capacity for the WTP during the winter months, providing a uniform AMD feed chemistry to the plant. Table 3 below provides a summary of the chemistry of typical average raw AMD from the collection ponds, as well as fully treated water discharged from the WTP. The table also provides values for the ANZECC/ARMCAMZ (2000) water quality guidelines for the protection of 95% of aquatic species, and the South Australian EPA (2003) guidelines for waterways for comparison. These are not the criteria against which remediation performance will be assessed. The proportional changes in water quality parameters following treatment are included, and demonstrate the marked improvement in water quality associated with the current treatment.

Table 2. Baseline water chemistry for Days Creek.

Parameter	Units	Sample Location		
		Days Creek Upstream of Mine Site	Days Creek Upstream of Mine Site	Days Creek Upstream of Mine Site
Date collected		31/05/2013	12/06/2013	22/07/2013
pH	---	5.8	7.14	7.04
EC	µS/cm	304	63	303
Total Alkalinity	mg/L $CaCO_3$	2	20	26
Acidity	mg/L $CaCO_3$	14	---	2
Sulfate	mg/L	34	<1	20
Nitrate as N	mg/L	0.54		0.22
Total Kjeldahl Nitrogen as N	mg/L	0.6	0.8	2.1
Total Nitrogen as N	mg/L	1.1	0.8	2.3
Total Phosphorus as P	mg/L	<0.01	0.04	0.06
Cl	mg/L	58	6	58
Ca	mg/L	8	2	7
Mg	mg/L	6	<1	5
Na	mg/L	31	8	39
K	mg/L	7	4	5
Dissolved Metals				
Al	mg/L	0.62		0.6
As	mg/L			
Cd	mg/L	0.0008		<0.0001
Cr	mg/L	0.001		0.002
Cu	mg/L	0.02		0.009
Pb	mg/L	0.004		0.002
Mn	mg/L	0.218		<0.001
Ni	mg/L	0.006		0.026
Zn	mg/L	0.159		0.01
Fe	mg/L	0.38		0.52
Total Metals				
Al	mg/L	0.63	0.31	0.54
As	mg/L			
Cd	mg/L	0.0008	0.0002	<0.0001
Cr	mg/L	<0.001	<0.001	0.002
Cu	mg/L	0.014	0.002	0.004
Pb	mg/L	0.003	<0.001	0.002
Mn	mg/L	0.231	0.041	<0.001
Ni	mg/L	0.004	0.001	0.014
Zn	mg/L	0.148	0.026	0.01
Fe	mg/L	0.34	0.25	0.5
Total Anions	meq/L	2.38	0.57	2.57
Total Cations	meq/L	2.42	0.55	2.59
Ionic Balance	%	0.76	1.68	0.24

Table 3. Comparison of average raw AMD from the acid water collection ponds and fully treated water discharged from the WTP in January 2004.

Parameter	Units	EPA Guideline	ANZECC / ARMCANZ Guideline (95%)	Average Raw AMD	Treatment Plant Discharge	% Increase (↑) or Decrease (↓) in Treated Water
pH		6.5-9.0	6.5-9.0	2.7	9.3	n/a
EC	µS/cm	no value	100-5,000	10,350	3,830	↓ 63.0%
ORP	mV	no value	no value	434	-22	n/a
Ca	mg/L	no value	1,000 livestock	418	733	↑ 75.4%
Mg	mg/L	no value	no value	762	45	↓ 94.1%
Na	mg/L	no value	no value	221	203	↓ 8.0%
K	mg/L	no value	no value	21	17	↓ 20.5%
Acidity	mg/L $CaCO_3$	no value	no value	10,377	6	↓ 99.9%
Alkalinity	mg/L $CaCO_3$	no value	no value	0	17	n/a
Sulfate	mg/L	1,000 livestock	1,000 livestock	11,360	1,673	↓ 85.3%
Cl	mg/L	0.003	0.003	458	346	↓ 24.5%
Al (diss.)	mg/L	0.1	0.055	898	0.5	↓ 99.9%
Al (total)	mg/L			1094	0.7	↓ 99.9%
As (diss.)	mg/L	0.05	0.024 (As III) 0.013 (As V)	0.01	0.001	↓ 91.3%
As (total)	mg/L			0.01	0.001	↓ 92.0%
Cd (diss.)	mg/L	0.002	0.0002	0.20	0.0001	↓ 100.0%
Cd (total)	mg/L			0.22	0.0001	↓ 100.0%
Cr (diss.)	mg/L	0.02 aquacult.	no value	0.12	0.001	↓ 99.2%
Cr (total)	mg/L			0.13	0.021	↓ 83.6%
Cu (diss.)	mg/L	0.01	0.0014	0.71	0.002	↓ 99.7%
Cu (total)	mg/L			0.74	0.024	↓ 96.8%
Fe (diss.)	mg/L	1.0	0.3 (low reliability)	925	1.4	↓ 99.8%
Fe (total)	mg/L			1,390	7.7	↓ 99.4%
Mn (diss.)	mg/L	0.5 (potable)	1.9	97	0.6	↓ 99.4%
Mn (total)	mg/L			98	0.6	↓ 99.4%
Ni (diss.)	mg/L	0.15	0.011	2.43	<0.001	↓ 100.0%
Ni (total)	mg/L			2.51	0.15	↓ 94.0%
Pb (diss.)	mg/L	0.005	0.0034	<0.001	<0.001	n/a
Pb (total)	mg/L			<0.001	<0.001	n/a
Zn (diss.)	mg/L	0.05	0.008	49	<0.1	↓ 100.0%
Zn (total)	mg/L			60	6.2	↓ 89.7%

Values exceeding either EPA (2003) or ANZECC/ARMCANZ (2000) guidelines (for the protection of aquatic ecosystems) are shaded grey; values exceeding both guidelines are shaded black.

Seepage Water Quality from Co-Disposed Waste

Water quality results for the leachate from column leach testwork on the optimal ratio of waste rock, tailings and limestone provide the best available indication of the water quality of seepage to groundwater or future seepage to surface from the co-disposed waste impoundment.

Results for the leachate water quality are summarised in Table 4. Key results of the water quality analyses include:

- pH values are near neutral (pH: 6.8)
- Moderate electrical conductivity (4,120 µS/cm) associated with elevated sulfate values (1,480 mg/L).
- Low acidity values (9 mg/L $CaCO_3$) and elevated alkalinity concentrations (726 mg/L $CaCO_3$).
- Dissolved Mn and Zn concentrations are elevated at 3.8 and 0.7 mg/L, respectively.

Table 4. Co-disposed waste leachate water quality.

Parameter	Units	Co-Disposed Waste Leachate Water Quality Results
Date collected		28-Aug
pH		6.77
EC	µS/cm	4,120
Acidity (calculated)	mg/L $CaCO_3$	9
Alkalinity	mg/L $CaCO_3$	726
Ca	mg/L	752
K	mg/L	15
Mg	mg/L	66
Na	mg/L	237
Sulfate	mg/L	1,480
Chloride	mg/L	313
Fluoride	mg/L	0.1
Dissolved Metals		
Al	mg/L	<0.01
As	mg/L	0.002
Cd	mg/L	0.0005
Cr	mg/L	<0.001
Cu	mg/L	0.02
Fe	mg/L	0.10
Mn	mg/L	3.76
Ni	mg/L	0.206
Pb	mg/L	<0.001
Zn	mg/L	0.666
Total anions	meq/L	60.3
Total cations	meq/L	53.8
Ionic balance	%	5.7

ATTACHMENT J
MANUAL OF GEOCHEMICAL LEACHING TRIALS 2010-2014

EXECUTIVE SUMMARY

The Brukunga mine site is a former open pit iron sulfide mine that continues to contribute to Acid and Metalliferous Drainage (AMD) to downstream waterways. Sources of AMD include the waste rock dumps and tailings storage facility.

In 2007 the Brukunga Mine Remediation Program commenced an assessment of long-term remediation options to rehabilitate the mine site. The current design involves the subaqueous disposal of co-disposed waste rock and tailings with a cover system to prevent ongoing oxidation of sulfidic materials.

To confirm the geochemical performance of the proposed design, a series of kinetic and geochemical tests were conducted to test various waste composition scenarios. The trials consisted of combining, compacting and saturating waste materials and limestone in various proportions at various scales and testing leachate and water cover chemistry over time.

The trials attempt to de-risk the remediation options and demonstrate its effectiveness plus identify any issues arising during the trials that would require further testwork. The aim of this manual is to report on the construction of leachate trials conducted at Brukunga between 2010 and 2014, when the following testwork was carried out:

- Bench test column leach trials
- Bin scale column leach testwork
- Field based geochemical test cell

The appendices provide further background to the monitoring, sampling and testing procedure carried out during the trial work. The many personnel involved over time are also acknowledged and include:

- Technical Advisory Group (TAG – geochemical)
- Brukunga mine site personnel
- Laboratory services
- DMITRE Brukunga team
- Vacation students

1 INTRODUCTION

1.1 BACKGROUND

The Brukunga mine site (located 4km north of Nairne in the Mt Lofty Ranges) represents an ongoing source of acid and metalliferous contamination to downstream waterways. Open pit mining of iron sulfide minerals (pyrite and pyrrhotite) between 1955 and 1972 has left a legacy of acid and metalliferous drainage (AMD) largely associated with two large waste rock dumps (WRD) and a tailings storage facility (TSF).

The South Australian Government took responsibility for the site in 1977 and commissioned a water treatment plant in 1980 to improve water quality in Dawesley Creek. Further remediation has included diverting the creek in an attempt to contain and treat acid drainage on the mine site and increasing the capacity of the water treatment plant.

1.2 REMEDIATION STRATEGY

The Brukunga Remediation Project Technical Advisory Group (TAG) is a group of national and international AMD specialists who have proposed a long-term remediation plan for the mine site (TAG, 2009). The design involves placement of co-disposed waste rock, tailings and limestone into two pits on the mine bench behind an engineered cut-off wall. Permanent saturation of the compacted co-disposed waste materials is designed to eliminate acidity generation caused by sulfide oxidation. The incorporated limestone aims to neutralize stored acid salts within the pore spaces.

1.3 GEOCHEMICAL TESTWORK AT BRUKUNGA

Various tests, trials, research and investigation have been carried out at Brukunga since 2007, focusing on the geochemistry of mine waste at the Brukunga mine site (Figure 1). Geochemical tests and trials were designed to demonstrate and refine the saturated co-disposed mine waste model proposed for the Brukunga remediation design. Trials carried out prior to 2010 included waste rock pile testwork and sulfate leach / oxygen consumption testwork.

The purpose of this manual is to document the methodology for construction, running and monitoring of geochemical leach trials at various scales that were carried out at Brukunga from 2010 to 2014. This can assist with future planning of repeat trials for characterizing the geochemistry of mine waste remediation. Testwork was scaled from laboratory /bench tests to field-base / pilot testing.

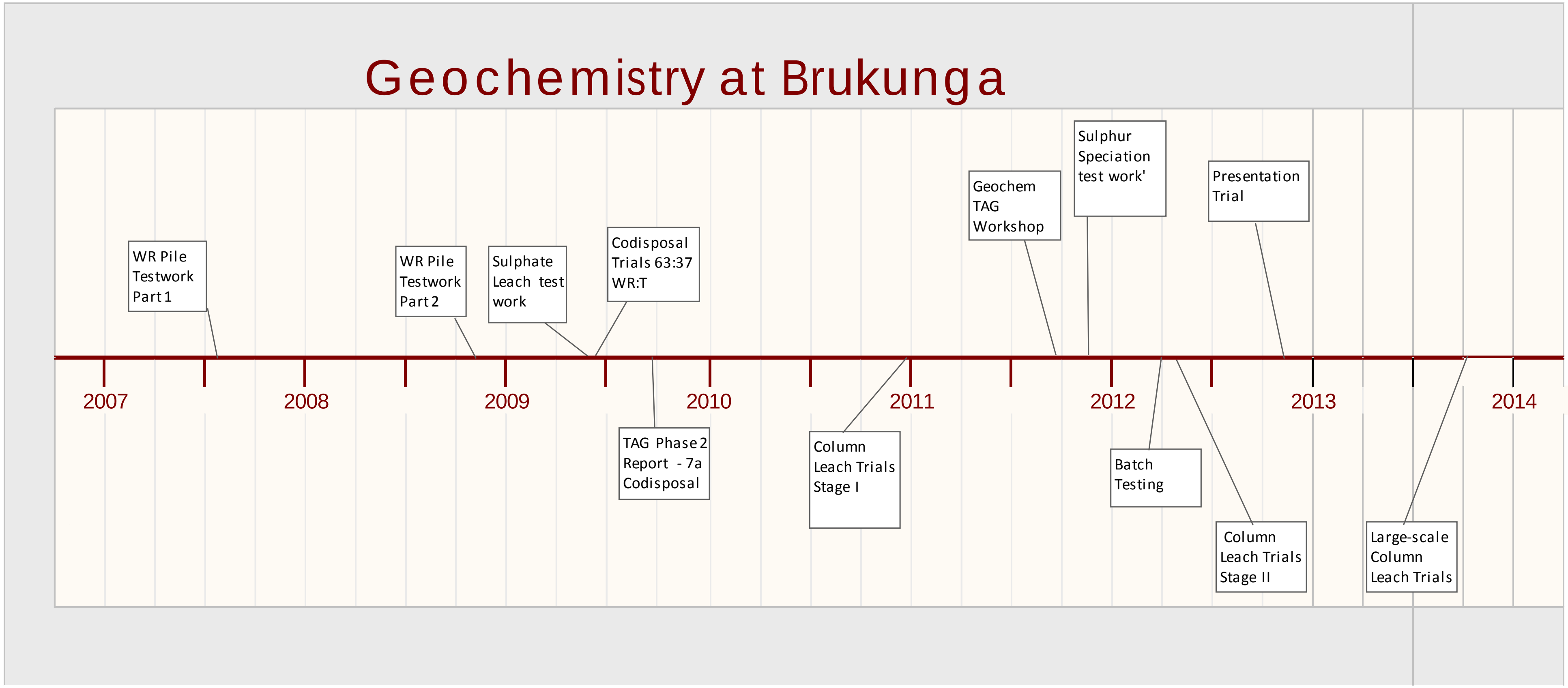


Figure 15. Timeline of Geochemistry testwork at Brukunga 2007 – 2014.

<u>Notes:</u>
WR = Waste Rock
T = Tailings
TAG = Technical Advisory Group

2 PRELIMINARY WORK

2.1 COLLECTION OF WASTE MATERIALS FOR TRIALS

Collection of waste materials for geochemical kinetic testwork conducted at the Brukunga mine site between 2010 and 2014 was supervised by the Brukunga technical advisory group (TAG). The following testwork (from smaller to larger scale) was carried out during this period:

- Bench test column leach trials (~25kg solids in 200 x 1000mm columns)
- Large-scale column leach trial (~400kg solids in 200 litre bins)
- Presentation trial (100 tonne geochemical cell)

This represents an up-scaling from laboratory to pilot testing (field scale) studies. A larger scale trial was conducted by the TAG prior to 2010 and involved the construction of seven test piles (pyramids) each of ~1000 tonnes of waste rock material (NB An even larger scale 10,000 tonne geotechnical trial has also been carried out in 2014).

Potential Acid Forming (PAF) materials at the Brukunga mine site include waste rock from the waste rock dump (WRD) and tailings from the Tailings Storage Facility (TSF). PAF materials for the geochemical trial testwork were excavated from preferred sites based on previous test drilling and geochemical analysis. Tailings were excavated (Figure 2) from a 2 m depth pit located at groundwater monitoring site T01 in the TSF. Tailings included a mix of oxidized (pale brown to orange) and less oxidized (grey) materials below one metre depth.

Figure 2. Excavation of tailings in February 2012 showing pale yellow brown oxidized tailings and grey un-oxidized materials below 1 m depth.

Waste rock was sourced from the Waste Rock Test Pile #3 (Pyramid #3) on the bench below the mine wall (Fig. 3). This material was originally sourced from the northern side of the Southern Waste Rock Dump (WRD) as being reasonably representative of waste rock on the mine site. Test Pile # 3 was a site of previous geochemical trial testwork (see Appendix 6.10) that had not been subjected to any alkaline treatment and was effectively a control for the earlier set of trials.

Sub-samples were collected for sulfur speciation test work which was undertaken to characterize potential acid forming (PAF) materials. A methodology for excavation and collection of waste materials including a sampling plan for sulfur speciation of waste rock and tailings was provided by Scott (2012).

Figure 3. Excavation of waste rock from Pyramid #3 with collection of sub-samples for sulfur speciation testwork.

2.2 GEOCHEMICAL CHARACTERIZATION

Sulphur speciation testwork (geochemical static testing) was carried out in 2011 to fully characterise the sulphur speciation of drillhole materials in mine wastes (tailings and waste rock). The recommended lab for analysis was Levay & Co Environmental Services.

Samples of waste rock (<25mm grain-size) and tailings materials were characterized for the following parameters:

- Gravimetric moisture content
- Total sulfur
- Chromium Reducible sulfur
- KCl- extractible Sulfur
- HCl- extractible Sulfur
- Acid Neutralization Capacity (ANC)
- Net Acid Generation (NAG)

Sulphur speciation testwork was also done to characterise all materials to be used in the geochemical trials (batch extraction testing, stage I and II column leach trials, 100t presentation trial).

- Tailings samples were submitted as two separate sub-samples (0-1m and 1-2m) from a pit excavated to 2 metres in the TSF
- Waste rock samples with PSD -200mm taken from pyramid #3, were to be used for the 100 tonne demonstration trial. Waste rock samples to be used for the Stage II column leach trial were screened to PSD -25mm
- NAF material (concrete sand, small river pebbles and mixed river pebbles) for the 100 tonne presentation trial were also tested. The small river pebbles were rejected as suitable NAF material due to a NAG pH of 3.9.

Measurement of particle size distribution (PSD) for source materials was also undertaken. Finer materials will be biased towards greater concentrations of AMD salts and acidity, reactivity, and surface area - on a per unit mass basis. Hence, small scale column tests (which cannot accommodate larger particle sizes) will tend to over-estimate the acidity per kg. Knowledge of PSDs are needed to convert the acidity per unit mass of a finer fraction that is tested to the acidity per unit of total mass of interest.

Analytical methods used for determining static geochemical parameters (sulphur speciation) is provided in a handbook (Amira International, 2002) and summarised in Earth Systems (2013a and b).

2.3 BULK LEACH / BATCH EXTRACTION TESTWORK

Bulk leach (bottle-roll) testwork was carried out in March 2012 by On Site Technology Pty Ltd. The aim being to quantify the amount of limestone necessary to neutralize the total mass of acidity that jarosite could potentially generate within the co-disposed mix. The outcome of this testwork identified an optimum ratio to effectively neutralize acidity in the co-disposed mix (Earth Systems, 2013a,b).

Bottle roll tests (Fig. 4), provide an ideal continuous mixing environment for the limestone – co-disposed waste mixtures. The advantage of this method is that it speeds up the chemical reactions (especially dissolution of jarosite), hence the optimum amount of limestone addition required to fully neutralize the jarosite can be estimated. The process represents an ideal fully mixed system.

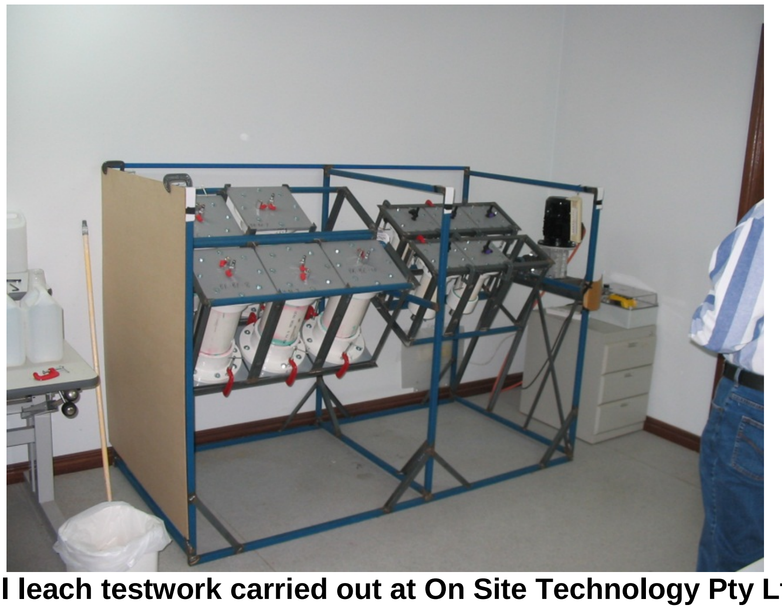


Figure 4. Bottle roll leach testwork carried out at On Site Technology Pty Ltd.

Waste materials used for this leach testwork were taken from the following samples as recommended by the TAG (EGi, 2012):

- Waste Rock (Drillhole W03, 12.5-13.3m and -6.7mm sieved fraction only)
- Tailings (Drillhole T01, 14-15.5m)
- Limestone (Penrice Ag Lime)

A 63:37 waste rock:tailings mix screened to 5mm was added to each PVC tube with five treatments - limestone weight percentages of 1, 2.5, 4, 6 and 8 per cent were trialled. De-ionised water was used for the mixing and extracting solution and two leaching rates were used (10 and 30 L/kg/day). This gave a total of 5x2 = 10 bulk leach tests conducted and was run over 35 days. Five large and five small diameter PVC tubes were used as tumblers (Figure 4). Tubes were filled from a third to half full of solid material and are therefore highly agitated, even at a tumbler speed of 10rpm.

There was approximately 3 litres of water in the large diameter tubes and 1.5L in the small diameter tubes with leachate being extracted daily and tested for the following parameters:

- pH, EC and TDS
- Acidity
- Hydroxide Alkalinity

- Carbonate Alkalinity
- Bicarbonate Alkalinity
- Total Alkalinity
- Chloride and Sulphate

3 LABORATORY-SCALE COLUMN LEACH TRIALS

3.1 INTRODUCTION

Kinetic geochemical testwork involves measuring chemical parameters over time and is used to identify the likely rate of acidity or metals release over time due to oxidation of sulfide minerals and assess likely leachate chemistry (Davis et al. 2014). For example, column leach trials provide a laboratory-scale approach to assessing the effectiveness of acidity neutralization while assessing the effects of variables such as grain size and concentration of jarosite and limestone. Test columns can simulate a fully saturated co-disposed waste materials with an:

- Overlying water cover / supernatant (providing a guide to surface water quality)
- Under-drain system (providing a guide to pore water quality and to indicate potential groundwater contamination issues).

Leachate trials can be conducted at various scales ranging from bench test trials conducted in the laboratory to pilot scale field trials. Larger column sizes can be utilized to examine scale-up factors and further up-scaled to field-based test pile trials. Kinetic leach tests need to operate for at least six months but can extend to one or two years before sufficient data are available to interpret AMD characteristic of materials (DITR, 2007).

The construction of 200mm leach columns using blended waste materials was conducted over a number of years at Brukunga. Stage I column testwork commenced in November 2010 and stage II commenced in April 2012.

<u>Stage I Column Leach Testwork (Nov 2010 to April 2012)</u>

This initial testwork was designed to investigate the effectiveness of a permanent water cover on preventing sulfide oxidation and to investigate the effectiveness of 1 wt.% limestone in neutralizing acidity in the co-disposed mix.

While the water cover was able to prevent further sulfide oxidation, it also caused the jarosite (a secondary acid salt) to dissolve and acidify both the leachate and the water cover. Further testwork was considered necessary to resolve the jarosite issue via greater additions of limestone to the co-disposed mix.

<u>Stage II Column Leach Testwork (April 2012 to August 2012)</u>

Bulk leach (bottle-roll) testwork (Section 2.3) was carried out to quantify the amount of limestone necessary to neutralize the total mass of acidity that jarosite could potentially generate. This testwork identified an optimum ratio of 60 wt.% waste rock, 36 wt.% tailings and 4 wt.% $CaCO_3$ to effectively neutralize acidity in the co-disposed mix. Stage II column leach tests were then carried out to determine whether the ideal optimum ratio would effectively neutralize leachate and supernatant acidity. A full report is provided by Earth Systems (2013a and b).

3.2 LEACH COLUMN CONSTRUCTION METHODOLOGY

Stages involve sample preparation, column set up and loading followed by field testing.
The following materials are required:

- Perspex tubing (190mm ID)
- Waste rock, tailings (characterized and assayed for sulfur forms, ANC and NAG)
- Limestone (Penrice Ag lime)
- Filter sand (Rocla glass sand)
- Creek water (from Dawesley Creek)

- Fittings for columns (taps, tubing, collection bags)
- Perspex lids for base and top of columns
- Weighing balance
- Clean plastic buckets
- Plastic wheelbarrow tub
- Spades and trowels

Sample Preparation

The weight of solids to be loaded into each column needs to be determined. This involves measuring the wet and dry moisture content of a sub-sample of the materials. To obtain a dry weight, samples need to be oven dried. Soil moisture data is entered into a spreadsheet (see example in Appendix 6.6) to calculate the weight of solids in the correct ratio. The methodology for mixing waste materials with other additives can be done as follows:

- Determine the total dry mass required to achieve 1800 kg/m^3 target compaction, within the volume of the tube that needs to be filled
- Calculate the dry mass of crushed limestone required to achieve the required wt.% of $CaCO_3$, (correcting for moisture and purity)
- Determine the corresponding 'wet' mass of limestone to be measured into the mixing bucket, by factoring in the antecedent moisture content
- Allocate the remaining dry mass in the ratio 63:37 between waste rock and tailings.
- Determine the corresponding 'wet' (moisture containing) masses of materials that will be measured into the mixing tub.

Each type of material is placed into a clean plastic bucket, weighed and then tipped into a plastic wheelbarrow tub for thorough mixing using a clean shovel.

Column Preparation

The majority of the leachate trails were constructed in a 1m length of clear acrylic Perspex 190mm internal diameter (ID) tubing, sealed at the base with a flat piece of Perspex. A tap valve is installed at the base of the column (Figure 5) to control effluent discharge. It is a good idea to check that the column does not leak by filling it with water and leaving it stand for a day.

Each new column needs to be labelled with a unique ID number and the depth to which materials need to go are marked on the side of the tube:

- 0-5cm basal filter layer
- 5-50cm solid materials
- 50-90cm water cover

The internal base of the columns requires a filter system. This can be done by placing a small diameter (40 - 50mm OD) perforated PVC tube on the base aligned with the outlet tap (Figure 5) and covering the perforated tube with a fabric filter mesh.

Column Loading

A filter layer of dry inert acid-washed pure quartz sand (Rocla Glass Sand©) provides a porous and non-reactive collection medium. The filter layer at the base of the column (around 5cm depth) should just cover the perforated PVC tube (Fig. 5). The mixed material is slowly loaded with minor compaction / consolidation to achieve a dry bulk density close to 1.8 t/m^3 (1800 kg/m^3). This can be achieved by adding the material in 10cm lifts up to the 50cm mark on the column and lightly compacting using a ram-rod with a flat end (Fig. 6). The material should be moist (~15%) but not too wet. Any left-over material can be used for additional testing (e.g. bulk density, sulfur speciation, paste pH etc.). Appendix 6.4 provides a standard operation procedure (SOP) for conducting a paste pH test.

Figure 5. Adding a filter layer of sand at base of new column.

A 40cm constant head water cover is then added to saturate the materials in the column. To prevent erosion to the top of the materials, water can be riffled using a cushioning device placed on top of the solid material. Once the water level has stabilised at the 90cm mark on the column, a loose fitting Perspex plate is placed on the top of the column to prevent evaporative loss.

Tables 1 and 2 provide physical and geochemical specifications for both stage I and stage II column leach testwork.

Table 1. Physical and geochemical specifications for column leach stage I testwork.

Focus	Column ID	Description
Standard design	ST1, ST2 ST3	Standard waste rock & tails mix with 1wt.% $CaCO_3$ 3 x replicates
Limestone quantity	L1 L2	Standard waste rock & tails mix with 0.5wt.% $CaCO_3$ Standard waste rock & tails mix, no added limestone
Ratios of waste materials	R1 R2	Waste rock with 1wt.% added $CaCO_3$ Tails with 1wt.% added $CaCO_3$
High sulfur	S1 S2	High sulfur waste rock & tails mix with 1wt.% $CaCO_3$ 2 x replicates
Oxidised tailings	O1	Standard waste rock & oxidised tails mix with 1wt.% $CaCO_3$
Staged build	SB	Standard waste rock & tails mix with 1wt.% $CaCO_3$ and built in 3 x ⅓ layers at intervals of 2-3 months
Treatment mix water	T1 T2	Standard waste rock & tails mix with 1wt.% $CaCO_3$ and adding treatment plant alkaline discharge water to the mix
Wet lime addition	WL1 WL2	Standard waste rock & tails mix with a pre-mixed slurry of 1wt.% $CaCO_3$
Surface water head	H1 H2 H3	1cm surface water head 10cm surface water head 100cm surface water head (2m tall column)
Acid groundwater added	A1	Standard waste rock & tails mix with 1wt.% $CaCO_3$ with injection of acidic water
Surface drying	D1	Standard waste rock & tails mix with 1wt.% $CaCO_3$ and built in 3 x ⅓ layers and subject to drying of surfaces
Worst case construction	WC	50:50 waste rock & tails mix, no added limestone
Excess flushing	Tall1,2,3	Rapid flushing of multiple pore volumes

Table 2. Physical and geochemical specifications for column leach stage II testwork.

No:	Column ID	Description
1	Mix-0	Standard waste rock & tails mix, no added limestone
2	Mix-2	Standard waste rock & tails mix with 2wt.% $CaCO_3$
3	Mix-4	Standard waste rock & tails mix with 4wt.% $CaCO_3$
4	Mix-4A	Standard waste rock & tails mix with 4wt.% $CaCO_3$ (with mid-level irrigation pipe)
5	Mix-6A	Standard waste rock & tails mix with 6wt.% $CaCO_3$ (with mid-level irrigation pipe)
6	WR-2	Waste rock (<25mm) with 2wt.% added $CaCO_3$
7	WR-4	Waste rock (<25mm) with 4wt.% added $CaCO_3$
8	WR(4)-2	Waste rock (<4mm) with 2wt.% added $CaCO_3$
9	WR(4)-4	Waste rock (<4mm) with 4wt.% added $CaCO_3$
10	WR(1.2)-2	Waste rock (<1.2mm) with 2wt.% added $CaCO_3$
11	WR(1.2)-4	Waste rock (<1.2mm) with 4wt.% added $CaCO_3$
12	T-2	Tails with 2wt.% added $CaCO_3$
13	T-4	Tails with 4wt.% added $CaCO_3$

Figure 6. Loading column and compacting solid material.

3.4 MONITORING AND SAMPLING

Columns should be allowed to stand for at least one week to allow secondary acid salts (e.g. jarosite) to be fully neutralized by the limestone before any testing of leachate commences.

For the purpose of mimicking groundwater conditions (with minimal exposure to air), leachate was collected in sealed medical drainage bags with a built-in tap for leachate sampling (Fig. 7). Leachate samples are allowed to freely drain from the column until 500 to 1000 mL are collected in the bags. Depending on permeability (which may be a function of compaction), the time taken to collect a sample may vary from less than an hour to half a day.

Two 90-degree pipe fittings were installed after the tap (at the base of the columns) for the purpose of raising the discharge water level in order to keep the bottom sand layer saturated. If this feature was not installed, leachate would drain more quickly from the sand layer than what could permeate through the column, resulting in the potential for sulfide oxidation at the base of the column.

Pore water chemistry is determined by both field testing and laboratory analysis. Water analysis includes a standard suite of metal assays, major cations and anions, pH, redox, EC and temperature measurements to enable geochemical modelling. PIRSA (2011) determined that this procedure would apply to all extraction and leaching tests (including batch testing, column leach trials and 100t presentation trial for both co-mix and cover material).

Field Testing

Field testing involves *in situ* field measurements and subjective visual observations of colour and odor for both the leachate and the tube surface water cover.

Sampling of the tube surface water involves collecting a sample from the near surface using a syringe. The syringe should be rinsed with the surface water three times and then withdraw 20mL of the supernatant. Measurement of field water quality parameters (see Appendix 6.2 for standard operation procedures) is then taken as soon as possible and all volume consumptions should be recorded.

Leachate sampling requires leachate to be collected into drainage bags. Leachate is allowed to drain freely from the column until a desired amount (500 to 1000mL) is collected in the bag. Once the leachate is discharged into a beaker, measurement of field parameters need to be taken as soon as possible with all volume consumptions being recorded.

It is recommended to use dedicated syringes for each column and separate ones for surface water and leachate water and each should be appropriately labelled. The following parameters are tested on a weekly basis:

- pH
- ORP
- EC
- Acidity

Waters, Pape and Taylor (2014) note that calculation of Total Acidity may be more accurate than laboratory-derived acidity measurements since metal concentrations are usually measured to a much greater accuracy than Total Acidity.

Upon completion of testing and sampling, each column is irrigated with a volume of creek water equivalent to the volume of water removed for sampling of supernatant and leachate. This should return the depth of water back up to the 90cm mark on the column.

Laboratory analysis

Water samples are collected for laboratory analysis at a NATA accredited laboratory and analysed for the following parameters.

- pH
- EC
- Acidity and Alkalinity
- Cations: Ca, K, Mg and Na
- Anions: Cl, SO_4, F
- Dissolved metals: Al, As, Cd, Cr, Cu, Fe, Pb, Mn, Ni and Zn

Sample bottles are supplied by the laboratory and need to be clearly labelled along with a Chain of Custody (COC) form to be filled out prior to delivery. Generally two plastic bottles are provided for sampling and includes a 500mL bottle for physical parameters and a 60mL bottle for total or dissolved metal analysis. Samples need to be kept chilled and are stored in an esky with ice or ice bricks. The turn-around-time for delivery needs to be observed for parameters analyzed.

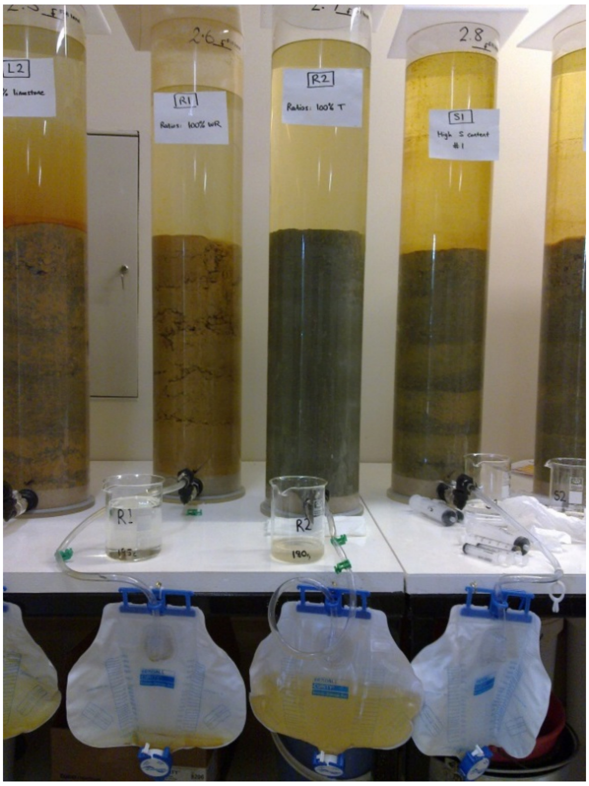


Figure 7. Collecting leachate from stage I columns into drainage bags.

Two sets of duplicate samples are required from each parent sample to satisfy QA/QC requirements. This includes:

- Intra-laboratory duplicate – a field duplicate analyzed as a 'blind' sample by the main laboratory performing the analysis and is done each time
- Intra-laboratory duplicate - a field duplicate sent to a second laboratory as an independent check and done monthly if sampling weekly.

3.5 ISSUES AND PROBLEMS

Leaks occasionally develop around tap seals and on a few occasions the drainage bags have failed – usually because taps have been left on for too long and the bags have over-filled. A maximum volume of 1.5L is recommended for collection in drainage bags.
The collection of leachate in some columns was very slow indicating that they may have been over-compacted in some cases. Only light tamping should be done when compacting the solid material and it should not be too moist.

Supernatant and leachate acidity were determined by the following methods:

- Field-based acidity titration of water sample following collection
- Laboratory analysis of leachate sample by titration
- Estimated acidity calculations based on pH and dissolved metal concentrations

Earth Systems (2013) observed that significant discrepancies were apparent between the three methods of determining acidity. Field and laboratory acidity values were substantially elevated above the actual calculated value which was put down to interference from Ca and Mg ions. They determined that calculated acidity represented the best reflection of actual values.

An important issue identified by the TAG was that field testing of stage I and stage II columns commenced too early. Enough time should be allowed for the lime to effectively neutralize jarosite in the waste rock material. Early sampling resulted in a first flush of high acidity and high salinity leachate.

4 LARGE-SCALE COLUMN LEACH TESTWORK

4.1 INTRODUCTION

This test work up-scales from the 200mm Perspex columns holding around 25kg kg of solid material to 200 litre heavy-duty plastic bins holding around 400-500 kg of solid material.

This trial was preceded by the 100 Tonne Presentation Trial (which had a design flaw), whereby reductive dissolution of jarosite [$KFe(OH)SO_4$] and ferrihydrite [$Fe(OH)_3$] resulted in leachate with significantly elevated iron (Fe) and sulfate (SO_4) concentrations. The large-scale column leach tests were set up to see if leachate quality could be improved in the presence of dissolved organic carbon (Earth Systems, 2013c).

The benefits of adding organic matter to co-disposed waste are that it helps to form reducing systems whereby metals and Fe are removed by the process of 'sulfidisation' and to encourage pyrite (FeS) precipitation to occur. Clogging and armouring of carbonate will be less of an issue if Fe is kept soluble. Outcomes would therefore provide assessment of the risk of using construction materials containing organic carbon.

4.2 METHODOLOGY

Five heavy duty plastic bins (240L) were used as large-scale columns and set up as indicated in the following table:

Table 3. Large-scale column leach trial configuration.

Bin No:	Configuration
1	Baseline (PAF + NAF sourced from 100T Presentation Trial)
2	Baseline + uniformly distributed organic matter in PAF
3	Baseline + basal layer of organic matter
4	Baseline (PAF sourced from pyramid 3 and TSF)
5	Control (NAF only)

Notes to table:
Baseline = 600mm of PAF overlain by 350mm of NAF within the large columns (bins)
PAF = Potential Acid Forming materials comprising 60 wt.% waste rock (WR) and 36 wt.% tailings (T)
NAF = Non Acid Forming materials comprising 60% concrete sand (0.1-0.5mm) and 40% mixed river pebbles (50-60mm).
TSF = Tailings Storage Facility

The heavy duty plastic bins have the following specifications:

- Nominal volume = 240L
- Internal height = 990mm (0.99m)
- Basal dimensions = 460 x 430mm (0.46 x 0.43m)
- Top dimensions = 570 x 510mm (0.57 x 0.51m)

Pipes and fittings

A basal drainage pipe was fitted to each of the five bins. The pipe comprised of 25mm PN18 pressure pipe with two rows of 2mm slots spaced at 60-70mm. The pipe was placed as near as possible to the base of the bins. A filter mesh sleeve of 100µm nylon was securely stitched with nylon thread around the slotted drainage pipe (Figure 8). A tap and pipe fittings were attached on the exterior of the bin to allow leachate to be readily collected and field tested *in-situ*.

Figure 8. Drainage pipe in large-scale column, wrapped in 100µm filter mesh.

The five bins were mounted on wooden pallets within an old greenhouse, thereby protected them from extremes of heat by the shade cloth. Each bin has a lid which remains closed except when irrigating from the nearby water tank. The bins are angled on a slight gradient to prevent a water sump collecting at the base of the bins (Fig. 9).

Loading the columns

PAF materials

As indicated in Table 3, five bins were loaded with co-disposed waste materials sourced from the dissembled 100T Presentation Trial as well as new waste materials sourced from Pyramid 3 and the TSF.

For Bins 1, 2 and 3, PAF material was excavated from the centre of the discontinued Presentation Trial and stockpiled into a trailer. The wet weight of PAF material added to 600mm depth was measured to be approximately 215 kg and was not compacted during loading. Larger stones (>150mm) were excluded from the bins.

Figure 9. Loading PAF material into a large-scale column (plastic bin).

For Bin #4, new PAF material was sourced from Pyramid 3 (see Section 2.1) and from the TSF. The new PAF material was mixed as follows in a wheelbarrow with plastic tub:

- 8 x shovels of WR sourced from Pyramid 3
- 6 x shovels of tailings sourced from the TSF
- 1 x shovel of Penrice Aglime.

This approximates to a mixing ratio of 60 wt.% WR : 36 wt.% T : 4 wt.% $CaCO_3$ The mixing procedure was repeated until the bin was filled to the 600mm mark. The material was not compacted or wetted during loading into the bin.

Organic Matter

Organic matter was added to bins 2 and 3. The selected material to be used was Spent Mushroom Compost sourced from Adelaide Mushrooms Nominees Pty Ltd based at Monarto near Murray Bridge. A Material Safety Data Sheet (MSDS) is available and includes a Typical Analysis.

For Bin #2, mushroom compost (5 wt.%) was mixed evenly into the PAF material. This was done by measuring out 10.7 kg of compost and 215 kg of PAF. The compost and the PAF were mixed in a wheelbarrow before loading into the bin.

For Bin #3, mushroom compost was compacted as a layer at the base of the bin with enough to cover the drainage pipe (Fig. 10). This amounted to approximately 100mm depth of compost and required a little over a 30L bag of compost (~ 13kg).

Figure 10. Compacting organic material in large-scale column.

NAF material

The NAF material for each bin was originally sourced from Pooraka Sand and Metal Landscape Supplies and included:

- Mixed river pebbles (50 - 60mm)
- Concrete sand (0.1 – 0.5mm)

The materials were well mixed in a ratio of 60% sand to 40% pebbles.

Each bin was filled to within 40mm to the top. The depth of NAF material amounted to 350mm and had a total weight of around 200 kg.

Bin #5, acted as a control column and the entire bin was filled with NAF material.

Saturation of materials
Based on the dimension of the bins, the total volume occupied by PAF materials is 0.135 m^3 and the total volume occupied by NAF materials is 0.095 m^3. With an estimated porosity of 35% for PAF materials and 45% for NAF materials, the total volume of water required to fully saturate the materials is 90L.

Each bin was fully saturated to the top of the NAF with water sourced from Dawesley Creek. A constant head water cover of 5-20mm was maintained on top of the NAF.

4.3 MONITORING AND SAMPLING

Field testing (pH, ORP and EC) commenced in November 2013 and continued on a weekly basis. Leachate was tested immediately following extraction from the outlet port tap. The volume of leachate extracted for testing was 100 to 300mL.

Field testing of acidity was not carried out as Waters et al. (2014) note that calculation of Total Acidity provides a more accurate and reliable indication of acidity than laboratory-derived acidity measurements.

Measurement of field parameters (see Appendix 6.2 for standard operation procedures) is then taken as soon as possible after sampling. The colour and odour (e.g. H_2S odour) of the leachate are also noted. An example of a field data monitoring sheet is shown in Appendix 6.8.

Upon completion of testing and sampling, each bin is irrigated with a volume of creek water equivalent to the volume of water removed for sampling.

4.4 ISSUES AND PROBLEMS

Two of the bins developed leaks some weeks into the sampling program. The leaks were occurring at the base of the bins. It was unclear if this was an inherent flaw in the bins or if it a stress related crack resulted from the weight of the materials.

Bins should be tested for water tightness before loading materials. The materials (especially if containing stones and larger pebbles) should be carefully placed into the bins/columns.

5 100 TONNE PRESENTATION TRIAL

5.1 INTRODUCTION

The construction of a 100 tonne geochemical trial at Brukunga was undertaken to validate the geochemical processes of the co-disposed mix by scaling-up from lab-columns to a full scale field trial constructed in a cement brick cell. The building of a besser-block field cell to house the waste materials took place in November 2011 and the trial was set up almost one year later in October 2012. The besser-block cell has internal dimensions of 12.13m x 2.235m x 1.58m. Construction details were provided by Earth Systems (2012).

5.2 METHODOLOGY

Prior to construction, the interior of the cement brick cell was washed and cleaned. Because the walls of the cell had been constructed about one year previously, there were some visible cracks evident in the fibreglass resin and these were sealed with silicone cement. The inherent structural weakness was to become a major issue which severely compromised the outcomes of the trial.

Three 50mm PVC tubes (with industrial slotting and wrapped in a 250 micron filter mesh) were laid lengthways along the base of the shell. It is recommended that Teflon tape be used on all threaded joins and 100 micron filter mesh is preferable. The tubes were bedded in an 80mm layer of sand/gravel (fully characterized NAF material was used). In hind-sight it would have been preferable to place an envelope of sand/gravel around each individual pipe (Jeff Taylor, Earth Systems, pers comm.).

The bottom half of the structure was filled with PAF material and the top half with NAF material.

<u>Addition of PAF material</u>
A small excavator was used to excavate and mix PAF materials on the mixing pad adjacent to the stockpiles (Figure 11).

Figure 11. Mixing waste rock, tailings and lime for 100t presentation trial.

The source of the limestone used was Penrice Ag lime which has a purity of 93-97% $CaCO_3$. The mixing ratio was 60.5WR : 35.5T : 4L wt.% which equated to 8 x excavator buckets of waste rock, 6 x buckets of tailings and 1 x bucket of limestone. A large front end loader then transported the mixed material to be tipped into the test-shell (Figure 12). Larger rocks (>250mm) were excluded.

Figure 12. Dumping PAF mix into the geochemical test-shell, composed of besser blocks.

Ten loads of PAF mix were tipped into the structure to an internal depth of 0.80m. Earth Systems (2012) indicated that around 39 tonnes of PAF material (assuming an average bulk density of 1.8 g/cm^3) would need to be added to bring it to the required height.

After each load of PAF material was dumped into the test-cell, it was evenly spread out using rakes and shovels. The material was wetted up (Figure 13) by spraying with a hose connected to the 23kL tank containing creek water and a pressure pump to aid delivery. The material was sprayed until the surface was glistening with moisture.

Figure 13. Wetting up and compacting the PAF mix within the geochemical test-cell.

A plate vibrator was run across the surface with just one pass and moving at a slow pace. Material was continued to be added and the wetting and compacting process repeated for each 10cm lift.

Addition of NAF material

This material was sourced from Pooraka Sand and Metal Landscape Supplies and included:

- Mixed river pebbles (50 - 60mm)
- Concrete sand (0.1 – 0.5mm)

The materials were to be well mixed in a ratio of 60% sand : 40% pebbles prior to delivery. Because the material was stockpiled on the ground, care was required to avoid contamination when scooping up the material to be placed in the test-cell. It was estimated that over 40 tonne of NAF material was tipped into the enclosure to bring the NAF layer almost level to the top of the besser-brick wall. The NAF layer was wetted and compacted in the same manner as the PAF layer.

Piezometer installation

Following on from the three slotted pipes laid lengthways along the base of the test-cell, three series of piezometers were installed horizontally cross-ways at either end of the test-cell (Figure 14). They were installed at the following depths:

- Middle of PAF layer (0.40m from base)
- Interface of PAF and NAF (0.80m from base)
- Middle of NAF layer (1.20m from base)

Figure 14. Piezometers placed horizontally across the width of the test-cell.

Piezometer specifications were 50mm PN18 PVC, machine slotted and wrapped in a 250 micron filter mesh. A 100 micron filter was recommended by the TAG but was unavailable from the supplier. The PVC tubes were levelled with a spirit level and were surrounded by a ~20cm envelope of sand/gravel filter pack (using fully characterised NAF material). The nine slotted pipes formed the nine water collection ports for pore water analysis.

A channel to simulate Days Creek was formed at the surface of the NAF layer (Figure 15). The channel was lined with slotted 150mm diameter stormwater PVC pipe cut in half lengthwise through its circular cross section. Upon full saturation of the NAF layer, the depth of water in the channel was maintained at ~40cm. A cover lid was placed on top of the shell to prevent lime dust from the treatment plant contaminating the materials.

Figure 15. NAF cover surface with gutter to simulate a creek-line (note: 23kL water storage tank on left and cover lid frame to the right).

Saturation procedure

Water for the trial was obtained from Dawesley Creek and stored in a 23,000 L tank with pressure pump (Figure 15). The recommended strategy was to slowly wet up the mix to prevent oxidation from occurring. The NAF layer was initially wetted to just below field capacity to prevent oxygen from getting down into the PAF material. After 3-4 weeks, the shell was then flooded to its full capacity. This would give time for the residual acidity in the PAF layer to be neutralised by the limestone (expected to take ~4 weeks). The NAF layer would remain unsaturated until all the jarosite in the PAF had been neutralised. The NAF layer would then be saturated and this process would simulate 'real-world' rehabilitation.

Water was added to the shell at a rate of 11 L/min. The NAF material is fully saturated when free water appears in the surface channel. During wetting up it was noted that most of the piezometers made water during and immediately following the additions of water, but then 'dried up' a few days later. A number of irrigations was therefore required to maintain a constant head of water in the NAF.

At an estimated porosity of 25% in the PAF material it was considered that it would take 5000 to 6000 litres of water to fully saturate the PAF material. At an estimated porosity of 50% in the NAF material it would take around 11,000 litres of water to fully saturate the NAF layer. The total amount of water required to fully saturate the test-cell was calculated to be 16,000 Litres, but in reality 20,000 litres was required.

Although not done in this trial it was suggested that for more accurate monitoring of the watertable, a pressure transducer (vibrating wire piezometer) should be used in preference to an open borehole (which could allow oxygen to enter the PAF layer).

5.3 MONITORING AND SAMPLING

Field testing for chemistry commenced around 2 weeks after construction to allow the limestone to neutralize the acidity of PAF materials in the test-cell. Laboratory sampling commenced a month after construction.

Field Testing

Field testing involves *in situ* field measurements and subjective visual observations of colour and odor for the leachate collected from the sampling ports. Leachate samples are allowed to drain freely from the ports until a desired amount is collected (e.g. 100mL). Taps need to be opened and closed quickly to prevent oxygen from entering the test-cell. Ports were not purged prior to taking a sample. The following parameters were tested on a weekly basis:

- pH
- ORP
- EC

Field testing of acidity was not carried out upon the recommendation of Earth Systems (J Taylor pers comm.). The calculation of Total Acidity provides a more accurate and reliable indication of acidity than laboratory-derived acidity measurements (Waters et al. 2014).

Laboratory analysis

Water samples (500-1000mL) are collected from selected ports for laboratory analysis at a NATA accredited laboratory. Field filtering was required for dissolved metals analysis. Samples were analysed for the following parameters:

- pH
- EC
- Acidity and Alkalinity
- Cations: Ca, K, Mg and Na
- Anions: SO_4, Cl, F and NO_3
- Total N, TKN, Total P
- COD, TOC and DOC
- Dissolved metals: Al, As, Cd, Cr, Cu, Fe, Mn, Ni, Pb and Zn

Upon completion of testing and sampling, the test cell is flooded to its full capacity with creek water. This was done by placing a delivery hose from the tank into the surface drain and pumping in water at a rate of ~10L/minute.

Hydrogeological Testing

Hydrogeological tests were conducted on the co-disposed waste materials to help establish baseline estimates of geotechnical parameters such as hydraulic conductivity. This involved flushing the porous base layer initially and then allowing leachate to drain freely from the middle basal port.

The test-cell was continually irrigated to maintain a hydrostatic head in the co-disposed materials. The discharge flow rate was measured at regular intervals along with field parameters of effluent leachate.

5.4 ISSUES AND PROBLEMS

It soon became apparent that the besser brick structure / enclosure was not entirely waterproof but became increasingly leaky over time. The more water that was added to the shell the worse that the leaks became. Salt efflorescences and iron crusting appeared on the outside walls over the period of the trial and despite many attempts to seal the leaks, the problem continued to worsen.

Part of the issue was that the brick structure was left to stand for one year between construction of the walls and the addition of materials and the wetting up process. The trial was eventually abandoned and in hindsight a plastic tank-liner should have been used.

6 APPENDICES

The following appendices are provided as a supplement to the geochemical trial work at Brukunga.

6.1 Safety procedures for field and laboratory leach trials

6.2 Standard Operation Procedure (SOP) - Field Water Quality Parameters

6.3 Standard Operation Procedure (SOP) - Titrations

6.4 Standard Operation Procedure (SOP) - Paste pH Test

6.5 Instrument calibration tracking record sheet

6.6 Example of spreadsheet for calculation of weight of solids used in column construction

6.7 Field test spreadsheet – leach columns

6.8 Field test spreadsheet – large-scale columns

6.9 Example of QC report for leachate sampling

6.10 Waste rock 1000 tonne pile (pyramid) testwork (2007-2009)

Appendix 6.1 Safety procedures for field and laboratory leach trials (adapted from the PIRSA OHS manual, 2010)

Introduction

The purpose of this document is to provide details on the safety procedures used in leachate trials at Brukunga mine field laboratory. This includes outlining the responsibilities of supervisors, employees, vocation students and other relative individuals while working for the program. This manual conforms and supports all OH&S directives and policies of the Primary Industries and Resources South Australia (now DMITRE). All individuals involved in field column trials are required to be familiar with this procedures and policies outlined in this document.

General Field Trials Safety

Individuals must become familiar with the location of safety showers, washing facilities and first aid equipment in the field. Everyone in the field facility has a responsibility to protect the safety of themselves and for others working together. A hazards checklist of the field work should be checked prior to commencing any experimental work.

i. PPE (Personal Protective Equipment)

a. Safety boots must be worn at all the time in the field. Open shoes or sandals are NOT allowed. Closed laces up shoes are preferred
b. Safety glasses must be worn all the time, person wearing prescription glasses must have toughened impact resistant lenses; otherwise safety glasses must be worn
c. Clothing must be able to cover significant parts of body (e.g. long pants and shirt)
d. Wear appropriate gloves for protection all the time while handing hazardous chemicals.

ii. General rules

e. Keep the field laboratory tidy and clean at all times
f. Report to the project manager if you are the last person to use a solution and reagent, make sure it refilled for the next experiment
g. Report to the project manager if you break any apparatus (including glassware)
h. Walkway and floor space must be clear
i. Never smoke, eat, drink in the area where chemicals are placed and experiments are in progress
j. Don't leave experiments or samples unlabeled and unattended
k. Wash your hands thoroughly after the experiment.

Chemical safety

This section conforms and supports all OH&S directives and policies of the Primary Industries and Resources South Australia (PIRSA) : PIRSAFE Procedure No: 11 Hazardous Substances Management. A collection of Material Safety Data sheet (MSDS) provides information on hazardous chemicals and correct handing protocols and procedures to minimize risk. MSDS are available via ChemGold III database (PIRSA inside website). Before using any chemical the user must check with the database to confirm if the chemical has any hazardous properties and follow the handing methods listed in the database. For leachate testwork, there are three chemicals involved in the field experiment: Sodium hydroxide (NaOH), hydrogen peroxide (H_2O_2) and Phenolphthalein ($C_{20}H_{14}O_4$) - see classification hazardous substance.

iii. General rules

a. All chemicals should be treated as being potentially hazardous
b. Refer to MSDS regularly and read the warning labels on unfamiliar chemicals
c. Label all containers

d. Unlabelled container will be considered waste and disposed if unclaimed at the end of the working day.

iv. Storage of chemicals

a. All chemicals shall be stored away from direct sunlight as sunlight can have detrimental effect on the integrity of some plastic

b. All chemicals shall be stored away from heating source

c. All quantities of chemicals stored within the acidity test kit are to be kept an absolute minimum for 2 months operation. (depend on the effective time of standard solution suggested by suppliers)

d. All chemical should be sealed after every use, minimize the time exposing to air.

Disposal of experimental waste

a. Small quantities of acid or alkali can be washed carefully down sink with excess volume of continuous flowing cold water

b. Waste acid water can be drained directly in the channel of wastewater treatment outside the field laboratory

c. Aqueous chemicals should be disposed in special bin provided in field laboratory

d. Broken glass should be disposed of in the designated glass bin

e. All other general waste should be disposed into the general bin in the field laboratory.

CHEMICAL HAZARDOUS

□ Material safety data sheets available and current
□ Hazardous substance labelled
□ Suitable containers
□ Inventory of hazardous substances available and up to date
□ All chemicals have been sealed and not leaking
□ Volume of chemicals not excessive

WASTE STORAGE

□ Designated paper and plastic bin
□ Designated bin for broken glass
□ Chemical wastes segregated
□ Regular waste disposal organized

Classification Hazardous Substances and Chemical Labels

The classification of chemicals is based on PIRSAFE Procedure No: 11 Hazardous Substances Management.

Name of chemcial	Class	Description
Sodium Hydroxide	**Low risk**	See MSDS
Hydrogen Peroxide	**Moderate Risk**	See MSDS
Phenolphthalein	**High Risk**	See MSDS

Appendix 6.2 Standard Operation Procedure Field Water Quality Parameters

Purpose and Scope:

This Standard Operation Procedure (SOP) describes the measurement of field parameters for rapid testing of water quality in the field. A multi- parameter water quality meter is used to measure pH, Redox potential (ORP), electrical conductivity (EC), total dissolved salts (TDS) and temperature. Field measurements should represent as closely as possible the natural condition of the water at the time of sampling.

Materials / Equipment / Chemicals:

The following materials are equipment are required:

- paper towels, safety glasses and latex gloves
- distilled water / wash bottles
- beakers
- instruments (TPS and Myron Ultrameter)
- standard calibration solutions and buffer solutions

Calibration of Instruments:

Multi-parameter water quality meters are used for measuring field parameters at Brukunga. Parameters to be read are temperature, pH, ORP and Conductivity. It is recommended that TDS not be read as this is a calculated value and the factor varies with the quality of the water being measured.

Instruments in use at Brukunga are the TPS and Myron Ultrameter water quality meters. A calibration procedure is described below for both instruments.

It is a good idea to maintain a calibration tracking record (see Appendix 6.5) to keep a check on the reliability of the meter. Each instrument should have a permanent log book for recording calibration data and instrument repairs and services. Note that calibration is only required occasionally if the electrodes are in good condition. The sensors / electrodes have a limited lifetime and should be replaced at least annually.

TPS METER

Calibration of Temperature

- Place a thermometer in a beaker of water and allow to stabilise for a couple of minutes
- Place conductivity / temperature probe in the same beaker
- Press [MENU] ☛ Press [F1] cal ☛ [F4 TEMP]
- Record temperature on thermometer and TPS (pre-cal value)
- Enter temperature from thermometer as [ACTUAL TEMPERATURE,] press [ENTER]

Calibration of pH

- Calibrate probe with pH 4 and 7 standards (2-point calibration)
- Wash probe with distilled water, dry and then immerse probe in pH 4 standard solution
- Press [MENU] ☛ press [F1] cal ☛ [F3] pH
- Record pre-cal value, press [ENTER], then record post-cal value
- Wash probe with distilled water, dry and repeat above procedure with pH 7 standard.

Calibration of Conductivity

- Remove conductivity probe from case and wash with distilled water. Immerse probe in standard solution so that hole at the top of the probe is covered. Allow the reading to stabilize which may take a minute or more
- Press MENU ☛ press F1 cal ☛ F2 conductivity
- Record pre-cal value in mS/cm, press ENTER, then record post-cal value in mS/cm

Rinse probes with distilled water thoroughly before testing sample or before storing the probes. The conductivity probe should be stored dry, while the pH/ORP electrode bulb is stored in electrode storage solution.

MYRON ULTRAMETER II

Myron instruments are factory calibrated with NIST traceable standard solutions and buffers. These are available from Freshwater Systems Pty Ltd.

The following standard solutions and buffers are used for calibration: pH=4, pH=7, TDS=442-3000 (optional), EC=7000.

- Rinse the Ultrameter 3x with distilled water
- Rinse RHS cell with pink buffer pH=4 solution 3x and fill the cell
- OK If reading is between 3.95-4.04, otherwise recalibrate
- Press CAL, then press the up or down keys to change the reading to match the known value, then press CAL again
- Repeat for pH=7 (green buffer solution), but do all the rinses first
- Rinse LHS cell with the TDS (442-3000) solution and press TDS button, OK if reading is between 2980 and 3020, otherwise recalibrate
- Repeat for EC (KCl-7000) and press COND button, OK if reading is between 6980 and 7020, otherwise recalibrate.

The meter should always be stored with the lid cap in place so the pH/ORP cell does not dry out. Before replacing the rubber cap, fill the well of the sensor with Sensor Storage Solution.

Taking Measurements:
Field measurements need to represent as closely as possible the natural condition of the water at the time of sampling. Measurements should therefore be taken immediately following collection of the water sample.

When using the Myron meter (Figure 16), rinse the sample cell 3x with distilled water and then 3x with the sample to be tested. Fill the sample cells with the tested sample and measure in turn temperature, ORP, pH, EC and TDS. In some cases it may take a minute or so for the reading to stabilize, in which case the trend should be noted along with the initial reading. For ORP measurements it is recommended that the initial reading be recorded along with the trend of the readout for at least one minute.

After use, rinse cells 3x with distilled water. Occasionally squirt in a foaming cleaner (e.g. Windex ®) to remove any oily films or scum which may have coated the electrodes and rinse with water.

Figure 16. Testing leachate samples with the Myron ultrameter.

Lab Supplies:
Laboratory supplies (glassware etc.) are available from:
ASIS SCIENTIFIC PTY LTD
474 Port Road
Hindmarsh SA 5007
Ph: 8340 8444
customerservice@asisscientific.com.au

Chemical supplies are available from:
FRESHWATER SYSTEMS AUSTRALIA PTY LTD
93 Sir Donald Bradman Drive
Hilton SA 5033
Ph: 8351 7800
jh@freshwatersystems.com.au

Related Documents / References:
Freshwater Systems. Advice on maintaining your Myron L 6P, 6PII & 6Psi water meters. Fact Sheet produced by Freshwater Systems Australia Pty Ltd.
Manual for field column test – Water collection and field analysis (TAG Factsheet, author(s) unknown).

Appendix 6.3 Standard Operation Procedure Titrations

Purpose and Scope:
Acidity is a measure of the concentration of H^+ ions in an aqueous solution. It is expressed as a mass of calcium carbonate equivalent per unit volume (mg/L of $CaCO_3$). One method of measuring acidity is by using the titration test-kit supplied by Earth Systems Pty Ltd. The test-kit measures total acidity to a value of pH 8.3.

This Standard Operation Procedure (SOP) describes the use of the acidity test kit at the Brukunga lab.

Materials / Equipment / Chemicals:
The following are required to carry out acidity titrations:

- paper towels, safety glasses and latex gloves
- distilled water / wash bottles

- beakers, pipettes, syringes
- acidity test kit with *risatec* ® micro-titrator
- phenolphthalein indicator (1%), hydrogen peroxide (30% H_2O_2)

OHS:
Chemicals used for testing are stored in lockable lab cupboards. Refer to Materials Safety Data Sheets (MSDS) sheets for handling, storage and accidental exposure to chemicals / reagents that are used with the acidity test kit.

Wear safety glasses and surgical gloves during the testing procedure.

Testing Procedure:
Use dedicated beakers, drainage bags or syringes to collect water / leachate samples. Turbid samples may need to be filtered as it is difficult to detect end-point colour changes if the solution is not transparent.

Micro-titrator reaction vessels are stored in an acid bath (2% nitric acid) in a lockable chemical cupboard. Remove vessel from the acid bath and rinse 3x with distilled water and dry.

- Select the low range reagent pipette device stored in the acidity test kit and fill titrant dispersing (hypodermic) syringe slowly with low range titrant (0.08 NaOH, 44M) so as not to introduce air bubbles; withdraw 100 units (1.0 mL) of titrant
- Rinse micro-titrator reaction vessel 3x with sample to be tested
- Transfer 10mL or 20mL of sample into the reaction vessel using a small plastic syringe (pre-rinse 3x with sample to be tested)
- Add 3 drops of phenolphthalein indicator and 5 drops of hydrogen peroxide to the aliquot in the reaction vessel
- Screw micro-titrator onto the reaction vessel and gently squeeze top of syringe to add titrant to the vessel drop by drop watching for a color change while swirling the vessel (Figure 17)
- The end-point is when the indicator turns pink (this is somewhat subjective as colors can range from pale pink to bright red). Record the volume of titrant added in mL (e.g. 0.16 mL).

The volume of titrant added is multiplied by a conversion factor to give the acidity concentration of the sample in mg/L of $CaCO_3$. There are a range of conversion factors used depending on the size of the sample aliquot and whether low or high range titrant has been used.

Figure 17. Testing leachate acidity in the Brukunga lab using an Earth Systems micro-titrator.

It is sometimes necessary to carry out a dilution of the sample to be tested. This is done by adding distilled water (DW) to 5 or 10mL of the sample and then swirling the beaker to thoroughly mix.

<u>1x dilutions:</u> take 10mL or 20mL of sample
<u>5x dilutions:</u> take 10mL of sample and 40mL of DW to make up 50mL
<u>10x dilutions:</u> take 10mL of sample and add 90mL of DW to make up 100mL
<u>20x dilutions:</u> take 5mL of sample and 95mL of DW to make up 100mL
<u>40x dilutions:</u> take 5mL of leachate and 195mL of DW to make up 200mL

Lab Supplies:
These are available from a local supplier (e.g. Freshwater Systems Australia Pty Ltd.)

- Hydrogen Peroxide (30% H_2O_2)
- Nitric Acid (70%)
- Phenolphthalein (1%)
- Sodium Hydroxide (0.08N)
- pH buffers and calibration standard solutions

Related Documents / References:
Earth Systems Pty Ltd Acidity Test Kit Manual and instruction card (further advice on use and maintenance of the test kit can be obtained from Earth Systems).

Appendix 6.4 Standard Operation Procedure Paste pH Test

Purpose and Scope:
This Standard Operation Procedure (SOP) describes a method for determining the paste pH and paste conductivity of rock and soil samples. Paste tests are used to evaluate the geochemical behavior of mine waste materials and estimate the pH (and EC) of pore water resulting from dissolution of secondary minerals on oxidized surfaces of weathered rock particles.

Materials / Equipment / Chemicals:
The following are required:

- pH and conductivity meter(s)
- Calibration standard solutions / buffer solutions (pH=4 and 7)
- Stirring rod
- narrow diameter glass beaker
- Distilled water
- Mortar and pestle, sieve
- Weighing scales
- Graduated measuring cylinder

OHS:
Wear safety glasses, dust mask, and surgical gloves when preparing materials for testing.

Procedure:
Stages involve sample preparation, meter calibration and field testing.

Calibrate pH (and EC probes) using standard solutions. Record calibration data on lab test data sheet (i.e. meter readings prior to and following calibration).

Tests should be carried out on both crushed and uncrushed samples as the undisturbed material provides a better indication of the extent of oxidation than the crushed sample.

The paste pH/EC is determined by equilibrating a sample in deionized water at a solid to water ratio of 1:2 (w/w) and then measuring the pH and EC. This gives an indication of the inherent acidity and salinity of the mine waste material when initially exposed in a waste emplacement area.

Sample Preparation
To prepare the slurry (for crushed samples), the rock or soil needs to be air-dried and pulverized and then sieved to particles <1.0mm size (i.e. gritty sandy texture). The procedure involves adding 2 x parts of water to 1 x part of solid material.

Weight/Volume method: Weigh the mass of material into a small diameter flask. To make up a 1:2 (w/v) ratio of soil:water, slowly add two parts of distilled water to the material. For example, if the weight of material is 25 g, then need to add 50 g of distilled water.

Weight/Weight method: For example if adding 0.100kg of material to a beaker, then need to add distilled water up to a weight of 0.300kg.

Mix thoroughly by stirring continuously while adding the deionized water.

Wait for the sample to equilibrate (one reference suggests leave stand for 10 minutes, while another suggests leave stand for up to 12 hours before testing).

The testing needs to be done *in-situ* (i.e. directly on the slurry). It is a good idea to use a small diameter flask / vessel as there is not very much supernatant to play with.

For the uncrushed rock sample, weigh the rock / particles, add 2 parts of water, lightly shake and leave stand without further disturbance.

Measurements
Tip beaker to one side to allow water to collect in the corner and dip pH probe into the slurry and stir supernatant by lightly swirling the electrode.

Don’t stir anymore once commencing the measurements. When the reading remains constant, record the pH. Take measurements at 1, 3, 5, 10, 15, 30, 60 minutes, then hourly. Check again in 24 hours and a week later.

Decontaminate the probe by rinsing with distilled water between tests.

Plot the pH versus time to determine when pH readings are reaching a plateau. Readings can then be terminated. Once pH testing is completed, use the Myron Ultrameter to test the supernatant for EC.

Interpretation
Low pH readings indicate that oxidation and acid generation has occurred. Readings taken on uncrushed samples often provide a better indication of the extent of oxidation than for crushed samples.

According to Environment Australia, (EA, 1997), the criteria for potentially acid forming rock material is for saturated paste pH to measure <4.

Relatively high electrical conductivity (EC) levels indicate a considerable store of contaminated salts, usually sulfates or other metal salts.

QA/QC
The accuracy of measurements can be verified by using standard solutions.

Following testing, place the probe(s) into standard solutions and record readings on the lab data sheet. If readings have drifted by more than 5%, recalibrate the probe and repeat the tests.

Related Documents / References:

EA (1997) Environment Australia. Managing sulfidic mine wastes and acid drainage, best environmental practice environmental management in mining.

Price, WA (1997) Guidelines and recommended methods for the prediction of metal leaching and acid rock drainage at mine sites in British Columbia.

Sobek, AA, Schuller, WA, Freeman, JR and Smith, RM (1978) Field and laboratory methods applicable to overburden and mine soils. EPA Report 600/2-78-054. US National Technical Information Service Report PB-280495.

Appendix 6.5 Instrument calibration tracking record sheet

Example of maintaining calibration records for field pH, EC and TDS measurement

Description of Standard solutions

Standard solution	TDS, ppm	EC, µS/cm	pH
KCl-7000		7000	
442-3000	3000		
pH buffer 1			4.0
pH buffer 2			7.0

TDS

Sample	Certificated value, B	Measured value, A	RPD, %	Comment
442-3000	3000 ppm			

EC

Sample	Certificated value, B	Measured value, A	RPD, %	Comment
KCl-7000	7000 µS			

pH

Sample	Certificated value, B	Measured value, A	RPD, %	Comment
pH buffer 1	4.0			
pH buffer 2	7.0			

Recorded by:
Date:
Remarks:

RPD,%=([A-B]/B)*100

Appendix 6.6 Example of spreadsheet for calculation of weight of solids used in column construction

63:37 <25mm WR 4% CaCO3

	Target dry density		Approx optimum moisture content		X-sectional area	Assumed density of competent / solid rock
	1800 kg/m³		15 %		0.028353	2550 kg/m³
	Waste rock	Tailings	Limestone			glass sand (at base of column)
						2 kg
Estimated (assumed) moisture content (%)	10.80	8.43	0.51			
Mixing ratio(%)	63	37	4			
Purity of limestone (% $CaCO_3$)			90			
Dry weight of component, per 50cm column (kg)	15.98	9.38	1.18	Total dry weight per 50cm column assuming target dry density	26.54	
					25.52	
Wet weight of component (including assumed moisture content), per 50cm column (kg)	17.70	10.17	1.19	Total wet weight per 50cm	29.06	
	17.02	9.78	1.14			
				Left over aft construction	2.50	
				actual/estimated weight	0.91	
				Approximate dry density achieved	1645.46	

Appendix 6.7 Field test spreadsheet – leach columns

DATA RECORD FOR FIELD COLUMN TEST

DATE: **RECORDER:**

Calibration	**pH4:**	
	pH7:	**EC-7000:**

Column	Surface water								Leachate									Colour	Volume leachate in bags (mL)	Volume irrigation refill (mL)
	pH Field	ORP Field (mV)	EC Field (uS/cm)	Temp Field (deg C)	Vol Samp (mL)	Dil acto	Volume Titrant (mL)	Acidity surface ng/L CaCO3 per mL titran	Vol Field (mL)	pH Field	ORP Field (mV)	EC Field (uS/cm)	Temp Field (deg C)	Acidity Vol Samp (mL)	Dil Facto	Volume Titrant (mL)	Acidity ng/L CaCO3 per mL titrant			
					20	×1								10	×5					
					20	×1								10	×5					
					20	×1								10	×5					

low range: 0.0786 NM NaOH

FILLED WATER:

ACIDITY: Unit conversion factors: Surface Water use 197; Leachate use 393

pH:

ORP:

EC:

T:

Appendix 6.8 Field test spreadsheet – large-scale columns

FIELD TESTING DATA SHEET

LARGE-SCALE COLUMN LEACH TESTWORK

Date:

Meter: Myron #6204821

Meter Check against Standard Solns: **pH 7:** **pH4:** **EC 7000:** **ORP 475:**

Bin No:	Configuration	Volume discharged (mL)	Temp (°C)	pH	ORP (mV)	EC (µS/cm)	Color	Odor	Volume irrigation refill (mL)	Comments
1	Baseline PAF + NAF									
2	Baseline O/M in PAF									
3	Baseline basal O/M									
4	Baseline PAF + NAF									
5	NAF only									
Tank	creek water									

Color Descriptions: B=Brown Y=Yellow R=Red p=pale d=dirty/muddy

Appendix 6.9 Example of QC report for leachate sampling

DATE:

Parameter	Units	Port 2			
		Lab#1	Lab#2	%difference	RPD%
pH		5.97	5.9	1.17	1.18
EC	µS/cm	12600	11200	11.11	11.76
Acidity	mg/L $CaCO_3$	4050	5630	-39.01	-32.64
Acidity - calculated	mg/L $CaCO_3$	8431	11801		
Alkalinity	mg/L $CaCO_3$	336	421	-25.30	-22.46
Residual alkalinity	mg/L $CaCO_3$	0	0		
Ca	mg/L	445	504	-13.26	-12.43
K	mg/L	547	772	-41.13	-34.12
Mg	mg/L	362	398	-9.94	-9.47
Na	mg/L	596	757	-27.01	-23.80
Sulphate	mg/L	9710	10700	-10.20	-9.70
Chloride	mg/L	308	215	30.19	35.56
Fluoride	mg/L	0.1	0.14	-40.00	-33.33
Nitrate	mg/L	<0.01	<0.06		
Total N	mg/L	21.5	27.1	-26.05	-23.05
TKN	mg/L	21.5	27.0	-25.58	-22.68
Total P	mg/L	0.24	0.668	-178.33	-94.27
COD	mg/L	618	577	6.63	6.86
TOC	mg/L	23	23.2	-0.87	-0.87
DOC	mg/L	20	20.0	0.00	0.00
Al	mg/L	<0.01	6.48		
As	mg/L	0.002	0.011	-450.00	-138.46
Cd	mg/L	0.0002	<0.001		
Cr		<0.001	<0.001		
Cu	mg/L	0.006	<0.001		
Fe	mg/L	3130	4370	-39.62	-33.07
Mn	mg/L	14.7	17.2	-17.01	-15.67
Ni	mg/L	0.003	0.006	-100.00	-66.67
Pb	mg/L	<0.001	<0.001		
Zn	mg/L	0.112	0.124	-10.71	-10.17
Total anions	meq/L	258.0	281.8		
Total cations	meq/L	204.6	268.4		
Ionic balance of analysis	%	11.6	2.4		

Appendix 6.10 Waste Rock 1000 Tonne Pile (Pyramid) Testwork (2007-2009)

A field-scale geochemical trial was designed and implemented by Earth Systems in 2007 to quantify the performance of three AMD management approaches to suppress acidity loads emanating from waste rock dumps:

- The effectiveness of alkaline capping materials
- The benefit of blending limestone with acid generating materials
- The role of soil covers in reducing AMD discharge.

The trials were designed to assess the effect of the following parameters on the minimisation / suppression of acidity loads:

- Amendment grain size
- Waste rock to blended alkaline amendment ratio
- Alkaline amendment solubility and dissolution rates.

The trial involved the construction of seven 1000 tonne waste rock test piles (see Table 4, taken from Struve and Henschke, 2012). Waste rock was thoroughly mixed prior to emplacement to ensure compositional homogeneity between each test pile. The test piles were fitted with a surface irrigation system to supplement rainfall and thus accelerate alkalinity dissolution and transport through the test piles. This would enhance the leaching processes, and ensure constant leachate production. Leachate samples were collected monthly for 12 months and analysed for:

- pH, EC, ORP, Cl, F, P, HCO_3, SO_4,
- Major cations
- Key metals: As, Cd, Cr, Cu, Ni, Pb, Zn, Mn, Al, Fe, Sr, Si (ICP-MS).

Follow-up testwork was conducted from November 2008 to August 2009 when pyramids 1 and 2 underwent a design modification to prevent rainfall and irrigation water infiltrating directly into uncapped sulfidic wastes.

Table 4. Waste rock pile / pyramid testwork.

Test Pile / Pyramid No.	Treatment	Variables
1	Alkaline cap	Caustic magnesia selected as the capping material
2	Alkaline cap	Ultra-fine limestone selected as the capping material (<8 µm)
3	Cover material	Impermeable cover applied to isolate waste rock from rainfall
4	None	Test control, representative of baseline conditions
5	Alkaline blending	Blended with 100 tonne of fine limestone (10% mix, grainsize < 2mm)
6	Alkaline blending	Blended with 20 tonne of ultra-fine grained limestone (2% mix, grainsize <8µm)
7	Alkaline blending	Blended with 100 tonne of ultra-fine grained limestone (10% mix, grainsize <8µm)

8 GLOSSARY

Some of the following definitions have been taken from the handbook DITR 2007, *Managing acid and metalliferous drainage, Leading Practice Sustainable Development Program for the mining industry*, Department of Industry Tourism and Resources

Acid	A measure of hydrogen ion (H^+) concentration; generally expressed as pH. Acid is not equivalent to acidity (see definition below)
Acid drainage	A form of Acid and Metalliferous Drainage (AMD), characterised by low pH, elevated toxic metal concentrations, high sulfate concentrations and high salinity
Acidity	A measure of hydrogen ion (H^+) concentration and mineral (latent) acidity; generally expressed as mg/L $CaCO_3$ equivalent; measured by titration in a laboratory or estimated from pH and water quality data
AMD	Acid and Metalliferous Drainage, also known as acid mine drainage or acid rock drainage; AMD can display one or more of the following chemical characteristics: - low pH (typical values range from 1.5 to 4) - high soluble metal concentrations (iron, aluminium, manganese, cadmium, - elevated toxic metal concentrations (copper, lead, zinc, arsenic and mercury) - elevated acidity values (e.g. 50–15 000 mg/L $CaCO_3$ equivalent) - high sulfate (typical sulfate concentrations range from 500–10,000 mg/L) - high salinity (typical EC range from 1000–20 000 µS/cm) - low concentrations of dissolved oxygen (< 6 mg/L) - low turbidity or total suspended solids
EC	Electrical Conductivity is commonly used as a measure of water salinity in units of milli-Siemens per centimetre (mS/cm) or micro-Siemens per centimetre (µS/cm)
Jarosite	Jarosite is a basic hydrous sulfate of potassium and iron ($KFe_3(SO_4)_2(OH)_6$) and is formed by the oxidation of iron sulfides and forms a yellowish or brownish mineral; the presence of Jarosite being an indicator of acidic sulfate rich conditions
Kinetic test	Procedure used to measure the magnitude and/or effects of dynamic processes, including reaction rates (such as sulfide oxidation and acid generation), material alteration and drainage chemistry and loadings that result from weathering; unlike static tests, kinetic tests measure the behaviour of a sample over time
NAF	Non-acid forming materials
O/M	Organic matter
ORP	Oxidation Reduction Potential
PAF	Potential acid forming materials
PIRSA	Primary Industries and Resources, SA (Government of South Australia)
Pyrite	The mineral pyrite, or iron pyrite, is an iron sulfide (FeS_2). Pyrite was mined at Brukunga from 1955-1972
Static test	Procedure for characterising the physical or chemical status of a geological sample at one point in time. Static tests include measurements of mineral and chemical composition and the analyses required for Acid Base Accounts
Sulfates	Salts resulting from the chemical action of sufuric acid. In the context of acid sulphate soils and AMD, the term refers to various iron sulfates
TAG	Technical Advisory Group for the Brukunga remediation design
Tailings	Finely ground materials from which the desired minerals have been largely extracted
TSF	Tailings Storage Facility designed for the storage of unsaturated tailings material produced during ore processing. These facilities, unlike tailings dams are not suitable for storage of supernatant water
Waste rock	Material such as soil or uneconomic mineralised rock that surrounds an orebody and must be removed in order to mine the ore
Water cover	Layer of surface water or groundwater intended to limit the ingress of oxygen into AMD-generating materials
WRD	Waste rock dump

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This document can be viewed on the DMITRE M-drive at:

MINERR\Mine Completion\Brukunga\Project Management\BR02 Chemical\BR02-06 Acidity Trials & Tests\BR02-06d Presentation Trial\Sampling plan for sulfur speciation of waste rock and tailings_NS.docx.

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ATTACHMENT K
OTHER TAG INVESTIGATIONS AND / OR REPORT SUMMARIES

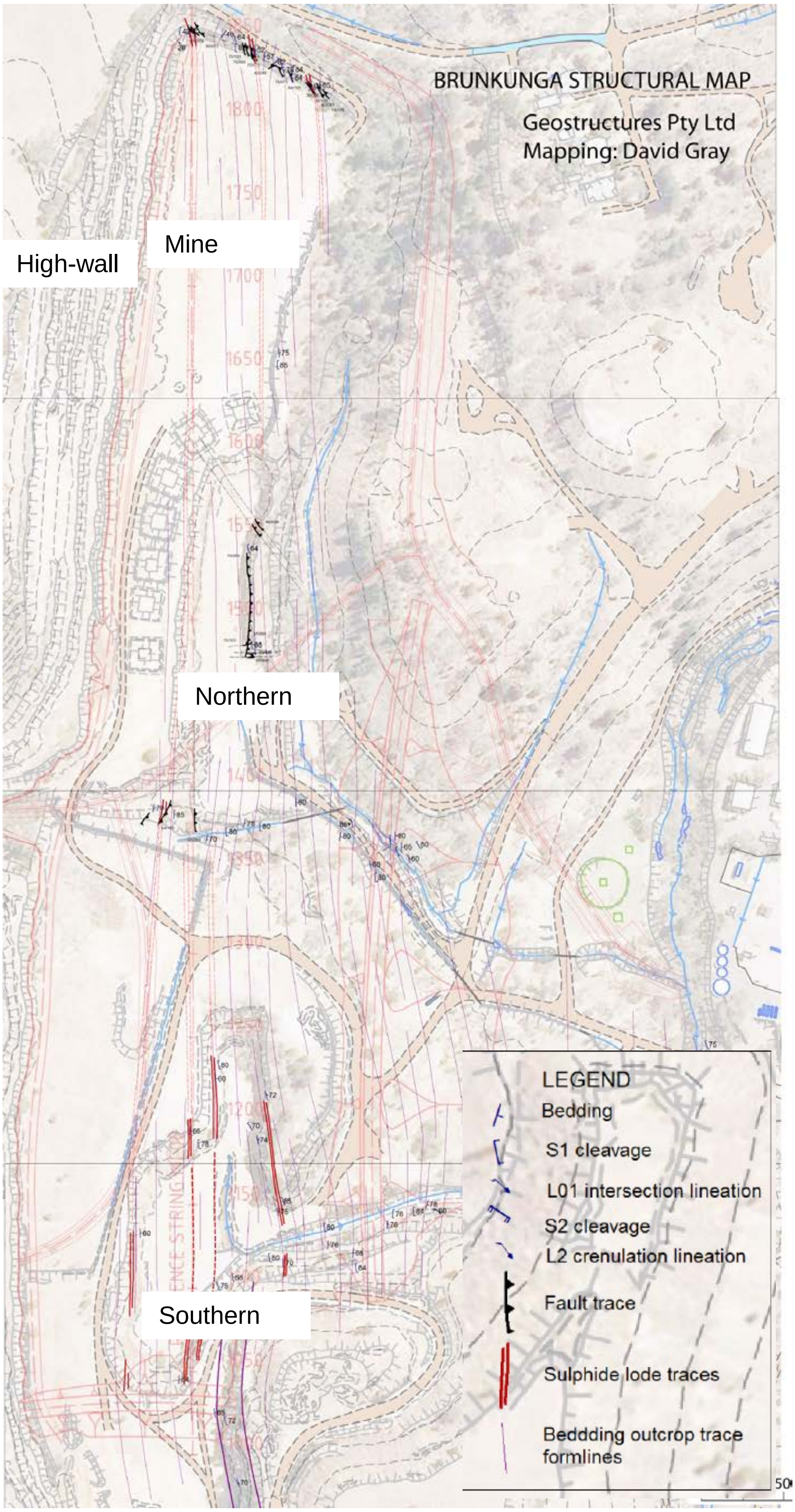

Figure1. Structural Geology of the Days Creek Domain.

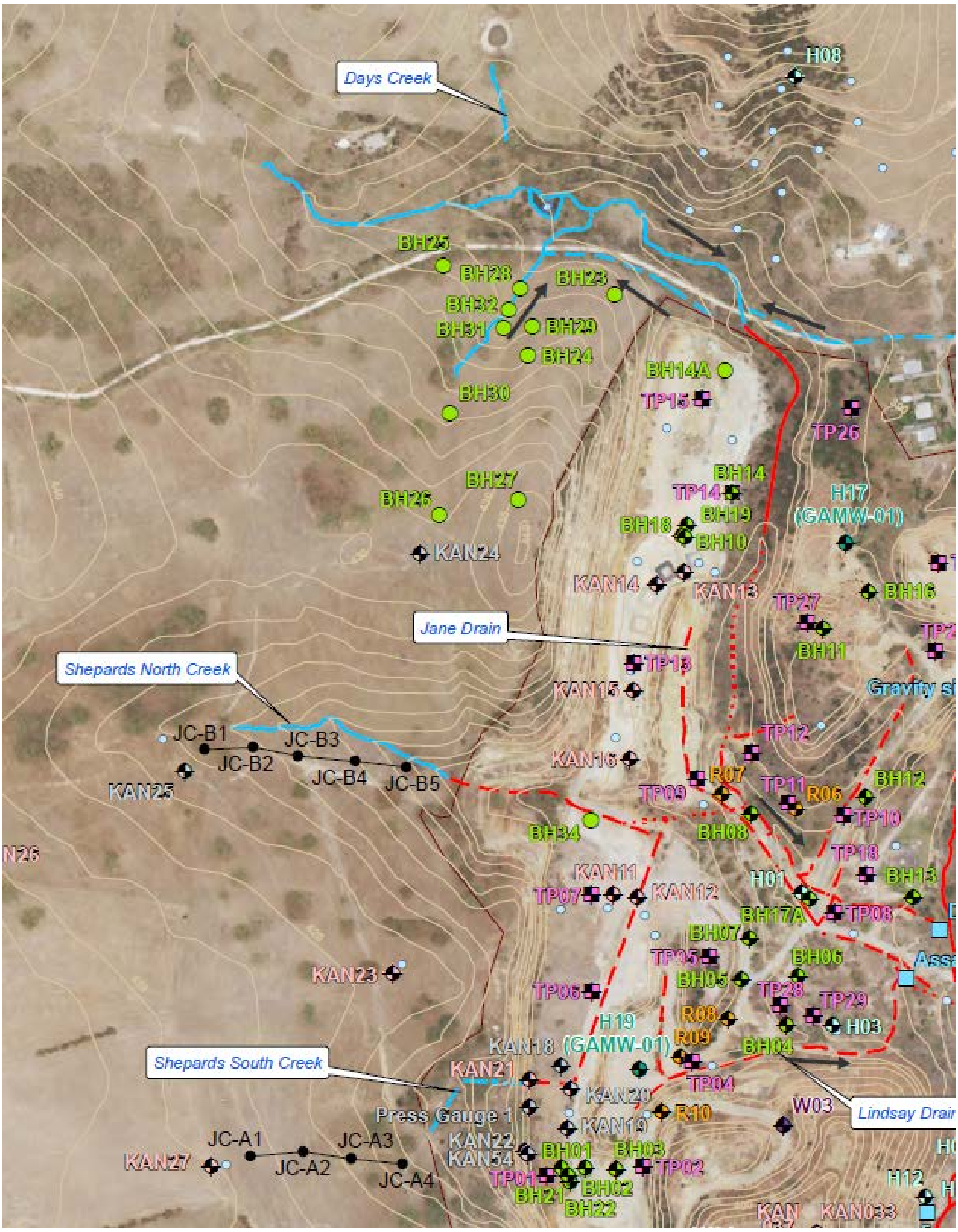

Figure 16. Investigation locations Days Creek Domain.

Boreholes in the bench area include BH01, BH02, BH03, BH10, BH14A, BH33, BH34, TP01, TP02, TP06, TP07, TP09, TP13, TP14 and TP15. The top of the weathered rock zone on the bench occurred at shallow depths ranging from 0 m BGL to 0.8 m BGL with competent rock encountered from 0.3 m BGL to 2.15 m BGL. Pyrite veins occurred in all core extracted on the bench.

Borehole Locations are presented in Figure 28. Of particular interest are the permeability tests in the mine bench area. These are shown in Table 1. Below 5 m the permeabilities are close to the required value. A review of cores shows that permeability is related to jointing and thus likely to respond well to grouting. Quaternary to Recent alluvial deposits are restricted to current creek lines.

Table 1. Permeability Tests – Mine area (from SKM 2009).

Location	SLUG TEST RESULTS		PACKER TEST RESULTS	
	Slug Test Interval (response zone) (m BGL)	Hydraulic Conductivity, k (m/s)	Packer Test Interval (m BGL)	Hydraulic Conductivity, k (m/s)
BH01	7 - 20	8×10^{-9}	6 - 20	2×10^{-8}
BH02	7 - 20	3×10^{-8}	10 - 20	4×10^{-8}
BH03	7 - 20	7×10^{-9}	7 - 20	5×10^{-8}
BH08	2 - 15	2×10^{-8}	-	-
BH10	7 - 20	3×10^{-9}	6 - 20	4×10^{-8}
BH14A	1 - 4	1×10^{-4} [2]	-	-
BH18	15 - 20	1×10^{-8}	-	-
BH19	2 - 5	1×10^{-4} [2]	-	-
BH21	15 - 20	1×10^{-7}	-	-
BH22	2 - 5	1×10^{-5}	-	-
BH33	1– 5 (open hole) [1]	1×10^{-4} [2]	-	-
BH34	1 – 5 (open hole) [1]	1×10^{-4} [2]	-	-

Note [1] Response zone in open hole bore was determined to be from the water level to the base of the bore
Note [2] Estimated value – rapid loss of head indicating high hydraulic conductivity