AUSTRALIAN ZIRCONIA LTD
(A wholly owned subsidiary of Alkane Resources Ltd)

Dubbo Zirconia Project

Groundwater Assessment

Prepared by

Environmental Earth Sciences NSW

September 2013

Specialist Consultant Studies Compendium
Volume 1, Part 5

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Groundwater Assessment

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Ref No: 612013_DZP_GWv4

September 2013

ENVIRONMENTAL EARTH SCIENCES
THE KNOW AND THE HOW

NOTE: Appendices A, B, C, D, E and F are only available on the Project CD. Printed Appendices can be viewed in colour on the Project CD.

ENVIRONMENTAL EARTH SCIENCES
THE KNOW AND THE HOW

REPORT NO. **612013_DZP_GW v4**

HYDROGEOLOGICAL INVESTIGATION OF THE DUBBO ZIRCONIA PROJECT, VIA TOONGI, NEW SOUTH WALES

ENVIRONMENTAL EARTH SCIENCES NSW
REPORT TO RW CORKERY & CO PTY LIMITED
9 SEPTEMBER 2013
VERSION 4

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EXECUTIVE SUMMARY

Objectives and Scope

The objective of this assessment is to develop a conceptual site model (CSM) that describes the local hydrogeological setting, assess potential impacts to groundwater resources of the proposed Dubbo Zirconia Project Site (hereafter referred to as the “DZP Site”), and make recommendations for mitigation and management to protect the local groundwater environment and users.

The following initial scope was undertaken:

- desk-top assessment of existing information on groundwater users, ecosystems, aquifer properties and groundwater quality;
- collection of additional physical groundwater data; and
- collection and assessment of groundwater quality data, including chemical analysis of further collected groundwater samples.

The proposed components of the Dubbo Zirconia Project (“the Proposal”) were described with emphasis on the key attributes of those components, which were considered of relevance to their potential impacts. The potential physical and chemical impacts of those components were then assessed and the interpreted risks of the different potential impacts were described and compared. The potential impacts with the greatest associated risks were identified. Recommendations were made for managing the risks and for groundwater monitoring to verify the protection of groundwater resources.

General Conceptual Hydrogeology

The DZP Site is located on high ground with the intrusive trachyte plug / extruded lava flow containing the ore body located at the divide between the catchments of Wambangalang Creek/Paddy’s Creek and Cockabroo Creek. There is more than 130 m of relief between the highest points close to the ore body and these creeks.

The geology of the study area consists of Triassic age sedimentary rocks of the Gunnedah Basin (intruded with / extruded upon by Jurassic age alkaline volcanics), overlain by Cainozoic age unconsolidated alluvial/colluvial sediments along the primary ephemeral creek systems that drain the catchments associated with the DZP Site. The primary aquifers are interpreted to be clean sands within the alluvial sediments in close proximity to the main creeks and fractured trachytes and basalts within the bedrock.

The water table surface is a subdued form of the topography such that groundwater flow is generally radial from the ore body area towards the major creeks. The interpretation of the flow system is supported by chemical data, with total dissolved salts (TDS) increasing radially along flow paths. There is water quality evidence from Wambangalang Creek that groundwater intermittently contributes to its baseflow during periods of low flow.

Rates of migration of groundwater are mostly low, with average linear velocities generally interpreted to be 2 m/year or less in the bulk of the fractured rock and in the generally clay-dominated alluvium. However, localised occurrences of higher permeability sands have been interpreted in the alluvium in close proximity to Wambangalang Creek, beyond the western boundary of the DZP Site, which are expected to have significantly greater average linear velocities up to approximately 60 m/year. Where present, due to their relatively high fracture permeability, the igneous rocks are interpreted to provide preferential pathways through which groundwater could flow at rates of more than 200 m/year.

Beneficial uses supported by the baseline groundwater quality consist of primary contact recreation, freshwater ecosystems, irrigation, stock watering and industrial usage. The primary realised beneficial uses are surface freshwater ecosystems that are reliant on shallow groundwater and stock watering.

Proposal Components

The Proposal components considered were the open cut, the Liquid Residue Storage Facility (LRSF), Solid Residue Storage Facility (SRSF), Salt Encapsulation Cells (SEC), Waste Rock Emplacement (WRE) and the Processing Plant Area.

A significant volume of brine, and ultimately salt, will be generated in the process of extracting the rare metals. The salt will be precipitated from the brine in the LRSF cells and deposited in the SECs. Salt is highly soluble and mobile and has the potential to significantly compromise the beneficial uses of groundwater. Therefore, the Proposal includes extensive measures to protect groundwater resources for the life of mine and into closure. These measures include double liners with leak detection for the SRSF and SEC, single liners for the LRSF, and bunded concrete areas in the Processing Plant Area. Quality assurance of the integrity of liners will include independent testing. Comprehensive groundwater monitoring will be used to verify the effectiveness of leak prevention systems.

Potential Impacts

For each component of the project, the likelihood, consequence, and associated risk of direct physical and chemical impacts and the risk of ensuing impacts to downgradient receptors were considered. All the proposed components of the Proposal contribute some level of risk of physical or chemical impacts to groundwater and ensuing impacts. However, on a four level risk scale of low, moderate, high and extreme, the majority of the risks were interpreted to be low to moderate. Two high risks were interpreted. No extreme risks were identified.

In practise, although breaches in the liner of the LRSF are expected to be uncommon, they are considered to be possible. As a result, the risk of direct chemical impacts to groundwater associated with the LRSF was conservatively interpreted to be high. However, due to the approach to liner construction and proposed monitoring of the LRSF groundwater conditions, any such breaches can be expected to be rare, localised and temporary rather than widespread and/or permanent. Therefore, the potential impact to groundwater would be temporary and localised, resulting salt concentrations in the groundwater would be attenuated down-gradient from the source due to dispersion, and the risk of ensuing down-gradient impacts and land salinisation is not considered to be high.

The risk of an increase in groundwater flux due to enhanced recharge associated with the open cut was also, when considered in isolation, interpreted to be high. However, the associated risk of chemical impacts is interpreted to be low and enhanced recharge due to the open cut is expected to be offset by reduced recharge in other areas. Thus, enhanced groundwater flux from the open cut could be considered to be positive and, in the context of all the Proposal components, it is not considered to be a significant impact.

The assessment of risks associated with the LRSF assumes construction above low permeability materials. If an extensive aquifer exists beneath a LRSF cell/s, the direct risk to groundwater and ensuing risk to down-gradient receptors would be increased due to the relatively high groundwater flow rate and the potential for impacts to extend over a larger area.

Recommended Verification and Risk Mitigation

It is recommended that further investigations, including hydraulic testing, are undertaken to confirm the ground conditions in and in the vicinity of the footprint of the proposed LRSF areas. To the extent possible, it is recommend that LRSF cells are not located above high permeability aquifers such as alluvial sands or basalt. However, it is understood that other site practicalities may mean this is not feasible.

Due to the increased risk of chemical impacts associated with a LRSF cell located above a laterally extensive aquifer, if further investigations reveal an aquifer beneath a proposed LRSF, we recommend that additional seepage prevention/mitigation measures be considered in the design of that LRSF. Such measures could include double lining, cut-off wall, seepage interception bores, or a combination of these measures.

It is important that all investigation boreholes drilled within the footprint of a proposed LRSF be properly abandoned by grouting the entire borehole such that vertical pathways for groundwater flow and/or potential seepage are not created when the LRSF is constructed.

We recommend a Groundwater Management and Mitigation Plan (GMMP), which would describe the objectives of the groundwater management and monitoring and detail the proposed types and locations of monitoring. It would also specify the monitoring observations which would trigger actions, and the proposed action and/or mitigation should triggers be exceeded.

Proposed Monitoring

All of the Proposal components will include comprehensive perimeter groundwater monitoring to provide early warning of groundwater impacts. We recommend a monitoring-bore spacing of no more than 100 m on the down-gradient side of storage facilities and the Processing Plant. The final bore spacing should be specified in the GMMP.

Monitoring of both groundwater levels and electrical conductivity would take place in these bores at a relatively high frequency. However, laboratory analyses would not be necessary, unless chemical impacts were interpreted from an increase in electrical conductivity. Due to the large number of bores, the most cost effective approach to this monitoring, including the potential for automation, should be considered in the GMMP.

In addition, we recommend that a broad network of bores across the site be monitored, including existing bores. Some existing bores would require decommissioning and replacement and some additional locations are recommended. A site-specific analytical suite has been recommended for quarterly sampling, which should be formalised in the GMMP.

On behalf of
Environmental Earth Sciences NSW

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1 INTRODUCTION AND OBJECTIVES

1.1 Introduction

This report presents the findings of a Hydrogeological (Groundwater) Assessment of the proposed Dubbo Zirconia Project ("DZP – the Proposal"). The report was prepared for R.W. Corkery and Co. Pty. Limited (RWC) on behalf of Australian Zirconia Ltd (AZL) a subsidiary of Alkane Resources Ltd ("the Applicant"). The site of the proposed mining, processing and associated waste management activities for the Dubbo Zirconia Project ("the DZP Site") would be located approximately 25 km South of Dubbo, near the village of Toongi, NSW (refer to **Figures 1** and **2**).

1.2 Objectives and scope of works

The objectives of this report are to describe the local hydrogeological setting within the areas of potential impact, to assess the potential impacts and recommend controls and mitigation measures.

The scope of work for this assessment was provided in the *Brief for a Groundwater Assessment for an Environmental Impact Statement* in December 2011(RWC, 2011). The specific scope of works set out in PO612010_V1 issued by Environmental Earth Sciences for and on behalf of RWC, answered the brief for the scope of work set out for this assessment. The scope of work was separated into two reporting frameworks, namely:

- Part 1: Existing Environment and Constraints:
  - describing the local hydrogeological setting within the areas of potential impact and potential constraints this may present.
- Part 2: Environmental Impact Assessment:
  - assess the impacts of the Proposal on the hydrogeological environment and recommend controls and mitigation measures.

The summary of the scope of works performed to achieve the objectives of this hydrogeological assessment is to:

- undertake a literature review of relevant background documentation including all available and relevant hydrogeological studies in the area;
- identify and describe legislation and guidelines that are relevant to the protection of groundwater resources in NSW;
- identify sensitive groundwater users that may be affected by the DZP Site and confirm / infer their current groundwater use;
- undertake additional site observation and groundwater assessment to build upon a previous hydrogeological assessment conducted in 2002 (Golder, 2002);
- identify and describe the groundwater resources in the vicinity of the DZP Site;
- identify salinity processes and conceptual model regarding groundwater interaction within the alluvial flats of the DZP Site;
- describe the existing hydrogeological environment including groundwater levels, flow and quality and potential surface water interactions;

- determine appropriate criteria for impact assessment;
- identify mining activities that have potential to impact on the quality and/or quantity of groundwater available at and adjacent to the DZP Site;
- assess potential impacts to groundwater at the DZP Site and quantify these impacts, where possible; and
- outline the mitigation measures that would be put in place to minimise impacts to groundwater resources in the vicinity of the DZP Site.

In order to meet the Proposal objectives outlined above, Environmental Earth Sciences NSW completed the following:

- review of legislation relevant to groundwater management to identify potential constraints for the DZP Proposal;
- review of available groundwater bore data, previous relevant assessments and geological information to assess the location and characteristics of groundwater aquifers located within and surrounding the DZP Site;
- establishment of a conceptual model of groundwater processes within and surrounding the DZP Site (“the Study Area”);
- assessment of groundwater quality and potential beneficial uses of groundwater within the Study Area;
- identification of available registered groundwater bore data to identify groundwater users within the Study Area from the NOW Registered Groundwater Bore database;
- assessment of the potential impacts to groundwater quality within the Study Area;
- assessment of the potential impacts on the availability of groundwater to other groundwater users within the Study Area;
- estimation of the volume of groundwater that would need to be pumped from the open cut during mining to a level of up to 32 m below current ground levels;
- assessment of the long term steady state groundwater conditions around the open cut after the cessation of mining; and
- assessment of the long term steady state groundwater conditions within the alluvial flats where salinity in shallow soils and groundwater may be impacted from landscape disturbance from residue storage facilities, evaporation ponds and other DZP Site infrastructure.

In this report, the existing environment and constraints are presented in Section 5 and potential impacts are discussed in Section 6.

2 DESCRIPTION OF THE PROPOSED PROPOSAL

2.1 Background

The DZP Site operations would involve the excavation of ore and waste rock from one open cut (refer to **Figure 3**). The open cut would be excavated to a depth of up to 32 m below current ground level (RWC, 2013). It is not planned to mine below the water table, which is at a depth of approximately 35 m below surface in the area of the proposed open cut. Excavated waste rock from the ore body margins would be placed in one dedicated waste rock emplacement (WRE) to the south-west of the open cut. Soil profiles above the waste rock and ore would be placed in dedicated soil stockpile areas (**Figure 3**). Ore would be processed on the DZP Site to separate the rare metals (zirconium, niobium and yttrium) and Rare Earth Elements (REE's) (hafnium and tantalum) from the remaining rock matrix.

The processing system would use a unique and purpose-designed process to be implemented which incorporates grinding, sulfation (addition of sulfuric acid and roasting), water leaching, filtering and solvent extraction of zirconium, niobium and REE products, thickening, washing and drying.

Solid waste residue left at completion of the ore processing would be neutralised with limestone and stored within a dedicated and lined Solid Residue Storage Facility (SRSF). Waste water from processing of ore would be pumped into a Liquid Residue Storage Facility (LRSF) which would be made up of a series of terraced salt crystallisation cells within four distinct areas of the DZP Site. The Applicant seeks approval to mine and process the rare metal and REE containing ore at a rate of approximately 1Mtpa, which based on the current open cut design provides for an initial life of mine (under this application) of 20 years.

The objectives for the DZP Site rehabilitation are centred upon the progressive restoration of areas of disturbance through the creation of a final landform, soil substrate and vegetative cover suitable for a level of agricultural productivity similar to existing levels, and/or passive nature conservation. A program of progressive rehabilitation of disturbed/constructed areas would also be implemented to minimise exposed surfaces and ensure slopes are stable.

The main distinction for the DZP Site rehabilitation is that the extensive lateral and vertical extent of the ore body (400m x 500m and 100m thick) will make progressive backfilling of the open cut unfeasible (as it would sterilise the ore body resource for future mining and ore recovery). Hence the open cut would be expected to remain open post-mining.

2.2 Study area

The area that is the subject of this groundwater assessment ("the DZP Site Investigation Area") includes an approximate 5 km radius from the proposed mining operations. This specifically refers to the major landscape disturbance areas such as open cut, solid and liquid residue storage facilities (SRSF and LRSF respectively) and salt encapsulation cells (see **Figure 3**). However, a 10 km radius was used to identify potential groundwater users (anthropogenic and environmental) from the NSW Office of Water (NOW) Registered Groundwater Bore database (www.nratlas.nsw.gov.au). Relevant Registered Groundwater Bore information identified during this assessment is also presented within this report as **Appendix A** and **Appendix B**.

The application area of the Proposal for development consent comprises four component areas. The four areas include:

- The DZP Site 2,864 ha);
- Toongi – Dubbo Rail Line and Gas Corridor (~30 km);
- Macquarie River Water Pipeline (7.6 km); and
- Investigation area for the 132kV power line corridor (~20 km).

This assessment for groundwater applies to the DZP Site only. Details of the other three component areas, relevant details, conceptual plans and dimensions are provided in the *Environmental Impact Statement* (RWC, 2013). The three component areas not assessed as part of this study are not likely to impact on groundwater as the majority of infrastructure disturbance would be above the ground surface and within previously built easements i.e. the rail line embankment and infrastructure.

Where there is potential for groundwater impacts from the other three components after final engineering designs, the study area may extend to these areas to assess groundwater implications and impacts. For example, the possibility of drawing water, to be delivered via the pipeline, from two aquifers (one alluvium and one fractured rock) adjacent to the Macquarie River, in addition to water from the river itself (RWC, 2013), has not been addressed herein.

The DZP Site would incorporate all areas of proposed Proposal-related disturbance associated with mining, processing, waste management and related activities. **Figures 2** and **3** provide the DZP Site investigation area and proposed layout.

The DZP Site is centred on the Toongi trachyte which forms one of several alkaline volcanic lava flows and intrusive bodies of Jurassic age (184 million years old [Myo]) in the region south of Dubbo, NSW. The Toongi trachyte deposit continues at depth with the current application restricted to mining 20 Mt of the 73 Mt that has been identified. Extending the limits on mining as part of this application was considered, however, it was determined that restricting the current application to mining above the groundwater table would reduce the complexity of the mining operations and assessment.

It should be noted that the perimeter or alignment of the study area components could be subject to modification following the completion of further Proposal planning and engineering design. Should this affect the potential impacts of the DZP Site, appropriate modification(s) to any issued development consent or other approval would be sought.

2.3 Proposed mining activities

The proposed mining activities include four component areas, the DZP Site on which all mining, processing and associated activities would be undertaken and ancillary infrastructure including a water pipeline, rail line and gas pipeline and 132 kV power line. **Figure 3** identifies the activities to be undertaken within the DZP Site and provides the conceptual layout of the principle components of the Proposal.

As discussed in Section 1.2, this assessment for groundwater applies to the DZP Site only. Details of the other three component areas, relevant details, conceptual plans and dimensions are provided in Section 2 of the EIS (RWC, 2013).

The DZP Site development footprint (~807.7 ha) component area includes the following proposed mining activities including estimated areas of disturbance (**Figure 3**):

- Open Cut Mine – 40.3ha.
- Waste Rock Emplacement Area – 20.4ha.
- ROM Pad – 4.2ha.
- Processing Plant and DZP Site Administration Area (incorporating the processing plant and associated reagent storage areas, rail siding and container laydown areas and site offices and administration complex) – 43.3ha.
- Solid Residue Storage Facility – 102.8ha.
- Liquid Residue Storage Facilities (Evaporation Ponds) – 425.4ha.
- Salt Encapsulation Cell – up to 34.6ha.
- Soil Stockpile Areas – up to 129.4ha.
- Internal Haul Roads – 7.3ha.

The DZP comprises the principal components and activities detailed in **Table 1**. The Proposal's objectives for rehabilitation are centred upon the progressive restoration of areas of disturbance through the creation of a final landform, soil substrate and vegetative cover suitable for a level of agricultural productivity similar to existing levels, and/or passive nature conservation (RWC, 2013).

TABLE 1 DUBBO ZIRCONIA PROPOSAL PRINCIPAL COMPONENTS

Component	Summary of Activity
Open Cut	A shallow Open Cut Mine of up to 32m in depth (not extending below the water table) from which the ore would be mined by standard drill and blast, load and haul methods.
Waste Rock Emplacement	Waste rock from the margins of the body would be transferred to a 20.4Ha Waste Rock Emplacement (WRE) to the southwest of the open cut.
Processing Plant and DZP Site Administration Area	The Processing Plant and DZP Site Administration Area are separated into the following three component areas: Processing Plant Area – The location where ore would be crushed and ground before the various rare metals and REE's are separated from the ore by sulphation leach, solvent extraction and precipitation processes. DZP Site Administration Area – Comprises the gatehouse and weighbridge, offices and lunch rooms, change rooms, a wash house and ablutions as well as staff and visitor parking and truck park-up bays. Rail Container Laydown and Storage Area – Where unloading of reagents from the rail line can be undertaken away from the Processing Plant area.
Solid Residue and Solid Residue Storage Facility	The solid residue (ground rock) produced by the processing of the ore would be mixed with lime (to neutralise the residue) and transported on a conveyor to a Solid Residue Storage Facility (SRSF) adjacent to the Internal Haul Road.
Liquid Residue Storage Facility Areas and Salt Encapsulation Cells	Water which cannot be recycled through the Processing Plant would be pumped to a Liquid Residue Storage Facility (LRSF) constructed in four distinct areas as illustrated on **Figure 3**. The resulting precipitate would ultimately be stored in the Salt Encapsulation Cells.

Component	Summary of Activity
Water Supply	The Processing Plant requires significant volumes of water of which 3-4,000ML would be sourced from the Macquarie River (under licence) and transferred to the DZP Site by water pipeline (from the Macquarie River).
Rail Loading Facility	A Rail Load-out Facility on the upgraded and reopened Toongi – Dubbo Rail Line would be constructed to accept reagents and processing materials, as well as despatch the final DZP products.
Chemical Reagents	The Processing Plant requires significant volumes of chemical reagents and other processing materials which would be delivered to the DZP Site either by road (via Obley Road which is to be upgraded) or the reopened Toongi – Dubbo Rail Line.
132kV Powerline	The DZP would be powered by mains power with a 132kV spur line from the Geurie – Dubbo 132kV power line to be constructed.
Natural Gas Pipeline	Natural gas (for heating) would be imported to the DZP Site, via a Natural Gas Pipeline spur developed from the Central West Pipeline (of APA Group) at Purvis Lane, Dubbo.
Haul Roads and Other Infrastructure	Additional DZP Site infrastructure such as internal haul and other roads and hardstand areas

2.4 Water supply and consumption

Maximum operational water requirements for processing operations are estimated to be 4.05kL per tonne of ore processed, i.e. up to 4,050 mega-litres per year (ML/a). In addition, approximately 40ML would be required for dust suppression purposes, primarily on the Mine Haul Road between the open cut and ROM Pad or WRE. The Applicant proposes to source this water from various sources, including the Macquarie River and possibly two aquifers in the vicinity of the river (under licence), however, any extraction of groundwater would be subject to further investigation and does not form part of the current development application (RWC, 2013).

The water to be extracted from the Macquarie River would be delivered to the Processing Plant via a pipeline to be constructed between the Macquarie River (on the “Mia Mia” property) and the DZP Site (a distance of approximately 7.6km). AZL understands that licence entitlement to extract and use the equivalent to the volume of water to be drawn from the river must be acquired and negotiations are advanced with a number of licence holders to purchase or lease part or all of existing entitlements.

The Applicant continues to investigate ways of further reducing the water requirements of the DZP. Additional water recovery and recycling remains a focus of processing plant optimisation.

3 GROUNDWATER LEGISLATION AND GUIDANCE

3.1 Regulatory environment

Environmental Earth Sciences completed an evaluation of legislation, regulatory instruments and guidance documents that may be relevant to the DZP. A summary of the regulatory environment is provided in **Table 2**.

TABLE 2 SUMMARY REGULATORY ENVIRONMENT

Document	Summary
Water Management Act 2000	Under this Act a Water Access Licence (WAL) is required to extract or interfere with groundwater in areas where a Water Sharing Plan (WSP) is in place. At the time this assessment was prepared the DZP Site was subject to WSPs for "NSW Murray-Darling Basin Porous Rock Groundwater (Gunnedah-Oxley Basin)" and the "Macquarie Bogan Unregulated and Alluvial" WSP. The Act also applies to surface water storages and therefore, would be relevant to the management of any surface water storages at the DZP Site.
Water Sharing Plan (WSP)	The DZP Site is subject to WSPs for both alluvial and bedrock groundwater systems: the "NSW Murray-Darling Basin Porous Rock Groundwater (Gunnedah-Oxley Basin) WSP"; and the "Macquarie Bogan Unregulated and Alluvial" WSP.
Guidelines for Groundwater Protection in Australia (ARMCANZ and ANZECC 1995)	This guideline provides a framework for preventing groundwater contamination in Australia.
NSW State Groundwater Policy and Framework Document (NSW Department of Land and Water Conservation 1997)	The Framework document sets out the overall direction of groundwater management in NSW and provides broad objectives and principles to guide groundwater management.
NSW State Groundwater Quantity Protection Policy (NSW Department of Land and Water Conservation 1998)	Builds on the concepts outlined in the framework document and provides more detail and guidance on how to manage and protect groundwater quantity.
NSW State Groundwater Quality Protection Policy (NSW Department of Land and Water Conservation 1998)	Builds on the concepts outlined in the framework document and provides more detail and guidance on how to manage and protect groundwater quality.
NSW State Groundwater Dependent Ecosystems Policy (NSW Department of Land and Water Conservation 2002)	This policy is specifically designed to protect valuable Groundwater Dependent Ecosystems (GDE's) which rely on groundwater for survival. It aims to maintain or restore the ecological processes and biodiversity of groundwater dependent ecosystems for the benefit of present and future generations.
Guidelines for Fresh and Marine Water Quality (ANZECC / ARMCANZ 2000)	These guidelines would be adopted to assess groundwater quality, potential beneficial use of groundwater at the DZP Site, and to assess potential impacts to groundwater quality from operation of the DZP.

Document	Summary
Approved Methods for the Sampling and Analysis of Water Pollutants in New South Wales (NSW EPA 2003)	These guidelines would be adopted where sampling and analysis of groundwater samples is required as part of this assessment and during groundwater monitoring
Groundwater Sampling and Analysis – A Field Guide (Geoscience Australia 2009)	The purpose of this field guide is to present a set of standard groundwater sampling protocols that focus on a range of groundwater quantity and quality issues throughout Australia.

3.2 Groundwater licenses

Under the *Water Management Act 2000*, any cutting, excavation or borehole that intersects groundwater is regarded as groundwater work and has to be licensed as such by NOW. The proposed open cut for the DZP Site is not expected to intersect groundwater and will not require a groundwater work licence. This is based on the current Proposals design and proposed open cut maximum depths for the 20 year DZP Site lifespan. Any additional groundwater monitoring bores installed for the Proposal would require a groundwater work licence.

4 ASSESSMENT OF DATA

4.1 Desktop study

Existing groundwater information is available at and around the DZP Site from registered bores and previously conducted groundwater and salinity investigations. Information obtained prior to the field works included a registered groundwater bore search for nearby bores within a 10 km radius of the proposed open cut and review of two previous studies carried out for the Proposal and regional catchments surrounding the DZP Site. Discussions were also held with AZL and some of the local land owners prior to the fieldworks with regards to existing bore locations, ground conditions and anecdotal discussion of groundwater levels in the region.

4.1.1 Registered groundwater bore search

Environmental Earth Sciences conducted a search of the NSW Office of Water (NOW) Registered Groundwater Bore database (www.nratlas.nsw.gov.au) on 2 March 2012 (NOW 2012b). Bores identified were separated into those within a 5 km radius of the proposed open cut and bores between a 5 and 10 km radius of the open cut. This separation was conducted based on the proposed open cut design, groundwater interception likelihood, DZP Site spatial area and catchment boundaries around and within the DZP Site.

4.1.2 Sensitive groundwater users and groundwater dependent ecosystems (GDEs)

Further assessment of groundwater usage is provided in Section 5.8 of this report. As part of the desktop assessment for the Proposal, investigations into the potential for the presence of GDEs in the vicinity of the DZP Site were undertaken. Based on information provided in BOM (2012), a map for the site and surrounding catchments was generated and has been provided as **Appendix I** of this report.

4.1.3 Review of previous reports and information

Two existing studies are available that provide information for the DZP Site. One study conducted by Golder Associates (2002) included detailed drilling and bore installation along with interpretation of surface water and groundwater conditions and potential impacts as related to the proposed DZP Site designs at the time. The Golder Associates fieldwork was conducted in 2001 with the draft report prepared in April 2002.

A regional scale groundwater and dryland salinity investigation was carried out in 2001 by the then NSW Department of Land and Water Conservation (DLWC). The study built upon salinity risk assessment work carried out in the Central West Catchment and was reported by Ann Smithson of the DLWC.

Both reports have been reviewed and are summarised as relevant in the following sections throughout this report. Information that has already been discussed in the previous sections of this report has not been duplicated such as regional climate and geological settings.

A summary of the most pertinent points relating to groundwater as reported in Golder (2002) is provided in **Appendix G** of this report.

A summary relating to groundwater as reported in Smithson (2001) is provided in **Appendix H** of this report.

4.2 Collection of additional data

A site inspection was undertaken over 14 and 15 March and 25 and 26 July 2012, and 13 and 14 February 2013. The initial site inspection consisted of a walk over most of the DZP Site and included sampling of selected bores and surface water. Subsequent visits involved groundwater sampling and physical testing of bores (slug tests and a constant discharge test). Observations of the environmental setting and DZP Site characteristics were noted. Photographs were taken and are presented in **Appendix F** (Plates 1 – 40) with accompanying notes on the aspects the photos show.

The bores sampled are listed in **Table 6** of this report, while the location of all groundwater bores of interest to this study is provided on **Figure 8**.

4.2.1 Groundwater sampling

Ten of the twenty three bores (DWB01 – DWB23) were sampled in March 2012 along with three additional bores and one large diameter well (refer to **Table 6**). Seven groundwater samples were collected for water quality analysis and four slug tests were performed at this time. All sampled and identified bores contained groundwater, although bore DW014 did not recover seven hours after it was purged for sampling.

An unregistered well found at the residence of Mr Malcolm Bye in the Toongi locality was also sampled and is referred to as ‘TWB’ in **Table 6**. The well was approximately 15-20 m deep and 0.8 m diameter and was for domestic use. The well was bricked lined, with Mr Bye suggesting it was associated with the old post office and could have been installed in the 1930 – 1940s. The presence and age of the well indicates that this relatively shallow groundwater has been accessed for a long period of time.

A stock water bore located near bore DWB011 (called DWB011a in **Table 6**) was also included in the investigation as the groundwater was overflowing the top of the casing. Anecdotal evidence suggests that this has been occurring for some time as the surrounding soil was saturated and sedges (plants adapted to wet conditions) were found down gradient in the wet area (Photo Plates 18 and 22, **Appendix F**).

Surface water and groundwater samples were collected using either a submersible pump, bailer or "Waterra" foot-valve, by withdrawing the water straight from surface water bodies or boreholes into clean sampling containers. The sample was only collected after the bores had been purged of standing water and redox potential (ORP), EC (electrolytic conductance) and pH had stabilised. The sample containers were securely capped, stored in ice-filled coolers and transported to Sydney Analytical Laboratories (SAL) for analysis.

Subsequent sampling and gauging events were also undertaken on 25 and 26 July 2012, and again over 13 and 14 February 2013. All field data collected is provided in **Table 6**.

4.2.2 Analytical program and results

As part of the Golder (2002) assessment, a number of groundwater samples were collected and analysis undertaken. In all 21 primary samples were analysed for the following parameters:

- Field measurement of:
    - pH, EC, ORP, standing water levels (SWL), dissolved oxygen (DO) and temperature;
- Laboratory analysis for:
    - full ionic balance suite – pH, TDS, cations (Na, Ca, Mg, K), anions (Cl, SO_4, HCO_3, PO_4, F) and nutrients (NH_3, NO_3 and NO_2); and
    - dissolved metals / metalloids including aluminium (Al), antimony (Sb), arsenic (As), barium (Ba), beryllium (Be), bismuth (Bi), boron (B), bromide (Br), cadmium (Cd), chromium (Cr), cobalt (Co), copper (Cu), iron (Fe), lead (Pb), manganese (Mn), mercury (Hg), molybdenum (Mo), nickel (Ni), selenium (Se), silver (Ag), strontium (Sr), uranium (U), vanadium (V) and zinc (Zn).

Environmental Earth Sciences collected groundwater samples for analysis from seven bores in March and July 2012 (bores DWB011, DWB014, DWB016, DWB019, and three bores near the Toongi township and Cockleshell Corner at the intersection of Eulandool and Springs Roads).

Samples were analysed for an ionic balance as described above, and results are provided in **Tables 8** and **9**, and in **Appendices C** and **E**.

4.2.3 Anecdotal information from landholder discussion

No groundwater monitoring data is known to have been collated or provided since the 2001/2002 investigation works by Golder Associates was undertaken. Anecdotal information was provided during a site walkover from local residents on 14 and 15 March 2012. There were no known nearby projects or activities that provide additional pertinent groundwater information for the proposed DZP Site investigation area or within the relevant catchment areas.

5 CONCEPTUAL SITE MODEL (CSM)

5.1 Introduction

A CSM is a two- to three-dimensional interpretation of the soil, geology and hydrogeology relationships within a catchment. Information assessed and presented includes inferred soil / rock weathering processes and groundwater / surface water flow characteristics. The CSM aims to inform an exposure assessment of any impact (or potential for impact) identified by demarcating sources, pathways and receptors of the groundwater flow system. The CSM is one of the primary planning tools used to support decision making processes, organising available information about a site or issue in a clear structure that facilitates the identification of data and information gaps.

It is often presented using a variety of media, including text, maps, cross sections, two- or three-dimensional graphics, tables and other visual representations (including Piper, Durov, Stiff or Schoeller Plots, for example). This report includes text and tables, along with appended figures including a 2D schematic cross section of the investigation area (**Figures 10a** and **10b**), and data tables and Schoeller Plots (Section 5.8 and **Appendix C**).

By gaining a greater understanding of the DZP Site, the model can also be used to assess which portions of the site may require further investigation or monitoring. The CSM presented herein is intended to help identify groundwater flow paths and environmental receptors using the available data. The CSM describes the existing hydrogeological environment and constraints.

5.2 Physical setting

5.2.1 Climate

Table 3 presents meteorological data sourced from the Dubbo Airport Bureau of Meteorology (BOM) station (station number 065070, year 1946 to present). The Dubbo Airport meteorological station is located approximately 25 km to the north of the DZP Site.

The climate in the Dubbo and Toongi catchment is generally semi-arid with hot summers and cool to cold winters. January is typically the hottest month of the year with a mean maximum temperature of 33.2°C and mean minimum temperature of 18.1°C being the highest throughout the year. The coldest month of the year is July with the lowest mean maximum temperature of 15.4°C and coldest mean minimum temperature of 3.1°C.

Data from the Dubbo Airport meteorological station indicates November has on average the highest rainfall per month with 70.5 mm. April has the least amount of rainfall in the year with only 35.6 mm. The late spring and summer months have the highest monthly average rainfall for the region. The highest humidity is typically in June and the lowest humidity in December.

Evaporation data for the Dubbo region was reported by Golder (2002) from a climatic weather station on Cooreena Road, Dubbo. Mean monthly pan evaporation data showed that average annual evaporation was significantly higher than the average annual rainfall. Average monthly evaporation also exceeded mean monthly rainfall for every month of the year.

Meteorological data has been reported in both Golder (2002) and Smithson (2001) using different data sets in terms of length of record and location of monitoring points. Therefore slight variation in climate reporting occurs between the two reports. In general, the overall climate and relevant climate statistics such as rainfall and evaporation for the region are similar. For both data sets, the water balance equation (rainfall vs evaporation) that indicates a net deficit for each month of the year on average for the region.

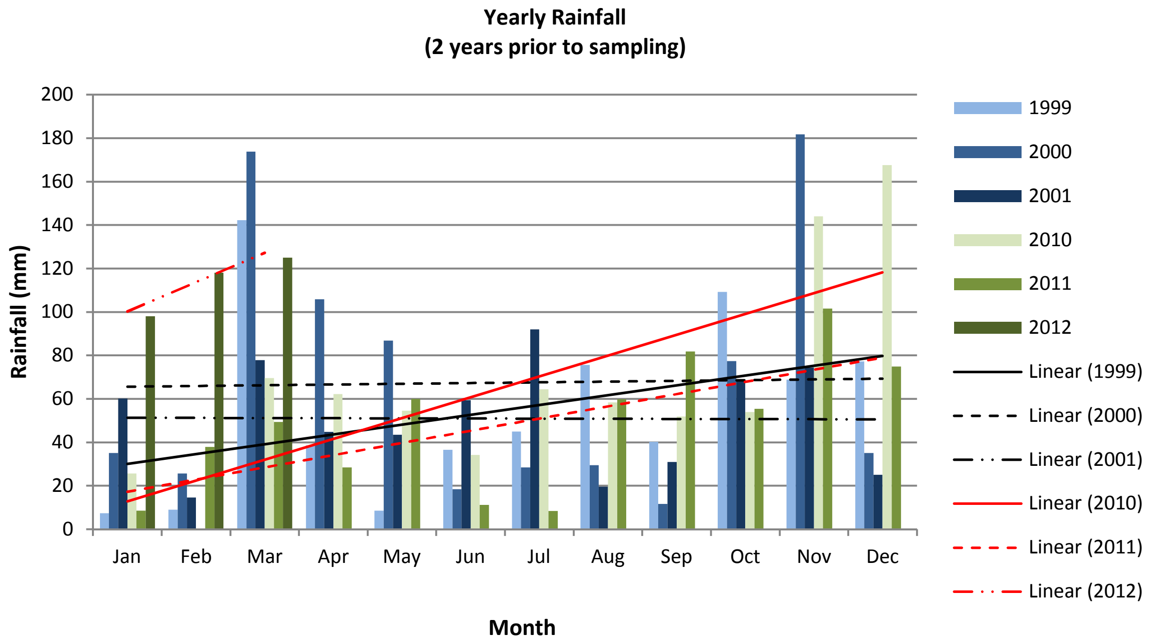
TABLE 3 DUBBO AIRPORT MONTHLY METEROLOGY DATA

-	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Temperature (^oC)													
Mean maximum temperature	33.2	31.8	28.7	24.6	19.9	16.2	15.4	17.4	21	24.5	28.2	30.8	24.3
Mean minimum temperature	18.1	17.7	14.4	10.1	6.5	4.3	3.1	3.4	6.2	9.3	13.5	15.7	10.2
Rainfall (mm)													
Mean monthly rainfall	52.4	45.2	48.9	35.6	41.1	43.2	41	39.4	42.3	49.2	70.5	62	572
Highest monthly rainfall	191	218.2	173.8	105.8	102.2	122	138	151.6	111.6	112	181.8	188.8	851
Lowest monthly rainfall	3.8	7	10	0.2	0.6	4.0	4.0	0.4	0.6	1.2	0.0	5.6	228.6
Highest daily rainfall	74	77	80	72	45	43	44	53	61	60	51	67.6	80
Relative Humidity (%)													
Mean 9am relative humidity	56	62	64	64	76	86	86	76	67	56	56	52	67
Mean 3pm relative humidity	32	36	36	37	47	57	55	47	43	36	35	30	41

Note(s): Source: BOM, Dubbo Airport, Station Number 065070, downloaded 9 February 2012. Temperature data collected from 1993, Rainfall data collected from 1994.

A comparison of rainfall data for approximately two years preceding the 2001 groundwater sampling and monitoring (Golder, 2002) and the March 2012 sampling conducted by Environmental Earth Sciences has been undertaken. A graph indicating monthly rainfall data for the period of 1999 – 2001 and 2010 – March 2012 is presented as **Graph 1**. The data is sourced from the Dubbo Airport BOM station number 065070.

The data indicates a higher rainfall linear trend for the years between 2010 – 2012 compared to the 1999 – 2001 data. Annual rainfall data indicates that within the preceding two years for each sampling and monitoring event, one year (2000 and 2010) had greater than 800 mm annual rainfall recorded.



Graph 1: Rainfall patterns preceding groundwater monitoring events (February 2010 data not available)

5.2.2 Topography

The DZP Site is located on high ground with the intrusive trachyte containing the ore body located at the divide between the catchments of Wambangalang Creek/Paddy's Creek and Cockabroo Creek. There is also a catchment of poorly defined drainage lines flowing into the Macquarie River to the north-east of the proposed DZP Site (refer to **Figure 4**). Paddy's Creek drains towards the north into Wambangalang Creek. Wambangalang Creek drains north-east and joins the Macquarie River approximately 7 km north of the Toongi Township. Cockabroo Creek flows eastward towards Little River from where it drains to the Macquarie River.

Most of the principal infrastructure required for the DZP Site would be located in the Wambangalang catchment. This is likely to include part of the open cut and waste rock emplacement, solid and liquid residue storage facilities and processing and administration area for the DZP Site. The SECs and part of the open cut and WRE would be located in the Cockabroo Creek catchment.

Alluvial plains and the lower terraces adjacent to Wambangalang Creek are described as slightly undulating with slope gradients between 2 – 5%. Elevation of these lower slopes is generally between 280 and 300 m AHD. Major drainage lines and Wambangalang Creek are deeply incised and eroded.

The lower to mid slopes consist of undulating low hills, some rocky, and ranges with slopes generally <6%. Elevations range between 300 and 350 m AHD and the drainage lines are quite deeply incised. Upper slopes and crests consist of undulating hills and rises with the slopes on the crests being up to 10%. There are major rock outcrops and shallow soils across this landscape with elevations between 350 and 400 m AHD.

5.2.3 Hydrology

Figure 4 identifies the relative areas of the DZP Site incorporated into these three main catchments, catchment boundaries and drainage lines.

Wambangalang Creek is an ephemeral creek which flows relatively regularly in response to local rainfall. Surface water monitoring within Wambangalang Creek, and Paddy's Creek which flows into Wambangalang Creek at Toongi (refer to **Figure 4**), was completed in 2001-2002 (Golder, 2002). Additional monitoring was undertaken again in 2012 (SEEC, 2013). Reference to these reports provides the full data set of monitoring results.

The results indicate elevated salinity levels at a number of the monitoring locations, both in 2001 and 2012 monitoring periods. Electrolytic conductivity (EC) ranges of between 1,830 to 3,800 µS/cm were observed during the two monitoring periods. Monitoring sites located within the streams of Wambangalang and Paddy's Creeks suggest the water quality of these streams is affected by groundwater discharge. It is likely to be dominated by, and therefore reflective of, the salinity of the groundwater discharge during periods of low flow. The ranges in salinity described above are commensurate with the average range for the entire Toongi catchment (Smithson, 2001).

Monitoring sites located within the streams of Wambangalang and Paddy's Creeks were observed to have a near neutral to alkaline pH with monitoring results ranging between 7.30 and 8.66. Measurements of metals and radiometrics (Uranium and Thorium) levels were generally found to meet the ANZECC / ARMCANZ (2000) aquatic ecosystems and livestock drinking water guideline levels respectively. Most elements were present at concentrations less than the laboratory limit of reporting (LOR), with metals such as aluminium, barium, boron, copper, manganese, molybdenum, strontium and zinc present at low but acceptable levels.

Monitoring in 2012 identified elevated nutrient levels (Total Phosphorous and Total Nitrogen) which may be indicative of the local catchment agricultural setting and may reflect a flushing of the catchment of accumulated nutrient levels.

Cockabroo Creek is an ephemeral creek with a much smaller catchment than Wambangalang Creek (refer to **Figure 4**). It flows less frequently than Wambangalang Creek and generally only following periods of heavier or prolonged local rainfall. Surface water monitoring in 2001 and 2012 included one site within this catchment. The 2012 sampling event was from a dam adjacent to the 2001 sampling point due to no flow at the time in Cockabroo Creek. Therefore the hydrochemistry results from this date may not be representative of the catchment system. This is reflected in the much higher nutrient levels (Total Phosphorous and Total Nitrogen) when compared to the 2001 sampling event.

Hydrochemistry results from the 2001 sampling event within the Cockabroo Creek catchment appears to be fresh, however relatively turbid. Concentrations of metals, radiometrics and nutrients all met ANZECC / ARMCANZ (2000) guideline trigger levels.

The Macquarie River (Undefined) Catchment flows via several ephemeral channels directly into the Macquarie River (refer to **Figure 4**). Surface water monitoring in 2001 and 2012 included one site within this catchment. The ephemeral channel sampled appears to drain directly the north towards Macquarie River with the sampling point approximately 1.5 km north east of the proposed open cut.

Hydrochemistry results from the 2001 and 2012 sampling events within the Macquarie River (Undefined) Catchment appear to be fresh with a low turbidity. Concentrations of metals, radiometrics and nutrients all met ANZECC / ARMCANZ (2000) guideline trigger levels. Monitoring in 2001 and 2012 identified elevated nutrient levels (Total Phosphorous and Total Nitrogen) which may be indicative of the local catchment agricultural setting.

5.3 Site and surrounding land uses

Land use across the catchment can be characterised as mixed dryland farming enterprises. Cereal cropping and introduced sown pastures (used for grazing and hay production) are restricted to the lower alluvial plains of Wambangalang Creek. There are also some Lucerne stands used for sheep and cattle grazing and hay production.

Mid and upper slopes are dominated by perennial native grass species and generally used for cattle and sheep grazing. Minor cropping is undertaken in these parts of the landscape. The plains, lower and midslope environments have been extensively cleared of native vegetation. On the steep upper slopes and crests, native tree stands are present comprising of eucalypts and white and black cypress pine. Shallow soil and large rock outcrops restrict agricultural use in this area.

A small area to the west of Obley Road had been subdivided into rural residential lots and the Township of Toongi contains four houses on small holdings.

Areas to the north and east of the local catchment along the terraces of the Little River and Macquarie River are also used for irrigated crops and pasture.

5.4 Surficial geology and soils

5.4.1 Soil landscape

Soil landscape is varied given the different geological units and landforms across the DZP Site (refer to **Figures 5** and **6**). Note that **Figure 5** (after Murphy and Lawrie 1998) groups soil landscapes on the basis of Great Soil Groups (Stace *et al*. 1968), whilst the following soil descriptions are provided on the basis of the updated Australian Soil Classification (ASC, after Isbell 2002). As such, the following relationships exist between current nomenclature (ASC) and the previously adopted Great Soil Group groups (in brackets):

- Tenosols (Alluvial Soil);
- Dermosols (Euchrozems);
- Kandosols (Red Brown Earths);
- Chromosols (Red Podzolic Soils); and
- Rudosols, Tenosols (Shallow Soils).

Deep Tenosols (undeveloped alluvial soil) are found on the lower active flood plains of Wambangalang Creek. Dermosols and Kandosols are prominent on the upper alluvial terraces and Chromosols in depressions and drainage lines within this environment (Murphy and Lawrie 1998).

On the lower to mid slopes of the catchment, Dermosols and Kandosols dominate with Chromosols on the upper slopes. Sodosols are common along drainage lines and can be associated with localised salinity (Murphy and Lawrie 1998), however, have not been mapped in the vicinity of the site (these would be classified as a Soloth under the Great Soil Groupings).

Shallow stony Rudosols and Tenosols are found across the crests and steep upper slope environments with Chromosols found on the moderately steep upper slopes (Murphy and Lawrie 1998).

5.4.2 Dryland salinity

A salinity risk assessment by Humphries (2000) found the Toongi catchment to have a high salinity hazard rating. However, an additional hydrogeological study into dryland salinity of the Toongi catchment (Smithson, 2001) found no moderately to highly saline areas within the DZP Site. Some indications of soil salinity (changes to vegetation) and small bare patches were noted within Paddy's Creek Catchment to the west of the DZP Site, although the noted areas were localised to the drainage channel.

Groundwater systems at Toongi consist of a combination of local, intermediate and regional groundwater. Potential groundwater discharge and saline sites within Toongi and the proposed DZP Site have been identified as surface drainage lines, break of slope and on the valley floors or alluvial flats (Smithson, 2001). Areas at greatest risk of dryland salinity are those where the groundwater table is less than 5 metres below natural ground surface.

These areas have been mapped for the regional catchments including the DZP Site (Smithson, 2001 – *Figure 6* and *Figure 13*). Based on observation of *Figure 6* from Smithson (2001) there are no recorded saline sites on the DZP Site, and observation of *Figure 13* from Smithson (2001) indicates that <5% of the DZP Site is expected to have water tables <5 m depth (all along the alluvium of Paddy's, Wambangalang and possibly Cockabroo Creeks). *Figure 6* and *Figure 13* of Smithson (2001) have been provided in **Appendix H** of this report.

Estimated depth to water table levels between 0 m to 10 m below surface do occur in the vicinity of Wambangalang Creek and Toongi Township (Smithson, 2001 – *Figure 13*), which are associated with alluvial flats. These areas were therefore identified by Smithson (2001) as having the highest likelihood of encountering risks of salinisation in the landscape.

However, it should be noted that the water table levels mapped by Smithson (2001) were based on using topographic contouring as a guide to water table levels at a regional scale. Therefore, DZP Site local scale interpretation for groundwater levels and contouring will be more realistic in regards to the likelihood of salinisation. Current monitoring of bores within the local catchment of the DZP Site has shown bores within the break of slope and drainage lines also have SWLs <10 m (e.g. bore DWB011, after Golder 2002). It should also be noted that the groundwater does not generally have a high salinity, with the greatest concentrations being moderately brackish (see **Table 6**).

During a site inspection conducted by a principal soil scientist from Environmental Earth Sciences (Stuart Brisbane) on 26 July 2012, a number of observations were made relating to salinity and potential occurrence of springs. In summary, no evidence of actual salinity was observed, and potential salinity is likely to be related to drainage lines and break of slopes especially where this coincides with a change in geology (i.e. from igneous to sedimentary, and consolidated to colluvial / alluvial).

The only locations of actual ground surface discharge at the time of inspection were to the north of the property in the vicinity of the proposed Area 4 LRSF (see **Figure 3**). These areas are thought to be associated with outcropping or shallow sub-cropping basalts facilitating surface expression of groundwater. Evidence of poor drainage (sedge-like vegetation and slightly higher salinity of run-off water at break of slope) was noted immediately upslope (to the east) of the proposed Area 2 LRSF. Further discussion of site observations from this inspection in relation to salinity and landscape are provided in **Appendix J**.

5.5 Bedrock geology

This geological description is based on that provided in RWC (2013) as well as Alkane (2012 and 2013). The DZP Site is located at the northern end of the Palaeozoic age Lachlan Fold Belt where volcanic-sedimentary intrusive sequences of Siluro-Devonian age are covered by on-lapping Mesozoic (Triassic) aged sediments of the Gunnedah Basin.

The DZP Site is centred on an alkaline suite of intrusive and extrusive rocks that intrude and in part inter-finger and overlie relatively flat lying sediments. The alkaline igneous rocks are of Jurassic age (180 to 200 million years old [My]) and are considered part of a relatively extensive alkaline igneous complex in the region south of Dubbo (in turn part of the major eastern Australian volcanic event).

Geological mapping has identified a number of trachytes in the region. Geochemical sampling by AZL, and others, has identified anomalous levels of niobium, yttrium and zirconium of potential economic significance within two of these trachytes. One of these is the Toongi deposit, a relatively small intrusive sill or lava flow comprised of hydrothermally altered trachyte.

The Toongi trachyte is a roughly elliptical in shape with outcrop dimensions of 600 m x 400 m and is approximately 100m thick. Weathering has been observed to approximately 15m depth, however the mineral assemblage is not impacted. The geology plan of the DZP Site (**Figures 6a** and **6b**) has been derived from detailed geological mapping of the ore body and immediate environs prepared by Multi Metal Consultants Pty Ltd (Chadwick, 2000), with more regional aspects obtained from the published Dubbo 1:250,000 geological map sheet (AGSO, 1999) with some updates and interpretation by Alkane personnel.

Table 4 and **Figure 6a** provide the general stratigraphy of the regional geology below the DZP Site and reference codes for regional geology. **Figure 6b** also shows the DZP Site and surrounds geology in more detail (after Alkane, 2012).

TABLE 4 REGIONAL GEOLOGICAL STRATIGRAPHY

System Age	Group	Formation	Reference Code (1:250 000 Map sheet)	Description
Quaternary	-	-	Qa	Alluvium
Quaternary	-	-	Qo	Colluvial gravel, sand and silt
Tertiary	-	-	Tb	Olivine basalt as flows, dykes and plugs
Jurassic	-	-	Jt/Js	Trachyte, quartz trachyte, minor phonlite, rhyolite and syenite as flows, tuffs, plugs and necks
Jurassic	-	-	Jb	Olivine basalt as flows, dykes and plugs
Triassic	Gunnedah Basin	Napperby	Rp	Siltstone, lithic quartz-sandstone, minor conglomerate
Devonian	Gregra	Berkley	Dge	Latitic lithic-crystalvolcaniclastic sandstone, minor breccia, siltstone, shale
Devonian	Gregra	-	Dgn	Sandstone, shale, siltatons, tuffaceous sediment, rhyolit, ash tuff

System Age	Group	Formation	Reference Code (1:250 000 Map sheet)	Description
Devonian	Gregra	Cuga Burga volcanics	Dgo	Latitic, crystal-lithic sandstone, breccia, siltstone, tuff, latite and lesser andesite, basalt
Devonian	-	-	Dmd	Dolerite dykes, diorite, gabbro sills and stocks
Devonian	Yeoval Complex	-	Dyg	Pink microgranite, farroh, astingsite biotite granite, red biotite microgranite
Siluro-Devonian	Toongi	-	S-Do	Sandstone, shale, siltstone, latitic sandstone, volcanoclastic sandstone
Silurian	Toongi	-	Sah	Fine and coarse cherty tuff, rhyolitic tuff
Silurian	Cudal	Hanover	Sce	Micaceous shale, siltstone, fine-grained sandstone, rhyolite-tuff, tuff-sandstone, latitic sandstone, breccia
Silurian	Toongi	Undifferentiated	So	Sandstone, shale, siltstone, latitic sandstone, volcanoclastic sandstone
Silurian	Toongi	Wirrabilla	Sob	Sandstone and siltstone

Note(s): Source: Dubbo 1:250,000 Geology Map (AGSO/DMR 1999)

5.6 Hydrostratigraphy and groundwater flow system

5.6.1 Background

Two connected groundwater systems are reported to exist in the Toongi catchment: a consolidated fractured rock system; and an unconsolidated sedimentary system consisting mostly of alluvium (with minor colluviums and Aeolian deposits). The alluvium overlies the fractured rock system, mostly filling past valleys and drainage lines beneath current day ephemeral creek lines (Smithson, 2001).

Smithson (2001) reports the thickness of alluvium in Toongi catchment at 16-20 m, while Golder (2002) reports a thickness of 43.5 m in bore DWB012, >32 m in bore DWB019 and 3.5 m in bore DWB014. Bore DWB014 recorded a weathered saprolytic trachyte profile from 3.5 m to the end of hole at 50 m (only partially weathered from 25m). This depth of weathering does not appear to be observed at any other location. For example, bore DWB015 contains a 6 m deep residual soil profile over weathered rock to 28 m, beyond which the basalt is described as fresh.

The general concept for groundwater occurrence below the DZP is that alluvial groundwater is unconfined and relatively shallow and fresh, as the water table responds relatively rapidly to recharge via rainfall. Fractured rock groundwater systems have generally been interpreted to be unconfined near the top of the aquifer (water table surface) but confined at depth, resulting in variations in flow paths (local, intermediate or regional flow systems). Fractured rock groundwater systems have been interpreted to be relatively saline due to longer time periods for geochemical interaction with the aquifer matrix (Smithson, 2001).

The salinity relationship described above may be reversed where the flow system moves from the fractured rock into alluvium at its down-gradient end.

It is apparent from observation of *Figure 14* from Smithson (2001) and *Figure 4* from Golder (2002) that the area of the DZP Site experiences radial groundwater flow from the topographic high to the south-east (Dowds Hill). Groundwater flows towards the local creek systems of Wambangalang and Paddy's to the west, Cockabroo to the south and the Macquarie River tributaries to the north.

Recharge mechanisms to the fractured rock aquifer have been identified where trachyte intrusions outcrop at the top of the catchment. Some local recharge is also expected along the alluvial valleys, either as direct rainfall recharge or recharge from the creeks during periods of flow.

5.6.2 Aquifers and aquitards

Within the bedrock, groundwater flow is expected to be controlled by fractures with preferential flow through formations with a relatively high density of open interconnected fractures. Within the alluvium, sands and gravels would be the primary aquifers with finer grained silts and clays acting as aquitards.

Along the east side of the Wambangalang Creek valley, the alluvium is known to be dominated by clay at several locations (e.g. DWB012 and DWB019). Recent drilling of three additional boreholes for the Soil and Land Capability Assessment for the DZP Proposal (SSM, 2013) has shown no evidence of coarse-grained alluvium within the proposed footprint of the Area 3 LRSF (see **Figure 3** for location). Multiple test pits have also been excavated to shallow depth in this area. None of these test pits revealed clean sands or gravels close to the ground surface.

There are known to be coarse grained sediments within the alluvium at some locations. Golder (2002) stated that the sands and gravels in the alluvium represent stream channel deposits that have become buried by other alluvial sediments. Some of these are likely to be isolated from the present day stream bed and others are likely to be in good hydraulic communication with it.

5.6.3 Results of registered bore search

A total of 38 registered bores were located within an approximate 5 km radius of the DZP Site. A total of 97 registered bores were located within an approximate 5 – 10 km radius of the DZP Site. All registered bores are presented in **Figure 8** with a summary of pertinent groundwater information presented in **Appendix A** for bores within the 5 km radius. All registered bore work summary forms are presented in **Appendix B** (135 work summaries in total). Eleven registered bores occur within the DZP Site Investigation Area and are presented in **Figure 7**. The available data for these bores are presented in **Table 5**.

Total drilled depths of the above mentioned bores were between 7.8 and 79.2 m, and were registered for a number of uses, intended for water supply, typically stock and domestic stock. Yields were generally low (less than 1 L/sec), with the exception of the bores drilled on the DZP Site in 1998 and 2005 (GW064727 and GW803000 – see **Figure 8**), which indicated yields of between 4.0 and 6.0 L/sec (most likely during airlift testing post-drilling). The identified water bearing zones were found to be within unconsolidated alluvium and colluvium sediments in the lower to mid catchments and likely fracturing of basement rocks in the upper catchment areas.

TABLE 5 REGISTERED GROUNDWATER BORES IN DZP SITE AREA

Bore ID	Reg Use	Depth (m)	Water Bearing Zones/Fracture Zones			Yield (L/sec)	Summary Geology	Date Installed
-	-	-	From depth (m)	to depth (m)	Thickness (m)	-	-	-
GW000655	NK	45.10	32.30	35.30	3.00	0.30	Unconsolidated	1921
GW003590	NK	37.50	34.40	34.40	0.00	0.46	Unknown	-
GW003867	Domestic stock	50.30	28.30	28.30	0.00	0.76	Unknown	1945
GW003889	Stock	79.20	1.80	10.00	8.20	0.08	Unknown	1946
			51.50	51.50	0.00	-	-	-
GW014908	Stock	28.00	19.50	20.10	0.60	0.06	Unknown	1963
			22.60	23.80	1.20	0.30	Unknown	-
			24.10	26.20	2.10	0.61	Consolidated	-
GW019345	NK	7.80	-	-	-	-	-	-
GW019346	NK	27.70	-	-	-	-	-	1961
GW056152	Domestic stock	27.40	-	-	-	-	-	-
GW064727	Domestic stock	51.00	30.00	34.00	4.00	0.32	Consolidated	1988
			50.00	51.00	1.00	4.73	Consolidated	-
GW803000	Domestic stock	72.00	30	36	6.00	6.00	-	2005

Note(s):
1. Source: Groundwater Works Summary from Department of Natural Resources, NSW (March, 2012)
2. NK – Not Known

The static water level (SWL) was reported in six out of the ten bores in **Table 5** (note data not presented in **Table 5**), with varying levels ranging between 12.2 and 30.0 m below ground level. Several bores had reported groundwater salinity data that typically indicated fresh water in the upper catchment areas of the DZP Site and brackish water in the lower catchment (salinity range 1001 – 3000 mg/L).

A number of off-site registered (and some unregistered) bores and wells exist at the intersection of Eulandool and The Springs Roads (known as Cockleshell Corner) to the south-west of the DZP Site (see **Figure 7**). One of these (GW802169) is licensed for irrigation use and has a reported yield of 8.83 L/sec (measured by air lift during installation). It was installed in 2004 into "gravel and shattered rock" from 4.0 to 6.0 m depth, but has never been equipped for use (location also provided on **Figure 8**). An adjacent bore (GW044705) is installed into "slate water supply" rock from 10.4 m to 22.4 m depth and yielded 2.08 L/sec.

There are also known to be several unregistered bores within and around the Toongi Township, some of which are used for domestic purposes (Golder, 2002). The location of one of these bores is shown on **Figure 8** and labelled TWB.

5.6.4 Potentiometric surface

Groundwater levels across the DZP Site catchment in August 2001 and February 2013 are presented in **Figures 9a** and **9b** respectively. For some bores, the water table elevation may differ slightly from the level shown due to the screened interval of the bore being below the water table. However, the groundwater elevations in **Figures 9a** and **9b** are generally considered to be representative of the water table elevation at the locations of the bores.

A hydrograph of groundwater levels at each of the four separate times of gauging (August 2001, March 2012, July 2012 and February 2013) is also presented as **Chart 1**, while field measurements and conversion to relative datum is included in **Table 6**. **Table 6** also reports chemical data recorded in the field.

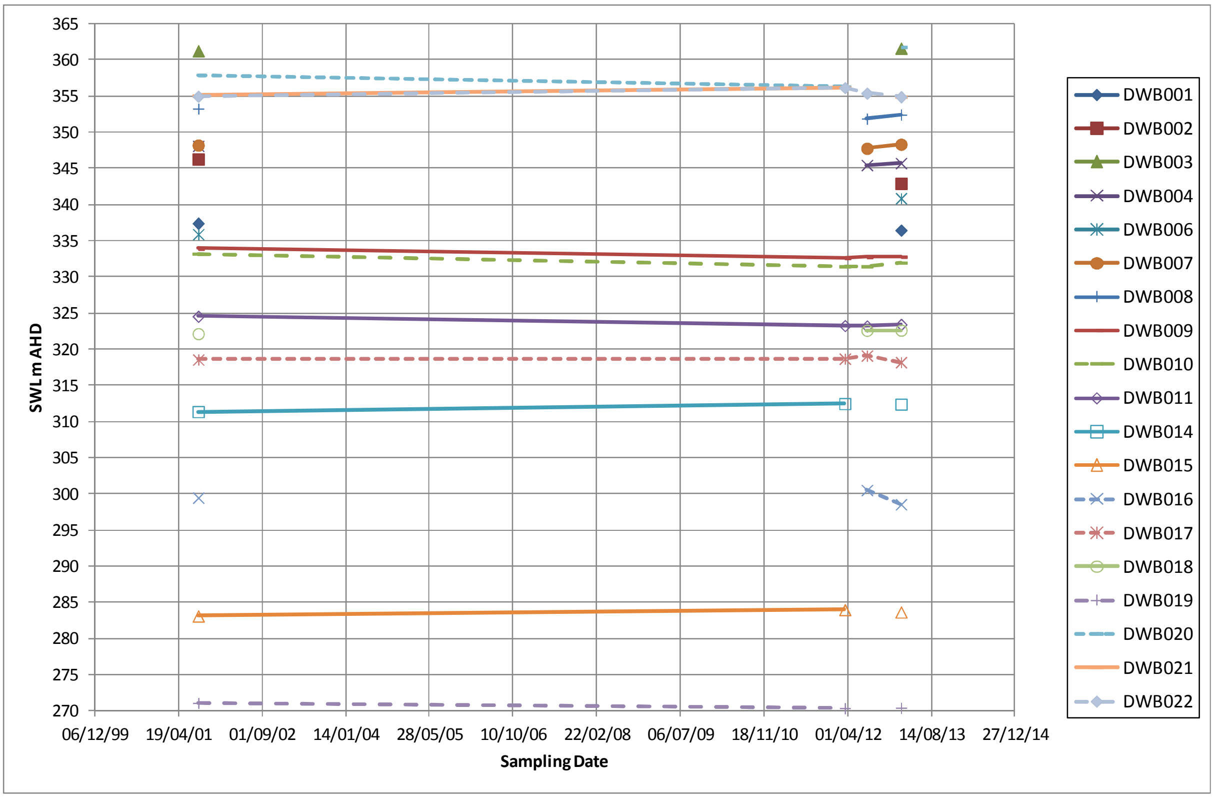


Chart 1: Bore Hydrograph, August 2001 – February 2013

At the time of the investigation by Environmental Earth Sciences in 2012, the local area had recently received approximately 122 mm of rain over four days (2 – 5 March 2012), following a wetter than average preceding summer period. The wetter summer resulted in high pasture growth and biomass across the landscape with near 100% ground cover. As a result, the bores were difficult to find and not all the bores were sampled and assessed over the allocated site inspection timeframe. Most of the major drainage lines contained running water.

TABLE 6 SUMMARY OF GROUNDWATER FIELD DATA

Bore	Date	Depth to Groundwater	Elevation of Measuring Point	Groundwater Elevation	DO	EC	pH	Redox	Temp	Comments
Units	**xx/xx/xxxx**	**m**	**m(AHD)**	**m(AHD)**	**ppm**	**µs/cm**		**mV**	**ºC**	
DWB001	15/08/2001	23.10	360.52	337.42	5.77	840	7.52	10.2	-	-
	14/02/2013	24.07		336.45	-	-	-	-	-	Pipe stuck in bore
DWB002	15/08/2001	15.03	361.32	346.29	5.01	1835	7.05	11.7	-	-
	14/02/2013	18.39		342.93	1.23	1564	6.70	-174	23	Turbid, grey, sulfur odour
DWB003	15/08/2001	25.78	387.04	361.26	1.74	637	6.50	12.6	-	-
	14/02/2013	25.43		361.61	-	-	-	-	-	Blockage at 10m
DWB004	15/08/2001	16.88	364.99	348.11	-	-	-	-	-	-
	25/07/2012	19.53		345.46	-	-	-	-	-	-
	14/02/2013	19.27		345.72	-	-	-	-	-	Blockage at 10m
DWB005	15/08/2001	4.63	352.07	347.44	1.67	1020	7.32	6.6	-	-
DWB006	15/08/2001	12.05	347.94	335.89	0.3	1747	7.56	12.6	-	-
	14/02/2013	7.07		340.87	4.62	1268	6.5	10	22	Clear, no odour
DWB007	15/08/2001	17.31	365.53	348.22	3.63	1408	7.22	10.3	-	-
	25/07/2012	17.75		347.78	-	-	-	-	-	-
	14/02/2013	17.19		348.34	1.23	1360	6.80	-151	23	Clear, slight sulfur odour
DWB008	15/08/2001	21.95	375.22	353.27	1.85	1335	6.85	9.1	-	-
	25/07/2012	23.34		351.88	2.71	1297	6.83	-163	19	-
	14/02/2013	22.78		352.44	7.01	1314	7.27	165	21	Clear, no odour

Bore	Date	Depth to Groundwater	Elevation of Measuring Point	Groundwater Elevation	DO	EC	pH	Redox	Temp	Comments
Units	xx/xx/xxxx	m	m(AHD)	m(AHD)	ppm	µs/cm		mV	ºC	
DWB009	15/08/2001	9.43	343.33	333.90	2.65	1618	4.05	7.2	-	-
	15/03/2012	10.73		332.60	0.4	-	6.70	-60	-	-
	25/07/2012	10.59		332.74	-	-	-	-	-	-
	14/02/2013	10.53		332.80	0.46	1214	6.50	-143	21	Clear, slight sulfur odour
DWB010	15/08/2001	11.82	345.03	333.21	2.22	1189	6.96	9.7		-
	15/03/2012	13.58		331.45	-	-	-	-	-	-
	25/07/2012	13.58		331.45	1.19	1860	6.42	-1	20	Bore pumped dry, silty sample
	14/02/2013	13.06		331.97	-0.01	2140	6.17	-97	-	Slightly turbid, brown, no odour
DWB011	15/08/2001	>0	324.25	324.55	4.1	1881	7.03	10.2	-	-
	15/03/2012	0.99		323.26	3.79	1499	6.70	89	21	-
	25/07/2012	1.05		323.20	-	-	-	-	-	-
	14/02/2013	0.83		323.42	2.58	1591	6.61	84	20	Clear, no odour
DWB011a	15/03/2012	>0	-	-	0.17		6.99	111	20	Unregistered bore next to DWB011
	14/02/2013	>0	-	-	-	-	-	-	-	Flowing
DWB012	15/08/2001	11.43	291.85	280.42	3.05	12990	6.68	5.8	-	-
DWB014	15/08/2001	21.47	332.84	311.37	4.08	6940	6.84	6.4	-	-
	15/03/2012	20.36		312.48	5.89	2510	6.43	80	-	-
	14/02/2013	20.44		312.40	3.78	8570	6.67	99	22	Brown silty
DWB015	15/08/2001	25.29	308.39	283.10	1.37	4570	6.90	8.7	-	-
	15/03/2012	24.42		283.97	4.28	10980	8.00	27	-	-

Bore	Date	Depth to Groundwater	Elevation of Measuring Point	Groundwater Elevation	DO	EC	pH	Redox	Temp	Comments
Units	xx/xx/xxxx	m	m(AHD)	m(AHD)	ppm	µs/cm		mV	ºC	
	14/02/2013	24.74		283.65	-	-	-	-	-	-
DWB016	15/08/2001	19.90	319.37	299.47	5.92	3010	6.87	11.5	-	-
	25/07/2012	18.85		300.52	4.27	2900	6.96	-104	20	Clear
	14/02/2013	20.82		298.55	3.2	2900	6.87	85	21.5	Brown silty, no odour
DWB017	15/08/2001	2.24	320.81	318.57	4.6	4190	7.08	12.3	-	-
	15/03/2012	2.12		318.69	8.1	-	6.32	150	-	-
	25/07/2012	1.70		319.11	-	-	-	-	-	-
	14/02/2013	2.61		318.20	0.65	2700	6.99	2	19.7	Clear, no odour
DWB018	15/08/2001	4.27	326.42	322.15	1.35	3050	7.57	11.4	-	-
	25/07/2012	3.81		322.61	0.44	2930	7.25	75	20	Clear, no odour
	14/02/2013	3.79		322.63	0.14	2900	7.37	-121	20.4	Clear, slight sulfur odour
DWB019	15/08/2001	10.14	281.23	271.09	7.8	1139	7.14	10.2	-	-
	15/03/2012	10.87		270.54	6.02	1117	5.97	55	-	-
	14/02/2013	10.82		270.59	4.1	1274	6.26	127	21.2	Turbid, no odour
DWB020	15/08/2001	32.60	390.47	357.87	4.65	486	6.88	11.2	-	-
	15/03/2012	34.17		356.30	-	-	-	-	-	-
	14/02/2013	28.69		361.78	-	-	-	-	-	-
DWB021	15/08/2001	35.53	390.59	355.06	2.75	686	7.02	10.8		-
	15/03/2012	34.36		356.23	-	-	-	-	-	-
	14/02/2013	35.66		354.93	-	-	-	-	-	Blockage, no cap

Bore	Date	Depth to Groundwater	Elevation of Measuring Point	Groundwater Elevation	DO	EC	pH	Redox	Temp	Comments
Units	**xx/xx/xxxx**	**m**	**m(AHD)**	**m(AHD)**	**ppm**	**µs/cm**		**mV**	**ºC**	
DWB022	15/08/2001	36.29	391.26	354.97	2.8	589	7.02	19.6		-
	15/03/2012	35.10		356.16	-	-	-	-	-	-
	25/07/2012	35.86		355.40	-	-	-	-	-	Blockage at 10m
	14/02/2013	36.36		354.90	-	-	-	-	-	Blockage
DWB023	15/08/2001	25.73	308.79	283.06	3.62	3810	7.37	10	-	-
TWB	15/03/2012	5.71	-	-	8.02	2910	8.14	49	21.5	Toongi unregistered domestic well
	14/02/2013	6.29	-	-	4.32	3130	7.01	118	21.6	Clear, no odour, pumped for 15 min at 1.43 L/sec and reduced SWL 0.58m
Cockleshell Corner well	25/07/2012	0.9	-	-	1.58	3830	6.99	113	18	Well excavated to 5.34m in cobbles
	14/02/2013	2.18	-	-	0.03	4120	6.84	225	19.4	Clear, no odour
Cockleshell well	25/07/2012	2.23	-	-	0.13	2091	7.70	-266	19	Windmill, 6.7m deep, silty turbid water, minor S odour, fast recovery
	14/02/2013	3.05	-	-	0.06	2189	7.83	-315	19	Brown organic colour, slight sulfur
GW008373	15/03/2012	13.11	-	-	-	-	-	-		Windmill
	25/07/2012	13.83	-	-	3.45	2149	6.53	152	19.3	-
	14/02/2013	14.88	-	-	5.75	2210	6.45	132	23.5	-
GW058221	14/02/2013	1.99	-	-	0.08	5980	8.00	-288	19.5	Clear, no odour

Note(s): this table includes data collected for this study (collected in 2012 and 2013) as well as previous data (Golder, 2001)

Figures 9a and **9b**, **Table 6** and **Chart 1** all indicate that groundwater levels have remained relatively consistent over time, despite considerable variation in climatic conditions. There is little difference between the water table surfaces shown in **Figures 9a** and **9b**, with hydraulic gradients typically in the range 0.02 to 0.03 but ranging between lower and upper limits of approximately 0.01 and 0.05.

The most elevated groundwater levels are at bores DWB003 and DWB020 at the top of the catchment above the proposed open cut, followed by bores DWB021 and DWB022 within the proposed open cut. Bores DWB015, DWB014 and DWB019 have consistently had the lowest groundwater levels, which is also reflective of topography. These contours clearly show the general direction of groundwater migration, from recharge via outcropping fractured rock at the top of the catchment, to discharge to the surrounding alluvial ephemeral creek systems.

The water table surface is obviously affected by the creeks and there is evidence that water quality in the creeks is affected by groundwater discharge. However, the creeks are reported to be ephemeral. It is likely that the flux of groundwater in this flow system is not sufficient to maintain flow in the creeks during dryer months, but the groundwater flow system may continue through the relatively permeable alluvium parallel to and beneath the creeks. Golder (2001) stated that there was likely to be seasonal interchange between the alluvial aquifers and the streams, with the aquifers discharging when the streams are low and recharging when the streams are high.

Table 6 shows that bores DWB005, DWB011/011a, DWB016, DWB017 and GW058221 have depths to water less than 5 m. The locations of these bores correlate well to areas where the water table is likely to be intersecting the ground surface as indicated on **Figures 9a** and **9b**.

Discussion with Terry Rothery who owns the “Toongi Valley” property to the north-west of the proposed open cut indicated that bore DWB011a, located immediately adjacent to bore DWB011 at the confluence of two drainage lines, started flowing again in recent years. This correlates with the increased rainfall recorded in 2010 and discussed above. Previously during the drought period (approximately 2003 – 2009) the SWL in bore DWB011 was slightly lower than the top of the casing, indicating a reduced pressure within the water bearing unit the bore is screened within.

5.6.5 Significance of relationship of groundwater flow system to topography

Overall, the water table surface is a subdued form of the topography, which is typical of all local and regional groundwater flow systems. Depths to groundwater are greatest in areas of groundwater recharge (e.g. in the vicinity of the proposed open cut) and shallowest in areas of groundwater discharge (e.g. DWB011).

Groundwater flows radially from the high ground area of the proposed open cut to the surrounding valleys. Radial flow paths that mimic topography have been identified to the west and north-west, north to north-east and south (south-west through to south-east) of the recharge zone at the top of the catchment (see **Figures 9a** and **9b**). The groundwater flow system is interpreted to continue into the alluvium in the valleys around the edges of the bedrock, and within the colluvium and alluvium infilling gullies in the higher ground areas.

Detailed mapping of springs has not been undertaken for this report and large-scale groundwater discharge features have not been observed. However in the process of constructing the groundwater surfaces in **Figures 9a** and **9b**, it was apparent that the water table effectively meets the ground surface in the gullies of the bedrock high ground area, and is locally lowered by the gullies. Therefore, there is groundwater discharge to the major gullies such as the gulley to the south-west of the ore body occupied by the North Tributary of Cockabroo Creek and the gulley to the north-west of the ore body in which bore DWB011 is located (identified as Watercourse B in the EIS).

Although groundwater discharge is interpreted to be taking place from the bedrock in these gullies, the seepage rate is considered to be relatively low such that the groundwater discharging from the bedrock passes through the colluvium in the base of the gullies. Hence, it does not result in continuous surface expression in the gullies.

The major creeks limit the extent of the groundwater flow from the DZP Site. The groundwater flow system radiating from the DZP Site is bounded to the west at Wambangalang Creek/Paddy’s Creek. Its extent is also limited to the south and north respectively by Cockabroo Creek and the tributary of the Macquarie River that drains the area in the vicinity of bore DWB023.

Conceptual cross sections representing hydrogeological processes across the site have been provided in **Figures 10a** (south to north-west) and **10b** (south-west to north, north-east), after Golder (2002). As well as predicted groundwater flow paths, these figures also show the proposed locations of DZP Site infrastructure across the catchments.

5.7 Hydraulic parameters and groundwater flow velocities

5.7.1 Previous data

Golder (2002) undertook initial hydraulic testing in the form of air lift yield tests and rising head tests on bores DWB012, DWB014, and DWB016-DWB019. Bores DWB012 and DWB019 are screened in alluvium. Bores DWB014, DWB016, DWB017 and DWB018 are screened in bedrock.

For the four bedrock bores tested, Golder’s hydraulic conductivity (K) estimates ranged between 2.6 x 10^{-3} m/day at bore DWB016 and 0.31 m/day at bore DWB014. Golder’s transmissivity (KD) estimates ranged between 0.1 m^2/day at bores DWB016 and DWB017 and 3.7 m^2/day at bore DWB014. Based on these results, a typical hydraulic gradient of approximately 0.02 and an effective porosity for fractured rock of 0.01, the average linear velocity of groundwater flow through the bedrock would be in the range 2 to 200 m/year.

If correct, the high yields of several L/s reported at two bores in the high ground area (see Section 5.5.3) show that there may be localised high conductivity zones within the bedrock, through which groundwater would be expected to move at much higher rates if they are laterally extensive.

The two bores tested in the clay alluvium (DWB012 and DWB019) indicated a K value of 5.8 x 10^{-3} and 1.1 x 10^{-2} m/day and a KD of 0.1 and 0.4 m^2/day. Based on a hydraulic gradient of 0.03 between DWB015 and DWB012 and an effective porosity for the clay alluvium of 0.1, the estimated average linear velocity between bores DWB015 and DWB012 would be approximately 0.6 m/year.

5.7.2 Recent constant discharge, slug and recovery tests

As part of the groundwater sampling program undertaken in March 2012, slug tests were undertaken on bores DWB011, DWB017 and DWB019. Bores DWB011 and DWB017 are installed in the fractured rock aquifer, and bore DWB019 is screened in fine-grained (clay) alluvium. A slug test was also attempted on bore DWB015, however, it did not recover following drawdown during pumping, and as such a test was unable to be conducted. This suggests that K at this location is lower than at the other bores tested.

'Rising head' tests were performed, in which a volume of water was removed from the casing and screen over a short period using a submersible pump, and the return of the water table to its (pre-slug) 'static' level was then measured. Analysis was attempted using the Cooper-Bredehoft-Papadopulos (CBP), Bouwer-Rice (BR) and Hvorslev methods (after Duffield 2007, Fetter 2001 and Kruseman and de Ridder 2000). Of these methods, the Bouwer-Rice method was considered the most applicable (the Ht/t relationship was relatively uniform).

In addition to the above slug tests, a constant discharge test was undertaken on well TWB in the Toongi Township in the vicinity of Wambangalang Creek (see **Figure 8** for location). This test consisted of 2½ hours of constant discharge at a rate of 1.35 L/sec from the 0.8 m diameter well, which had an initial SWL of 6.25 m and is approximately 16 m deep. Recovery was also monitored. Only one metre of drawdown was recorded for the removal of over 12 m^3 of water, and the results of the analysis reflect this high specific capacity.

A summary of results obtained from the Bouwer-Rice slug test data interpretation and the test of well TWB is provided in **Table 7**, and the data is presented in **Appendix D**. **Table 7** also includes previous estimates of K and KD by Golder (2002) and estimates of groundwater velocity at each location based on the local hydraulic gradients interpreted from **Figure 9b**.

TABLE 7 RESULTS OF RISING HEAD / RECOVERY TEST DATA INTERPRETATION

Bore	Aquifer	Test Analysis	Q	K	KD	Approximate Hydraulic Gradient	Average linear velocity, v
Units			m^3/day	m/day	m^2/day	m/m	m/year
DWB012	**Clay Alluvium**	Golder (2002)	-	0.011	0.4	0.02	0.8
DWB019	**Clay Alluvium**	EES (2012)	-	0.01	0.2	0.01	0.4
		Golder (2002)	-	0.006	0.1	0.01	0.2
TWB	**Coarse Grained Alluvium**	EES (2012) Jacob	117	5	50	0.003	60
DWB011	**Fractured Rock – Sedimentary**	EES (2012)	-	0.001	0.06	0.026	1.0
		Golder (2002)	-	-	-	-	-
DWB016	**Fractured Rock – Sedimentary**	Golder (2002)	-	0.003	0.1	0.02	1.9
DWB017	**Fractured Rock – Sedimentary**	EES (2012)	-	0.0007	0.02	0.01	0.3
		Golder (2002)	-	0.003-0.06	0.1-1.6	0.01	1.1-22
DWB014	**Fractured Trachyte**	Golder (2002)	-	0.31	3.7	0.02	230
DWB018	**Fractured Trachyte**	Golder (2002)	-	0.05	2.1	0.01	18

Note(s): 1. K hydraulic conductivity; KD transmissivity
2. v average linear velocity was calculated assuming an effective porosity of 0.1 in alluvium and 0.01 in bedrock (Freeze and Cherry, 1979)

The sedimentary (sandstone / siltstone of the Triassic aged Napperby Formation) bedrock analyses show a relatively low K in the order of 0.001 m/day and average linear velocity through the bedrock of up to 2 m/year.

The volcanic (trachyte of Jurassic age that have extruded onto the Triassic aged Napperby Formation sediments) bedrock analyses show K in a higher range of 0.05-0.3 m/day. As a result, the average linear velocity through this igneous bedrock is calculated to be up to approximately 200 m/year (i.e. two orders of magnitude greater than the sedimentary bedrock in both K and velocity values). Hence, there may be preferential pathways in the igneous bedrock at some locations through which groundwater can migrate at significantly higher rates than in sedimentary rock or in igneous rocks with a lesser degree of fracturing.

This correlates with high yields of several L/s reported previously in two bores (see Sections 5.5.3 and 5.6.1), the water bearing zones of which reported ‘shale’ and ‘limestone’ lithology’s. Yields of several L/s would require localised transmissivity of at least 10 m^2/day and a hydraulic conductivity of at least 1 m/day. There are also likely to be zones of much lower hydraulic conductivity in the bedrock with very low rates of groundwater flow.

The hydraulic conductivity of the clay alluvium at bore DWB019 was interpreted by Environmental Earth Sciences to be 0.01 m/day, which is approximately double the value previously interpreted for bore DWB019, and is similar to the value previously interpreted for bore DWB012.

The K and KD of the alluvium in which well TWB is screened are approximately 3 orders of magnitude greater than for the clay alluvium at bores DWB012 and DWB019. The K of the alluvium at well TWB is considered to be typical of a relatively “clean sand” (Freeze and Cherry, 1979). Therefore, it is assumed that this well is installed in fluvial sand. Although the hydraulic gradient is relatively low along the Wambangalang Creek valley, the average linear velocity of groundwater through any laterally continuous fluvial sands parallel to and in the vicinity of Wambangalang Creek would be orders of magnitude greater than the average linear velocity through the clay alluvium or the bedrock.

The majority of the DZP Site is underlain by sedimentary bedrock and clay-dominated alluvium/ colluvium which have the hydraulic properties of aquitards, i.e. relatively low hydraulic conductivity and transmissivity. However, there are interpreted to be some sand-dominated alluvial sediments in the vicinity of Wambangalang Creek which have the hydraulic properties typical of an aquifer, i.e. a relatively high hydraulic conductivity and transmissivity.

There are also some volcanic rocks in the bedrock high ground area which are interpreted to have an intermediate range of hydraulic properties such that, in places, they would be considered to be aquifers (see Glossary for definitions of aquitard and aquifer). Areas of volcanic rock outcrop have been mapped beneath the proposed Area 4 LRSF and the southern half of the Processing Plant Area (see **Figure 6b**). The southern half of the proposed Plant Area has been confirmed to have “extremely weathered basalt” within 0.6m of the current ground surface (SSM, 2012).

5.8 Estimated recharge rates and water balance

Crosby *et al*. 2010b state that, for the soil types along the creek systems of the catchment (Tenosols, Kandosols and Chromosols), recharge would be expected to be in the range of 5-20 mm/year.

5.9 Hydrogeochemistry

5.9.1 Introduction

Collection of physical information from the site has been supported by chemical data, with a clear indication of fresh water recharge in the high ground in the central part of the DZP Site and an increase in salinity along the flow paths to the discharge areas in the valleys (**Figure 12**). In places, the alluvial groundwater has been observed to be subsequently diluted (e.g. at the location of bore DWB019, as shown on **Figure 12**), likely by fresh recharge from rainfall and ephemeral creek flows.

Based on the results presented in **Tables 6, 8** and **9**, the groundwater can be characterised on the basis of beneficial use protection and hydrogeochemical evolution from recharge to discharge zones along the local flow path that has been identified at the DZP Site. This local flow path consists of recharge on the crest of the catchment in the vicinity of the proposed open cut, to discharge to the alluvial sediments associated with the ephemeral creek systems of the region.

From a water quality perspective, the data presented in **Tables 6, 8** and **9**, and in **Appendix C**, shows groundwater beneath the DZP Site as having a generally neutral pH and being fresh to slightly brackish, with low concentrations of most dissolved metals. TDS ranges from 336-7,600 mg/L (average 1,540 mg/L) and chemistry is dominated by the cations sodium (Na) and magnesium (Mg) and the anions chloride (Cl) and bicarbonate (HCO_3). Calcium (Ca) and sulfate (SO_4) are sub-dominant.

There is no evidence that the salinity has been significantly enhanced by evaporation or evapo-transpiration. However, at two locations there are significant changes in salinity with time between the sampling events of 2001 and 2012. In bore DWB015, the TDS doubled but the water type remained relatively consistent, changing from Na(Ca)Cl >$MgHCO_3$ dominated to Na(Mg)Cl dominated. In contrast, in bore DWB017 the TDS reduced by over an order of magnitude (from 2,890 to 245 mg/L) but once again the water type remained relatively consistent, changing from Na(Ca)Cl = $MgHCO_3$ dominated to NaCl = $MgCaHCO_3$.

A possible reason for the change at DWB015 is that this bore is a deep bore screened in basaltic bedrock and the groundwater in the screened interval is stratified with relatively high TDS groundwater towards the base of the bore, which may reflect a deeper flow system. Bore DWB017 is screened in sandstone and has a SWL relatively close to the ground surface (1.7-2.6m as shown in **Table 6**), suggesting this bore could be accepting fresh recharge from the surface. The data from this bore may reflect a localised shallow flow system.

TABLE 8 GROUNDWATER INORGANIC CHEMISTRY RESULTS (ACIDITY, SALINITY, CATIONS AND ANIONS)

Bore	Date	pH	TDS	Na	Ca	Mg	K	NH_4	Cl	SO_4	HCO_3	NO_3	PO_4	F
DWB001	15/08/01	**7.51**	486	44	55	50	7	—	28	5	496	6.4	—	—
DWB002	14/08/01	7.22	1020	207	57	73	22	—	298	25	601	21.2	—	—
DWB003	16/08/01	6.91	350	62	34	13	22	—	40	8	295	0.04	—	—
DWB005	11/08/01	6.88	554	86	58	42	20	—	63	14	547	0.04	—	—
DWB006	11/08/01	7.18	1220	113	95	109	16	—	130	142	809	0.5	—	—
DWB007	12/08/01	**7.59**	786	116	77	60	20	—	110	3	712	0.3	—	—
DWB008	12/08/01	7.16	682	34	99	98	8	—	73	8	802	<0.1	—	—
DWB009	12/08/01	7.36	810	88	93	94	8	—	189	23	663	17.4	—	—
DWB010	13/08/01	**7.51**	667	95	59	50	14	—	127	16	491	0.04	—	—
DWB011	13/08/01	**7.64**	1080	134	95	107	3	—	259	22	737	**34.7**	—	—
	15/03/12	6.9	695	125	46	57	1.5	<0.1	195	9	405	**35**	<0.1	0.57
DWB012	9/08/01	7.32	3620	628	206	326	7	—	1480	214	1280	1.8	—	—
DWB014	9/08/01	7.21	3820	306	259	596	18	—	2040	112	1004	18.3	—	—
DWB015	9/08/01	7.11	2890	471	210	176	22	—	1120	93	884	5.7	—	—
	15/03/12	6.8	**7600**	2550	110	160	3.6	<0.1	4320	27	180	**170**	<0.1	0.14
DWB016	15/08/01	7.33	1850	197	137	190	11	—	609	48	863	15.4	—	—
DWB017	15/08/01	7.12	2890	431	129	237	9	—	905	78	1195	15.5	—	—
	15/03/12	6.8	245	40	25	16	2.5	<0.1	67	7	135	12	0.12	0.15
DWB018	15/08/01	**7.9**	1720	635	44	9	5	—	580	48	833	<0.1	—	—
DWB019	10/08/01	7.2	820	95	57	47	3	—	241	23	238	0.18	—	—

Bore	Date	pH	TDS	Na	Ca	Mg	K	NH_4	Cl	SO_4	HCO_3	NO_3	PO_4	F
	15/03/12	6.6	565	105	43	41	1.5	<0.1	250	11	185	2.3	0.18	0.26
DWB020	16/08/01	7.15	336	81	10	3	4	—	18	18	218	<0.1	—	—
DWB021	16/08/01	7.17	448	117	16	7	10	—	38	8	343	<0.1	—	—
DWB022	16/08/01	7.47	426	82	27	11	3	—	17	3	328	1.3	—	—
DWB023	14/08/01	**7.66**	2840	530	133	149	21	—	980	110	786	<0.1	—	—
CCWell	25/07/12	7.3	2120	325	240	140	15	<0.1	960	160	430	4.4	0.18	0.23
CCWindmill	25/07/12	7.2	995	220	56	56	11	**16**	565	1	130	<0.1	<0.1	0.16
TWB	15/03/12	**7.80**	1570	505	23	33	0.8	<0.1	670	27	415	26.0	0.31	0.57
Criteria														
Ecological		**6.5-7.5**	NE	NE	NE	NE	NE	**2.09***	NE	NE	NE	**31.9**[3]	NE	NE
Health		6.5-8.5	1200#	180#	NE	NE	NE	0.5#	250#	500	NE	50	NE	1.5
Recreation / Direct Contact		6.5-8.5	NE	NE	NE	NE	NE	NE	NE	5000	NE	500	NE	15
Livestock		NE	**4000**	**NE**	**1000**	**600**	**NE**	NE	**NE**	**1000**	**NE**	400	**NE**	**2.0**
Irrigation		4.5-9.0	1500	115-460	NE	NE	NE	5	175-700	NE	NE	20	0.15	1.0

Note(s): 1. all table entries in mg/L except pH; — not analysed; see **Appendix E** for full transcripts; * based on an average groundwater pH of 7.1
2. **bold and shaded** values exceed relevant criteria; **bold** values indicate relevant criteria; # aesthetic only hence no recreational criteria
3. [3] value derived after Hickey (2002); NH_4-N x 1.29 = NH_4; NH_3-N x 1.21 = NH_3; NO_2-N x 3.3 = NO_2; NO_3-N x 4.43 = NO_3
4. TDS total dissolved salts; Na sodium; Ca calcium; Mg magnesium; K potassium; NH_4 ammonium; Cl chloride; SO_4 sulfate; HCO_3 bicarbonate (alkalinity); NO_3 nitrate; PO_4 phosphate; F fluoride

TABLE 9 GROUNDWATER RESULTS – DISSOLVED HEAVY METALS AND ARSENIC

Bore	Date	pH	Sb	As	Ba	Be	B	Cu	Cd	Cr	Fe	Mn	Mo	Ni	Pb	U	Zn
DWB001	15/08/01	**7.52**	2	<10	240	<1	50	2	<1	<1	<100	51	58	15	11	—	12
DWB002	14/08/01	7.05	1	<10	60	7	40	1	<1	<1	<100	26	28	9	<1	—	13
DWB003	16/08/01	6.5	<10	10	208	<1	200	<1	<1	<1	<100	188	54	5	<1	—	4
DWB005	11/08/01	7.32	<1	<10	258	<1	<100	<1	<1	<1	2330	148	<1	2	<1	<1	5
DWB006	11/08/01	**7.56**	<1	<10	49	<1	<100	<1	<1	<1	200	703	36	<1	<1	—	<1
DWB007	12/08/01	7.22	**8**	<10	1030	<1	<100	<1	<1	<1	<100	91	139	<1	<1	—	<1
DWB008	12/08/01	6.85	<1	10	190	<1	40	<1	<1	<1	<100	104	7	20	<1	—	5
DWB009	12/08/01	7.05	<1	<10	355	<1	50	<1	<1	<1	<100	52	4	12	<1	—	8
DWB010	13/08/01	6.96	<1	**40**	586	<1	<100	<1	<1	<1	197	125	31	15	<1	2	4
DWB011	13/08/01	7.03	<1	10	110	<1	<100	1	<1	<1	11	3	7	6	<1	10	18
DWB012	9/08/01	6.68	**8**	<10	142	<1	<100	<1	<1	<1	<100	51	15	<1	<1	—	<1
DWB014	9/08/01	6.84	**11**	<10	222	<1	170	<1	<1	<1	<100	<1	14	<1	<1	—	<1
DWB015	9/08/01	6.9	<1	<10	470	<1	80	1	<1	<1	<100	**5110**	2	6	<1	—	8
DWB016	15/08/01	6.87	<1	<10	100	<1	70	<1	<1	<1	<100	6	1	<1	<1	—	5
DWB017	15/08/01	7.08	<1	<10	590	<1	<100	1	<1	<1	<100	1390	3	6	<1	—	18
DWB018	15/08/01	**7.57**	<1	<10	140	<1	<100	<1	<1	<1	<100	21	18	<1	<1	—	<1
DWB019	10/08/01	7.14	2	<10	92	<1	<100	<1	<1	<1	<100	107	5	<1	<1	—	<1
DWB020	16/08/01	6.88	<1	<10	22	14	<100	<1	<1	<1	<10	219	4	<1	<1	36	2
DWB021	16/08/01	7.02	<1	<10	33	8	<100	<1	<1	<1	14	765	5	<1	<1	68	29
DWB022	16/08/01	7.02	<1	10	9	13	<100	<1	<1	<1	<10	39	<1	<1	<1	81	10

Bore	Date	pH	Sb	As	Ba	Be	B	Cu	Cd	Cr	Fe	Mn	Mo	Ni	Pb	U	Zn
DWB023	14/08/01	7.37	<1	<10	290	<1	180	1	<1	<1	<100	860	7	16	<1	—	17
Criteria																	
Ecological		**6.5-7.5**	9*	**24**	NE	0.13*	NE	**19**[1]	**3**[1]	**13**[1]	**NE**	**1900**	34*	**151**[1]	**171**[1]	0.5*	**110**[1]
Health		6.5-8.5	3	7	2000	60	4000	2000	2	50	300^	500	50	20	10	17	3000
Direct Contact		6.5-8.5	30	70	20,000	600	40,000	20,000	20	500	NE	5000	500	200	100	170	NE
Livestock		NE	**3**[2]	500	**2000**[2]	**100***	**5000**	500	10	1000	NE	10,000*	**150**	1000	100	**200**	20,000
Irrigation		4.5-9.0	NE	100	NE	100	500	200	10	100	200	200	10	200	2000	10	2000

Note(s):

1. all table entries in µg/L other than pH (field measurement); [1] adjusted for hardness according to ANZECC / ARMCANZ (2000) Table 3.4.3; [2] derived from health criteria
2. NE no criteria exist; — not analysed
3. **bold and shaded** values exceed relevant criteria; **bold** values indicate relevant (most sensitive) criteria; ^aesthetic only hence no recreational criteria
4. dissolved Al, Hg, Se and Ag results have not been shown as they were all non-detectable; * low reliability value

5.9.2 Comparison of data to water quality criteria

The groundwater quality results are generally considered to be representative of baseline groundwater quality in the study area. This dataset provides a good baseline for comparison against results for monitoring throughout the life of mine and into closure.

The pH of groundwater at a number of discrete locations exceeds the recommended upper limit of 7.5 for the protection of ecosystems. The average pH of groundwater at the site is 7.1, and the maximum reading is 8.14. These mild levels of alkalinity are considered to be natural. TDS exceeds stock watering criteria at one location on one sampling occasion (bore DWB015 in March 2012), however overall is considered suitable for this beneficial use. On the basis of TDS, groundwater in both the fractured rock and alluvial aquifers is not suitable as drinking water.

Localised elevations of nutrients have also been observed, with nitrate (NO_3) present at most locations and ammonium (NH_4) at one location. These levels are expected to be a result of agricultural use of fertilizers in the catchment, however concentrations are generally acceptable for the protection of freshwater ecosystems (after Hickey 2002).

All dissolved metal concentrations are suitable for stock watering use, other than antinomy (Sb) at three locations (bores DWB007, DWB012 and DWB014). However, there are no actual livestock criteria and the guideline value listed in **Table 9** is defaulted from the drinking water criteria, and the maximum concentration detected is 11 µg/L. Therefore the levels detected are considered background and not of concern for stock watering.

Arsenic (As) and manganese (Mn) each exceeded ecological criteria at one discrete location (bores DWB010 and DWB015 respectively).

5.9.3 Geochemical evolution of groundwater in the catchment

When TDS measurements across the DZP Site are viewed spatially (as shown on **Figure 12**), the following chemical evolution is noted:

- fresh water recharge at the top of the catchment proceeds to an accumulation of dissolved salts along the flow path (via interaction with the aquifer matrix); while
- localised recharge of fresh water along the creek systems can then be seen to be diluting dissolved salts (such as at bore DWB019) that have recharged the alluvial aquifer from the underlying / up-gradient fractured rock aquifer.

A Schoeller Plot of groundwater chemistry along the catchment flowpath (from the proposed open cut location to Wambangalang, Spring and Cockabroo Creeks) has been provided as **Chart 2**.

Chart 2 (and the data presented in **Appendix C**) shows that HCO_3 is the dominant anion for all bores in the upper catchment. Chloride (Cl) becomes dominant in lower catchment bores in fractured rock (bores DWB014, DWB015, DWB016, DWB017, DWB018 and DWB023) and all bores in the clay alluvium (bores DWB012 and DWB019, as well as bores TWB, CCWell and CCWindmill). Sodium (Na) is the dominant cation at the up-gradient end of the system, however Mg becomes dominant mid-catchment / flow-path in bores DWB001, DWB006, DWB008, DWB009, DWB011 and DWB014.

It is likely that the chemical signature of Na-HCO_3 in the upper catchment bores is reflective of the dominance of alkaline volcanics (basalt and trachytes) at these locations along with fresh rainwater recharge (Na-Cl dominant as shown on **Chart 2**). The mid slope chemistry of

Mg-HCO_3 is considered to be indicative of increasing chemical dominance of the volcanic aquifer matrix.

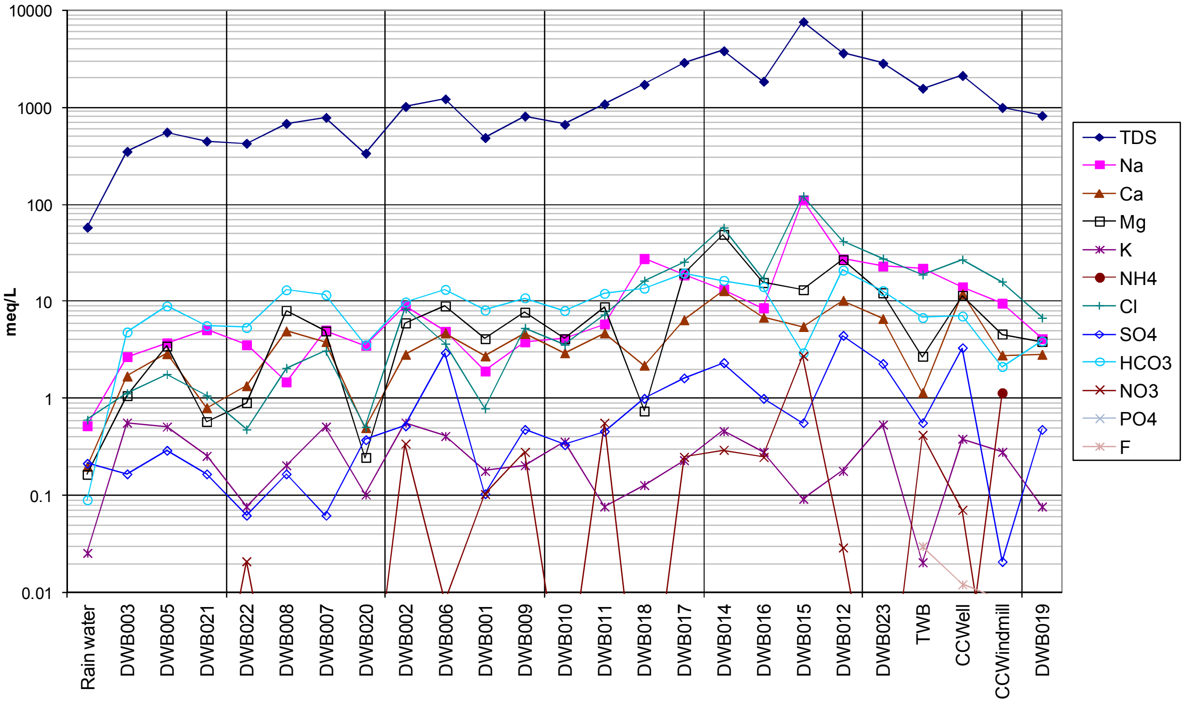


Chart 2: Schoeller Plot – groundwater chemistry along the catchment flowpath

Na-Cl becomes the dominant chemistry in bores DWB015 and DWB023 in the fractured rock aquifer towards the down-gradient end of the flow paths. This could reflect the natural influence of the sedimentary rock matrix (Triassic aged Gunnedah Basin sediments) on the groundwater quality.

Further insights to hydrogeochemical evolution can be gained from assessing ionic ratios (see data presented in **Appendix C**). Bores DWB020, DWB021 and DWB022 (all located at the top of the catchment at or in the vicinity of the proposed open cut) all have Na/Cl ratios >3, strongly suggesting recently recharged groundwater (Jankowski 1999). Conversely, Na/Cl ratios are <0.45 for bores DWB012, DWB014, DWB016, DWB019, CCWell and CCWindmill in the lower catchment, strongly indicating (along with TDS) that these are older groundwaters as would be expected towards the down-gradient end of the flow system.

5.10 Groundwater usage and receptors

5.10.1 Introduction

As the current predominant land use for the proposed DZP Site and surrounding areas is either dryland cropping or some mixed grazing, both surface water and groundwater sources are used. The use consists of both farm earthen dams and groundwater bores for stock watering. The stock watering bores are typically fitted with small pumps or wind mills.

The search of the NOW registered groundwater bore database discussed in Section 5.5.3, indicates modest yields from the majority of the bores installed within the DZP Site. Additionally, the water quality is variable across the DZP Site with the lower flats within

Wambangalang Catchment affected by increased salinity that make the shallow groundwater at some locations only suitable for stock watering or some domestic uses.

There are several unregistered bores within the Township of Toongi (refer to **Figure 8**) that are used for a mixture of stock and domestic water. Some of these bores and wells intercept shallow groundwater of the Wambangalang Creek alluvium. There is one registered irrigation bore (see discussion in Section 5.5.3 above), however field inspection confirmed that this bore has never been equipped or used since installation in 2004.

There are no known large scale groundwater users within a 10 km radius of the DZP Site such as industrial or large scale irrigation purposes, other than potential irrigation users along the Macquarie River and associated alluvium between 8-10 km to the north, north-east of the DZP Site (refer to **Figure 7**).

5.10.2 Potential beneficial users

Beneficial reuse of groundwater in NSW is governed by water quality objectives and associated criteria (DLWC, 1998). Potential beneficial uses of an aquifer are directly associated with potential yield (sustainable or otherwise) and quality. All groundwater, regardless of yield or quality, is required to be protective of the natural ecosystem within which it resides and in particular discharges to, including any groundwater dependent ecosystems (GDEs).

In order to determine potential beneficial uses of an aquifer, a water quality and quantity assessment is undertaken, including:

- desk-top assessment of existing users and ecosystems (including GDEs), as well as any information on yield and quality;
- assessment of potential groundwater yields (quantity), including existing information and collection of additional physical data; and
- assessment of groundwater quality based on existing information, collection of field data and chemical analysis of collected groundwater samples.

A summary of each potential beneficial use of the aquifers beneath the site is provided within the following sub-sections.

5.10.3 Drinking water

The water bearing zones beneath the site are not known drinking water aquifers, due primarily to poor / variable yield (see **Table 5**) and marginal quality (see Section 5.8). Registered bores in the catchment are invariably used for domestic purposes associated with agriculture / horticulture (stock watering and small scale domestic irrigation). This was confirmed by field assessment, which included measurement of groundwater salinity (as electrolytic conductivity, EC) as presented in **Table 6**. For a total of 50 measurements over the four sampling events undertaken, EC has ranged between 486-12,990 µS/cm, with a mean value of 2,750 µS/cm and median value of 1,990 µS/cm.

The above discussion covers the requirements of Appendix 2 of DEC (2007) in that:

- the DZP Site is not located in an area containing a major drinking water aquifer (the Lower Macquarie alluvium is located approximately 45km to the west, after PB 2011, and the Macquarie River alluvium is located 7 km to the north, after RWC 2013);

- actual groundwater users have been identified in the vicinity of the DZP Site, and no users of groundwater for drinking have been identified (backed up by chemistry and yield information); and
- an assessment of groundwater quality on the basis of TDS and EC has been undertaken, and has confirmed that groundwater is not of suitable quality for human consumption.

Thus protection of groundwater for drinking supply is not a relevant beneficial use for this site, however as TDS is generally <2,000 mg/L drinking water criteria will still be cited in assessment of the data (as required by DEC 2007).

5.10.4 Recreation, direct contact and aesthetics

Despite conclusions discussed in Section 5.10.3, groundwater is expected to protect human health via potential exposure from recreational, commercial and industrial activity. As such, guidelines provided by NHMRC / NRMMC (2008 and 2011) have been considered. NHMRC / NRMMC (2008) state that criteria for recreational / direct contact quality can be derived from the values presented in NHMRC / NRMMC (2004, which was updated in 2011), by applying a multiplication factor of 10-20 for non-volatile chemicals. The reasoning for this is that the drinking water criteria are calculated based on the assumption that the average person consumes 2 L of water per day, and the rate of assumed incidental ingestion during a daily swimming session is 100-200 mL.

Drinking criteria and the consequent direct contact / recreational criteria have been included in **Tables 8** and **9**. Also included in these tables are aesthetic criteria for certain chemicals relevant to the Proposal / DZP Site that have potential odour, discolouration and taste issues (TDS, Na, Cl, NH_3 and Fe).

5.10.5 Irrigation

For reasons similar to the discussion above for drinking water quality (Section 5.10.3), groundwater in the vicinity of the proposed DZP Site is of marginal quality for use as irrigation water. For this reason (in addition to that of generally insufficient yields), groundwater is not utilised for irrigation in the catchment, based on field observations and discussions, and assessment of water quality data. An average and median salinity of groundwater for the catchment in the range of 2,000-3,000 µS/cm indicates that this water has a “medium” salinity rating and is only suitable for “moderately tolerant”, “tolerant” and “very tolerant” crops (ANZECC / ARMCANZ 2000, Chapter 9.2).

However, there are pockets of relatively low TDS groundwater in areas of relatively high transmissivity / yield, such as well TWB in the alluvium close to Wambangalang Creek (**Figure 8**).

Further to the above, the sodium adsorption ratio (SAR) of groundwater analysed from the catchment has a mean value of 5.7 and is as high as 20 for individual samples (see **Appendix C** for groundwater chemistry data tables). As ANZECC / ARMCANZ (2000) recommends SAR be ≤5 for clay soil (Table 9.2.6), sodicity would be a potential issue were groundwater to be used for irrigation. Sodium (Na) and chloride (Cl) concentrations, as well as TDS, manganese (Mn), molybdenum (Mo) and uranium (U), in groundwater are also likely to limit potential groundwater use for irrigation (see **Tables 8** and **9**).

Additionally, analysis of data presented in **Appendix C** of this report shows that the groundwater hardness is on average 655 mg/L as $CaCO_3$, with very few locations below the desired level of 180 mg/L as $CaCO_3$. The saturation indices (Langelier and Ryzner) also indicate that this water is corrosive.

One bore (GW802169) to the south-west of the DZP Site (see **Figure 8**) is registered for irrigation use but has never been equipped or tested for such use. This bore is installed into “gravel and shattered rock” from 4.0 m to 6.0 m depth.

5.10.6 Stock watering

The primary use of groundwater in the catchment is stock watering. As such, this is a relevant beneficial use that requires protection. Criteria for stock watering are based on values provided in ANZECC / ARMCANZ (2000), and default to NHMRC / NRMMC (2011) where specific stock watering criteria are otherwise unavailable.

5.10.7 Discharge to surface water (ecosystem protection)

Ecosystem protection is a primary beneficial use of the aquifer, particularly as all ephemeral creeks about the DZP Site have a high to moderate potential to be at least partially “reliant on surface expression of groundwater” (BOM, 2012). As such, water quality criteria for protection of 95% of species have been adopted from ANZECC / ARMCANZ (2000), and are provided in **Tables 8** and **9**.

5.10.8 Groundwater dependent ecosystems (GDEs)

The GDE map provided in **Appendix I** (after BOM, 2012) shows that, in the vicinity of the site, Paddy’s Creek to the west is listed as having a “high potential for groundwater interaction”. Groundwater interaction refers to a surface water system that is “reliant on surface expression of groundwater”.

Wambangalang Creek to the north of Obley Road and Cockabroo Creek to the north of Eulandool Road are both listed as having a “moderate potential for groundwater interaction”. There is no vegetation in the vicinity of the DZP Site listed as being reliant on subsurface groundwater, and no subterranean GDEs (caves or aquifers). Based on these findings, it can be concluded that the creek systems to the west and south of the DZP Site rely on groundwater discharge to support their ecosystems, but there are no other known GDEs within the DZP Site groundwater flow system.

5.10.9 Local industry

There are no local industrial users of groundwater in the locality. Major reasons for this are the low yield of the aquifers under consideration (alluvium and fractured rock), as well as the isolated location of the DZP Site away from the nearest industrial centre (Dubbo is located approximately 25 km to the north). As such, this potential beneficial use requires no further consideration. It is however noted that groundwater sourced from alluvial and fractured rock aquifers on the DZP Site could provide a supplementary water supply for the proposed Processing Plant, following an adequate exploration and testing program.

5.10.10 Summary of groundwater usage

Based on the above discussion (Sections 5.10.3 to 5.10.10), the relevant beneficial users of groundwater (in order of priority and importance) are:

- the freshwater ecosystems of the local ephemeral creek systems;
- stock watering;
- recreational, direct contact and aesthetic use; and
- possible irrigation on alluvium adjacent to creek systems.

Tables 8 and **9** list the relevant criteria values adopted, which have been derived to ensure water quality is protective of the relevant uses.

The local groundwater is not considered to have potential beneficial use as drinking water, whilst use for irrigation is not currently occurring and is considered unlikely. It should be noted, however, that if an individual proponent did want to commission a bore or borefield for any of the above uses (for example bore GW802169), additional assessment would be required at that time. This includes the potential use of groundwater from the DZP Site as a supplementary water supply to the proposed Processing Plant.

6 ASSESSMENT OF POTENTIAL IMPACTS

This section presents an assessment of the potential physical and chemical impacts of the Proposal, including consideration of the potential impacts to beneficial uses of the groundwater.

6.1 Methodologies used

Potential impacts to groundwater beneficial users as a result of the proposed mining operations have been assessed in the context of the local hydrogeological setting, i.e. the CSM, and the relevant legislation and guidelines. The CSM was based on:

- a desktop assessment of existing information relating to the Proposal and catchment hydrogeology.
- further assessment of aquifer physical properties at existing individual locations; and
- further assessment of aquifer chemical properties at existing individual locations.

The nature of the groundwater flow system, i.e. a local flow system discharging to the local creeks, means that all potential impacts of the Proposal are considered to be locally constrained. The area of potential impacts is constrained to the west by Wambangalang and Paddy's Creeks and to the south by a tributary of Cockabroo Creek in the vicinity of bore DWB016 (**Figure 8**).

All of the potential sources of impacts are currently planned to be located within the groundwater flow systems flowing to Wambangalang / Paddy's Creek and to Cockabroo Creek, with the exception of some of the proposed LRSF which overlap the catchment divide between Wambangalang Creek and undefined drainage to the Macquarie River (**Figures 3** and **4**).

The assessment of impacts is based on the CSM and on knowledge and experience of the authors of flow systems in similar environments and of similar projects. Where appropriate, calculations of groundwater flow velocity, volumetric groundwater flow rate (flux), and travel time are evaluated, based on Darcy's law (Freeze and Cherry, 1979).

Groundwater flow or transport modelling was not justifiable given that the open cut would be developed so as to remain above the water table and as such dewatering and associated drawdown would not take place. Groundwater extraction for use on the DZP Site was not considered as it is understood that water is likely to be sourced off site.

The different components of the Proposal are described in Section 6.2. The potential impacts associated with the components of the Proposal are described in Sections 6.3, 6.4 and 6.5. Potential groundwater impacts are listed in a summary table in which the likelihood, consequence and the resulting potential risk associated with each potential impact is considered (**Table 10**). The interpreted risks of the different components are compared in Section 6.6, with reference to **Table 10**.

6.2 Description of key components of the Proposal

Proposed design drawings for the on-site storage facilities have been provided in DE Cooper & Associates (2012). These drawings indicate the following key designs associated with minimising the risk of stored liquids impacting on groundwater levels or quality (see **Figure 3** for the locations of these facilities):

- Solid Residue Storage Facility (SRSF) Cells:
  - proposed to contain double HDPE liner with leak detection;
  - outfall pipes from leak detection system with pump out pits at embankment toes;
  - store and release cover on final surface;
  - 1:3 slopes on final surfaces;
  - numerous groundwater monitoring bores are proposed around these cells (see **Figure 14**);
- Liquid Residue Storage Facility (LRSF) Cells:
  - proposed to contain a HDPE liner on a foundation of compacted sub-soil;
  - freeboard of 1 m for 5 m of liquid storage (i.e. 6 m high embankments);
  - 1:2 downstream slope on lower embankment;
  - precipitated salt to be excavated and placed in salt encapsulation cells, with salt harvesting from the LRSF Cells taking place during mining activities;
  - numerous groundwater monitoring bores are proposed around these facilities (see **Figure 13** for conceptual placement and construction in cross section and **Figure 14** showing a plan view including LRSF perimeter monitoring);
- Salt Encapsulation Cells (SECs):
  - proposed to contain double HDPE liner with leak detection;
  - proposed to contain a seepage detection sump for each outer cell (4) beyond embankment toes;
  - two to three groundwater monitoring bores are proposed for each outer cell (see **Figure 14**);
  - salt to be placed in layers using low ground pressure machinery;
  - store and release cover on final surface;
  - freeboard of 1m for 15m high embankments; and
  - 1:2 downstream slope on lower embankment.

In addition to the above, the proposed Processing Plant Area is also a key component of the Proposal. The Processing Plant Area includes the following key subcomponents:

  - crushing and ore handling;

- o mixing, roasting and leaching;
- o effluent and solid waste neutralisation and handling;
- o product handling – includes zirconium (Zr) and niobium (Nb), iron (Fe) and aluminium (Al), and heavy rare earths;
- o reagent handling (receipt, storage and distribution) – includes sulfuric acid and sulfur prill, limestone, sodium chloride, soda ash, hydrochloric acid, lime, anhydrous ammonia, sodium sulfide and sulfate, aluminium powder, hematitie and perlite; and
- o numerous groundwater monitoring bores are proposed around this area (see **Figure 14**).

6.2.1 Solid Residue Storage Facility (SRSF)

The SRSF would be constructed in bedrock high ground areas where the baseline water table is interpreted to be in the range 5-25 m below the ground surface and typically approximately 10-20 m below the ground surface (**Figure 9b**). SRSF would be constructed with a double liner, with a leak detection system between the two liners. The upper liner would likely be HDPE, with the lower liner constructed from clay or HDPE. Each liner used would provide for a vertical hydraulic conductivity (K_v) not exceeding $1x10^{-9}$ m/s over a thickness of 900 mm (or equivalent). This K_v is an order of magnitude lower than the lowest hydraulic conductivities encountered in the underlying bedrock (Section 5.6).

There would be no water released from the solid residue. However, during placement and compaction, the cells would be exposed to incident rainfall. The SRSF cells would be constructed with an internal drainage system and rainfall run-off from the surface of the SRSF cells would be collected in solid concrete sumps constructed beneath the ground surface prior to SRSF construction. Any run-off that accumulates in the sumps would be pumped to the LRSF.

At closure, it is likely that the upper surface of the residue in each cell will be slightly domed to enable the majority of rainfall runoff to be shed. The final cover will be based on the “store and release” system which will allow heavy rainfall to flow off the surface but hold, and then release by evaporation, lighter rainfall. Further details will be provided for approval well before the closure of the facility.

There will be minimal water passing through the cover to the compacted residue. The double liner, with an inter-liner monitoring system, will ensure that there is no release of seepage to the environment.

6.2.2 Liquid Residue Storage Facility (LRSF)

LRSF would be constructed both in bedrock high ground areas where the baseline water table is interpreted to be typically in the range 10-30 m below the ground surface and in lowland alluvium areas where the baseline water table is interpreted to be typically in the range 5-15 m below the ground surface (**Figure 9b**).

The objective of the LRSF is the disposal of excess water from the plant by evaporation and the collection of the salts from the water by crystallisation in the terraced cells. The water would initially have a salinity of 62,500 ppm when leaving the plant (DE Cooper & Associates, 2012). The salinity in the LRSF would gradually increase with the loss of volume by evaporation. As the salinity increases, salts would be deposited on the bases of the LRSF cells. The total area of the LRSF would be approximately 425 ha (**Figure 9b**). The cells are not intended to allow infiltration into the ground. Therefore, they would be lined. It is understood that the LRSF are intended to be used for the 20 year life of this proposal.

The LRSF would be constructed in four distinct areas with each consisting of several terraced cells to maximise pond area and, therefore, evaporation potential. It is intended that the fill for the embankments would be taken from within each cell area. The embankments would be constructed with an average height of 6 m. The bases of the ponds and the faces of the embankments which form the ponds would be lined with a single 1.5 mm HDPE welded sheet. The liner would be placed over a prepared foundation comprising compacted fine-grained *in-situ* material or, where the ground cannot be made sufficiently smooth, a layer of imported sand or a sheet of geo-textile.

Liner Integrity - Design

All lining material will be certified by the manufacturer prior to leaving the factory. The number of all individual batches of the lining material will be registered and the date and location of the use of each roll recorded by the contractor. The foundations of the cells will be constructed to the lines and grades shown on the design drawings (DE Cooper and Associates, 2013). The finished surface will be free of all roots, rocks and other matter which could impact on the liner. The area in each cell will be lightly tyned, moisture conditioned and compacted prior to the placement of the lining.

If there is a delay of more than 48 hours between the completion of the foundations and the application of the liner, the area will be proof rolled again prior to rolling out the lining. Areas which are not deemed suitable for the direct application of the liner by the supervising engineer will be covered with a layer of compacted sand with a minimum depth of 150 mm prior to constructing the liner.

The integrity of the HDPE liner will be fundamental to the minimisation of impacts of the LRSF. HDPE lining of the LRSF cells will be carried out by an experienced contractor who has a proven track record in the installation of large areas of lining. All lining material and construction methods and testing will conform to the relevant Australian Codes. The contractor will use the most up to date equipment in the work. All equipment shall be certified prior to the start of the project and at regular intervals (in accordance with the manufacturer's recommendations and the relevant Australian Codes) during the work.

The welding of the liner will be tested both by the contractor and by an independent testing organisation engaged by the proponent. Small sections of the liner will be regularly removed for off-site laboratory testing in accordance with the relevant code. Should any test results return negative results, the work carried out between tests shall be fully reviewed.

Prior to the installation of the liner in each cell, the area will be surveyed and a depth/volume curve prepared for each cell. This will allow the volume of liquid residue in each cell to be determined by measuring the level of the liquid in each cell. The volume of water delivered to each cell will be accurately monitored by reading the flow meters on each delivery pipe. Evaporation losses from the cells will be compared with that from several Class A Australian Standard Evaporation pans located adjacent to each group of cells. Rain gauges will be positioned adjacent to each group of cells.

Data from the evaporation pans, rain gauges and flow meters will be fed back into the Water Balance Model from the early stages of the operation to enable a Pan Factor to be determined relating Class A pan evaporation to actual cell water loss. Continuous monitoring of liquid residue level, flow in, and evaporation loss out will enable any major water loss due to a liner failure to be identified.

Liner Integrity - Verification

Groundwater monitoring bores will be positioned close to the downstream toe of all external embankments (see **Figure 13** and **Figure 14**). The bores will enable both groundwater level and quality to be monitored. These bores will be used to verify the prevention of impacts to groundwater (See Section 7).

Initial groundwater level changes are possible close to a LRSF when ponds are initially filled due to the change in weight. However, such changes in groundwater level are expected to dissipate over a period of weeks. Any permanent increases in groundwater level or increases in salinity in monitoring bores will trigger an investigation into the source of the water which is impacting on the groundwater.

If a trend of increasing groundwater level or salinity is observed, the initial action will be to, as quickly as practicable, evacuate the liquid in the closest cell by transfer pumping to an adjacent cell(s). If the removal of the water produces a measurable sustained reduction in groundwater level in the down-gradient monitoring bore(s), further investigations into the integrity of the liner will take place.

The following actions may be applicable.

- Total removal of any remaining liquid from the cell.
- Removal of any accumulated salts from the base of the cell.
- Inspection of the joins in the liner following cleaning by high pressure water jetting.
- Testing of the joins to determine the area of failure.
- If no obvious failures are discovered the remainder of the liner will be cleaned to allow a general inspection to be carried out.
- If this action still does not locate the point of leakage, the whole liner may be removed.
    - An inspection of the foundations should then determine the location of the failure.
    - If the decision is made to repair the liner and bring the cell back into service, all contaminated soil to a depth of 3 m or to the depth of the water table, whichever is greater, will be removed and replaced with uncontaminated soils prior to installing a new liner.
    - The new liner will be subject to the same testing regime as the original liner.
    - If the decision is made to abandon the cell (for a period or permanently) the cell will continue to be monitored but allowed to remain dry.

Over the life of the LRSF, crystallised salt from each cell would be removed and disposed of it in the Salt Encapsulation Cells (SECs). Removal of salts will occur periodically, with the salt to be removed to an elevation of no less than 1m above the surveyed elevation of the underlying liner. The purpose of the 1m buffer is to prevent the integrity of the liner being compromised by the salt harvesting process. This buffer will be maintained using earth moving equipment incorporating surveying (likely GPS-based) technology that is capable of sub-centimetre vertical accuracy (e.g. road graders or road stabilisers).

Should any part of the liner be compromised during the salt removal process, the liner for the cell would be replaced and its integrity verified in the same way as during initial construction.

Following decommissioning, liners will be removed and the LRSF area will be restored to the original contours, topsoil replaced and the area would be rehabilitated as productive farmland.

6.2.3 Salt Encapsulation Cells (SECs)

All SECs would be constructed in a bedrock high ground area in the upper part of the Cockabroo Catchment where the baseline water table is interpreted to be in the range 5-25 m below the ground surface (**Figure 9b**). This is close to, and in a similar environment to, the SRSF. As for the SRSF, the SECs would be constructed with a double HDPE liner, with a leak detection system between the two liners. As for the SRSF, this liner system would have a K_v that is an order of magnitude lower than the lowest bedrock hydraulic conductivities encountered in the underlying bedrock (Section 5.6).

The leak detection system would allow any water which passes through the upper liner to drain to monitor pits downstream of the external embankments. The pits could also be used to collect and pump water to the plant for treatment. If leakage is detected following the closure of the Proposal, arrangement would be made to install permanent solar operated pumps to deliver the seepage to one of the previously used LRSF cells for evaporation.

It has been assumed that at closure, the SECs would be removed from the DZP Site. Should they remain on the DZP Site following closure, it is likely that the upper surface of the SECs will be slightly domed to enable the majority of rainfall runoff to be shed. The final cover will be based on the “store and release” system which will allow heavy rainfall to flow off the surface but hold, and then release by evaporation, lighter rainfall. Further details will be provided for approval well before the closure of the facility (DE Cooper & Associates, 2013). The double liner, with an inter-liner monitoring system, will prevent the release of seepage to the environment.

6.2.4 Waste Rock Emplacement (WRE) area

The WRE area is estimated to be about 20 ha in area and is planned to accept an estimated 3.5Mt of overburden (soil and weathered material) and low grade rock. It can be assumed that whilst the material stored in the WRE area is expected to be relatively chemically benign, reduction of run-off in the WRE footprint would likely enhance recharge to the ground beneath the structure.

6.2.5 Open cut

The open cut is planned to be 40 ha in area, with approximately 19.5Mt of ore to be extracted at an expected rate of 1.1Mt per year (20 to 22 year expected mine life). The ore is proposed to be extracted from the near surface to a maximum depth of 32 m (355m AHD). The current plan is to mine in two stages, with Stage 1 (0-10 years) encompassing the western portion of the proposed open cut area, and Stage 2 (11-20 years) the eastern portion (see **Figure 3**). The open cut is not planned to extend below the water table.

6.2.6 Processing Plant Area (PPA)

The proposed Processing Plant Area, including the administration area, rail siding laydown and storage area, and run of mine (ROM) pad, is close to 50 ha in area (see **Figure 3**). A detailed layout of the proposed area is provided in TZMI (2013).

Most of the Processing Plant Area will be sealed. The laydown area will comprise a bunded concrete pad, inside of which will be separately bunded storage areas for each of the four reagents (sulfur, hydrochloric acid, soda ash, anhydrous ammonia and caustic soda). Bund wall heights will be in accordance with relevant specifications for each reagent, and in the case of HCl the bunded volume will be equal to at least 110% of the stored acid.

The three reagent stores, laboratory and final product storage areas are all designated as being fully enclosed storage/buildings with concrete floors, however where necessary, liquid reagents and final products will additionally be stored within suitably bunded areas (as required) in accordance with the relevant specifications for storage. On site raw material supply and mixing areas, along with all processing areas (reagents are stored here prior to use in the process) will be on suitably designed bunded concrete pads/floors.

6.3 Potential physical impacts to groundwater during operations and post closure

There is no dewatering planned during mining operations because the open cut is not proposed to extend below the water table and there are no current plans for the Proposal to source groundwater for use throughout its operations. Therefore, there would be no drawdown of groundwater levels associated with the Proposal.

Throughout most of the DZP Site negligible changes in groundwater levels are expected to occur throughout the life of the Proposal and after mine closure. The potential physical impacts of the SRSF, LRSF, and SECs are described separately below. The planned locations of these components of the Proposal are shown in **Figure 3**. The management of the solid and liquid residues in the SRSF and LRSF is described in greater detail in DE Cooper and Associates (2013).

6.3.1 SRSF

The net effect of the design of the SRSF cells would be to significantly reduce the rate of recharge over the footprint of the SRSF area (approximately 103 ha) both during the Proposal and following the Proposal. The SRSF area represents less than 5% of the total DZP Site. Therefore, the effect on the total groundwater flux through the local groundwater flow systems within the Wambangalang Creek catchment and the Cockabroo Creek Catchment is expected to be minor (see ‘Consequence of Impact’ in **Table 10**).

However, there is predicted to be a moderate reduction in the level of the water table (on the order of one to three metres) beneath and in the vicinity of the SRSF cells due to the reduction in the recharge rate in this area both during the Proposal and post closure (see ‘Likelihood of Impact’ in **Table 10**).

6.3.2 LRSF

Potential Impact – Effective Liner

Assuming the liner is effective at preventing infiltration of the liquid contained in the LRSF, the net effect of this design would be to significantly reduce the rate of recharge over the footprint of the combined LRSF area (approximately 425 ha) during the Proposal, but not following the Proposal. The four areas of the proposed LRSF are all located within the Wambangalang Creek Catchment and the Undefined Macquarie River Catchment to the north-east (see **Figure 4** for catchment boundaries).

The combined LRSF area represents approximately 17% of the total area of these catchments within the DZP Site. Therefore, during the Proposal there is predicted to be a moderate reduction in the total groundwater flux through the local groundwater flow system within these catchments (resulting in a moderate risk of occurrence as detailed in Table 10). After the Proposal, the recharge rate over the footprint of the LRSF is expected to return to close to the baseline rate.

A reduction in recharge caused by the LRSF during the Proposal would be expected to cause a reduction in the level of the water table in the range from tens of centimetres up to several metres, beneath and in the vicinity of the LRSF. In high ground areas, the level of the water table is expected to be more sensitive to direct local recharge than in the lowland alluvial, colluvial areas. Therefore, any decreases in water table elevation caused by the interception of recharge by the LRSF are expected to be greatest in the high ground areas.

After closure of the mine, due to the removal of the liner, the water table elevation in the vicinity of a LRSF would be expected to return to close to its baseline level, i.e. the groundwater level would recover from any drawdown associated with reduced recharge at the LRSF.

Potential Impacts – Ineffective Liner

Leakage Flux

The above discussion assumes the liner beneath the LRSF is 100% effective at preventing infiltration of liquid from the LRSF. It is the intent of the LRSF design to prevent the leakage of brine into the groundwater. Details of the approach to liner construction, the verification of liner integrity and the response if leaks are suspected are provided above in Section 6.2. Although the LRSF design is intended to prevent leaks, it is necessary to consider the potential impact of the LRSF due to a breached liner.

In practise, it is considered possible that there would be some breaches of the integrity of the liner. However, due to the approach to liner construction, and the proposed monitoring of the LRSF and of perimeter groundwater conditions (described in Section 6.2), it can be expected that any such breaches would be localised and temporary rather than widespread and/or permanent.

If a breach were to occur in the liner, the downward hydraulic gradient caused by the liquid level in the pond above the breach would cause a leakage flux from the LRSF into the ground. This leakage would initially infiltrate downwards, and subsequently laterally. The rate of migration of the liquid would be controlled, in part, by the hydraulic conductivity (K) of the underlying materials.

If the leak was significant and the underlying ground had a low hydraulic conductivity, the water table could rise to the ground surface beneath the LRSF cell. In a low permeability environment, such as is typical at the DZP Site (see Section 5.7), the lateral flux from beneath the LRSF would ultimately be constrained by the low lateral transmissivity (KD or T) of the ground and the horizontal gradient, in addition to the extent of any liner breach(es).

LRSF over Alluvium:

The following is a calculation of what is considered to be the “worst-case” potential flux of leakage from a LRSF in a lowland area, where the LRSF would be underlain by clay alluvium and the liner is ineffective due to a breach or breaches. This worst case analysis is based on the assumption that relatively high permeability clean sand is not present beneath the footprint of the LRSF. There is no evidence of clean sand being present beneath a LRSF cell footprint.

Following the filling of a pond with brine over a breached liner, the effective footprint of the source of the infiltrating liquid would increase relatively rapidly to a larger area than any individual breach/tear in the liner, due to lateral spreading beneath the liner. This lateral spreading effect would be particularly significant if relatively permeable fill (e.g. sand) had been used to level the ground during pond construction.

The following is a calculation of worst-case physical impacts for a LRSF cell/s over alluvium, based on the following assumptions:

1. Lateral transmissivity of clay alluvium, T = 0.4 m^2/day (based on hydraulic testing reported in Section 5.6);
2. Hydraulic conductivity, K, of clay alluvium = 0.01 m/day (based on hydraulic testing reported in Section 5.6); and
3. Maximum horizontal hydraulic gradient (*i*) beneath the embankment = approximately 15/30 = 0.5 m/m at early time.

Based on the above assumptions, maximum lateral flux beneath the embankment, per m length of the embankment, at early time after leakage first takes place, Q = K*i*A = T*i*L = 0.4 x 0.5 = 0.2 m^3/day/m, i.e. 200 L/day/m. The leakage from a breach of a liner could spread laterally beneath the liner. If the effective length of the embankment under which leakage were taking place was 50 m, the leakage flux beneath the embankment would be 10 m^3/day.

It should be noted that the above calculation does not take into account discharge of seepage that may take place at the toe of the embankment. In a situation in which seepage had taken place through breaches in a liner, it is possible that, once the underlying ground has become saturated, discharge could also take place to the ground surface at the toe of the embankment.

LRSF over Bedrock:
According to the geological mapping (**Figure 6b**), the Area 5 LRSF appears to be positioned primarily on Triassic aged sedimentary rock, whilst the Area 4 LRSF is positioned partly on Triassic aged sedimentary rock and partly on Jurassic aged basalts.

The data presented in Section 5.6 (**Table 7**) of this report indicates a large range of K in the bedrock, depending in part on the type of bedrock. The typical K of the sedimentary bedrock was found to be approximately an order of magnitude less than the K evaluated for the clay alluvium (Section 5.6). Therefore, based on this and assuming other factors (hydraulic gradient, etc.) are similar, the maximum potential flux from a leaking LRSF in Area 5 of the bedrock high-ground area is predicted to be approximately an order of magnitude less than in the lowland alluvial area, i.e. a maximum initial seepage flux on the order of 20 L/day/m, which would reduce with a decreasing hydraulic gradient.

In contrast, the estimated K of the trachyte bedrock has a range of 0.05-0.3 m/day, with a lateral transmissivity 5 to 10 times that estimated for the alluvium (2-4 m^2/day compared to 0.4 m^2/day, as shown in **Table 7**). Using the same assumptions as discussed above for the alluvium, a potential maximum lateral flux through volcanic rocks beneath the embankment at early time after leakage first takes place would be 1-2 m^3/day/m. In practise, lower permeability overburden would be expected to impede the fracture permeability of the upper part of any fractured bedrock such that the potential leakage flux would be less than calculated above. Due to the proposed monitoring of the LRSF and of perimeter groundwater conditions, any leaks from LRSF cells would be expected to be temporary such that the above calculation of fluxes would be the initial worst-case flux only. As described in Section 6.2, if a leak were considered likely from groundwater monitoring or cell monitoring, the LRSF cell would be drained and the leak would be investigated. Therefore, the source of the leak and the hydraulic gradient driving the leak would not be maintained and the leakage flux would be temporary.

Increase in Water Table

If the leak was significant and the underlying ground had a low hydraulic conductivity, the water table could rise to the ground surface beneath the LRSF cell. For LRSF cells constructed in alluvial/ colluvial areas, the baseline water table is expected to be 10-15 m below the ground surface at the lower embankment. Therefore, in the event of a leaking LRSF cell over alluvium, the water table has the potential to rise as much as 15 m. For LRSF cells constructed in bedrock areas, the baseline water table could be as much as 30 m below the ground surface at the lower embankment. Therefore, in the event of a leaking LRSF cell over bedrock, the water table has the potential to rise as much as 30 m.

Any significant rise in the water table beneath a LRSF cell would have the effect of increasing the water table in monitoring wells located around the perimeter of the cell. This would be one of the indicators used to detect possible leaks. If potential liner leakage was interpreted from groundwater monitoring, then the LRSF cell would be drained and the leak would be investigated (Section 6.2). Therefore, it can be expected that any increase in the water table due to a leaking LRSF would be localised to within tens of metres of the LRSF and would be temporary.

6.3.3 SECs

The net effect of the design of the SECs would be to significantly reduce the rate of recharge over the footprint of the SEC area (approximately 40 ha) in the latter part of, and following, the Proposal. The SEC area represents less than 2% of the total DZP Site, therefore the effect on the total groundwater flux through the local groundwater flow systems within the Cockabroo Creek Catchment is expected to be minor (see ‘Consequence of Impact’ in **Table 10**). However, there is predicted to be a moderate reduction in the level of the water table (on the order of one to three metres) beneath and in the vicinity of the SECs due to the reduction in the recharge rate in this area both during the Proposal and post closure.

6.3.4 WRE

Given the assumption that the WRE footprint would not be lined, the potential physical impacts from the WRE would be to enhance the rate of recharge over the footprint of the WRE area (approximately 20 ha) both during the Proposal and following the Proposal. The WRE area represents less than 1% of the total DZP Site, therefore the effect on total groundwater flux through the local groundwater flow systems is expected to be minor (see ‘Consequence of Impact’ in **Table 10**).

6.3.5 Open Cut

During mining operations, it is expected that any standing water from precipitation that accumulates in the open cut would be pumped out. However, minor additional recharge is expected to take place within the area of the open cut during mining operations which would subsequently cause minimal increases in groundwater levels in the vicinity of the open cut. It is understood that the open cut is not to be backfilled. Under post closure conditions, runoff that accumulates in the open cut from direct precipitation would not be pumped out. This water will either evaporate or infiltrate to become groundwater recharge.

The magnitude of the proportion that infiltrates and becomes groundwater recharge rather than evaporating would be dependent partly on the local fracture permeability and partly on the rate of evaporation at the base of the open cut. The maximum possible increase in recharge rate, which could take place if there is significant fracture permeability in the base of the open cut, would be equivalent to the typical runoff over the open cut area. Assuming a runoff coefficient of 11% of rainfall (SEEC, 2013) and an average annual rainfall of 0.6 m, the maximum possible increase in the recharge rate over the area of the open cut compared to baseline conditions would be approximately 26 ML/a.

In the immediate vicinity of the open cut, there is a possibility of increased fracture permeability due to blasting and the unloading of the bedrock beneath the open cut. However, a proportion of the runoff into the open cut is expected to evaporate following ponding within the open cut, such that the net increase in the recharge rate over this area is expected to be considerably less than 26 ML/a. Increased recharge over the area of the open cut would potentially raise the water table beneath the void by up to a few metres, thereby locally increasing the hydraulic gradient away from the open cut.

Any net increase in the recharge rate in comparison to baseline conditions would be balanced by a net increase in the discharge rate to the local gullies. The discharge may be manifested in springs which did not exist prior to the Proposal. This impact is not predicted to extend to the alluvial and colluvial sediments surrounding the high ground.

6.3.6 Processing Plant Area

The net effect of the design of the Processing Plant, given it is a virtually completely paved area (TZMI, 2013), would be to significantly reduce the rate of recharge over its footprint (approximately 50 ha in total). It is expected that run-off from the area would be redirected via a stormwater collection and distribution system, ultimately to Wambangalang Creek (SEEC, 2013).

The Processing Plant Area represents close to 2% of the total DZP Site, therefore the effect on the total groundwater flux through the local groundwater flow systems within the Wambangalang Creek Catchment is expected to be minor (see 'Consequence of Impact' in **Table 10**). However, there is predicted to be a slight reduction in the level of the water table (less than one metre) beneath and in the vicinity of the Processing Plant, due to the reduction in the recharge rate in this area during the Proposal.

6.4 Potential chemical impacts to groundwater during operations and post closure

6.4.1 Introduction

Potential chemical impacts on groundwater beneath and about the DZP Site are primarily related to the potential for leakage from proposed site structures (e.g. the open cut, LRSF, SRSF, WRE and SECs) and to the potential for dryland salinity associated with increased water tables. The Proposal has been designed to minimise the potential for chemical impacts using physical barriers to leakage, such as HDPE liners, as described in Section 6.2.

The primary potential contaminant of the groundwater is salinity. There is considered to be negligible potential for acid metalliferrous drainage (AMD) due to the lack of sufur in the ore or in surrounding rocks (ANSTO, 2010 and pers. comm. Terry Ransted, 2013).

Salts are conservative contaminants in water, i.e. they effectively move at the rate of groundwater migration with no significant attenuation or retardation. Reduction in concentrations would be by dispersion within *in-situ* and naturally flowing groundwater only.

Salinity impacts on groundwater beneath the DZP Site have the potential to migrate down-gradient along the alluvial aquifers associated with the major creeks and to impact the creeks themselves and their ecosystems (see Section 6.5). The baseline groundwater quality has potential beneficial uses of stock watering, irrigation, primary contact recreation and industrial. The beneficial uses of stock watering, irrigation and primary contact recreation all have the potential to be compromised by increased salinity.

6.4.2 SRSF Cells

The construction and management of the SRSF is described above in the description of key Proposal components (Section 6.2). As a result of the design, there would be no opportunity for liquid to migrate into the groundwater from the SRSF. Therefore, chemical impacts to groundwater as a result of the SRSF are predicted to be negligible. It therefore follows that there is no perceived potential for the SRSF cells to impact any beneficial users of groundwater.

6.4.3 LRSF

It is the intent of the LRSF design to prevent the leakage of brine into the groundwater. Details of the approach to liner construction, the verification of liner integrity and the response if leaks are suspected are provided above in Section 6.2. Although the LRSF design is intended to prevent leaks, it is necessary to consider the potential impact of the LRSF due to a breached liner.

In practise, it is considered possible that there would be breaches of the integrity of the liner. However, due to the approach to liner construction, and the proposed monitoring of the LRSF and of perimeter groundwater conditions (described in Section 6.2), it can be expected that any such breaches would be rare, localised and temporary rather than widespread and/or permanent.

The LRSF would contain brine at an initial concentration of 62,500 mg/L (DE Cooper and Associates, 2012), which would increase with evaporation of the water. Therefore, any leakage from a LRSF would transmit high concentration brine into the groundwater beneath the LRSF.

In addition to brine, liquid residue in the LRSF would also contain low levels of metals (based on *Table 7.1* of DE Cooper & Associates 2013) such as Al, Mn, U and Zr, and a significant portion (11.8%) as sulfur (S) species. It is therefore considered that a possible chemical risk associated with the LRSF is that the liquid residue would become acidic (from oxidation of S to form H_2SO_4) and thereby release metals into solution.

This risk is considered very low, as much (or all) of the S species are likely to be in oxidised forms (such as SO_4) which are further likely to be precipitates such as gypsum ($CaSO_4$), and completely neutralised by carbonates (lime and limestone). However any leakage into the subsurface could induce reductive processes to occur and as such create a source of S (regardless of oxidation state).

Due to the high salinity of the water in the LRSF, any leakage would have a significant impact on the groundwater quality directly beneath the LRSF, which would locally compromise beneficial uses associated with ecosystems, stock watering, recreational (including direct contact and aesthetic) use, irrigation and drinking at the point of impact. The only potential beneficial use that would not be compromised in groundwater directly beneath a leaking liner is industrial use. However, the high salinity imparted by the leakage would also impact a significant proportion of potential industrial uses. The potential impact to beneficial uses down-gradient is discussed in Section 6.5.

However, in the event of a breached liner, it can be expected that the leak would be detected by groundwater monitoring and repaired as described above such that the leak would be temporary and its consequent effects would be minimised. Although it would be unlikely that a significant proportion of any brine that leaks into the groundwater could be effectively removed, it can be expected that the total volume of leakage would be small in comparison to the total volume of groundwater beneath and down-gradient from the LRSF (see Section 6.5).

Consider the example described above in Section 6.3 in which a leakage flux of 10 m^3/day is taking place from a LRSF over alluvium. For a leak of this order of magnitude, it can be expected that there would be a relatively rapid increase in groundwater levels in the monitoring bores such that the leak would be identified and the leaking liner would be repaired within a period of weeks to months. Therefore, the total volume of brine seeping into the groundwater would be expected to be less than 2,000 m^3 (based 10 m^3/day for 200 days).

For comparison, a volume of saturated alluvium which is 50 m in width perpendicular to groundwater flow direction x 100 m in length parallel to the flow direction x 30 m thick beneath a LRSF can be expected to contain a volume of greater than 50,000 m^3 of water (based on a porosity of greater than 0.3).

6.4.4 SECs

The construction and management of the SECs is described above in the assessment of physical impacts. As a result of the design and as long as monitoring of leakage takes place, there would be no opportunity for liquid to migrate into the groundwater from the SRSF. Therefore, chemical impacts to groundwater as a result of the SECs are predicted to be negligible. However, the validity of this conclusion depends on continuous monitoring of the leak detection system for a period of decades following mine closure.

The only potential for the SECs to affect beneficial users of groundwater is if leakage occurs and is not captured by the leak detection and collection system that is proposed. Even with the occurrence of such undetected and captured leakage, the overall level of risk is moderate (see **Table 10**). It would be important to ensure the leak detection system is operational for the life of mine and post-closure (as long as the SECs remain in place).

6.4.5 WRE

As a result of the proposed WRE design, whilst recharge beneath this structure is expected to be enhanced (based on the assumption that it would not be lined), there is not considered to be any opportunity for chemically impacted or acidic liquid to migrate into groundwater due to the expected benign nature of the waste rock to be emplaced. Therefore potential chemical impacts to groundwater are predicted to be negligible, as is the potential for any impact to beneficial users and receptors (see 'Likelihood of Impact' and resulting 'Overall Level of Risk' in **Table 10**).

6.4.6 Open Cut

Slight increases in the concentrations of dissolved metals are possible in groundwater in the vicinity of the open cut, both during and post mining, due to the increased recharge and the exposure of the rock to weathering in the open cut.

The solubility of most heavy metals is controlled by acidity. There is no evidence from the geochemistry of the surrounding rocks at the open cut that acid mine drainage is likely either during mining or following closure. Sulfide concentrations are very low to non-detectable. Therefore, it is considered unlikely that the chemistry of the groundwater, and therefore the beneficial uses of that groundwater, will be affected by the predicted enhanced recharge in the open cut following closure.

6.4.7 Processing Plant Area

Part of the Processing Plant Area is located over basalt, which is considered likely to have significant fracture permeability and, consequently, the transmissivity of an aquifer. The Processing Plant Area consists primarily of processing and ore handling areas, as well as storage and distribution facilities for product, reagents (in particular acids and sulfur) and wastes and effluent. As such, there is a significant volume of chemicals that will be handled and stored in this area of the DZP Site. Should the chemicals stored and used at the Processing Plant enter the groundwater, the direct and ensuing down-gradient consequences could be very significant.

For this reason, all of the above-listed areas are to be paved and bunded with concrete (TZMI, 2013), such that in the event of a spill or leak, it can be readily contained and prevented from seeping into the ground. Due to the proposed design, it is considered very unlikely that there would be any significant seepage of these chemicals into the ground. As a result, the overall chemical risk to groundwater resources due to the Processing Plant Area is considered to be moderate.

The proposed monitoring bore network will enable both groundwater level and quality to be monitored. These bores will be used to verify the prevention of impacts to groundwater (see Section 7). Any impact would be expected to be detected via chemical change in groundwater quality (in particular) as a result of any spill or leak that was able to access the sub-surface in the Processing Plant Area.

6.5 Consequential impacts

Apart from the groundwater resources themselves, the potential receptors of physical and chemical impacts of the Proposal are the major creeks and associated ecosystems, and groundwater users within the local groundwater flow system. Groundwater users more than approximately 100 m to the west of Wambangalang Creek are unlikely to be affected by the DZP Site as they are outside the local flow system. The most sensitive users appear to be those within the Wambangalang Catchment including the unregistered bore usage in the Toongi Township (owned by the Proponent) and the cluster of bores around Cockleshell Corner (intersection of Eulandool and Springs Roads, see **Figures 7** and **8**).

There are eleven registered bores and wells within the DZP Site and several additional unregistered bores and wells which could potentially be affected by any impacts to groundwater as they are within the local groundwater flow system of the DZP Site. Most of these bores and wells are located in the Wambangalang Creek / Paddy's Creek valley. Bores and wells in the Toongi township area would be most likely to be subject to impact, should they occur, as this area is down-gradient of the LRSF.

6.5.1 Ensuing physical impacts

The major creeks, such as Wambangalang Creek, at the perimeters of the Proposal are ephemeral (SEEC, 2013). Therefore, in their baseline condition they do not depend on groundwater inflow to maintain their flow year-round. Also, the sandy alluvial aquifer in the vicinity of Wambangalang Creek is likely to receive its recharge from groundwater flow from other flow systems outside the DZP Site as well as from the creek itself. Therefore, although it is considered possible that the groundwater level and the total groundwater flux would be reduced slightly in the sandy alluvium in the vicinity of Wambangalang Creek as a result of reduced flux through the local flow system of the DZP Site, this is not expected to have significant consequences for ecosystems or groundwater users.

6.5.2 Ensuing chemical impacts

The primary potential impacts to ecosystems, groundwater users or to the major creeks would be as a result of possible groundwater contamination due to seepage from proposed structures (e.g. the open cut, LRSF, SRSF, WRE, SECs and Processing Plant Area) discharging to the primary alluvial aquifers, the creeks or migrating to bores via relatively high permeability pathways.

As described in Section 6.4, it is considered unlikely that the chemistry of the groundwater will be modified by the predicted enhanced recharge in the open cut following closure. Therefore, ensuing chemical impacts due to the open cut are considered unlikely.

Other components of the Proposal have been designed to minimise the potential for chemical impacts using physical barriers to leakage, such as HDPE liners and concrete pads, as described in Section 6.2. It is considered to be very unlikely that the integrity of the double liner systems of the SRSF and SEC, or the concrete pads of the Processing Plant area would be compromised. Considerable measures will be implemented to optimise the integrity of the single liners of the LRSF. However, it is considered possible that breaches could occur in the single liner of a LRSF. Therefore, the potential ensuing impacts of such leaks are discussed below. Due to the slow rate of groundwater flow, the potential impacts are likely to extend beyond the period of mining.

The LRSF in Areas 2 and 3 are proposed to be located within approximately 250 m of Wambangalang Creek (**Figure 13**) and SECs are proposed to be located within 150 m of a northern tributary of Cockabroo Creek (**Figure 3**). Based on the hydraulic properties of the clay alluvium, the expected travel time of any leakage from the LRSF in Areas 2 or 3 to Wambangalang Creek would be several decades. However, if sandy alluvium extends close to the LRSF, this travel time could be less.

As described previously in this section, in the event of a breached liner, it can be expected that the leak would be detected and repaired in a timely manner such that the leak would be temporary and its consequent effects would be minimised. Although any brine that leaks through breaches in the liner would initially be concentrated at the underlying water table beneath the LRSF, its volume can be expected to be minor in comparison to the volume of groundwater beneath and down-gradient from the LRSF.

Therefore, although groundwater flow would transport a plume of brine down-gradient at the average linear velocity of the groundwater following any leak (i.e. a few metres per year at most in clay alluvium), dispersion through *in-situ* groundwater and the limited duration of the source would together have the effect of significantly reducing the concentration with distance from the LRSF. Therefore, ensuing effects to down-gradient receptors such as Wambangalang Creek and associated groundwater dependent ecosystems or groundwater users are considered to be unlikely.

For a LRSF constructed over low permeability bedrock, the risk of ensuing impacts as a result of LRSF liner breaches would be similar to a LRSF constructed over clay alluvium. In the summary of risks listed in **Table 10**, it has been assumed that a LRSF will not be constructed above areas of relatively permeable trachyte or basalt which extend laterally beyond the lower embankment of the LRSF.

In bedrock areas with significant fracture permeability such as trachyte and basalt, or in areas of sandy alluvium, it can be expected that the average linear velocity of leakage would be tens to hundreds of metres per year due both to the relatively high hydraulic conductivity and the low effective porosity of the bedrock. Therefore, any leakage from the LRSF into such aquifers has the potential to migrate rapidly to discharge areas in minor on-site drainages. In this situation, the ensuing risk due to the LRSF would be considered high, notwithstanding the relatively low-permeability zone that is likely to be present at the ground surface. The risk in this situation could be reduced to moderate if additional measures were incorporated into the design of the LRSF such as a double lining, cut-off wall, seepage interception bores, or a combination of these measures.

6.5.3 Land salinisation

At any location where the water table is raised to within 2 m of the ground surface there is the potential for land salinization to take place. However, this is not predicted either during or following mining operations.

Assuming the liners of the LRSF are effective at preventing leakage, there would be negligible potential for land salinisation impacts due to the LRSF because the water table is not predicted to increase as a result of the Proposal.

As described in Section 6.3, in the event of a breached liner, it can be expected that the leak would be detected and repaired within a period of a few weeks to months such that the leak would be temporary and its effect of groundwater quality would be localised. This also means that any increase in the water table as a result of a liner leak would be localised and temporary. Should the water table rise to within 3 m of the ground surface near the toe of the lower embankment of a LRSF, trenching may be implemented to intercept seepage and/or maintain the water table at more than 2 m below ground level. At decommissioning, all salt will be removed from the LRSF and the ground surface will be re-contoured to its original level. Therefore, long-term land salinization as a result of LRSF leaks is considered unlikely.

6.6 Comparison of risks associated with groundwater impacts

Table 10 presents a summary list of the primary potential groundwater impacts of the different components of the Proposal. The individual impacts are considered separately in terms of their likelihood and consequence; scores are attributed to both likelihood and consequence on a scale from 1 to 5 in each case. The risk is, in turn, scored as the sum of the likelihood and consequence scores. A high likelihood and the most significant consequences are given low scores and a low likelihood and least significant consequences are given a high score. As a result, the potential impacts with the highest perceived risks have the lowest risk scores.

The risks are also colour coded, with high risk shown in orange, moderate risk in yellow, and low risk in green. The table considers the components of the Proposal as described in Section 6.2, without any additional mitigation measures. The majority of the risks listed in **Table 10** are considered to be low to moderate. There are two interpreted high risks, each with a risk score of 5, and there are no extreme risks identified in **Table 10**. Of the two risks identified as high, the chemical risk associated with a leaking LRSF is considered to be the more significant.

Section 6.2 describes extensive measures that will be put in place to ensure LRSF liner integrity, to monitor groundwater conditions, and to respond in a timely manner by draining the pond and repairing the liner. This means that any liner leak can be expected to be localised and temporary. As a result, the volume of any leak can be expected to be small in comparison to the volume of the *in-situ* groundwater beneath and in the vicinity of a LRSF (Section 6.4). Therefore, salinity concentrations would be expected to be attenuated significantly by dispersion with groundwater flow such that the likelihood of ensuing impacts to down-gradient receptors would be low.

The direct risk to the groundwater resource associated with LRSF leakage is considered to be high, largely because of the consequences to the groundwater resource. The high salinity of the brine stored in the LRSF, combined with the high mobility of dissolved salts in groundwater, mean that the potential impact of such leaks is significant. Despite the extensive measures that will be in place to prevent leaks, the likelihood of such leaks has been conservatively assessed as possible rather than unlikely. This is because the LRSF cover a large combined area, are single lined, and salt will be excavated from them.

The measures that will be in place to respond to leaks mean that the consequences of such leaks are considered to be major rather than critical in that they would be expected to be localised and temporary. The ensuing risks to beneficial uses further down-gradient are considered to be moderate rather than high for the same combined reasons and due to the attenuation of salt concentrations that would result from dispersion with groundwater flow.

It should be noted that the LRSF assessment in **Table 10** is based on LRSF construction above low permeability materials (either alluvium/ colluvium or bedrock), which would help in limiting the extent of the impact of any leaks. In a situation in which there are relatively high permeability materials extending from beneath a LRSF cell to beyond the lower embankment of that cell, the direct risk to groundwater would be greater due to the potential for leakage impacts to cover a large area. The ensuing risk of impacts to ecosystems and groundwater users would therefore be considered high in such a scenario (which has not been observed during the assessment phase).

The above discussion is considered to remain relevant, notwithstanding the relatively low-permeability weathered zone that is likely to be present at the ground surface above higher permeability materials. The risk in this situation could be reduced to moderate if additional measures were incorporated into the design of the LRSF, such as a double lining, cut-off wall, seepage interception bores, or a combination of these measures.

There is currently insufficient data to demonstrate the lack of high permeability aquifers in the vicinity of all the LRSF areas. At the proposed location of the Area 4 LRSF, the recent geological map shows basalts beneath the footprint of the LRSF which may extend outside the footprint (**Figures 3** and **6b**). Based on the hydraulic testing reported in Section 5, it is considered likely that these basalts would have relatively high hydraulic conductivity in comparison to sedimentary bedrock, such that groundwater would be expected to flow relatively quickly through them. Due to its potential to enhance the risk associated with the LRSF, it will be important to establish the extent of the basalt in this area.

The risk of an increase in groundwater flux due to enhanced recharge associated with the open cut is interpreted to be high in **Table 10**. However, it should be noted that this line item considers the physical risk only. Although this is scored as a high risk by this methodology, an interpreted "high risk" of enhanced groundwater flow is more a function of the itemised risk methodology than a true issue of concern.

TABLE 10 SUMMARY ASSESSMENT OF POTENTIAL IMPACTS

Proposal Component	Aspect of Proposal Component	Potential Impacts to Groundwater	Likelihood of Impact	Consequence of Impact	Overall Level of Risk	Comments
LRSF	Leakage due to Breached Liner	Physical Impact to Groundwater	Possible (3)	Minor (4)	**Moderate (7)**	Would increase groundwater level
		Chemical Impact to Groundwater	Possible (3)	Major (2)	**High (5)**	Localised risk. See Section 6 for further discussion
		Ensuing Physical Impact to Ecosystems or Groundwater Users	Unlikely (4)	Minor (4)	**Low (8)**	
		Ensuing Chemical Impact to Ecosystems or Groundwater Users	Unlikely (4)	Major (2)	**Moderate (6)**	
		Ensuing Land Salinisation	Unlikely (4)	Major (2)	**Moderate (6)**	
	Negligible recharge due to Liner	Physical Impact to Groundwater	Likely (2)	Minor (4)	**Moderate (6)**	Planned outcome
		Chemical Impact to Groundwater	Very unlikely (5)	Minor (4)	**Low (9)**	
		Ensuing Physical Impact to Ecosystems or Groundwater Users	Possible (3)	Minor (4)	**Moderate (7)**	
		Ensuing Chemical Impact to Ecosystems or Groundwater Users	Very unlikely (5)	Minor (4)	**Low (9)**	

TABLE 10 SUMMARY ASSESSMENT OF POTENTIAL IMPACTS (CONTINUED)

Proposal Component	Aspect of Proposal Component	Potential Impacts to Groundwater	Likelihood of Impact	Consequence of Impact	Overall Level of Risk	Comments
SRSF or SEC	Leakage due to Breached Liner	Physical Impact to Groundwater	Very unlikely (5)	Minor (4)	**Low (9)**	
		Chemical Impact to Groundwater	Very unlikely (5)	Major (2)	**Moderate (7)**	Most likely post closure
		Ensuing Physical Impact to Ecosystems or Groundwater Users	Very unlikely (5)	Minor (4)	**Low (9)**	
		Ensuing Chemical Impact to Ecosystems or Groundwater Users	Very unlikely (5)	Critical (1)	**Moderate (6)**	Most likely post closure
		Ensuing Land Salinisation	Very unlikely (5)	Major (2)	**Moderate (7)**	
	Negligible recharge due to Liner	Physical or Chemical Impact to Groundwater	Likely (2)	Minor (4)	**Moderate (6)**	Planned outcome
		Ensuing Physical or Chemical Impact to Ecosystems or Groundwater Users	Possible (3)	Minor (4)	**Moderate (7)**	
Open Cut	Enhanced Recharge due to no runoff	Physical Impact to Groundwater	Likely (2)	Moderate (3)	**High (5)**	Primarily localised post closure impact. See Section 6 for further discussion
		Chemical Impact to Groundwater	Unlikely (4)	Minor (4)	**Low (8)**	Primarily post closure issue
		Ensuing Physical Impact to Ecosystems or Groundwater Users	Unlikely (4)	Minor (4)	**Low (8)**	Relatively large distance to receptors
		Ensuing Chemical Impact to Ecosystems or Groundwater Users	Unlikely (4)	Moderate (3)	**Moderate (7)**	Relatively large distance to receptors

TABLE 10 SUMMARY ASSESSMENT OF POTENTIAL IMPACTS (CONTINUED)

Proposal Component	Aspect of Proposal Component	Potential Impacts to Groundwater	Likelihood of Impact	Consequence of Impact	Overall Level of Risk	Comments
WRE	Enhanced Recharge	Physical Impact to Groundwater	Likely (2)	Minor (4)	**Moderate (6)**	
		Chemical Impact to Groundwater	Unlikely (4)	Major (2)	**Moderate (6)**	
		Ensuing Physical Impact to Ecosystems or Groundwater Users	Unlikely (4)	Minor (4)	**Low (8)**	
		Ensuing Chemical Impact to Ecosystems or Groundwater Users	Unlikely (4)	Major (2)	**Moderate (6)**	
Processing Plant Area	Leakage due to Cracks/Breaches in Paved Area	Physical Impact to Groundwater	Very unlikely (5)	Minor (4)	**Low (9)**	
		Chemical Impact to Groundwater	Very unlikely (5)	Critical (1)	**Moderate (6)**	
		Ensuing Physical Impact to Ecosystems or Groundwater Users	Very unlikely (5)	Minor (4)	**Low (9)**	
		Ensuing Chemical Impact to Ecosystems or Groundwater Users	Very unlikely (5)	Critical (1)	**Moderate (6)**	
		Ensuing Land Salinisation	Very unlikely (5)	Major (2)	**Moderate (7)**	
	Negligible recharge due to Pavement	Physical or Chemical Impact to Groundwater	Likely (2)	Minor (4)	**Moderate (6)**	Planned outcome
		Ensuing Physical or Chemical Impact to Ecosystems or Groundwater Users	Possible (3)	Minor (4)	**Moderate (7)**	

Note(s):
1. Likelihood scale has five categories with scores from 5 to 1, i.e. Very Unlikely (5), Unlikely (4), Possible (3), Likely (2), Very Likely (1)
2. Consequence scale has five categories with scores from 5 to 1, i.e. Negligible (5), Minor (4), Moderate (3), Major (2), Critical (1)
3. Overall risk value = Consequence value + Likelihood value; consequence and likelihood are considered separately
4. Red denotes Extreme Risk (scores of 2-3), Orange denotes High Risk (scores of 4-5), Yellow denotes Moderate risk (scores of 6-7), Green denotes low risk (8-10)

The most likely effect of increased groundwater flux would be enhanced groundwater discharge/spring flow in the highland gullies, which could be considered to be a positive impact. If this change had potential chemical impacts associated with it, it would be considered more significant. In addition, it should be noted that any enhanced recharge caused by the open cut would likely be offset by reduced recharge caused by the SRSF and SEC. Thus, although in isolation the open cut would be likely to enhance post-closure recharge, the net effect of the Proposal on post-closure groundwater recharge and resulting groundwater flux is expected to be minimal.

7 RECOMMENDED MITIGATION, VERIFICATION AND MANAGEMENT MEASURES

7.1 Verification and risk mitigation recommendations

Impact mitigation measures incorporated into the Proposal to protect groundwater resources beneath and down-gradient from the DZP Site for the life of mine and into closure have been described in Section 6.2. These include double liners with leak detection for the SRSF and SEC, single liners for the LRSF, and bunded concrete paved above-ground storage, processing and handling areas for the Processing Plant Area. All of these Proposal components will include comprehensive groundwater monitoring around the perimeter to provide early warning of groundwater impacts. The monitoring is described in more detail below, with proposed monitoring bore locations on **Figure 14**.

The chemical risk to groundwater associated with the LRSF components of the Proposal is conservatively considered to be relatively high in comparison to the risks associated with other components (Section 6.6). However, liner integrity procedures included in the Proposal are comprehensive both in their design and quality control at the time of construction (Section 6.2). Groundwater monitoring that indicates leakage from any LRSF cell will trigger a response which would likely include draining of the pond, inspection and repair of the liner.

In general, LRSF cells are not planned to be located above areas where relatively high permeability materials are known to exist and the assessment of risks to groundwater resources and ensuing risks, presented in Section 6, is based on the assumption that LRSF cells will not be constructed over extensive aquifers. This means that the risks to groundwater are expected to be localised and temporary and ensuing risks to beneficial uses away from the LRSF are reduced.

However, if there are laterally continuous aquifers beneath any LRSF cell/s, the effect would likely be to enhance the flux of any leakage that occurs in comparison to a low permeability subsurface environment, and to transmit that leakage more rapidly to potential receptors. The accelerated leakage effect would likely occur even if there is a low permeability layer separating the liner of the LRSF from the underlying aquifer (e.g. alluvial clay in an alluvial environment or weathered rock in a bedrock environment). As a result, the risks of direct and ensuing impacts would increase in comparison to those described in Section 6. Therefore, to the extent possible, we recommend that LRSF cells are not located above high permeability aquifers such as alluvial sands or basalt.

In addition to the monitoring bores, several boreholes have been drilled within the footprint of the proposed LRSF in Area 3. These boreholes have verified that the alluvium consists of clay in this area and none of the boreholes have shown the presence of clean sands or gravels in the alluvium (SSM, 2013). However, there is currently insufficient data to demonstrate the lack of high permeability aquifers in the vicinity of all the proposed LRSF areas. We recommend that additional boreholes along the perimeters of the proposed LRSF are drilled and hydraulic testing is undertaken to evaluate aquifer properties.

It is important that any borehole drilled within the footprint of a proposed LRSF cell be properly abandoned by grouting the entire borehole such that a vertical pathway for groundwater flow and/or potential seepage is not created. We also recommend that the extent of the basalt mapped within the footprint of the proposed Area 4 LRSF is investigated and that the nature of the alluvium beneath the proposed Area 2 LRSF is verified. The aquifer property information would be used to finalise the planned spacing of the monitoring bores around the perimeter of the facilities.

If laterally continuous high permeability materials are encountered beneath a LRSF cell and it is not practical to relocate the LRSF to an alternate location, it is recommended that consideration be given to the following:

- constructing the LRSF cells with a double liner system with leakage detection similar to the SRSF and incorporating the capability to pump any leakage back into the pond; and
- design and/or installation of a quick response seepage interception system as part of the Groundwater Management and Mitigation Plan (see Section 7.2).

The up-gradient perimeters proposed for the LRSF cells in Areas 2 and 3 are located at the break in slope between the bedrock area and the alluvium. Groundwater pressure and discharge is likely at this break in slope. This should be considered in the design of the ponds, including the liners.

7.2 Groundwater management and mitigation plan

We recommend a Groundwater Management and Mitigation Plan (GMMP), which would describe the objectives of the groundwater management and monitoring and detail the proposed types and locations of monitoring. It would also describe the monitoring observations which would trigger actions, and the proposed action and/or mitigation should triggers be exceeded (DEC, 2007). The following includes a preliminary recommendation for the groundwater monitoring program which should be considered in development of a GMMP.

In summary, while many bores to be installed as part of storage structures on the DZP Site would be monitored frequently for static water level (SWL), a network of 21 bores pre-mining across the DZP Site and a larger number of project component perimeter bores during mining are recommended for quarterly water level and quality monitoring. The recommended monitoring program is intended to facilitate closure-focussed interpretation of the data.

We recommend that the monitoring bore spacing, and consequently the total number of monitoring bores along the perimeters of the storage structures, be finalised following additional hydraulic testing of boreholes. From the information available at the time of writing of this document, we recommend a spacing of no more than 100 m on the down-gradient side of storage facilities and the Processing Plant. See **Figure 13** for a conceptual representation of monitoring bore placement, depth and construction at the toe of LRSF cells, and **Figure 14** for the lateral distribution of proposed monitoring bore locations across the entire DZP Site (see the note on **Figure 14** relating to perimeter bore spacing).

7.2.1 Summary of mitigation recommendations

The GMMP would include an action plan in the event of suspected leakage into the groundwater. This would include triggers as well as responses. The GMMP would also include consideration of seepage interception. The following is a preliminary consideration of likely approaches to interception in the event of brine leakage from a LRSF cells/, or contamination leakage from another component of the Proposal such as the Processing Plant Area. The approach to interception of that leakage would be based on the best available information regarding hydraulic conductivity of the ground, which, we recommend, would be evaluated by hydraulic testing.

In an aquitard (low hydraulic conductivity), interception of impacted groundwater using conventional interception wells would likely be impractical due to the very limited yields and capture zones. In this situation, if the water table were within a few metres of the ground surface, a linear interception system such as a trench may be the most practical approach. If the water table is relatively deep, horizontal wells may be the most cost effective approach to interception.

In the event of leakage into an aquifer, interception using conventional vertical interception bores is likely to be the most cost effective approach. The spacing and pumping rates of interception bores would be designed based on the hydraulic properties, which would first need to be evaluated by pumping tests of test bores.

7.2.2 Summary of monitoring recommendations

All of the Proposal components will include comprehensive perimeter groundwater monitoring to provide early warning of groundwater impacts (**Figure 14**). We recommend a monitoring-bore spacing of no more than 100 m on the down-gradient side of storage facilities and the Processing Plant. The final bore spacing should be specified in the GMMP. Monitoring of both groundwater levels and electrical conductivity would take place in these bores at a relatively high frequency. However, the collection of samples from these bores and laboratory analyses of these samples would generally not be necessary, unless chemical impacts were interpreted from an increase in electrical conductivity.

Due to the large number of these bores, the most cost effective approach to this monitoring, including the potential for automation, should be considered in the GMMP.

In addition, we recommend that a broad network of bores across the site be monitored, including existing bores. Some existing bores would require decommissioning and replacement and some additional locations are recommended. This monitoring would build on the groundwater data presented in this report, in order to provide a substantial baseline of data prior to mining operations commencing. A site-specific analytical suite has been recommended for quarterly sampling of these bores, which should be formalised in the GMMP.

The locations of the current bores are generally considered appropriate for on-going monitoring. However, due to the lack of a seal installed in them, it is recommended at all bores DWB001 to DWB011 (if included in the list below) be appropriately decommissioned and replaced to ensure representative data is obtained and to prevent possible pathways for contamination to enter the groundwater from the ground surface.

Apart from the bores along the perimeters of the Proposal components, the recommended groundwater bore network for on-going quarterly monitoring is illustrated in **Figure 14** and details of that network are described below:

- Background bores: replacements of bores DWB002, DWB003, DWB004 and DWB006;
- Within the proposed open cut : bores GWB021 and DWB022 until mining commences;
- Down-gradient of the open cut and up-gradient of RSF's: replacement of bores DWB007, DWB010 and DWB011, and continued monitoring of bore DWB020;
- Lower catchment bores: bores DWB015, DWB016, DWB019 and DWB023; and
- Additional bores to be placed down-gradient of the LRSF, SRSF and Salt Encapsulation Cells:
    - at least one in the vicinity of bore GW008373;
    - one south of bore DWB019 between the proposed LRSF cells and Wambangalang Creek;
    - one to the north of bore GWB012 between the LRSF Area 2 and Wambangalang Creek;
    - one to the north of bore DWB015 between the LRSF Area 3 and the Processing Plant;
    - one between the Processing Plant and the confluence of Wambangalang and Paddy's Creeks; and
    - one south of each of the SRSF and the Salt Encapsulation Cells.

As such, 21 bores are proposed to be included in the general site-wide monitoring network for assessing groundwater levels and quality prior to and during mining operations.

The bores along the perimeters of the LRSF, SRSF and SEC in **Figure 14** are shown with a typical spacing of hundreds to several hundred metres between bores. In reality, the spacing between monitoring bores on the down-gradient side of LRSF cells in particular is likely to be on the order of 100 m or less, such that there would be considerably more bores than illustrated in **Figure 14**.

It is important that as part of on-going SWL measurement, all bores are initially surveyed to a common datum, such that the elevation of groundwater levels are known and can be compared.

7.2.3 Chemical analysis recommendations

The recommended analytical suite for quarterly monitoring of the general site-wide monitoring bores includes the following:

- Field measurement of:
  - pH, EC, ORP, SWL, purging flow rate, volume purged and turbidity;
- Laboratory analysis for:
  - full ionic balance suite – pH, TDS, cations (Na, Ca, Mg, K), anions (Cl, SO_4, HCO_3, PO_4, F) and nutrients (NH_3, NO_3 and NO_2);
  - dissolved metals / metalloids including aluminium (Al), antimony (Sb), arsenic (As), barium (Ba), beryllium (Be), boron (B), bromide (Br), cadmium (Cd), chromium (Cr), copper (Cu), iron (Fe), lead (Pb), manganese (Mn), molybdenum (Mo), nickel (Ni), selenium (Se), strontium (Sr), uranium (U), vanadium (V) and zinc (Zn).

8 LIMITATIONS

This report has been prepared by Environmental Earth Sciences NSW ABN 109 404 006 in response to and subject to the following limitations:

1. The specific instructions received from RW Corkery & Co Pty Limited;
2. The specific scope of works set out in PO612010_V1 issued by Environmental Earth Sciences NSW for and on behalf of RW Corkery & Co Pty Limited;
3. May not be relied upon by any third party not named in this report for any purpose except with the prior written consent of Environmental Earth Sciences NSW (which consent may or may not be given at the discretion of Environmental Earth Sciences NSW);
4. This report comprises the formal report, documentation sections, tables, figures and appendices as referred to in the index to this report and must not be released to any third party or copied in part without all the material included in this report for any reason;
5. The report only relates to the site referred to in the scope of works being located at the proposed Dubbo Zirconia Project (“the DZP Site”);
6. The report relates to the site as at the date of the report as conditions may change thereafter due to natural processes and/or site activities;
7. No warranty or guarantee is made in regard to any other use than as specified in the scope of works and only applies to the depth tested and reported in this report;
8. Fill, soil, groundwater and rock to the depth tested on the site may be fit for the use specified in this report. Unless it is expressly stated in this report, the fill, soil and/or rock may not be suitable for classification as clean fill if deposited off site; and
9. Our General Limitations set out at the back of the body of this report.

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10 GLOSSARY OF TERMS

The following descriptions are of terms used in the text of this report. A list of the references used in providing this glossary is presented in Section 15 of this report.

Aquifer. A rock or sediment in a formation, group of formations, or part of a formation which is saturated and sufficiently permeable to transmit economic quantities of water to wells and springs.

Aquifer, confined. An aquifer that is overlain by a confining bed with significantly lower hydraulic conductivity than the aquifer.

Aquifer, perched. A region in the unsaturated zone where the soil is locally saturated because it overlies soil or rock of low permeability.

Aquitard. A low permeability unit that can store groundwater and also transmit it slowly – typically from one aquifer to another.

Background. The natural level of a property.

Baseline. An initial value of a measure.

Biodegradation. A biochemical process of microbial oxidation of complex organic compounds, to simpler chemical products. Micro-organisms derive the energy and cell carbon for growth from oxidation of organic compounds.

Bore. A hydraulic structure that facilitates the monitoring of groundwater level, collection of groundwater samples, or the extraction (or injection) of groundwater. Also known as a well, monitoring well or piezometer, although piezometers are typically of small diameter and only used for measuring the groundwater elevation or potentiometric surface.

Borehole. An uncased well drill hole.

Capillary Fringe. The zone immediately above the water table, where water is drawn upward by capillary attraction.

Confined Aquifer. An aquifer that is confined between two low-permeability aquitards. The groundwater in these aquifers is usually under hydraulic pressure, i.e. its hydraulic head is above the top of the aquifer.

Confining layer. A layer with low vertical hydraulic conductivity that is stratigraphically adjacent to one or more aquifers. A confining layer is an aquitard. It may lie above or below the aquifer.

Diffusion. A process by which species in solution move, driven by concentration gradients (from high to low).

Dilution. The mixing of a small volume of contaminated leachate with a large volume of uncontaminated water. The concentration of contaminants is reduced by the volume of the lower concentrated water. However the physical process of dilution often causes chemical disequilibria resulting in the destruction of ligand bonds, the alteration of solubility products and the alteration of water pH. This usually causes precipitation by different chemical means of various species.

Discrete sample. Samples collected from different locations and depths that will not be composited but analysed individually.

Dispersion. A process by which species in solution mix with a second solution, thus reducing in concentration. In particular, relates to the reduction in concentration resulting from the movement of flowing groundwater.

Dissolved Oxygen (DO). Oxygen in the gaseous phase dissolved in water. Measured either as a concentration in mg/L or as a percentage of the theoretical saturation point, which is inversely related to temperature. At 19, 20 and 21 degrees Celsius, the oxygen concentrations in mg/L corresponding to 100% saturation are 9.4, 9.2 and 9.0 respectively.

Drawdown. Lowering of hydraulic head.

Dryland salinity. Dryland salinity occurs when salts within the soil profile are precipitated, as either groundwater levels rise or surface infiltration is impeded. Dryland salinity problems are generally caused by factors that either: increase the surface recharge rate of water; or reduce natural discharge, e.g. through land clearing that reduces rates of evapotranspiration losses. Changes in surface topography and drainage may also exhibit a causal relationship with dryland salinity where road or rail embankments induce salt mobilisation and precipitation in the landscape.

Electrical Conductivity (EC). The EC of water is a measure of its ability to conduct an electric current. This property is related to the ionic content of the sample, which is in turn a function of the total dissolved (ionisable) solids (TDS) concentration. An estimate of TDS in fresh water can be obtained by multiplying EC by 0.65.

Ephemeral stream. A stream that flows only during periods of precipitation and briefly thereafter, or during periods of elevated water table levels when the stream is in direct hydraulic connection with the underlying unconfined aquifer (i.e. receives base-flow).

Flow path. The direction in which groundwater is moving.

Fracture. A break in the geological formation, e.g. a shear or a fault.

Gradient. The rate of inclination of a slope. The degree of deviation from the horizontal; also refers to pressure.

Groundwater. The water held in the pores in the ground below the water table.

Groundwater Elevation. The elevation of the groundwater surface measured relative to a specified datum such as the Australian Height Datum (mAHD) or an arbitrary survey datum onsite, or "reduced level" (mRL).

Hydraulic Conductivity (*K*). A coefficient describing the rate at which water can move through a permeable medium. It has units of length per time. The units for hydraulic conductivity are typically m^3/day/m^2 or m/day.

Hydraulic Gradient (*i*). The rate of change in total head per unit of distance of flow in a given direction – the direction is that which yields a maximum rate of decrease in head. Hydraulic Gradient is unitless.

Hydraulic Head (*h*). The sum of the elevation head and the pressure head at a point in an aquifer. This is typically reported as an elevation above a fixed datum, such as sea level.

Infiltration. The passage of water, under the influence of gravity, from the land surface into the subsurface.

Injection well. A groundwater bore constructed for the purpose of pumping water into an aquifer.

Ionic Exchange. Adsorption occurs when a particle with a charge imbalance, neutralises this charge by the attraction (and subsequent adherence of) ions of opposite charge from solution. There are two types of such a charge: pH dependent; and pH independent or crystalline charge. Metal hydroxides and oxy-hydroxides represent examples of the former type, whilst clay minerals are representative of the latter and are normally associated with cation exchange.

Ions. An ion is a charged element or compound as a result of an excess or deficit of electrons. Positively charged ions are called cations, whilst negatively charged ions are called anions. Cations are written with superscript +, whilst anions use - as the superscript. The major aqueous ions are those that dominate total dissolved solids (TDS). These ions include: Cl^-, SO_4^{2-}, HCO_3^-, Na^+, Ca^{2+}, Mg^{2+}, K^+, NH_4^+, NO_3^-, NO_2^-, F^-, PO_4^{3-} and the heavy metals.

Leachate. Water that flows through waste material (or other material) will liberate soluble molecules to form leachate.

Nitrogenous compounds. Most nitrogen occurs as a gas (N_2) in the atmosphere. Nitrogen compounds are transformed by biological processes. In the presence of oxygen, organically bound nitrogen is oxidised: ammonium (NH_4^+) to nitrite (NO_2^-) to nitrate (NO_3^-). However in the leachate from refuse tips the oxygen demand is great, as expressed by high COD and as a result nitrogen compounds are reduced, i.e. the reverse of oxidation.

Perched Aquifer (or water table). A body of water located above an impermeable geological formation. These perched aquifers (or water tables) are nearly always seasonal or periodic.

Perched Groundwater. Unconfined groundwater separated from an underlying main body of groundwater by an unsaturated zone. Perched groundwater typically occurs in discontinuous, often ephemeral, lenses, with unsaturated conditions both above and below.

Permeability (*k*). Property of porous medium relating to its ability to transmit or conduct liquid (usually water) under the influence of a driving force. Where water is the fluid, this is effectively the hydraulic conductivity. A function of the connectivity of pore spaces.

Piezometric or Potentiometric Surface. A surface that represents the level to which water will rise in cased bores. The water table is the potentiometric surface in an unconfined aquifer.

pH. A logarithmic index for the concentration of hydrogen ions in an aqueous solution, which is used as a measure of acidity.

Plume. The spreading of a contaminant from a point source, under the influence of dispersion, diffusion and the like.

Porosity (*n*). The ratio of the volume of void spaces in a rock or sediment to the total volume of the rock or sediment. Typically given as a percentage.

Porosity, effective (n_e). The volume of the void spaces through which water or other fluids can travel in a rock or sediment divided by the total volume of the rock or sediment.

Porosity, primary. The porosity that represents the original pre openings when a rock or sediment formed.

Porosity, secondary. The porosity that has been caused by fractures or weathering in a rock or sediment after it has been formed.

QA/QC. Quality Assurance / Quality Control.

Recharge Area location of the replenishment of an aquifer by a natural process such as addition of water at the ground surface, or by an artificial system such as addition through a well

Recovery. The rate at which a water level in a well rises after pumping ceases.

Saprolite. A fine grained clay material formed by the *in-situ* deep weathering of crystalline igneous and metamorphic rocks under humid tropical and sub-tropical conditions.

Static Water Level (SWL). The depth to the groundwater surface in a well or bore measured below a specific reference point – usually recorded as metres below the top of the well casing or below the ground surface.

Storativity. The volume of water stored or released by an aquifer per unit volume (of porous medium) per unit change in head.

Stratigraphy. A vertical sequence of geological units.

Total Dissolved Salts (TDS). The total dissolved salts comprise dissociated compounds and undissociated compounds, but not suspended material, colloids or dissolved gases.

Trachyte. A silica saturated or over-saturated alkaline volcanic rock.

Transmissivity. The rate at which water is transmitted through a unit width aquifer under a unit hydraulic gradient.

Turbidite. A rock deposit formed from a turbulent subaqueous current of suspended sediment driven by gravity down slopes of <1°, or even upslope.

Turbidity. Describes the degree of opaqueness produced in water by suspended particulate matter.

Unconfined Aquifer. An aquifer in which the water table forms the upper boundary.

Unsaturated Zone. The zone between the land surface and the water table, in which the rock or soil pores contain both air and water (water in the unsaturated zone is present at less than atmospheric pressure). It includes the root zone, intermediate zone and capillary fringe. Saturated bodies such as perched groundwater may exist in the unsaturated zone. Also referred to as the Vadose Zone.

Vadose Zone. See unsaturated zone, above.

Water Table. The interface between the saturated zone and unsaturated zones. The surface in an aquifer at which pore water pressure is equal to atmospheric pressure.

Well. A hydraulic structure that facilitates the monitoring of groundwater level, collection of groundwater samples, or the extraction (or injection) of groundwater. Also known as a Bore.

ENVIRONMENTAL EARTH SCIENCES GENERAL LIMITATIONS

Scope of services

The work presented in this report is Environmental Earth Sciences response to the specific scope of works requested by, planned with and approved by the client. It cannot be relied on by any other third party for any purpose except with our prior written consent. Client may distribute this report to other parties and in doing so warrants that the report is suitable for the purpose it was intended for. However, any party wishing to rely on this report should contact us to determine the suitability of this report for their specific purpose.

Data should not be separated from the report

A report is provided inclusive of all documentation sections, limitations, tables, figures and appendices and should not be provided or copied in part without all supporting documentation for any reason, because misinterpretation may occur.

Subsurface conditions change

Understanding an environmental study will reduce exposure to the risk of the presence of contaminated soil and or groundwater. However, contaminants may be present in areas that were not investigated, or may migrate to other areas. Analysis cannot cover every type of contaminant that could possibly be present. When combined with field observations, field measurements and professional judgement, this approach increases the probability of identifying contaminated soil and or groundwater. Under no circumstances can it be considered that these findings represent the actual condition of the site at all points.

Environmental studies identify actual sub-surface conditions only at those points where samples are taken, when they are taken. Actual conditions between sampling locations differ from those inferred because no professional, no matter how qualified, and no sub-surface exploration program, no matter how comprehensive, can reveal what is hidden below the ground surface. The actual interface between materials may be far more gradual or abrupt than an assessment indicates. Actual conditions in areas not sampled may differ from that predicted. Nothing can be done to prevent the unanticipated. However, steps can be taken to help minimize the impact. For this reason, site owners should retain our services.

Problems with interpretation by others

Advice and interpretation is provided on the basis that subsequent work will be undertaken by Environmental Earth Sciences NSW. This will identify variances, maintain consistency in how data is interpreted, conduct additional tests that may be necessary and recommend solutions to problems encountered on site. Other parties may misinterpret our work and we cannot be responsible for how the information in this report is used. If further data is collected or comes to light we reserve the right to alter their conclusions.

Obtain regulatory approval

The investigation and remediation of contaminated sites is a field in which legislation and interpretation of legislation is changing rapidly. Our interpretation of the investigation findings should not be taken to be that of any other party. When approval from a statutory authority is required for a project, that approval should be directly sought by the client.

Limit of liability

This study has been carried out to a particular scope of works at a specified site and should not be used for any other purpose. This report is provided on the condition that Environmental Earth Sciences NSW disclaims all liability to any person or entity other than the client in respect of anything done or omitted to be done and of the consequence of anything done or omitted to be done by any such person in reliance, whether in whole or in part, on the contents of this report. Furthermore, Environmental Earth Sciences NSW disclaims all liability in respect of anything done or omitted to be done and of the consequence of anything done or omitted to be done by the client, or any such person in reliance, whether in whole or any part of the contents of this report of all matters not stated in the brief outlined in Environmental Earth Sciences NSW's proposal number and according to Environmental Earth Sciences general terms and conditions and special terms and conditions for contaminated sites.

To the maximum extent permitted by law, we exclude all liability of whatever nature, whether in contract, tort or otherwise, for the acts, omissions or default, whether negligent or otherwise for any loss or damage whatsoever that may arise in any way in connection with the supply of services. Under circumstances where liability cannot be excluded, such liability is limited to the value of the purchased service.

FIGURES

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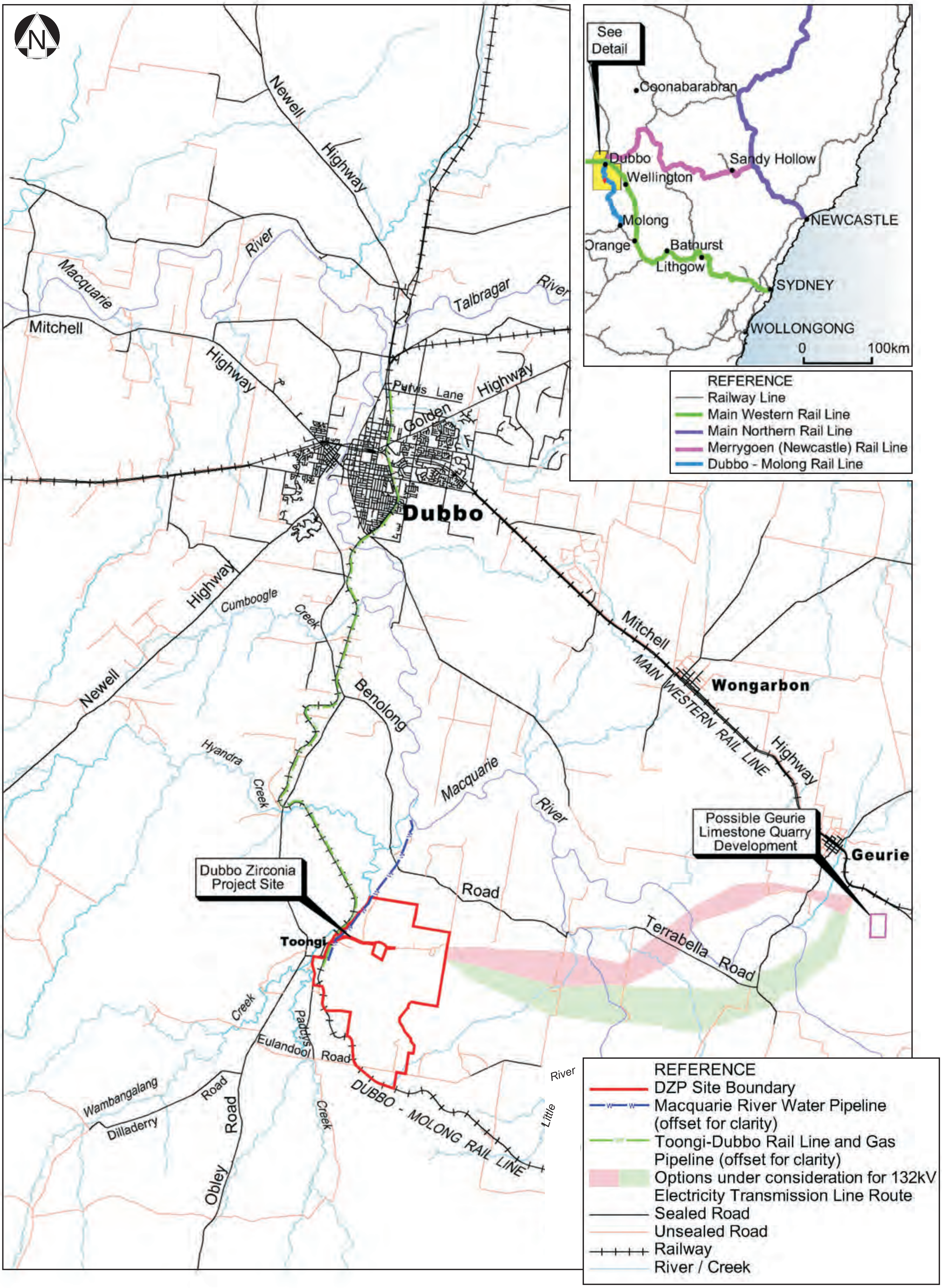
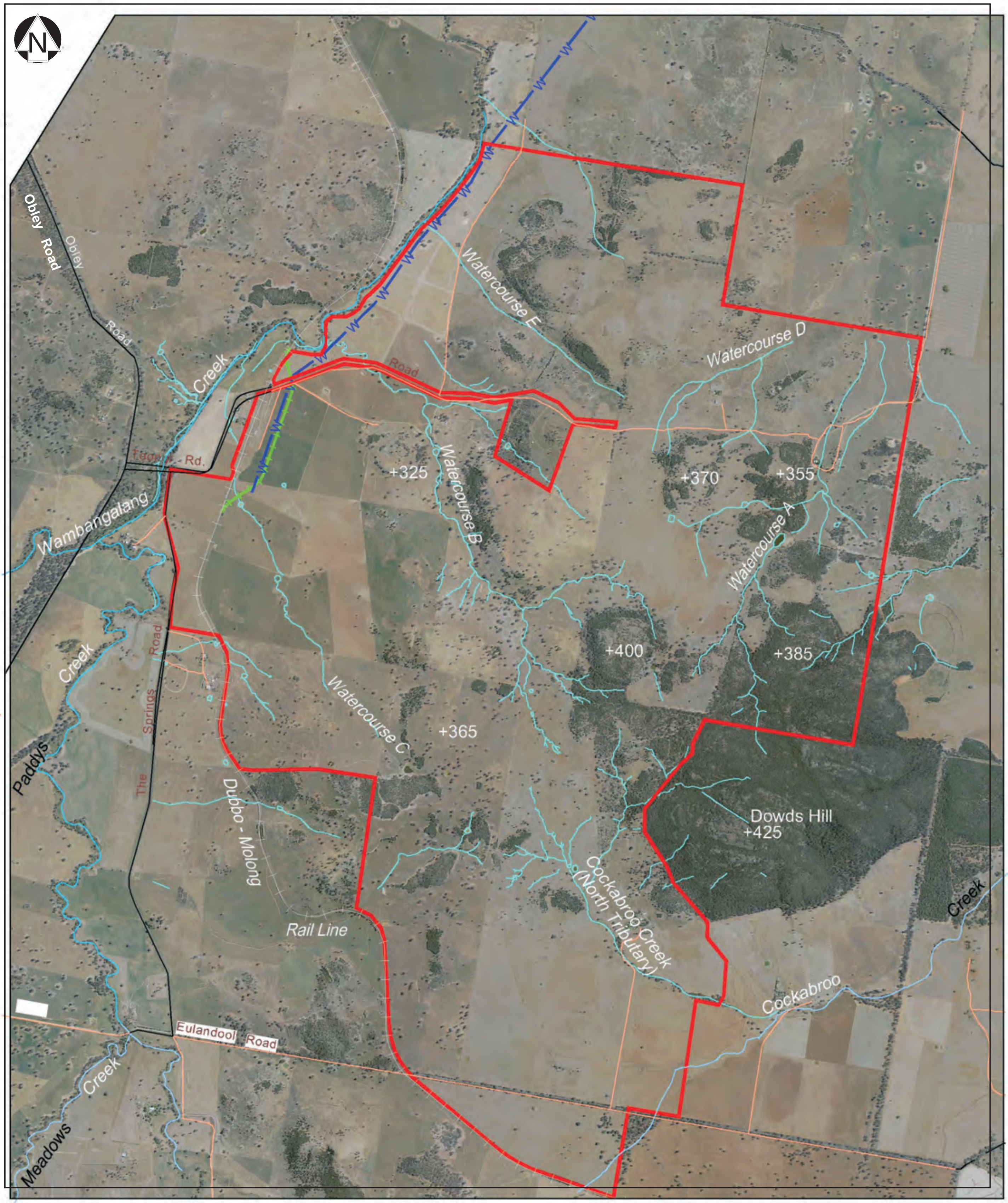


0 2 4 6 8 10 Kilometres

ENVIRONMENTAL EARTH SCIENCES
THE KNOW AND THE HOW

Title: **Regional Locality Map**			
Location: **Toongi, NSW**			
Client: **Australian Zirconia Ltd**		Job No: **612013**	
Project Man: **MS**	Scale: **As Shown**	**Figure 1**	
Drawn By: **LB**	Date: **Sept. 2013**		



0 0.5 1 2 Kilometres

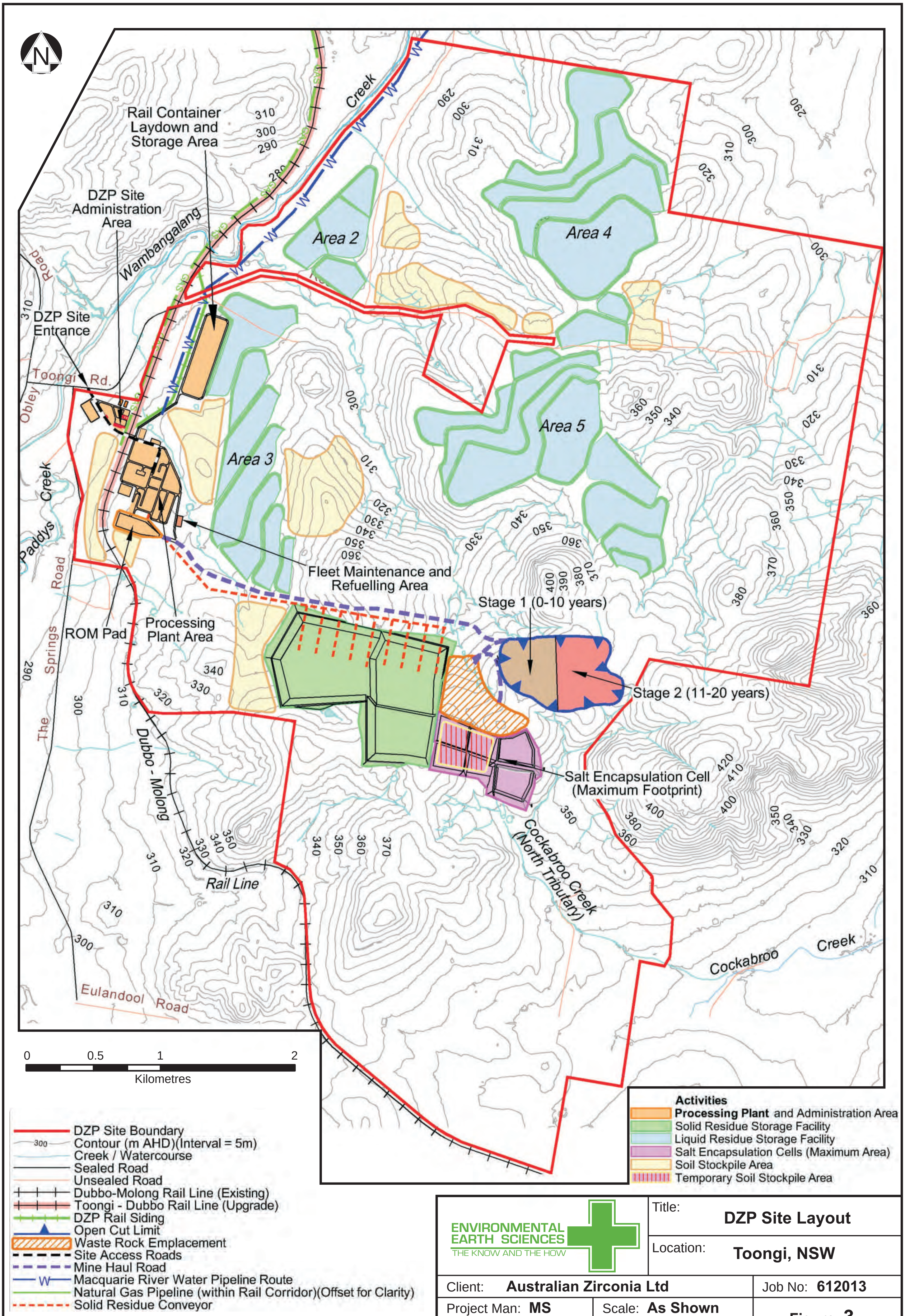
LEGEND:

- DZP Site Boundary
- Creek / Watercourse
- Sealed Road
- Unsealed Road
- Dubbo-Molong Rail Line (Existing)

ENVIRONMENTAL EARTH SCIENCES
THE KNOW AND THE HOW

Title: **DZP Site Investigation Area**		
Location: **Toongi, NSW**		
Client: **Australian Zirconia Ltd**		Job No: **612013**
Project Man: **MS**	Scale: **As Shown**	**Figure 2**
Drawn By: **LB**	Date: **Sept. 2013**	

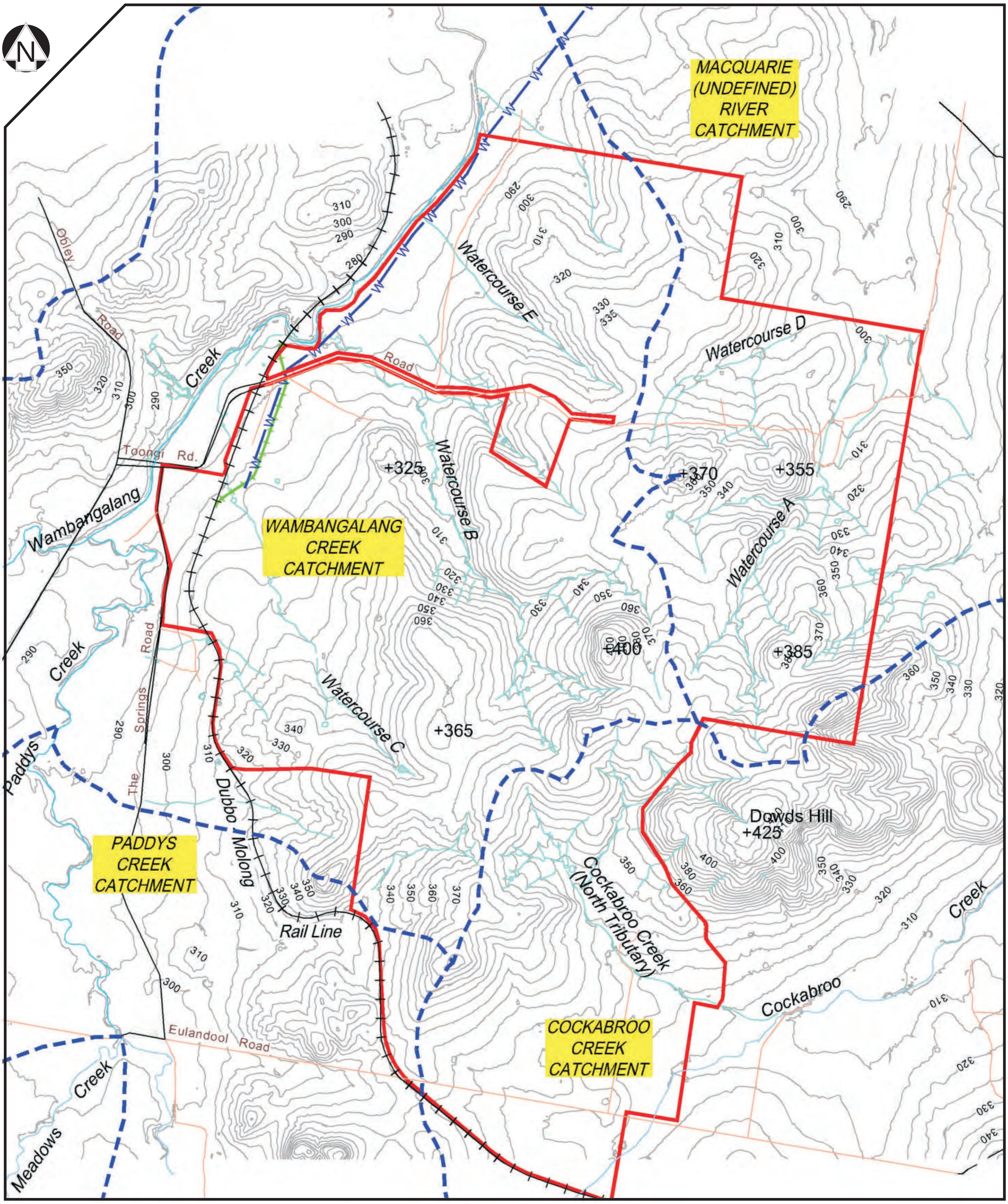
Base map source: Geurie 1:50,000 Topographic Map (1981)



Base map source: Fugro Spatial solutions Pty Ltd - Date: 17 May 2011

ENVIRONMENTAL EARTH SCIENCES
THE KNOW AND THE HOW

Title:	DZP Site Layout
Location:	Toongi, NSW
Client: Australian Zirconia Ltd	Job No: 612013
Project Man: MS	Scale: As Shown
Drawn By: LB	Date: Sept. 2013
	Figure 3

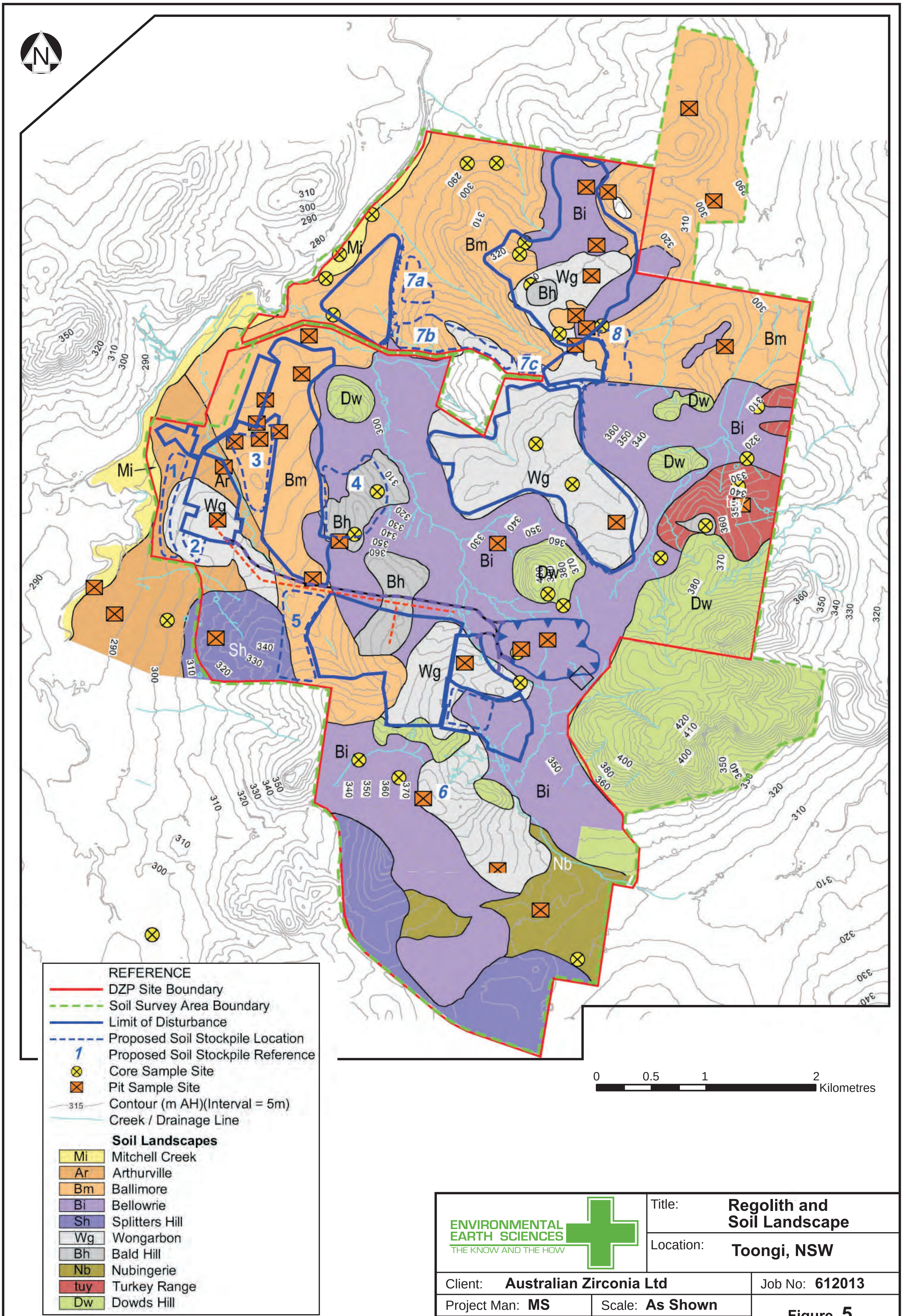


LEGEND:

	DZP Site Boundary
300	Contour (m AHD)(Interval = 5m)
	Creek / Watercourse
	Sealed Road
	Unsealed Road
	Dubbo-Molong Rail Line (Existing)
	Catchment Boundary
+375	Spot Height (m AHD)

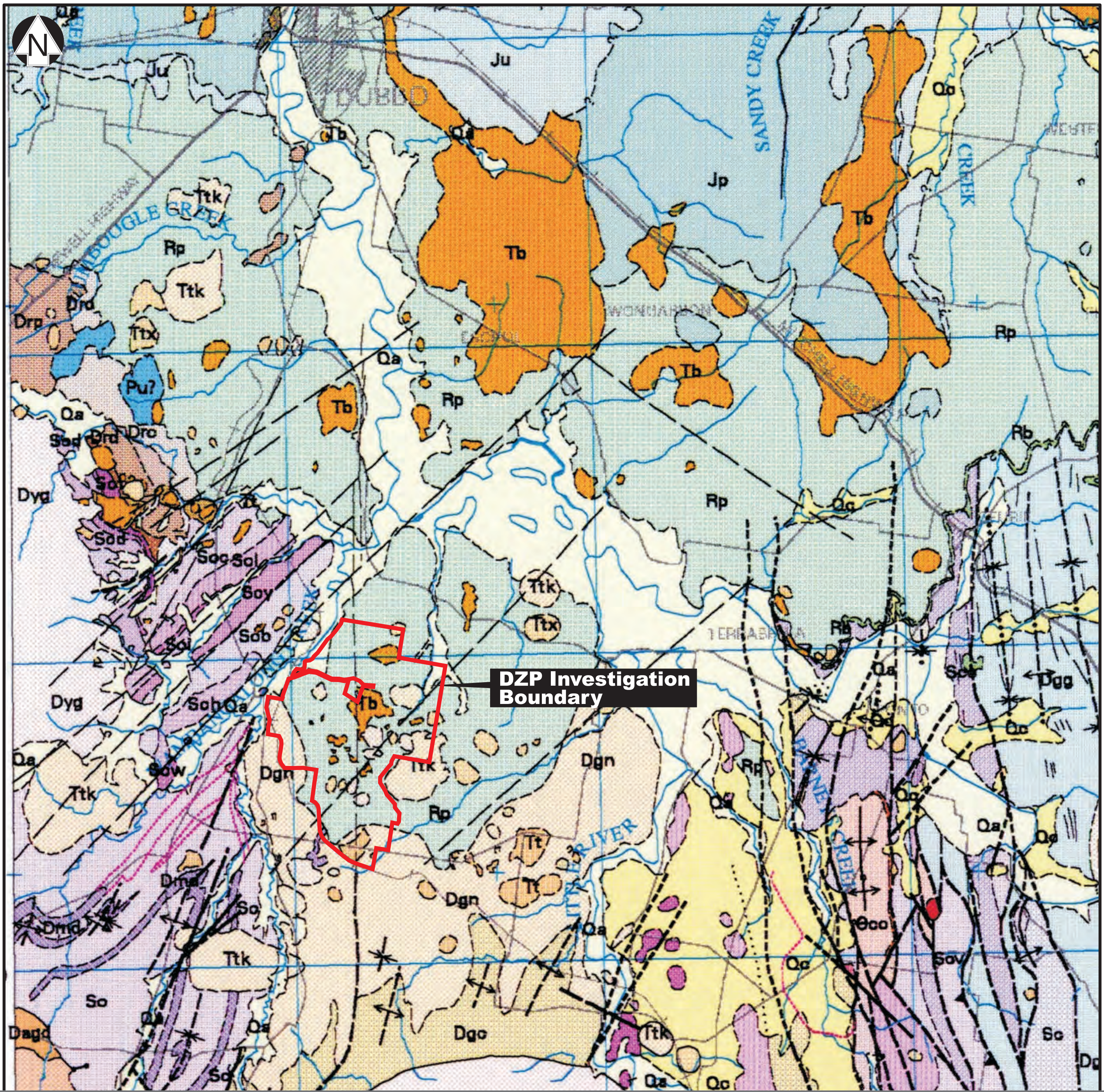
Base map source: Fugro Spatial solutions Pty Ltd - Date: 17 May 2011

ENVIRONMENTAL EARTH SCIENCES THE KNOW AND THE HOW		Title: Topography	
		Location: Toongi, NSW	
Client: Australian Zirconia Ltd			Job No: 612013
Project Man: MS	Scale: As Shown		Figure 4
Drawn By: LB	Date: Sept. 2013		



Source: Sustainable Soils Management (2013) - Figure 13

ENVIRONMENTAL EARTH SCIENCES THE KNOW AND THE HOW	Title: **Regolith and Soil Landscape**	
	Location: **Toongi, NSW**	
Client: **Australian Zirconia Ltd**		Job No: **612013**
Project Man: **MS**	Scale: **As Shown**	**Figure 5**
Drawn By: **LB**	Date: **Sept. 2013**	



System	Group	Formation	Reference Code	Description
Quaternary	-	-	Qa	Alluvium
Quaternary	-	-	Qo	Colluvial gravel, sand and silt
Tertiary	-	-	Tb	Olivine basalt as flows, dykes and plugs
Tertiary	-	-	Ttk	Trachyta, syenite, minor phonolite-geophysics indic ates that the body has elevated K, and is low in Th and U; flows, tuffs, and intrusive plugs and necks
Tertiary	-	-	Ttx	Trachyta, syenite, minor phonolite-geophysics indicates that the body is rich in K, Th ans U; occurs predominantly as intrusive plugs and necks
Jurassic	-	-	Jt	Trachyte, quartz trachyte, minor phonlite, rhyolite as flows, tuffs, plugs and necks
Triassic	Gunnedah Basin	Napperby	Rp	Siltstone, lithic quartz-sandstone, minor conglomerate
Devonian	Gregra	Berkley	Dge	Latitic crystal-lithic sandstone, breccia, siltstone, tuff, minor andesite, basalt, limestone
Devonian	Gragra	Nubingerie	Dgn	Sandstone, shale, siltatons, tuffaceous sediment, rhyolit, ash tuff
Devonian	Gregra	Cuga Burga volcanics	Dgo	Mafic to intermediate lava and intrusives, lithic volcanistic sandstone
Devonian	-	-	Dmd	Dolerite dykes, diorite, gabbro sills and stocks
Devonian	Yeoval Complex	-	Dyg	Pink microgranite, farroh, astingsite biotite granite, red biotite microgranite
Siluro-Devonian	Toongi	-	S-Do	Sandstone, shale, siltstone, latitic sandstone, volcanoclastic sandstone
Silurain	Toongi	Strathgled	Sah	Fine and coarse cherty tuff, rhyolitic tuff
Silurain	Cudal	Hanover	Sce	Micaceous shale, siltstone, fine-grained sandstone, rhyolite-tuff, tuff-sandstone, latitic sandstone, breccia
Silurain	Toongi	Undifferentiated	So	Sandstone, shale, siltstone, cherty sediment, tuffaceous sediment, rhyolite, rhyolite tuff, ash tuff
Silurain	Toongi	Wirrabilla	Sob	Sandstone and siltstone

Source: Dubbo 1:250,000 Geology Map (AGSO/DMR 1999)

0 1.25 2.5 5 Kilometres

ENVIRONMENTAL EARTH SCIENCES
THE KNOW AND THE HOW

Title: **Regional Geology**

Location: **Toongi, NSW**

Client: **Australian Zirconia Ltd**

Job No: **612013**

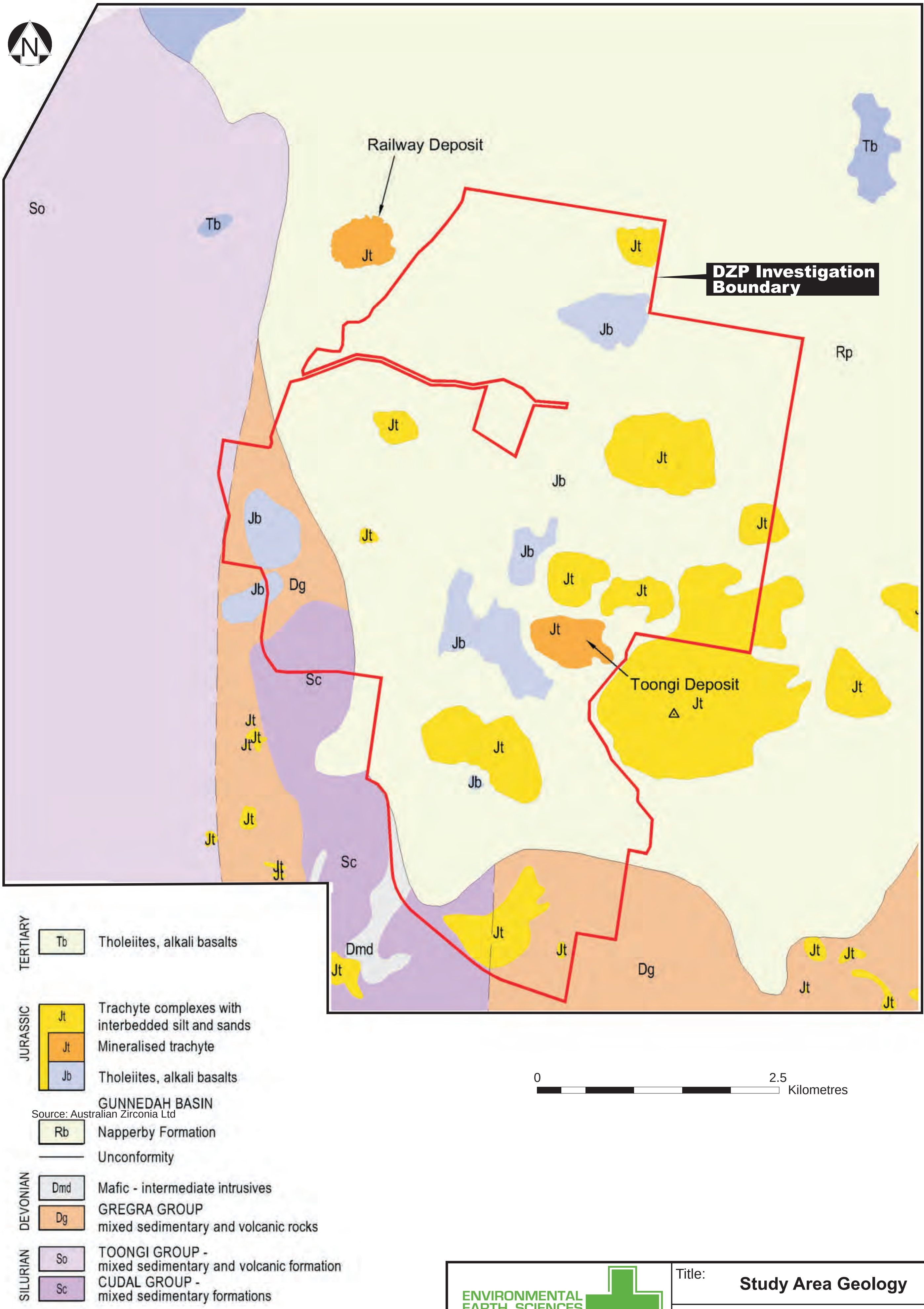
Project Man: **MS**

Scale: **As Shown**

Drawn By: **LB**

Date: **Sept. 2013**

Figure 6a



Source: Modified after Meakin and Morgan (1999)

ENVIRONMENTAL EARTH SCIENCES
THE KNOW AND THE HOW

Title: **Study Area Geology**

Location: **Toongi, NSW**

Client: **Australian Zirconia Ltd**

Job No: **612013**

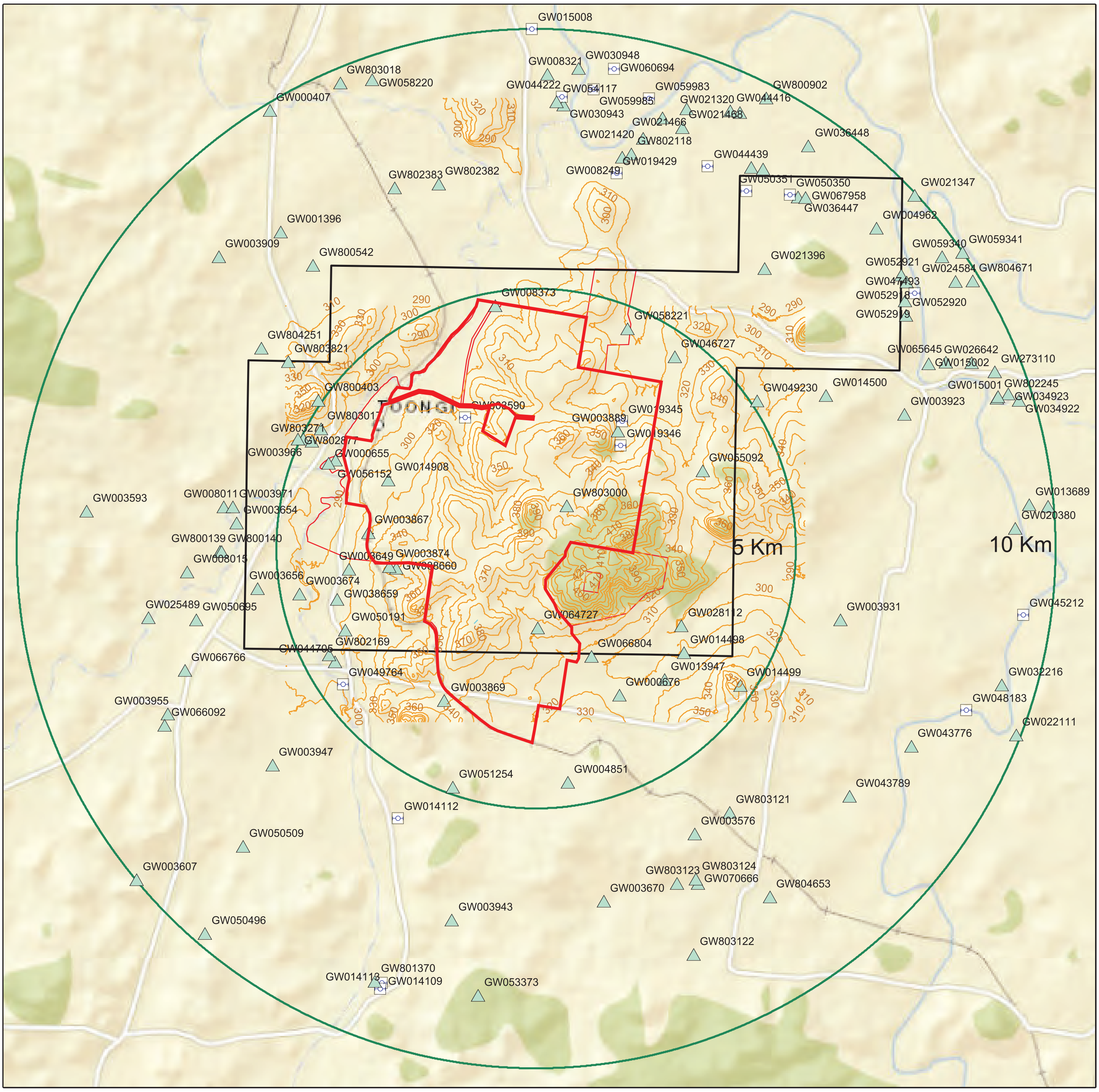
Project Man: **MS**

Scale: **As Shown**

Drawn By: **LB**

Date: **Sept. 2013**

Figure 6b



LEGEND:

- DZP Investigation Areas

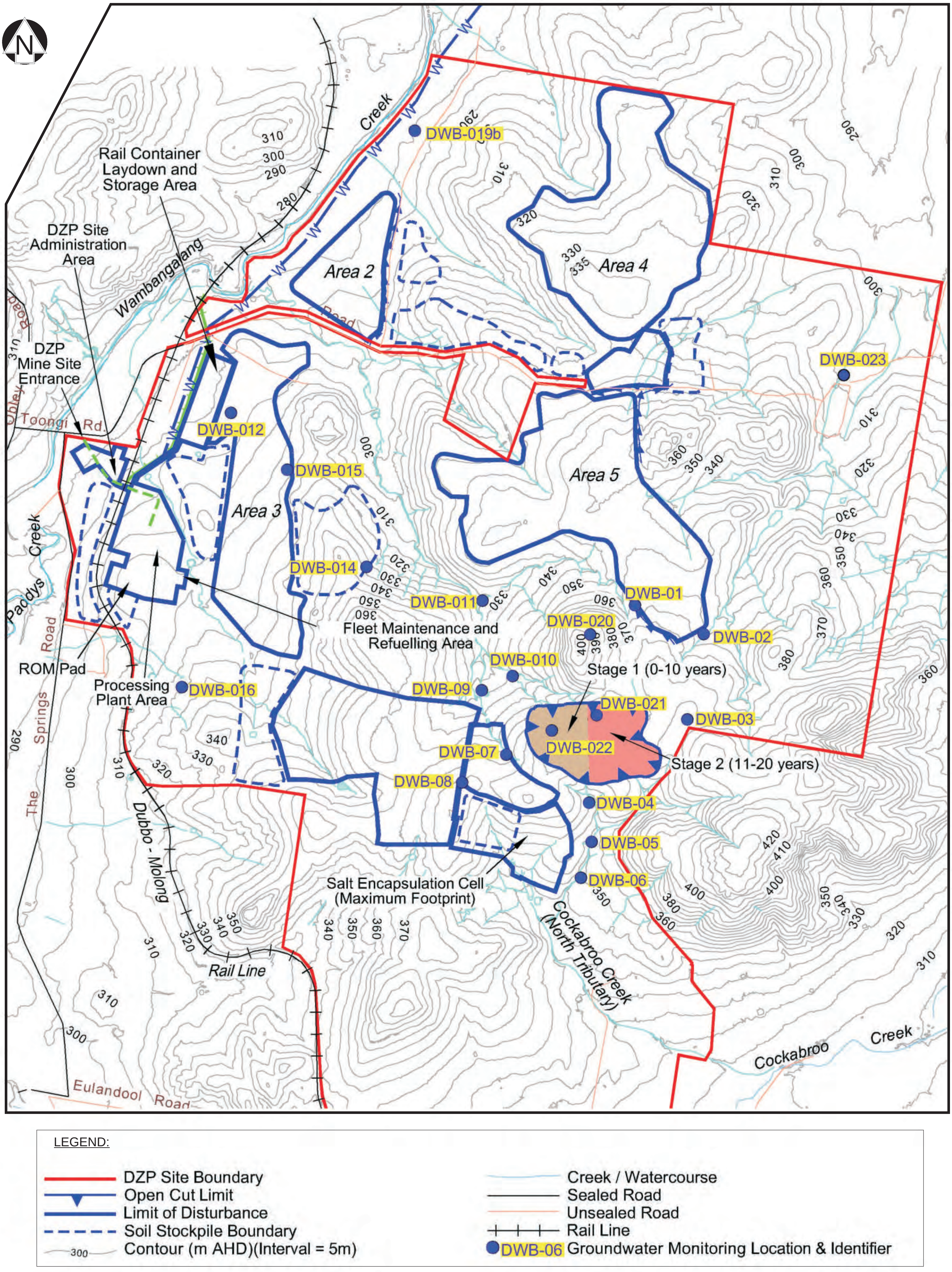
NSW GW Works

- Bore
- Well
- 10 m Contours
- Railway- Line
- Roads
- 5 and 10 km Open Cut Buffer
- Mining Lease EL5548

0 1.25 2.5 5 Kilometres

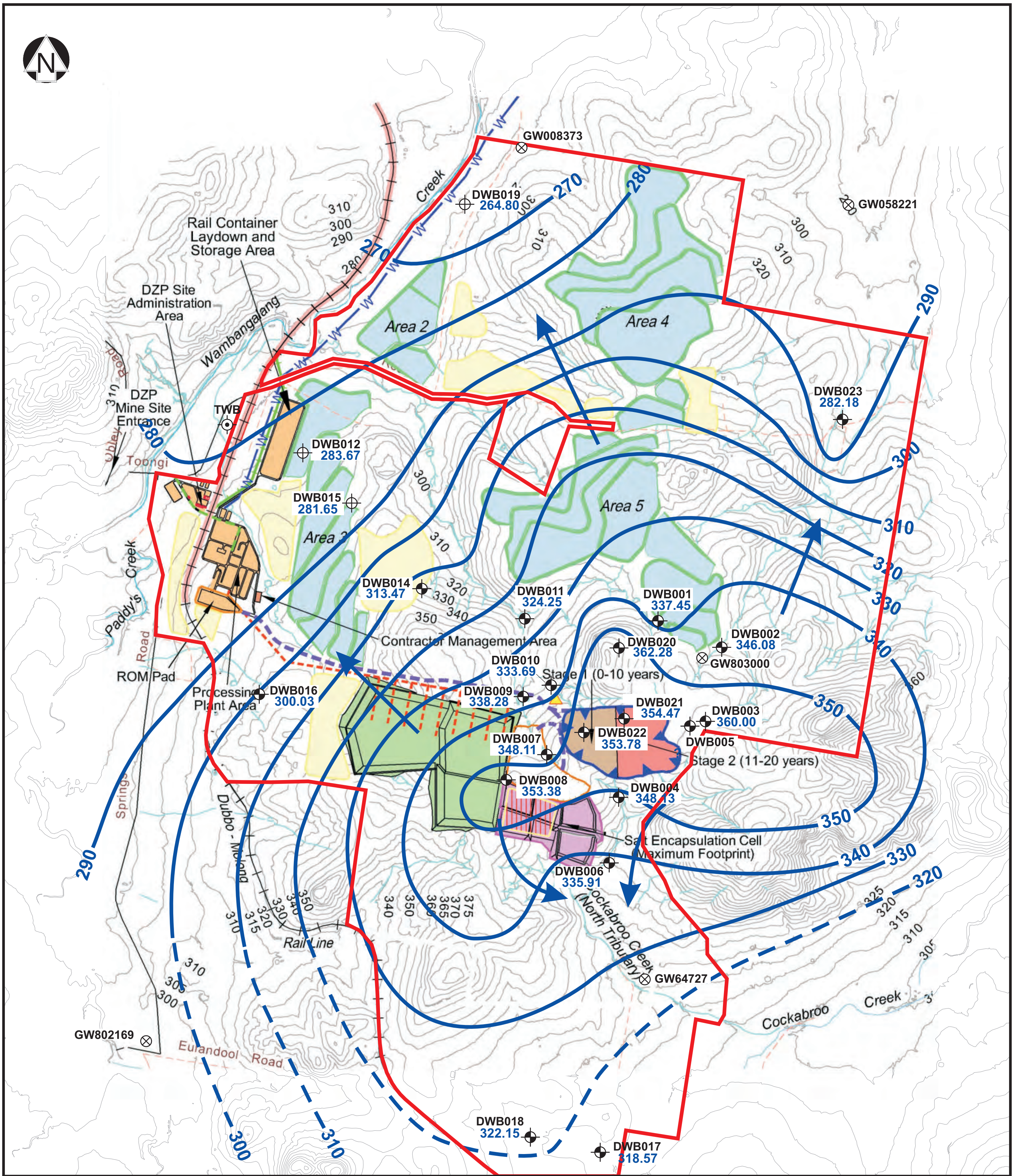
ENVIRONMENTAL EARTH SCIENCES
THE KNOW AND THE HOW

Title: **Registered Groundwater Bore Loactions**			
Location: **Toongi, NSW**			
Client: **Australian Zirconia Ltd**		Job No: **612013**	
Project Man: **MS**	Scale: **As Shown**	**Figure 7**	
Drawn By: **LB**	Date: **Sept. 2013**		



Base map source: Fugro Spatial solutions Pty Ltd - Date: 17 May 2011

ENVIRONMENTAL EARTH SCIENCES THE KNOW AND THE HOW	Title: **Groundwater Bores of the DZP Site and Surrounds**		
	Location: **Toongi, NSW**		
Client: **Australian Zirconia Ltd**			Job No: **612013**
Project Man: **MS**	Scale: **As Shown**		**Figure 8**
Drawn By: **LB**	Date: **Sept. 2013**		



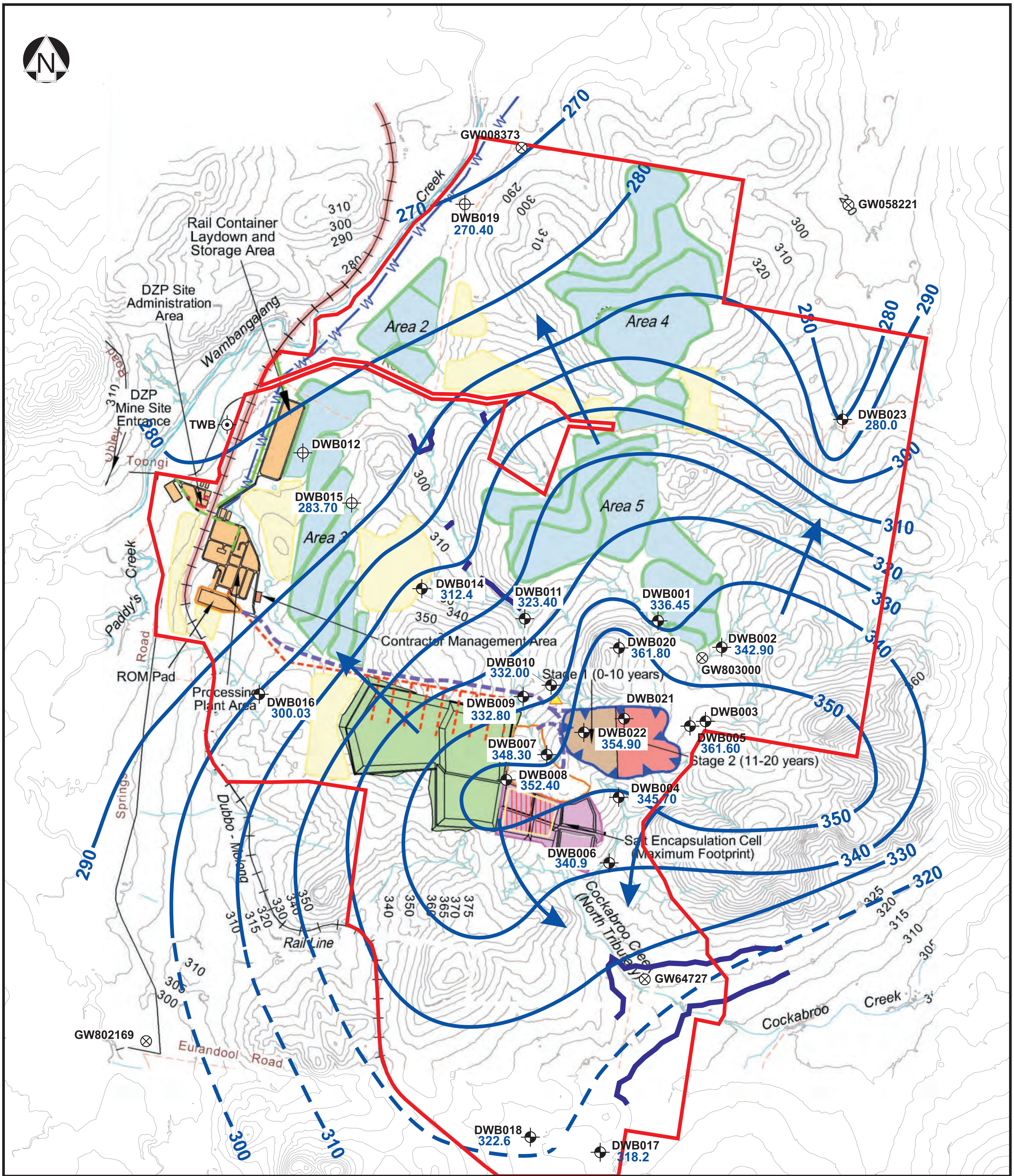
LEGEND:

- DZP investigation area
- Fractured rock bore location
- Alluvium bore location
- NSW registered bore location
- Inferred groundwater contour (mAHD)
- Inferred groundwater flow direction

0 0.5 1 2

ENVIRONMENTAL EARTH SCIENCES
THE KNOW AND THE HOW

Title:	Approximate Water Table Elevation - August 2001
Location:	Toongi, NSW
Client: Australian Zirconia Ltd	Job No: 612013
Project Man: MS	Scale: As Shown
Drawn By: LB	Date: Sept. 2013
	Figure 9a



LEGEND:

	DZP investigation area
	Fractured rock bore location
	Alluvium bore location
	NSW registered bore location
	Inferred groundwater contour (mAHD)
	Inferred groundwater flow direction
	Potential spring eruption points

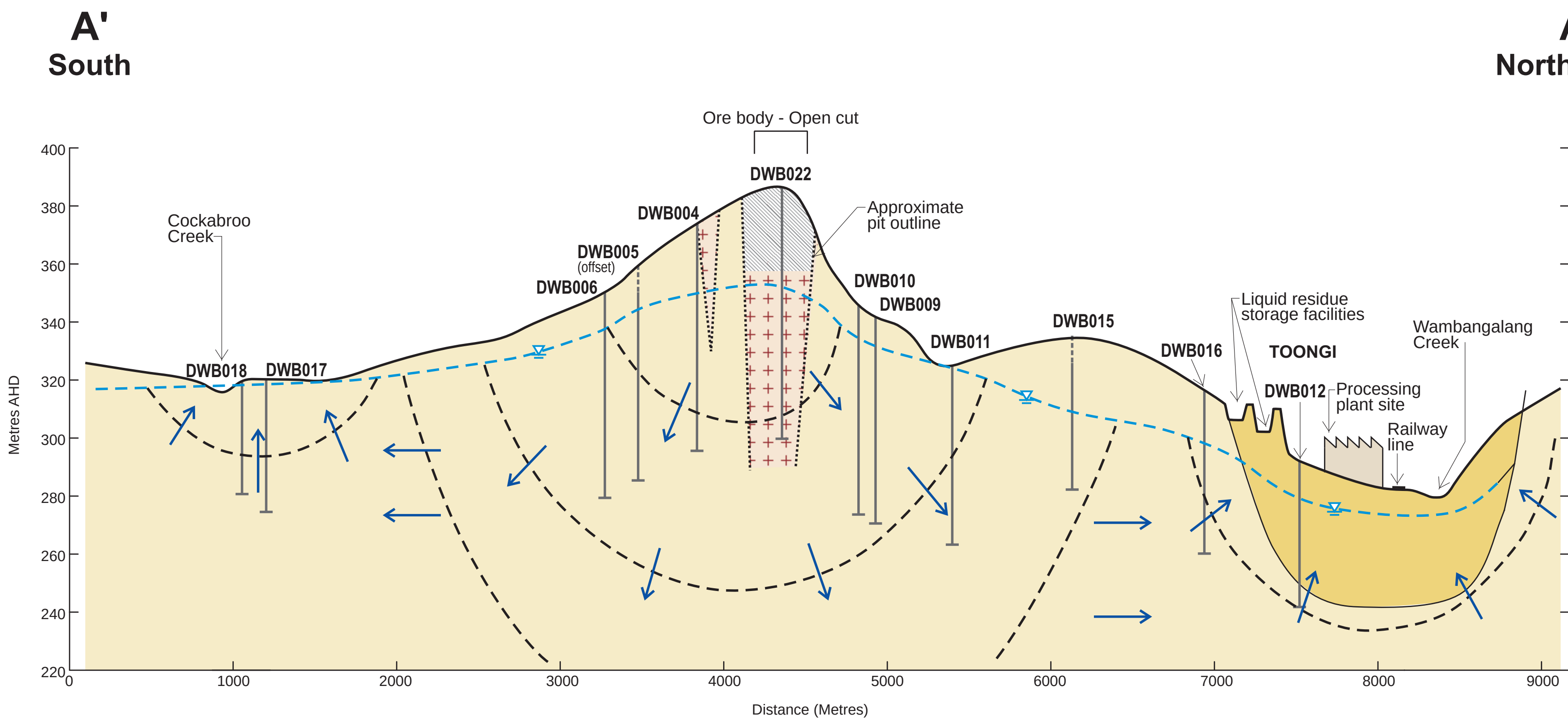
0 0.5 1 2 Kilometres

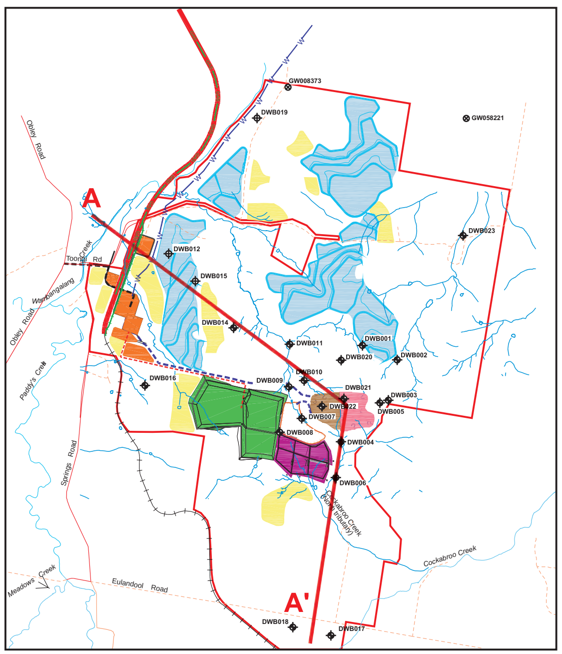
ENVIRONMENTAL EARTH SCIENCES
THE KNOW AND THE HOW

Title: **Approximate Water Table Elevation - 14.02.2013**

Location: **Toongi, NSW**

Client: **Australian Zirconia Ltd**		Job No: **612013**	
Project Man: **MS**	Scale: **As Shown**	**Figure 9b**	
Drawn By: **LB**	Date: **Sept. 2013**		



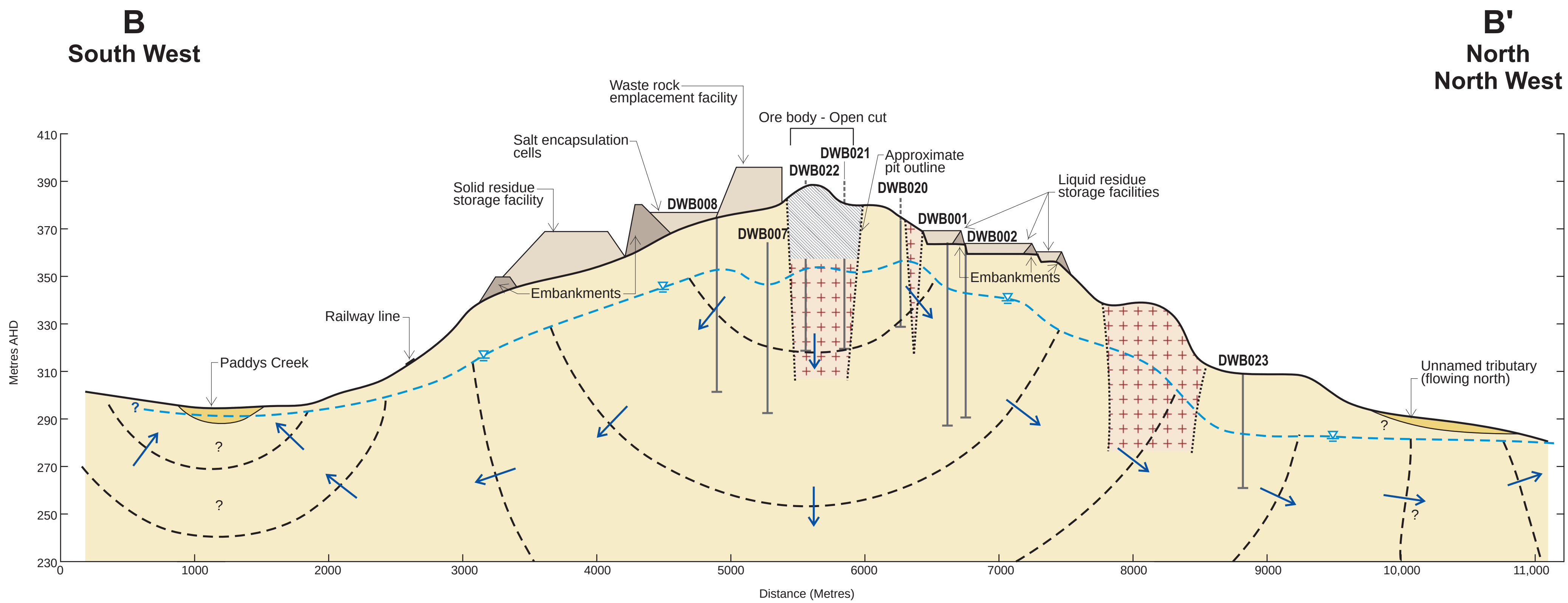


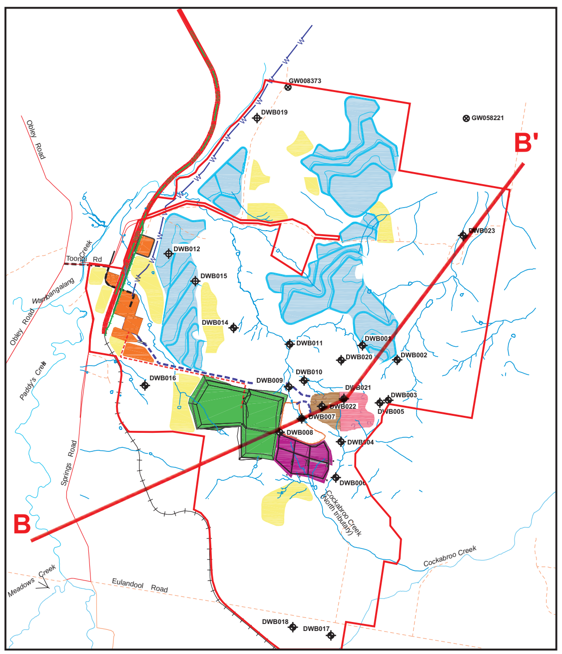
LEGEND:

Alluvium (sand, silt, clay)	Water table
Trachytic complex	Equipotential lines (inferred)
Undifferentiated sediments and volcanics intruded by trachytic complexes	Flow lines (inferred)

ENVIRONMENTAL EARTH SCIENCES
THE KNOW AND THE HOW

Title:	Hydrogeological Section A - A'		
Location:	Toongi, NSW		
Client:	Australian Zirconia Ltd	Job No:	612013
Project Man: MS	Scale: As Shown	Figure 10a	
Drawn By: LB	Date: Sept. 2013		





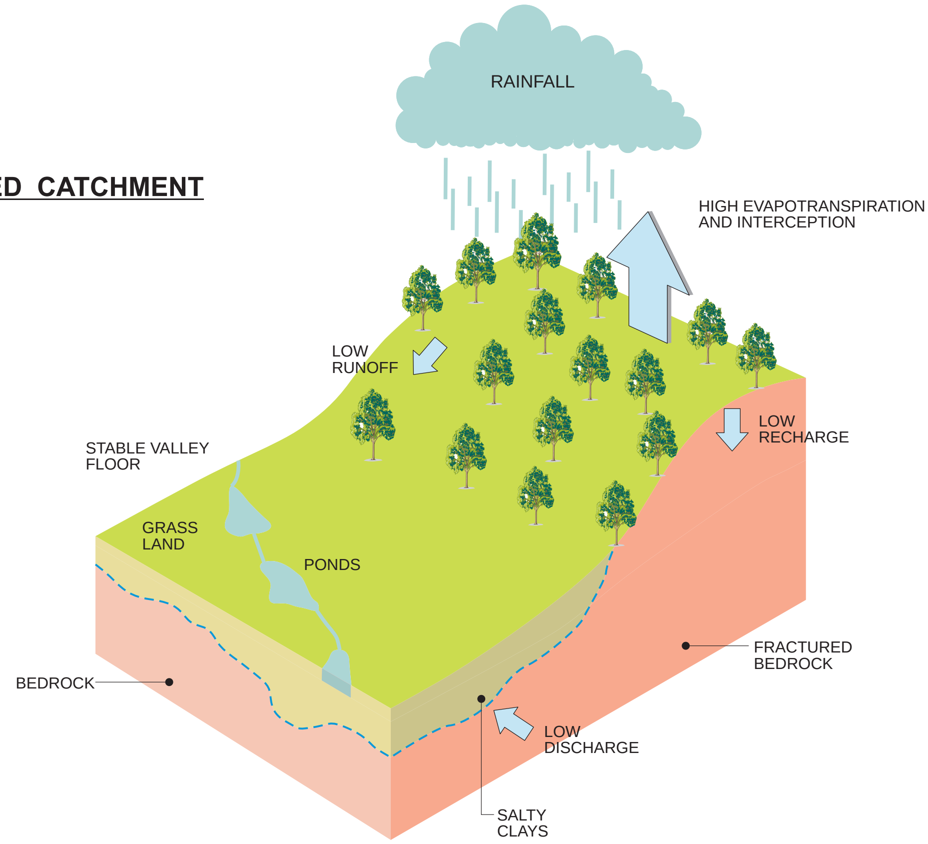
LEGEND:

	Alluvium (sand, silt, clay)		Water table
	Trachytic complex		Equipotential lines (inferred)
	Undifferentiated sediments and volcanics intruded by trachytic complexes		Flow lines (inferred)

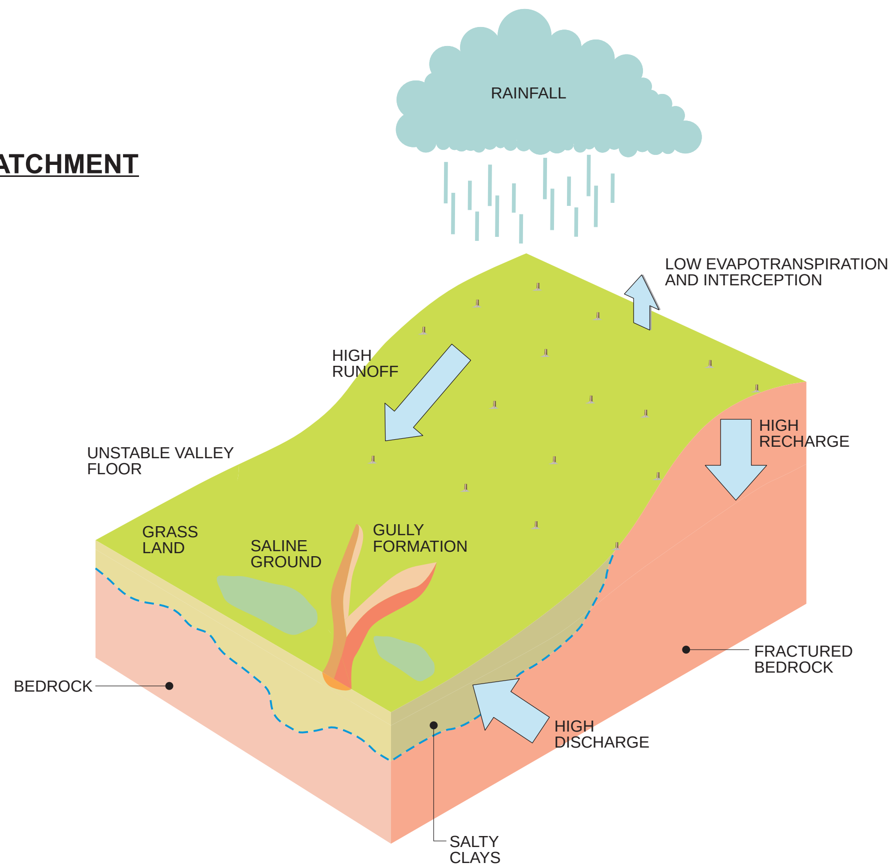
ENVIRONMENTAL EARTH SCIENCES
THE KNOW AND THE HOW

Title:	Hydrogeological Section B - B'		
Location:	Toongi, NSW		
Client:	Australian Zirconia Ltd	Job No:	612013
Project Man: MS	Scale: As Shown	Figure 10b	
Drawn By: LB	Date: Sept. 2013		

UNDISTURBED CATCHMENT

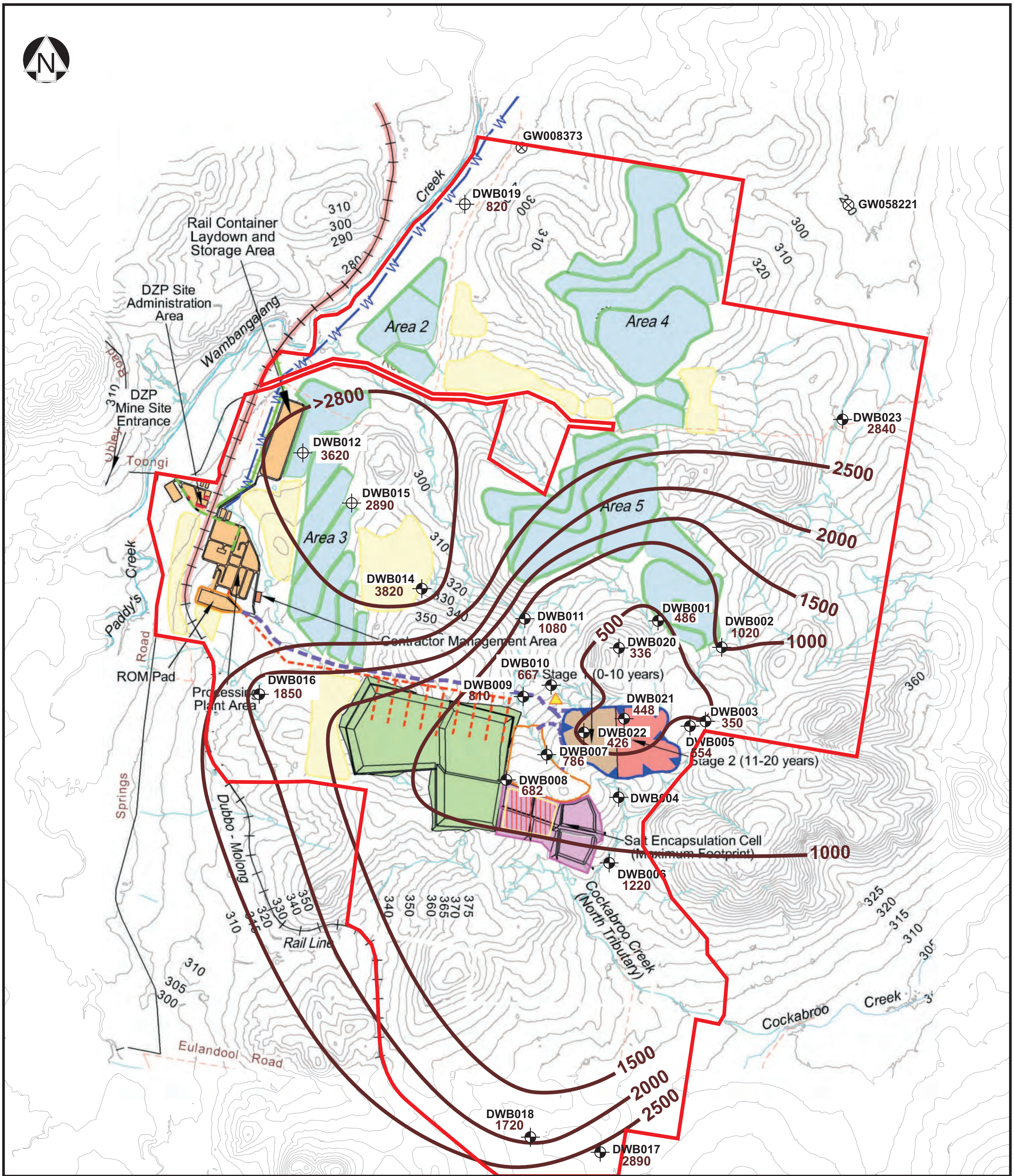


CLEARED CATCHMENT



ENVIRONMENTAL EARTH SCIENCES
THE KNOW AND THE HOW

Title: **Conceptual Site Model of Catchment Dryland Salinity**		
Location: **Toongi, NSW**		
Client: **Australian Zirconia Ltd**		Job No: **612013**
Project Man: **MS**	Scale: **As Shown**	**Figure 11**
Drawn By: **LB**	Date: **Sept. 2013**	



0 0.5 1 2 Kilometres

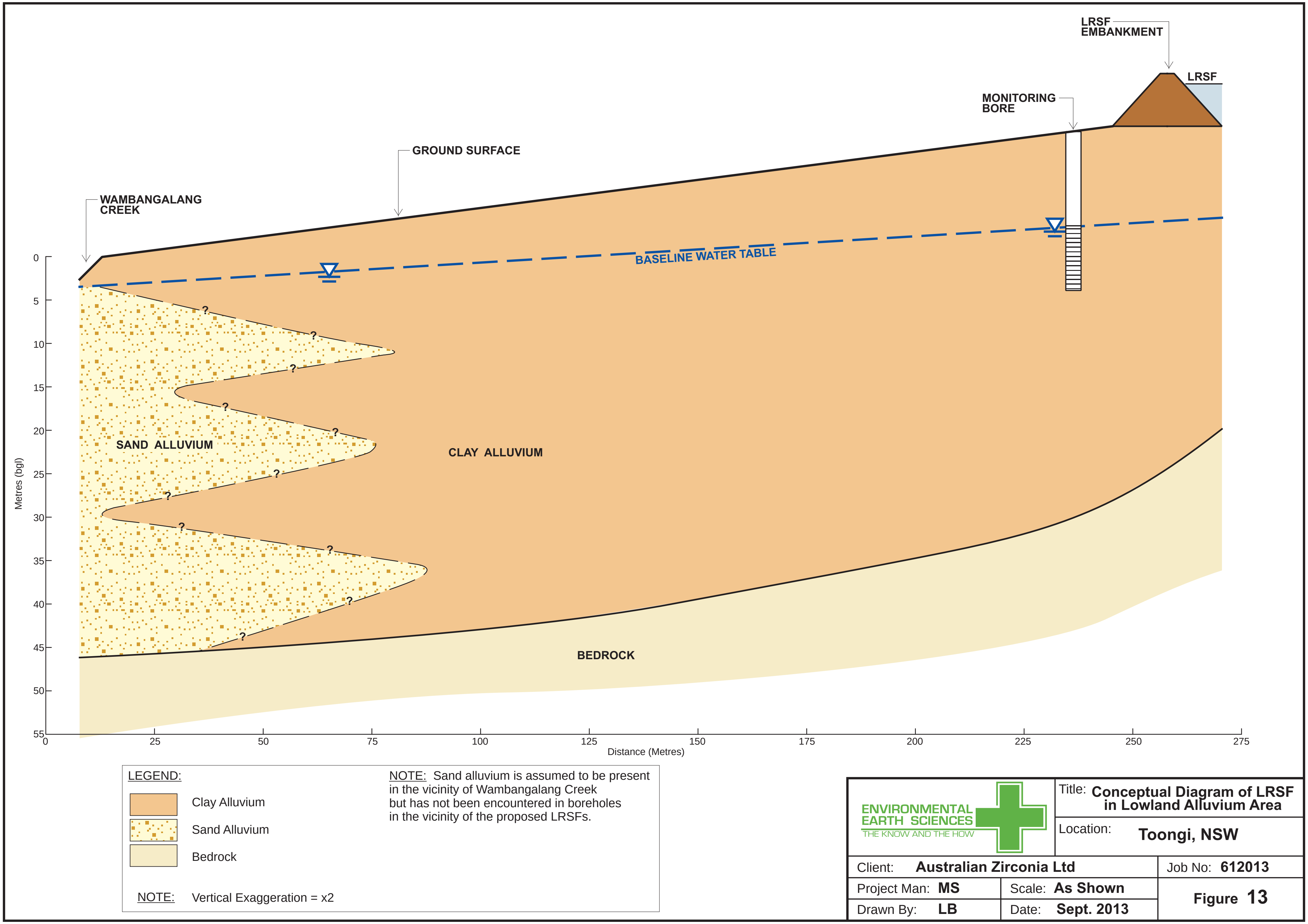
LEGEND:

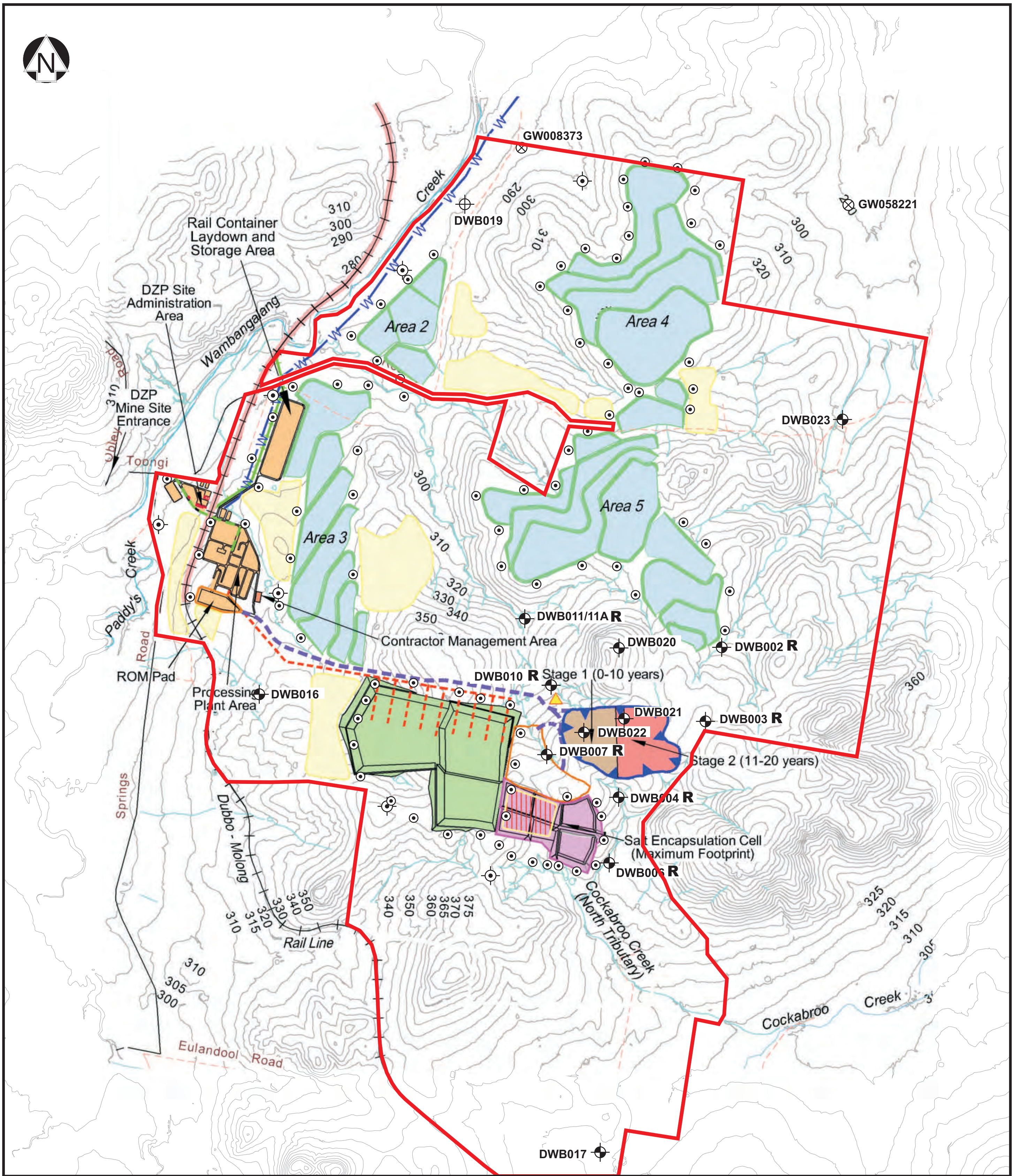
TDS contour

ENVIRONMENTAL EARTH SCIENCES
THE KNOW AND THE HOW

Title:	TDS Contours (mg/L) August 2001
Location:	Toongi, NSW
Client:	Australian Zirconia Ltd
Job No:	612013
Project Man:	MS
Scale:	As Shown
Drawn By:	LB
Date:	Sept. 2013

Figure 12


LRSF EMBANKMENT
LRSF
MONITORING BORE
GROUND SURFACE
WAMBANGALANG CREEK
BASELINE WATER TABLE
SAND ALLUVIUM
CLAY ALLUVIUM
BEDROCK
Metres (bgl)
0
5
10
15
20
25
30
35
40
45
50
55
0
25
50
75
100
125
150
175
200
225
250
275
Distance (Metres)
LEGEND:
Clay Alluvium
Sand Alluvium
Bedrock
NOTE: Vertical Exaggeration = x2
NOTE: Sand alluvium is assumed to be present in the vicinity of Wambangalang Creek but has not been encountered in boreholes in the vicinity of the proposed LRSFs.
ENVIRONMENTAL EARTH SCIENCES
THE KNOW AND THE HOW
Title: Conceptual Diagram of LRSF in Lowland Alluvium Area
Location: Toongi, NSW
Client: Australian Zirconia Ltd
Job No: 612013
Project Man: MS
Scale: As Shown
Drawn By: LB
Date: Sept. 2013
Figure 13



LEGEND:

Mine site investigation area

Contour (mAHD) (5m interval)

Creek / Drainage line

Fractured rock bore location

Alluvium bore location

NSW registered bore location

Proposed new bores

Proposed new shallow bores (after DE Cooper, 2012)

R Bore to be decommissioned and reinstalled

NOTE: The locations of proposed shallow bores are indicative only, to show proximity to the perimeters of Proposal components. In reality, these bores are likely to be more closely spaced and greater in number, particularly around LRSF Areas.

0 0.5 1 2 Kilometres

ENVIRONMENTAL EARTH SCIENCES
THE KNOW AND THE HOW

Title:	Proposed On-going Groundwater Monitoring Network
Location:	Toongi, NSW
Client: Australian Zirconia Ltd	Job No: 612013
Project Man: MS	Scale: As Shown
Drawn By: LB	Date: Sept. 2013
Figure 14	

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