Appendix 6

Groundwater Quality Investigation

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Groundwater Quality Investigation

No.3 Shaft, Perilya North Mine, Broken Hill

for Perilya Broken Hill Limited
December 2011

J1262.9R-rev0

CMJA

C. M. Jewell & Associates Pty Ltd

Groundwater Quality Investigation - No.3 Shaft, Perilya North Mine, Broken Hill
December 201111

J1262.9R-rev0

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Measures

µg/L	micrograms per litre
km	kilometre
L	litre
m	metre
m^2	square metre
µS/cm	microsiemens per centimetre
mS/cm	millisiemens per centimetre
mg/kg	milligrams per kilogram
mg/L	milligrams per litre
mm	millimetre

General

AHD	Australian Height Datum
AMG	Australian Map Grid
ANZECC	Australian and New Zealand Environment and Conservation Council
AST	above-ground storage tank
CLM Act	Contaminated Land Management Act
CMJA	C. M. Jewell & Associates Pty Ltd
COPC	contaminants of potential concern
DA	development application
DEC	Department of Environment and Conservation
DECC	Department of Environment and Climate Change
DECCW	Department of Environment, Climate Change and Water
DLWC	Department of Land and Water Conservation
DNAPL	dense non-aqueous-phase liquid
DNR	Department of Natural Resources
DP	deposited plan
DQO	data quality objectives
EPA	Environment Protection Authority
ESA	Environmental Site Assessment
GDE	groundwater dependent ecosystems
HDPE	high-density polyethylene
MNA	monitored natural attenuation
NATA	National Association of Testing Authorities
NEPM	National Environment Protection Measure
PID	photoionisation detector
PQL	practical quantitation limit
ppmv	parts per million volume
PSH	phase-separated hydrocarbons
QA	quality assurance
QC	quality control
RAP	remediation action plan
RL	relative level
RPD	relative percentage difference
SWL	standing water level
TCLP	Toxicity Characteristics Leaching Procedure
THI	target hazard index
TOC	top of casing
TWA	time weighted average
UCL	upper confidence limit
UST	underground storage tank

List of Abbreviations

Analytes – Organic

BaP	benzo(a)pyrene
BTEX	benzene, toluene, ethylbenzene, xylene
OCP	organochlorine pesticides
OPP	organophosphorus pesticides
PAH	polycyclic aromatic hydrocarbons
PCB	polychlorinated biphenyls
SVOC	semivolatile organic compounds
TPH	total petroleum hydrocarbons
VHC	volatile halogenated compounds
VOC	volatile organic compounds

Analytes – Inorganic

As	Arsenic
Cd	Cadmium
Cr	Chromium
Cu	Copper
Fe	Iron
Hg	Mercury
Mn	Manganese
Ni	Nickel
Pb	Lead
Zn	zinc

1.0 INTRODUCTION

1.1 Background

The groundwater quality investigation that this report describes, relates to the west cage of the No.3 Shaft (west cage), Perilya North Mine, Broken Hill.

The North mine is situated in high-grade metamorphic rocks of the Early Proterozoic Willyama Supergroup in the Broken Hill Block of western New South Wales.

The Broken Hill orebody is one of the largest known base metal deposits in the world, having produced over 200 million tonnes of high-grade ore over the 126 years of mining. The ore deposit, which consists of six or more distinct lode horizons, is generally strata-bound, with intense structural modification along shears and related folds causing complex ore geometries and upgrading of mineralisation.

The Broken Hill mine is currently being actively mined by Perilya Broken Hill Limited (Perilya), who acquired the mine from Pasminco Limited in 2002. Perilya manages over 1024 square kilometres of prospective terrain, including exploration licences over the historic Little Broken Hill and Pinnacles areas, and mine leases incorporating the Southern Operations, North Mine, and Potosi Line.

Perilya's Broken Hill operation predominantly produces two products, a zinc concentrate and a lead concentrate. Concentrates are a premium coarse-grained product, being of low complexity and containing a grade of about 50% zinc in the zinc concentrate and 70% lead in the lead concentrate.

Perilya is continuously re-appraising known mineral deposits in the area and reviewing all historical data in order to identify new resource targets. As part of these works, Perilya has identified the known mineral resources in the lowermost levels of the North Mine – referred to as the North Mine Deeps – and the ore remaining in the Fitzpatrick Lode, as one of the key mine expansion programs that would extend the life of the Broken Hill mine. Previous mineral resource drilling has shown that the remaining ore in the North Mine Deeps contains an estimated mineral resource of 3.7 million tonnes at 11.3% zinc, 13.5% lead and 219 g/t silver, making it an attractive proposition.

However, given that it has been over 20 years since deep mining activities were undertaken at the North Mine, Perilya is facing the challenge of dewatering the old working prior to the recommencement of any future operations in the North Mine Deeps. This is considered to be a significant task, particularly when assessing the treatment options for the groundwater upon extraction, which Perilya has identified as a key issue in deciding whether the lower levels of the North Mine – including the Fitzpatrick Lode – will become realistic operational target in the future.

In 2006, as part of the pre-planning phase of works, Perilya commissioned C. M. Jewell & Associates Pty Ltd (CMJA) to conduct a preliminary assessment of the quality of the groundwater stored in the old workings, to identify suitable reuse and possible disposal options for the water. The groundwater was highly saline and heavy metal concentrations, in particular – manganese, iron and zinc – were above the relevant criteria for the options considered. Overall, it was concluded that the water in the North Mine would require some sort of treatment (i.e. oxidation, filtration and/or desalination) before most reuse options become feasible.

As five years have passed since CMJA's preliminary assessment, Perilya considered that an additional (up-to-date) groundwater assessment was required. Accordingly, Brain Kelty of Perilya commissioned CMJA on 10 August 2011 to:

- conduct further investigation of the quality of groundwater stored in the North Mine workings, and

- provide Perilya with recommendations regarding reuse or disposal options for the water,

as outlined in CMJA's Proposal for Water Level Measuring and Sampling – Shaft No.3 North Mine, Broken Hill (ref. J1262.8L, dated 20 July 2011).

This report presents the results of that additional assessment.

1.2 Project Objectives

As indicated above, the objectives of the project were to provide Perilya with an overview of quality of the water in the No. 3 Shaft, and to provide Perilya with recommendations regarding reuse or disposal options for the water.

1.3 Scope of Work

The scope of work carried out to achieve the project objectives included the following.

- Camera survey of the No.3 Shaft (West Cage) in order to provide Perilya with video documentation of the condition of the infrastructure within the shaft. Camera surveys were also carried out in order to ensure that the selected profiling run was clear of any blockages or obstructions that could hinder the geophysical logging and groundwater sampling programs.
- Water level measurements (+/- 1.0 metre).
- Geophysical profiling of the water column of the No.3 Shaft – Profiling consisted of two combined fluid resistivity and temperature (including differential temperature) runs between approximately 724 and 1177 metres depth through the floor of the West Cage carriage.
- Assessment of the geophysical profiling results and selection of target intervals for water quality characterisation purposes.
- Collection of three groundwater samples from selected intervals of the accessible water column (i.e. 780 metres, 970 metres and 1160 metres depths RL) using discrete interval groundwater sampling techniques.

  Note: An additional geophysical run was conducted while the samples were obtained.
- Submission of samples to a NATA accredited laboratory for analysis for:
  - major anions (chloride, sulphate, carbonate and bicarbonate);
  - major cations (sodium, calcium, magnesium and potassium);
  - heavy metals (arsenic, cadmium, chromium (total, Cr III and Cr VI), copper, lead, manganese, nickel, zinc, iron, mercury, silver);
  - sulphide;
  - total dissolved solids (TDS);
  - total suspended solids (TSS); and
  - oil and grease.
- Interpretation of the analytical results in reference to relevant criteria including the *Australian Drinking Water Guidelines* (ANZECC/ARMCANZ 2011) and the *Australian and New Zealand Guidelines for Fresh and Marine Water Quality* (ANZECC 2000).
- Preparation of this report.

1.4 Report Format

Section 2 of this report provides a brief description of the site, history of the North Mine, and a brief overview of the local geology and hydrogeology.

Section 3 identifies the contaminants of concern and the applicable assessment criteria.

Section 4 presents an overview of the work undertaken during the assessment, including a description of the down-shaft camera and geophysical surveys, groundwater sampling methodology and sample handling procedures. An overview of the scope of works carried out, including a timetable of site activities, is also included in this section.

Section 5 presents the results of the geophysical survey and analytical works carried out by the environmental laboratory.

Section 6 provides an overview of reuse and treatment options for the water within the workings including oxidation, filtration and desalination processes. Given the concentrations evident within the water in the North Mine it is anticipated that the use of several of these options may be required to reduce concentrations to suitable levels for reuse options to be explored.

Section 7 presents the conclusions and recommendations of the investigation.

In addition to the information presented and discussed within the text, factual and supporting data used during the investigation are included in a series of appendices at the end of the report.

A copy of the Borehole Summary Worksheet for registered borehole GW021882 – which is discussed in Section 2 of this report – is presented in Appendix A. Information presented on the log includes the depth of the bore, geological formations encountered during drilling and general information relating to the quality of groundwater in the vicinity of the bore.

Appendix B of this report presents an overview of groundwater quality information for several boreholes drilled in the southern lease areas around Broken Hill. Analytical results provide an insight into the quality of groundwater occurrences in this area and, given that these boreholes were drilled as part of mineral exploration and mineral resource assessments along the Broken Hill Line of Lode, are considered to provide information regarding the quality of groundwater occurrences for similar workings in the area, including the North Mine.

Appendix C presents an extract of a technical review regarding Hydrasleeve™ discrete groundwater sampling bladders. The extract has been taken from a review of groundwater sampling methods and technologies carried out by the United States Army Corps of Engineers which details the use, benefits and limitations of the bladders compared with other groundwater sampling methodologies. The article also provides a description of how the bladders function – particularly given their relatively simplistic design – and their reliability in controlled environments, particularly when dealing with volatile and oxidation-reduction (redox) sensitive analytical suites.

Appendix D of this report includes copies of the chain-of-custody and sample-receipt-advice documentation for the samples submitted for laboratory analysis.

A copy of the certificate of analysis forwarded by the analytical laboratory is provided in Appendix E.

Appendix F provides copies of the quality assurance (QA) and quality control (QC) information, including the details and results of laboratory control samples including surrogate, matrix spikes and method blank samples. A discussion regarding the analytical methods, QA/QC outliers such as

holding time non-compliances, quality control frequencies and sample preservation issues – and internal performance of the laboratory is also provided on the certificates.

Appendix G presents copies of relevant water quality trigger values for a range of water uses in Australia including drinking water, surface water and irrigation water. Trigger values include the Health Guidelines listed in the *Australian Drinking Water Guidelines* (2011), and trigger values set for the protection of 95% of species in fresh water, and short- and long-term trigger values for heavy metals and metalloids in irrigation water listed in Tables 3.4.1 and 4.2.10 respectively as listed in the *Australian and New Zealand Guidelines for Fresh and Marine Water Quality* (2000). These tables have been included in this report in order to provide Perilya with a reference point for future water disposal investigations and also to present the current guideline values that would need to be met if such avenues are explored.

Copies of the logs produced during the geophysical logging of the West Cage shaft are provided with this report. The logs visually display the resistivity and temperature of the water column in the No. 3 Shaft measured during each of the geophysical runs, with differential temperature also shown. The logs were produced by the NSW Office of Water (NOW) on completion of the fieldwork and have been presented in full with this report.

1.5 Limitations and Intellectual Property Matters

This report has been prepared by C. M. Jewell & Associates Pty Limited for the use of the client identified in Section 1.1, for the specific purpose described in that section. The project objectives and scope of work outlined in Sections 1.2 and 1.3 were developed for that purpose, taking into consideration any client requirements and budgetary constraints set out in the proposal referenced in Sections 1.1.

The work has been carried out, and this report prepared, utilising the standards of skill and care normally expected of professional scientists practising in the fields of hydrogeology and contaminated land management in Australia. The level of confidence of the conclusions reached is governed, as in all such work, by the scope of the investigation carried out and by the availability and quality of existing data. Where limitations or uncertainties in conclusions are known, they are identified in this report. However, no liability can be accepted for failure to identify conditions or issues which arise in the future and which could not reasonably have been assessed or predicted using the adopted scope of investigation and the data derived from that investigation. An information sheet – 'Important Information about your Environmental Site Assessment' – is provided with this report. The report should be read in conjunction with that information sheet.

Where data collected by others have been used to support the conclusions of this report, those data have been subjected to reasonable scrutiny but have essentially, and necessarily, been used in good faith. Liability cannot be accepted for errors in data collected by others.

This report, the original data contained in the report, and its findings and conclusions remain the intellectual property of C. M. Jewell & Associates Pty Ltd. A licence to use the report for the specific purpose identified in Section 1.1 is granted to the persons identified in that section on the condition of receipt of full payment for the services involved in the preparation of the report.

This report should not be used by other persons or for other purposes than those identified in Section 1.1, and should not be reproduced except in full and with the permission of C. M. Jewell & Associates Pty Ltd.

2.0 BACKGROUND

2.1 Location

The North Mine is located on the Barrier Highway on the north-eastern outskirts of the township of Broken Hill; its location is shown on Figure 1.

Mining operations at the North Mine have historically been carried out from a vast complex of underground stopes and drives which were accessed by three shafts – namely the No. 1, No. 2 and No. 3 Shafts – and an open-cut pit towards the southern end of the former lease.

2.2 Perilya's Broken Hill Operations

Mining in the Broken Hill area, under Perilya's management, commenced in July 2002. Mining is principally carried out using a longhole open stope method, with variations developed for extraction of the secondary resource located in the previously worked pillars area. Longhole stoping accounts for about 70% of underground production, with pillar extraction and development ore contributing to 30% respectively of the total.

The Broken Hill operation produces two premium coarse-grained products: a zinc concentrate and a lead concentrate, which contain a grade of about 50% zinc and 70% lead, respectively. Both concentrates are railed to Port Pirie in South Australia where, in general, the lead concentrate is smelted and the zinc concentrate is exported.

Between 2002 and 2010, Perilya mined over 15 million tonnes of ore and exported over 800,000 tonnes of zinc and 450,000 tonnes of lead.

Perilya currently owns both the North Mine and South Mine. Production at the North Mine ceased in August 2008, but a pre-feasibility study into the viability of mining the lower levels has commenced in order to ascertain the viability of re-opening the North Mine (upper and deep lodes).

The Southern operation's underground workings are accessed through three shafts and a decline. The shafts include the Main Haulage shaft, the Main Service Shaft and the Southern Cross Shaft. At its current deepest point, the mine reaches about 1200 metres below the surface, and there are more than 90 kilometres of accessible drives.

2.3 History of the North Mine

The North Mine was born in mining lease Block 17, which was pegged out by Julius Nickel and James Anderson on 22 December 1883. In 1885, the lease was acquired for £15,000 by a Melbourne syndicate, which formed the Broken Hill North Silver Co. Limited; however, the company quickly fell on difficult times and a new company was registered to work the lease in 1888. This company also fell on difficult times owing to falling global base metal prices, and eventually went into voluntary liquidation in the mid 1890s. It was later sold for £1750.

Throughout the 1890s turbulent economic times meant that shareholders in the venture did not see a dividend until 1899, and in 1901 operations ceased owing to a downturn in the economic cycle.

In 1904 the increase in global base metals prices saw the mine open again. Later that year the company acquired the Victorian Cross lease – located immediately to the north of Block 17 – which was found to contain a much larger and richer ore deposit than the original lease. In the following decades, the mine purchased numerous other mining leases, including the British (1923), the Junction (1929), Junction North (1931) and Block 14 (1942) leases, all of which proved to be fruitful to varying degrees; with the exception of Junction North, these blocks were transferred to the ailing Broken Hill South Company in 1962, and subsequently to Mineral, Mining and Metallurgy in 1972.

As mining operations moved northwards and away from conventional open-cut mining methods, new access shafts and infrastructure were required to chase the plunging lode. The No. 1 Shaft was excavated in 1905, quickly followed by the No. 2 Shaft in 1928. During the early 1940s it was clear that the lode was plunging further away from No. 2 Shaft, and it was decided that a third shaft was needed further north along the strike in order to chase out the ever-plunging lode. The No. 3 Shaft – which is elliptical in shape compared to its circular predecessors – was completed in 1947, and by 1962 had reached a depth of 1300 metres. Between 1966 and 1972 it was deepened and eventually reached 1580 metres.

In 1975, the Fitzpatrick Lode – consisting of an estimated 2 million tonnes of high-grade lead, silver and zinc ore was discovered further down-plunge of the No. 3 Shaft. Owing to its depth and its distance from the older workings an internal shaft was constructed at the lower levels of the No. 3 Shaft reaching from the 32 level to the 36 level. In 1989, work began on an extension of the internal shaft to the 40 level, and by this time a new company, Pasminco, had been formed to merge the lead and zinc interests of North Broken Hill Peko Limited and CRA, then the operator of the South Mine.

With the formation of Pasminco, the northern and southern Broken Hill mining activities were managed and operated as one entity. This however was a relatively short-lived venture with operations at the North Mine ceasing in February 1993.

This history of the North Mine between 1993 and 2002 remains unclear, although it is understood that Perilya purchased the North Mine in 2002 when is was still operating. Perilya's operations at the North Mine ceased in August 2008.

The North Mine has produced over 32 million tonnes of ore from its underground workings and nearly 2.5 million tonnes from its open pit operations, and there are plans to extend the life of the mine through the Fitzpatrick Lode (as discussed within this report).

2.4 Geological Setting

The geology of the Broken Hill area has been intensively studied, perhaps more so than that of any other comparably-sized area in Australia. This work has revealed stratigraphy, structure and mineralisation of great complexity. Although a detailed description of these features is clearly beyond the scope of the report, a summary is deemed appropriate in order to provide an understanding of the geochemistry of the water within the North Mine. The following paragraphs have been distilled from a number of sources, including Cooper (1975), Stevens and Stroud (1983), Burton (1994), Barnes (1988) and Stevens et al. (2003).

The metamorphic rocks underlying Broken Hill and the immediately surrounding area form part of the Willyama Supergroup, which is of Proterozoic age. Radiometric dating indicates depositional ages ranging from 1700 to 1640 million years (Ma) for these rocks. Around Broken Hill, and in the ranges to the north and west, the Willyama Supergroup crops out at the surface. In the eastern and southern part of the extended area, and to the east of the Broken Hill block, the Proterozoic rocks are blanketed by sediments of much younger (Cainozoic) age.

The generalised stratigraphic sequence for the Willyama Supergroup is shown on Figure 2. The Supergroup is composed of medium to high-grade metamorphic rocks – originally volcanic, volcaniclastic and sedimentary deposits, now transformed to pelite, psammite, gneiss and migmatite. The rocks have all been deeply buried, and subjected to high temperatures and pressures; kyanite and staurolite mineral assemblages suggest that the rocks were subjected to pressures up to 4 kilobars (kb) – equivalent to a burial depth between 12 and 20 kilometres – and heated to temperatures of about 700 degrees Celsius (°C). The highest-grade rocks, the migmatites, have been completely melted, and the

others have undergone recrystallisation that has radically changed their mineralogy and internal structure, and resulted in the complete elimination of their original pore-space.

Structurally, the rocks in the area are part of the Broken Hill Block, one of the main structural/ stratigraphic units of the area. The rocks have been heavily deformed by multiple phases of folding, and are also faulted. Two main groups (Group 1 folds, which have deformed the lithologic layering and generated the regional schistosity. and Group 2 folds, which have deformed the regional schistosity) and two minor groups of folds have been mapped.

The Proterozoic rocks in the Broken Hill area have been intensively mineralised. The Broken Hill main lode, which extends for more than 7 kilometres along a north-east strike, alone contained more than 280 million tonnes (Mt) of lead–zinc–silver mineralisation prior to the commencement of mining; it is also thought that some 80 to 90 Mt of ore rock has also been removed predominantly in solution from the lode during the last 65 million years. There are also many lesser lodes in the area.

The primary ores are massive and disseminated sulphides – principally galena and sphalerite – hosted in garnet–quartz rocks. There was an extensive gossan (oxidised) zone above the sulphide ore. Whilst several theories for ore genesis have been proposed, the currently favoured explanation is that the ores were precipitated onto the sea-floor from brines expelled from the upper mantle. Figure 3 shows the geology and mineralisation of the Broken Hill area in greater detail.

2.5 Overview of Ore Body Geology and Geochemistry

The Broken Hill mine is situated in high-grade metamorphic rocks of the Early Proterozoic Willyama Supergroup in the Broken Hill Block of western New South Wales.

The Broken Hill Lode consists of six or more distinct lode horizons, and is globally significant due to its high metal content – albeit with the significant absence of high gold and/or copper grades. It is generally strata-bound, and exhibits intense structural modification along shears and complex ore geometries, although it is markedly different from other sediment-hosted exhalative deposits owing to the lack of abundant pyrite (FeS_2), pyrrhotite (FeS) barite ($BaSO_4$) and other sulphates.

The Broken Hill Lode is also significantly different from other lead, silver and zinc deposits in that its mineralogy is typically 'sulphur poor'. Its mineralogy is dominated by ferroan sphalerite and gahnite, plumbian orthoclase (a lead-enriched feldspar), sulphur-poor antimonides, native metals and rare base metal-bearing silicates and oxides; its high manganese, calcium, halide (especially fluoride and bromide), phosphorus and uranium content are also striking features which make it one of the most diverse mineral deposits in the world.

Mineralisation in the Broken Hill Lode consists of a series of parallel silver-lead rich and zinc-lead rich lenses that have been deformed and structurally complicated resulting in zones of localised sulphide enrichment. Economic mineralisation predominantly consists of galena (lead sulphate) and iron-rich sphalerite (iron zinc sulphide), whilst other common ore minerals include pyrrhotite (an iron sulphide), chalcopyrite (copper iron sulphide), arsenopyrite (iron arsenide sulphide), loellingite (silver chloride) and cerrusite (lead carbonate); gangue mineralogy (i.e. the 'waste' materials left over after removing the minerals of interest from the ore) includes quartz, feldspar, gahnite, garnet calcite, fluorite and a variety of manganese silicates including spessartine and tephroite.

Economic mineralisation is typically distinguished by the presence of quartz-gahnite, quartz-garnet schists and gneisses, blue quartz and plumbian orthoclase which form common ore-identifying marker units throughout the area. The orebodies are hosted within pelitic-psammitic metasediments, basic gneiss, quartz-spessartine (a quartz and manganese-rich garnet rock commonly referred to as garnet sandstone), quartz-gahnite (a quartz and zinc aluminium oxide rock rock), and 'Potosi-type' gneiss a

quartz-feldspar, biotite-garnet gneiss that dominates the host lithology at the Potosi open-pit mine just to the north-east of the North Mine. These rocks are termed lode horizon rocks.

Mineralisation primarily occurs in small discontinuous lenses or as weak disseminations in the lode rock. In total there are six known lenses that have undergone multiphase coeval deformation and high-grade metamorphism which has resulted in structurally complicated zones of sulphide enrichment and complex mineral assemblages. In many places, the lode rocks are complexly folded in sympathy with the country rocks, with the ore lenses themselves showing substantial thickening at fold hinges and closures. Due to remobilisation during ductile deformation, tonnage and grade is significantly higher in the hinges of folds and during brittle deformation, particularly where high grade Lead Lode has been transposed into shear zones.

2.6 Overview of Groundwater Quality of the Willyama Supergroup

Borehole summary worksheets held by NOW report water quality in boreholes extracting from the Willyama rocks and regolith as generally 'good', occasionally 'brackish'. The water quality suffices for stock watering.

Samples from Borehole GW021882 (of which a full analytical summary is provided in Table 1) had total dissolved solids content ranging from 3700 to 3900 milligrams per litre (mg/L), with sulphate of about 650 mg/L and chloride of about 1500 mg/L. This bore is located at Farmcote Station, about 10 kilometres south-west of the centre of Broken Hill, and was drilled to a depth of 67.1 metres.

A copy of the Borehole Summary Worksheet is provided in Appendix A.

TABLE 1
Groundwater Chemistry – Bore GW021882
All concentrations in mg/L[α] (ppm[β])

Date	pH[ɣ]	Major Cations				Major Anions				TDS[η]	NO_3[φ]	Fe	SiO_2[ς]
		Ca	Mg	Na	K	CO_3[δ]	HCO_3[ε]	SO_4[ϕ]	Cl				
17 Mar 1978	7.8	160	158	920	17	0	384	605	1446	3690	14	2	21
18 Jun 1979	7.2	188	160	954	18	0	409	648	1514	3891	14	2	19
19 Sep 1979	7.6	176	155	963	17	0	391	663	1540	3905	16	3	20

Notes:
α milligrams per litre
β parts per million
ɣ reported in pH units
δ carbonate; reported as milligrams per litre of calcium carbonate
ε bicarbonate; reported as milligrams per litre of calcium carbonate
ϕ sulphate
η total dissolved solids
φ nitrate
ς silica

A program of groundwater sampling carried out from exploration boreholes in the southern leases indicated total dissolved solids generally in the range 8000 to 10,000 mg/L, with sulphate typically 1500 to 2800 mg/L and chloride 2500 to 5000 mg/L.

Heavy metal concentrations in groundwater derived from the lode horizons are elevated. The data indicate that cadmium, manganese, lead and zinc, as well as iron, are present at significant concentrations with cadmium concentrations exceeding those considered suitable for stock use.

A summary of the groundwater quality data for the southern leases is presented in Appendix B.

3.0 DISSOLVED COMPONENTS OF INTEREST AND APPLICABLE CRITERIA

3.1 Contaminants of Concern

To assess the water quality, the following suite of analytes were selected:

- major anions (chloride, sulphate, carbonate and bicarbonate)
- major cations (sodium, calcium, magnesium and potassium)
- heavy metals (arsenic, cadmium, chromium (total, Cr III and Cr VI), copper, lead, manganese, nickel, zinc, iron, mercury, silver)
- sulphide
- total dissolved solids (TDS)
- total suspended solids (TSS)
- oil and grease

3.2 Assessment Criteria

In order to provide a human health and environmental context to the measured dissolved-phase concentrations, the analytical results have been assessed against relevant criteria.

For the assessment of potential human health issues relating to the consumption of untreated water from the North Mine, it is considered that the appropriate criteria are those presented within the Health Guidelines listed in the *Australian Drinking Water Guidelines* (2011), jointly prepared by the National Health and Medical Research Council (NHMRC) in collaboration with the Natural Resource Management Ministerial Council (NRMMC). These levels relate specifically to water that is to be used for human consumption, and although they do not represent mandatory standards for the quality of water for human consumption, they do offer a framework for identifying acceptable water quality.

For the assessment of potential environmental impacts arising from the interaction of untreated water from the North Mine with freshwater aquatic ecosystems (such as the Imperial Lake), it is considered that the appropriate criteria are those trigger values set for the protection of 95 per cent of species in fresh water and listed in Table 3.4.1 of ANZECC's *Australian and New Zealand Guidelines for Fresh and Marine Water Quality* (2000).

Trigger values included in Table 2 are the values applying to slightly–moderately disturbed systems, and have been derived for use in assessing surface waters. In the absence of specific levels for groundwater, the surface-water trigger values have been used.

For the assessment of issues relating to the use of the water for irrigation purposes, it is considered that the appropriate criteria are those values presented in Table 4.2.10 of ANZECC's *Australian and New Zealand Guidelines for Fresh and Marine Water Quality* (2000). The values presented in this table represent long-term (up to 100 years) and short-term (up to 20 years) trigger values for heavy metals and metalloids in irrigations water; the soil cumulative contaminant loading limit (identified as the CCL) triggers for heavy metals and metalloids are also presented in this table.

The relevant criteria for both human health and environmental concerns are presented in Table 2. Additionally, the criteria adopted for this investigation are indicated.

TABLE 2
Criteria for Groundwater Quality Assessment
(mg/L)

Analyte	*Australian Drinking Water Guidelines* (2011)[#]		*ANZECC* (2000) Table 3.4.1: Trigger Values for the Protection of 95% of Species in Freshwater	*ANZECC* (2000) Table 4.2.10: Agricultural irrigation LTV, STV and CCL triggers for heavy metals and metalloids			Adopted Criteria
	Aesthetic	Health		CCL (kg/ha)[a]	LTV[b]	STV[c]	
pH	6.5 – 8.5	-	6.5 – 7.5	-	-	-	6.5 – 7.5
TDS	500	-	-	-	-	-	500
Sodium	180	-	-	-	-	-	180
Chloride	250	-	-	-	-	-	250
Sulphate	250	500	-	-	-	-	500
Arsenic (total)	-	0.007	-	20	0.1	2.0	0.007
Arsenic (As III)	-	-	0.024	-	-	-	0.024
Arsenic (As V)	-	-	0.013	-	-	-	0.013
Cadmium	-	0.002	0.0002	2	0.01	0.05	0.0002
Chromium (total)				-	0.1	1	0.1
Chromium (Cr VI)	-	0.05	0.001^	-	-	-	0.001
Copper	1	2	0.0014	140	0.2	5	0.0014
Iron	0.3	-	-	-	0.2	10	0.3
Lead	-	0.01	0.0034	260	2	5	0.0034
Manganese	0.1	0.5	1.9	-	0.2	10	0.1
Mercury	-	0.001	0.0006*	2	0.002	0.002	0.0006
Nickel	-	0.02	0.011	85	0.2	2	0.011
Silver	-	0.1	0.00005	-	-	-	0.00005
Zinc	3	-	0.008	300	2	5	0.008

Notes:
[#] NHMRC 2011
^ Figures may not protect key species from chronic toxicity
* Inorganic form of mercury
- No criteria currently available
a Suggested soil cumulative contaminant level (CCL) (kg/ha)
b Long-term trigger values (LTV) in irrigation water (long-term use – up to 100 years (mg/L)
c Short-term trigger values (STV) in irrigation water (long-term use – up to 20 years (mg/L)

4.0 FIELDWORK

4.1 Overview of Scope of Works

Table 3 provides an overview of the work completed under the conditions of the contract.

Note: The base of the concrete slab in the floor of the carriage was used as the reference point for depth, consistent with CMJA's investigation in 2006.

TABLE 3
Overview and Timetable of Fieldwork

Date	Event	Comments
15 November 2011	Camera survey of West Cage	The camera run terminated at 1176.3 metres depth due to an obstruction in the cage shaft; blockage appeared to be corrugated iron mesh, which is likely to have dislodged from the wall of the shaft. The water table was encountered at 724.4 metres depth. The obstruction previously identified at 302.5 metres depth was identified, however, it did not halt the camera. Other previously identified obstructions at 666.1 and 669.5 metres depth were no longer evident.
	Geophysical logging of West Cage	Fluid resistivity and temperature profile of the water column was conducted. Logging was terminated at 1176.3 metres depth (due to the obstruction in the shaft) and was rerun when the instruments were withdrawn from the shaft.
	Groundwater sampling of West Cage	A groundwater sampling run of West Cage was conducted. Groundwater samples were collected from the top (at about 780 metres depth), from the middle (about 970 metres depth), and at the base of the accessible water column (1160 metres depth).
	Transport groundwater samples to South Mine for overnight storage	The groundwater samples were transported to the South Mine office, where they were stored and refrigerated overnight.
16 November 2011	pH measurement of groundwater samples.	The pH of each groundwater sample was measured using a calibrated TPS FLMV90 multi-parameter meter.
	Forwarded groundwater samples to NATA accredited laboratory for analysis	Samples were checked and repacked within an insulated ice chest before being dispatched to a NATA accredited laboratory by courier; samples arrived and were processed on 17 November 2011.

4.2 Camera Surveys of the No. 3 Shaft

A camera survey of the No.3 Shaft (West Cage) was conducted on 15 November 2011 by Mr Johnny Woods of NSW Office of Water (NOW).

The camera used during the survey was specially designed for use within 100 to 200 millimetre diameter boreholes and groundwater wells, and had a pressure rating of up to 1500 metres head of water. Given the camera's intended function, it only provided down-hole camera views in real time and could not swivel or view particular sections of interest.

The camera survey of the West Cage began at 9:30am on 15 November 2011. The camera was lowered into the shaft at a rate of about 22 metres per minute, although the rate slowed significantly when the water table was intercepted. The base of the concrete slab in the floor of the carriage was used as the reference point for depth.

Note: It was evident that water was entering the shaft at various levels between the reference point (surface) and the water table, as water droplets were observed falling down the shaft.

The obstruction identified in 2006 at 302.5 metres depth was visible (either a girder of piece of corrugated iron), however, it did not halt the survey. Other previously identified obstructions at 666.1 and 669.5 metres depth were no longer visible.

The water table was intercepted at approximately 724.4 metres depth. Based on this water level measurement and the water level measurement reported in 2006, the elevation of the water table appears to have increased by 167 metres.

Note: Once the camera entered the water, image resolution declined significantly, possibly owing to the amount of suspended solids in the water.

The survey of the shaft proceeded unhindered until a blockage was encountered at 1176.3 metres depth. The blockage appeared to be a piece of corrugated iron mesh that had been dislodged from the wall of the shaft. Unfortunately, the blockage was sufficient to halt the survey, and the camera was subsequently withdrawn from the shaft.

4.3 Geophysical Profiling of the No.3 Shaft

Geophysical logging of the No. 3 Shaft was carried out by NOW under the supervision of CMJA. Similar to the camera survey, access to the shaft was gained through the floor of the West Cage carriage, with the logging runs consisting of two combined fluid temperature and resistivity profiles.

Note: The temperature tool is rated to 70° Celsius and the Resistivity tool to 200 ohm metres.

The first run was carried out at 11:15am on 15 November 2011. The instruments were lowered into the water column at approximately 8 metres per minute, and the run was terminated at 1177.55 metres depth (i.e. about 453 metres below the water table).

A change is water chemistry was evident at approximately 758 metres depth, where it is believed that fresh water (as seen entering the shaft) intercepted more saline groundwater.

Once the results of the run had been reviewed, a second geophysical run was carried out when the instruments were being withdrawn from the water column, in order to confirm the results of the first survey.

Note: An additional geophysical run was conducted while the samples were being collected.

During each run, the following measurements were recorded:

- Fluid resistivity (recorded in units of ohm-metres),
- Induction conductivity (recorded as millisiemens per metre – mS/m),
- Temperature (recorded as °C),
- Differential temperature (recorded as temperature change in °C), and
- Depth (recorded as metres).

Information was continually displayed on a floating chart, and was recorded at the end of each run. Graphical logs for each geophysical run are presented on the logs accompanying this report.

4.4 Sample Collection and Handling

Groundwater sampling began at 2:15pm on 15 November 2011. The sampling was carried out by attaching HydraSleeve™ sample bladders at selected intervals to the wireline cable of the logging truck and then lowering the bladders into the shaft. The sample locations were selected based on:

- the geophysical profile of the water column;
- the water table elevation; and
- the (accessible) depth of the shaft.

Bladders were attached to the cable at both the top and the bottom of each bladder using polyethylene cable ties, and further held in place by duct tape. The bladders were placed at intervals that would correspond to the top, middle and bottom of the accessible water column (i.e. depths of about 780, 970 and 1160 metres depth RL). In total, nine sample bladders were used – three for each of the three sample locations.

The sample bladders were attached to the cable at the appropriate locations as the cable was gradually lowered to 1176.3 metres depth, where the bladders were allowed to equilibrate with the respective water pressures. When sufficient time had elapsed, the wireline was withdrawn from the shaft and the samples collected from the water column; it is the upward motion during the withdrawing of the wireline cable that opens the bladder and allows the sample to be collected.

When the bladders emerged from the shaft, they were punctured with the sample straw supplied with each bladder.

Note: A separate sample straw was used for each sample location.

Samples were then placed directly into the appropriate laboratory-supplied pre-treated containers and then within an insulated cool box; samples for heavy metals were filtered through a 0.45 micrometre membrane prior to being placed within the appropriate (unpreserved due to transport requirements) sample bottle.

Disposable gloves were used for sample collection and handling, with a new pair used for each sample.

Sample preservation and containers are described below in Table 4; further information regarding the Hydrasleeve™ bladders and their use in the environmental industry is provided in Appendix C.

TABLE 4
Sample Preservation

Bottle Type[π]	Preservative	Field Filtered	Analyte					
			TSS[γ], TDS[π]	Anions[α]	Cations[β]	Sulphide	Metals[ψ] - Dissolve	Oil and Grease
1-litre polyethylene	Nil	No	✓	✓	✓			
250-ml[ϖ] polyethylene	$Zn(O_2CCH_3)_2$[φ] + NaOH[ε]	No				✓		
125-ml polyethylene	Nil[ϕ]	Yes[κ]					✓	
1-litre glass bottle	H_2SO_4	No						✓

Notes:
- π supplied and pre-treated by the laboratory
- γ total suspended solids
- π total dissolved solids
- α chloride, sulphate, carbonate and bicarbonate
- β calcium, magnesium, sodium and potassium
- ψ arsenic, cadmium, chromium (total), trivalent chromium, hexavalent chromium, copper, iron, lead, manganese, mercury, nickel and silver
- φ zinc acetate
- ε sodium hydroxide (added to sample bottles on site by CMJA)
- ϕ nitric acid was not permitted to be transported by the airline, and was required to be added when the laboratory received the samples.
- κ sample filtered through a 0.45 micron membrane

All samples were immediately placed into an insulated cool-box and transported to the South Mine office for overnight storage within a refrigerated unit. The samples were cushioned using bubble-wrap.

The following morning, the samples were re-packed in insulated cool-box, which was filled with ice to maintain the temperature at less than or equal to 4°C. The lid of the cool-box was then taped shut and a security seal placed over the lid and side.

A courier then transported the samples directly to the Australian Laboratory Services Pty Ltd (ALS) at Smithfield; chain-of-custody records were maintained throughout sampling and transportation. ALS is certified by NATA to undertake analysis of the selected analytes.

Samples were dispatched from Broken Hill on 16 November 2011 and arrived at the laboratory on 17 November 2011. Nominated employees from the laboratory documented confirmation of sample arrival and condition on the supplied chain-of-custody (COC) form. Copies of the completed COC forms and sample-receipt-advice returns are provided in Appendix D.

The water temperature and induction conductivity were measured during geophysical profiling of the West Cage. The pH of each water sample was measured at 8:30am on 16 November 2011, using a calibrated TPS FLMV90 multi-parameter probe.

4.5 QA and QC Procedures

During the collection of the groundwater samples, all work was conducted in accordance with industry-accepted standards and in accordance with CMJA's standard operating and quality assurance procedures. Field QC during the investigation consisted of the following:

- preparation of a sampling and analysis plan designed to meet the project objectives and data quality objectives;
- sample collection procedures appropriate to the analytes of concern;

- the appropriate storage of samples during collection and transportation;
- extraction and analysis of all samples within the relevant method holding times; and
- the selection of appropriate sampling methods and data quantitation limits to satisfy the project data quality objectives.

No equipment wash blank samples were collected or submitted for laboratory analysis, given that a new sample bladder was used for each sample; a duplicate sample was not collected due to the limited number of sample bladders available.

5.0 RESULTS

5.1 Geophysical Profiling

The geophysical works carried out during the investigation identified that the upper 34 metres of the water column composed of slightly fresher water (fluid resistivity measurements at about 0.30 ohm/m, while induction conductivity measurements were below 800 mS/m).

The remainder of the water column (i.e. from 758 to 1177 metres depth) was more saline, well mixed and uniform with little to no signs of any stratification of water quality differentiation with depth. Overall:

- Fluid resistivity measurements were consistent throughout the profile, slightly fluctuating between -0.18 and -0.20 ohm/m.
- Induction conductivity measurements were typically between 1200 and 1300 mS/m.
- The temperature of the water was approximately 29°C.

Within an open shaft a reasonable inverse qualitative relationship between fluid resistivity and induction conductivity would be expected, and this was found to be the case.

The original copies of the geophysical logs produced by NOW accompany this report.

5.2 Analytical Results

Results of the groundwater samples collected from the West Cage of the No. 3 Shaft are presented in Table 5; whilst copies of original laboratory reports are provided in Appendix E.

TABLE 5
Field Parameters and Analytical Results
West Cage, No. 3 Shaft, North Mine

Analyte	Units	LOR	Adopted Criteria	WC: 780	WC: 970	WC: 1160
Physio-chemical Parameters						
pH	pH units	0.01	6.5 – 7.5	6.91	6.68	6.63
Electrical conductivity$^{\rho}$	µS/cm	0.1		≈ 12,972	≈ 12,833	≈ 12,698
Temperature	°C	0.1		28.9	28.9	28.9
TDS and TSS						
Total Dissolved Solids	mg/L	5	500	**6470**	**8200**	**8610**
Total Suspended Solids	mg/L	5		98	32	33
Major Anions and Cations						
Bicarbonate Alkalinity as $CaCO^3$	mg/L	1		76	67	67
Carbonate Alkalinity as $CaCO^3$	mg/L	1		<1	<1	<1
Hydroxide Alkalinity as $CaCO^3$	mg/L	1		<1	<1	<1
Total Alkalinity as $CaCO^3$	mg/L	1		76	67	67
Sulfate as SO^4	mg/L	1	500	**2140**	**2620**	**2560**
Chloride	mg/L	1	250	**1660**	**2220**	**2780**
Calcium	mg/L	1		518	682	728
Magnesium	mg/L	1		168	214	238
Potassium	mg/L	1		48	62	67
Sodium	mg/L	1	180	**1390**	**1690**	**1870**
Heavy Metals						
Arsenic	mg/L	0.001	0.007	**0.073**	**0.099**	**0.098**
Cadmium	mg/L	0.0001	0.0002	**0.0101**	**0.0092**	**0.0101**
Chromium	mg/L	0.001	0.1	<0.001	<0.001	<0.001
Copper	mg/L	0.001	0.0014	**0.005**	**0.006**	**0.006**
Iron	mg/L	0.05	0.3	**23.8**	**29.7**	**29**
Lead	mg/L	0.001	0.0034	**0.082**	**0.167**	**0.198**
Manganese	mg/L	0.001	0.5	**107**	**112**	**112**
Nickel	mg/L	0.001	0.011	**0.151**	**0.171**	**0.171**
Silver	mg/L	0.001	0.00005	<0.001	<0.001	<0.001
Zinc	mg/L	0.005	0.008	**35.7**	**38.8**	**39**
Mercury	mg/L	0.0001	0.0006	<0.0001	<0.0001	<0.0001
Trivalent Chromium	mg/L	0.01		<0.01	<0.01	<0.01
Hexavalent Chromium	mg/L	0.01	0.001	<0.010	<0.010	<0.010
Sulfide						
Sulfide as S2-	mg/L	0.1		<0.1	<0.1	<0.1
Ionic Balance						
Total Anions	meq/L	0.01		92.9	118	133
Total Cations	meq/L	0.01		101	127	139
Ionic Balance	%	0.01		4.36	3.36	2.17
Oil and Grease						
Oil and Grease	mg/L	5		<5	<5	<5

Notes: LOR limit of reporting

$^{\rho}$ Determined from the fluid resistivity values measured during geophysical profiling and cross-checked against TDS concentrations for each of the samples collected during the project

µS/cm microsiemens per centimetre
mg/L milligrams per litre
meq/L milliequivalents per litre

From the results presented in Table 5, it can be seen that relative uniformity exists between each of the samples collected from the No. 3 Shaft, supporting the results of the geophysical profiling. The samples show that the water profile (between 780 and 1160 metres) is well mixed and not stratified.

Concentrations of manganese, iron and zinc were significantly above the adopted criteria for all samples submitted for analysis, reflecting the nature and occurrence of mineralisation in the area. Specifically:

- The difference in manganese concentrations between samples was negligible, ranging from 107 mg/L (WC:780) to 112 mg/L (WC:970 and WC:1160).
- The concentration of manganese is groundwater has increased since CMJA's previous investigation in 2006, where the maximum concentration reported was 68.1 mg/L at 890 metres depth.
- The difference in iron concentrations between samples was negligible, ranging from 23.8 mg/L (WC:780) to 29.7 mg/L (WC:970).
- Iron concentrations have slightly decreased since 2006 (minimum concentration of 30.6 mg/L at 890 metres depth). and there no longer appears to be a relationship between iron concentration and depth.
- The concentrations of zinc slightly increased with depth, ranging from 35.7 mg/L (WC:780) to 39 mg/L (WC:1160).
- Zinc concentrations have significantly increased since 2006 (maximum concentration of 12.2 mg/L at 1030 metres depth).

The high concentration of manganese in each of the samples is thought to reflect the abundance of manganese-rich rocks and minerals associated with ore lenses of the Broken Hill Lode.

As mentioned in Section 2.5 of this report, mineralisation at Broken Hill is hosted within a wide range of rock types including quartz-garnet gneisses and schists and quartz-spessartine rock – a quartz and manganese rich garnet rock which is commonly referred to as garnet sandstone, whilst rhodonite – a manganese silicate mineral – is common gangue mineral associated with economic ore horizons. Similarly, the high concentrations of iron in the samples are not considered to be surprising, given the abundance of available iron in a wide variety of minerals evident in the Broken Hill Lode; such minerals include pyrite (FeS_2), sphalerite (Fe, ZnS) – which is particularly iron-rich in the Broken Hill area, pyrrhotite (an iron sulphide), chalcopyrite ($CuFeS_2$) and arsenopyrite (FeAsS).

The high concentrations of iron in all samples analysed are consistent with the correspondingly high concentrations of manganese. Geochemically, both of these metals behave in relatively similar ways in groundwater systems and are soluble over quite a large range of pH and redox values.

The high concentrations of zinc in each of the samples is thought to reflect the high zinc grades and accompanying presence of sphalerite amongst the Broken Hill Lode; it is understood that sphalerite was never a key mineral of ore production at the North Mine, with the emphasis of mine operations placed on chasing out the high-grade galena lenses of the lode.

Other heavy metals, i.e. arsenic, cadmium, copper, lead and nickel, were reported at concentrations above the adopted criteria. Although these results are not entirely comparable to the 2006 results (based on different sampling intervals), concentrations of arsenic appear to have slightly decreased, while concentrations of cadmium, copper, lead and nickel appear to have slightly increased.

Consistent with previous results, no concentrations of chromium (either the trivalent or hexavalent species), mercury, silver, sulphide or oil and grease were detected at concentrations greater than the limit of reporting for each sample.

The low resistivity of the water column observed during geophysical logging of the West Cage is reflected in the high concentration of TDS in each of the samples. As presented in Table 5:

- TDS concentrations increased with depth and ranged from 6470 mg/L (WC:780) to 8610 mg/L (WC:1160),
- Major anion and cation concentrations were typically of the order of 92.9 to 139 milliequivalents per litre (meq/L).
- Sodium is considered to be the dominant cation for all samples, with a maximum concentration of 1870 mg/L (WC:1160).
- Chloride and sulphate are considered to be the dominant anions for all samples, with maximum concentrations of 2780 mg/L (WC:1160) and 2620 mg/L (WC:970), respectively.
- Concentrations of bicarbonate, calcium, magnesium and potassium were relatively low.
- Concentrations of carbonate and hydroxide were below the limit of reporting and would not be expected at the measured pH.

The sulphate present is likely to be derived from the oxidation of abundant sulphide minerals associated with the lode and surrounding geology.

These concentrations correlate well with the measurements of fluid resistivity recorded during the geophysical profiling and are consistent with those results previously reported by CMJA. For comparative purposes, the dissolved solids content of seawater is about 35,000 mg/L.

A trilinear diagram showing the composition of the three samples obtained during this investigation is shown in Figure 4.

The pH of the groundwater indicates that it is slightly acidic to neutral. Given the abundance of sulphate throughout the water column and the oxidised nature of the groundwater (evident by the abundance of sulphate and lack of discernible sulphide), low pH conditions (acidic) were expected. However, the relatively neutral pH could be indicative of pH buffering by carbonate minerals or the continuing dilution of groundwater in the shaft by relatively fresh groundwater ingress.

6.0 GROUNDWATER USE AND DISPOSAL OPTIONS

Consideration of re-use potential was part of CMJA's original scope of works, and this section has been included for completeness. Water of almost any quality can be treated to make it suitable for almost any purpose – at a price. In normal circumstances, treatment of water of the quality encountered in the North Mine would be considered uneconomic.

However, circumstances at Broken Hill are not normal, so all options could at least be considered.

6.1 Overview of the Nature and Behaviour of Iron and Manganese

From the results presented in Section 4.2, it can be seen that the total salinity together with iron and manganese, and less notably zinc concentrations, are the largest issues when trying to ascertain suitable reuse or disposal options for the water from the North Mine. Characteristics of each of these metals are discussed below.

Iron occurs commonly in soil and rocks as the oxide, sulphide and carbonate minerals. In water, it is present as ferric (Fe^{3+}) [oxidised] or ferrous (Fe^{2-}) [reduced] ions or ion complexes. In aerated surface waters, iron is often complexed with organic matter such as humic material, or adsorbed onto suspended matter. In uncontaminated surface waters, dissolved iron concentrations are usually less than 1 mg/L, but, water supplied through rusting iron pipes can have concentrations of 5 mg/L or higher.

In oxygen-depleted ground water, iron concentrations of up to 100 mg/L have been recorded. Iron has a taste threshold of about 0.3 mg/L in water, and becomes objectionable above 3 mg/L. High iron concentrations give water an undesirable rust-brown appearance and can cause staining of laundry and plumbing fittings, fouling of ion-exchange softeners, and blockages in irrigation systems; growths of iron bacteria, which concentrate iron, may cause taste and odour problems and lead to pipe restrictions, blockages and corrosion.

Manganese is present in the environment in the divalent (Mn^{2-}), tetravalent (Mn^{4+}), and heptavalent (Mn^{7+}) states. Most of the divalent compounds are soluble in water; the most common tetravalent compound, manganese dioxide, is insoluble, but the heptavalent permanganate is soluble.

Zinc is widely distributed and occurs in small amounts in almost all rocks, commonly as the sulphide sphalerite. In surface and ground waters, the zinc concentrations from natural leaching is usually less than 0.01 mg/L, however tap water can contain much higher concentrations as a result of corrosion of zinc-coated pipes and fittings; concentrations in galvanised iron rainwater tanks are typically 2 mg/L to 4 mg/L but have been reported as high as 11 mg/L.

Taste problems can occur if the zinc concentration in drinking water exceeds 3 mg/L. Water with zinc concentrations in excess of 5 mg/L tends to be opalescent and develop a greasy film when boiled; it also has an undesirable dry metallic taste.

Uncontaminated rivers and streams generally have low concentrations of manganese, ranging from 0.001 mg/L to 0.6 mg/L. High concentrations may occur in polluted rivers or under anoxic conditions such as at the bottom of deep reservoirs or lakes, or in groundwater. At concentrations exceeding 0.1 mg/L manganese imparts an undesirable taste to water and stains plumbing fixtures and laundry, and at concentrations of 0.02 mg/L it will form a coating on pipes that can slough off as a black ooze; some nuisance microorganisms can also concentrate manganese and give rise to taste, odour and turbidity problems in distribution systems.

In general, oxygen-rich water will have only low levels of iron and manganese as both iron and manganese react with oxygen to form compounds which prefer to precipitate rather than stay in

dissolved state. Surface water and shallow groundwater usually have enough dissolved oxygen to maintain iron and manganese in an insoluble state, whilst in surface water iron and manganese are most likely to be trapped within suspended organic matter particles.

Waters that do not have contact with the atmosphere tend to be low in oxygen. Iron and manganese carbonates in an oxygen-poor environment are relatively soluble and can cause high levels of dissolved iron and manganese. However, if iron is associated with sulphur as iron sulphide rather than iron carbonate, dissolved iron remains low. Dissolved oxygen generally decreases with depth, so these types of conditions are more likely to occur in deep wells or the shafts evident along the alignment of the Broken Hill Lode where any available oxygen would be consumed by reactions with sulphides; sometimes oxygen-poor conditions can also occur in relatively shallow wells that have stagnant water with very slow turnover.

6.2 Untreated Reuse or Disposal of the North Mine Water

A brief assessment of whether the water in its current condition could be used is provided in the paragraphs below. The assessment looks at whether it is possible to dispose of the water to Stephens Creek Catchment as potable water, pump the water to Imperial Lake just to the north-east of the North Mine, and finally use the water for long and short-term irrigation purposes.

For the assessment of potential human health issues relating to the consumption of untreated water from the North Mine, it is considered that the appropriate criteria are those presented within the Health Guidelines listed in the *Australian Drinking Water Guidelines* (2011). These levels relate specifically to water that is to be used for human consumption, and although they do not represent mandatory standards for the quality of water for human consumption, they do offer a framework for identifying acceptable water quality.

For the assessment of potential environmental impacts arising from the interaction of untreated water from the North Mine with freshwater aquatic ecosystems (such as Imperial Lake), it is considered that the appropriate criteria are those trigger values set for the protection of 95 per cent of species in fresh water and listed in Table 3.4.1 of the *Australian and New Zealand Guidelines for Fresh and Marine Water Quality* (2000).

For the assessment of issues relating to the use of the water for irrigation purposes, it is considered that the appropriate criteria are those values presented in Table 4.2.10 of the *Australian and New Zealand Guidelines for Fresh and Marine Water Quality* (2000). The values presented in this table represent long-term (up to 100 years) and short-term (about 20 years) trigger values for heavy metals and metalloids in irrigation water; the soil cumulative contaminant loading limit (identified as the CCL) triggers for heavy metals and metalloids are also presented in this table.

Copies of the relevant criteria for both human health and environmental concerns are presented in Appendix G; values included are those values applying to slightly–moderately disturbed systems, and have been derived for use in assessing surface waters. In the absence of specific levels for groundwater, the surface-water trigger values have been used; no criteria are currently available for the parameters that are absent in Appendix G yet included in the analytical schedule used during the groundwater sampling and analysis program.

On the basis of the analytical results presented in Section 4.2 it is clear that the water in the North Mine will require some sort of treatment before any reuse options can realistically be considered. It can be clearly seen that concentrations of all of the heavy metals included in the analytical suites, particularly manganese, iron and zinc, exceed their relevant threshold and trigger levels presented in Appendix G, with numerous exceedances also noted for several of the less abundant heavy metals including arsenic, lead and nickel.

High sodium, chloride and sulphate concentrations (as noted by the low fluid resistivity and high TDS concentrations) and are also of concern.

Even use for dust suppression would need to be carefully considered, given the salt accumulation on roads and consequent corrosion hazards. Dust suppression on non-traffic areas would be possible without treatment.

6.3 Water Treatment Options

There are a number of commercial treatment processes that remove manganese, iron and zinc from water and that are expected to also assist in removing some of the less abundant metals from the water. Iron can be effectively removed by settlement or by using aeration, oxidation with chlorine, pH adjustment or lime softening, followed by coagulation and settlement or filtration.

Converting soluble forms to insoluble precipitates followed by filtration can reduce manganese concentrations in water. Chlorine can be used to oxidise some forms of manganese whilst lime softening at high pH may also be effective in removing some forms.

Treatment options for high zinc concentrations are much simpler methods such as alum coagulation at pH 6.5 to pH 7 (about 30% removal) or by lime softening at pH 9.5 to pH 10 (roughly 60% removal).

Treatment processes for the less abundant metals and salinity include:

- coagulation and lime-softening for the partial or complete removal of arsenic, lead and cadmium, the later with ferric chloride;
- co-precipitation of nickel during the treatment of water for high iron and manganese concentrations; and
- desalinisation via reverse osmosis or electrodialysis/electrodialysis reversal for the treatment of water for salinity (in this instance high chloride, sodium and sulphate concentrations).

Given the very high concentrations of iron and manganese, a combination of treatment processes is likely to be required if Perilya wishes to pursue water reuse options.

Some of the abovementioned treatment options are further discussed below.

6.3.1 Oxidation

Before iron and manganese can be filtered, they need to be oxidised to a state in which they can form insoluble complexes. Oxidation involves the transfer of electrons from the iron, manganese, or other chemicals being treated to the oxidising agent. Ferrous iron (Fe^{2+}) is oxidised to ferric iron (Fe^{3+}), which readily forms the insoluble iron hydroxide complex $Fe(OH)_3$; reduced manganese (Mn^{2+}) is oxidised to (Mn^{4+}), which forms insoluble MnO_2.

The most common chemical oxidants in water treatment are chlorine, chlorine dioxide, potassium permanganate, and ozone. Oxidation using chlorine or potassium permanganate is frequently applied in small groundwater systems where the dosing is relatively easy, requires simple equipment, and is fairly inexpensive; chlorination is widely used for oxidation of divalent iron and manganese.

As an oxidant, potassium permanganate ($KMnO_4$) is normally more expensive than chlorine and ozone, but for iron and manganese removal, it has been reported to be as efficient and it requires considerably less equipment and capital investment; the dose of potassium permanganate, however, must be carefully controlled.

Ozone may be used for iron and manganese oxidation.

A low-cost method of providing oxidation is to use the oxygen in air as the oxidising agent in a tray aerator. Water is simply passed down a series of porous trays to provide contact between air and water; no chemical dosing is required, which allows unattended operation; a complication is that the rate of reaction between oxygen and manganese is very slow below pH values of 9.5.

6.3.2 Filtration

Chemical oxidation followed by filtration is the main method of iron and manganese removal when concentrations exceed 10 mg/L.

In general, manganese oxidation is more difficult than iron oxidation because the reaction rate is slower. A longer detention time (10 to 30 minutes) following chemical addition is needed prior to filtration to allow the reaction to take place. A number of specialist filtration media are available for the removal of iron and manganese.

6.3.3 Desalination

There are many technologies available to desalinate (remove salt from) saline or brackish water. Only those technologies that are likely to be economically viable for improving the quality of brackish groundwater at Broken Hill are discussed below.

Reverse Osmosis

Reverse osmosis (RO) is a membrane process in which solutions are desalinated or concentrated using relatively high hydraulic pressure as the driving force across a membrane that is semi-permeable, allowing the fluid that is being purified to pass through it, while rejecting the contaminants that remain. The higher the pressure, the greater the driving force. As the concentration of the fluid being rejected by the membrane increases, the driving force required to continue the process increases. RO is also known as hyperfiltration.

Most RO technology uses a process known as crossflow to allow the membrane to continually clean itself. As some of the fluid passes through the membrane the rest continues downstream, sweeping the rejected species away from the membrane.

RO is capable of rejecting bacteria, salts and other constituents that have a molecular weight of greater than 150 to 250 daltons. The separation of ions with RO is aided by charged particles. This means that dissolved ions that carry a charge, such as salts, are more likely to be rejected by the membrane than those that are not charged, such as organics. The larger the charge and the larger the particle, the greater the likelihood of rejection. Typically, the product of RO plants has a salinity of less than 500 mg/L TDS.

RO is a maturing technology and is very scalable – the range extends from units with capacities starting at 400 litres per day, to very large plants capable of supplying major towns. Large RO plants utilising brackish groundwater feed have been in use in the Middle East since the mid-1980s, and most of the installed desalination capacity in Australia, including the major plants in Sydney, the Gold Coast and Perth, and those under construction/commissioning in Melbourne and Adelaide, is RO. Recently, small package units directly coupled to photovoltaic (solar electric) cells have become available. Groundwater RO feed has a number of issues not apparent in surface water sources, including iron and hydrogen sulphide fouling. Brine disposal is also a significant issue in inland areas.

RO is used to treat groundwater extracted from the Great Artesian Basin to make it suitable for potable use in the town of Roxby Downs. The unit cost of water supply in Roxby Downs is about Aus$2.40 per kilolitre; costs quoted in product literature are often less – about Aus$1.70 per kilolitre.

Electrodialysis/Electrodialysis Reversal

Electrodialysis (ED) also involves the movement of water through a membrane. Instead of pressure, a low-voltage DC electric field supplies the motive force. An ED cell contains compartments separated by membranes that are permeable to either anions or cations. Under the influence of the electric field, ions migrate through the appropriate membrane, leaving reduced-salinity water behind.

Electrodialysis Reversal (EDR) is a relatively recent enhancement that involves a reversal of water flow in order to break up and flush out scales and slimes.

Economic factors have limited the uptake of ED technology. It is really only a practical proposition for brackish waters with a salinity less than about 12,000 mg/L TDS. However, ED requires less pre-treatment than RO, and EDR in particular is very competitive with RO for scaling waters with salinity less than 3000 mg/L TDS.

Table 6 provides a comparison of RO and ED advantages and disadvantages.

TABLE 6
Comparison of RO and ED Advantages and Disadvantages

Technology	Advantages	Disadvantages
RO	• Quick and cheap to build and simple to operate. There are few components; durable plastics and non-metal materials are mainly used – pre-treatment of the feedwater to prevent fouling of the membrane is the only potential problem. • Can handle a large range of flow rates, from a few litres per day to 750,000 L/day for brackish water. The capacity of the system can be increased at a later date if required by adding on extra modules. • High space/production capacity ratio, ranging from 25,000 to 60,000 L/day/m^2. • Low energy consumption. • Can remove other contaminants in the water as well as the salt. • Low chemical consumption for cleaning purposes. • No need to shut down the entire plan for scheduled maintenance due to the modular design of the plant. Rapid startup and shutdown.	• RO membranes are expensive and have a life expectancy of 2-5 years. • High quality materials and equipment are required. • An extensive spare parts inventory is necessary. • There is a possibility of bacterial contamination. This would be retained in the brine stream, but bacterial growth on the membrane itself can cause the introduction of tastes and odours into the product water. • Pre-treatment of the feedwater is required to remove particulates so that the membranes last longer. • The plant operates at high pressures; mechanical failure of equipment may occur due to the high pressures used.
ED/EDR	• High recovery ratio (85-94% for one stage). • Can treat feedwater with a higher level of suspended solids. • Pre-treatment has a low chemical usage. • Energy usage is proportional to the salts removed, and not to the volume of water being treated. • Membranes have a life expectancy of 7-10 years, which is longer than for RO. • Membranes are not susceptible to bacterial attack or silica scaling. • Scaling can be controlled whilst the process is on line; the membranes can also be manually cleaned. • Can be operated at low to moderate pressure.	• Periodic cleaning of the membranes with chemicals is required (less with EDR). • Leaks sometimes occur in the membrane stacks. • Bacteria, non-ionic substances and residual turbidity are not removed by the system and can therefore remain in the product water.

The only beneficial use available without treatment would be dust suppression in non-traffic areas.

7.0 CONCLUSIONS AND RECOMMENDATIONS

Given the analytical results presented in Section 5.2 of this report, it is clear that the groundwater entering the North Mine will require some sort of treatment before most reuse options become feasible.

It is evident that concentrations of all of the heavy metals included in the analytical suite, particularly those of manganese, iron and zinc, exceed the adopted criteria and trigger values relating to suggested untreated water disposal or reuse options. Specifically,

- manganese concentrations ranged from 107 mg/L (WC:780) to 112 mg/L (WC:970 and WC:1160),
- iron concentrations ranged from 23.8 mg/L (WC:780) to 29.7 mg/L (WC:970), and
- zinc concentrations ranged from 35.7 mg/L (WC:780) to 39 mg/L (WC:1160),

which is thought to reflect the nature and occurrence of mineralisation in the area.

Additionally, numerous exceedances were noted for several of the less abundant heavy metals including arsenic, lead and nickel.

The low resistivity of the water column observed during geophysical logging of the West Cage is reflected in the high concentration of TDS in each of the samples. Major anion and cation concentrations were typically of the order of 92.9 to 139 meq/L, with measured concentrations of TDS varying between 6470 and 8610 mg/L. These concentrations correlate well with the measurements of fluid resistivity recorded during the geophysical profiling works. In each sample, sodium is the dominant cation, while chloride and sulphate the dominant anions. The pH of the groundwater indicates that it is slightly acidic to neutral.

There are a number of commercial applications that can remove manganese, iron and zinc from water and that are expected to also assist in removing some of the less abundant metals from the water, including coagulation followed by filtration. Groundwater supplies with a high iron and manganese content can be treated to form iron precipitates using aeration, oxidation with chlorine, pH adjustment or lime softening.

Given the concentrations of iron, manganese and salinity, it is highly likely that a combination of water treatment methods will be required.

Undoubtedly, treatment of the volume of water estimated to be present in the workings would be expensive, and in most circumstances would simply be uneconomic. Unusual circumstances do however exist in Broken Hill, and a detailed appraisal of the economic viability of metal removal followed by desalination based on projected volumes generated by dewatering program would be worthwhile.

REFERENCES

ANZECC 2000, *Australian and New Zealand Guidelines for Fresh and Marine Water Quality*, National Water Quality Management Strategy, Australian and New Zealand Environmental and Conservation Council, Agriculture and Resource Management Council of Australia and New Zealand.

ANZECC 2011, *Australian Drinking Water Guidelines*, National Water Quality Management Strategy, National Health and Medical Research Council, Agriculture and Resource Management Council of Australia and New Zealand.

Barnes, R. G. 1988, *Metallogenic studies of the Broken Hill and Euriowie Blocks, New South Wales*. Volume 1. Styles of mineralisation in the Broken Hill Block. Volume 2. Mineral deposits of the southwestern Broken Hill Block. Geological Survey of New South Wales, Bulletin **32** (1, 2).

Burton, G. R. 1994, *Metallogenic studies of the Broken Hill and Euriowie Blocks, New South Wales*. Volume 3. Mineral deposits of the South-Eastern Broken Hill Block. Geological Survey of New South Wales, Bulletin 32 (3).

Cooper, P. F., K. D. Tuckwell, L. B. Gilligan, & R. M. D Meares, 1975, *Torrowangee — Fowlers Gap 1:100 000 geological sheet, 7135 & 7235*. Geological Survey of New South Wales, Sydney.

Stevens, B. P. J. & W. J. Stroud eds. 1983, *Rocks of the Broken Hill Block: their classification, nature, stratigraphic distribution, and origin.* Geological Survey of New South Wales, Records 21(1).

Stevens, B. P. J., R. Page, C. Connor, W. Preiss, A. Crooks, S. Robertson, G. Gibson & C. Foudoulis 2003, *SHRIMP U-Pb Geochronolgoy in the Curnamona Province: Improving the Framework for Mineral Exploration.* Broken Hill Exploration Initiative: Abstracts of papers presented at the July 2003 conference in Broken Hill. Geoscience Australia Record: 2003/13.

http://www.oocities.org/bhhsi/tracing-history15.html *North Mine Ceases Operation after 110 Years*. Oocities, Tracing History, Broken Hill.

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Water and Environmental Management
ABN 54 056 283 295

Important Information About Your Environmental Site Assessment

These notes will help you to interpret your hydrogeological and Environmental Site Assessment (ESA) reports.

Why are ESAs conducted?

An ESA is conducted to assess the environmental condition of a site. It is usually, but not always, carried out in one of the following circumstances.

- As a pre-purchase assessment, on behalf of either purchaser or vendor, when a property is to be sold.
- As a pre-development assessment, if a property or area of land is to be redeveloped, or if its use is to change (for example, from a factory to a residential subdivision) – to meet a requirement for development approval.
- As a pre-development assessment of a 'greenfield' (undeveloped) site - to establish baseline conditions and to assess environmental, geological and hydrological constraints to the proposed development.
- As an audit of the environmental effects of an ongoing operation.

Each type of assessment requires its own specific approach. In all cases, however, the aim is to identify and if possible quantify the risks posed by unrecognised contamination. Such risks may be financial (for example, clean-up costs or limitations on site use), or physical (for example, health risks to site users or the public).

What are the limitations of an ESA?

Although the information provided by an ESA can reduce exposure to these risks, no ESA, however diligently carried out, can eliminate risks altogether. Even a rigorous professional assessment may not detect all contamination on a site. The following paragraphs explain why.

ESA 'findings' are professional estimates

The ground surface conceals a complex 3-dimensional subsurface environment. Subsurface materials, whether placed by geological processes or human activities, are always heterogeneous. Large variations in lithology and hydraulic properties can occur over short distances. Surface observation, and data obtained from boreholes and test pits, can never give us a complete picture of the subsurface.

All data from sampling and laboratory testing must be interpreted by a qualified professional – a geologist, engineer or scientist. They then render an opinion - about overall subsurface conditions, the nature and extent of contamination, its likely impact on the proposed development, and appropriate remediation measures.

Interpretation and professional judgement are thus essential to the assessment process.

Accuracy depends on the scope of work

Site assessment identifies actual subsurface conditions only at those specific points where samples are taken and when they are taken. The accuracy of the entire process depends on sampling frequency and sampling methods - yet the extent of sampling and soil analysis must necessarily be limited.

Sampling generally targets those areas where contamination is considered to be most likely, on the basis of visual observation and the site's history. This approach does maximise the probability of identifying contaminants, but it may not identify contamination in unexpected locations or from unexpected sources.

No professional, no matter how qualified, and no subsurface exploration program, no matter how comprehensive, can reveal what is hidden by earth, rock and time. For example, there may be contaminants in areas not surveyed or sampled; furthermore, they may migrate to areas that showed no signs of contamination at the time of sampling.

Conditions between sample locations can only be inferred – from estimates of geological and hydrogeological conditions, and from the nature and extent of identified contamination. Soil, rock and aquifer conditions are often variable, and so the distribution of contaminants across a site can be difficult to assess. Actual conditions in areas not sampled may differ from predictions.

The accuracy of an assessment is therefore limited by the scope of work undertaken.

Statistical tools can be helpful, but the validity of conclusions still depends entirely on the degree to which the original data reflect site conditions.

Uncertainty is also inevitable when it comes to assessing chemical fate and transport in groundwater and surface water systems, and calculating human health and environmental exposure risks. It is inevitable, too, when estimating remediation performance and time frames.

Your CMJA report includes a statement of the uncertainty associated with this particular project; you should read it carefully.

We can offer solutions

We cannot prevent the unanticipated, but we can minimise its impact. For this reason we recommend that you retain CMJA's services through the remediation and development stages. We can identify differences from predicted conditions, conduct additional tests as required, and recommend solutions for problems encountered on site.

Don't rely on out-of-date information

Subsurface conditions are changed by natural processes and the activity of people. Your ESA report is based on conditions that existed at the time of subsurface exploration. Don't make decisions on the basis of an ESA report whose adequacy may have been affected by time. Speak with CMJA to learn if additional tests are advisable.

If things change, contact us

Every report is based on a unique set of project-specific factors. If any one of these factors changes after the report is produced, its conclusions and recommendations may no longer be appropriate for the site.

Your environmental report should not be used:

- if the nature of the proposed development is changed - for example, if a residential development is proposed instead of a commercial one;
- if the size or configuration of the proposed development is altered;
- if the location or orientation of the proposed structure is modified;
- if there is a change of ownership; or
- for application to an adjacent site.

To help avoid expensive problems, talk to CMJA. We will help you to determine how any factors that have changed since the date of the report may affect its recommendations.

Your ESA report is prepared specifically for you

Every hydrogeological study and ESA report is prepared to meet the specific needs of specific individuals. A report prepared for a consulting civil engineer may not be adequate for a construction contractor, or even for another consulting civil engineer. A report should not be used by anyone other than the client, and it should not be used for any purpose other than that originally intended. Any such proposed use must first be discussed with CMJA.

Beware of misinterpretation

Costly problems can occur if plans are based on misinterpretations of an ESA. These problems can be avoided if CMJA is retained to work with appropriate design professionals. We will explain the relevant findings and review the adequacy of plans and specifications.

Logs and laboratory data should not be separated from the report

Final borehole or test pit logs are developed by CMJA's environmental scientists, engineers or geologists, using field logs (assembled by site personnel) and laboratory evaluation of field samples. Our reports usually include only the final logs, which must not under any circumstances be redrawn for inclusion in other documents.

Similarly, our reports often include field and laboratory data, and laboratory reports. These data should not be reproduced separately from the main report, which provides guidance on their interpretation and limitations.

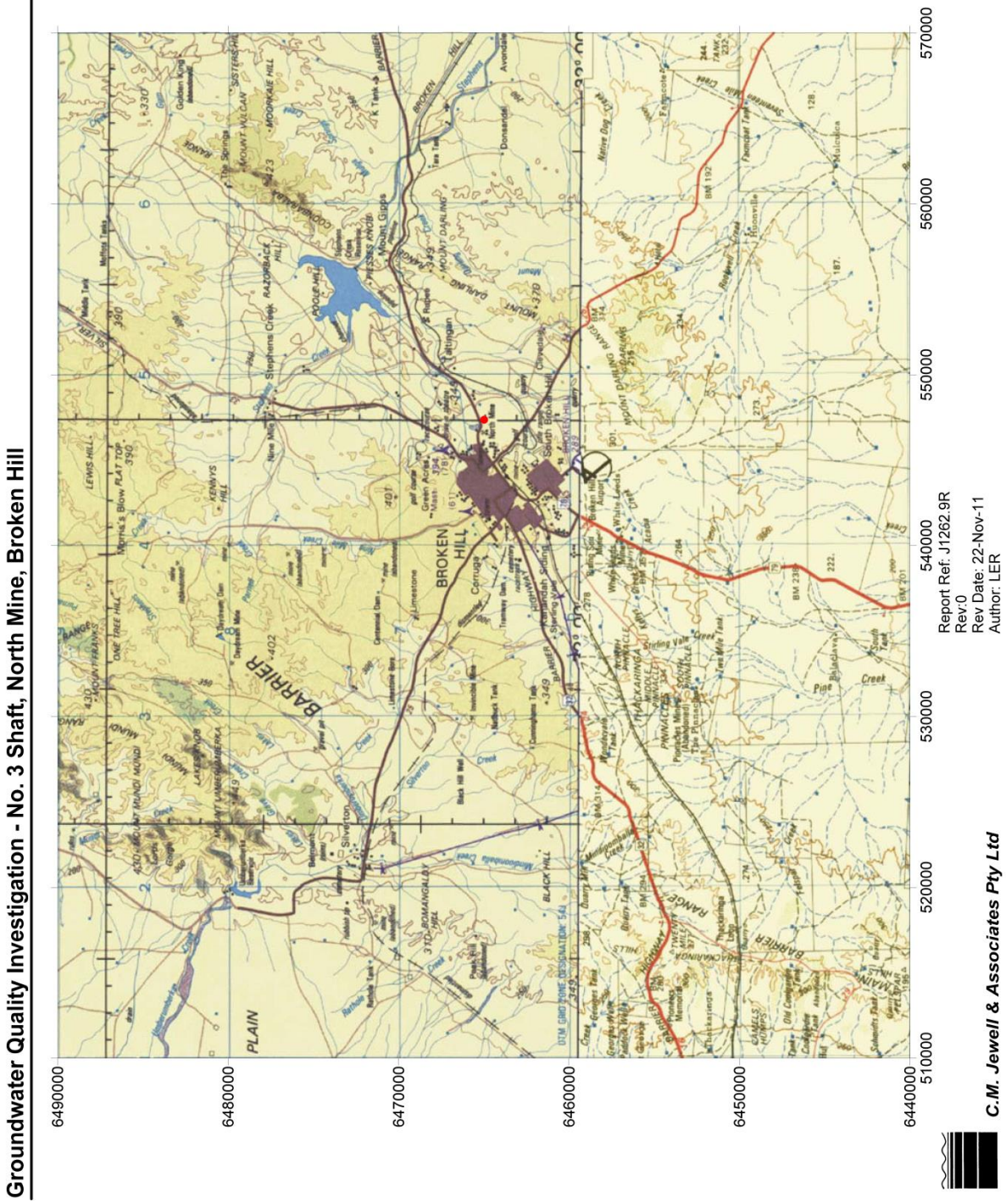
To reduce the likelihood of misinterpretation, only the complete report should be made available for the use of persons or organisations involved in the project, such as contractors. Consult CMJA before distributing reports, and we will assist with any additional interpretation that is required.

Always read responsibility clauses closely

To avoid misunderstandings, our report includes qualifying statements that explain the level of certainty associated with our findings and recommendations, and responsibility clauses that indicate where our responsibilities to clients and other parties begin and end.

These qualifying statements and responsibility clauses are an important part of your report. Please read them carefully. They are not there to transfer our responsibilities to others but to help all parties understand where individual responsibilities lie.

These notes were prepared by C. M. Jewell & Associates Pty Ltd (CMJA) using guidelines prepared by the National Ground Water Association (NGWA) and other sources.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Groundwater Quality Investigation - No. 3 Shaft, North Mine, Broken Hill
Figure 1
Local Setting
BROKEN HILL
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Report Ref: J1262.9R
Rev:0
Rev Date: 22-Nov-11
Author: LER
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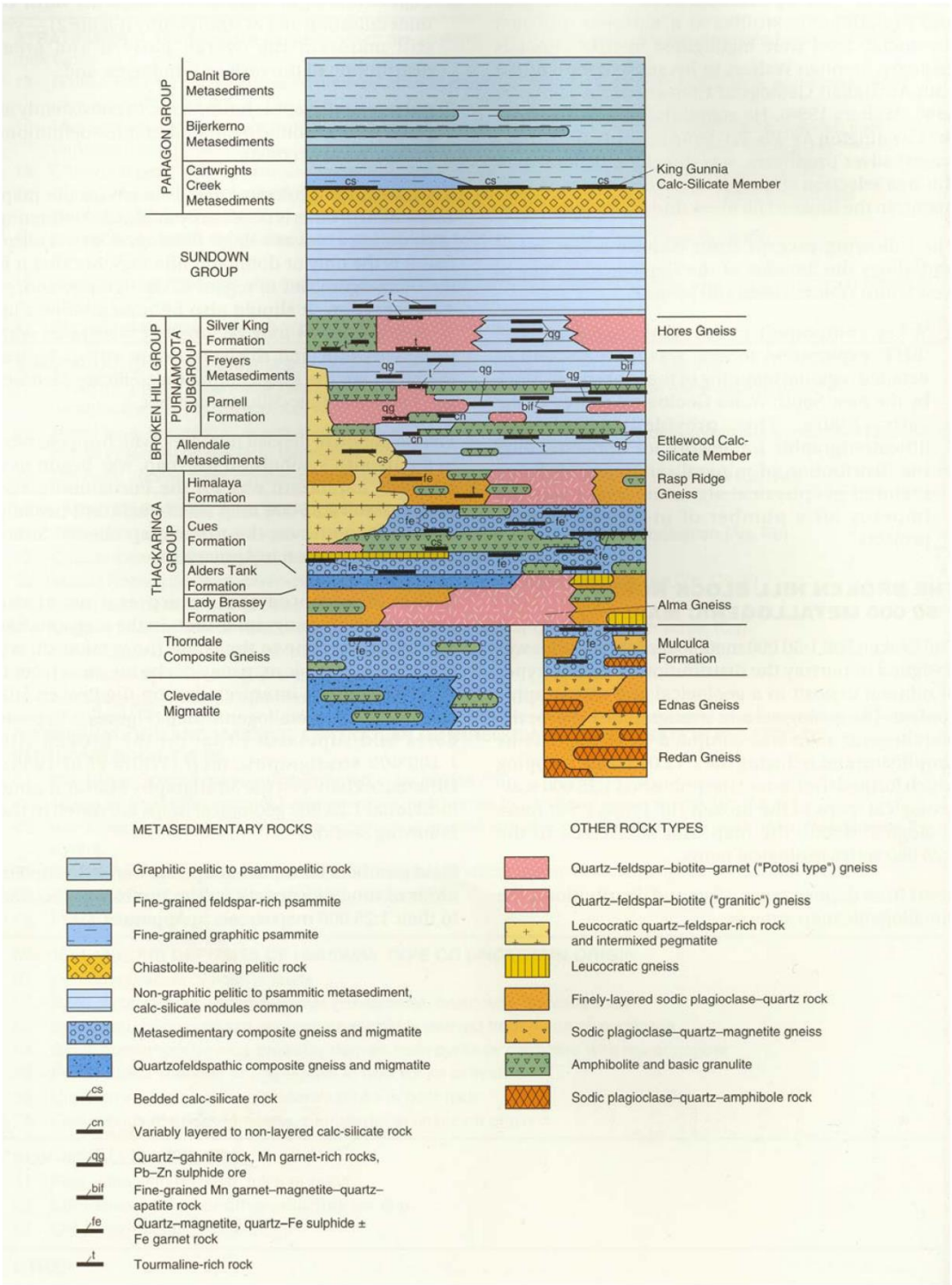
Groundwater Quality Investigation - No. 3 Shaft, North Mine, Broken Hill



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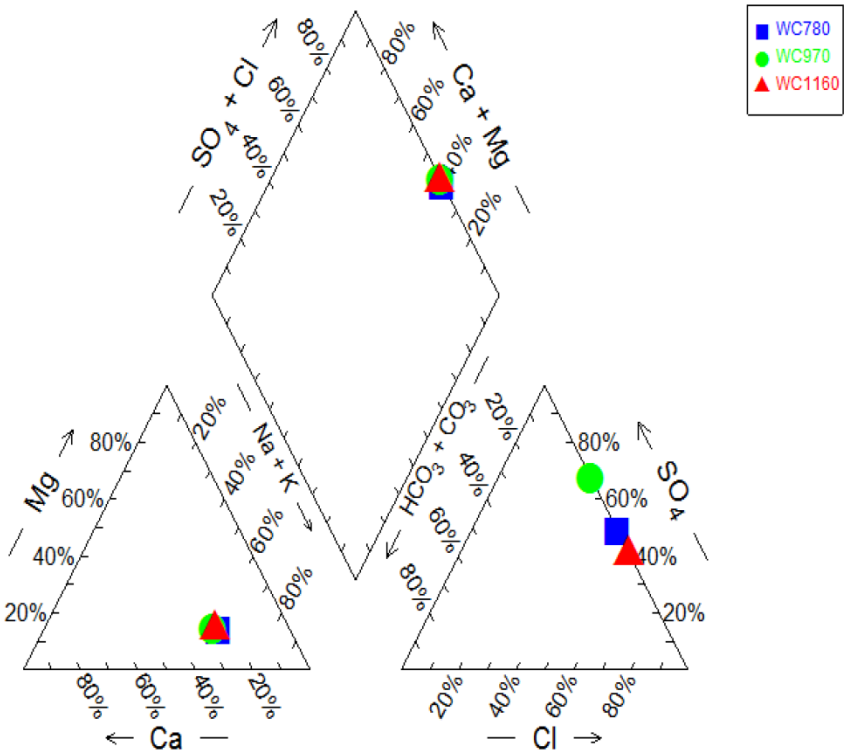
Rev: 0
Date: 22-Nov-11
Author: LER

Figure 2
Generalised Stratigraphy of the Willyama Supergroup

Figure 3
Geology and Mineralisation of the Broken Hill Area

Groundwater Quality Investigation - No. 3 Shaft, North Mine, Broken Hill



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Author: LER

Figure 4
Trilinear Diagram
Water Composition

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APPENDIX A

Borehole Summary Worksheet for Borehole GW021882

29-01-04;16:55 ; ; # 13/ 1

DEPARTMENT OF INFRASTRUCTURE, PLANNING AND NATURAL RESOURCES
Work Summary

GW021882 *Converted From HYDSYS*

License : 80BL013984

Work Type : Bore
Work Status : (Unknown)
Construct. Method : (Unknown)
Owner Type : Private

Authorised Purpose(s)	Intended Purpose(s)
STOCK	STOCK

Commenced Date :
Completion Date : 01-Feb-1964

Final Depth : 67.10 m
Drilled Depth : 67.10 m

Contractor Name :
Driller :

Property : - FARMCOTE STATION
GWMA : -
GW Zone : -

Standing Water Level :
Salinity :
Yield :

Stock

Site Details

Site Chosen By	County	Parish	Portion/Lot DP
	Form A : YANCOWINNA	invalid code	WLL 1389
	Licensed : YANCOWINNA	NIL	LT DP

Region : 80 - MACQUARIE-WESTERN
River Basin : 425 - DARLING RIVER
Area / District :

CMA Map : 7233 REDAN
Grid Zone : 54/2
Scale : 1:100,000

Elevation :
Elevation Source : (Unknown)

Northing : 6457600
Easting : 556150

Latitude (S) : 32° 0' 58"
Longitude (E) : 141° 35' 40"

GS Map : 0043B1 AMG Zone : 54

Coordinate Source : GD_ACC.MAP

Construction

Negative depths indicate Above Ground Level|H-Hole;P-Pipe;OD-Outside Diameter;ID-Inside Diameter;C-Cemented;S-Slot Length;A-Aperture;GS-Grain Size;Q-Quantity

No	Component	Type	From (m)	To (m)	OD (mm)	ID (mm)	Interval	Details
1	Casing	Threaded Stud	-0.40	4.50	152			(Unknown)

Water Bearing Zones

From (m)	To (m)	Thickness (m)	WBZ Type	S.W.L. (m)	D.D.L. (m)	Yield (L/s)	Hole Depth (m)	Duration (hr)	Salinity (mg/L)
61.00	61.00	0.00	(Unknown)	45.70		0.32			Stock

Drillers Log

From (m)	To (m)	Thickness (m)	Drillers Description	Geological Material	Comments
0.00	1.83	1.83	Soil Red	Soil	
0.00	1.83	1.83	Mixed Rubble		
1.83	60.96	55.13	Granite Decomposed Some Limestone	Granite	
1.83	60.96	59.13	Quartzite Coloured	Quartzite	
60.96	67.06	6.10	Gravel Coarse Water Supply	Gravel	

Willyama

Remarks

*** End of GW021882 ***

Warning To Clients: This raw data has been supplied to the Department of Land and Water Conservation (DLWC) by drillers, licensees and other sources. The DLWC does not verify the accuracy of this data. The data is presented for use by you at your own risk. You should consider verifying this data before relying on it. Professional hydrogeological advice should be sought in interpreting and using this data.

12

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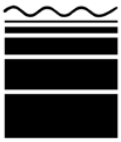


APPENDIX B

Groundwater Quality, Southern Leases

TABLE 4 - GROUNDWATER CHEMISTRY - SOUTHERN LEASES, OCTOBER 1983
All concentrations in mg/l (ppm)

Drill-Hole No.	pH	Major Elements Ca	Mg	Na	K	SO_4	Cl	TSS	Heavy Metals Ag	Cd	Cu	Mn	Pb	Zn	Cr	Fe
3	8.9	50	87	1240	34	360	1510	3281	bld	bld	bld	0.062	bld	0.415	0.005	bld
4	7.8	325	565	4240	41	2370	6010	13551	bld	bld	bld	0.610	bld	0.610	0.010	0.165
5	7.4	81	45	275	13	195	470	1079	bld	bld	bld	0.900	.020	0.965	0.010	0.070
8	6.9	520	350	1730	28	1620	3240	7488	bld	0.020	bld	0.011	bld	1.475	0.020	0.060
15	7.3	410	420	2030	28	2270	3540	8718	0.010	bld	bld	0.445	bld	0.425	0.020	14.300
16	6.7	660	320	1800	27	3290	2690	8787	bld	0.045	bld	4.225	bld	6.650	0.015	0.145
17	7.5	690	395	2170	32	2600	4000	9887	0.010	0.005	bld	1.915	.100	0.850	0.020	0.130
21	7.5	810	555	2930	27	2440	5780	12542	0.010	0.025	bld	0.905	.320	0.875	0.025	0.115
24	6.9	845	252	3730	75	4150	5700	14752	0.005	0.010	bld	12.470	.060	2.060	0.020	3.740
25	7.4	1400	2160	10400	41	3880	11300	29181	0.040	0.220	bld	10.151	1.420	4.200	0.065	0.270
Decant	-	800	116	2360	119	3055	3920	10370	0.030	0.010	bld	12.150	.100	1.320	0.045	0.200
Toe Drain	-	855	96	1930	103	2900	3340	9224	0.035	0.010	bld	25.550	.390	1.360	0.035	0.175

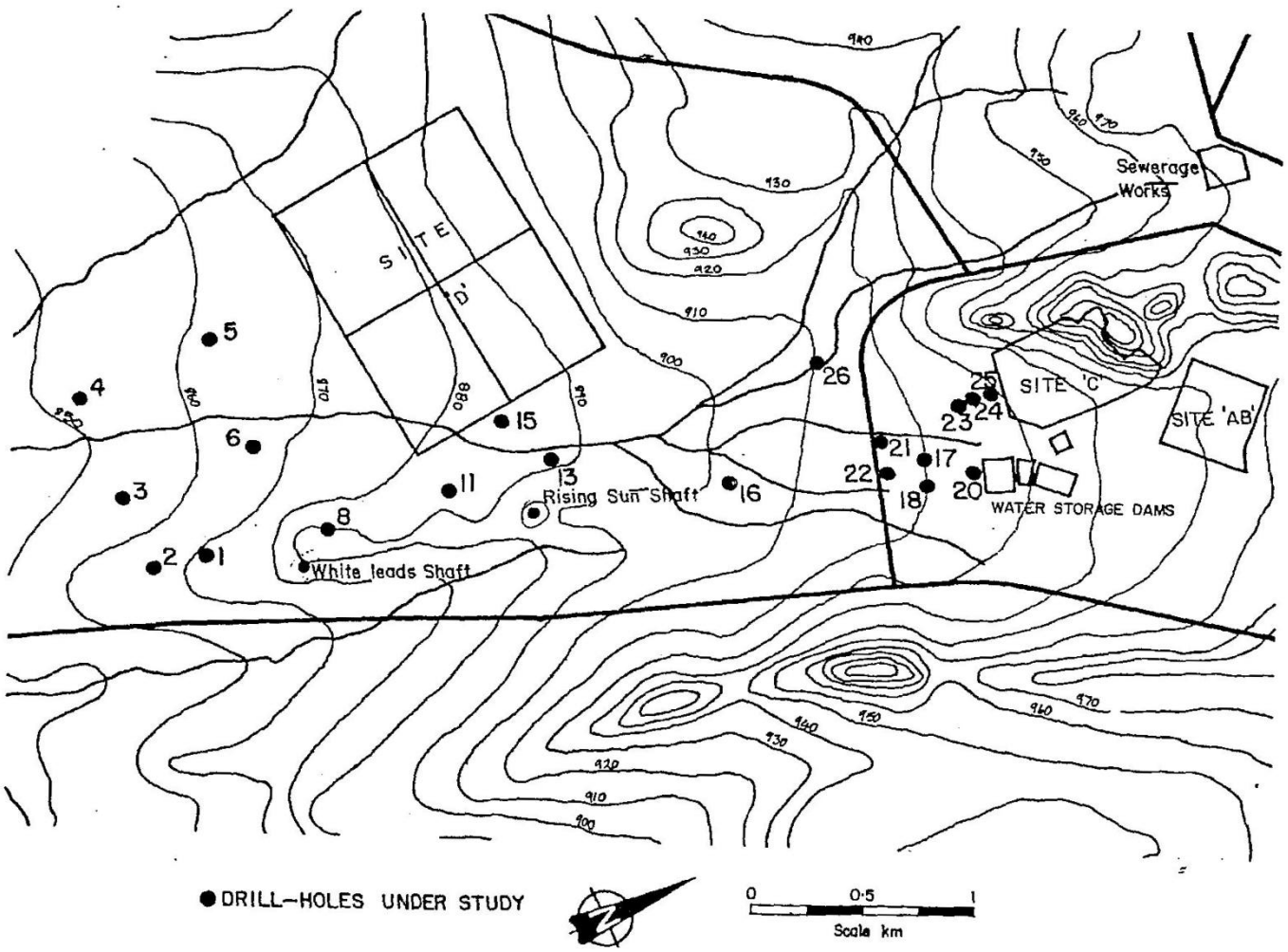
bld denotes below level of detection

TABLE 5 - GROUNDWATER CHEMISTRY - SOUTHERN LEASES, JANUARY 1984
All concentrations in mg/l (ppm)

Drill-Hole No.	pH	Major Elements Ca	Mg	Na	K	SO_4	Cl	TSS	Heavy Metals Ag	Cd	Cu	Mn	Pb	Zn	Cr	Fe
3	7.4	28	55	1380	39	565	1723	3790	bld	bld	bld	0.325	bld	0.045	0.010	0.040
4	-	315	675	4570	30	2430	6785	14805	bld	bld	bld	0.890	bld	0.010	bld	bld
5	8.4	-	-	-	-	-	-		bld	bld	bld	0.070	bld	0.055	bld	0.090
11	7.2	570	455	1960	36	1480	4055	8556	bld	bld	bld	1.590	bld	0.420	bld	19.100
15	7.4	450	408	2000	28	1980	3476	8342	bld	bld	bld	0.830	bld	0.150	bld	5.550
16	7.2	600	285	1770	27	2750	2524	7956	bld	0.035	bld	5.690	bld	5.520	0.010	0.050
21	7.2	740	410	2300	22	1990	4639	10,101	bld	0.020	0.010	0.275	bld	1.370	0.015	0.040
24	7.0	-	-	-	-	-	-		bld	0.135	bld	10.800	0.310	3.150	bld	bld
25	6.9	780	475	4880	16	4250	6890	17291	bld	bld	bld	0.740	bld	0.105	bld	bld
Decant	7.3	970	90	2150	105	2590	3250	9155	bld	.008	bld	19.400	1.680	bld	-	bld
Toe Drain	7.3	900	135	2640	125	2680	4090	10570	bld	bld	bld	14.100	bld	1.135	bld	bld

bld denotes below level of detection

Groundwater Quality Investigation - No.3 Shaft, Perilya North Mine, Broken Hill



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Report Ref: J1262.9R
Rev:0
Rev Date: 22-Nov-11
Author: LER

Figure B1
Southern Leases Drill-hole Locations

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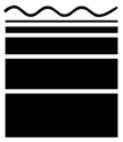


APPENDIX C

Overview of the Hydrasleeve™ Discrete Interval Sampler

APPENDIX C
OVERVIEW OF THE HYDRASLEEVE DECSRETE INTERVAL SAMPLER

The HydraSleeve™ (Figure 2) is a grab-type sampling device comprised of a long polyethylene bag with a reed valve at the top and a weight attached to the bottom. The sampler dimensions can be customized to meet project-specific sample volume requirements and well diameters.

To initiate the collection process, the closed sampler is lowered into the screened interval by a suspension line attached to a stainless steel weight. The sampler is allowed to sit undisturbed to allow for equilibration. After the prescribed time, the sampler is pulled upward at a minimum rate of 1 foot per minute. The upward motion causes the reed valve to open and water to enter the sleeve.

Earlier versions of the HydraSleeve™ were equipped with a check valve, which required that the device be moved up and down in the well to bring water into the bag. This practice disrupted the water column and increased turbidity in some wells. With the reed valve, the HydraSleeve™ induces only minimal agitation of the well water. The internal water pressure keeps the reed valve closed when the bag is filled so that mixing with water above the screened interval cannot occur.

Once withdrawn from the well, the sample should be squeezed out of the bag into appropriate containers through a tube inserted below the check valve. For sampling of LTM wells at regular frequency, the HydraSleeve™ can be left sealed in the screened well interval for indefinite periods between sampling events.

MacMillan, D. & D. E. Splichal 2005, *Review of Field Technologies for Long-Term Monitoring of Ordnance-Related Compounds in Groundwater*, Environmental Quality and Technology Program. US Army Corps of Engineers, Engineer Research and Development Centre, 2005, *pp 12 – 14*; ERDC/EL TR-05-14 (http://el.erdc.usace.army.mil/elpubs/pdf/trel05-14.pdf)

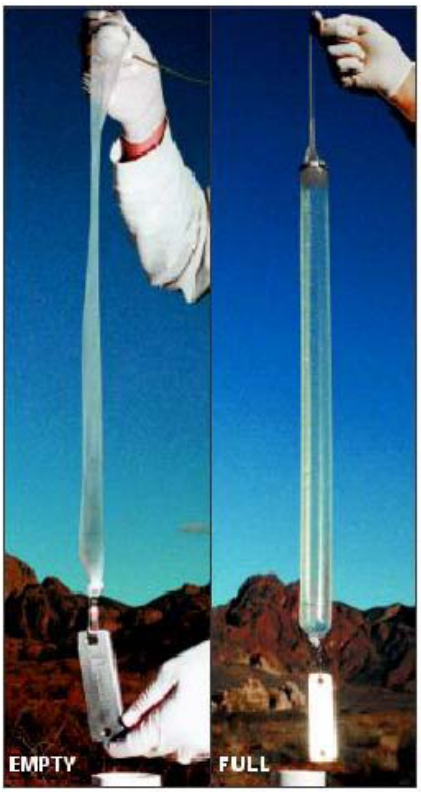


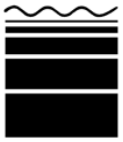
Figure 2. The HydraSleeve™. Photo used with permission. (http://www.hydrasleeve.com/)

This sampling technique has been demonstrated for many environmental contaminants of concern to the military, including volatile organics, explosives and redox sensitive elements. No significant differences in recoveries of volatile organic compounds and explosives were observed between samples collected with the HydraSleeve™ versus control samples (Parker and Clark 2002). There are many advantages to using the HydraSleeve™ over other sampling techniques, including its compatibility with deployment in a monitoring well for long periods of time prior to sample collection. Bio-fouling is not a factor since compounds do not diffuse into the bags.

The manufacturer reports 50 to 80% sampling cost savings can be obtained using this device. Since the bags can be reused in the same well, decontamination of sampling equipment is not necessary.

Parker, L. V. & C. H. Clark 2002, *Study of five discrete interval-type groundwater sampling devices*, ERDC/CRREL TR-02-12, US Army Engineer Research and Development Center, Hanover, NH

Further information can be found on the company's website http://www.dsienv.com/Hydrosleeve.htm



APPENDIX D

Chain-of-Custody and Sample Receipt Documentation

ALS Sydney: 277-289 Woodpark Road, Smithfield, NSW 2164. Phone (02) 8784 8555; Facsimile (02 8784 8500. Email Samples.Sydney@alsenviro.com

CMJA

CHAIN OF CUSTODY DOCUMENTATION

Australian Laboratory Services Pty Ltd (ALS)

CLIENT: C.M. Jewell & Associates Pty Ltd	SAMPLER: Lesley Randall
ADDRESS / OFFICE: P.O.Box 10, Wentworth Falls, Australia 2782	MOBILE: 0428 619 804
PROJECT MANAGER (PM): Lesley Randall	PHONE: 47 59 3251
PROJECT ID: J262	EMAIL REPORT TO: lesley@cm-jewell.com.au
SITE: North Mine, Broken Hill P.O. NO.:	EMAIL INVOICE TO: (if different to report)
RESULTS REQUIRED : **Normal TAT** QUOTE NO.: SY/274/10	**ANALYSIS REQUIRED including SUITES** (note - suite codes must be listed to attract suite prices)

FOR LABORATORY USE ONLY
COOLER SEAL (circle appropriate)
Intact: Yes No N/A
SAMPLE TEMPERATURE
CHILLED: Yes No

COMMENTS / SPECIAL HANDLING / STORAGE OR DISPOSAL:

All heavy metals (dissolved) field filtered

As, Cd, Cr (total), CrIII, CrVI, Cu, Pb, Mn, Ni, Fe, Hg, Ag

Heavy metal bottles are NOT preserved

Notes: e.g Highly contaminated samples
e.g "High PAHs expected"
Extra Volume for QC or trace LORs etc.

SAMPLE INFORMATION (note: S = Soil, W=Water)					CONTAINER INFORMATION		Major Anions and Cations	Heavy Metals	Sulphide	TDS and TSS	Oil and Grease				
ALS ID	SAMPLE ID	MATRIX	DATE	Time	Type / Code	Total bottles									
1	WC: 780	Water	15/11/11	4:00pm	P, N, Z, SG	4	X	X	X	X	X				
2	WC: 970	Water	15/11/11	4:15pm	P, N, Z, SG	4	X	X	X	X	X				
3	WC: 1160	Water	15/11/11	4:20pm	P, N, Z, SG	4	X	X	X	X	X				
[redacted]															

Environmental Division
Sydney
Work Order
ES1125312

Telephone : +61-2-8784 8555

RELINQUISHED BY:		RECEIVED BY		METHOD OF SHIPMENT
Name: Lesley Randall	Date: 16 Nov 2011	Name: David	Date: 17/11	Con' Note No:
Of: C.M Jewell & Associates	Time: 10:00am.	Of: ALS	Time: 1900	
Name:	Date:	Name:	Date:	Transport Co:
Of:	Time:	Of:	Time:	

Water Container Codes: P = Unpreserved Plastic; N = Nitric Preserved Plastic; ORC = Nitric Preserved ORC; SH = Sodium Hydroxide/Cd Preserved; S = Sodium Hydroxide Preserveed Plastic; AG = Amber Glass Unpreserved; V = VOA Vial HCl Preserved; VS = VOA Vial Sulphuric Preserved; SG = Sulfuric Preserved Amber Glass; H = HCl preserved Plastic; HS = HCl preserved Speciation bottle; SP = Sulfuric Preserved Plastic; F = Formaldehyde Preserved Glass; Z = Zinc Acetate Preserved Bottle; E = EDTA Preserved Bottles; ST = Sterile Bottle; ASS = Plastic Bad for Acid Sulphate Soils; B = Unpreserved Bag.

G:\Enviro\Quotes\Marketing Master Forms\ALS COC Blank V1.xls

CMJA