Groundwater Report F

Australasian
Groundwater
and Environmental
Consultants Pty Ltd
(AGE)

Report on

Eastern Leases Project
Groundwater Report

Prepared for
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Table of contents

Page No.

Table of contents
(continued)

Page No.

Table of contents
(continued)

Page No.

Table of contents
(continued)

Page No.

List of figures

Table of contents
(continued)

Page No.

List of tables

List of appendices

Abbreviations

AGE	Australasian Groundwater and Environmental Consultants Pty Ltd
AHD	Australian Height Datum
ALS	ALS Environmental Laboratories (ALS)
ANZECC	Australian and New Zealand Environment and Conservation Council
CRD	Cumulative Rainfall Departure
DLRM	Department of Land and Resource Management
EC	electrical conductivity
EIS	Environmental Impact Statement
EL	Eastern Lease
ELR	Exploration Licence in Retention
NT EPA	Northern Territory Environment Protection Authority
GDA94	Geocentric Datum of Australia 1994
GEMCO	Groote Eylandt Mining Company Pty Ltd
L/s	litres per second
m	metres
Ma	Million years (before present)
mAHD	metres above Australian Height Datum
mbGL	meters below ground level
mbTOC	meters below top of casing
m/day	metres per day
mE	Easting
mN	Northing
mg/L	milligram per litre
ML	megalitres
ML/a	megalitres per annum
ML/day	megalitres per day
NATA	National Association of Testing Authorities
No.	number
RMS	root mean square
ToC	Top of Casing
ToR	Terms of Reference
TDS	total dissolved solids
TPH	Total Petroleum Hydrocarbons
%	percentage

Glossary

Aquifer - 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. The confining bed has a significantly lower hydraulic conductivity than the aquifer.

Aquifer, unconfined - An aquifer in which there are no confining beds between the zone of saturation and the surface. There will be a water table in an unconfined aquifer. Water-table aquifer is a synonym.

Aquitard - A low permeability unit that can store groundwater and also transmit it slowly from one aquifer to another. Typically, a geological formation of layers comprised of either clay bearing material or non-porous rock that restricts water flow from one aquifer to another.

Concretionary - Formed by concretion; consisting of concreted matter or masses.

Drawdown - A lowering of the water table of an unconfined aquifer or the potentiometric surface of a confined aquifer caused by pumping of ground water from wells or excavations.

Equipotential - Represents a line along which the pressure head of water is equal, therefore, groundwater flow is perpendicular to an equipotential line.

Falling head test - Falling head tests involve rapidly displacing the head of water in the bore and measuring the rate of recovery; from this the hydraulic conductivity of the aquifer is calculated. (see also rising head test).

Hydraulic Conductivity – Also referred to as permeability, it is the measure of the rate at which water moves through a soil/rock mass. It is the volume of water that moves within a unit of time under a unit hydraulic gradient through a unit cross-sectional area that is perpendicular to the direction of flow.

Hydraulic gradient - The change in total head with a change in distance in a given direction. The direction is that which yields a maximum rate of decrease in head.

Infiltration - The flow of water downward from the land surface into and through the upper soil layers.

K - Hydraulic conductivity.

massive - A competent rock being homogenous and showing no internal layering.

MODFLOW- SURFACT – A commercial derivative of the standard MODFLOW code widely used for numerical groundwater modelling and presently considered the industry standard.

Model calibration - The process by which the independent variables of a digital computer model are varied in order to calibrate a dependent variable such as a head against a known value such as a water-table map.

Monitoring bores – Other terms which are often substituted include an 'observation well' or a 'piezometer.' Monitoring bores are drilled specifically to obtain information/data on groundwater and include bores to observe water levels, water quality or to intersect and monitor targeted contaminants.

Oolite - Sedimentary rock made of ooids, which are concretionary grains - which resemble pisoids but are less than 2 mm in diameter.

Pisolite - Sedimentary rock made of pisoids, which are concretionary grains - which resemble ooids but are greater than 2 mm in diameter.

Porosity - The ratio of the volume of void spaces in a rock or sediment to the total volume of the rock or sediment. Porosity is not necessarily directly proportional to permeability. Porosity is an important factor in understanding the stability of soils and rock.

Potentiometric surface - A surface that represents the level to which water will rise in tightly cased wells. If the head varies significantly with depth in the aquifer, then there may be more than one potentiometric surface. The water table is a particular potentiometric surface for an unconfined aquifer.

Pumping Test - A test made by pumping a well for a period of time and observing the response/change in hydraulic head in the aquifer.

Rising head test - Rising head tests involve rapidly displacing the head of water in the bore and measuring the rate of recovery; from this the hydraulic conductivity of the aquifer is calculated. (see also Falling head test).

Slug Test - A test made by the instantaneous addition, or removal, of a known volume of water to or from a well. The subsequent well recovery is measured.

Stratabound - Deposit confined to a particular stratigraphic layer or unit.

Strataform - Descriptive of a layered mineral deposit of either igneous or sedimentary origin.

Supergene enrichment - Re-precipitation of sulphides and oxides by descending acidic groundwater which has leached the surface zone of an ore deposit.

Outstation - A post, station, or settlement in a remote or outlying area.

Transmissivity - A measure of the rate at which water moves through an aquifer of unit width under a unit hydraulic gradient. Transmissivity is the average permeability multiplied by the saturated thickness.

Eastern Leases Project
Groundwater Report

1 Introduction

Australian Groundwater and Environmental Consultants Pty Ltd (AGE) was commissioned by Hansen Bailey on behalf of BHP Billiton Manganese Australia Pty Ltd to complete a groundwater assessment as part of the Environmental Impact Statement (EIS) for the Eastern Leases Project (the project).

The project proponent is the Groote Eylandt Mining Company Pty Ltd (GEMCO), which has two shareholders, namely South32 Pty Ltd (60%) and Anglo Operations (Australia) Pty Ltd (40%). BHP Billiton Manganese Australia Pty Ltd was previously a shareholder in GEMCO, however its interest is now represented by South32.

The project involves the development of a number of open cut mining areas to the east of the existing GEMCO manganese mine on Groote Eylandt in the Gulf of Carpentaria, approximately 650 km south-east of Darwin (Figure 1). The proposed additional mining areas are located on the Eastern Leases (EL), which are two Exploration Licences in Retention (ELRs). ELR28161 is termed the Northern Eastern Lease (Northern EL) and ELR28162 is termed the Southern Eastern Lease (Southern EL).

The Eastern Leases are located 2 km east of the existing GEMCO mine at the closest point. The township of Angurugu is located approximately 6 km to the north-west of the Eastern Leases, and is the closest residential community (Figure 2). The Eastern Leases are located on Aboriginal land, scheduled under the *Aboriginal Land Rights (Northern Territory) Act 1976*. The land within the Eastern Leases comprises natural bushland, with the Emerald River and a small section of the Amagula River traversing the Northern EL and Southern EL respectively.

The project involves:

- Developing a number of open cut mining areas (termed “quarries”) within the Eastern Leases and mining manganese ore by the same mining methods that are in use at the existing GEMCO mine;
- Constructing limited mine related infrastructure in the Eastern Leases (dams, water fill points, crib hut, truck park up areas and laydown storage areas); and
- Transporting the ore by truck on a new haul road to be constructed between the existing GEMCO mine and the Eastern Leases.

Ore will be processed at the concentrator at the existing GEMCO mine and the concentrate would be transported to market via the existing port. No changes or upgrades to the existing GEMCO mine facilities are required as a result of the project. Ore mined from the Eastern Leases will supplement production from the existing GEMCO mine, but the project will not increase GEMCO’s annual production rate of approximately 5 Million tonnes per annum of product manganese. The EIS does not include any assessment of operations within the existing GEMCO mine, given that these operations are subject to existing environmental approvals, and will not be altered by the project.

The project site for the purposes of the EIS is the Northern and Southern ELs and the new section of haul road linking the Eastern Leases to the existing GEMCO mine. The project site is approximately 4,600 ha.

Mining in the Eastern Leases would take place concurrently with the operation of the existing GEMCO mine. According to current planning, construction in the Northern EL would commence in 2017 and mining activities would commence in 2018. Construction in the Southern EL is scheduled to commence approximately 4 years later in 2022 and mining would then take place in both of the tenements until approximately 2031.

1.1 Background to assessment

The project site is located on Groote Eylandt. There is a long history of mining and exploration data relating to the manganese orebody across the west of the island. This data has been supplemented by recent groundwater studies for the existing mining operations. The local geology and hydrogeology are therefore well understood.

Elevated rocky areas in the centre of the project site form regional catchment divides, and represent outcropping of the geological basement of the island. The low lying areas between these elevated areas represent later sedimentary sequences that contain the manganese ore.

Quarry development has the potential to result in depressurisation of the target manganese ore and surrounding geology. Depressurisation of the local geology can potentially induce dewatering of groundwater bearing strata in the vicinity of the quarry, and influence the local and regional hydrogeology. The availability of groundwater resources, the reliability of water supplies, and groundwater expression in surface waters and springs can potentially be affected as a result.

This report presents an assessment of depressurisation effects arising from the development of proposed quarries in the project site. A numerical model has been developed to quantify these depressurisation effects in terms of groundwater level change and groundwater inflow rates during the operations phase and post mine closure. The report provides an assessment of the potential impacts of these changes on groundwater users and the surrounding environment. The report also provides an assessment of the potential impacts of the project on groundwater quality.

1.2 Scope of assessment

The scope of work for this groundwater assessment includes:

- reviewing relevant groundwater, geotechnical and environmental reports to develop an appreciation of the geological and hydrogeological setting of the project;
- reviewing exploration bore data;
- reviewing hydrogeological data held on the Northern Territory Department of Land Resource Management (DLRM) Water Data Portal for existing water bores;
- undertaking a census of existing water supply bores in the area to confirm bore locations, usage and water quality;
- developing a network of dedicated monitoring bores and production bores for measuring groundwater levels, quality and hydraulic parameters;
- analysis of all data and conceptualising the groundwater regime of the project and surrounding areas;
- developing a numerical model and undertaking predictive modelling of the scale and extent of mining impacts upon water levels, water quality and groundwater users at various stages during mine operations and post closure;
- assessing groundwater impacts and developing feasible mitigation and management strategies where potential adverse impacts are identified;
- developing a baseline groundwater monitoring program; and
- addressing requirements of the Terms of Reference (ToR) issued by the Northern Territory Environment Protection Authority (NT EPA) for the project.

1.3 Report structure

This report is structured as follows:

- Section 1 – Introduction: provides an overview of the project and the assessment scope;
- Section 2 – Regulatory Setting: describes the regulatory framework relating to groundwater;
- Section 3 – Project Setting: describes the environmental setting of the project including the climate, topography, land uses and other environmental features relevant to the project;
- Section 4 – Geological Setting: describes the geological setting of the project including the regional geology and local stratigraphy;
- Section 5 – Investigation Methodology: describes the assessment method including the collection and analysis of hydrogeological data;
- Section 6 – Hydrogeological Data: provides an interpretive summary of the hydrogeological data used in the groundwater assessment;
- Section 7 – Existing Hydrogeology: describes the existing local groundwater regime for the project site and surrounding area;
- Section 8 – Impact Assessment: provides a detailed description of the proposed mining activities and the potential effects on the local groundwater regime. This section also presents the predicted effects on groundwater and the assessment of resulting impacts on groundwater users and the receiving environment;
- Section 9 – Groundwater Monitoring and Management Plan: describes the proposed measures for monitoring and management of groundwater impacts; and
- Section 10 – Conclusions.

Appendix A provides a detailed description of the field investigations undertaken as part of this assessment. This appendix comprises a summary of the investigation methods and is supported by a detailed summary of bore data for on-site and private bores, and construction details and quality data for bores drilled during the field investigations.

Appendix B provides a detailed description of the numerical modelling undertaken for the project, including details of model construction, calibration and validation.

2 Regulatory framework

The following section summarises Northern Territory groundwater legislation and policy relevant to the project.

2.1 Northern Territory Water Act and water regulations

The Northern Territory *Water Act* and subordinate *Water Regulations* are the primary legislation regulating groundwater resources in the Northern Territory. The purpose of this legislation is to control the allocation, use and management of water resources. This legislation provides the regulatory system for allocating water to people, the environment and industry, with the following sections of the *Water Act* being particularly relevant:

- Section 15 prohibits obstructing or interfering with waterways. Waterways include shallow groundwater associated with the bed or banks of a waterway.
- Section 16 prohibits the unauthorised pollution of groundwater. Pollution of groundwater includes any unauthorised actions that, either directly or indirectly allow pollution of water. Authorisation can be provided by a licence granted under Section 63 or 74 of the *Water Act*.
- Part 6 regulates a wide range of groundwater related activities, including the licensing of groundwater drilling, permitting of bore construction, the licensing of groundwater extraction and recharge, and the licensing of waste disposal.

Under Section 7 of the *Water Act*, mining activities are exempt from these requirements. The project will consequently not require authorisation under the *Water Act* for any mining activities that could result in potential groundwater impacts. These mining activities will be regulated under the *Mining Management Act* and it will be necessary to obtain authorisations under the *Mining Management Act* before the project commences.

However, Section 7(2) of the *Water Act* states that mining activities are not exempt from regulation under the *Water Act* in situations where underground waste migrates off site. The management of unconfined underground wastes in these situations is regulated under the *Water Act*.

The *Water Act* also provides a legislated process for the management of water quality through the establishment of Beneficial Uses. This process is intended to reduce the impacts of water pollution through the protection of water resources. The Beneficial Use process includes:

- identifying and declaring beneficial uses or environmental values that include environmental, cultural and human use values (domestic and industrial); and
- establishing water quality objectives or standards for the protection of the identified beneficial uses.

Water uses and environmental values are established in consultation with community stakeholders.

Beneficial uses have been declared for the Groote Eylandt Marine Waters area ('the beneficial use area'). The beneficial use area comprises the marine waters between North West Bluff and Tasman Point up to the high water mark of tidal waters (Figure 1). It also includes all named and unnamed rivers and creeks entering these waters, including the Emerald River, the Angurugu River and minor drainages. The project site is partly located within the Emerald River and Angurugu River catchments that form part of the beneficial use area. The remainder of the project site is located in the Amagula River catchment that is not part of the beneficial use area. The project catchment setting is described in Section 3.2.

The declared beneficial uses for the beneficial use area are protection of aquatic ecosystems, cultural and spiritual values, recreation and aesthetics. The potential project impacts on the declared beneficial uses are discussed in Section 8.

The DLRM is responsible for administering and enforcing the *Water Act*. The Department of Mines and Energy is responsible for enforcing the *Mining Management Act*, including regulation of any impacts on groundwater.

3 Project setting

3.1 Location and land use

The project is located on Groote Eylandt in the Gulf of Carpentaria, approximately 650 km south-east of Darwin (Figure 1). The Eastern Leases are located 2 km east of the existing GEMCO mine, and 15 km east of the coastline at the closest point (Figure 2).

The land within the Eastern Leases comprises natural bushland. No farming or agriculture activities are undertaken within the Eastern Leases or surrounding areas.

The proponent has been undertaking exploration activities across the Eastern Leases since 2001.

3.2 Topography and drainage

Surface topography and surface water drainage are shown on Figure 3.

The central areas of Groote Eylandt are characterised by elevated rock outcrops that form hills and escarpments with limited vegetation and soil cover. Between these hills and escarpments, the low-lying topography forms densely vegetated, gently sloping valleys that open onto flat coastal plains. The hills and escarpments define the surface catchments across the majority of the island.

The project site is located in the upper reaches of the Emerald, Amagula, and Angurugu River Catchments (Figure 3).

The Emerald River and its tributaries drain the majority of the Northern EL and the western area of the Southern EL. The upper reaches of the Emerald River Catchment typically drains as overland sheet flow toward the west of the island, across open valley areas to the coast. The surface waters from the western area of the southern EL travel as unchannelised overland sheet flow toward a southern tributary of the Emerald River. As the valley floor drops in the west, overland flow paths coalesce with the main Emerald River channel and its tributaries, draining into the waters of the Gulf of Carpentaria downstream of the project site.

The tributaries of the Amagula River drain the eastern area of the Southern EL. Surface waters drain toward the south from elevated central hills through rock gullies that widen into rocky channels that enter the Amagula River to the south of the Southern EL. The Amagula River then flows to the southern coast of the island, draining into the waters of the Gulf of Carpentaria downstream of the project site.

A small section of the Northern EL lies within the Angurugu River catchment (Figure 3). This area drains to the main channel of the Angurugu River which flows northwest to the coast, draining into the waters of the Gulf of Carpentaria downstream of the project site.

Although the majority of watercourses within the project site are ephemeral, some sections of watercourses are predicted to receive groundwater inflows which contribute to surface water baseflow. Figure 4 shows the sections of watercourses that have been mapped as perennial, based on the results of the aquatic ecology impact assessment, the geomorphology study and groundwater modelling predictions.

The existing catchment and drainage setting, including the surface water flow regime and baseflow data, is discussed in detail in the EIS Surface Water section and the EIS Baseline Surface Water Monitoring Report. The influence of groundwater on perennial flows is assessed in Section 8 of this report.

The surface elevation of the Northern EL reaches 120 m Australian Height Datum (AHD) in upland areas and falls to 30 mAHD in the low-lying areas. The elevation across the Southern EL ranges from 80 mAHD to 10 mAHD.

3.3 Climate

The climate of Groote Eylandt is tropical and experiences two distinct seasons; a monsoonal wet season from November to April, typified by significantly higher humidity, temperature and evaporation rates, followed by a slightly cooler dry season from May to October. The area regularly encounters tropical cyclones during the wet season.

The annual average rainfall recorded at the Groote Eylandt Airport Meteorological Station (No. 14518) between 1999 and 2014 is 1,326.4 mm. The majority (97 %) of the rainfall occurs during the wet season. Relative humidity remains high throughout the year.

The Groote Eylandt Airport is located approximately 10 km to the northeast of the project area at an elevation of 14 m AHD. The average monthly rainfall is typically the highest in March (333.1 mm) and lowest in August (0.9 mm)

Recent rainfall years have been put into historical context using the Cumulative Rainfall Departure (CRD) method. This method is a summation of the monthly departure of rainfall from the long-term average monthly rainfall. A rising trend in the CRD plot indicates periods of above average rainfall, whilst a falling slope indicates periods when rainfall is below average. Figure 5 presents the CRD graph for the Groote Eylandt Airport.

The CRD graph indicates that the area has experienced distinct cycles of above average and below average rainfall. The CRD graph indicates that the island has experienced generally below average rainfall since 2011. The current climate cycle was preceded by above average rainfall from 2006 to 2011 and below average rainfall from 2001 to 2006.

Mean daily evaporation data was recorded at the Angurugu Meteorological Station (No. 014506) which operated between the years 1967 to 1988. Angurugu is located 3.3 km from the Groote Eylandt Airport at the same elevation of 14 m AHD. These records show that evaporation exceeds rainfall from April through to December with an average annual evaporative loss of 2,151 mm.

4 Geological setting

The geological setting has been informed by the following data sources:

- All drilling logs and geological data compiled from exploration drilling across the project site up to June 2014;
- Drilling logs from exploration drilling within the existing GEMCO mine;
- High resolution GEMCO geological model surfaces for the Eastern Leases area; and
- Geological data from registered bores held on the DLRM database.

The proponent has undertaken extensive exploration drilling across the Eastern Leases and the existing GEMCO mine. Exploration drilling has confirmed the geological units present at the project site and in the surrounding area. The proponent has developed a high-resolution geological model from the exploration drilling database which has been used to confirm the stratigraphy and distribution of geological units across the project site and surrounding area. The geological model provided the structural framework for developing a 3D numerical groundwater model by AGE. Appendix B provides a detailed description of the groundwater modelling approach.

4.1 Geology of Groote Eylandt

Groote Eylandt was formed on a stable basement of Proterozoic quartzite. This basement quartzite forms extensive elevated outcrops in the centre of the island.

The Proterozoic basement was eroded and redeposited during the early Cretaceous period, forming a sandstone unit comprising reworked quartzite.

A blanket of Cretaceous marine sediments was subsequently deposited over the paleosurface of the basement and reworked basement materials in the west of the island. The distribution of the Cretaceous marine sediments is generally confined to the western plains and valleys of the island. The upper Cretaceous sediments contain the manganese ore.

The manganese ore is a sedimentary layer, consisting of manganese strata occurring between clay and sand beds. The orebody is essentially stratabound and strataform in character and it represents a continuous horizon up to 11 m thick. The orebody consists of pisolitic and oolitic manganese oxides.

Much of the Cretaceous sediment profile (including some of the manganese ore) has been extensively modified by a long period of tropical weathering (or laterisation) during the Tertiary period. This has resulted in the development of thick laterite profiles up to 25 m thick.

A thin veneer of Quaternary sediment typically overlies the lateritic materials.

4.2 Geology of the Eastern Leases

The main stratigraphic units occurring within the Eastern Leases are summarised in Table 1.

Table 1 Stratigraphy of the Eastern Leases

Age	Unit	Lithology
Quaternary 2 Ma to Present	Quaternary sediments	Fine to very fine sand and clay, loose
Tertiary 66 Ma to 2 Ma	Laterite	Ferricrete, clay, and sandy clay
	Lateritic clays	Clay and sandy clay
Cretaceous 145 Ma to 66 Ma	Marine claystone	Claystone with siltstone, sandstone Hosts the manganese orebody in the upper sequence
	Marine sandstone	Fine to medium quartz sandstone, occasionally clayey
	Reworked basement	Fine to coarse sandstone, sub-rounded quartz clasts
Proterozoic 2,500 Ma to 542 Ma	Proterozoic basement	Strongly jointed, massive quartzite

Figure 6 and Figure 7 show the surface geology and typical stratigraphy of the project site and the surrounding area, respectively. The following sections describe the stratigraphic units that occur within the project site. Appendix A1 provides detailed logs indicating the depth and distribution of these strata across the project site. Figure 8 presents a conceptual geological cross section through the project site.

4.3 Proterozoic basement

The Proterozoic basement is a strongly jointed, massive, quartzite. The quartzite forms rugged, sparsely vegetated hills and scarps where it outcrops. Between the outcropping areas, the basement is typically overlain by a sequence of later sedimentary deposits.

Where exposed, the quartzite exhibits weathering and a joint-controlled topographic expression, which is clearly evident as linear features in aerial photography. Joint sets and weathering are likely to be uniform across the upper quartzite unit.

The Proterozoic basement is estimated to be 500 m to 1000 m thick beneath the project site and dips gently to the south at 1 to 2 degrees.

4.4 Cretaceous sediments

The Cretaceous sediments comprise several distinct units, including:

- reworked basement (sandstone);
- marine sandstone;
- marine claystone; and
- manganese orebody.

The total thickness of the Cretaceous sediments is highly variable due to the strongly undulating basement profile, and may exceed 100 m towards the west and southwest of the Eastern Leases. Distribution of the Cretaceous sediments is confined to palaeovalleys between basement outcrops.

4.4.1 Reworked basement

The sediments overlying the Proterozic basement consist of poorly sorted fine to coarse quartz sandstone derived from weathering and erosion of the underlying quartzite. The thickness of the reworked basement varies from less than 10 m to greater than 30 m.

4.4.2 Marine sandstone

The base of the marine sedimentary sequence consists of a fine to medium grained quartz sandstone which shows very similar lithological properties to the underlying reworked basement. The two units are lithologically indistinct during drilling.

The marine sandstone was deposited during a single marine transgression during the early Cretaceous period. This unit overlaps the underlying reworked basement and the Proterozoic basement. The thickness of the marine sandstone is typically less than 11 m across the project site.

4.4.3 Marine claystone

The upper Cretaceous sedimentary sequence comprises a marine claystone with minor interbedded sandstone and siltstone. The marine claystone is low strength and highly variable in colour, ranging from mottled red and yellow to dark green and grey. The contact between this unit and the underlying marine sandstone is gradational and represents a change in the depositional environment from nearshore to shallow marine. The thickness of the marine claystone varies from less than 0.5 m near basement outcrops to 30 m thick elsewhere in the Eastern Leases.

The marine claystone unit hosts the primary manganese orebody which is described in more detail in the following section.

4.4.4 Manganese orebody

The manganese orebody comprises primary pisolitic and oolitic manganese oxides and a secondary massive manganese oxide horizon. Pisolites (>2 mm) and oolites (<2 mm) are concretionary grains deposited as a chemical precipitate in wave-affected shallow sea-floor environments during a period of rising and falling sea levels. Supergene enrichment during the Tertiary period remobilised the primary manganese oxide minerals in the loose pisolites forming massive manganese oxide layers within the orebody.

Regionally, the manganese orebody forms an almost continuous horizon with a lateral extent of over 50 km. At the Eastern Leases, the orebody is open and contiguous in the west, and forms discrete lenses in the east where it abuts the elevated Proterozoic basement. The manganese orebody ranges in thickness up to 11 m. Although boundaries between sediment types tend to be vertically gradational, sharp boundaries do exist.

Exploration data indicates the massive manganese horizon generally overlies the pisolitic horizon and consists entirely of manganese oxide. The pisolitic horizon consists of cemented pisolities /oolites or loose pisolites within clay or sandy clay gangue material.

Minor disseminated manganese is also present in other strata in the Eastern Leases.

4.5 Tertiary laterite

During the Tertiary period, lower sea levels exposed sediments to deep tropical weathering, which resulted in the development of a lateritic weathered profile (up to 25 m thick) in the Cretaceous sediments.

During the lateritic weathering process, sediments are leached of their soluble ions in the wet season. During the following dry season, the leached ions are drawn to the surface by capillary action where they are deposited. This process results in a sequence of weathered claystones, siltstones, and sandstones depleted of major ions, in particular calcium, magnesium, sodium, and potassium. Heavy elements such as aluminium and iron are preferentially enriched, leading to the formation of iron-cemented horizons (ferricrete).

4.5.1 Lateritic clay

A lateritic clay overlies the manganese orebody. The unit comprises mottled yellow to red clay, sandy clay and silt. This unit varies in thickness and reaches approximately 12 m within the Eastern Leases.

4.5.2 Laterite

A laterite horizon characterised by ferricrete is present across most of the Eastern Leases. This unit comprises sediments which have been cemented by iron oxide, forming a hard, erosion-resistant unit at or near the present day surface. This laterite unit varies in thickness from less than 1 m to 10 m.

4.6 Quaternary sediments

Quaternary sediments within the project site typically comprise loose fine quartz sand grading to silt. This unit forms a thin cover that ranges from a few centimetres up to 3 m thick across the Eastern Leases.

4.7 Geological structure

Figure 6 shows a distinct set of joint patterns in the Proterozoic basement (visible as linear features on the surface outcrops of the Proterozioc basement). These joint sets are effectively minor fractures in the basement rock. No significant geological displacement is associated with these joint sets. Section 7 discusses the hydrogeological behaviour of these joints in relation to the basement.

No significant or extensive faults have been detected within the project site or surrounding area.

5 Investigation methodology

This section outlines the methodology adopted for the collection of hydrogeological data to inform the groundwater assessment. A detailed description of the field investigation methods and findings is provided in Appendix A. Groundwater data including field investigation results from the project site and the surrounding area are presented in Section 6.

5.1 Overview of methodology

A detailed background study was undertaken to develop an understanding of the hydrogeological setting of the project. This included:

- Review of local groundwater studies and other relevant technical reports, including reports prepared in relation to the existing GEMCO mine;
- Review and interpretation of regional and local geological data, including an extensive exploration and geological database collected by the proponent;
- Review of hydrogeological data held on the DLRM groundwater database for existing registered private water bores; and
- An extensive field investigation which involved a drilling and testing program to refine the understanding of the groundwater regime at the Eastern Leases. This included:
    - Targeted drilling and installation of groundwater monitoring bores and production bores;
    - Completion of field tests to determine local hydrogeological characteristics;
    - Completion of a census of unregistered private bores to confirm groundwater use and quality in the vicinity of the project; and
    - Collection of water samples from monitoring and private bores to characterise groundwater quality.

All relevant hydrogeological data was compiled and analysed to conceptualise the groundwater regime in detail. A numerical groundwater model was developed to predict the scale and extent of any changes to the groundwater regime throughout the mine operations phase and post closure. These predictions were used to assess the potential project and cumulative impacts on groundwater resources and levels, water quality, and groundwater users. Appropriate groundwater monitoring and management strategies were developed to address any potential for significant adverse impacts and validate the findings of the assessment.

5.2 Previous investigations

No previous groundwater investigations or assessments have been undertaken within the Eastern Leases.

The existing GEMCO mine is located to the west of the Eastern Leases. While the stratigraphy of the existing GEMCO mine is broadly comparable to that of the project, the coastal setting and lower elevation result in a significantly different hydrogeological setting.

The key hydrogeological studies undertaken on Groote Eylandt, and which are considered relevant to the existing GEMCO mine, are as follows:

- Aquaterra (2001) developed a groundwater model using existing data to simulate groundwater flow in and around the GEMCO mine.
- Coffey Projects (2008) reported on the development of dewatering bores to manage groundwater in the north of GEMCO mine.
- Coffey (2012A) investigated the hydrogeology of the active mining area. The purpose of the investigation was to assess the impacts of mining activities on the groundwater and surface water systems, and to provide estimates of dewatering rates. The investigation included hydraulic testing on key wells across the GEMCO mine and modelling of groundwater flow in the north and south of the GEMCO mine. The field investigation included installing 31 monitoring bores and production bores into the shallow groundwater system. The purpose of the bores was to target seepage of groundwater contamination into the shallow permeable zones and to assess the groundwater relationship between shallow groundwater and the Angurugu River. In-situ permeability tests were carried out, involving six rising head tests and three constant rate pumping tests to target groundwater in the shallow sediments overlying the manganese orebody.
- Coffey (2012B) investigated the effect of proposed mining activities on the surface water and groundwater hydrology within the GEMCO mine. The investigation involved:
    - installing seven monitoring bores to a depth of up to 20 m; and
    - undertaking seven rising head permeability tests.

5.3 Project site field investigations

A groundwater field investigation program was developed for the project site. Based upon the project setting, regulatory context and understanding of the local geology, the key objectives of the field investigation program were to:

- Collect detailed site-specific geological data to refine the understanding of the project site geology, including confirmation of the extents of key hydrogeological units across the project site;
- Collect detailed drilling logs and core samples from all stratigraphic units to accurately characterise the units that are likely to govern the local groundwater regime;
- Target specific drilling depths and distribution to stratigraphic units that are known water bearing strata or confining units;
- Target stratigraphic units overlying the target manganese orebody;
- Extend geological drilling depths in order to target stratigraphic units below the manganese orebody to provide information on the composition, distribution and hydraulic properties of the underlying materials;
- Extend geological drilling depths as far as practical to maximise the groundwater intersected across the project site;
- As far as practicable, target the drilling layout so that it surrounds the proposed quarries (Figure 9) and ensures that long-term data can continue to be gathered following commencement of operations; and
- Cluster bores to allow the vertical profile of the groundwater regime to be characterised.

Field investigations into the hydrogeology of the Eastern Leases were undertaken between November 2013 and May 2014, and comprised:

- drilling, constructing and developing a groundwater monitoring network;
- post-drilling measurements of groundwater quality and hydraulic properties including falling head; and
- a census of private bores to confirm the extent of existing groundwater use and surface expression of groundwater.

A summary of these field investigations is provided below. A more detailed description of the field investigations is presented in Appendix A. Appendix A1 presents composite logs and construction details for each monitoring bore. Data collected during the field investigations is presented and interpreted in Section 6.

5.3.1 Groundwater monitoring network

A total of 19 monitoring bores were installed at 10 monitoring locations across the Eastern Leases as shown in Table 2. Figure 9 shows the monitoring locations and bores.

Table 2 Monitoring bores

Project area	Monitoring location	Monitoring bore	Geological unit	Main lithology
Northern EL	ELNMB01	MB01S	Laterite /Lateritic Clay	Cemented lateritic sand and clay over firm plastic lateritic clay
		MB01D	Reworked Basement / Marine Sandstone	Silty clastic sandstone
	ELNMB02	MB02S	Laterite / Manganese Ore / Marine Claystone	Cemented gravel and clay over massive manganese and firm plastic clay with disseminated manganese
		MB02D	Marine Sandstone	Silty clastic sandstone
	ELNMB03	MB03S	Laterite / Manganese Ore / Marine Claystone	Cemented lateritic sand over massive manganese and firm plastic clay
		MB03D	Reworked Basement	Silty clastic sandstone
	ELNMB04	MB04S	Lateritic Clay	Soft silty sandy lateritic clay
		MB04D	Reworked Basement	Clastic sandstone
Southern EL	ELSMB05	MB05	Marine Claystone	Soft clay with manganese
	ELSMB06	MB06S	Quaternary Sediments / Laterite	Loose sand over coarse clastic lateritic sand
		MB06D	Reworked Basement	Clastic sandstone
	ELSMB07	MB07S	Laterite / Manganese Ore	Clastic sandy lateritic gravel
		MB07D	Reworked Basement / Marine Sandstone	Clastic sandstone
	ELSMB08	MB08S	Laterite / Lateritic Clay	Silty lateritic clay over silty sandy lateritic clay
		MB08D	Marine Claystone	Soft clay and disseminated manganese
	ELSMB09	MB09S	Marine Claystone / Manganese Ore	Soft to firm clay
		MB09D	Reworked Basement	Clastic sandstone

Project area	Monitoring location	Monitoring bore	Geological unit	Main lithology
	ELSMB10	MB10S	Laterite / Lateritic Clay	Clastic silty lateritic sand over soft silty lateritic clay
		MB10D	Marine Claystone	Soft plastic clay

Note: *Monitoring bore (and location) nomenclature is as follows:*

- *EL – Eastern Leases;*
- *MB – Monitoring Bore;*
- *S – Shallow Bore targeting groundwater table typically hosted by strata above the manganese orebody;*
- *D – Deep Bore targeting groundwater body typically hosted by strata below the manganese orebody.*

The groundwater monitoring network comprised four monitoring locations in the Northern EL (i.e. ELNMB01 to ELNMB04) and six monitoring locations in the Southern EL (i.e. ELNMB05 to ELNMB10). A pair of monitoring bores was installed at each monitoring location, excepting ELSMB05 where a single bore was established.

Each paired bore was nominally drilled as either a 'shallow' or 'deep' bore, and targeted geology with potential to act as aquifers or aquitards. Deep bores were typically targeted to the reworked basement and marine sandstone units as geological and hydrogeological information indicated that these geological units represented a potential aquifer. The shallow bores were typically targeted to intersect a range of units above and adjacent the manganese orebody.

A single monitoring bore was installed at monitoring location ELNMB05 with the intention it would screen the basement quartzite. However, due to the significant depth of the quartzite at this location, the bore was relocated to the disseminated manganese horizon in the marine claystone because it was considered more relevant to the assessment of understanding potential project impacts.

Construction details and logs for monitoring bores are presented in detail in Appendix A1. Monitoring bores were drilled and constructed by a Northern Territory licenced water bore driller under the supervision of an AGE hydrogeologist. All monitoring bores were drilled and installed in accordance with Northern Territory drilling regulations and Minimum Construction Requirements for Water Bores in Australia (2012)

5.3.2 Groundwater production bores

A total of four high capacity production bores were installed at four monitoring locations across the Eastern Leases as shown in Table 3.

Table 3 Production bore details

Project area	Monitoring location	Production bore	Geological unit	Lithology
Northern EL	ELNMB01	PB01	Reworked basement / marine sandstone	fine to coarse sandstone, sub rounded quartz clasts
	ELNMB03	PB03	Reworked basement / marine sandstone	fine to coarse sandstone, sub rounded quartz clasts
Southern EL	ELNMB07	PB07	Reworked basement / marine sandstone	fine to coarse sandstone, sub rounded quartz clasts
	ELNMB09	PB09	Reworked basement / marine sandstone	fine to coarse sandstone, sub rounded quartz clasts

The purpose of the production bores was to provide additional detailed information on the hydraulic characteristics of geological units that yield groundwater. The location of each production bore was based on proximity to the proposed quarries and drilling observations from the deep monitoring bores.

Figure 9 shows the monitoring locations where each production bore was installed. Construction details and logs for production bores are presented in detail in Appendix A1.

5.3.3 Hydraulic testing

An extensive hydraulic testing program was undertaken across the Eastern Leases.

A total of 15 in-situ falling/rising head permeability tests were conducted in monitoring bores where groundwater was present. These permeability tests were designed to evaluate the hydraulic conductivity of material surrounding the bore screen. The distribution of these tests by geological unit is shown in Table 4.

Table 4 In-situ permeability test results

Geological Unit	No. of tests
Laterite	4
Lateritic Clay	1
Marine Claystone	4
Marine Sandstone / Reworked Basement	6

A total of four 24-hour constant rate pumping tests were also completed across each of the four production bores. Prior to each constant rate test, a step drawdown test was undertaken to determine the optimal pumping rate for the constant rate tests. Section 6.2 discusses the results of the hydraulic testing.

Figure 9 shows the locations where hydraulic testing was undertaken. Appendix A2 presents the details of each permeability test and constant rate pumping test.

5.3.4 Private bore census

A private bore census was designed to determine the nature and extent of existing groundwater use both within the project site and its immediate surrounds. This was carried out in order to understand the potential impacts the project on private groundwater supplies .

The bore census was intended to capture any bores that could potentially be impacted by the project. Based upon the local geology, land use information and limited number of residential outstations, a search radius of 5 km from the Eastern Leases boundary was adopted.

An initial search to identify potential bores included:

- Engagement with GEMCO Environmental and External Affairs staff who provided information and background knowledge of groundwater use in the vicinity of the project site;
- The involvement of representatives from the Groote Eylandt Bickerton Island Enterprises (GEBIE) Civil and Construction Pty Ltd who provided local knowledge and assisted in the identification of groundwater use in the vicinity of the project site; and
- A search of local mapping and databases.

Bores identified though the initial search were inspected during field surveys undertaken in November 2013. Water levels and bore depths were recorded from all accessible bores.

Section 6.3 presents the bore census results.

5.3.5 Water quality sampling and analysis

A total of 55 groundwater samples were collected from groundwater monitoring bores over six monthly rounds of sampling conducted between January and July 2014. Samples were collected using the low flow method to ensure clear samples with minimal sediment were collected. Blank and duplicate samples were also collected to ensure quality assurance of sampling and analytical procedures.

Water samples were submitted within the appropriate holding times to ALS Environmental Laboratories (ALS) for analysis. ALS is accredited under the National Association of Testing Authorities (NATA). The water samples were analysed for the following suite of parameters:

- physical parameters (total suspended solids, alkalinity, and total hardness);
- major anions (CO_3, HCO_3, Cl, SO_4);
- major cations (Ca, Mg, Na, K);
- minor ions (F);
- dissolved and total metals (Al, As, Ba, Be, B, Cd, Cr, Co, Cu, Fe, Hg, Pb, Mn, Ni, Se, U, V, and Zn);
- nutrients (nitrite, nitrate, nitrite + nitrate, TKN, total nitrogen, total phosphorus); and
- total petroleum hydrocarbons (TPH).

Field determinations for pH, electrical conductivity (EC), and total dissolved solids (TDS) were also collected during each sampling event. Each sample was collected in laboratory-supplied containers. Samples requiring dissolved metal analysis were filtered in the field, using a 0.45 micron filter, prior to being transferred to the laboratory. All samples were itemised on a Chain of Custody Form, which accompanied the samples to the laboratory.

The laboratory analysis results are discussed in Section 6.4. Laboratory reports are provided in Appendix A3.

6 Groundwater data and results

This section provides a summary of the data collected from the field investigations discussed in the previous section.

6.1 Groundwater distribution and flow

Groundwater level readings provide useful information on the vertical and lateral hydraulic gradients, and can also be used to interpret hydraulic conditions such as groundwater distribution and recharge, flow and discharge.

Figure 10 presents groundwater level hydrographs recorded in the monitoring bores. Figure 11 and Figure 12 present horizontal hydraulic gradients, showing interpolated equipotential contours for the shallow and deep bores, respectively.

Water levels in the shallow bores range from approximately 38 mAHD to 45 mAHD in the Northern EL and 25 mAHD to 53 mAHD in the Southern EL. Standing groundwater level is generally within 3 m of ground level. Water levels within the deep monitoring bores are lower and vary between approximately 26 mAHD to 30 mAHD in the Northern EL and 20 mAHD to 38 mAHD in the Southern EL.

Key trends demonstrated by water level data are as follows:

- Groundwater levels (or head) within the shallow laterite and deeper sandstone monitoring bores differ by up to 15.5 m, and confirm that there is a vertical gradient between these units. The shallow groundwater monitoring bores have a higher groundwater head than the deep groundwater bores due to hydrogeological properties of the intervening materials. The vertical gradient is therefore downward.
- Groundwater in the shallow monitoring bores is strongly influenced by local geomorphology and is confined to the valleys between outcropping basement. Groundwater within the Emerald River surface water catchment drains towards Emerald River. Groundwater in the Amagula River catchment (i.e. the east of the Southern EL) drains towards the Amagula River. Figure 9 shows the water table elevation and flow direction recorded in the shallow bores.
- Groundwater levels in the deeper bores show less topographic influence, with groundwater flow more generally toward the west coast of the island. Figure 12 shows the potentiometric groundwater surface and flow direction recorded in the deeper bores.
- Shallow bores show a strong correlation to rainfall, indicating the screened laterite is rapidly recharged.
- Deep monitoring bores screened in the marine claystone show a limited recharge response indicating that this is a low permeability unit that is likely to act as a confining unit to groundwater movement. Downward movement of recharge from the overlying laterite is likely to be retarded, resulting in the formation of a shallow water table in these shallow sediments.
- Bores screened in the reworked basement and marine sandstone underlying the orebody showed a delayed response to wet season rainfall recharge. A gradual decline in water level was recorded over the wet season. This followed by a gradual increase in water level from February to June 2014. This pattern indicates that recharge to this unit is slow due to the low permeability of the overlying marine sediments.
- Overall, the difference in head, distribution and flow confirm that the groundwater regime is characterised by an unconfined shallow water table in the laterite and a deeper confined groundwater associated with the reworked basement and marine sandstone.
- Outcropping basal materials act as a regional groundwater divide and recharge zone.

- The vertical hydraulic gradient (i.e. the degree of head difference) between the shallow and deep groundwater decreases in the vicinity of the Amagula River main channel. This indicates that the potentiometric surface of the deeper confined groundwater body becomes shallower in this area, ultimately intersecting the ground surface and discharging as baseflow to the river. This situation is likely to be mirrored in the Emerald River to the west of the Eastern Leases.

The reported results are consistent between the Northern EL and Southern EL.

6.2 Hydraulic testing

Figure 13 graphs the results of the 15 in-situ permeability tests and the 4 pumping tests undertaken at the Eastern Leases. Key trends demonstrated from recorded data include:

- Geology screened in the shallow bores generally exhibits lower permeability than the units screened in the deeper bores;
- The laterite is considered moderately permeable, although shows lower hydraulic conductivity than the underlying lateritic clay;
- The marine claystone and manganese exhibit hydraulic conductivity two to three orders of magnitude lower than the underlying sandstone units;
- The reworked basement and marine sandstone show a greater hydraulic conductivity than the other units in the vicinity of the project and are typically highly permeable;
- The Quaternary sediments are considered to be highly permeable; and
- Pumping tests show that the sandstone units are highly permeable with a high groundwater storage capacity.

Appendix A2 includes all hydraulic testing results, including the measured drawdown and recovery curves.

6.3 Bore census

As discussed within Section 5.3.4, the bore census collated data from all DLRM registered bores and unregistered outstation bores within the vicinity of the Eastern Leases.

Where available, groundwater data from DLRM registered bores and unregistered outstation bores was incorporated into the wider field investigation dataset and informed the understanding of the hydrogeological setting (described in Section 7). The bore census was also used to assess the current level of groundwater use within the vicinity of the Eastern Leases.

The bore census identified that two bores are located at Aboriginal outstations within 5 km of the Eastern Leases. These outstation bores comprise:

- an unregistered bore located at the Yedikba outstation; and
- a water supply bore (RN27979) at the Wurrumenbumanja outstation.

Yedikba is an Aboriginal outstation located approximately 2.2 km to the west of the Southern EL and comprises three outstation buildings. Yedikba is not a permanently occupied outstation and is reported to have varying levels of use, from occasional visitation to sporadic residency. There were no occupants present in Yedikba during the bore census in November 2014. The Yedikba outstation bore was installed by the proponent in 2012. Although the bore is equipped with a solar powered electro-submersible pump and control panel, anecdotal information provided by GEMCO (M. Chapman, pers. comm. 2014) indicates that when present the outstation occupants preferentially source water from the adjacent Emerald River. This bore is screened within the marine sandstone and reworked basement.

Wurrumenbumanja is an Aboriginal outstation located approximately 3.5 km to the south of the Southern EL and comprises four outstation buildings. Wurrumenbumanja is not a permanently occupied outstation and is reported to have low levels of use, typically limited to occasional visitation. There were no occupants present in Wurrumenbumanja during the bore census in November 2014. The bore census confirmed that one bore (RN27979) has been constructed at the Wurrumenbumanja Outstation. Bore RN27979 is a functioning water supply bore installed in 1992 and includes a solar powered electro-submersible pump and control panel. This bore is screened within the marine sandstone and reworked basement.

In addition, five DLRM registered monitoring bores are also present within 5 km vicinity of the Eastern Leases. These bores are owned and maintained by GEMCO and any potential impacts on these bores that could result from the mining of the Eastern Leases will be monitored by the proponent. These bores are not considered further in this assessment.

Figure 14 shows the location of the two outstation bores relative to the Eastern Leases.

6.4 Groundwater quality

Groundwater quality data provides useful information on the geology and groundwater regime. This data can also be assessed against the known uses and values of groundwater. Appendix A3 presents a full summary of the water quality data collected during the project field investigation.

Groundwater results for dissolved minerals are summarised in Table 5. These results are typically used as indicators of groundwater recharge rate, hydraulic permeability and residency times. High concentrations of dissolved minerals can indicate limited recharge, low permeability or high residency times. Low concentrations of dissolved minerals can indicate high recharge, high permeability or low residency times. Low concentrations can also reflect the highly weathered nature of the geology. These results show that groundwater associated with the laterite unit and the deeper marine sandstone and reworked basement units is typically low in dissolved minerals.

Salinity can be described by total dissolved solid (TDS) concentrations. TDS concentrations are commonly classified on a scale ranging from fresh (or non-saline) water to extremely saline water (FAO, 2013). TDS concentrations below 500 mg/L are classed as fresh water (i.e. non-saline water). TDS results show that groundwater across all geological units is fresh water. It is noted that salinity is markedly higher in the low permeability claystone (and manganese ore) than either the overlying laterite unit or the deeper marine sandstone and reworked basement units.

Table 5 Summary of dissolved mineral concentrations

Parameter	Laterite	Marine claystone and manganese	Marine sandstone and reworked basement
Total Dissolved Solids	70.2	143.6	46.4
Calcium	2.5	4.7	1.6
Magnesium	1.4	4.8	1.4
Sodium	17.9	35	10.1
Potassium	0.8	1.3	0.7
Chloride	14.9	45.3	11.4
Sulphate	11.5	6.8	2.4
Bicarbonate	24.2	46.6	19.8

Note: All values presented are average values of all water quality data from all bores screened in each geological unit. Values are presented in milligrams per litre unless otherwise shown.

The average pH of groundwater in the shallow bores ranges from pH 5.1 to pH 6.9 (i.e. moderately acidic to neutral). Groundwater in the deep bores ranges from pH 4.8 to pH 6.5 (i.e. slightly to moderately acidic). During the later stages of each pumping test (i.e. following almost 24 hrs of pumping) the pH stabilised between pH 4.4 and pH 4.8 across all production bores. This lower range better reflects the natural pH of groundwater in the reworked basement and marine sandstone units intersected by the deep monitoring bores.

Groundwater quality has been assessed in terms of the declared beneficial uses of surface waters to be protected or enhanced in the vicinity of the project site (i.e. aquatic ecology, and recreational and aesthetic values), and the potential use as a drinking water supply.

For the purposes of this assessment, groundwater quality data has been compared to default guideline trigger values from the National Water Quality Management Strategy Paper 4: Australian and New Zealand Guidelines for Fresh and Marine Water Quality (2000) (the ANZECC guidelines) for aquatic ecosystems and the health and aesthetic guideline values for physical and chemical characteristics of drinking water from the Australian Drinking Water Guidelines (NHMRC and NRMMC, 2011)_as these are more stringent than recreational guidelines.

Comparison with the adopted guidelines indicates the following key trends:

- Groundwater from the majority of bores shows consistently elevated levels of zinc and copper above the freshwater aquatic guidelines for all monitoring rounds.
- Groundwater from a number of both shallow and deep bores exhibited elevated nickel, manganese, aluminium and iron compared to both drinking water standards and freshwater aquatic guidelines. These exceedances were observed to be more prevalent in the later post-wet season sampling rounds.
- A single exceedance of the drinking water standard for chloride was recorded from a shallow bore (ELNMN01S) during the initial sampling round. Subsequent samples are within the drinking water standard for chloride at all locations.
- The stabilised pH values within the reworked basement and marine sandstone units is below (i.e. more acidic) than the drinking water standard lower threshold.

Nutrient and hydrocarbon concentrations were typically below the limits of detection across the Eastern Leases.

7 Existing hydrogeology

This section details the existing hydrogeology of the Eastern Leases and surrounding area, by describing the hydrogeological properties of each geological unit based on the data collected as discussed in Section 5.

Table 6 summarises the stratigraphic units occurring within the Eastern Leases and immediate surrounds. The primary groundwater bearing units are the shallow laterite, and the deeper marine sandstone and reworked basal sediments. The deeper sandstone units are considered to form a single aquifer unit, henceforth referred to as the Cretaceous sandstone.

Table 6 Groundwater characteristics of geological units

Geological age	Geological unit	Status
Quaternary	Quaternary sediments	Ephemeral groundwater present
Tertiary	Laterite	Unconfined aquifer
	Lateritic clay	Aquitard / Confining unit
Cretaceous	Marine claystone and manganese orebody	
	Marine sandstone	Confined aquifer
	Reworked basement	
Proterozoic	Proterozoic basement	Aquitard

Section 7.1 describes the processes that control or influence the movement and storage of groundwater in a hydrogeological system. Figure 16 presents a west - east cross section through the project site, identifying the movement of groundwater within the region. Sections 7.2 to 7.7 provide a detailed description of each hydrogeological component of the groundwater regime.

7.1 Overview of existing conceptual groundwater regime

Regionally, the geology comprises jointed basement materials overlain by sedimentary sequences. The basement paleosurface is deeply incised and has been in filled by subsequent sediment deposition. Basement high points are observed to outcrop across the natural ground surface, with sediment deposits thinning in the vicinity of these outcrops.

The regional groundwater flow occurs from the elevated basement highs located in the centre of the island towards the ocean. The regional hydrogeology is characterised by two distinct groundwater regimes:

- confined groundwater associated with Cretaceous sandstones overlying the basement; and
- an unconfined water table within the laterite.

Groundwater flows will naturally occur from areas of high pressure to low pressure. The weathered and jointed basement outcrops within the project site form an area of high pressure where regional groundwater is recharged. This recharge is enhanced at the break of slope (i.e. the slopes of the outcropping hills meets the flatter topography of the valleys) where runoff infiltrates following rainfall events. Recharge will also occur from direct rainfall to the ground surface seeping into the shallow underlying Quaternary sediments and laterite. Measured hydraulic gradients also show that downward seepage from the marine claystone also recharges the sandstone aquifer.

Groundwater associated with the Cretaceous sandstone flows in a westerly direction and is confined by the low permeability of thick overlying marine claystone and clay sequences. The confined aquifer provides baseflow to surface water systems including the Amagula River and Emerald River, particularly in low lying coastal areas where the aquifer units subcrop beneath rivers and the overlying marine clay aquitard thins substantially. However, the main discharge point for the Createaceous sandstone is the marine waters of the Gulf of Carpentaria. Groundwater associated with the Cretaceous Sandstone is typically fresh. Water supply bores are known to have been constructed at outstations, although their use is likely to be limited and sporadic.

Although the laterite exhibits variable permeability, this geological unit is more permeable than the underlying lateritic clays and marine clays. As a result, an unconfined groundwater table that is recharged via direct rainfall to the valley sediments has formed in this unit. The groundwater table in the laterite aquifer closely follows the natural surface topography, resulting in groundwater flows towards the major creeks and rivers. Seepage from this aquifer to the underlying sandstone is limited by the low permeability clay which results in strong separation of these aquifers. Groundwater discharge predominantly occurs where the laterite outcrops coincide with surface water channels. During the wet season, discharge from this aquifer will form a component of baseflow to the main surface water systems (including the Emerald and Amagula Rivers). The quality of the groundwater in the laterite is fresh, however, no water supply bores are known to have been constructed in this unit.

7.2 Proterozoic basement

7.2.1 Distribution

The Proterozoic basement is a strongly jointed, massive, quartzite. This geological unit forms the elevated areas and escarpments within and surrounding the project site. Elsewhere this unit underlies the Cretaceous sandstone.

Groundwater is inferred to occur at depth. Limited outcropping areas are unsaturated to depths that correlate to levels in the Cretaceous sandstone.

7.2.2 Hydraulic parameters

Physical inspection of the outcropping quartzite indicates a very low primary porosity and hydraulic conductivity where the unit is massive. Joint planes show red staining (due to iron), indicating preferential flow and recharge of groundwater along these structures.

In general, this assessment of hydraulic conductivity is comparable to previous groundwater studies on Groote Eylandt. Previous studies have regarded this unit as exhibiting a low permeability to groundwater flow, except along structural features and joint sets (Coffey 2008). Aquaterra (2001) and Coffey (2012B) accounted for this variability by assuming a moderate hydraulic conductivity of 0.1 m/day.

Weathering in the upper profile of this unit is likely to exhibit higher hydraulic conductivity, similar to the overlying Cretaceous sandstone.

7.2.3 Recharge, flow and discharge

Recharge occurs via direct rainfall infiltration on the weathered outcropping areas. Recharge is likely to be via secondary porosity associated with the joint sets and any weathering which may have occurred in the upper profile of this unit. The hydraulic gradient is representative of the regional topography with flow from higher elevation areas towards the coast. Discharge will occur into the overlying Cretaceous sandstone via jointing.

7.2.4 Yield and Use

Due to the significant depth to groundwater and typically low yield of this low permeability unit, no bores or groundwater users are present.

7.3 Cretaceous sandstone

Based upon the geological information available, the reworked basement and marine sandstone are hydrogeologically equivalent and are therefore essentially identical for the purposes of groundwater assessment.

7.3.1 Distribution

The Cretaceous sandstone comprises quartz sandstone derived from weathering and erosion of the underlying older Proterozoic basal materials and shallow marine depositional environment.

This unit forms a high transmissivity aquifer within the project site and surrounding area. This unit is uniformly saturated across the project site, and confined by the low permeability of the overlying sediments. It becomes unconfined and unsaturated as the unit thins against the outcropping basement.

7.3.2 Hydraulic parameters

The hydraulic testing within the project site shows that this unit has a very high hydraulic conductivity ranging from 4.5 m/day to 68 m/day. The geometric mean of hydraulic test results is 19 m/day. These results confirm that the unit is a highly permeable and productive aquifer where saturated.

Figure 13 shows that the hydraulic conductivity of this unit is significantly higher than the overlying material, and supports the assessment that this layer will act as a conduit for groundwater movement.

Hydraulic conductivity data which was collected for this unit is comparable with data obtained from previous groundwater studies undertaken on Groote Eylandt. Aquaterra (2001) and Coffey (2012B) each reported an average hydraulic conductivity of 25 m/day for this unit. Registered Bore RN 027979, located near Leske Pools south of the Southern EL, recorded a hydraulic conductivity of 28 m/day in this unit (Northern Territory Land Information Systems, 2014).

7.3.3 Recharge, flow and discharge

The high permeability (and very low salinity) of this geological unit confirms that the average rate of recharge is very high. The Cretaceous sandstone is recharged via:

- infiltration of runoff at the break of slope, where the Cretaceous sediments thin and lap onto the Proterozoic basement;
- slow drainage of groundwater though the overlying lateritic and marine claystone units; and
- upward flow from the underlying basement.

The potentiometric surface (or unconfined groundwater level) in the Cretaceous sandstone does not respond rapidly to rainfall events. This is evident from the observed lag of several months between the end of the wet season and the subsequent rise in the potentiometric surface of the Cretaceous sandstone due to wet season rainfall recharge.

The potentiometric surface becomes progressively shallower to the west, and is close to ground level near the coast and the lower reaches of the Emerald and Amagula rivers. Groundwater flows therefore reflect surface topography and catchments, with limited discharge into the overlying formations. Within low lying areas, the Amagula and Emerald Rivers are also inferred discharge zones for this unit.

The distribution of these inferred discharge zones has been mapped on Figure 15 using the potentiometric groundwater surface and the existing topography.

7.3.4 Yield and use

There are two bores located at outstations that are interpreted intersect this unit within 5 km of the Eastern Leases (Figure 14). These bores were not in use at the time of field investigation Potential yields from these outstation bores are likely to be high due to the hydrogeological properties of this unit..

Four constant rate pumping tests were performed at rates between 5.1 L/s and 13.3 L/s in the test production bores within the Eastern Leases. Despite these high flow rates, up to 14 m of available drawdown remained at the end of each test, confirming that the Cretaceous sandstone is very high yielding. Slightly lower yields occur where the Cretaceous sandstone thins across basement highs, or localised variations in the sandstone permeability reduce yields.

7.3.5 Groundwater quality

The quality of groundwater within the Cretaceous sandstone was observed to be of a consistent quality across the project site.

Overall, groundwater exhibits low concentrations of dissolved minerals and low salinity relative to groundwater samples from the overlying marine claystone (Table 5). Groundwater is classed as fresh water, with a median TDS of 26 mg/L. The lower concentration of dissolved minerals in the sandstone reflects the following factors:

- groundwater has a shorter residence time within the aquifer, which corresponds to the high aquifer permeability; and
- the Cretaceous sandstone consists almost entirely of quartz (silica) so the rock itself is very low in dissolved minerals.

The measured pH confirmed that groundwater is less than pH 5 and is considered acidic.

The two outstation bores identified from the bore census both intersect this unit. The water quality of the sandstone does not meet the drinking water quality standards for pH and several metals and metalloids. The Cretaceous sandstone also shows consistently elevated levels of zinc and copper above the freshwater aquatic guidelines. This is most likely a function of the naturally low pH levels measured in the Cretaceous sandstone unit, resulting in leaching of these metals.

7.4 Marine claystone and manganese ore

7.4.1 Distribution

The marine claystone is confined to the paleo-valleys that correspond to present day low lying areas and valleys. The marine claystone varies in thickness across the Eastern Leases, from less than 1 m at its margins to approximately 30 m. The marine claystone unit hosts the primary manganese orebody. The thickness of the manganese orebody varies considerably but it is generally less than 5 m.

The marine claystone (and the overlying lateritic clays) forms a confining layer across the underlying Cretaceous sandstone and associated groundwater. The potentiometric groundwater surface is therefore typically confined by this unit except in thin areas where they lap onto the basement quartzite.

This is consistent with anecdotal observations from a number of active mining areas in the main operations. Quarries within the existing GEMCO mine have experienced high rates of groundwater inflow where the marine claystone is absent, significantly thinned or connection has occurred via open exploration holes.

7.4.2 Hydraulic parameters

Measured vertical gradients confirm the presence of a confining layer above the Cretaceous sandstone. The hydraulic conductivity of the bulk marine claystone varies between 0.0046 m/day and 0.06 m/day. This unit therefore typically has a very low hydraulic conductivity, particularly where the clay sequence is thick. This material, along with the manganese and lateritic clay, forms a low permeability cap over the Cretaceous sandstone.

Localised sandy clays and disseminated manganese exhibit slightly higher hydraulic conductivity. However, these discrete zones are not considered to significantly influence the overall conductivity of this unit as the field data confirms a steep vertical gradient, low permeability and strong discretisation of the deep and shallow groundwater.

The existing GEMCO mine has encountered high rates of groundwater seepage to the existing mining areas where this unit is thin or not present, and therefore the manganese orebody directly overlies the Cretaceous sandstone.

Groundwater storage within the marine claystone is generally limited by the low porosity, cohesive nature of these materials.

The pisolitic and oolitic manganese has limited porosity and the surrounding matrix is dominated by low permeability clay materials. The massive manganese oxide has a very low permeability and consequently tends to form aquitards which have a limited ability to transmit groundwater flow.

7.4.3 Recharge, flow and discharge

The recharge / discharge mechanisms and flow directions in the marine claystone are equivalent to those of the Cretaceous sandstone. The marine claystone experiences very low recharge that occurs through the infiltration of runoff at the edge of the basement outcrops, and via seepage from both the overlying lateritic clays and underlying Cretaceous sandstone.

The potentiometric surface and flow directions reflect the natural topography with groundwater movement occurring in a westerly direction towards the coast. The low permeability of this hydrogeological unit and the thickness of overlying sediments result in a very slow response to recharge.

This unit discharges into the ocean. However because of its low permeability, the groundwater residence time will be significantly longer than that of the underlying Cretaceous sandstone aquifer.

7.4.4 Yield and use

No groundwater users are known within this unit.

Field investigations undertaken as part of the groundwater impact assessment confirmed that this hydrogeological unit is generally very low yielding, with a maximum flow rate of 0.25 L/s (at ELSMB05).

7.4.5 Groundwater quality

Groundwater within the marine claystone shows a consistent water quality across the project site.

Overall, groundwater exhibits low concentrations of dissolved minerals and is classed as slightly to moderately acidic, fresh water. Dissolved mineral concentrations are high relative to groundwater samples from the underlying Cretaceous sandstone (Table 5). The distinction in groundwater quality between these units illustrates the markedly higher residence times and lower permeability of the marine claystone relative to the underlying Cretaceous sandstone.

The water quality of the marine claystone does not meet the drinking water quality standards for aluminium and iron. The marine claystone also shows consistently elevated levels of zinc and copper above the freshwater aquatic guidelines. Elevated concentrations of dissolved manganese are particularly evident in groundwater associated with the manganese ore. This is most likely a function of the naturally low pH levels measured in this unit, resulting in leaching of these metals.

7.5 Lateritic clays

7.5.1 Distribution

The tropical environment and relatively high rainfall that characterised the Tertiary period has deeply weathered the sediments exposed at the surface resulting in a lateritic clay profile overlying the manganese and below the iron-cemented laterite. This unit is not always present between the manganese and laterite but where it is it acts as an aquitard. The lateritic clay is unsaturated at higher elevations and near the margins of the extent of the Cretaceous sediments.

7.5.2 Hydraulic parameters

The lateritic clays are typically dry and unsaturated in elevated areas and adjacent to areas where the Proterozoic basement outcrops at the surface. A water table forms where the basement elevation falls and the sediments thicken between these outcrops. Where drilling intersected saturated lateritic clays, testing has reported a low hydraulic conductivity of 0.007 m/day. As part of the groundwater impact assessment, field investigations confirm that the geological unit has a low permeability and acts as a confining layer (aquitard).

Figure 13 shows that permeability of the lateritic clay is lower than both the underlying marine claystone and the overlying laterite. This supports the view that this hydrogeological unit will act to confine the underlying groundwater and reinforces the observed vertical hydraulic gradient between shallow and deeper groundwater bearing units.

The hydraulic conductivity data collected for the lateritic clays are comparable to that collected for previous groundwater studies on Groote Eylandt.

7.5.3 Recharge, flow and discharge

Recharge is very low, occurring at the edge of the basement outcrop where runoff infiltrates and via seepage through the overlying laterite, and to a lesser extent the underlying marine claystone.

The potentiometric surface and flow directions reflect the surface topography with groundwater movement occurring in a westerly direction towards the coast. The low permeability of this unit and the thickness of overlying sediments result in a very slow response to recharge.

This hydrogeological unit slowly discharges into the underlying marine claystone. However because of its low permeability, the groundwater residence time is significantly longer than compared with the underlying Cretaceous sandstone aquifer.

7.5.4 Groundwater yield and use

The lateritic clay acts as an aquitard resulting in a very low yield. Where this hydrogeological unit is saturated, the yield is considered too low to produce a –sustained volume of water. There are no known water supply bores located within this unit.

7.5.5 Groundwater quality

Groundwater quality within this hydrogeological unit is generally consistent across the project site. Overall, the groundwater was found to exhibit low concentrations of dissolved minerals and can be classed as slightly to moderately acidic freshwater. TDS in a single sample from ELSMB08S was classed as slightly brackish (707 mg/L) (Appendix A3).

Dissolved mineral concentrations are high relative to groundwater samples from other units at the Eastern Leases. The higher salinity levels reflect the very low yield and longer groundwater residence time of this unit.

7.6 Laterite

7.6.1 Groundwater distribution

The laterite is a distinct iron-cemented horizon overlying the lateritic clay. This hydrogeological unit blankets the low lying land between basement outcrops. The laterite thins against these outcrops.

The laterite is considered to be dry and unsaturated adjacent to areas where the basement outcrops. A water table generally forms where the land surface falls away and the sediments thicken between the outcrops. The water table within the laterite is highly seasonal, fluctuating by up to 3.7 m over the wet and dry seasons.

7.6.2 Hydraulic parameters

Where drilling was found to intersect the saturated laterite, testing revealed a hydraulic conductivity ranging from 0.008 m/day to 12 m/day with a median of 0.19 m/day. The data reflects the highly heterogeneous nature of the unit. Cemented materials, which constitute the bulk of the laterite, exhibit low permeability while minor granular layers exhibit higher permeability. Bore ELSMB07S intersected coarse sand and lithic clasts with a low clay content and returned the highest permeability (12 m/day).

7.6.3 Groundwater recharge, flow and discharge

Recharge of the laterite unit occurs via diffuse rainfall seepage through the thin overlying Quaternary sediments. Recharge is enhanced where the laterite is present beneath ephemeral drainage lines and where it is exposed at the surface.

Groundwater flows reflect both the natural topography and catchment boundaries, with discharge occurring predominantly via seepage to the underlying lateritic clay, marine claystone and manganese horizons. There is also potential for some limited discharge to drainage channels. During the wet season, the water table may rise above the surface of channel beds forming shallow pools in surface depressions.

7.6.4 Groundwater yield and use

Groundwater yield is highly variable due to the heterogeneous nature of the lithology. Airlift flow rates during bore development range between zero flow in hydraulically tight cemented layers to 1.5 L/s in the unconsolidated sediment layers.

There are no known water supply bores located within this unit.

7.6.5 Groundwater quality

Groundwater within the marine claystone shows consistent water quality across the project site.

Overall, the quality of the groundwater exhibits low concentrations of dissolved minerals, consistent with groundwater samples obtained from the deeper Cretaceous sandstone (Table 5). Groundwater is classed as fresh and slightly acidic.

The water quality of this unit typically meets the ANZECC drinking water quality standards, although there are isolated exceedances of metals and metalloids. This unit also shows consistently elevated levels of zinc and copper above the freshwater aquatic guidelines. This is most likely a function of the naturally low pH levels measured in this hydrogeological unit, resulting in leaching of these metals.

7.7 Quaternary sediments

7.7.1 Groundwater distribution

Quaternary sediments consist of a thin surficial layer of sand covering the entire site except the basement outcrops. The layer is generally less than three meters thick and unsaturated. During the wet season a shallow water table may form at the base of the sands in low lying areas.

7.7.2 Groundwater recharge, flow and discharge

Recharge of the Quaternary sediments occurs via direct rainfall. This water gradually seeps to the underlying laterite at a rate controlled by the properties of the underlying material (as described in Section 7.6.2).

7.7.3 Groundwater yield and use

When the sand is saturated the yield will be less than 0.1 L/s.

7.7.4 Hydraulic parameters

Although the hydraulic parameters of the sand are considered to be highly variable, a typical range for the hydraulic conductivity is between 1 m/day and 10 m/day.

7.7.5 Groundwater quality

Due to the very short residence time for water in this layer the water quality will be comparable to rainfall (i.e. fresh and slightly acidic).

8 Impact assessment

8.1 Introduction

The following proposed activities have the potential to impact the local groundwater regime:

- the excavation of overburden materials and the underlying manganese orebody resulting in direct impacts on the groundwater in surrounding water-bearing strata; and
- the limited use of hydrocarbons and minor quantities of chemicals which have the potential to cause groundwater contamination. The use and application of hydrocarbons and chemicals as part of the mining process, specifically dewatering and blasting activities, and management controls proposed are discussed in Section 8.9.3.

This section provides a detailed assessment of these potential impacts and is structured as follows:

- Section 8.2 provides an overview of the proposed mining activities and includes a general explanation of the way in which open cut mining can impact groundwater.
- The impact of the proposed mining activities has been assessed through development of a groundwater model. Section 8.3 provides an overview of the groundwater model that has been developed. Appendix B provides a detailed technical description of the model development, construction and calibration.
- Section 8.4 and 8.5 provide the predictions of the groundwater modelling and includes an assessment of groundwater inflow to the quarries; groundwater level impacts on individual water-bearing strata due to mining; impacts on outstation bores; cumulative impacts, and post closure recovery of groundwater within the backfilled quarries.
- Section 8.6 describes potential impacts to groundwater users.
- Section 8.7 describes potential impacts to surface waters.
- Section 8.8 describes the cumulative impacts from the project and the existing GEMCO mine.
- Section 8.9 describes the potential for groundwater contamination.

8.2 Overview of mining

8.2.1 Proposed mine plan

The project involves developing a number of open cut mining areas (termed “quarries”) within the Eastern Leases and mining manganese ore by the same mining methods that are in use at the existing GEMCO mine.

Quarry development will involve the removal of overburden associated with the manganese ore. All overburden will be emplaced in mined out quarry areas, or may be temporarily stored in designated out-of-pit emplacement areas until quarry areas become available for backfilling and rehabilitation.

The mine schedule and groundwater assessment refer to Project Years, rather than calendar years, with Project Year 1 being the first year of construction.

The development of detailed mine plans and schedules was undertaken by the proponent using the software package Blasor Stratiform. Development of the mine plans has been undertaken with consideration of the requirements of closure, ensuring that an acceptable post-mining landform is achieved. Outputs from the Blasor Stratiform mine planning and scheduling model have also been integrated with the development of the groundwater model in order to understand the impacts of the project on groundwater resources during the operational and post-mining phases.

Mining in the Eastern Leases would take place concurrently with the operation of the existing GEMCO mine. According to current planning, construction in the Northern EL would commence in 2017 (Project Year 1) and mining activities would commence in the second half of 2018 (Project Year 2). Construction in the Southern EL is scheduled to commence approximately 4 years later in 2022 (Project Year 6) and mining would then take place in both of the tenements until approximately 2031 (Project Year 15). This equates to a total of 13 years of mining operations (i.e. mining of ore).

8.2.2 Open cut mining impacts

Based upon the proposed mine plan and the assessment of the existing groundwater setting, the potential groundwater impacts associated with the project are as follows:

- Groundwater inflow to the quarries from the laterite aquifer, and the impact of these flows on groundwater levels in the wider laterite aquifer;
- Groundwater inflow to the quarries from the Cretaceous sandstone, and the impacts of depressurisation on the wider Cretaceous sandstone aquifer and groundwater users of this aquifer;
- Changes in groundwater levels as a result of groundwater inflow to quarries, impacting groundwater baseflow to the surface waters;
- Cumulative impacts with the existing GEMCO mine; and
- Post mining impacts on groundwater regime.

Detailed assessment of these potential project groundwater impacts are specifically discussed in the following sections.

8.3 Overview of groundwater modelling

A 3D numerical groundwater flow model was developed for the project using MODFLOW-SURFACT. A detailed description of the modelling logic is provided in Appendix B.

The model represented the key geological units in an eight layer model extending of 32 km north-south and 28 km east-west, and comprised 86,294 active model cells.

Development of the model was based on the high resolution geological surfaces developed by the proponent. The geological model was further enhanced by inclusion of published lithological logs within the model extents. The model extents include the existing GEMCO mine and future mining areas. This approach provides a robust baseline against which the project impacts have been assessed.

The model was built around the conceptual groundwater model summarised in Section 7 and detailed in Appendix B.

The selection of appropriate boundary conditions, locations and alignments was based upon a detailed review of all available geological and hydrogeological information, as well as topography and the project setting relative to groundwater users and the existing GEMCO mine. Where this information indicated a clear, logical choice of boundary condition this was selected (i.e. the ocean accepting unlimited groundwater flow from the east is logically represented as a constant head boundary). Where the model boundary condition could be interpreted in a number of ways, the alternatives have been considered and those conditions which represent the most conservative modelling approach in terms of mining impacts were selected. Therefore, by adopting those values which provide the most conservative mining impacts, any potential uncertainty has been accommodated.

The model was calibrated to pre-mine groundwater levels using measurements from the project site and from surrounding bores to achieve the best fit in accordance with modelling guidelines (Barnett et al, 2012). The calibration achieved a Scaled RMS error of less than 10% which is well within the acceptable limits as recommended by in the modelling guidelines. The model calibration is therefore considered robust and suitable for addressing the potential groundwater impacts of the project.

Once calibrated, the model was used to predict the groundwater level behaviour in response to simulated mining of the proposed quarries. The model simulated mining to the base of the manganese orebody defined as Layer 5 in the groundwater model.

The model simulated the mining progress over the proposed project life. The model predicted changes in groundwater levels, flows and fluxes within the model extent. A sensitivity analysis was then used to determine the sensitivity of the model calibration to variations in model parameters. The analysis included varying model parameters and design features that could most influence the model predictions. The model parameters were adjusted to encompass the range of likely uncertainty in key parameters. Sensitivity analysis included testing the effects of changes in horizontal hydraulic conductivity, vertical hydraulic conductivity, specific yield and specific storage and the rainfall recharge rate across the model domain. These changes capture extremes in the potential behaviour of the groundwater regime.

Overall, the sensitivity analysis confirmed that the measured sensitivity of the model calibration and predictions to changes in model parameters is in all instances acceptable

The following sections describe the predictions of the groundwater model. Appendix B provides a detailed description of the model development, calibration and predictions.

8.4 Groundwater inflow predictions

Open cut mining will intersect water-bearing strata and result in the inflow of groundwater to the active quarry voids. The rate of groundwater inflow is dictated by the hydraulic properties of these materials. Groundwater inflows will depressurise the surrounding units and subsequently influence groundwater levels.

Groundwater inflow to the mining operations will predominantly occur from the shallow laterite aquifer. The quarries will also intersect the manganese orebody, Quaternary sediments and lateritic clay units, although the contributions of these units to groundwater inflows are relatively small.

Figure 15 shows the total predicted rate of groundwater inflow into the proposed quarries, and the relative groundwater inflows experienced at the Northern and Southern ELs.

The inflow rates are predicted to fluctuate throughout the mine life. As shown on Figure 15, these fluctuations show a high degree of periodicity which reflects the dominant influence of inflows from the laterite aquifer to the overall inflow volume. This is mainly due to the rapid response of laterite to recharge from wet season rainfall. Active quarry depth and extents, hydraulic permeability of strata and hydraulic gradients also contribute to the underlying increase in groundwater inflow rate over the life of the mine.

Numerical modelling shows that groundwater inflows rates are generally low in initial years of mining (Project Years 2 to 5). At this stage, mining occurs at shallow depth and is typically above the groundwater table in the laterite. As mining progresses below the groundwater surface, groundwater inflow rates gradually increase to a peak of 212 ML/a (approximately 0.9 ML/day) during Project Year 14.

Cumulative total groundwater inflow at the end of mining (Project Year 15) is predicted to be 854 ML.

The actual volume of water pumped from the mining area will be less than the volume predicted by the model because a component of this water will evaporate from within mine workings, or be held as moisture within the excavated overburden and ore. The volumes of water predicted to be removed from the water-bearing strata annually over the mine life is presented in Appendix B.

Groundwater inflows to the quarries will be managed as part of the proposed mine water management system discussed in the EIS Surface Water Section.

8.5 Groundwater level predictions

Open cut mining will reduce water pressures in the surrounding geology. The extent of the zone of depressurisation is dictated by the hydraulic properties of these materials. This zone is referred to as the zone of depressurisation, and is greatest at the quarry highwall and gradually reduces with distance away from the active quarries.

The mining sequence (i.e. the mine plan) will also dictate the extent of groundwater depressurisation at each stage of the mine development. The project involves the staggered development of numerous quarries.

The mine schedule will result in some quarries being completed (i.e. mined and backfilled) while other quarries are still active or have not yet been developed. Groundwater recovery will therefore occur in the completed quarries (e.g. those quarries in the Northern EL developed early in the mine life) while mining activities are ongoing in other areas (i.e. those quarries in the Southern EL developed late in the mine life). This sequencing has been captured in the modelling. The maximum depressurisation extents are discussed below, and represent a conservative representation of the aggregated depressurisation extents over the 13 operational years of the project. The end of mining (i.e. Project Year 15) depressurisation extents are also presented, and clearly illustrate the rapid recovery of quarries completed early in the project life.

The radius of depressurisation is conservatively defined by a 1 m decrease in water table elevation for unconfined aquifers, or a 1 m decrease in the potentiometric groundwater surface for confined aquifers. A 1 m threshold is conservatively adopted in defining the radius of depressurisation as it represents the effective limit of accuracy for modelling and field measurement of groundwater levels. It falls within the range of natural groundwater fluctuation between wet and dry seasons.

The modelled development and extents of depressurisation are described in Appendix B, along with modelling results for all water-bearing units.

The numerical model was used to simulate the recovery of groundwater levels post mining. This simulation removed all drain cells used to represent mining of the manganese orebody, thus allowing the groundwater levels in the in-pit overburden emplacements and the surrounding strata to recover. Mine areas are proposed to be backfilled and rehabilitated to form a free-draining landform comparable to the existing topography. The post closure final landform has been designed so that it does not include any residual final voids, and therefore the project will not generate a final void pit lake.

8.5.1 Predicted groundwater drawdown and recovery in the laterite

Localised depressurisation is predicted in the laterite around the proposed quarries. The maximum predicted extent of depressurisation is less than 1 km from the proposed quarries and is largely contained within the boundary of the project site. The maximum decrease in water table elevation in the laterite aquifer is predicted to be less than 14 m in the north of the Southern EL (Figure 16). The maximum life of mine decrease in groundwater elevation occurs in the area where the quarry depth is greatest.

By the end of mining (i.e. Project Year 15), the groundwater elevation will have recovered from the maximum decreases due to the high rate of recharge to the laterite (Figure 17). This recovery is particularly evident in the Northern EL where quarries were developed early in the life of the project.

The post mining model was run until groundwater conditions reached equilibrium. Post mining groundwater levels in the laterite aquifer are predicted to recover rapidly following completion of mining. 35% of the drawdown is predicted to recover within 1 year of mining and 80% is predicted to recover within 5 years of mining. Almost total recovery of groundwater levels (i.e. to pre-mining levels) is expected to be achieved within 20 years of mine closure (figure 18). Full groundwater recovery (i.e. 100%) will ultimately be achieved as shown on Figure 18. This rapid groundwater recovery is due to the high rate of recharge to the laterite aquifer.

During the recovery period, the project will behave as a groundwater sink until levels fully recover. Once stabilised, groundwater levels will fluctuate around the pre-mining levels in response to rainfall recharge.

8.5.2 Predicted groundwater depressurisation and recovery in the Cretaceous sandstone

No significant depressurisation of the sandstone aquifer is predicted for the following reasons:

- The thick marine clay unit is an aquitard that overlies the sandstone unit;
- The proposed quarry floor elevations are generally above the potentiometric groundwater surface of the sandstone aquifer, meaning that there will be no upward groundwater gradient towards the pits over the majority of the project site; and
- The sandstone unit has a very high recharge rate and storage capacity which effectively buffers any minor project-related losses from the aquifer.

8.6 Project impacts on surrounding groundwater users

Two outstation bores have been identified from the bore census, and both intersect the Cretaceous sandstone aquifer (Figure 14). No users of groundwater from the laterite aquifer have been identified.

Modelling indicates that the project will not result in significant depressurisation of the Cretaceous sandstone aquifer. Groundwater levels and yield at these bores are therefore not predicted to be impacted by the project.

8.7 Project impacts on surface water

The project catchment and drainage setting is described in Section 3.2. The majority of the watercourses within the project site are ephemeral, with perennial flows limited to the western part of the Emerald River – Tributary 2, the southern part of the Amagula River – Tributary 1 and the Amagula River – Main Channel (Figure 4).

Figure 21 shows those areas where drawdown in the laterite is predicted to impact groundwater interaction with watercourses. The figure indicates that drawdown does not extend to the perennial reaches of the major rivers. Drawdown in the laterite is predicted to extend to ephemeral reaches of Emerald and Amagula rivers which will result in small changes in baseflow. Table 7 presents the maximum predicted changes in baseflow to the Emerald and Amagula rivers during the life of the project and at post mining equilibrium.

Table 7 Total change to baseflow

River	Baseflow change during mining		Baseflow change post mining	
	(ML)	(%)	(ML/a)	(%)
Emerald River	-39.4	-0.16	+6.6	+0.3
Amagula River	+3.2	+0.004	+39.7	+0.7

During mining, the model predicts a 3.2 ML/a change in baseflow to Amagula River. This represents a predicted 0.004% change in baseflow. These changes would therefore be negligible in terms of total surface water flows in the river, and would be imperceptible in downstream locations including any recreational areas. The downstream reaches of the Emerald River are predicted to experience a temporary reduction in baseflow during mining. This change in baseflow is induced by minor depressurisation in the vicinity of the upper reaches of the Emerald River at the Eastern Leases. Baseflow is predicted to decrease by up to 39.4 ML over the 13 years of mining. Measured baseflow at historical gauging station G9290211 located on the downstream reaches of the Emerald River are in the order of 1,900 ML/a. The predicted reduction in baseflow therefore represents 0.16% of measured baseflow. These changes would be negligible in terms of total surface water flows in the river, and would be imperceptible in downstream locations.

Post mining the pits will be backfilled and no open voids will remain. This will prevent any permanent ongoing evaporative loss of groundwater, and therefore no significant impact to baseflow post mining will occur. Table 7 presents the change in baseflow to the Emerald and Amagula rivers predicted by the model post mining. These baseflow predictions represent less than 1% change in baseflow to each river. These changes would therefore be negligible in terms of total surface water flows in the river, and would be imperceptible in downstream locations including any recreational areas.

8.8 Cumulative groundwater impacts

Appendix B provides a detailed description of the modelling approach adopted for the assessment of cumulative mining impacts. The model extents adopted for the prediction of groundwater impacts included included proposed mining in the Eastern leases and also represented the approved mining in the GEMCO mine. Mining north of the Angurugu River was not represented in the model as it was sufficiently distant from the Eastern Leases that no cumulative impacts would occur. The GEMCO mine and project activities were modelled to determine the relative groundwater impacts of each.

This cumulative assessment addresses those water bearing strata that the project is predicted to depressurise or affect groundwater level (i.e. laterite aquifer). As the project is not predicted to significantly depressurise the Cretaceous sandstone aquifer, there will be no cumulative impacts upon this unit or outstation bores screened within this unit.

Figure 22 shows the maximum predicted extents of depressurisation associated with both the GEMCO mine and the project for the laterite aquifer. Where the extents of depressurisation associated with the GEMCO mine and the project intersect there is potential for cumulative mining impacts on groundwater levels. In areas where the extents of depressurisation do not intersect each other, no cumulative impacts on groundwater levels are predicted.

There are no areas where the zones of depressurisation associated with the GEMO mine and the project intersect, and therefore no cumulative impacts on groundwater levels are predicted.

The Eastern Leases span the Emerald River, Amagula River and Angurugu River catchments and are predominantly drained by the Emerald and Amagula Rivers. As discussed in Section 8.7, the project is not predicted to give rise to significant impacts to surface water baseflow in any of these rivers in isolation. The project is therefore not predicted to contribute to any associated cumulative impacts on surface waters.

8.9 Impacts on groundwater quality

This section describes the potential sources of groundwater contamination associated with the project and the pathways by which groundwater contamination could occur, and provides an assessment of the potential contamination of the local groundwater regime.

8.9.1 Temporary out of pit overburden emplacement areas

Quarries are proposed to be backfilled ensuring that there are no out of pit overburden emplacements at the end of the mine life. However, it will be necessary to construct a number of temporary out of pit overburden emplacements during periods when mine scheduling does not allow for quarries to be immediately backfilled.

The temporary out of pit overburden emplacements will be constructed of overburden material that will exhibit variable permeability on a small scale. However, the bulk overburden material will exhibit broadly comparable permeability properties to that of in-situ sediments. This material will be trafficked by site machinery (i.e. truck/excavator emplacement) resulting in compaction of exposed surfaces as they build up with time. These compacted surfaces will ultimately form low permeability layers, including a low permeability crust on the upper and outer surfaces. In addition, the landform will be shaped and contoured to shed rainfall runoff. The compacted layers will therefore reduce the infiltration capacity of the overburden materials, and rainfall will tend to runoff from the emplacement surface rather than infiltrating. Rainfall which does infiltrate the overburden emplacement is likely to form minor perched phreatic surfaces on the compacted layers within the bulk material, with the water migrating laterally to discharge around the sides of the emplacement. Any water captured by perimeter collection drains shall be managed in accordance with the project drainage strategy which is discussed in the EIS Surface Water section. Based on the above, the overburden emplacements will have a limited capacity to contain (store) water with an elevated phreatic surface as a result of rainfall infiltration.

As discussed above, significant seepage to underlying strata or soil profiles is not expected to occur. However, in the unlikely event that seepage was to occur, it is important to refer to the geochemical characterisation studies of the overburden material. The EIS Geochemistry Report indicates that the surface runoff and seepage from overburden materials is likely to be pH neutral and show low levels of salinity following surface exposure. The concentration of soluble metals and salts in runoff and seepage from these materials is unlikely to present any environmental risk for on-site or downstream water quality. Therefore it is concluded that in the unlikely event that seepage does occur from the overburden emplacements to the subsurface, it would not cause any significant or adverse impact on underlying groundwater quality. Any seepage generated in the overburden emplacements is therefore unlikely to be considered a source of contamination.

As described in Section 9, groundwater monitoring will be undertaken to confirm the groundwater quality throughout the proposed mine life. The proposed groundwater monitoring network has been established to detect any unanticipated seepage and/or water quality issues.

8.9.2 In pit overburden emplacement areas

In pit overburden emplacements are expected to exhibit comparable hydraulic characteristics to the out of pit emplacements. Post mining groundwater modelling shows that groundwater levels within the overburden emplacements will stabilise, consistent with approximate pre mining levels.

Therefore, backfilled quarries will not form a permanent sink post mining. Instead, water leaching through the backfilled quarries will flow as per the surrounding groundwater regime.

As discussed above, the EIS Geochemistry Report indicates that seepage from overburden materials within the backfilled quarries is unlikely to cause any significant or adverse impact on surrounding groundwater quality. Any seepage generated in the overburden emplacements is therefore unlikely to be considered a source of contamination.

8.9.3 Hydrocarbons

The project is an additional mining area that will be operated as part of the existing mine, rather than an independent mine. There will consequently be very limited infrastructure on the project site and storage of diesel and chemicals will be limited to small scale, portable containers.

The refuelling of pit dewatering pumps, lighting plants and other ancillary generators and the basic servicing of vehicles and equipment in the project site will occur in areas with adequate bunding. These areas will also be equipped with spill kits to manage any minor hydrocarbon spillage and prevent contamination. These controls represent standard practice and a legislated requirement at mine sites for preventing the contamination of the groundwater regime.

9 Groundwater monitoring plan

The groundwater monitoring program established as part of EIS groundwater investigations will be continued throughout the life of the project. Any monitoring bores that are removed by mining during the life of the project will be replaced.

9.1 Water level monitoring

The recording of groundwater levels from existing monitoring bores (as shown on Figure 9) will continue from pre to post-mining to enable natural water level fluctuations (such as responses to rainfall and river/creek flows) to be distinguished from potential water level impacts due to mining induced groundwater depressurisation.

Groundwater monitoring bores are equipped with electronic loggers to record water levels at regular intervals to assist with the collection of background groundwater level data. In addition to the maintenance of groundwater level loggers, groundwater levels will be manually measured at quarterly intervals for validation purposes.

The frequency of this water level monitoring program will be reviewed periodically throughout the project life.

9.2 Water quality monitoring

Groundwater quality sampling of existing monitoring bores will continue for the following reasons:

- to build on the established understanding of the baseline groundwater quality; and
- to assess the potential for groundwater quality impacts during and post-mining.

The quarterly water quality monitoring program will include the testing and analysis of the following parameters:

- pH, electrical conductivity, TDS, salinity, temperature and dissolved oxygen
- Total hardness and alkalinity;
- Major anions (CO_3, HCO_3, Cl, SO_4);
- Major cations (Ca, Mg, Na, K); and
- Dissolved and total metals (Al, As, B , Ba, Be, Cd, Cr, Co, Cu, Fe, Hg, Mn, Ni, Pb, Se, U, V, Zn).

In addition to the quarterly monitoring program, samples will be analysed for the following parameters on an annual basis:

- Nutrients (ammonium, nitrite, nitrate, total phosphorus); and
- Total petroleum hydrocarbons and total recoverable hydrocarbons.

Periodic review of the data will be undertaken to establish which water quality parameters should continue to be monitored and the frequency of this monitoring.

The collection, storage and transport of water quality samples for laboratory analysis will be undertaken in accordance with existing GEMCO procedures and in accordance with relevant guidelines and Australian Standards. Data will be reported at appropriate intervals in accordance with operating requirements.

10 Conclusions

The results of the modelling and overall findings of the groundwater assessment are summarised as follows:

- Shallow laterite and deeper Cretaceous sandstone units represent the main water bearing strata in the project site and surrounding area. These strata exhibit distinct groundwater regimes for the purposes of groundwater assessment. Each is underlain by lower permeability strata that are considered to behave as aquitards.
- Modelling indicates that the project will have limited interaction with the Cretaceous sandstone aquifer, and is not likely to result in significant impacts to the two outstation bores within this unit.
- Modelling results confirm that the laterite will be locally depressurised by mining activities although the extents of any associated drawdown are essentially localised to the Eastern Leases.
- Modelling indicates that surface water baseflow will not be significantly impacted by the project.
- Modelling indicates that groundwater inflows to the proposed quarries will be low but increase progressively over the life of the project.
- Groundwater levels in the vicinity of the quarries will recover and stabilise within a short-term post mining timeframe. No significant long term groundwater impacts are predicted.
- There is negligible change in groundwater baseflow to the Emerald River and Amagula River, and these changes will be imperceptible in downstream areas and at any associated recreational areas.
- Modelling indicates that there is a very low potential for cumulative groundwater impacts with the GEMCO mine.
- There is a low potential for groundwater contamination from the project.

11 References

Aquaterra Consulting Pty Ltd (2001) *"GEMCO mine area groundwater model"*, prepared for BHP Billiton - GEMCO, Project No. 024, Document No. R003-A, September 2001.

ANZECC (2000) *"Australia and New Zealand Guidelines for Fresh and Marine Water Quality",* National Water Quality Management Strategy, Chapt. 4 Primary Industries.

Barnett *et al*, (2012) *"Australian Groundwater Modelling Guidelines"*, Waterlines report, National Water Commission, Canberra.

Bureau of Meteorology. Climate Data Online. http://www.bom.gov.au/climate/data/ [Accessed 2014]

Bouwer, H., and Rice, R.C., (1976) *A slug test method for determining hydraulic conductivity of unconfined aquifers with completely or partially penetrating wells*, Water Resources Research, vol. 12, no. 3, pp. 423-428.

Butler, J.J., Jr., (1998) *The design, performance, and analysis of slug tests*, Lewis Publishers, New York, 252p.

Coffey (2008) "*Groote Eylandt F3 pit groundwater excess management system, preliminary design summary - draft"*, prepared for BHP Billiton - GEMCO, version: GEOTPARA08030AA-AB, 8th August 2008.

Coffey (2012A) "*Water management project"*, prepared for BHP Billiton - GEMCO, version: NSYSPARA09017AD-RO1b, 10th May 2012.

Coffey (2012B) "*A South Quarry hydrology study, Angurugu, Groote Eylandt"*, prepared for BHP Billiton - GEMCO, version: ENVIABTF08649AK-R01b, 11th December 2012.

Doherty, J. (2010) "*PEST: Model-Independent Parameter Estimation, User Manual":* 5th Edition, Watermark Numerical Computing.

Food and Agricultural Organisation (FAO) of the United Nations (2013) Saline Waters as Resources.

Hantush, M.S., and Jacob, C.E., (1955). *Non-steady radial flow in an infinite leaky aquifer*, Am. Geophys. Union Trans., vol. 36, no. 1, pp. 95-100.

Hill and Tiedeman (2007) *"Effective Groundwater Model Calibration, with Analysis of Data, Sensitivities, Predictions, and Uncertainty"* By Mary C. Hill and Claire R. Tiedeman Published by John Wiley and Sons, New York, in 2007.

Hvorslev, M.J., (1951), *Time lag and soil permeability in ground-water observations*, Bull. No. 36, Waterways Exper. Sta. Corps of Engrs, U.S. Army, Vicksburg, Mississippi, pp. 1-50.

Middlemis et al (2000), "*Murray Darling Basin Commission Groundwater Modelling Guidelines*". November 2000, Project No. 125, Final guideline issue January 2001.

Department of Land Resource Management. Water Data Portal. http://www.lrm.nt.gov.au/water/water-data-portal [Accessed 2014].

National Uniform Drillers Licensing Committee (2012) Minimum Construction Requirements for Water Bores in Australia – Third Edition.

NHMRC, NRMMC (2011) Australian Drinking Water Guidelines Paper 6 National Water Quality Management Strategy. National Health and Medical Research Council, National Resource Management Ministerial Council, Commonwealth of Australia, Canberra.

Northern Territory Land Information Systems (2014) "*Bore Report RN027979, Final statement of bore*", viewed 11/07/2014, http://www.ntlis.nt.gov.au/hpa-services/borereport?bore=RN027979

Northern Territory of Australia, "*Water Act*", as in force at 28 August 2013.

Northern Territory of Australia, "*Water Regulations*", as in force at 26 November 2008.

Northern Territory of Australia, "*Mining Management Act*", as in force at 1 October 2013.

Schlumberger Water Services (2011), "*Aquifer Test 2011.1*".

Watermark Numerical Computing (2012) MODFLOW-SUFACT.

Figure 1 Location plan

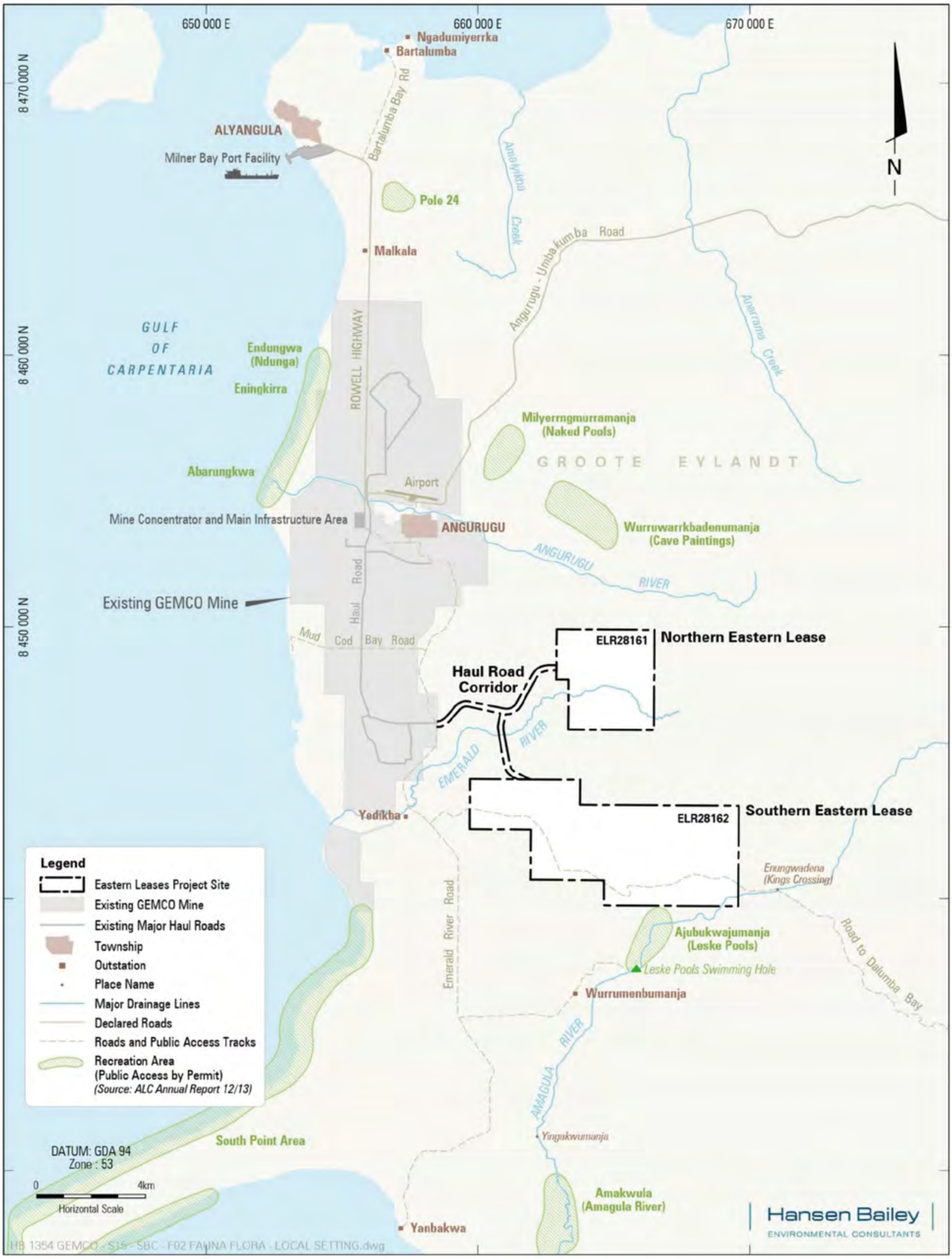


Figure 2 Local setting

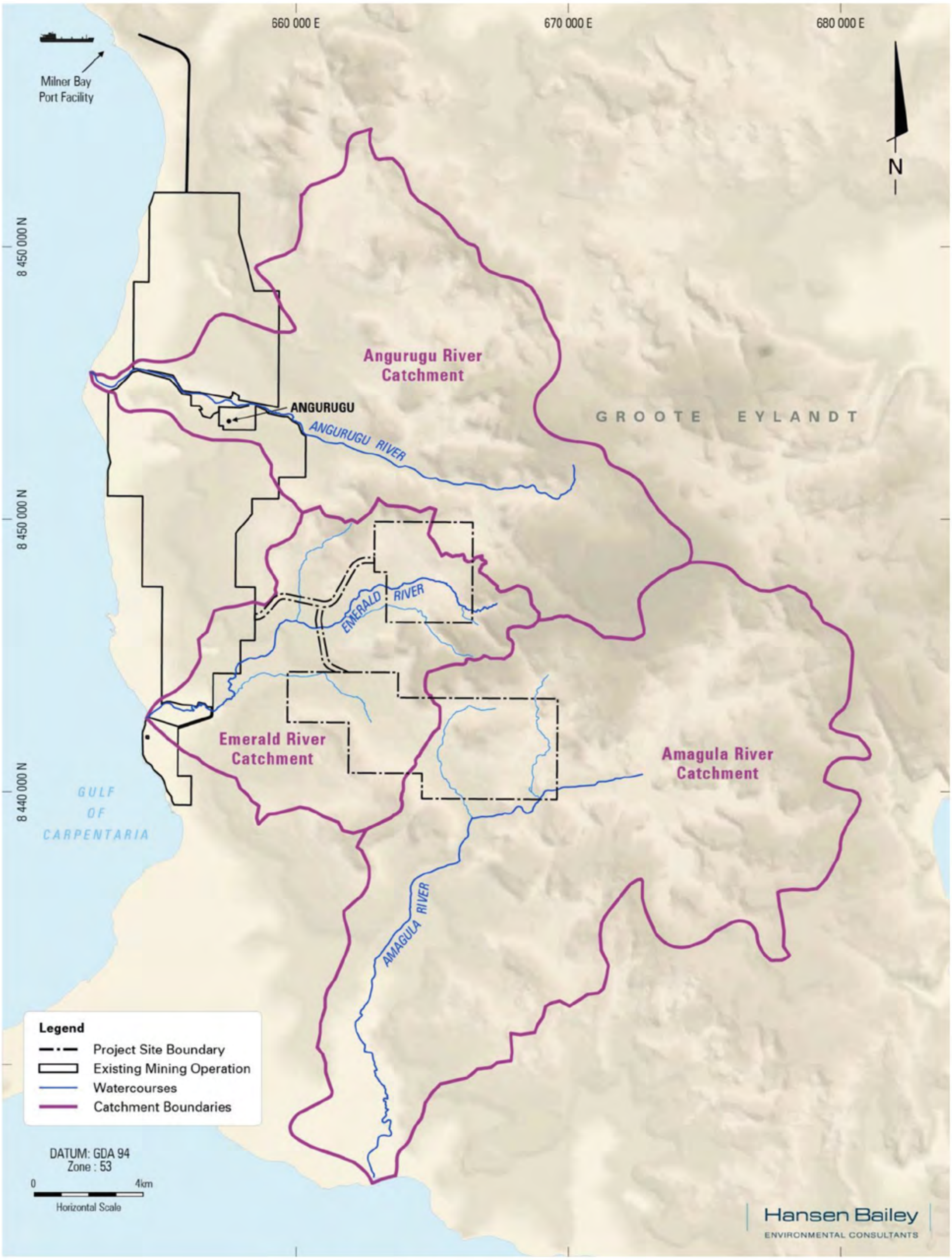


Figure 3 Topography and drainage

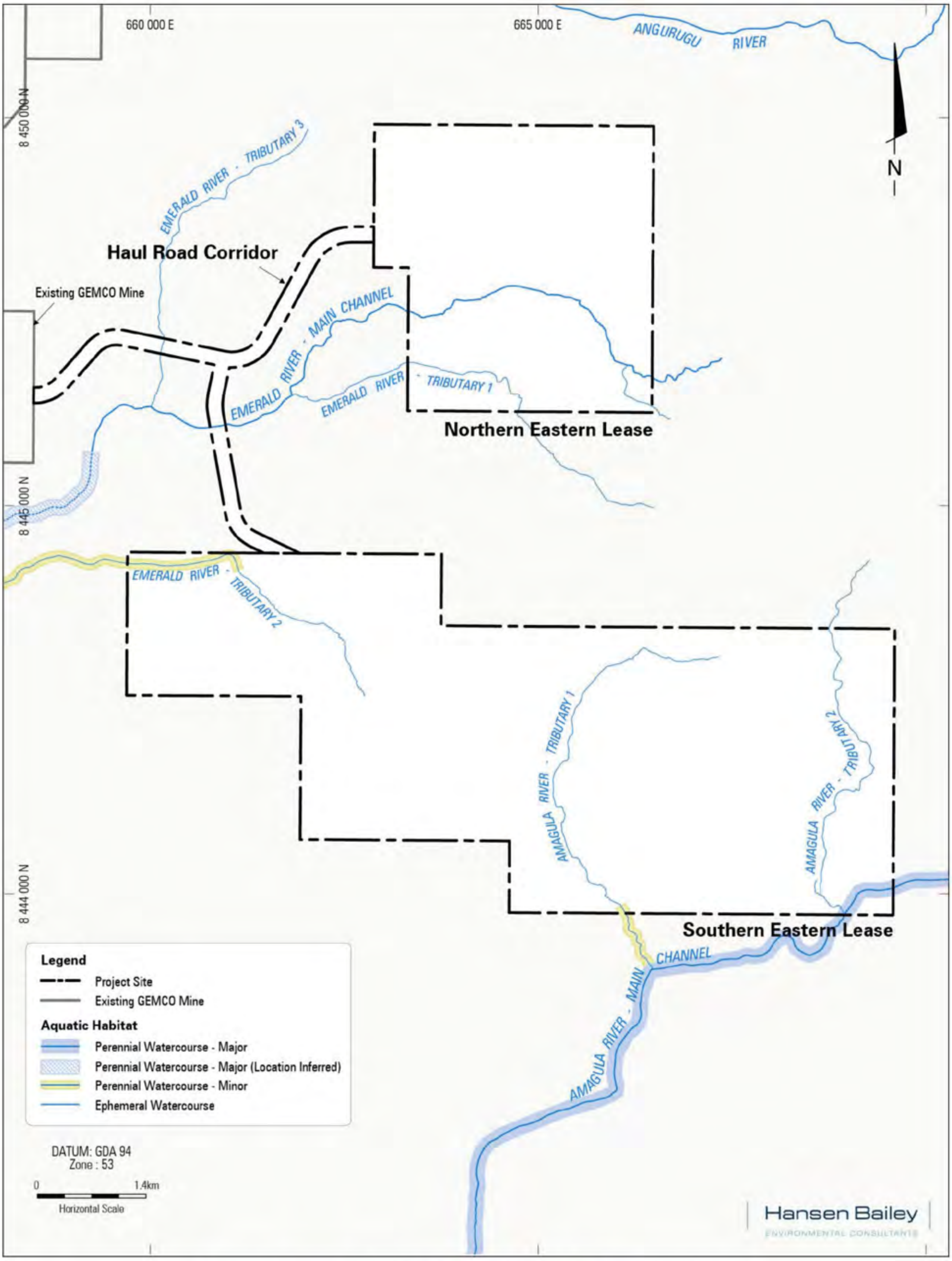


Figure 4 Extents of the perennial watercourses

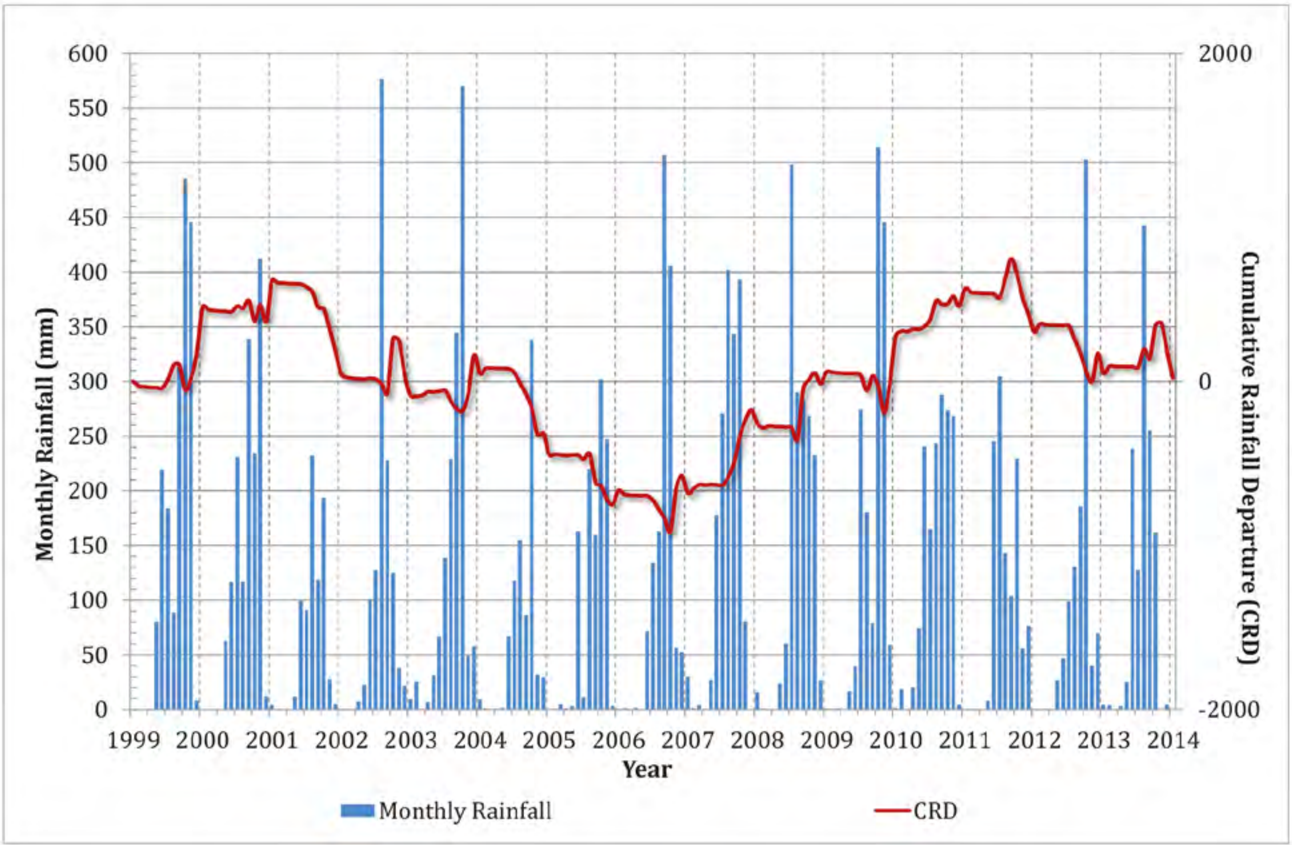
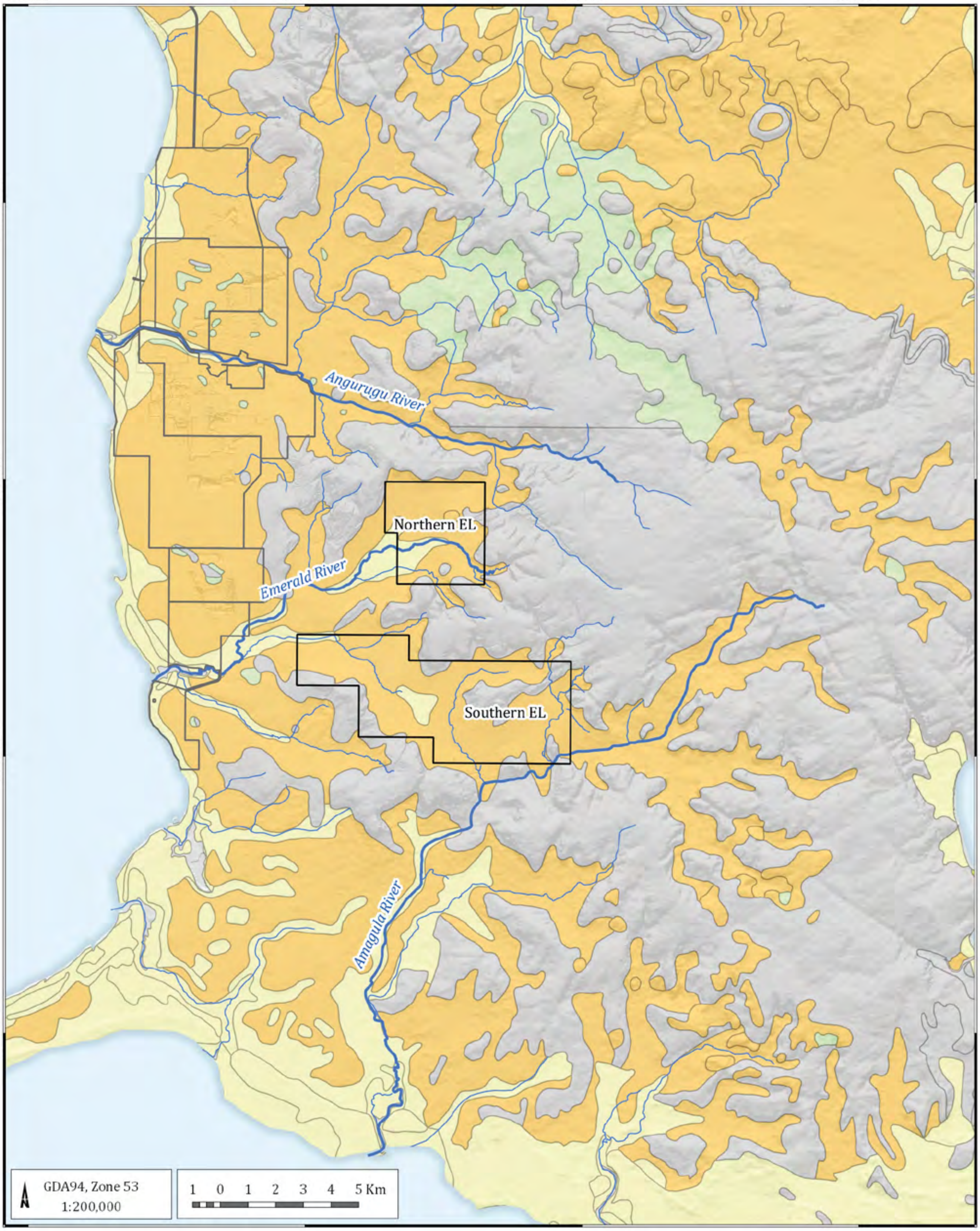


Figure 5 Cumulative rainfall departure graph



LEGEND

- Eastern leases
- Mine lease
- Major drainage
- Minor drainage
- Ocean

Surface geology

- Quaternary sediments
- Tertiary laterite / Lateritic clay
- Cretaceous sediments
- Proterozoic basement

GEMCO (G1663)

Surface geology

DATE 3/3/2015

FIGURE No: 6

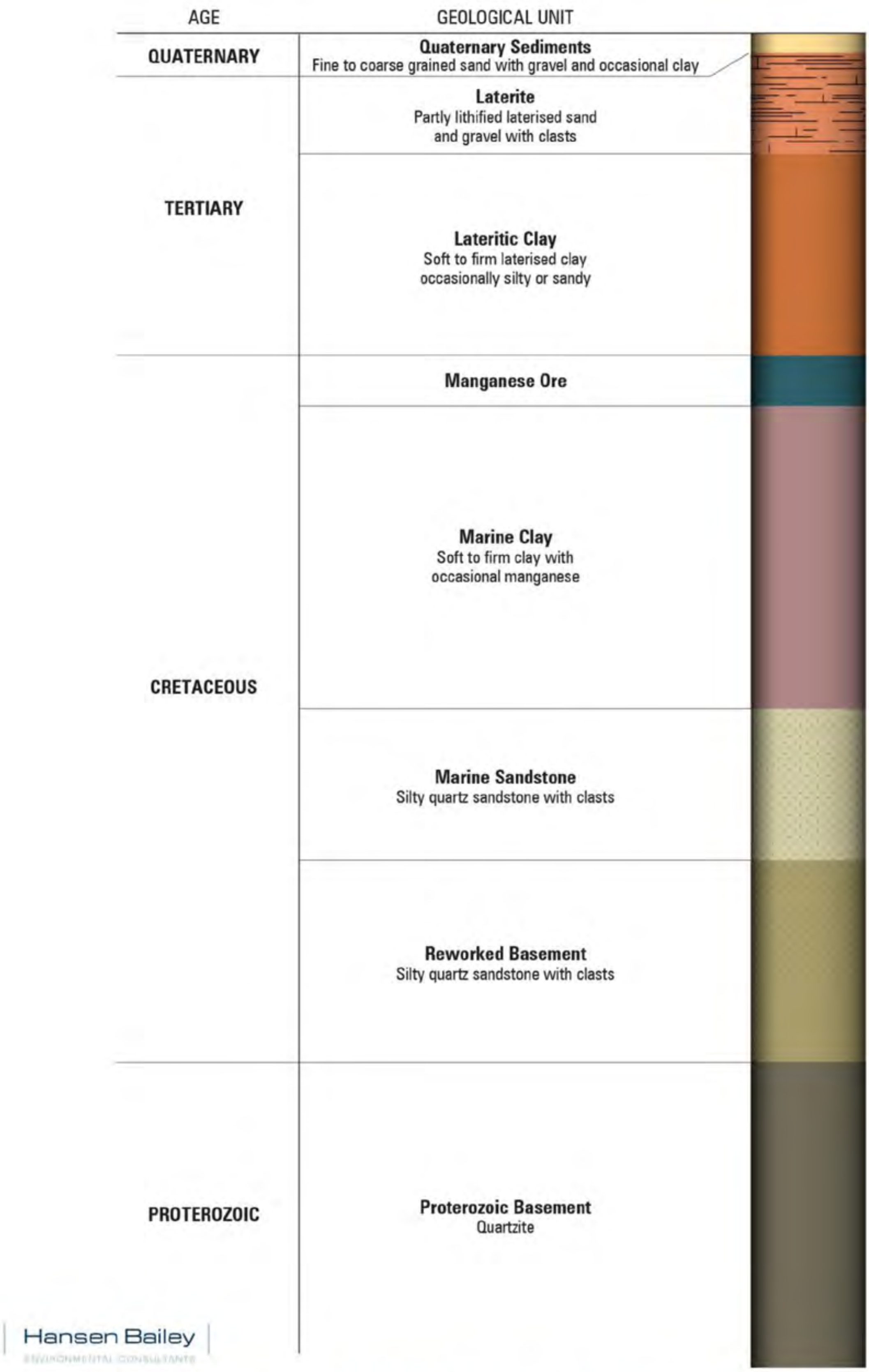


Figure 7 Stratigraphic profile (source Hansen Bailey)

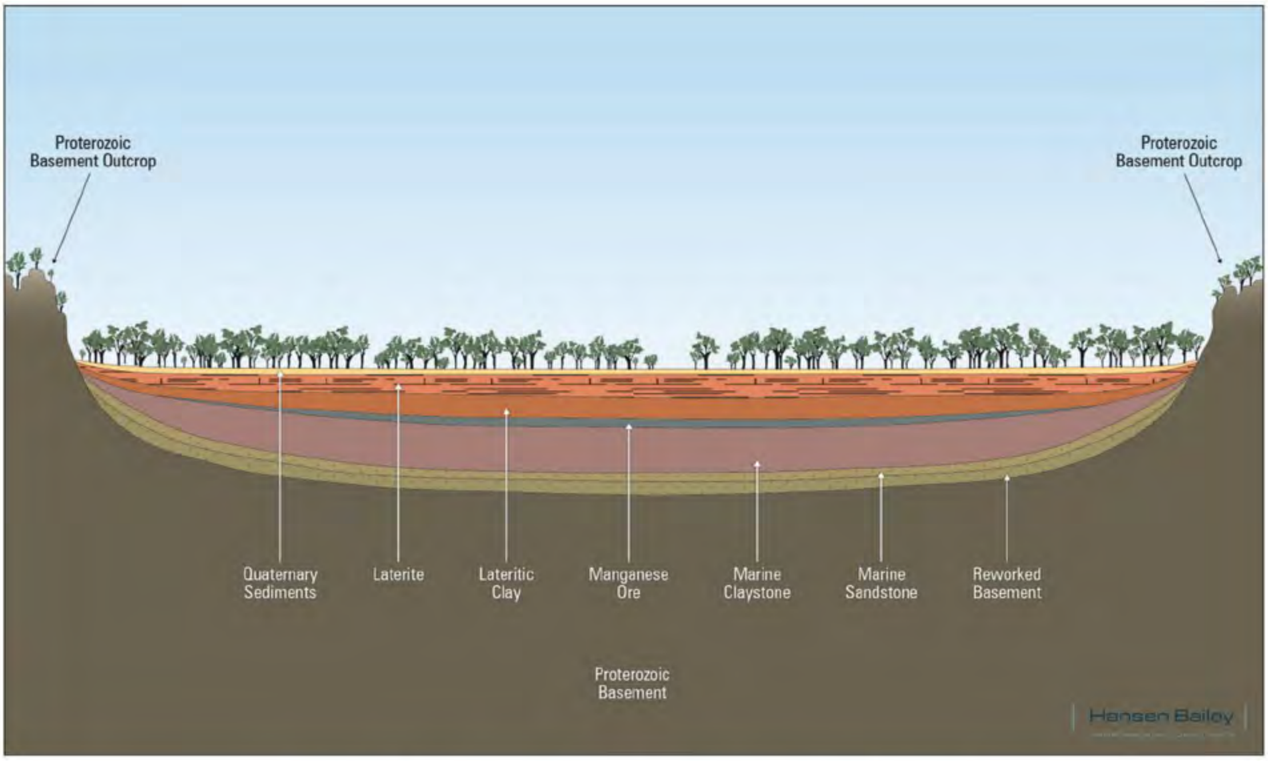
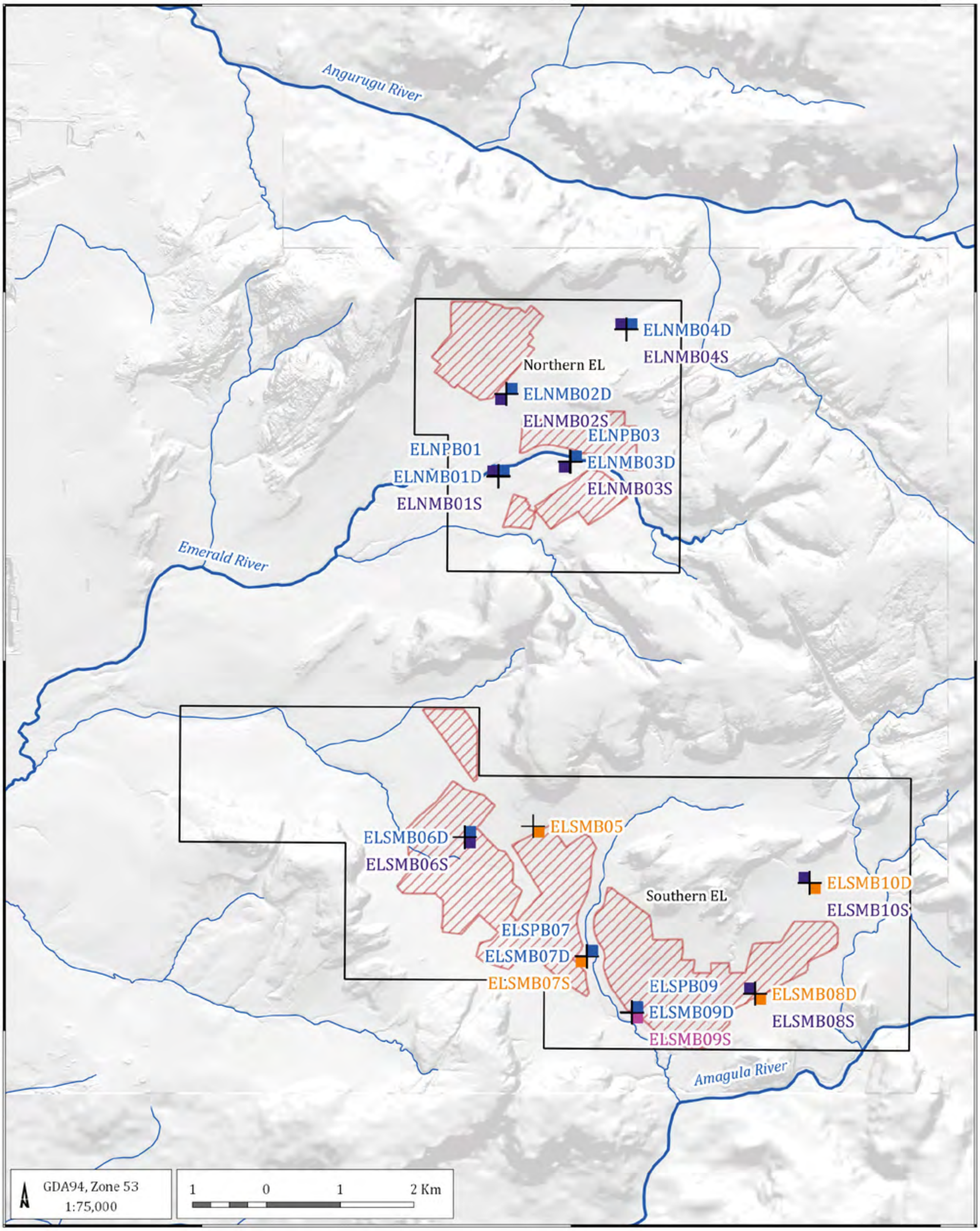


Figure 8 Conceptual geological cross section



LEGEND

- Quaternary Sediments / Laterite
- Laterite / Lateritic Clay
- Laterite / Manganese Ore
- Laterite / Manganese Ore / Marine Claystone
- Marine Claystone / Manganese Ore
- Marine Claystone
- Reworked basement / Marine sandstone
- Proposed pit area
- Eastern leases
- Major drainage
- Minor drainage

GEMCO (G1663)

Field investigation

DATE 3/3/2015

FIGURE No: **9**

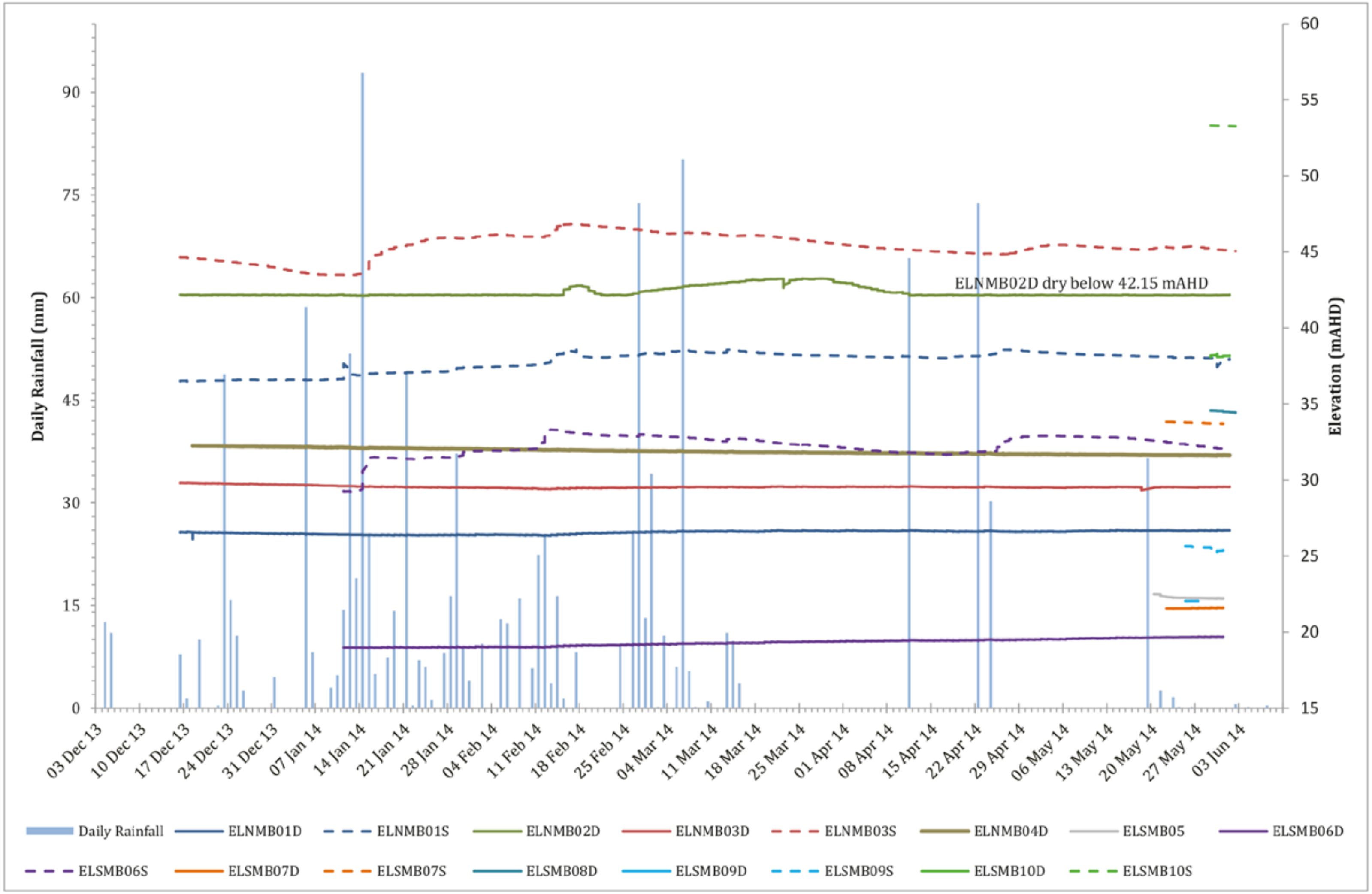
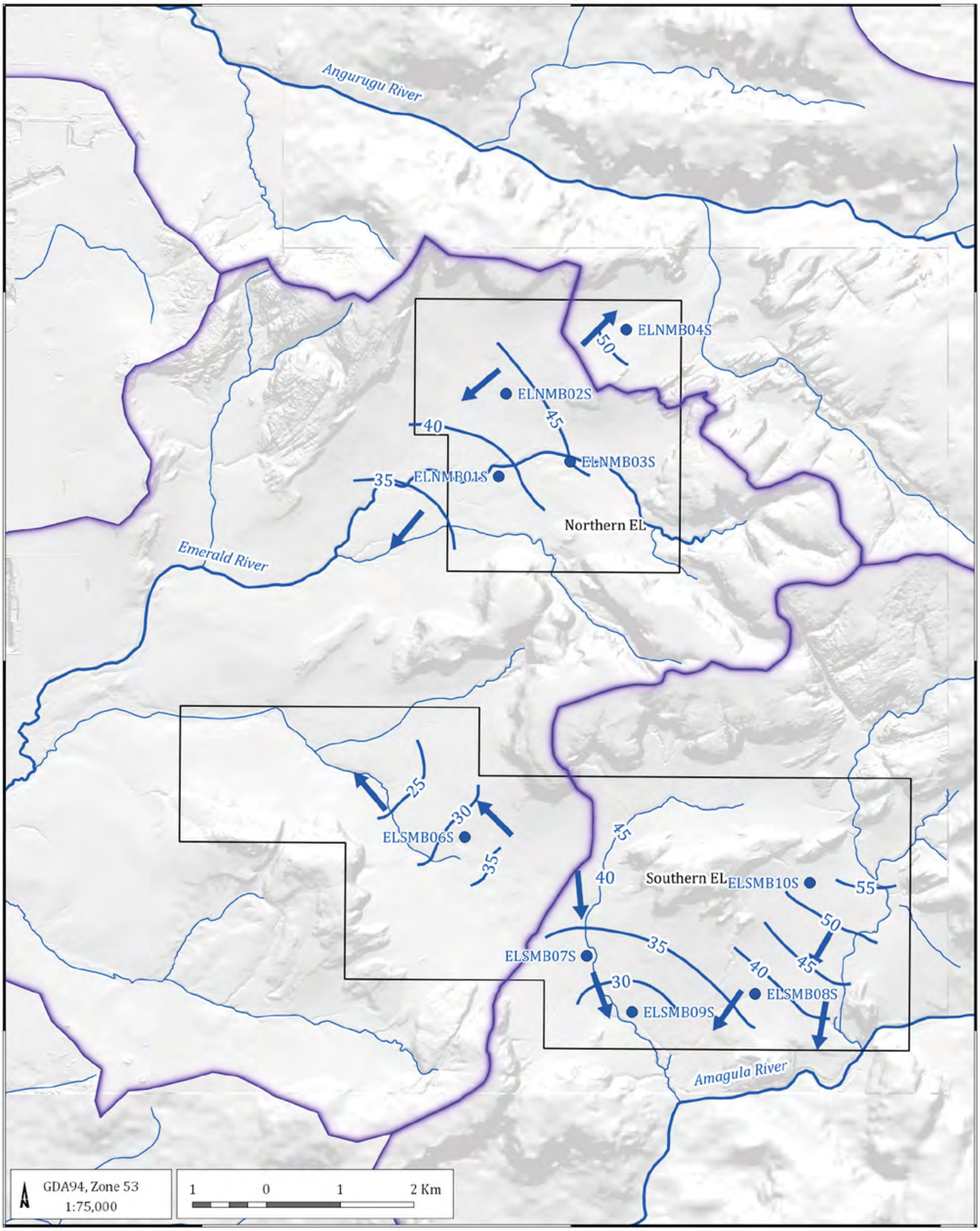


Figure 10 Groundwater level hydrographs



LEGEND

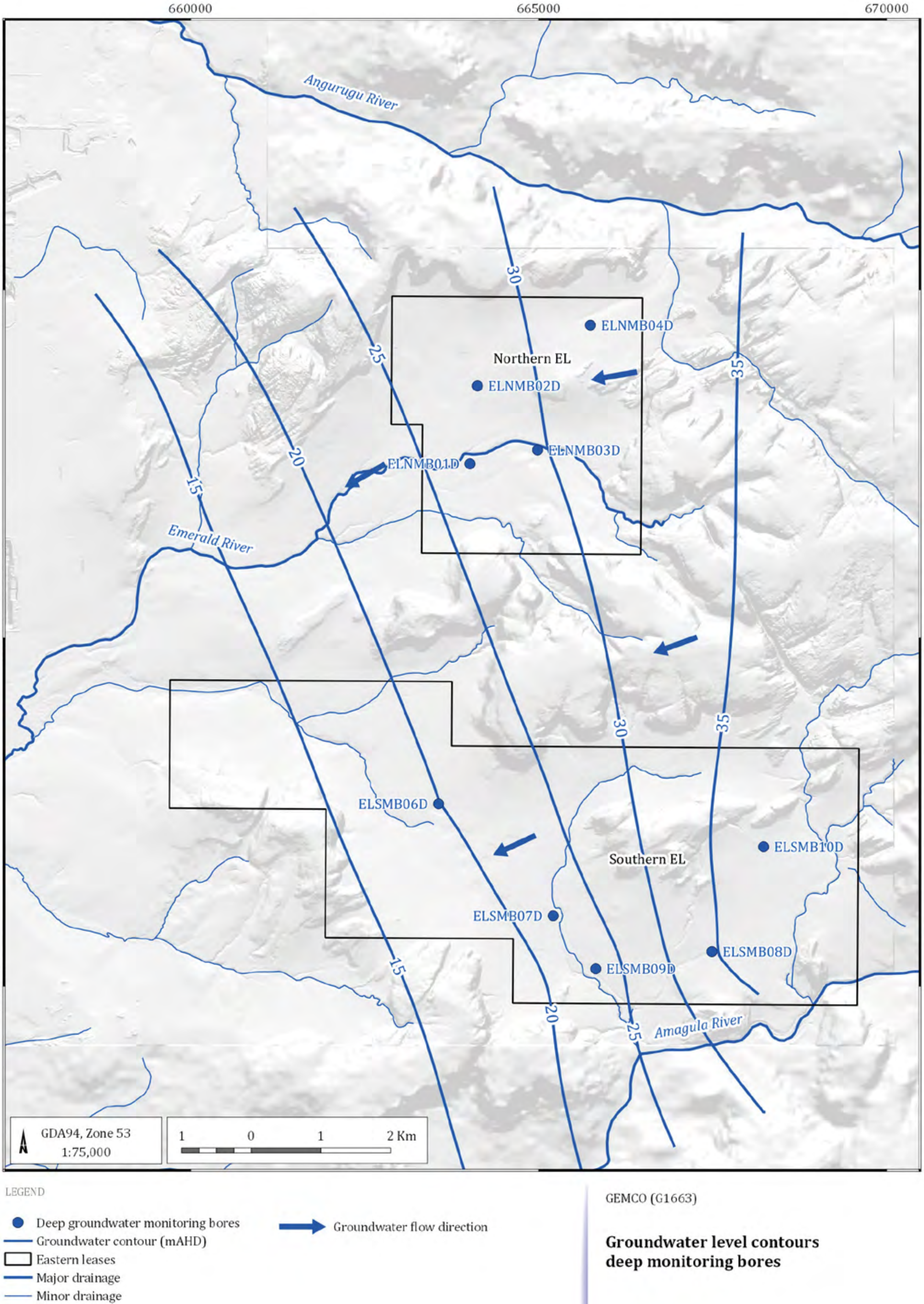
- Shallow groundwater monitoring bore
- Groundwater contour (mAHD)
- Eastern leases
- Major drainage
- Minor drainage
- Groundwater flow direction

GEMCO (G1663)

Groundwater level contours shallow monitoring bores

DATE 3/3/2015

FIGURE No: **11**

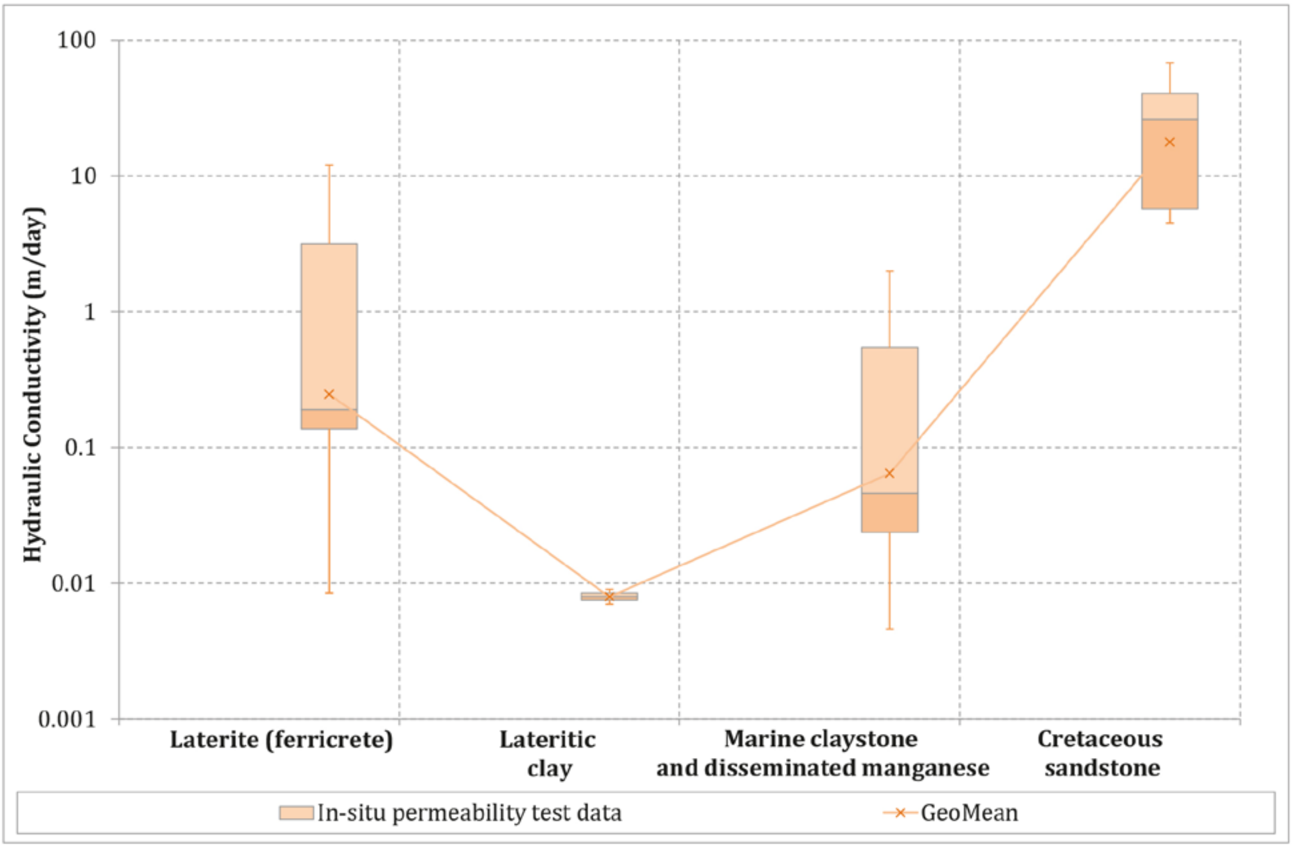


GEMCO (G1663)

Groundwater level contours deep monitoring bores

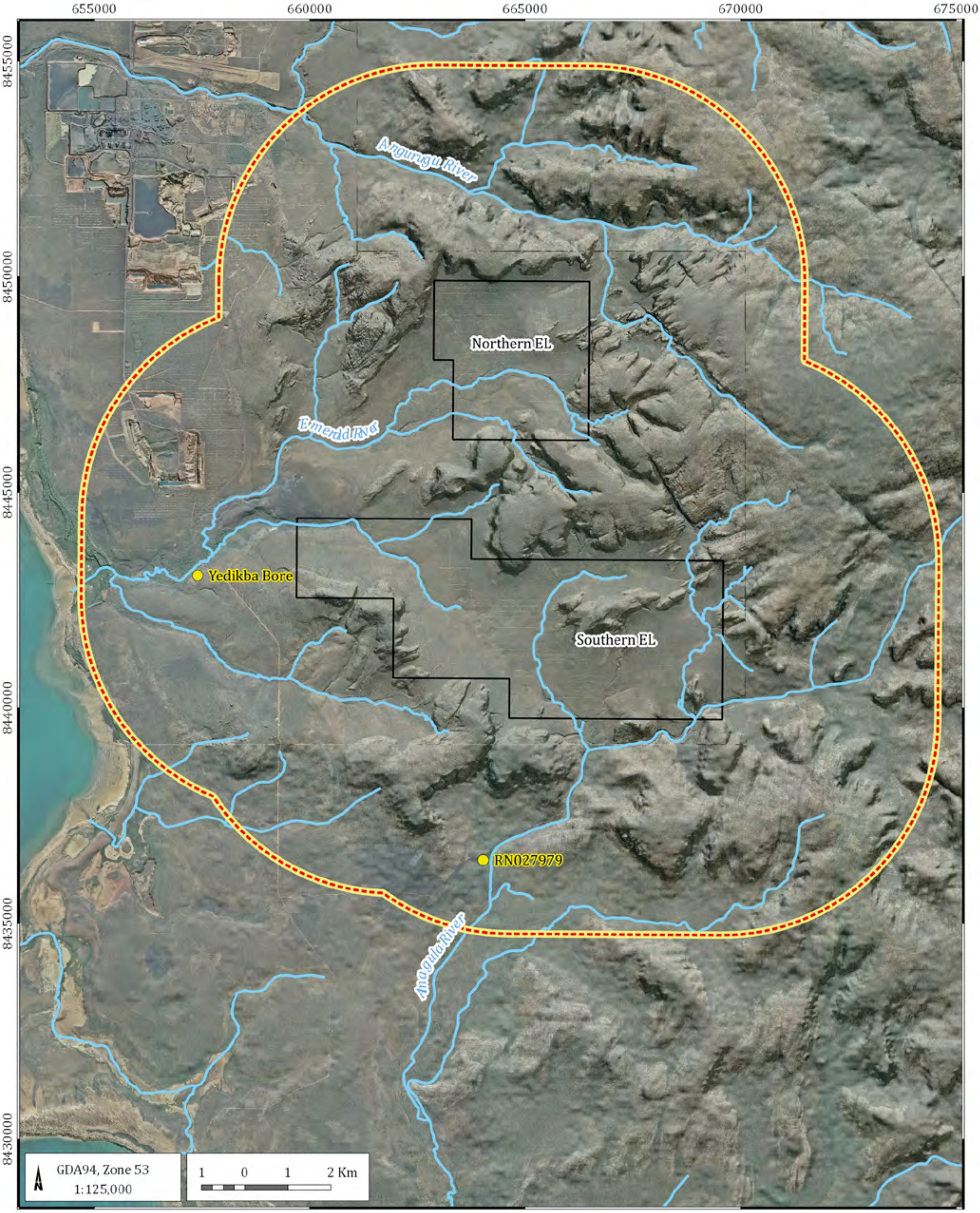
DATE 3/3/2015

FIGURE No: **12**



Note: upper bound of box is the 75th percentile, the lower bound is the 25th percentile and the change in colour represents the median

Figure 13 Combined hydraulic conductivity results



LEGEND

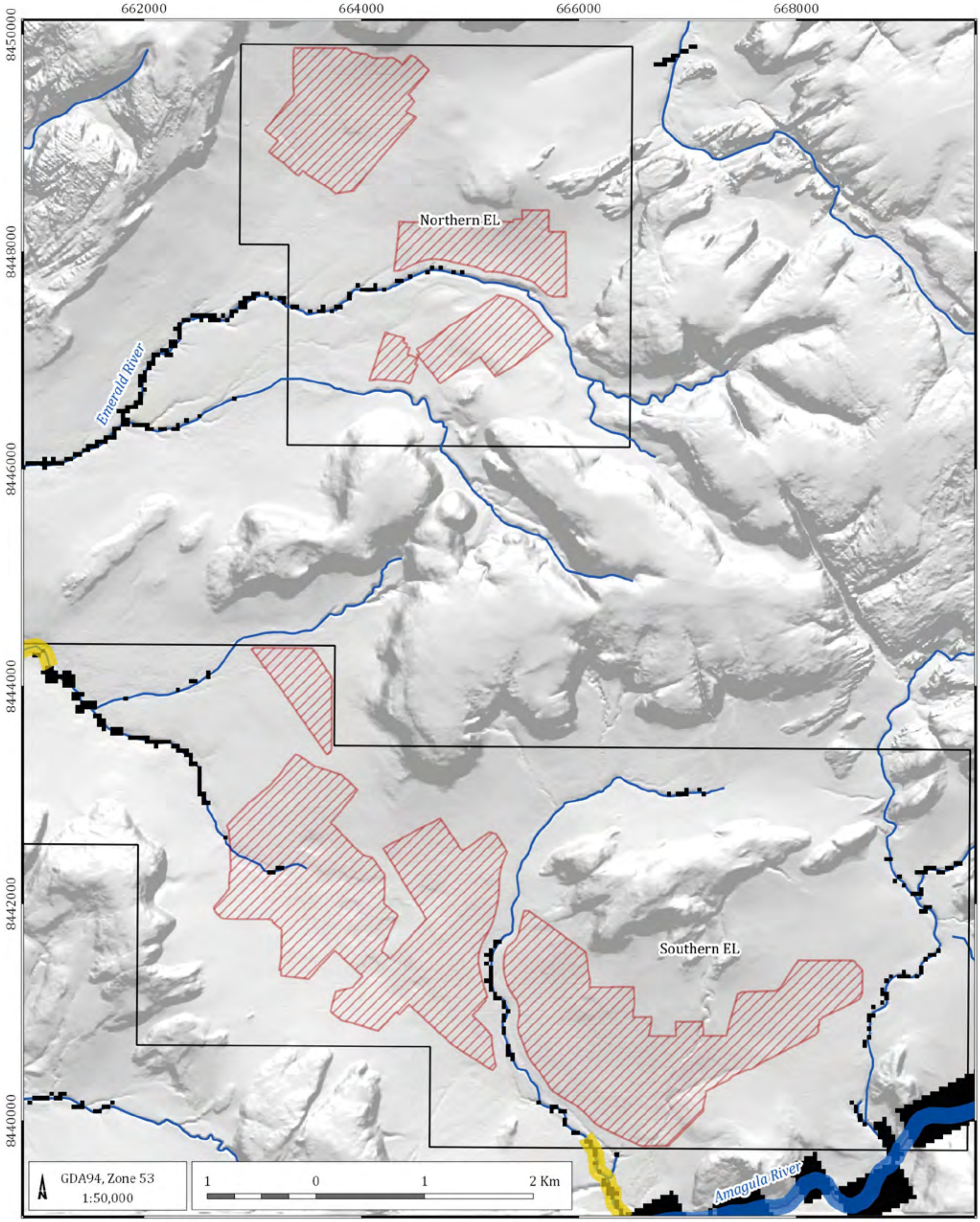
- Eastern leases
- 5 km buffer around Eastern Leases
- Outstation bore
- Minor drainage

GEMCO (G1663)

Outstation bores

DATE 3/3/2015

FIGURE No: **14**



LEGEND

Proposed Quarry
Area of potential groundwater discharge with watercourse

Aquatic habitat

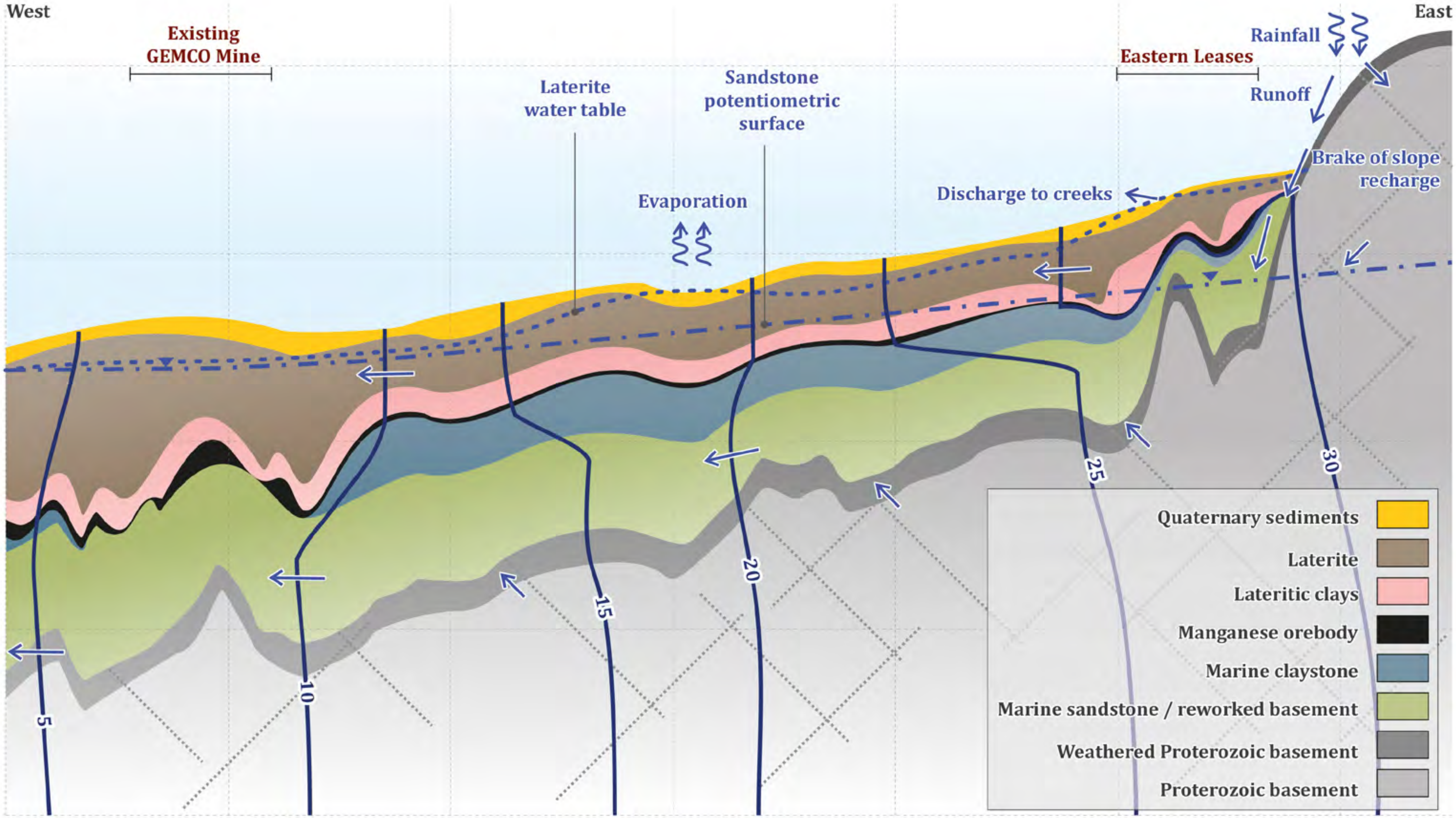
Perenial watercourse - major
Perenial watercourse - minor
Ephemeral watercourse

GEMCO (G1663)

Inferred zones of groundwater discharge to surface waters

DATE 12/3/2015

FIGURE No: **15**



Conceptual model (West - East)

Figure 16

GEMCO (G1663)

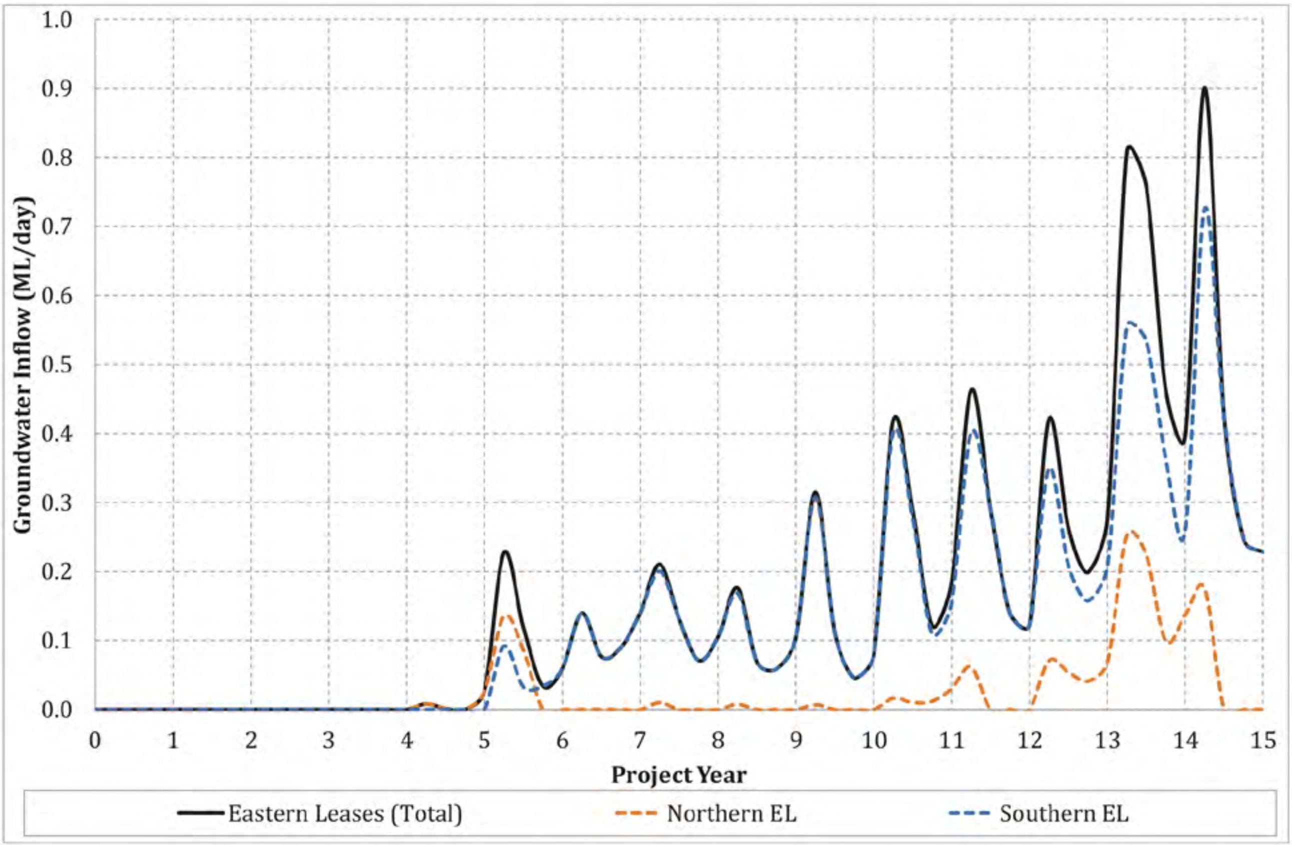
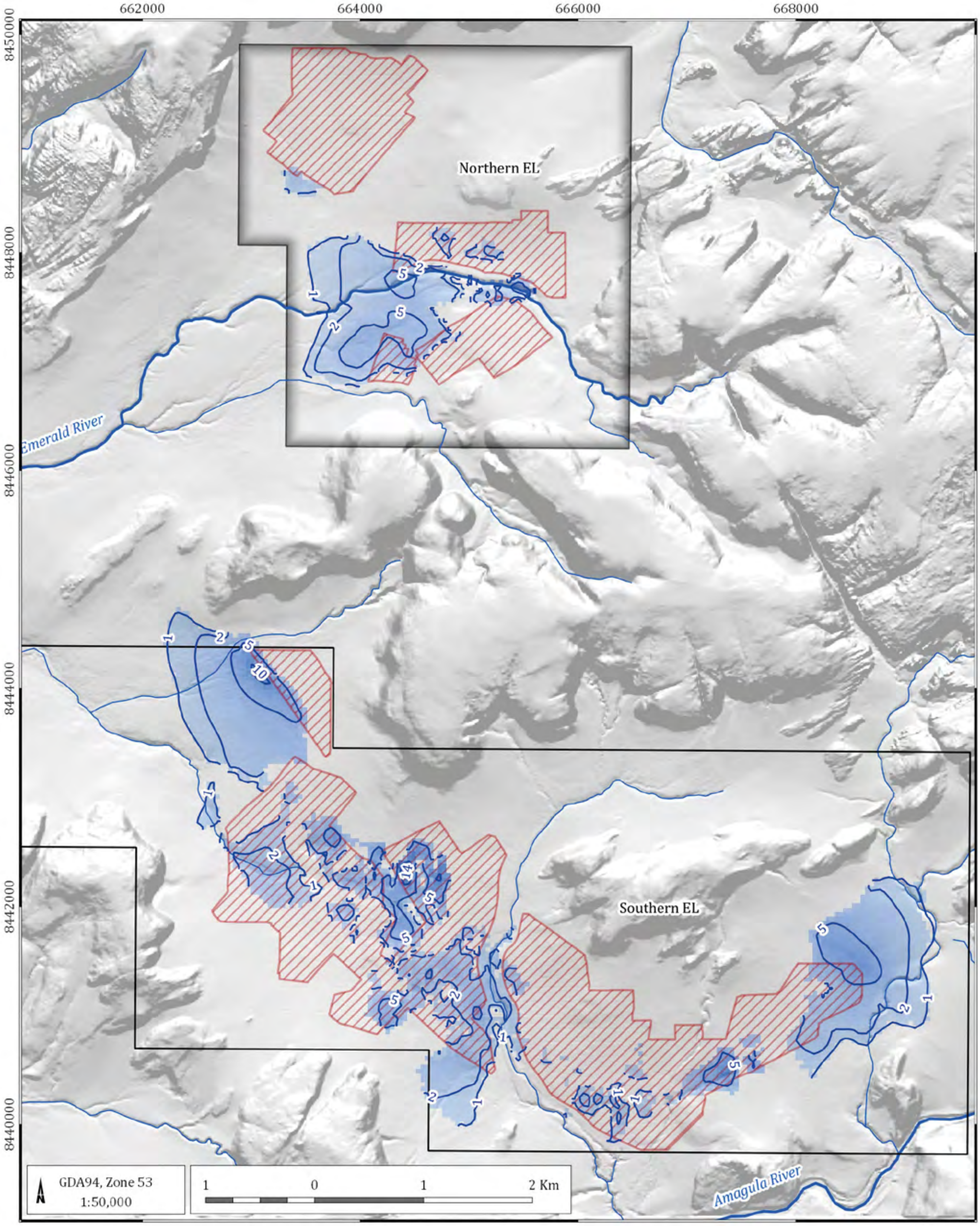


Figure 17 Simulated inflow to proposed quarries



LEGEND

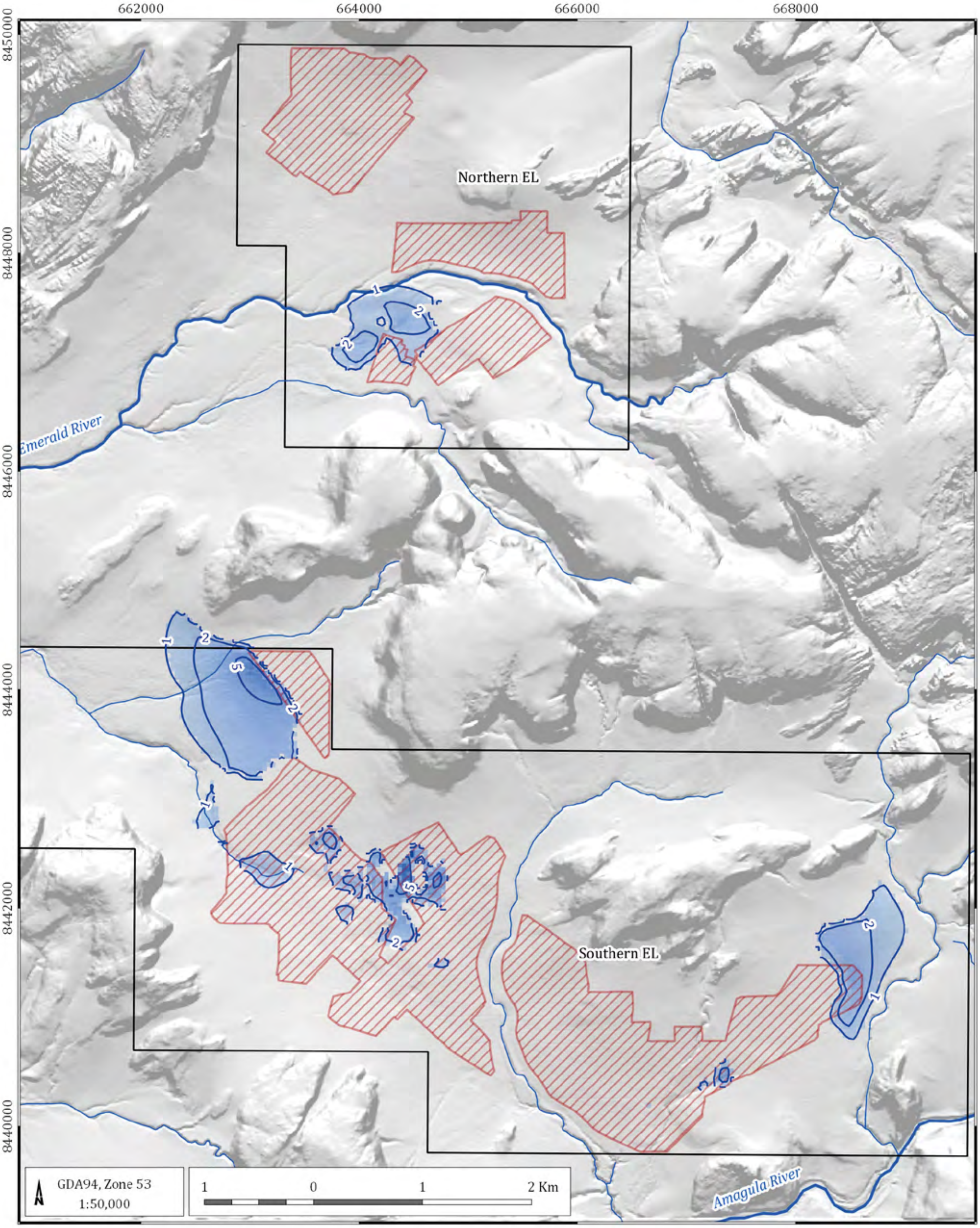
Proposed Quarry
Major drainage
Minor drainage
Water table drawdown contour (m)

GEMCO (G1663)

Zone of water table drawdown in the laterite

DATE 3/3/2015

FIGURE No: **18**



LEGEND

- Proposed Quarry
- Major drainage
- Minor drainage
- Water table drawdown contour (m)

GEMCO (G1663)

End of mining zone of water table drawdown in the laterite

DATE 3/3/2015

FIGURE No: **19**

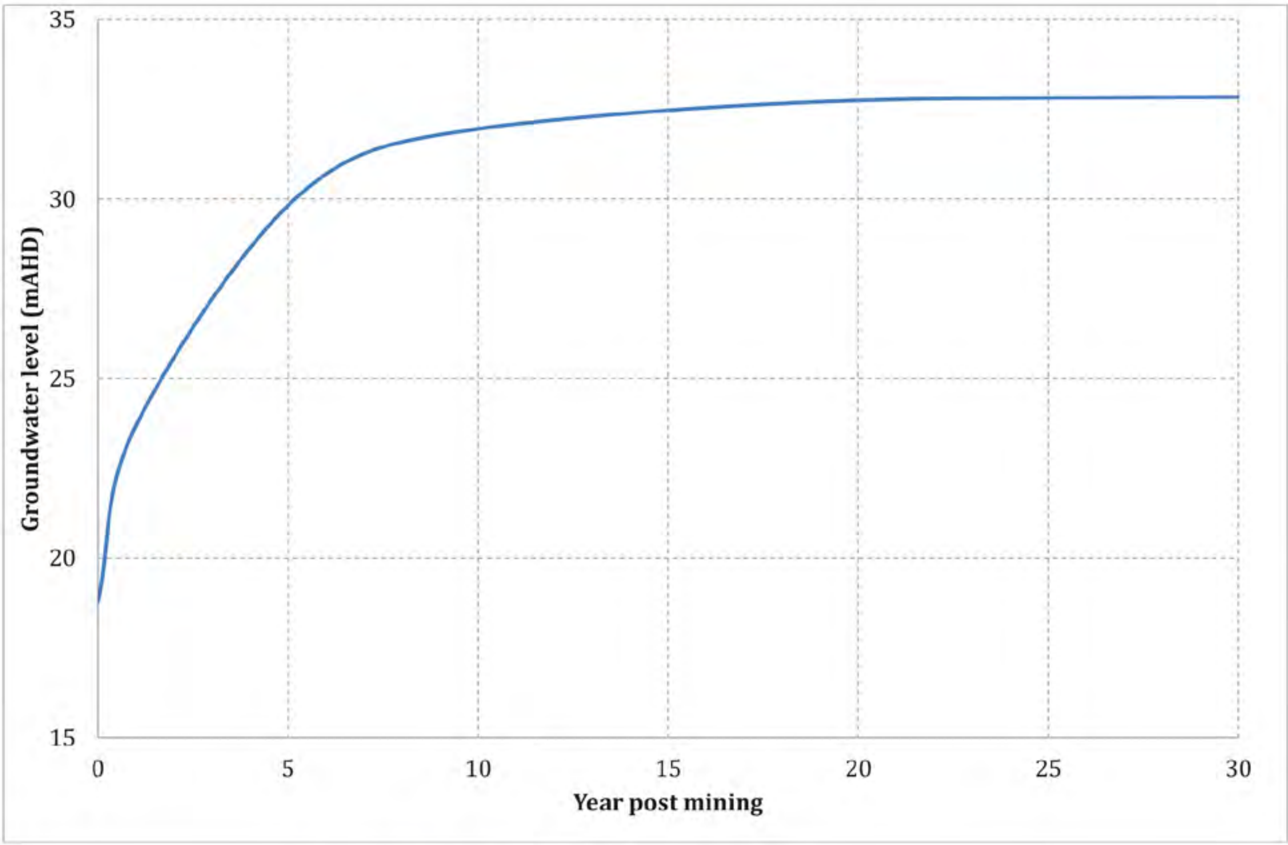
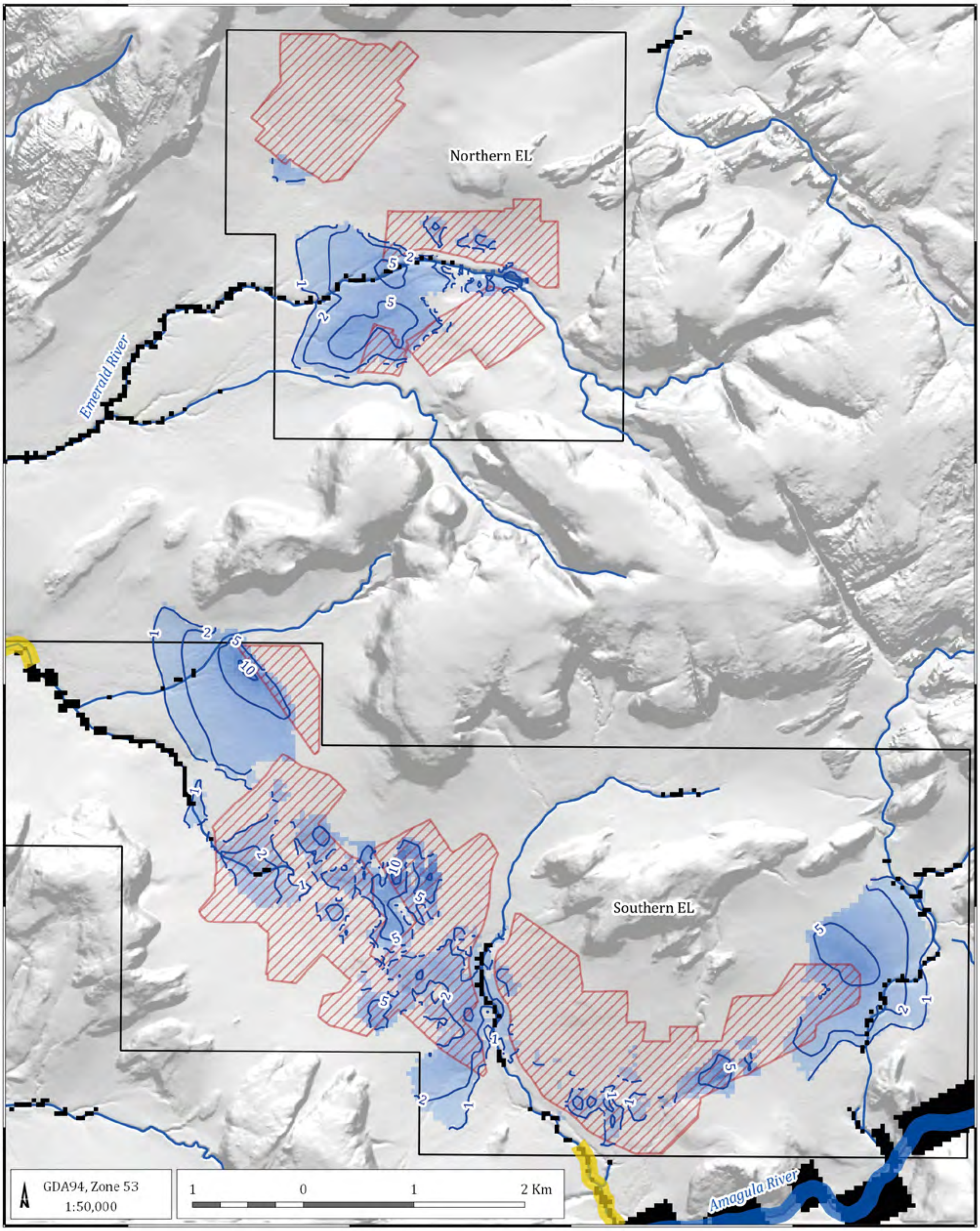


Figure 20 Post mining groundwater recovery



LEGEND

- Proposed Quarry
- Water table drawdown (m)
- Area of potential groundwater discharge with watercourse

Aquatic habitat

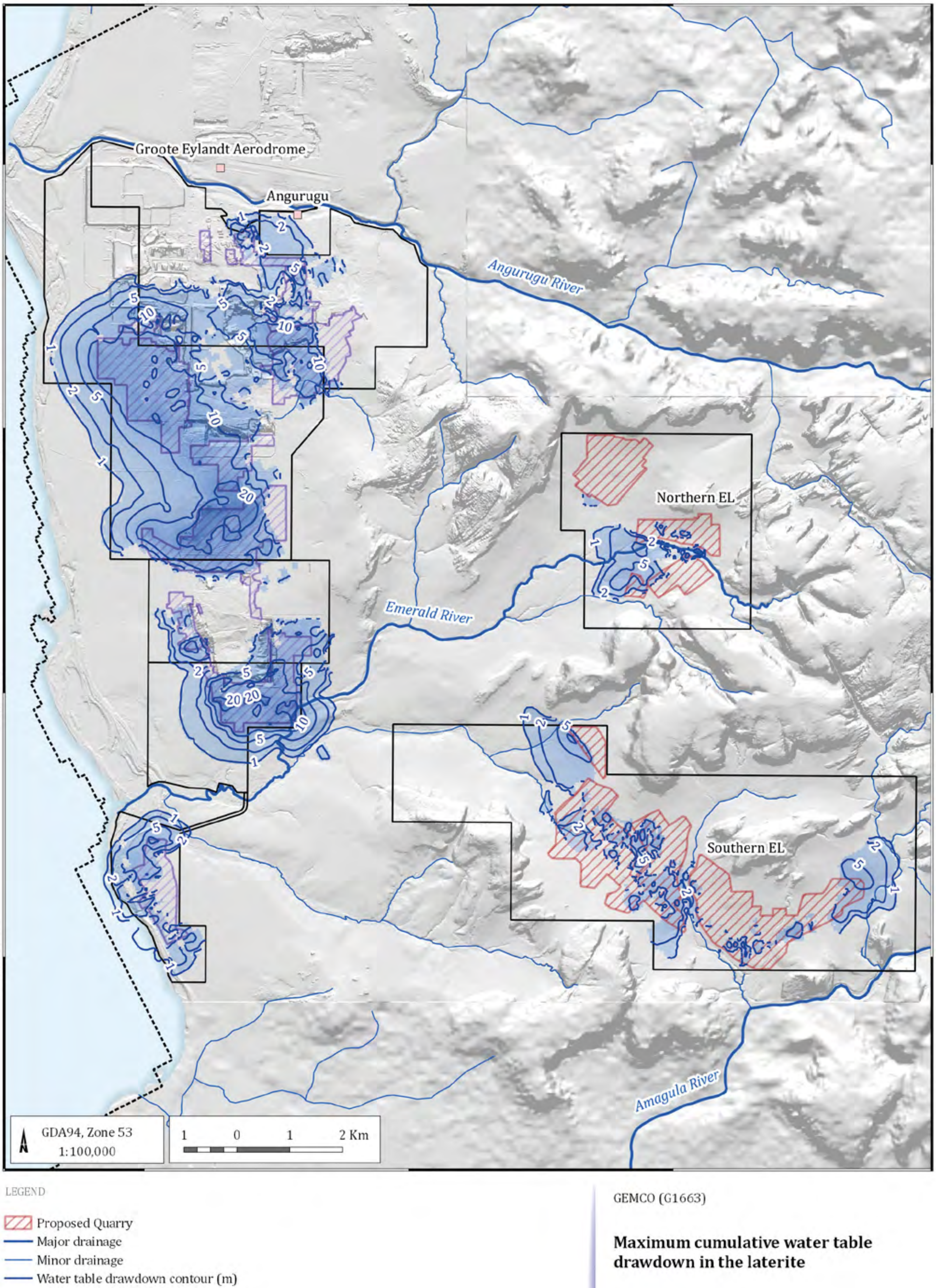
- Perenial watercourse - major
- Perenial watercourse - minor
- Ephemeral watercourse

GEMCO (G1663)

Potential impact to rivers from drawdown in the laterite

DATE 12/3/2015

FIGURE No: **21**



GEMCO (G1663)

Maximum cumulative water table drawdown in the laterite

DATE 3/3/2015

FIGURE No: **22**

Appendix A

Fieldwork Investigation Report

A1 Field investigations

Hydrogeological field investigations were undertaken between November 2013 and July 2014 and included:

- installing a network of groundwater monitoring bores;
- measuring hydraulic conductivity of key units;
- measuring groundwater levels;
- installing data loggers; and
- collecting water samples for analysis.

Each of the field investigations are described in the sections below.

A2 Groundwater bore installations

J & S Drilling installed a bore network comprising 23 bores at 10 locations between November 2013 and July 2014. The network comprised 19 monitoring bores and 4 test production bores installed under the supervision of Class 2 licensed water bore driller. AGE provided technical guidance, including lithological logging and bore design. The bores intersected two main water bearing units: the Tertiary laterite above the manganese orebody; and the Cretaceous sandstone aquifer (comprising the reworked basement and marine sandstone geological units) underlying the manganese orebody.

The completed network comprised:

- five monitoring locations each with two monitoring bores; one into the shallow sediments and one into the deep sediments (ELNMB02, ELNMB04, ELSMB06, ELSMB08, and ELSMB10);
- four monitoring locations each with a shallow and deep monitoring bore and also a test production bore (ELNMB01, ELNMB03, ELSMB07, and ELSMB09); and
- one site consisted of only one monitoring bore (ELS05)

Table A.1 provides construction details for all monitoring and production bores, and Appendix A 1 includes the bore construction logs.

All holes were drilled and constructed according to the guidelines presented in the 'Minimum Construction Requirements for Water Bores in Australia'[1]. The following sections document the drilling and construction of the monitoring bores and pumping test bores.

[1] National Uniform Drillers Licensing Committee (2013) "*Minimum Construction Requirements for Water Bores in Australia*" Ed.3 Revised February 2013.

Table A.1 Groundwater bores – construction details

Site ID (Monitoring Location)	Bore ID (Monitoring / Production Bore)	Coordinates		Geological unit	Elevation (mAHD)		Screen depth (mbGL)	Gravel pack (mbGL)	Static water level	
		mE	mN		ToC	Ground level			(mbtoc)	(mAHD)
ELNMB01	ELNMB01D	664,012.09	8,447,502.29	Reworked Basement / Marine Sandstone	40.39	39.48	33 - 42	30 - 43.8	13.53	26.86
	ELNMB01S	664,016.22	8,447,502.49	Laterite /Lateritic Clay	40.42	39.51	4 - 7	3 - 7.5	2.34	38.08
	ELNPB01	664,016.28	8,447,511.56	Reworked Basement / Marine Sandstone	39.97	39.5	35 - 38	31 - 42	13.13	26.84
ELNMB02	ELNMB02D	664,120.5	8,448,621.93	Marine Sandstone	50.27	49.51	6 - 8	5.5 - 8.1	dry bore	
	ELNMB02S	664,117.91	8,448,622.16	Laterite / Manganese Ore / Marine Claystone	50.19	49.44	3 - 4	2 - 4.5	dry bore	
ELNMB03	ELNMB03D	664,983.5	8,447,701.01	Reworked Basement	49.73	49.06	23.3 - 32.3	21 - 33.5	20.2	29.53
	ELNMB03S	664,984.32	8,447,705.19	Laterite / Manganese Ore / Marine Claystone	49.69	49.07	4 - 7	3 - 7.8	4.7	44.99
	ELNPB03	664,994.51	8,447,701.34	Reworked Basement / Marine Sandstone	49.66	49.11	31 - 34	23.9 - 37.5	20.13	29.53
ELNMB04	ELNMB04D	665,742.68	8,449,493.7	Reworked Basement	61	60.29	34 - 43	25 - 43.8	29.36	31.64
	ELNMB04S	665,745.42	8,449,493.02	Lateritic Clay	60.91	60.16	6 - 9	5 - 10	9.51	51.4
ELSMB05	ELSMB05	664,485.01	8,442,765.44	Marine Claystone	49.49	48.78	39.1 - 45.1	36.5 - 45.5	27.33	22.16
ELSMB06	ELSMB06D	663,560.48	8,442,618.6	Reworked Basement	34.56	33.87	33 - 42	31 - 43	14.87	19.69
	ELSMB06S	663,556.93	8,442,618.95	Quaternary Sediments / Laterite	34.5	33.82	2 - 5	1.5 - 6	2.56	31.94
ELSMB07	ELSMB07D	665,206.81	8,441,009.71	Reworked Basement / Marine Sandstone	36.36	35.63	34 - 43	24 - 44	14.81	21.55
	ELSMB07S	665,209.81	8,441,009.83	Laterite / Manganese Ore	36.35	35.59	2.5 - 4.5	2.1 - 5	2.56	33.79

Site ID (Monitoring Location)	Bore ID (Monitoring / Production Bore)	Coordinates		Geological unit	Elevation (mAHD)		Screen depth (mbGL)	Gravel pack (mbGL)	Static water level	
		mE	mN		ToC	Ground level			(mbtoc)	(mAHD)
	ELSPB07	665,213.95	8,440,998.55	Reworked Basement / Marine Sandstone	35.67	35.35	35 - 38	23 - 42	14.23	21.44
ELSMB08	ELSMB08D	667,487.7	8,440,495.71	Marine Claystone	43.79	43.1	23 - 26	21 - 27	9.23	34.56
	ELSMB08S	667,489.96	8,440,495.53	Laterite / Lateritic Clay	43.9	43.2	3 - 7.5	2 - 8	6.54	37.36
ELSMB09	ELSMB09D	665,819.03	8,440,248.4	Reworked Basement	29.8	29.06	34 - 43	28 - 44	7.72	22.08
	ELSMB09S	665,821.42	8,440,248.35	Marine Claystone / Manganese Ore	29.84	29.11	5 - 8	4 - 8.5	4.32	25.52
	ELNPB09	665,826.14	8,440,240.1	Reworked Basement / Marine Sandstone	29.49	29.02	20 - 23	19 - 27.6	7.4	22.09
ELSMB10	ELSMB10D	668,229.77	8,442,001.12	Marine Claystone	60.29	59.5	30 - 36	29 - 37.6	22.19	38.1
	ELSMB10S	668,229.7	8,441,999.02	Laterite / Lateritic Clay	60.27	59.49	4 - 7	3 - 7.5	6.92	53.35

Notes:

Co-ordinates GDA94, Zone 53

mbGL = metres below ground level

mAHD = metres above Australian Height Datum

mbtoc = metres below top of casing

Water levels recorded between 31st May and 2nd June 2014

A2.1 Monitoring bore drilling and construction

The monitoring bores were installed in a 158 mm diameter bore hole, drilled using open-hole, rotary mud drilling techniques to maintain hole integrity during construction. Bores were located on existing resource drilling pads to minimise site disturbance.

At the time of site selection, the GEMCO Eastern Leases geological model, along with drillhole data, and existing geological and hydrogeological reports were used to select each drill site.

Each bore was constructed with 50 mm diameter, flush threaded, Class 9 uPVC with Class 18 machine slotted (1 mm aperture) uPVC screen. A filter pack of clean rounded to sub-rounded quartz gravel of 1.6 mm to 3.2 mm diameter was placed in the annulus to a height that covered the screened interval. Bentonite pellets were placed above the filter gravel to form a seal to hydraulically isolate the screened section, and the remainder of the annulus was sealed by pumping a cement/bentonite (4 %) grout via a tremie line. A monument style, lockable steel protector was cemented around the protruding casing at the surface.

Table A.1 summarises the construction details for each bore. Appendix A 1 contains the composite bore logs for each site, showing the lithology intersected and the bore construction.

A2.2 Test production bore installations

A total of four test production bores, two on each of the Northern and Southern ELs, were drilled and constructed between December 2013 and May 2014. These boreholes were drilled using the same mud rotary drilling techniques to maintain hole integrity during construction.

The location and depth of each test production bore was based on proximity to the proposed quarries and geological log obtained from the co-located deep monitoring bore.

The test production bores were installed in a 254 mm diameter bore hole. Each bore was constructed with 154 mm (ID) diameter, joint welded steel casing. A 3 m length stainless steel wire wound, 1.5 mm aperture screen with a 3 m sump was installed in each bore. The sump was installed below each screen to allow the pump to be placed deeper if required.

A filter pack of clean rounded to sub-rounded quartz gravel of 1.6 mm to 3.2 mm diameter was placed in the annulus to a height that covered the screened interval. Bentonite pellets were placed above the filter gravel to form a seal to hydraulically isolate the screened section, and the remainder of the annulus was sealed by pumping a cement/bentonite (4 %) grout via a tremie line. The bore head was fitted with a table D flange (with M16 galvanised bolts) to conform to the standard AS2129.

Table A.1 summarises the construction details with Appendix A 1 containing the composite bore logs for each site showing the lithology intersected and the bore details.

A2.3 Bore development

Bores were airlift developed between one hour and five hours to remove drilling fines and enhance hydraulic conductivity within the surrounding aquifer. Developing continued until all fines were removed and field water quality parameters (for pH and electrical conductivity) had stabilised. A chlorine solution was flushed through the hole prior to development to help break down the muds used during drilling.

Some of the monitoring bores did not yield sufficient flow to enable adequate development. In this situation, water was circulated through the bore until most of the fines were removed from the gravel pack.

Appendix A 1 contains bore development data, including the duration and post development water quality presented on the bore logs.

A2.4 Groundwater levels and logger installations

Groundwater levels were measured manually using a water level dipper for all monitoring bores between May and June 2014 and are summarised in Table A.1.

Solinst leveloggers were installed in all monitoring bores and set to record at 6-hourly intervals.

A barometric logger was placed inside the protective collar of ELNMB01S and set to record concurrently with the other data loggers.

A2.5 Survey of bore locations

On completion of the drilling program all bores were surveyed by a licensed surveyor to accurately measure their position and height. Table A.1 presents the surveyed bore coordinates and elevations for each bore.

A3 Hydraulic testing

A3.1 In-situ permeability testing

As a part of the investigation, in-situ permeability tests using either falling head or rising head methods were conducted in each monitoring bore. The testing was designed to evaluate the hydraulic conductivity of aquifer material surrounding the bore screen. Falling head and rising head tests involve rapidly displacing the head of water in the bore and measuring the rate of recovery; from this the hydraulic conductivity of the aquifer is calculated.

Three methods were used to analyse the data depending on the aquifer type and the response from the test. The shallow bores were analysed using Bouwer & Rice (1976)[2] for unconfined aquifers. Deep bores were analysed using the Hvorslev Method (1953)[3] for confined aquifers, or the Butler High K (1998)[4] for highly conductive aquifers.

The data was analysed using Aquifer Test 2011.1 software[5]. Table A.2 shows the details for each test; Appendix A 2 includes the in-situ permeability testing data sheets.

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[2] Bouwer, H., and Rice, R.C., (1976) *A slug test method for determining hydraulic conductivity of unconfined aquifers with completely or partially penetrating wells*, Water Resources Research, vol. 12, no. 3, pp. 423-428.

[3] Hvorslev, M.J., (1951), *Time lag and soil permeability in ground-water observations*, Bull. No. 36, Waterways Exper. Sta. Corps of Engrs, U.S. Army, Vicksburg, Mississippi, pp. 1-50.

[4] Butler, J.J., Jr., (1998) *The design, performance, and analysis of slug tests*, Lewis Publishers, New York, 252p.

[5] Schlumberger Water Services (2011), "*Aquifer Test 2011.1*".

Table A.2 In-situ permeability test details

Hole ID	Date	Test type	Aquifer type	Analysis method	Hydraulic conductivity (m/day)	Geological unit
ELNMB01D	11-Jan-14	falling head test	confined	Hvorslev	4.7	Reworked Basement / Marine Sandstone
ELNMB01S	23-May-14	falling head test	unconfined	Bouwer & Rice	0.0085	Laterite /Lateritic Clay
ELNMB03D	10-Jan-14	rising head test	confined	Hvorslev	4.5	Reworked Basement
ELNMB03S	22-May-14	rising head test	unconfined	Bouwer & Rice	0.2	Laterite / Manganese Ore / Marine Claystone
ELNMB04D	20-May-14	rising head test	confined	Butler High K	22.8	Reworked Basement
ELSMB05	20-May-14	falling head test	confined	Hvorslev	2	Marine Claystone
ELSMB06D	30-May-14	falling head test	confined	Butler High K	4.7	Reworked Basement
ELSMB06S	15-May-14	rising head test	unconfined	Bouwer & Rice	0.18	Quaternary Sediments / Laterite
ELSMB07D	27-May-14	falling head test	confined	Hvorslev	8.68	Reworked Basement / Marine Sandstone
ELSMB07S	22-May-14	rising head test	unconfined	Bouwer & Rice	12	Laterite / Manganese Ore
ELSMB08D	29-May-14	falling head test	confined	Hvorslev	0.062	Marine Claystone
ELSMB08S	29-May-14	falling head test	unconfined	Bouwer & Rice	0.007	Laterite / Lateritic Clay
ELSMB09D	25-May-14	falling head test	confined	Butler High K	35.2	Reworked Basement
ELSMB09S	17-Jun-14	falling head test	unconfined	Bouwer & Rice	0.0046	Marine Claystone / Manganese Ore
ELSMB10D	29-May-14	rising head test	confined	Hvorslev	0.03	Marine Claystone

The screen interval was unsaturated in five bores (ELNMB02D and ELNMB02S, ELNMB04S, ELSMB08S, and ELSMB10S). The in-situ permeability testing (rising head tests) of the unsaturated sediments provided anomalous results due to the limitation of rising head testing under these unsaturated conditions. As such, these unrepresentative test results were removed from the overall dataset to ensure a robust and consistent hydraulic dataset.

A3.2 Step drawdown tests

Prior to the constant rate pumping test, a step drawdown test was completed for each test bore to determine the optimal pumping rate for the 24 hour constant rate test period. Step tests consisted of a series of stages each with a different discharge rate. The discharge rate was maintained at a constant rate during each stage and the drawdown response recorded. The discharge rate was stepped up after the drawdown stabilised. Each step was between 30 to 60 minutes duration until drawdown had stabilised. Table A.3 summaries each step test.

Table A.3 Step test details

Step test	Date	Maximum drawdown (m)	Multi-rate step	Time since pumping began (minutes)	Pumping rate (L/s)	Maximum drawdown (m)
ELNPB01	21-Jun-14	20	1	60	5.1	1.93
			2	120	8.1	3.19
			3	180	10.1	5.75
			4	240	12	6.92
			5	290	0	0
ELNPB03	23-May-14	20	1	40	3	1.32
			2	80	4	1.85
			3	120	5.4	2.56
			4	155	0	0
ELSPB07	25-Jun-14	19	1	60.5	4.1	1.17
			2	120	5.5	1.8
			3	180	6.7	2.45
			4	240.5	11.2	4.73
			5	254	0	0
ELSPB09	30-Jun-14	11	1	60	5.5	2
			2	120	7.3	2.82
			3	180	9	4.69
			4	240	13.4	6.19
			5	256	0	0

For each test, the pump was run at its maximum capacity for the fourth step.

A3.3 Constant rate tests

Four constant rate pumping tests were completed in the test production bores ELNPB01, ELNPB03, ELSPB07, and ELSPB09. All tests were approximately 24 hours in duration; the discharge rate was set based on the step test data outlined in Section A3.2. The data was analysed using Aquifer Test 2011.1 software[5]. Table A.4 contains the details for each pumping test. The results of the each pumping test indicate probable aquifer recharge during each constant rate test, indicating 'leaky aquifer' conditions. As such, each test was analysed using the Hantush and Jacob method (1955)[6] for leaky aquifer. Appendix A 2 contains the pumping test analysis.

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[6] Hantush, M.S., and Jacob, C.E., (1955). *Non-steady radial flow in an infinite leaky aquifer*, Am. Geophys. Union Trans., vol. 36, no. 1, pp. 95-100.

Table A.4 Pumping test details

Test production well	Date	Test duration (hours)	Actual discharge Rate (L/s)	Pre-test standing water level (mbGL)	Maximum drawdown (m)
ELNPB01	22-Jun-14	24	12.3	12.78	7.2
ELNPB03	24-May-14	28	5.1	19.58	2.5
ELSPB07	26-Jun-14	24	12.3	13.59	5.2
ELSPB09	30-Jun-14	24	13.3	7.03	7.4

A 30 m (for ELNPB03) to 100 m (for ELNPB01, ELSPB07, and ELSPB09) lay-flat line was used to direct discharge away from the pumping and observations bores. This reduced the potential for interference from localised recharge during the test.

Pressure sensor data loggers were used to record water levels in the pumping bore and observation bores during each pumping test. Spot water levels were also measured in the monitoring bores. During each test, all monitoring bores on the same EL as the current pumping test site were monitored to ensure maximum data capture (i.e. during ELNPB01 and ELNPB03 all groundwater monitoring bores on the Northern EL were monitored). Only the deep monitoring bore adjacent to the pumping bore showed a response to the pumping.

During the period of each test, there was no rainfall recorded at the site or within the nearby region.

Following cessation of each constant rate pumping test, the water level recovery in the test bore and observation bores was monitored for a period up to three days.

A4 Groundwater quality and sampling

A4.1.1 Groundwater quality sampling and laboratory analysis

Six groundwater sampling events were conducted monthly between January and July 2014. Sampling events targeted available monitoring bores, and the sampling program expanded as new bores were constructed and added to the sampling program.

Bores were sampled by EcOz Environmental Services using low flow (minimal drawdown) sampling methods. Field water quality parameters were measured using a portable water quality meter and laboratory samples collected from the groundwater monitoring bores for each sampling event.

Each sample was collected in a laboratory supplied container. Samples requiring dissolved metal analysis were filtered in the field using a 0.45 micron filter. All samples were itemised on a Chain of Custody Form, which accompanied the samples to the laboratory.

Groundwater samples collected during the field investigations were analysed for the following suite of parameters:

- physical parameters (total suspended solids, alkalinity, and total hardness);
- major anions (CO_3, HCO_3, Cl, SO_4);
- major cations (Ca, Mg, Na, K);
- minor ions (F);
- dissolved and total metals (Al, As, Ba, Be, B, Cd, Cr, Co, Cu, Fe, Hg, Pb, Mn, Ni, Se, U, V, and Zn);
- nutrients (nitrite, nitrate, nitrite + nitrate, TKN, total nitrogen, total phosphorus); and
- total petroleum hydrocarbons (TPH).

Three bores ELNMB02D, ELNMB02S, and ELNMB04S were dry and could not be sampled. Groundwater samples were not collected from the test production bores.

The water samples were submitted to and analysed by ALS Environmental Laboratories (ALS) which is National Association of Testing Authorities (NATA) accredited. Laboratory results are provided in Appendix A-3 and compared against the ANZECC (2000) guidelines for long term drinking water and fresh aquatic water, as well as Australian drinking water guidelines (NHMRC, 2011).

A4.1.2 Field water quality sampling

Field water quality measurements were recorded during each sampling event, including electrical conductivity (EC), total dissolved solids (TDS), pH, oxygen reduction potential (ORP), and dissolved oxygen (DO). Table A.5 contains the average of each parameter over the six sampling rounds. Appendix A 3 provides the measured parameters for each sampling event.

Table A.5 Average field water quality data

Bore ID	EC (µS/cm)	TDS (mg/L)	pH	Oxygen reduction potential (mV)	DO (% sat)
ELNMB01D	48.1	31.3	5	267.8	56.2
ELNMB01S	492.3	319.1	6.1	235	18
ELNMB02D	127.7	83	6.3	181	58.4
ELNMB03D	58.9	38.2	4.8	325	42.6
ELNMB03S	61	39.8	5.4	304.6	24.2
ELNMB04D	43.3	28.2	5.5	258.2	61.5
ELSMB05	115.7	75.2	5.8	265	43
ELSMB06D	66.2	43	5	318.6	46
ELSMB06S	47.7	31.1	5.3	276	15.4
ELSMB07D	328.1	213.1	6.5	-52.5	6
ELSMB07S	42.5	27.6	5.1	346	32.3
ELSMB08D	158.3	102.7	5.8	128.5	32.2
ELSMB08S	974	633	6.8	-81	12.9
ELSMB09D	76.6	49.8	5.5	273	49.8
ELSMB09S	559	63	5.7	221	12.5
ELSMB10D	286.3	185.6	6.3	153	45.9
ELSMB10S	343.5	223.3	6.9	51	13.1

A5 Bore census and site assessment of groundwater connection to creek systems

A bore census was completed between 28th November and 2nd December 2013. The aim of the bore census was to identify the condition and use of all registered and unregistered bores within a 5 km radius around the Eastern Leases.

Each of the bores identified was then inspected by a hydrogeologist to collect bore details.

Results from the bore census are outlined in the main report.

Appendix A 1

Bore construction logs

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BOREHOLE LOG

page:1 of 1

ELNMB01D

PROJECT No: **G1663**
PROJECT NAME: **Groote Eylandt**
DATE DRILLED: **1st Dec 2013**
LOGGED BY: **HM (AGE)**

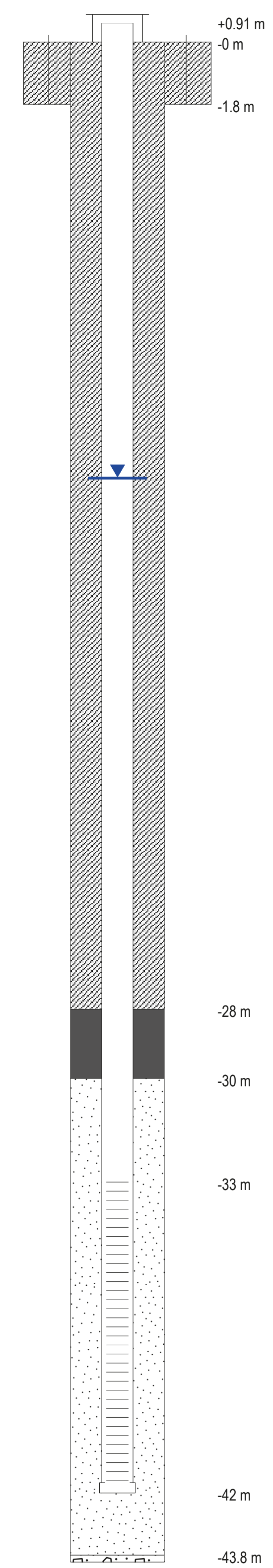
DRILLING COMPANY: **J & S Drilling**
DRILLER: **G. Despotakis (155NT/330WA)**
DRILLING METHOD: **Mud Rotary**
DRILL RIG: **Fraste XL Max**

EASTING: **664012.09 mE**
NORTHING: **8447502.29 mN**
DATUM: **MGA94 (z53)**
RL: **39.48 mAHD**
TD: **43.8 mBGL**

COMMENTS:

Stratigraphic Cloumn		Soil or Rock Field Material Description
	100	SAND: coarse sand, angular, lithic clasts, silty matrix, variegated, loose
Laterite	200	LATERITE: fine sand to medium sand, iron cemented, dark reddish brown, medium strength, minor clay in samples
Lateritic clay	300	CLAY: high plasticity, light orange / grey, firm
		CLAY: low plasticity, light grey, stiff
		CLAY: low plasticity, light grey, stiff, disseminated manganese throughout
	400	MANGANESE: black, hard
Marine claystone	900	CLAY: low plasticity, light grey, stiff, disseminated manganese throughout
		CLAY: high plasticity, dark grey, firm
		CLAY: low plasticity, orange, firm
Marine sandstone	1000	SANDSTONE: fine sand to medium sand, sub-rounded, quartz clasts, silty matrix, white, low strength
Reworked basal sediments	1100	SANDSTONE: fine sand to fine gravel, rounded, quartz clasts, granular, silty matrix, white, low strength
		SANDSTONE: medium sand to fine gravel, rounded, quartz clasts, granular, silty matrix, white, low strength

Graphic Log | Depth (mBGL) | R.L. (mAHD) | Bore Construction



Bore Description

Protective lockable steel collar: +0.97 m
Stick up: +0.91 m

305 mm Blade bit: 0 m to 1.8 m (Mud rotary)

158.8 mm Blade bit: 1.8 m to 43.8 m (Mud rotary)

219.1 mm (OD) steel (6.4 mm) surface casing: -0.2 m to 1.8 m

Bentonite grout (4 %): 0 m to 28 m

50 mm PN9 uPVC blank casing: +0.71 m to 33 m

SWL: 12.62 mBGL on the 1st Jun 2014

Bentonite seal: 28 m to 30 m

1.6 - 3.2 mm washed, rounded, quartz gravel pack: 30 m to 43.8 m

50 mm PN9 uPVC machine slotted casing, slot apperture: 1 mm, slot length: 45 mm, 131 slots / m, 33 m to 42 m

Bore development: 3 hrs; EC: 38.14 µS/cm; pH: 5.43

Airlift flow rate: 0.6 L/s

End cap

End of hole: 43.8 m BGL

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BOREHOLE LOG

page:1 of 1

ELNMB01S

PROJECT No: **G1663**
PROJECT NAME: **Groote Eylandt**
DATE DRILLED: **2nd Dec 2013**
LOGGED BY: **HM (AGE)**

DRILLING COMPANY: **J & S Drilling**
DRILLER: **G. Despotakis (155NT/330WA)**
DRILLING METHOD: **Mud Rotary**
DRILL RIG: **Fraste XL Max**

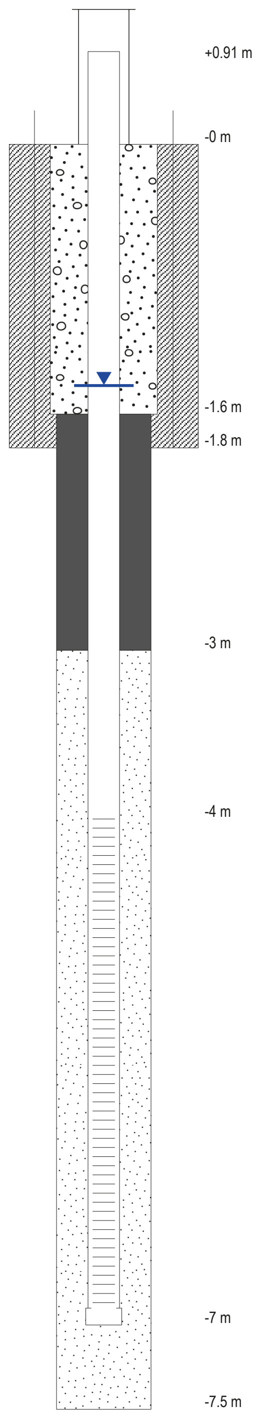
EASTING: **664016.22 mE**
NORTHING: **8447502.49 mN**
DATUM: **MGA94 (z53)**
RL: **39.51 mAHD**
TD: **7.5 mBGL**

COMMENTS: **Lithology from ELNMB01D**

Stratigraphic Cloumn	Soil or Rock Field Material Description
Sand (100)	SAND: coarse sand, angular, lithic clasts, silty matrix, variegated, loose
Laterite (200)	LATERITE: fine sand to medium sand, iron cemented, dark reddish brown, medium strength, light grey clay throughout
Lateritic clay (300)	CLAY: high plasticity, light orange / grey, firm

R.L. (mAHD): 40, 38, 36, 34, 32
Depth (mBGL): 0, 2, 4, 6, 8

Bore Construction



Bore Description

Protective lockable steel collar: +0.95 m

Stick up: +0.91 m

305 mm Blade bit: 0 m to 1.8 m (Mud rotary)

158.8 mm Blade bit: 1.8 m to 7.5 m (Mud rotary)

219.1 mm (OD) steel (6.4 mm) surface casing: -0.2 m to 1.8 m

50 mm PN9 uPVC blank casing: +0.78 m to 4 m

SWL: 1.43 mBGL on the 1st Jun 2014
Gravel backfill: 0 m to 1.6 m

Bentonite seal: 1.6 m to 3 m

1.6 - 3.2 mm washed, rounded, quartz gravel pack: 3 m to 7.5 m

50 mm PN9 uPVC machine slotted casing, slot apperture: 1 mm, slot length: 45 mm, 131 slots / m, 4 m to 7 m

Bore development: 3 hrs

No flow during development, water used to clean gravel pack

End cap

End of hole: 7.5 m BGL

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BOREHOLE LOG

page:1 of 1

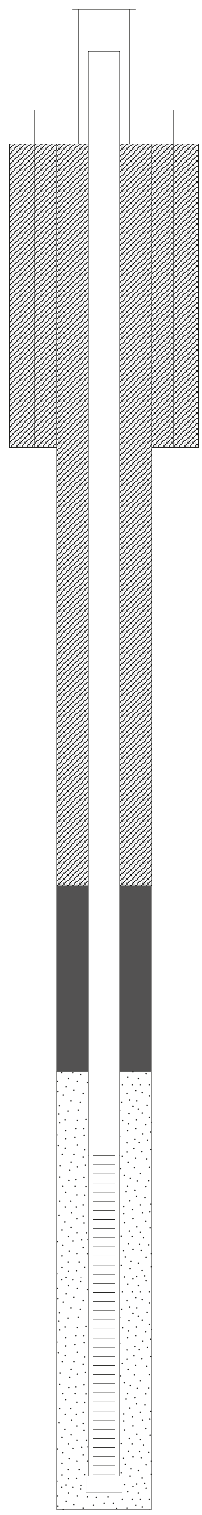
ELNMB02D

PROJECT No: **G1663**	DRILLING COMPANY: **J & S Drilling**	EASTING: **664120.5 mE**
PROJECT NAME: **Groote Eylandt**	DRILLER: **C. Foster (352WA)**	NORTHING: **8448621.93 mN**
DATE DRILLED: **10th Dec 2013**	DRILLING METHOD: **Mud Rotary**	DATUM: **MGA94 (z53)**
LOGGED BY: **HM (AGE)**	DRILL RIG: **Fraste XL Max**	RL: **49.51 mAHD**
COMMENTS:		TD: **8.1 mBGL**

Stratigraphic Cloumn	Soil or Rock Field Material Description
Sand (100)	SAND: coarse sand, sub-angular, lithic clasts, dark reddish brown, loose
Laterite (200)	LATERITE: medium gravel, sub-angular to sub-rounded, lithic clasts, iron cemented, dark reddish brown, medium strength, probably a laterised gravel conglomerate, significant water loss during drilling
Manganese orebody (400)	MANGANESE: black, very high strength, massive
Marine claystone (900)	CLAY: medium plasticity, white, firm, manganese throughout as layers within clay unit
Marine claystone	CLAY: low plasticity, mottled red / yellow, hard
Marine sandstone (1000)	SANDSTONE: very fine sand to fine sand, quartz clasts, silty matrix, white, high strength
(1100)	QUARTZITE: white, very high strength, drill bit refusal

Graphic Log | R.L. (mAHD): 50, 48, 46, 44, 42 | Depth (mBGL): 0, 2, 4, 6, 8

Bore Construction



Bore Description

Protective lockable steel collar: +0.78 m

Stick up: +0.76 m

305 mm Blade bit: 0 m to 1.8 m (Mud rotary)

158.8 mm PCD bit: 1.8 m to 8.1 m (Mud rotary)

219.1 mm (OD) steel (6.4 mm) surface casing: -0.2 m to 1.8 m

50 mm PN9 uPVC blank casing: +0.74 m to 6 m

Bentonite grout (4 %): 0 m to 4.4 m

Logger the in bore over the wet season identified the water level rose to 6.25 mBGL on the 22nd March 2014 then gradually fell

Bentonite seal: 4.4 m to 5.5 m

1.6 - 3.2 mm washed, rounded, quartz gravel pack: 5.5 m to 8.1 m

50 mm PN9 uPVC machine slotted casing, slot apperture: 1 mm, slot length: 45 mm, 131 slots / m, 6 m to 8 m

Bore development: 2 hrs 30 mins

No flow during development, water used to clean gravel pack
bore dry on the 1st Jun 2014

End cap
End of hole: 8.1 m BGL

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BOREHOLE LOG

page:1 of 1

ELNMB02S

PROJECT No: **G1663**
PROJECT NAME: **Groote Eylandt**
DATE DRILLED: **11th Dec 2013**
LOGGED BY: **HM (AGE)**

DRILLING COMPANY: **J & S Drilling**
DRILLER: **C. Foster (352WA)**
DRILLING METHOD: **Mud Rotary**
DRILL RIG: **Fraste XL Max**

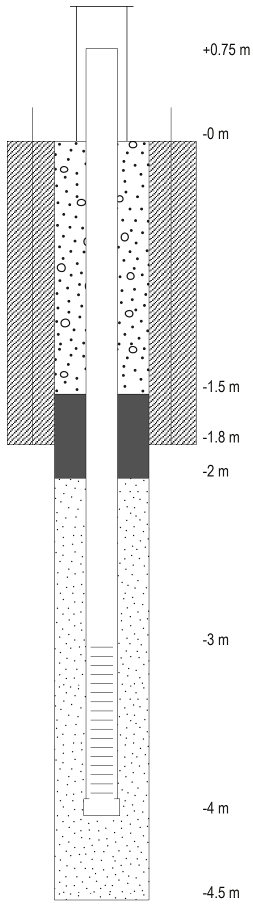
EASTING: **664117.91 mE**
NORTHING: **8448622.16 mN**
DATUM: **MGA94 (z53)**
RL: **49.44 mAHD**
TD: **4.5 mBGL**

COMMENTS: **Lithology from ELNMB02D**

Stratigraphic Cloumn	Soil or Rock Field Material Description	Depth (mBGL)
Sand (100)	SAND: coarse sand, sub-angular, lithic clasts, dark reddish brown, loose	0 – 1
Laterite (200)	LATERITE: medium gravel, sub-angular to sub-rounded, lithic clasts, iron cemented, dark reddish brown, medium strength, probably a laterised gravel conglomerate, significant water loss during drilling	1 – 3.5
Manganese orebody (400)	MANGANESE: black, very high strength, massive	3.5 – 4.3
900	CLAY: medium plasticity, white, firm, manganese throughout as layers within clay unit	4.3 – 4.5

R.L. (mAHD) scale: 49, 47, 45, 43, 41
Depth (mBGL) scale: 0, 2, 4, 6, 8

Bore Construction



Bore Description

Protective lockable steel collar: +0.80 m

Stick up: +0.75 m

305 mm Blade bit: 0 m to 1.8 m (Mud rotary)

158.8 mm PCD bit: 1.8 m to 4.5 m (Mud rotary)

219.1 mm (OD) steel (6.4 mm) surface casing: -0.2 m to 1.8 m

Gravel backfill: 0 m to 1.5 m

Bentonite seal: 1.5 m to 2 m

1.6 - 3.2 mm washed, rounded, quartz gravel pack: 2 m to 4.5 m
50 mm PN9 uPVC blank casing: +0.74 m to 3 m

50 mm PN9 uPVC machine slotted casing, slot apperture: 1 mm, slot length: 45 mm, 131 slots / m, 3 m to 4 m

End cap

End of hole: 4.5 m BGL

Bore development: 2 hrs 30 mins

No flow during development, water used to clean gravel pack
bore dry on the 1st Jun 2014

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BOREHOLE LOG

page:1 of 1

ELNMB03D

PROJECT No: **G1663**
PROJECT NAME: **Groote Eylandt**
DATE DRILLED: **3rd Dec 2013**
LOGGED BY: **HM (AGE)**

DRILLING COMPANY: **J & S Drilling**
DRILLER: **G. Despotakis (155NT/330WA)**
DRILLING METHOD: **Mud Rotary**
DRILL RIG: **Fraste XL Max**

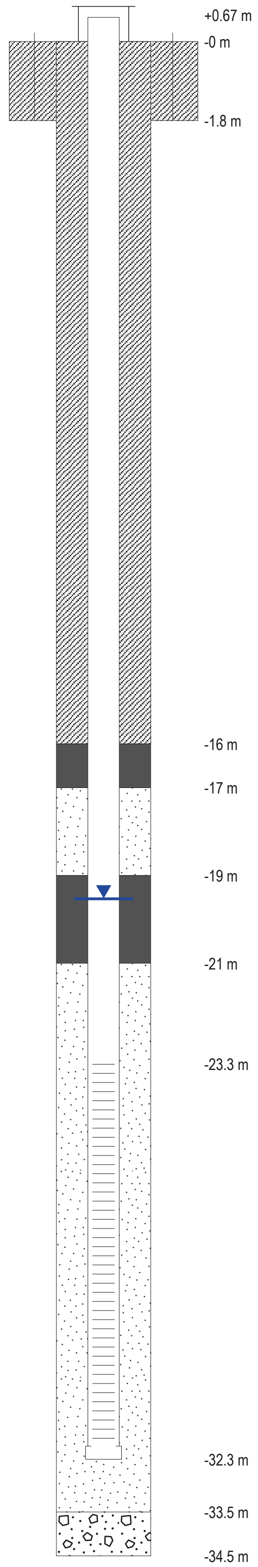
EASTING: **664983.5 mE**
NORTHING: **8447701.01 mN**
DATUM: **MGA94 (z53)**
RL: **49.06 mAHD**
TD: **34.5 mBGL**

COMMENTS:

Stratigraphic Cloumn	Code	Soil or Rock Field Material Description
Sand	100	SAND: coarse sand, sub-rounded, quartz and lithic clasts, variegated, loose
	200	LATERITE: fine sand, lithic clasts, iron cemented, red / grey / black, low strength, manganese nodules throughout
	400	MANGANESE: black, very high strength
Marine claystone	900	CLAY: high plasticity, mottled red / grey, firm, manganese mineralisation throughout
		CLAY: high plasticity, light brown / grey, firm
		MANGANESE & CLAY: black, high strength manganese layers alternating with high plasticity, white, soft clay
Marine sandstone	1000	SANDSTONE: fine sand, sub-rounded, quartz clasts, silty matrix, white, low strength
		SANDSTONE: fine sand, sub-rounded, quartz clasts, silty matrix, white, low strength
Reworked basal sediments	1100	SANDSTONE: fine to coarse sand, sub-rounded, quartz clasts, silty matrix, white, low strength
		SANDSTONE: fine sand, sub-rounded, quartz clasts, silty matrix, white, low strength, poor sample return from 28 m, sand too fine for sieve

Depth (mBGL)	R.L. (mAHD)
0	49
2	47
4	45
6	43
8	41
10	39
12	37
14	35
16	33
18	31
20	29
22	27
24	25
26	23
28	21
30	19
32	17
34	15

Bore Construction



Bore Description

- Protective lockable steel collar: +0.72 m
- Stick up: +0.67 m
- 305 mm Blade bit: 0 m to 1.8 m (Mud rotary)
- 158.8 mm PCD bit: 1.8 m to 34.5 m (Mud rotary)
- 219.1 mm (OD) steel (6.4 mm) surface casing: -0.2 m to 1.8 m
- Bentonite grout (4 %): 0 m to 16 m
- 50 mm PN9 uPVC blank casing: +0.68 m to 23.3 m
- Bentonite seal: 16 m to 17 m
- Gravel backfill: 17 m to 19 m
- SWL: 19.53 mBGL on the 1st Jun 2014
- Bentonite seal: 19 m to 21 m
- 1.6 - 3.2 mm washed, rounded, quartz gravel pack: 21 m to 33.5 m
- 50 mm PN9 uPVC machine slotted casing, slot apperture: 1 mm, slot length: 45 mm, 131 slots / m, 23.3 m to 32.3 m
- Bore development: 2 hrs 40 mins; EC: 47.53 µS/cm; pH: 6.19
- Airlift flow rate: 0.45 L/s
- End cap
- Hole collapse: 33.5 m to 34.5 m
- End of hole: 34.5 m BGL

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BOREHOLE LOG

page:1 of 1

ELNMB03S

PROJECT No: **G1663**
PROJECT NAME: **Groote Eylandt**
DATE DRILLED: **5th Dec 2013**
LOGGED BY: **HM (AGE)**

DRILLING COMPANY: **J & S Drilling**
DRILLER: **G. Despotakis (155NT/330WA)**
DRILLING METHOD: **Mud Rotary**
DRILL RIG: **Fraste XL Max**

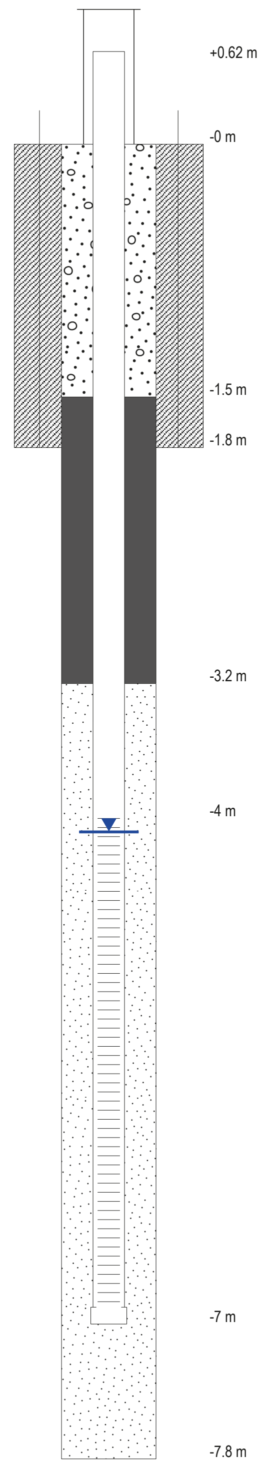
EASTING: **664984.32 mE**
NORTHING: **8447705.19 mN**
DATUM: **MGA94 (z53)**
RL: **49.07 mAHD**
TD: **7.8 mBGL**

COMMENTS: **Lithology from ELNMB03D**

Stratigraphic Cloumn	Code	Soil or Rock Field Material Description
Sand	100	SAND: coarse sand, sub-rounded, quartz and lithic clasts, variegated, loose
Laterite	200	LATERITE: fine sand, lithic clasts, iron cemented, red / grey / black, low strength, manganese nodules throughout
Manganese orebody	400	MANGANESE: black, very high strength
Marine claystone	900	CLAY: high plasticity, mottled orange / grey, firm, manganese mineralisation throughout

R.L. (mAHD)	Depth (mBGL)
49	0
47	2
45	4
43	6
41	8

Bore Construction



Bore Description

- Protective lockable steel collar: +0.80 m
- Stick up: +0.62 m
- 305 mm Blade bit: 0 m to 1.8 m (Mud rotary)
- 158.8 mm PCD bit: 1.8 m to 7.5 m (Mud rotary)
- 219.1 mm (OD) steel (6.4 mm) surface casing: -0.2 m to 1.8 m
- 50 mm PN9 uPVC blank casing: +0.63 m to 4 m
- Gravel backfill: 0 m to 1.5 m
- Bentonite seal: 1.5 m to 3.2 m
- 1.6 - 3.2 mm washed, rounded, quartz gravel pack: 3.2 m to 7.8 m
- SWL: 4.08 mBGL on the 1st Jun 2014
- 50 mm PN9 uPVC machine slotted casing, slot apperture: 1 mm, slot length: 45 mm, 131 slots / m, 4 m to 7 m
- Bore development: 4 hrs 30 mins; EC: 353.4 µS/cm; pH: 7.64
- No flow during development, water used to clean gravel pack
- End cap
- End of hole: 7.8 m BGL

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BOREHOLE LOG

page:1 of 1

ELNMB04D

PROJECT No: **G1663**
PROJECT NAME: **Groote Eylandt**
DATE DRILLED: **13th Dec 2013**
LOGGED BY: **HM (AGE)**

DRILLING COMPANY: **J & S Drilling**
DRILLER: **C. Foster (352WA)**
DRILLING METHOD: **Mud Rotary**
DRILL RIG: **Fraste XL Max**

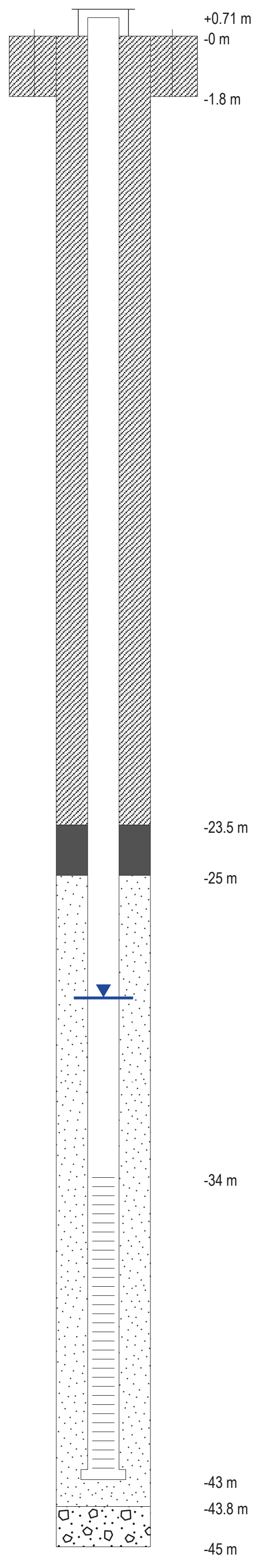
EASTING: **665742.68 mE**
NORTHING: **8449493.7 mN**
DATUM: **MGA94 (z53)**
RL: **60.29 mAHD**
TD: **45 mBGL**

COMMENTS:

Stratigraphic Column	Code	Soil or Rock Field Material Description
Sand	100	CLAYBOUND SAND: fine sand to medium sand, sub-rounded to rounded, quartz clasts, light reddish brown, medium strength
Lateritic clay	300	SANDY CLAY: silty matrix, red, soft, lithic gravel clasts at base
Lateritic clay		SANDY CLAY: fine sand, quartz clasts, mottled yellow / red, soft
	400	MANGANESE: black, very high strength
Marine claystone	900	CLAY: white, soft, manganese mineralisation throughout
Marine claystone		MANGANESE: black, very high strength
Marine claystone		CLAY: white, soft, manganese mineralisation throughout
	1000	SANDSTONE: fine sand, quartz clasts, white, poor sample return, very hard drilling
Reworked basal sediments	1100	SANDSTONE: fine sand, sub-rounded, quartz clasts, light reddish white, very low strength, minor coarse sand at 17 m to 18 m
Reworked basal sediments		SANDSTONE: fine sand to coarse sand, rounded, quartz clasts, variegated, very low strength, predominantly coarse sand with minor fine sand and fine gravel component
Reworked basal sediments		CLAY: mottled yellow / red, soft, probably sandy clay lens
Reworked basal sediments		SANDSTONE: fine sand to coarse sand, rounded, quartz clasts, light yellow, very low strength
Reworked basal sediments		SANDSTONE: fine sand to coarse sand, rounded, quartz clasts, white, very low strength

Graphic Log | R.L. (mAHD): 61, 59, 57, 55, 53, 51, 49, 47, 45, 43, 41, 39, 37, 35, 33, 31, 29, 27, 25, 23, 21, 19, 17, 15 | Depth (mBGL): 0, 2, 4, 6, 8, 10, 12, 14, 16, 18, 20, 22, 24, 26, 28, 30, 32, 34, 36, 38, 40, 42, 44, 46

Bore Construction



Bore Description

Protective lockable steel collar: +0.76 m
Stick up: +0.71 m

305 mm Blade bit: 0 m to 1.8 m (Mud rotary)

158.8 mm PCD bit: 1.8 m to 45 m (Mud rotary)

219.1 mm (OD) steel (6.4 mm) surface casing: -0.2 m to 1.8 m

Bentonite grout (4 %): 0 m to 23.5 m

50 mm PN9 uPVC blank casing: +0.72 m to 34 m

Bentonite seal: 23.5 m to 25 m

1.6 - 3.2 mm washed, rounded, quartz gravel pack: 25 m to 43.8 m

SWL: 28.65 mBGL on the 1st Jun 2014

50 mm PN9 uPVC machine slotted casing, slot apperture: 1 mm, slot length: 45 mm, 131 slots / m, 34 m to 43 m

Bore development: 4 hrs 15 mins; EC: 45.64 µS/cm; pH: 7.17
Airlift flow rate: 0.45 L/s

End cap

Hole collapse: 43.8 m to 45 m

End of hole: 45 m BGL

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BOREHOLE LOG

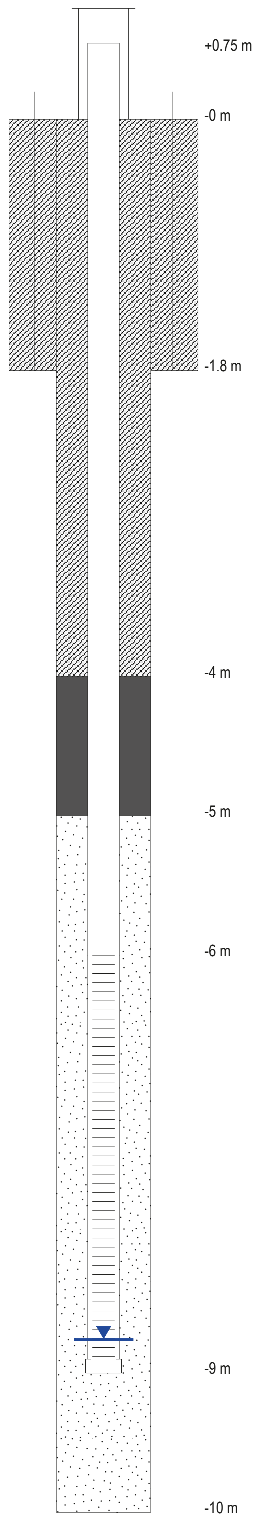
page:1 of 1

ELNMB04S

PROJECT No: **G1663**	DRILLING COMPANY: **J & S Drilling**	EASTING: **665745.42 mE**
PROJECT NAME: **Groote Eylandt**	DRILLER: **C. Foster (352WA)**	NORTHING: **8449493.02 mN**
DATE DRILLED: **14th Dec 2013**	DRILLING METHOD: **Mud Rotary**	DATUM: **MGA94 (z53)**
LOGGED BY: **HM (AGE)**	DRILL RIG: **Fraste XL Max**	RL: **60.16 mAHD**
COMMENTS: **Lithology from ELNMB04D**		TD: **10 mBGL**

Stratigraphic Cloumn	Soil or Rock Field Material Description	Graphic Log	Depth (mBGL) / R.L. (mAHD)
Sand (100)	CLAYBOUND SAND: fine sand to medium sand, sub-rounded to rounded, quartz clasts, light reddish brown, medium strength		0 / 60
Lateritic clay (300)	SANDY CLAY: silty matrix, red, soft, lithic gravel clasts at base		2 / 58; 4 / 56; 6 / 54; 8 / 52
	SANDY CLAY: fine sand, quartz clasts, mottled yellow / red, soft		10 / 50

Bore Construction



Bore Description

Protective lockable steel collar: +0.80 m

Stick up: +0.75 m

305 mm Blade bit: 0 m to 1.8 m (Mud rotary)

158.8 mm PCD bit: 1.8 m to 10 m (Mud rotary)

219.1 mm (OD) steel (6.4 mm) surface casing: -0.2 m to 1.8 m

50 mm PN9 uPVC blank casing: +0.74 m to 6 m

Bentonite grout (4 %): 0 m to 4 m

Bentonite seal: 4 m to 5 m

1.6 - 3.2 mm washed, rounded, quartz gravel pack: 5 m to 10 m

50 mm PN9 uPVC machine slotted casing, slot apperture: 1 mm, slot length: 45 mm, 131 slots / m, 6 m to 9 m

Bore development: 1 hr 30 mins

No flow during development, water used to clean gravel pack

SWL: 8.76 mBGL on the 1st Jun 2014

End cap

End of hole: 10 m BGL

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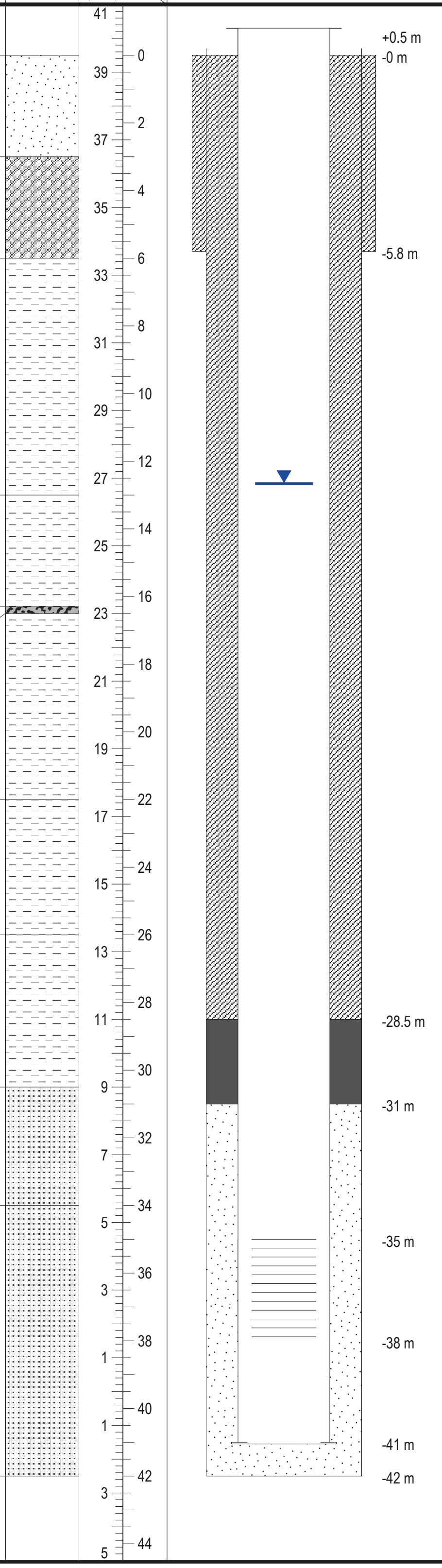
BOREHOLE LOG

page:1 of 1

ELNPB01

PROJECT No: **G1663**	DRILLING COMPANY: **J & S Drilling**	EASTING: **664016.28 mE**
PROJECT NAME: **Groote Eylandt**	DRILLER: **C. Foster (352WA)**	NORTHING: **8447511.56 mN**
DATE DRILLED: **17th Dec 2013**	DRILLING METHOD: **Mud Rotary**	DATUM: **MGA94 (z53)**
LOGGED BY: **HM (AGE)**	DRILL RIG: **Fraste XL Max**	RL: **39.5 mAHD**
COMMENTS:		TD: **42 mBGL**

Stratigraphic Cloumn	Soil or Rock Field Material Description
Sand (100)	SAND: coarse sand, angular, lithic clasts, silty matrix, variegated, loose, poor sample return
Laterite (200)	LATERITE: iron cemented, dark reddish brown, low strength
Lateritic clay (300)	CLAY: low plasticity, light grey / orange, stiff
	CLAY: low plasticity, light grey / orange, stiff, manganese throughout as layers within clay unit
(400)	MANGANESE: black, very high strength
Marine claystone (900)	CLAY: low plasticity, light grey / orange, stiff, manganese throughout as layers within clay unit
	CLAY: high plasticity, grey, soft
	CLAY: high plasticity, mottled / orange, soft
Marine sandstone (1000)	SANDSTONE: fine sand, quartz clasts, white, low strength
Reworked basal sediments (1100)	SANDSTONE: fine sand to fine gravel, quartz clasts, white, low strength



Bore Description

Headworks; Table D flange

Stick up: +0.47 m

368.3 mm Blade bit: 0 m to 5.8 m (Mud rotary)

158.8 mm Blade bit: 5.8 m to 28.5 m (Mud rotary)

158.8 mm PCD bit: 28.5 m to 42 m (Mud rotary)

254 mm Blade bit: 5.8 m to 42 m (Mud rotary)
Bentonite grout (4 %): 0 m to 29 m

273.1 mm (OD) steel (9.3 mm) surface casing: -0.2 m to 5.8 m

SWL: 12.68 mBGL on the 1st Jun 2014

168.3 mm (OD) steel (7.1 mm) surface casing: +0.5 m to 35 m

Rod string dropped in bore, casing integrity checked with downhole camera, a hole was identified in the base of the casing and approx 1.5 m of gravel at base of bore. A J-plug was installed in the sump to seal hole. No damage to the screen was identified

Bentonite seal: 29 m to 31 m

1.6 - 3.2 mm washed, rounded, quartz gravel pack: 31 m to 42 m

154.1 mm stainless steel wire wound, slot apperture: 1.5 mm, 35 m to 38 m

Bore development: 2 hrs 30 mins; EC: 40.48 µS/cm; pH: 5.93
Airlift flow rate: 5.7 L/s

3 m sump and end cap: 38 m to 41 m

End of hole: 42 m BGL

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BOREHOLE LOG

page:1 of 1

ELNPB03

PROJECT No: **G1663**
PROJECT NAME: **Groote Eylandt**
DATE DRILLED: **7th Dec 2013**
LOGGED BY: **HM (AGE)**

DRILLING COMPANY: **J & S Drilling**
DRILLER: **G. Despotakis (155NT/330WA)**
DRILLING METHOD: **Mud Rotary**
DRILL RIG: **Fraste XL Max**

EASTING: **664994.51 mE**
NORTHING: **8447701.34 mN**
DATUM: **MGA94 (z53)**
RL: **49.11 mAHD**
TD: **43.5 mBGL**

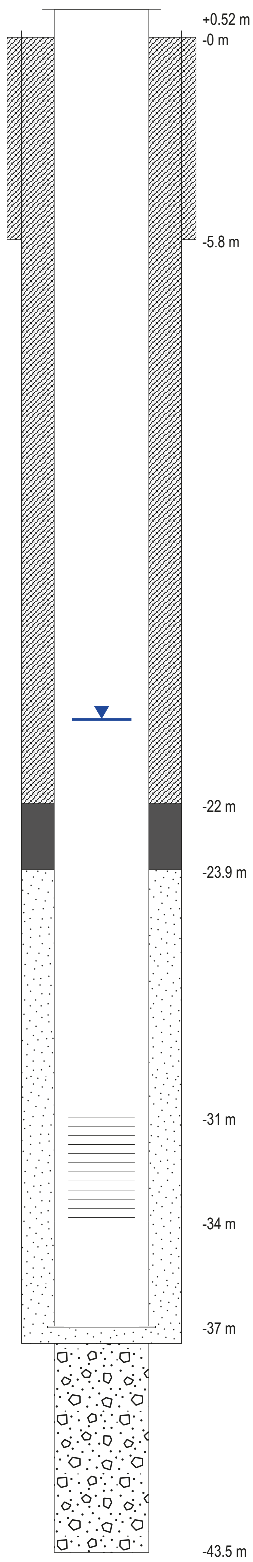
COMMENTS:

Stratigraphic Cloumn	Code	Soil or Rock Field Material Description
Sand	100	SANDSTONE: medium sand to coarse sand, rounded, quartz clasts, variegated, loose
Laterite	200	LATERITE: iron cemented, dark red / black, high strength, significant manganese mineralisation throughout
	400	MANGENESE: black, very high strength
Marine claystone	900	CLAY: high plasticity, mottled orange / grey, firm, manganese mineralisation throughout
		MANGANESE & CLAY: black, high strength manganese layers alternating with high plasticity, white, soft clay
Marine sandstone	1000	SANDSTONE: fine sand to medium sand, sub-rounded, quartz clasts, silty matrix, light reddish black, low strength
		SANDSTONE: fine sand, sub-rounded, quartz clasts, silty matrix, white, low strength
Reworked basal sediments	1100	SANDSTONE: fine to coarse sand, sub-rounded, quartz clasts, white, low strength
		SANDSTONE: fine sand, sub-rounded, quartz clasts, clay matrix, white, very low strength, matrix supported, soft clay
		SANDSTONE: fine sand to medium sand, sub-rounded to rounded, quartz clasts, white, very low strength

Graphic Log

R.L. (mAHD)	Depth (mBGL)
49	0
47	2
45	4
43	6
41	8
39	10
37	12
35	14
33	16
31	18
29	20
27	22
25	24
23	26
21	28
19	30
17	32
15	34
13	36
11	38
9	40
7	42
5	44

Bore Construction



Bore Description

Headworks; Table D flange

Stick up: +0.55 m

359.9 mm Tri-cone: 0 m to 5.8 m (Mud rotary)

158.8 mm PCD bit: 5.8 m to 43.5 m (Mud rotary)

Reamed using 254 mm PCD bit: 5.8 m to 37.5 m (Mud rotary)
168.3 mm (OD) steel (7.1 mm) surface casing: +0.52 m to 31 m
273.1 mm (OD) steel (9.3 mm) surface casing: -0.2 m to 5.8 m

Bentonite grout (4 %): 0 m to 22 m

SWL: 19.58 mBGL on the 1st Jun 2014

Bentonite seal: 22 m to 23.9 m

1.6 - 3.2 mm washed, rounded, quartz gravel pack: 23.9 m to 37.5 m

154.1 mm stainless steel wire wound, slot apperture: 1.5 mm, 31 m to 34 m

3 m sump and end cap: 34 m to 37 m

Bore development: 5 hrs; EC: 42.59 µS/cm; pH: 6.16

Airlift flow rate: 3.6 L/s

Trace fine sand remaining at the end of bore development

Hole collapse from 37.5 m

End of hole: 43.5 m BGL

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BOREHOLE LOG

ELSMB05

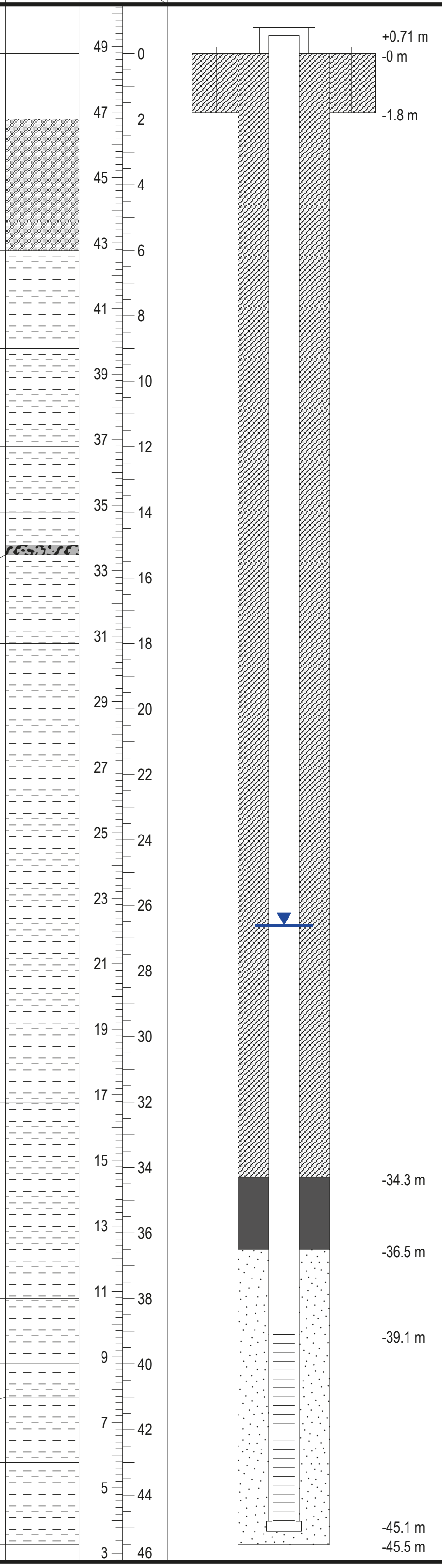
PROJECT No: **G1663**
PROJECT NAME: **Groote Eylandt**
DATE DRILLED: **16th May 2014**
LOGGED BY: **HM (AGE)**

DRILLING COMPANY: **J & S Drilling**
DRILLER: **G. Despotakis (155NT/330WA)**
DRILLING METHOD: **Mud Rotary**
DRILL RIG: **Fraste XL Max**

EASTING: **664485.01 mE**
NORTHING: **8442765.44 mN**
DATUM: **MGA94 (z53)**
RL: **48.78 mAHD**
TD: **45.5 mBGL**

COMMENTS:

Stratigraphic Cloumn	Soil or Rock Field Material Description
Sand (100)	NO SAMPLE RETURN: chip samples not collected
Laterite (200)	LATERITE: sub-rounded to rounded, lithic clasts, mottled red / white, low strength, clasts comprised of medium grained sandstone
Lateritic clay (300)	CLAY: low plasticity, mottled red / grey, low strength, soft, possibly weathered claystone
Lateritic clay (300)	CLAY: high plasticity, orange / grey, low strength, soft
Lateritic clay (300)	CLAY: high plasticity, yellow, low strength, soft
Lateritic clay (300)	CLAY: high plasticity, red / grey, low strength, soft
400	MANGANESE: black, very high strength
Marine claystone (900)	CLAY: high plasticity, yellow, low strength, soft
Marine claystone (900)	CLAY: high plasticity, grey, low strength, soft
Marine claystone (900)	CLAY: medium plasticity, dark greenish grey, low strength, soft
Marine claystone (900)	MANGANESE & CLAY: black, high strength manganese with significant clay throughout
Marine claystone (900)	CLAY: high plasticity, light black, soft, manganese dispersed throughout
Marine claystone (900)	MANGANESE & CLAY: black, high strength manganese with clay dispersed throughout
Marine claystone (900)	CLAY: lithic clasts, orange, soft, manganese dispersed throughout



Bore Description

- Protective lockable steel collar: +0.78 m
- Stick up: +0.71 m
- 305 mm Blade bit: 0 m to 1.8 m (Mud rotary)
- 158.8 mm PCD bit: 1.8 m to 45.5 m (Mud rotary)
- 219.1 mm (OD) steel (6.4 mm) surface casing: -0.2 m to 1.8 m
- Bentonite grout (4 %): 0 m to 34.3 m
- 50 mm PN9 uPVC blank casing: +0.71 m to 39.1 m
- SWL: 26.62 mBGL on the 1st Jun 2014
- Bentonite seal: 34.3 m to 36.5 m
- 1.6 - 3.2 mm washed, rounded, quartz gravel pack: 36.5 m to 45.5 m
- 50 mm PN9 uPVC machine slotted casing, slot apperture: 1 mm, slot length: 45 mm, 131 slots / m, 39.1 m to 45.1 m
- Bore development: 4 hrs 15 mins; EC: 134.4 μS/cm; pH: 7.12
- Airlift flow rate: 0.25 L/s
- End cap
- End of hole: 45.5 m BGL

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BOREHOLE LOG

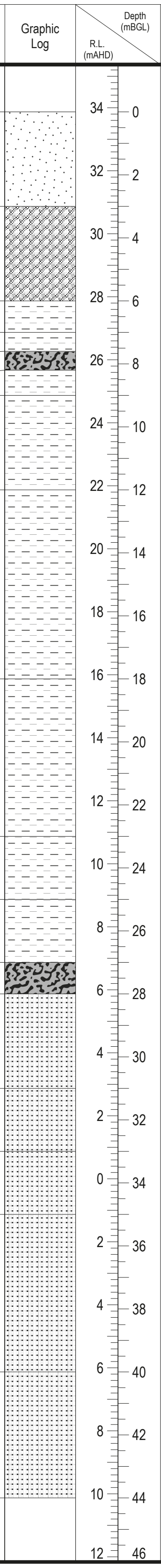
page:1 of 1

ELSMB06D

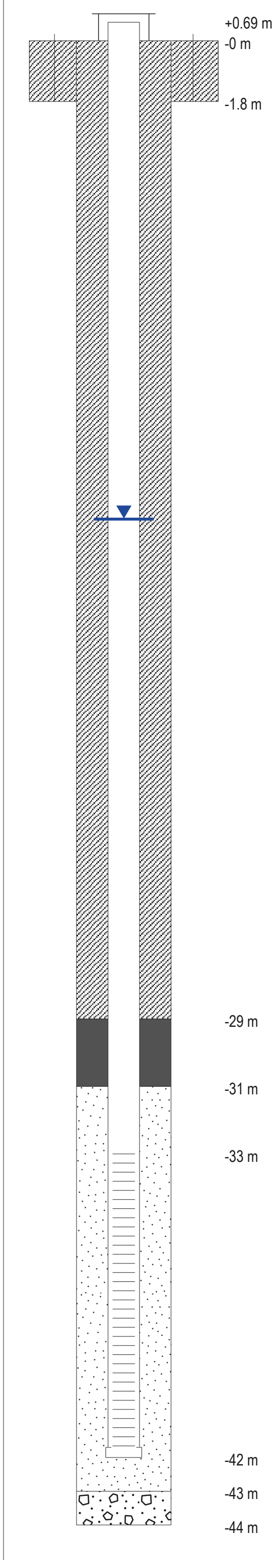
PROJECT No: **G1663**	DRILLING COMPANY: **J & S Drilling**	EASTING: **663560.48 mE**
PROJECT NAME: **Groote Eylandt**	DRILLER: **G. Despotakis (155NT/330WA)**	NORTHING: **8442618.6 mN**
DATE DRILLED: **9th Jan 2014**	DRILLING METHOD: **Mud Rotary**	DATUM: **MGA94 (z53)**
LOGGED BY: **HM (AGE)**	DRILL RIG: **Fraste XL Max**	RL: **33.87 mAHD**
COMMENTS:		TD: **45 mBGL**

Stratigraphic Cloumn		Soil or Rock Field Material Description
Sand	100	SAND: sub-angular, quartz clasts, red / brown, loose
Laterite	200	LATERITE: coarse sand, angular, lithic clasts, poorly graded, reddish brown, loose
	300	CLAY: medium plasticity, grey
		CLAY: low plasticity, mottled cream / black, very stiff
	400	MANGANESE: black, medium strength
Marine claystone	900	CLAY: mottled orange / cream, firm
		CLAY: mottled brown / cream, firm
		CLAY: mottled cream / yellow, firm
		CLAY: grey, stiff
		CLAY: red, stiff
		CLAY: light yellow, stiff
		MANGANESE: black, medium strength
Marine sandstone	1000	SANDSTONE: fine sand, rounded, quartz clasts, well graded, light yellow
Reworked basal sediments	1100	SANDSTONE: fine to medium sand, rounded, quartz clasts, light very low strength
		SANDSTONE: fine to coarse sand, rounded, quartz clasts, white / red / yellow, very low strength
		SANDSTONE: medium sand to coarse sand, rounded, quartz clasts, light cream, very low strength
		SANDSTONE: very fine sand, rounded, quartz clasts, light cream, very low strength, poor sample return

Graphic Log | R.L. (mAHD) | Depth (mBGL)



Bore Construction



Bore Description

- Protective lockable steel collar: +0.76 m
- Stick up: +0.69 m
- 305 mm Blade bit: 0 m to 1.8 m (Mud rotary)
- 158.8 mm PCD bit: 1.8 m to 44 m (Mud rotary)
- 219.1 mm (OD) steel (6.4 mm) surface casing: -0.2 m to 1.8 m
- Bentonite grout (4 %): 0 m to 29 m
- 50 mm PN9 uPVC blank casing: +0.7 m to 33 m
- SWL: 14.18 mBGL on the 31st May 2014
- Bentonite seal: 29 m to 31 m
- 1.6 - 3.2 mm washed, rounded, quartz gravel pack: 31 m to 43 m
- 50 mm PN9 uPVC machine slotted casing, slot apperture: 1 mm, slot length: 45 mm, 131 slots / m, 33 m to 42 m
- Bore development: 2 hrs 15 mins; EC: 48.17 µS/cm; pH: 5.64
- Airlift flow rate: 1.9 L/s
- End cap
- Hole collapse: 43 m to 44 m
- End of hole: 44 m BGL

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BOREHOLE LOG

page:1 of 1

ELSMB06S

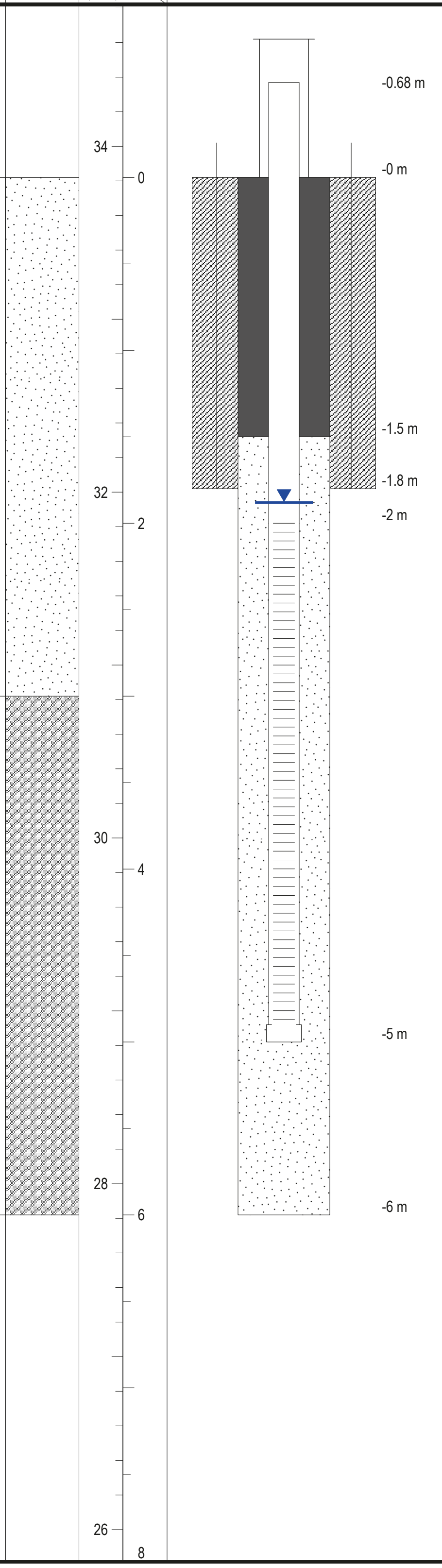
PROJECT No: **G1663**
PROJECT NAME: **Groote Eylandt**
DATE DRILLED: **10th Jan 2014**
LOGGED BY: **HM (AGE)**

DRILLING COMPANY: **J & S Drilling**
DRILLER: **G. Despotakis (155NT/330WA)**
DRILLING METHOD: **Mud Rotary**
DRILL RIG: **Fraste XL Max**

EASTING: **663556.93 mE**
NORTHING: **8442618.95 mN**
DATUM: **MGA94 (z53)**
RL: **33.82 mAHD**
TD: **6 mBGL**

COMMENTS: **Lithology from ELSMB06D**

Stratigraphic Cloumn	Soil or Rock Field Material Description	Depth (mBGL)	R.L. (mAHD)
Sand (100)	SAND: sub-angular, quartz clasts, red / brown, loose	0 – 3	33.82 – 30.82
Laterite (200)	LATERITE: coarse sand, angular, lithic clasts, poorly graded, reddish brown	3 – 6	30.82 – 27.82



Bore Description

- Protective lockable steel collar: +0.78 m
- Stick up: +0.68 m
- 305 mm Blade bit: 0 m to 1.8 m (Mud rotary)
- 158.8 mm Blade Bit: 1.8 m to 6 m (Mud rotary)
- 219.1 mm (OD) steel (6.4 mm) surface casing: -0.2 m to 1.8 m
- Bentonite seal: 0 m to 1.5 m
- 50 mm PN9 uPVC blank casing: +0.68 m to 2 m
- SWL: 1.88 mBGL on the 31st May 2014
- 1.6 - 3.2 mm washed, rounded, quartz gravel pack: 1.5 m to 6 m
- 50 mm PN9 uPVC machine slotted casing, slot apperture: 1 mm, slot length: 45 mm, 131 slots / m, 2 m to 5 m
- Bore development: 3 hrs 15 mins, bore flushed with fresh water
- No flow at the time of drilling
- End cap
- End of hole: 6 m BGL

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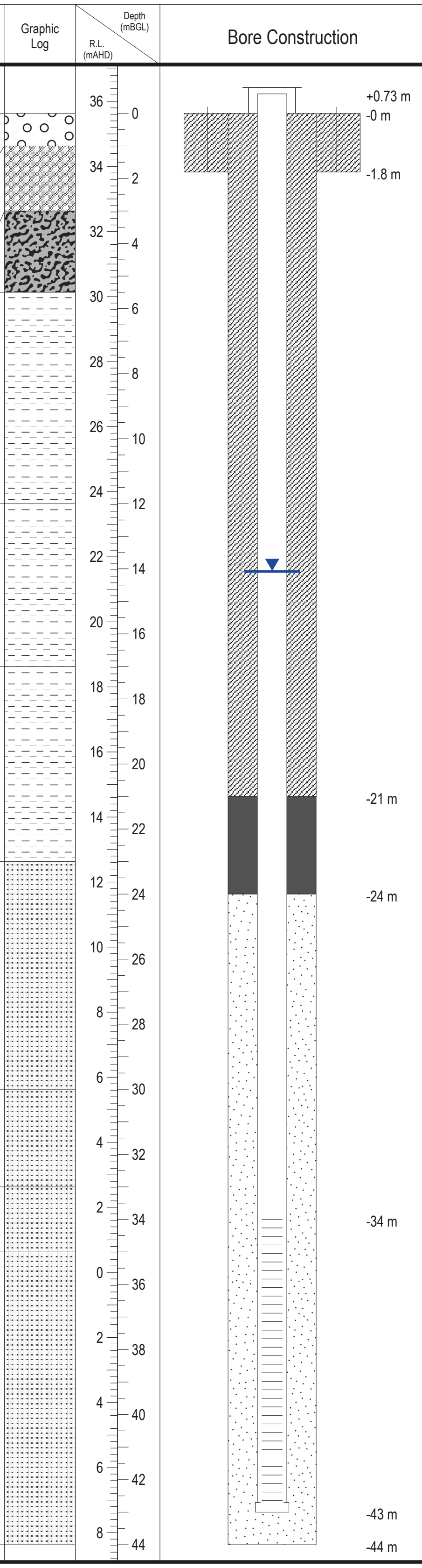
BOREHOLE LOG

page:1 of 1

ELSMB07D

PROJECT No: **G1663**	DRILLING COMPANY: **J & S Drilling**	EASTING: **665206.81 mE**
PROJECT NAME: **Groote Eylandt**	DRILLER: **G. Despotakis (155NT/330WA)**	NORTHING: **8441009.71 mN**
DATE DRILLED: **17th May 2014**	DRILLING METHOD: **Mud Rotary**	DATUM: **MGA94 (z53)**
LOGGED BY: **HM (AGE)**	DRILL RIG: **Fraste XL Max**	RL: **35.63 mAHD**
COMMENTS:		TD: **44 mBGL**

Stratigraphic Cloumn	Code	Soil or Rock Field Material Description
	100	GRAVEL: coarse gravel to fine sand, sub-angular, lithic clasts, poorly graded, dark reddish brown, low strength, loose, clasts consist of fine to medium sandstone
Laterite	200	LATERITE: coarse gravel to fine sand, sub-angular, lithic clasts, poorly graded, dark reddish brown, low strength, loose, clasts consist of fine to medium sandstone and manganese, laterised gravel
Manganese orebody	400	MANGANESE: black, high strength, generally massive manganese, pisolites at base
Marine claystone	900	CLAY: high plasticity, mottled greyish orange, low strength, soft, disseminated manganese throughout
Marine claystone		CLAY: high plasticity, grey, low strength, soft
Marine claystone		CLAY: high plasticity, mottled orange / grey, low strength, soft, disseminated manganese in samples between 18-19 m and 20-22 m
Marine sandstone	1000	SANDSTONE: medium sand to fine sand, rounded, quartz clasts, poorly graded, black / white, low strength, disseminated manganese throughout
Marine sandstone		SANDSTONE: very fine sand to fine sand, sub-rounded, quartz clasts, poorly graded, white, low strength
Reworked basal sediments	1100	SANDSTONE: medium sand to coarse sand, sub-rounded, quartz clasts, poorly graded, white, low strength
Reworked basal sediments		SANDSTONE: coarse sand to medium sand, quartz clasts, poorly graded, white / yellow, low strength, trace fine sand



Bore Description

- Protective lockable steel collar: +0.78 m
- Stick up: +0.73 m
- 305 mm Blade bit: 0 m to 1.8 m (Mud rotary)
- 158.8 mm PCD bit: 1.8 m to 44 m (Mud rotary)
- 219.1 mm (OD) steel (6.4 mm) surface casing: -0.2 m to 1.8 m
- Bentonite grout (4 %): 0 m to 21 m
- 50 mm PN9 uPVC blank casing: +0.74 m to 34 m
- SWL: 14.08 mBGL on the 31st May 2014
- Bentonite seal: 21 m to 24 m
- 1.6 - 3.2 mm washed, rounded, quartz gravel pack: 24 m to 44 m
- 50 mm PN9 uPVC machine slotted casing, slot apperture: 1 mm, slot length: 45 mm, 131 slots / m, 34 m to 43 m
- Bore development: 2 hrs 45 mins; EC: 56.92 μS/cm; pH: 6.35
- Airlift flow rate: 1.62 L/s
- End cap
- End of hole: 44 m BGL

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BOREHOLE LOG

page:1 of 1

ELSMB07S

PROJECT No: **G1663**
PROJECT NAME: **Groote Eylandt**
DATE DRILLED: **17th May 2014**
LOGGED BY: **HM (AGE)**

DRILLING COMPANY: **J & S Drilling**
DRILLER: **G. Despotakis (155NT/330WA)**
DRILLING METHOD: **Mud Rotary**
DRILL RIG: **Fraste XL Max**

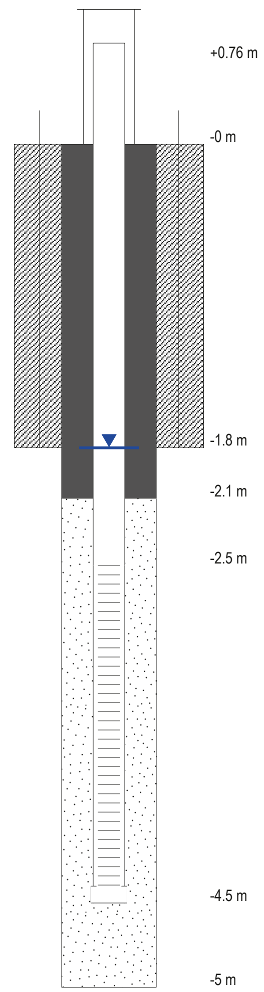
EASTING: **665209.81 mE**
NORTHING: **8441009.83 mN**
DATUM: **MGA94 (z53)**
RL: **35.59 mAHD**
TD: **5 mBGL**

COMMENTS: **Lithology from ELSMB07D**

Stratigraphic Cloumn	Soil or Rock Field Material Description	Graphic Log	Depth (mBGL) / R.L. (mAHD)
Sand (100)	GRAVEL: coarse gravel to fine sand, sub-angular, lithic clasts, poorly graded, dark reddish brown, low strength, loose, clasts consist of fine to medium sandstone		0 – 1 m (depth); 36 mAHD shown above
Laterite (200)	LATERITE: coarse gravel to fine sand, sub-angular, lithic clasts, poorly graded, dark reddish brown, low strength, loose, clasts consist of fine to medium sandstone and manganese, laterised gravel		1 – 3 m (depth); 34 mAHD, depth 2
Manganese orebody (400)	MANGANESE: black, high strength, generally massive manganese, pisolites at base		3 – 5 m (depth); 32 mAHD, depth 4

Depth scale (mBGL): 0, 2, 4, 6, 8
R.L. scale (mAHD): 36, 34, 32, 30, 28

Bore Construction



Bore Description

Protective lockable steel collar: +0.82 m

Stick up: +0.76 m

305 mm Blade bit: 0 m to 1.8 m (Mud rotary)

158.8 mm Blade Bit: 1.8 m to 5 m (Mud rotary)

219.1 mm (OD) steel (6.4 mm) surface casing: -0.2 m to 1.8 m

Bentonite seal: 0 m to 2.1 m

50 mm PN9 uPVC blank casing: +0.8 m to 2.5 m

SWL: 1.8 mBGL on the 31st May 2014

1.6 - 3.2 mm washed, rounded, quartz gravel pack: 2.1 m to 5 m

50 mm PN9 uPVC machine slotted casing, slot apperture: 1 mm, slot length: 45 mm, 131 slots / m, 2.5 m to 4.5 m

Bore development: 1 hr 30 mins; EC: 40.7 µS/cm; pH: 6.58

Airlift flow rate: ~1.5 L/s

End cap

End of hole: 5 m BGL

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BOREHOLE LOG

page:1 of 1

ELSMB08D

PROJECT No: **G1663**
PROJECT NAME: **Groote Eylandt**
DATE DRILLED: **25th May 2014**
LOGGED BY: **HM (AGE)**

DRILLING COMPANY: **J & S Drilling**
DRILLER: **G. Despotakis (155NT/330WA)**
DRILLING METHOD: **Mud Rotary**
DRILL RIG: **Fraste XL Max**

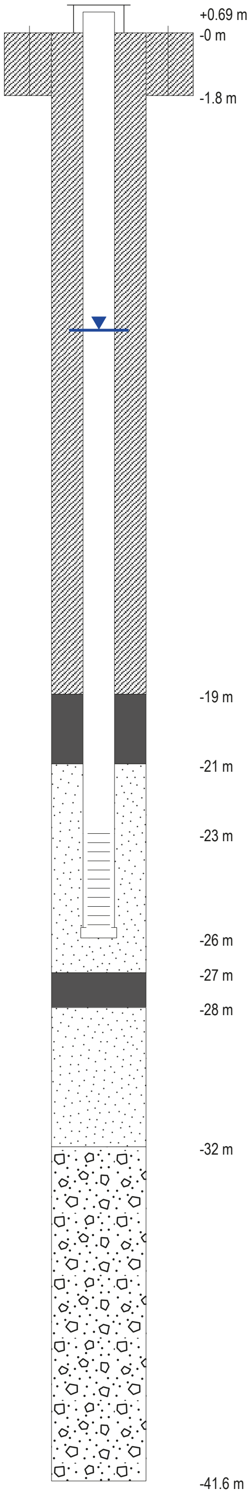
EASTING: **667487.7 mE**
NORTHING: **8440495.71 mN**
DATUM: **MGA94 (z53)**
RL: **43.1 mAHD**
TD: **41.6 mBGL**

COMMENTS:

Stratigraphic Cloumn	Soil or Rock Field Material Description
100	
200 Laterite	LATERITE: fine sand, quartz clasts, silty matrix, reddish low strength
300 Lateritic clay	SILTY CLAY: high plasticity, silty matrix, mottled orange / white, low strength, soft, trace coarse sand component
	CLAY: high plasticity, mottled reddish white, low strength, soft
400	MANGANESE: black, high strength, clay dispersed throughout
900 Marine claystone	CLAY: high plasticity, mottled reddish white, low strength, stiff, probably claystone
	CLAY: high plasticity, light grey, low strength, soft
	CLAY: light yellow, low strength, soft
	CLAY: light yellow, low strength, soft, manganese disseminated throughout
	SANDY CLAY & MANGANESE: mottled red / brown / grey, low strength, alternating manganese and clay layers
	CLAY: high plasticity, dark greenish grey, low strength
	CLAY: high plasticity, red, low strength, soft
	SILTY CLAY: medium plasticity, light yellow, low strength, alternating manganese and clay layers

R.L. (mAHD)	Depth (mBGL)
43	0
41	2
39	4
37	6
35	8
33	10
31	12
29	14
27	16
25	18
23	20
21	22
19	24
17	26
15	28
13	30
11	32
9	34
7	36
5	38
3	40
1	42
1	44

Bore Construction



Bore Description

- Protective lockable steel collar: +0.73 m
- Stick up: +0.69 m
- 305 mm Blade bit: 0 m to 1.8 m (Mud rotary)
- 158.8 mm Blade Bit: 1.8 m to 41.6 m (Mud rotary)
- 219.1 mm (OD) steel (6.4 mm) surface casing: -0.2 m to 1.8 m
- SWL: 8.54 mBGL on the 31st May 2014
- 50 mm PN9 uPVC blank casing: +0.7 m to 23 m
- Bentonite grout (4 %): 0 m to 19 m
- Bentonite seal: 19 m to 21 m
- 1.6 - 3.2 mm washed, rounded, quartz gravel pack: 21 m to 27 m
- 50 mm PN9 uPVC machine slotted casing, slot apperture: 1 mm, slot length: 45 mm, 131 slots / m, 23 m to 26 m
- End cap
- Bentonite seal: 27 m to 28 m
- Gravel backfill: 28 m to 32 m
- Bore development: 1 hr 45 mins; EC: 123.8 µS/cm; pH: 7.47
- Airlift flow rate: 0.14 L/s
- Drill cuttings backfill: 32 m to 41.6 m
- End of hole: 41.6 m BGL

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BOREHOLE LOG

ELSMB08S

PROJECT No: **G1663**
PROJECT NAME: **Groote Eylandt**
DATE DRILLED: **26th May 2014**
LOGGED BY: **HM (AGE)**

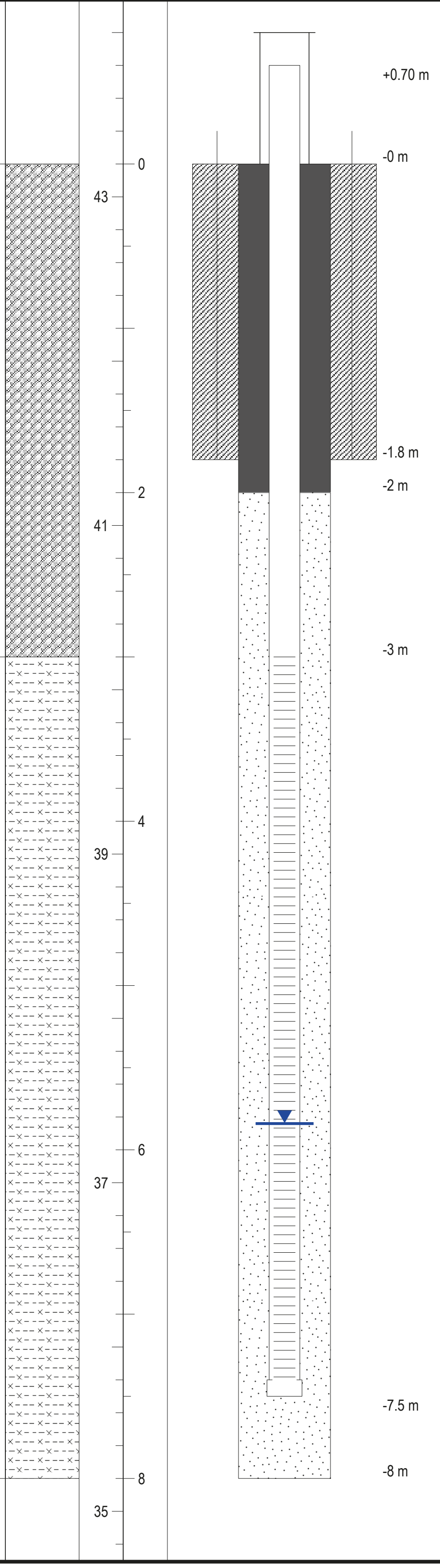
DRILLING COMPANY: **J & S Drilling**
DRILLER: **G. Despotakis (155NT/330WA)**
DRILLING METHOD: **Mud Rotary**
DRILL RIG: **Fraste XL Max**

EASTING: **667489.96 mE**
NORTHING: **8440495.53 mN**
DATUM: **MGA94 (z53)**
RL: **43.2 mAHD**
TD: **8 mBGL**

COMMENTS: **Lithology from ELSMB08D**

Stratigraphic Cloumn	Soil or Rock Field Material Description
Sand (100–200)	
Laterite (200–300)	LATERITE: fine sand, quartz clasts, silty matrix, reddish low strength
Lateritic clay (300)	SILTY CLAY: high plasticity, silty matrix, mottled orange / white, low strength, soft, trace coarse sand component

Graphic Log | Depth (mBGL) / R.L. (mAHD) | Bore Construction



Bore Description

Protective lockable steel collar: +0.77 m

Stick up: +0.70 m

305 mm Blade bit: 0 m to 1.8 m (Mud rotary)

158.8 mm Blade Bit: 1.8 m to 8 m (Mud rotary)

219.1 mm (OD) steel (6.4 mm) surface casing: -0.2 m to 1.8 m

Bentonite seal: 0 m to 2 m

50 mm PN9 uPVC blank casing: +0.72 m to 3.0 m

1.6 - 3.2 mm washed, rounded, quartz gravel pack: 2 m to 8 m

50 mm PN9 uPVC machine slotted casing, slot apperture: 1 mm, slot length: 45 mm, 131 slots / m, 3 m to 7.5 m

Bore development: 1 hr

no flow during development, water used to clean gravel pack

SWL: 5.84 mBGL on the 31st May 2014

End cap

End of hole: 8 m BGL

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BOREHOLE LOG

page:1 of 1

ELSMB09D

PROJECT No: **G1663**
PROJECT NAME: **Groote Eylandt**
DATE DRILLED: **22nd May 2014**
LOGGED BY: **HM (AGE)**

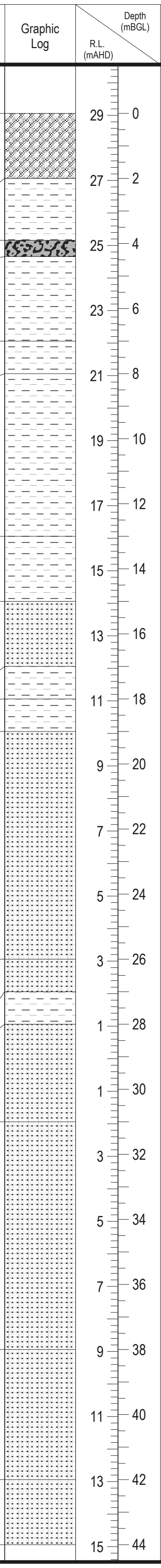
DRILLING COMPANY: **J & S Drilling**
DRILLER: **G. Despotakis (155NT/330WA)**
DRILLING METHOD: **Mud Rotary**
DRILL RIG: **Fraste XL Max**

EASTING: **665819.03 mE**
NORTHING: **8440248.4 mN**
DATUM: **MGA94 (z53)**
RL: **29.06 mAHD**
TD: **44 mBGL**

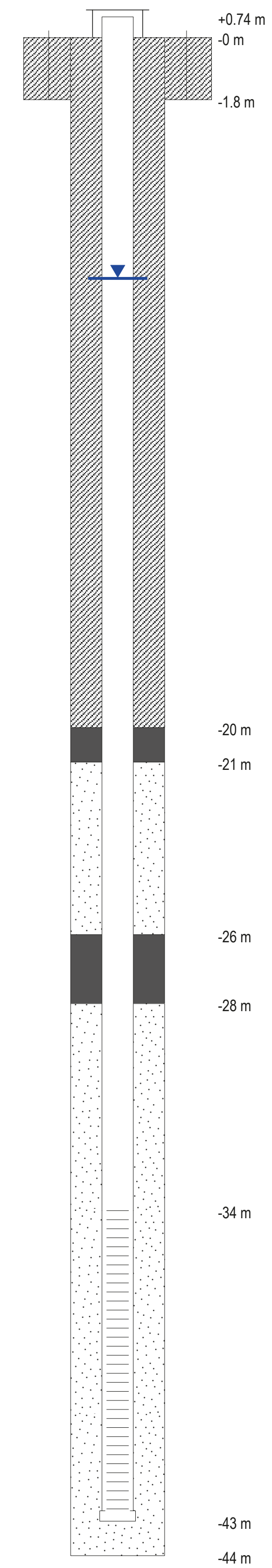
COMMENTS:

Stratigraphic Cloumn	Soil or Rock Field Material Description
Laterite (100, 200)	LATERITE: coarse gravel, sub-angular, dark reddish brown, low strength, loose, clasts consist of manganese cemented sandstone and manganese nodules, laterised gravel
Lateritic clay (300)	CLAY: high plasticity, mottled cream / orange, low strength, soft
(400)	MANGANESE: black, high strength
Marine claystone (900)	CLAY: high plasticity, orange, low strength, soft, red staining on planar surfaces
	CLAY: low plasticity, light low strength, stiff, purple staining on planar surfaces
	CLAY: high plasticity, mottled orange / grey, low strength, soft
	CLAY: high plasticity, red, low strength, stiff
	SANDSTONE & MANGANESE: fine sand, quartz clasts, light yellow, very low strength, extremely weathered, manganese has infilled the sandstone matrix
	CLAY: high plasticity, brown
	CLAY: high plasticity, light low strength, soft
Marine sandstone (1000)	SANDSTONE: fine sand to medium sand, rounded, quartz clasts, low strength
	SANDSTONE: coarse sand to medium sand, sub-angular, quartz clasts, poorly graded, white, low strength
Reworked basal sediments (1100)	CLAY: silty matrix, light orange, soft
	SANDSTONE: coarse sand to medium sand, sub-angular, quartz clasts, poorly graded, white, low strength
	SANDSTONE: fine sand to medium sand, sub-angular, quartz clasts, poorly graded, white, low strength
	SANDSTONE: medium sand to coarse sand, sub-angular, quartz clasts, poorly graded, white, low strength
	SANDSTONE: coarse sand, sub-angular, quartz clasts, poorly graded, white / orange, low strength

Graphic Log | R.L. (mAHD) | Depth (mBGL)



Bore Construction



Bore Description

Protective lockable steel collar: +0.79 m
Stick up: +0.74 m
305 mm Blade bit: 0 m to 1.8 m (Mud rotary)
158.8 mm Blade Bit: 1.8 m to 44 m (Mud rotary)
219.1 mm (OD) steel (6.4 mm) surface casing: -0.2 m to 1.8 m
SWL: 6.98 mBGL on the 2nd Jun 2014
Bentonite grout (4 %): 0 m to 20 m
50 mm PN9 uPVC blank casing: +0.71 m to 34 m
Bentonite seal: 20 m to 21 m
Gravel backfill: 21 m to 26 m
Bentonite seal: 26 m to 28 m
1.6 - 3.2 mm washed, rounded, quartz gravel pack: 28 m to 44 m
50 mm PN9 uPVC machine slotted casing, slot apperture: 1 mm, slot length: 45 mm, 131 slots / m, 34 m to 43 m
Bore development: 2 hrs; EC: 54.18 µS/cm; pH: 5.44
Airlift flow rate: 5.3 L/s
End cap
End of hole: 44 m BGL

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BOREHOLE LOG

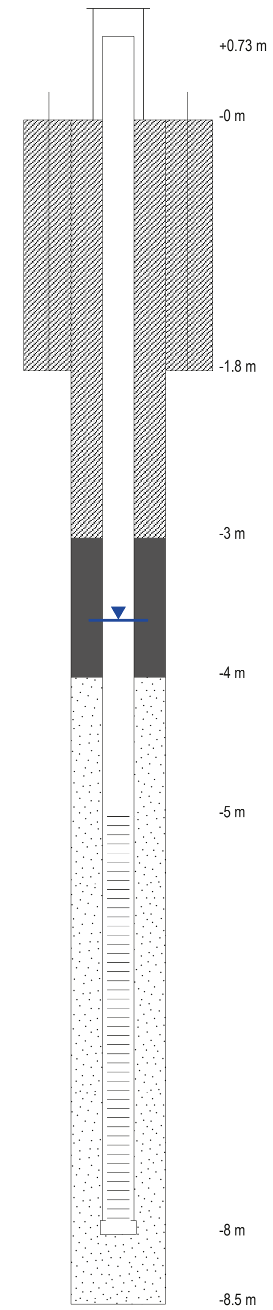
ELSMB09S

PROJECT No: **G1663**	DRILLING COMPANY: **J & S Drilling**	EASTING: **665821.42 mE**
PROJECT NAME: **Groote Eylandt**	DRILLER: **G. Despotakis (155NT/330WA)**	NORTHING: **8440248.35 mN**
DATE DRILLED: **23rd May 2014**	DRILLING METHOD: **Mud Rotary**	DATUM: **MGA94 (z53)**
LOGGED BY: **HM (AGE)**	DRILL RIG: **Fraste XL Max**	RL: **29.11 mAHD**
COMMENTS: **Lithology from ELSMB09D**		TD: **8.5 mBGL**

Stratigraphic Cloumn	Code	Soil or Rock Field Material Description	Depth (mBGL)
Laterite	100		0
Laterite	200	LATERITE: coarse gravel, sub-angular, dark reddish brown, low strength, loose, clasts consist of manganese cemented sandstone and manganese nodules, laterised gravel	0 – 2
Lateritic clay	300	CLAY: high plasticity, mottled cream / orange, low strength, soft	2 – 3.8
	400	MANGANESE: black, high strength	3.8 – 4.3
Marine claystone	900	CLAY: high plasticity, orange, low strength, soft, red staining on planar surfaces	4.3 – 6.9
Marine claystone		CLAY: low plasticity, light low strength, stiff, purple staining on planar surfaces	6.9 – 7.9
Marine claystone		CLAY: high plasticity, mottled orange / grey, low strength, soft	7.9 – 8.5

Graphic Log; R.L. (mAHD): 29, 27, 25, 23, 21, 19; Depth (mBGL): 0, 2, 4, 6, 8, 10

Bore Construction



Bore Description

Protective lockable steel collar: +0.80 m

Stick up: +0.73 m

305 mm Blade bit: 0 m to 1.8 m (Mud rotary)

158.8 mm Blade Bit: 1.8 m to 8.5 m (Mud rotary)

219.1 mm (OD) steel (6.4 mm) surface casing: -0.2 m to 1.8 m

Bentonite grout (4 %): 0 m to 3 m

50 mm PN9 uPVC blank casing: +0.69 m to 5 m

Bentonite seal: 3 m to 4 m

SWL: 3.59 mBGL on the 2nd Jun 2014

1.6 - 3.2 mm washed, rounded, quartz gravel pack: 4 m to 8.5 m

50 mm PN9 uPVC machine slotted casing, slot apperture: 1 mm, slot length: 45 mm, 131 slots / m, 5 m to 8 m

Bore development: 1 hr

no flow during development, water used to clean gravel pack

End cap

End of hole: 8.5 m BGL

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BOREHOLE LOG

page:1 of 1

ELSMB10D

PROJECT No: **G1663**
PROJECT NAME: **Groote Eylandt**
DATE DRILLED: **27th May 2014**
LOGGED BY: **HM (AGE)**

DRILLING COMPANY: **J & S Drilling**
DRILLER: **G. Despotakis (155NT/330WA)**
DRILLING METHOD: **Mud Rotary**
DRILL RIG: **Fraste XL Max**

EASTING: **668229.77 mE**
NORTHING: **8442001.12 mN**
DATUM: **MGA94 (z53)**
RL: **59.5 mAHD**
TD: **37.6 mBGL**

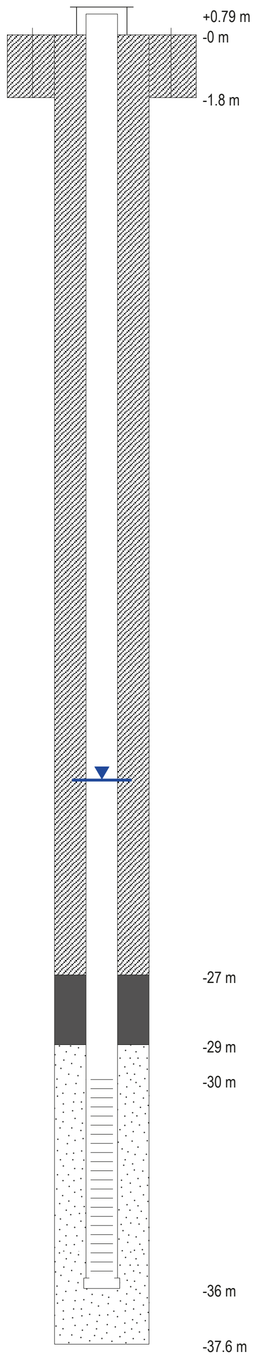
COMMENTS:

Stratigraphic Cloumn	Code	Soil or Rock Field Material Description
Sand	100	SILTY CLAY: low plasticity, coarse sand, rounded, quartz clasts, red, low strength, soft
Laterite	200	LATERITE: fine sand, quartz clasts, silty matrix, yellow / red, medium strength, fine sandstone laterite
Lateritic clay	300	SILTY CLAY: fine sand, quartz clasts, mottled white / yellow, low strength, soft, probably weathered sandstone
	400	SANDY CLAY & MANGANESE: dark medium strength, alternating layers of clay and manganese
Marine claystone	900	CLAY: light grey, low strength, soft, manganese throughout forming alternating layers of clay and manganese
Marine claystone		CLAY: high plasticity, mottled red / grey, low strength, soft
Marine claystone		CLAY: high plasticity, mottled red / grey, low strength, soft, disseminated manganese throughout
Marine claystone		CLAY: high plasticity, mottled red / grey, low strength, soft
Marine claystone		SANDY CLAY: dark greenish grey, low strength
Marine claystone		CLAY: medium plasticity, mottled grey, low strength, soft
Marine claystone		SILTY CLAY: low plasticity, fine sand, quartz clasts, low strength, soft, probably weathered sandstone

R.L. (mAHD): 61, 59, 57, 55, 53, 51, 49, 47, 45, 43, 41, 39, 37, 35, 33, 31, 29, 27, 25, 23, 21, 19, 17, 15

Depth (mBGL): 0, 2, 4, 6, 8, 10, 12, 14, 16, 18, 20, 22, 24, 26, 28, 30, 32, 34, 36, 38, 40, 42, 44

Bore Construction



Bore Description

Protective lockable steel collar
Stick up: +0.79 m

305 mm Blade bit: 0 m to 1.8 m (Mud rotary)

158.8 mm Blade Bit: 1.8 m to 37.6 m (Mud rotary)

219.1 mm (OD) steel (6.4 mm) surface casing: -0.2 m to 1.8 m

Bentonite grout (4 %): 0 m to 27 m

50 mm PN9 uPVC blank casing: +0.79 m to 30 m

SWL: 21.4 mBGL on the 1st Jun 2014

Bentonite seal: 27 m to 29 m

1.6 - 3.2 mm washed, rounded, quartz gravel pack: 29 m to 37.6 m

50 mm PN9 uPVC machine slotted casing, slot apperture: 1 mm, slot length: 45 mm, 131 slots / m, 30 m to 36 m

End cap

End of hole: 37.6 m BGL

Bore development: 2 hrs 45 mins; EC: 314.1 μS/cm; pH: 8.16
Airlift flow rate: 0.08 L/s

Australasian Groundwater & Environmental Consultants Pty Ltd

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BOREHOLE LOG

page:1 of 1

ELSMB10S

PROJECT No: **G1663**
PROJECT NAME: **Groote Eylandt**
DATE DRILLED: **28th May 2014**
LOGGED BY: **HM (AGE)**

DRILLING COMPANY: **J & S Drilling**
DRILLER: **G. Despotakis (155NT/330WA)**
DRILLING METHOD: **Mud Rotary**
DRILL RIG: **Fraste XL Max**

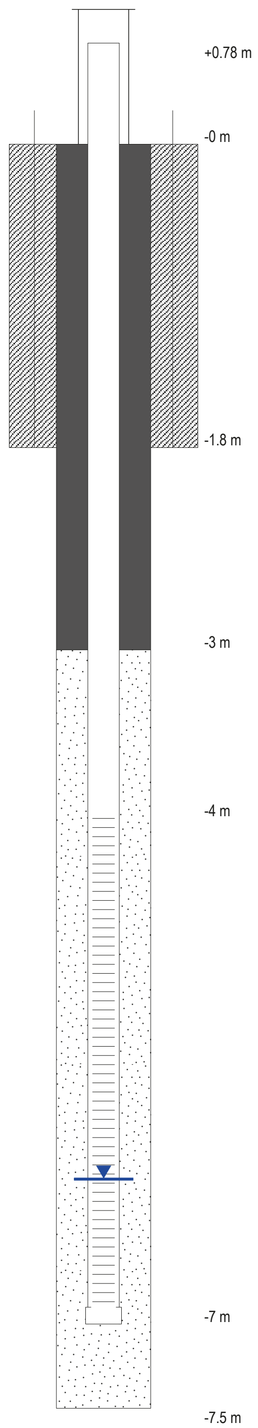
EASTING: **668229.7 mE**
NORTHING: **8441999.02 mN**
DATUM: **MGA94 (z53)**
RL: **59.49 mAHD**
TD: **7.5 mBGL**

COMMENTS: **Lithology from ELSMB10D**

Stratigraphic Cloumn	Soil or Rock Field Material Description	Graphic Log	Depth (mBGL)
Sand	SILTY CLAY: low plasticity, coarse sand, rounded, quartz clasts, red, low strength, soft		0 – 3
Laterite	LATERITE: fine sand, quartz clasts, silty matrix, yellow / red, medium strength, fine sandstone laterite		3 – 7
Lateritic clay	SILTY CLAY: fine sand, quartz clasts, mottled white / yellow, low strength, soft, probably weathered sandstone		7 – 7.5

Depth scale (mBGL): 0, 2, 4, 6, 8. R.L. scale (mAHD): 59, 57, 55, 53, 51.

Bore Construction



Bore Description

Protective lockable steel collar

Stick up: +0.78 m

305 mm Blade bit: 0 m to 1.8 m (Mud rotary)

158.8 mm Blade Bit: 1.8 m to 7.5 m (Mud rotary)

219.1 mm (OD) steel (6.4 mm) surface casing: -0.2 m to 1.8 m

Bentonite seal: 0 m to 3 m

50 mm PN9 uPVC blank casing: +0.75 m to 4 m

1.6 - 3.2 mm washed, rounded, quartz gravel pack: 3 m to 7.5 m

50 mm PN9 uPVC machine slotted casing, slot apperture: 1 mm, slot length: 45 mm, 131 slots / m, 4 m to 7 m

Bore development: 1 hr

no flow during development, water used to clean gravel pack

SWL: 6.14 mBGL on the 1st Jun 2014

End cap

End of hole: 7.5 m BGL

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BOREHOLE LOG

page:1 of 1

ELSPB07

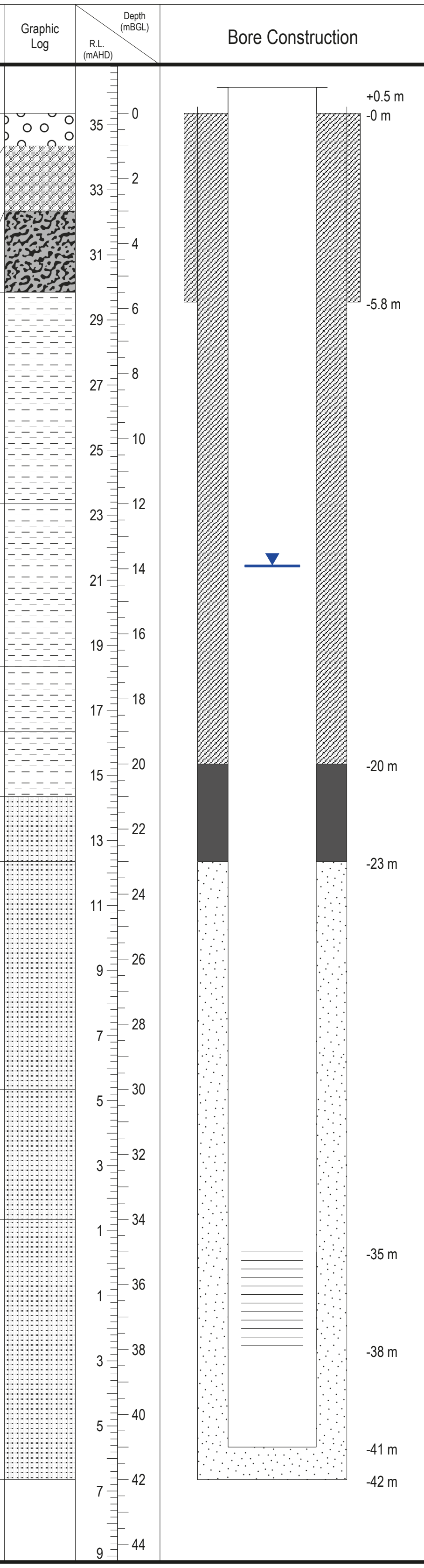
PROJECT No: **G1663**
PROJECT NAME: **Groote Eylandt**
DATE DRILLED: **20th May 2014**
LOGGED BY: **HM (AGE)**

DRILLING COMPANY: **J & S Drilling**
DRILLER: **G. Despotakis (155NT/330WA)**
DRILLING METHOD: **Mud Rotary**
DRILL RIG: **Fraste XL Max**

EASTING: **665213.95 mE**
NORTHING: **8440998.55 mN**
DATUM: **MGA94 (z53)**
RL: **35.35 mAHD**
TD: **42 mBGL**

COMMENTS:

Stratigraphic Cloumn	Soil or Rock Field Material Description
100	GRAVEL: coarse gravel to fine sand, sub-angular, lithic clasts, poorly graded, dark reddish brown, low strength, loose, clasts consist of fine to medium sandstone
200 Laterite	LATERITE: coarse gravel to fine sand, sub-angular, lithic clasts, poorly graded, dark reddish brown, low strength, loose, clasts consist of fine to medium sandstone and manganese, laterised gravel
400 Manganese orebody	MANGANESE: black, high strength, generally massive manganese, pisolites at base
900 Marine claystone	CLAY: high plasticity, dark greenish grey / orange, low strength, soft, disseminated manganese throughout
	CLAY: high plasticity, greenish grey / yellow, low strength, soft
	CLAY: mottled low strength, soft
	CLAY: high plasticity, yellow, low strength, soft
	SANDSTONE: fine sand to medium sand, quartz clasts, black with white speckles, high strength, manganese forms the sandstone matrix
1000 Marine sandstone	SANDSTONE: medium sand, sub-rounded, quartz clasts, poorly graded, black / white, low strength, trace manganese throughout
	SANDSTONE: fine sand to medium sand, sub-rounded, quartz clasts, poorly graded, low strength, trace coarse sand
1100 Reworked basal sediments	SANDSTONE: medium sand to coarse sand, sub-rounded, quartz clasts, poorly graded, low strength



Bore Description

Headworks; Table D flange

Stick up: +0.32 m

359.9 mm Tri-cone: 0 m to 5.8 m (Mud rotary)

254 mm Tri-cone: 5.8 m to 42 m (Mud rotary)

273.1 mm (OD) steel (9.3 mm) surface casing: -0.2 m to 5.8 m

Bentonite grout (4 %): 0 m to 20 m

168.3 mm (OD) steel (7.1 mm) surface casing: +0.5 m to 35 m

SWL: 13.73 mBGL on the 31st May 2014

Bentonite seal: 20 m to 23 m

1.6 - 3.2 mm washed, rounded, quartz gravel pack: 23 m to 42 m

Bore development: 3 hrs; EC: 56.5 µS/cm; pH: 6.25

Airlift flow rate: 4 - 5 L/s

Initially the airlift flow rate was approx 6 - 7 L/s, after about 15 minutes the bore began to surge producing apporximately 4

154.1 mm stainless steel wire wound, slot apperture: 1.5 mm, 35 m to 38 m

3 m sump and end cap: 38 m to 41 m

End of hole: 42 m BGL

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Level 2, 15 Mallon Street, Bowen Hills, Queensland 4006

BOREHOLE LOG

ELSPB09

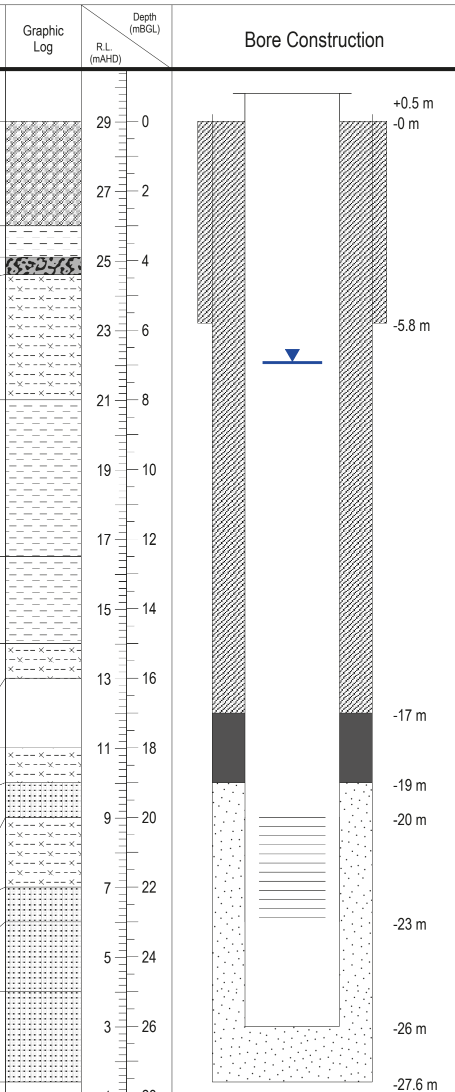
PROJECT No: **G1663**
PROJECT NAME: **Groote Eylandt**
DATE DRILLED: **30th May 2014**
LOGGED BY: **HM (AGE)**

DRILLING COMPANY: **J & S Drilling**
DRILLER: **G. Despotakis (155NT/330WA)**
DRILLING METHOD: **Mud Rotary**
DRILL RIG: **Fraste XL Max**

EASTING: **665826.14 mE**
NORTHING: **8440240.1 mN**
DATUM: **MGA94 (z53)**
RL: **29.02 mAHD**
TD: **27.6 mBGL**

COMMENTS:

Stratigraphic Cloumn	Code	Soil or Rock Field Material Description
Laterite	100, 200	LATERITE: fine sand, quartz clasts, dark grey, medium strength, manganese cemented sandstone clasts in laterite
	300	CLAY: light grey, low strength, weathered claystone
	400	MANGANESE: black, high strength
Marine claystone	900	SANDY CLAY: mottled grey / orange, low strength, manganese throughout clay
		CLAY: high plasticity, light grey, low strength, soft, probably claystone
		CLAY: high plasticity, red, low strength
		SILTY CLAY: high plasticity, coarse sand, sub-rounded, red, low strength, manganese cemented sandstone clasts
Marine sandstone	1000	NO SAMPLE RETURN: drilling samples mixed up
		SILTY CLAY: low plasticity, fine sand, quartz clasts, mottled red / yellow / white, low strength
		SANDSTONE: coarse sand to fine sand, sub-rounded to sub-angular, quartz clasts, poorly graded, low strength, manganese cemented sandstone clasts
		SILTY CLAY: low plasticity, fine sand to coarse sand, quartz clasts, mottled white / red, low strength
Reworked basal sediments	1100	SANDSTONE: fine sand to medium sand, sub-rounded, quartz clasts, white, low strength
		SANDSTONE: fine sand to coarse sand, sub-rounded to sub-angular, quartz clasts, white, low strength
		SANDSTONE: fine sand to medium sand, sub-rounded, quartz clasts, white, low strength



Bore Description

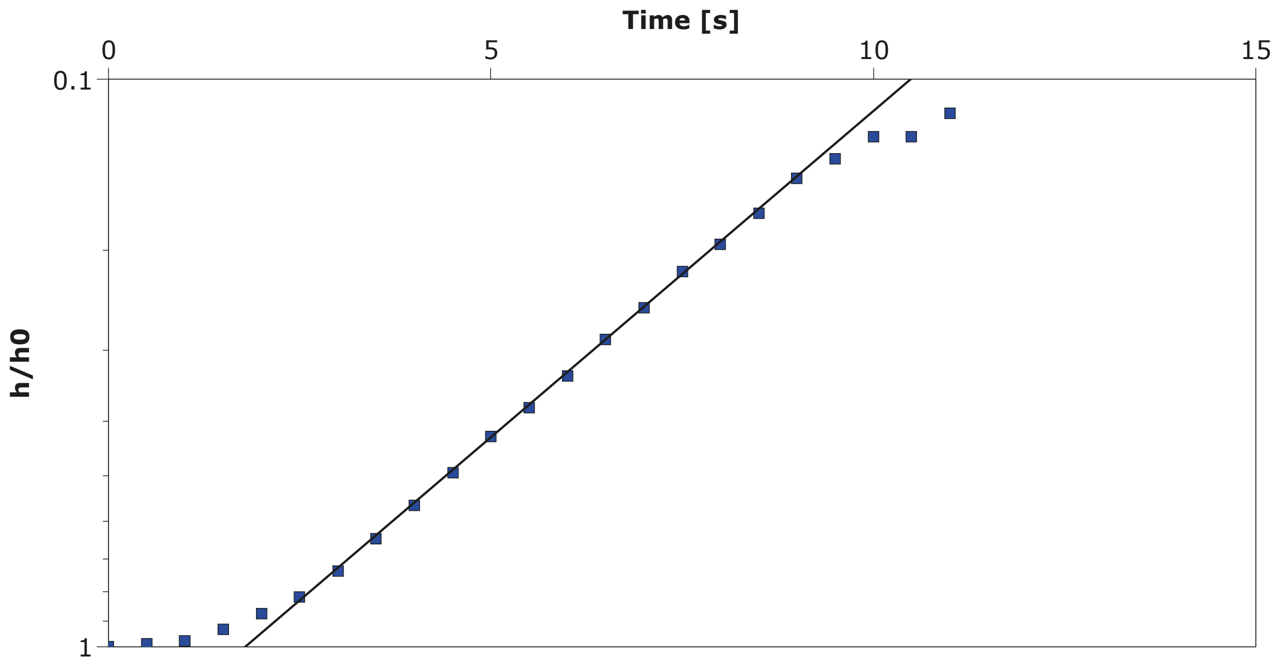
Headworks; Table D flange
Stick up: +0.47 m
359.9 mm Tri-cone: 0 m to 5.8 m (Mud rotary)
254 mm Tri-cone: 5.8 m to 27.6 m (Mud rotary)
273.1 mm (OD) steel (9.3 mm) surface casing: -0.2 m to 5.8 m
SWL: 6.93 mBGL on the 2nd Jun 2014
Bentonite grout (4 %): 0 m to 17 m
168.3 mm (OD) steel (7.1 mm) surface casing: +0.47 m to 20 m
Bentonite seal: 17 m to 19 m
1.6 - 3.2 mm washed, rounded, quartz gravel pack: 19 m to 27.6 m
154.1 mm stainless steel wire wound, slot apperture: 1.5 mm, slot length: n/a mm, n/a slots / m, 20 m to 23 m
3 m sump and end cap: 23 m to 26 m
End cap
End of hole: 27.6 m BGL
Bore development: 3 hrs 30 mins; EC: 71.3 µS/cm; pH: 5.82
Airlift flow rate: 6.4 L/s
trace fine sand still present at the end of bore development

Appendix A 2

Hydraulic test data sheets

AGE Consultants Level 2/15 Mallon St Bowen Hills, QLD, 4006	**Slug Test Analysis Report**
	Project: Gemco
	Number: G1663
	Client: Hansen Bailey

Location: Groote Eylandt, NT	Slug Test: ELSMB01D: falling head	Test Well: ELNMB01D
Test Conducted by: H. McCarthy		Test Date: 11/01/2014
Analysis Performed by: H. McCarthy	Hvorslev	Analysis Date: 30/06/2014
Aquifer Thickness: 13.00 m		

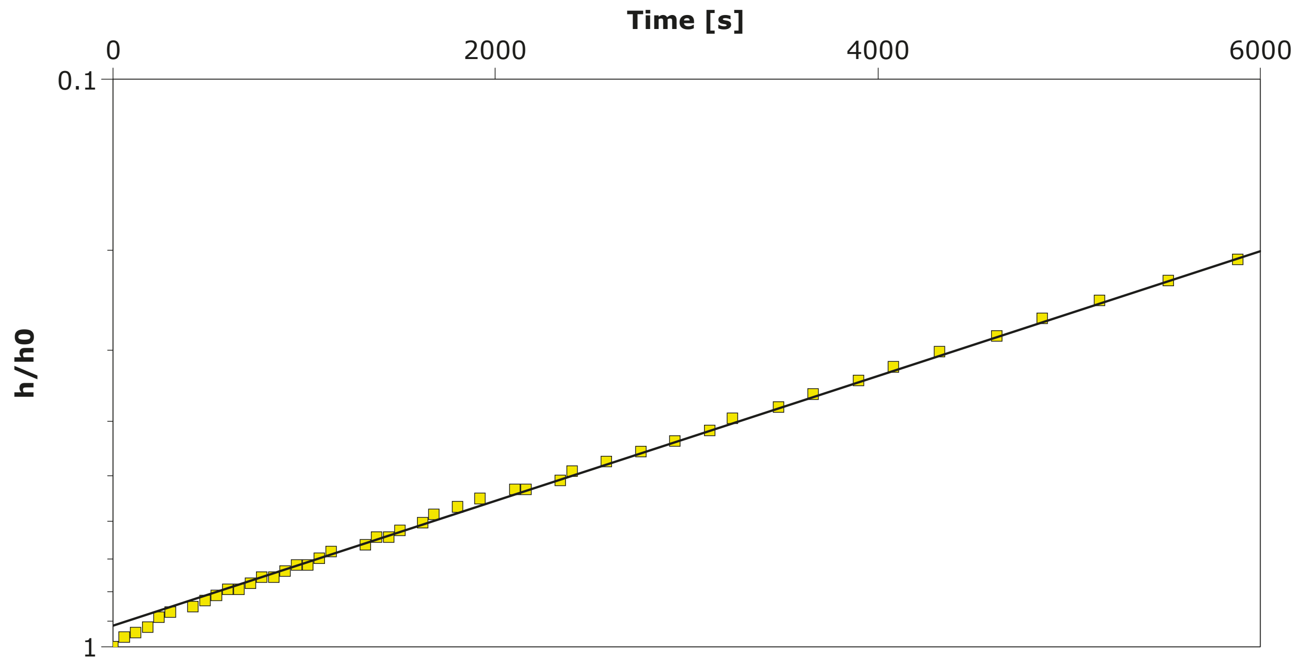


Calculation using Hvorslev

Observation Well	Hydraulic Conductivity [m/d]
ELNMB01D	4.70×10^{0}

AGE Consultants **Level 2/15 Mallon St** **Bowen Hills, QLD, 4006**	**Slug Test Analysis Report**
	Project: Gemco
	Number: G1663
	Client: Hansen Bailey

Location: Groote Eylandt, NT	Slug Test: ELSMB01S: falling head	Test Well: ELNMB01S
Test Conducted by: H. McCarthy		Test Date: 23/05/2014
Analysis Performed by: H. McCarthy	Bouwer & Rice	Analysis Date: 30/06/2014
Aquifer Thickness: 6.00 m		

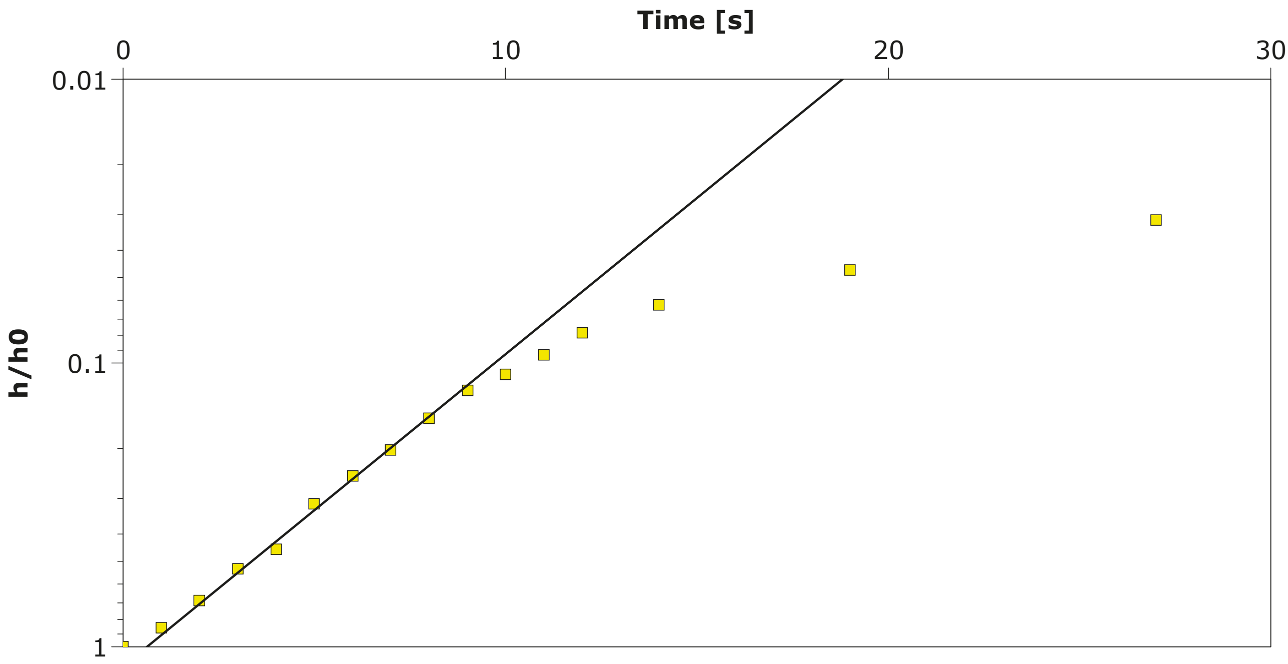


Calculation using Bouwer & Rice

Observation Well	Hydraulic Conductivity [m/d]	
ELNMB01S	8.50×10^{-3}	

AGE Consultants **Level 2/15 Mallon St** **Bowen Hills, QLD, 4006**	**Slug Test Analysis Report** Project: Gemco Number: G1663 Client: Hansen Bailey

Location: Groote Eylandt, NT	Slug Test: ELSMB03D: rising head	Test Well: ELNMB03D
Test Conducted by: H. McCarthy		Test Date: 10/01/2014
Analysis Performed by: H. McCarthy	Hvorslev	Analysis Date: 30/06/2014
Aquifer Thickness: 21.50 m		

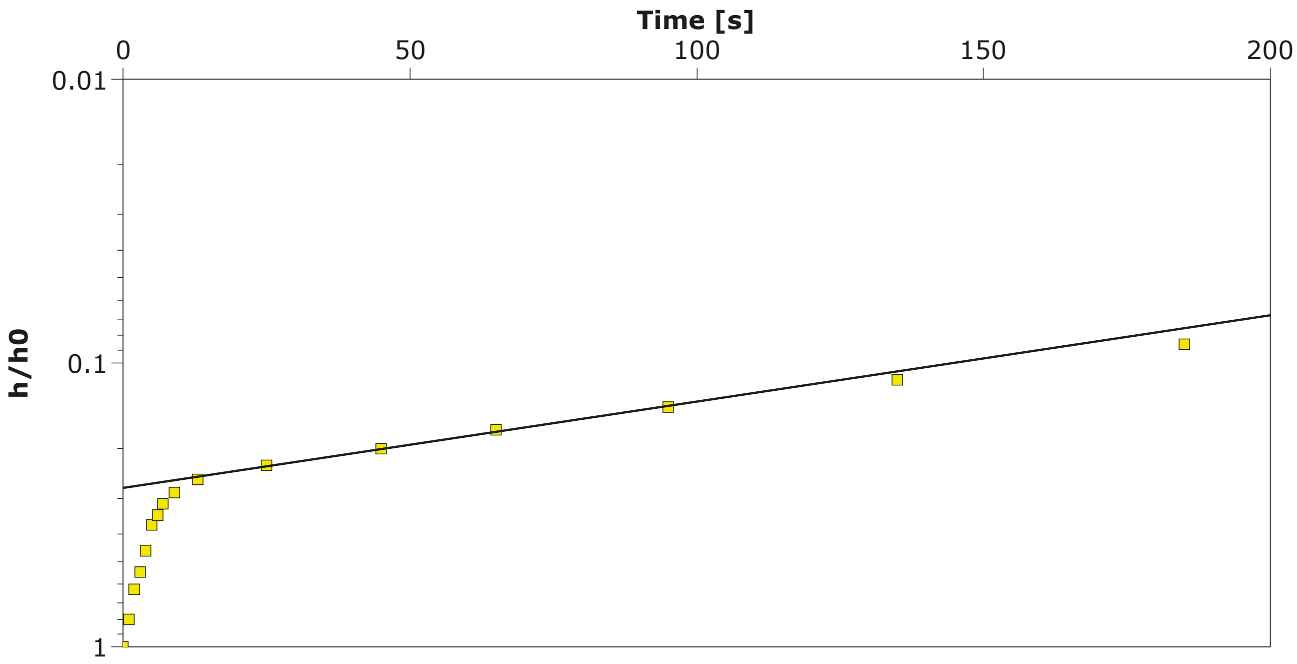


Calculation using Hvorslev

Observation Well	Hydraulic Conductivity [m/d]
ELNMB03D	4.50×10^{0}

AGE Consultants **Level 2/15 Mallon St** **Bowen Hills, QLD, 4006**	**Slug Test Analysis Report**
	Project: Gemco
	Number: G1663
	Client: Hansen Bailey

Location: Groote Eylandt, NT	Slug Test: ELSMB03S: rising head	Test Well: ELNMB03S
Test Conducted by: H. McCarthy		Test Date: 22/05/2014
Analysis Performed by: H. McCarthy	Bouwer & Rice	Analysis Date: 30/06/2014
Aquifer Thickness: 8.00 m		



Calculation using Bouwer & Rice

Observation Well	Hydraulic Conductivity [m/d]	
ELNMB03S	2.34×10^{-1}	

AGE Consultants
Level 2/15 Mallon St
Bowen Hills, QLD, 4006

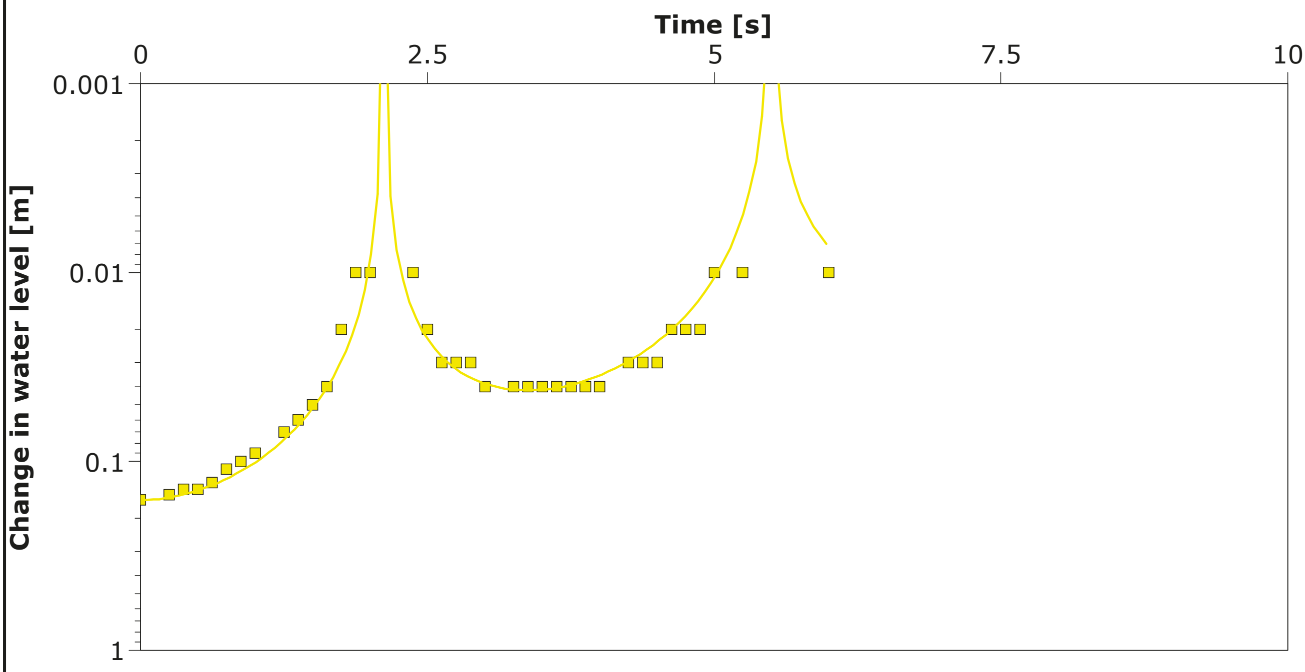
Slug Test Analysis Report

Project: Gemco

Number: G1663

Client: Hansen Bailey

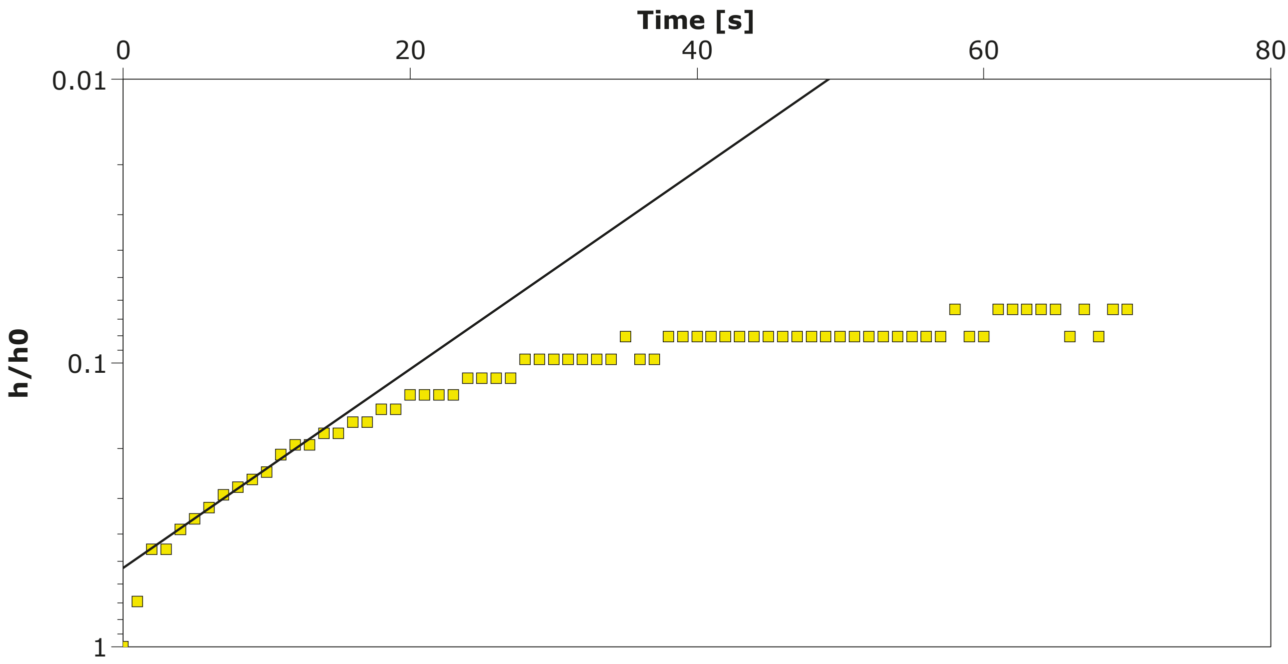
Location: Groote Eylandt, NT	Slug Test: ELSMB04D: rising head	Test Well: ELNMB04D
Test Conducted by: H. McCarthy		Test Date: 20/05/2014
Analysis Performed by: H. McCarthy	Butler High-K	Analysis Date: 30/06/2014
Aquifer Thickness: 30.00 m		



Calculation using Butler High-K

Observation Well	tD/t	Hydraulic Conductivity m/d	CD	
ELNMB04D	1.01×10^{0}	2.28×10^{1}	7.84×10^{-1}	

AGE Consultants **Level 2/15 Mallon St** **Bowen Hills, QLD, 4006**		**Slug Test Analysis Report** Project: Gemco Number: G1663 Client: Hansen Bailey
Location: Groote Eylandt, NT	Slug Test: ELSMB05: falling head	Test Well: ELSMB05
Test Conducted by: H. McCarthy		Test Date: 20/05/2014
Analysis Performed by: H. McCarthy	Hvorslev	Analysis Date: 30/06/2014
Aquifer Thickness: 9.00 m		



Calculation using Hvorslev

Observation Well	Hydraulic Conductivity [m/d]	
ELSMB05	2.00×10^{0}	

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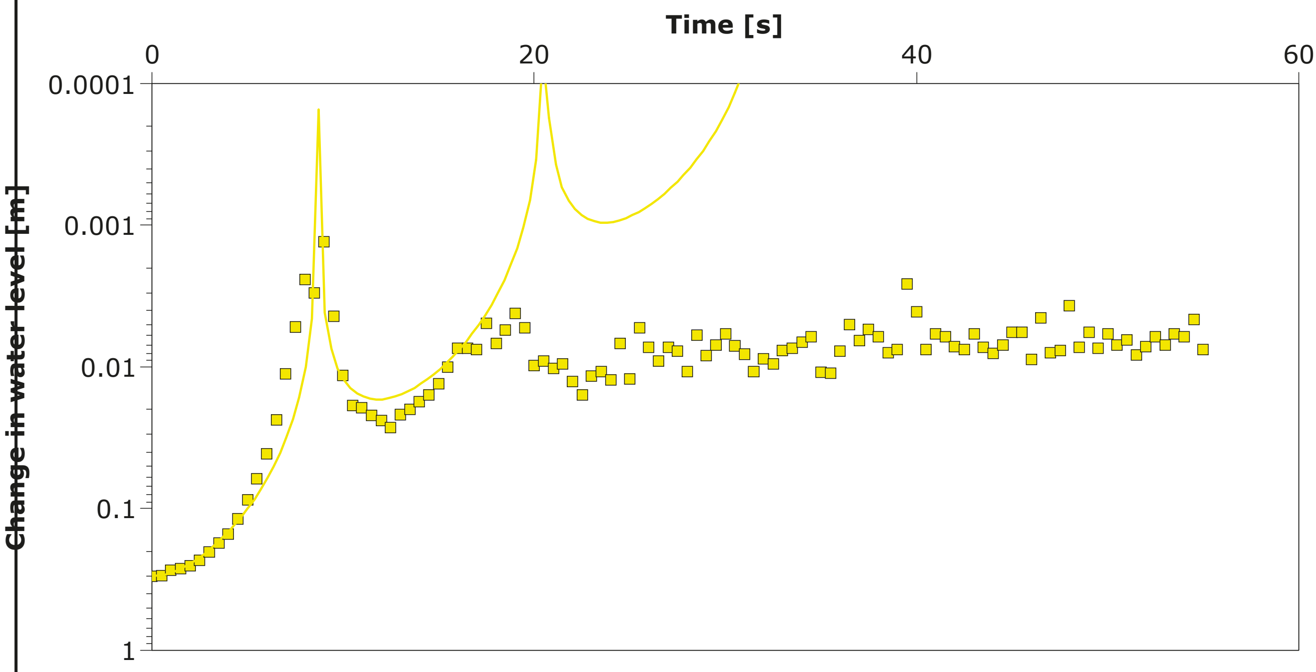
Slug Test Analysis Report		
Project: Gemco		
Number: G1663		
Client: Hansen Bailey		
Location: Groote Eylandt, NT	Slug Test: ELSMB06D: falling head	Test Well: ELSMB06D
Test Conducted by: H. McCarthy		Test Date: 30/05/2014
Analysis Performed by: S. Jones	Butler High-K	Analysis Date: 30/06/2014
Aquifer Thickness: 16.00 m		

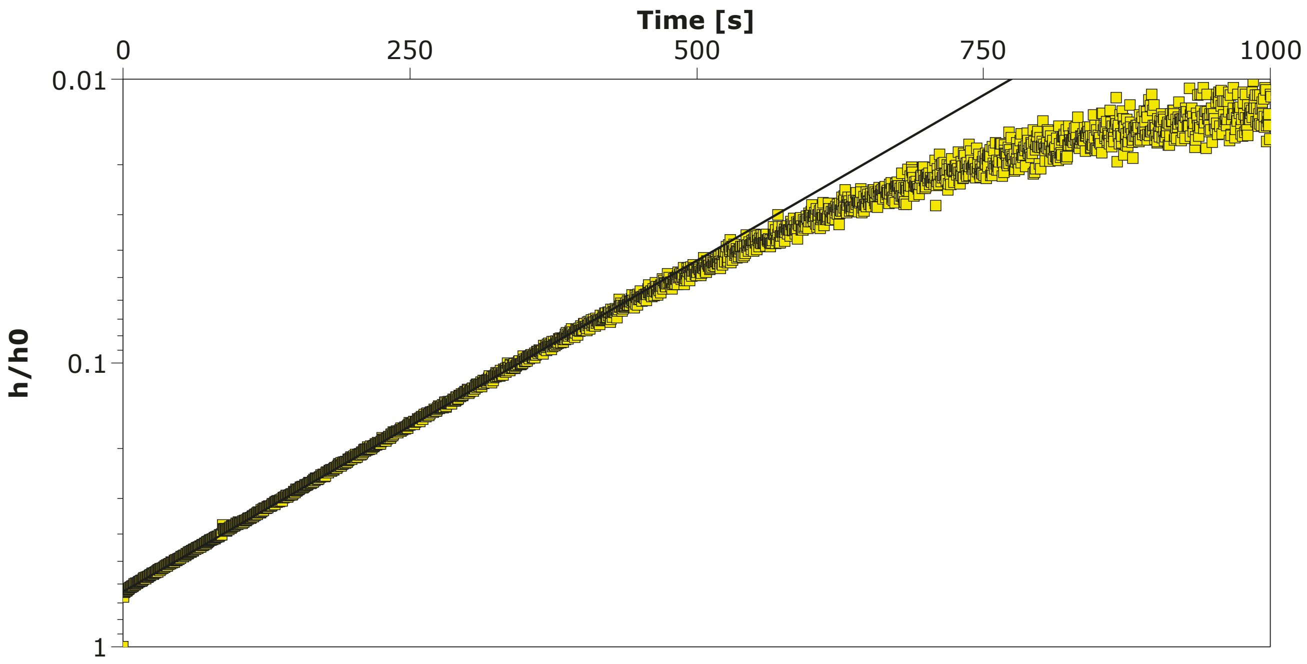


Calculation using Butler High-K

Observation Well	tD/t	Hydraulic Conductivity m/d	CD	
ELSMB06D	3.60×10^{-1}	4.71×10^{0}	1.35×10^{0}	

AGE Consultants **Level 2/15 Mallon St** **Bowen Hills, QLD, 4006**	**Slug Test Analysis Report**
	Project: Gemco
	Number: G1663
	Client: Hansen Bailey

Location: Groote Eylandt, NT	Slug Test: ELSMB06S: rising head	Test Well: ELSMB06S
Test Conducted by: H. McCarthy		Test Date: 15/05/2014
Analysis Performed by: H. McCarthy	Bouwer & Rice	Analysis Date: 30/06/2014
Aquifer Thickness: 6.00 m		



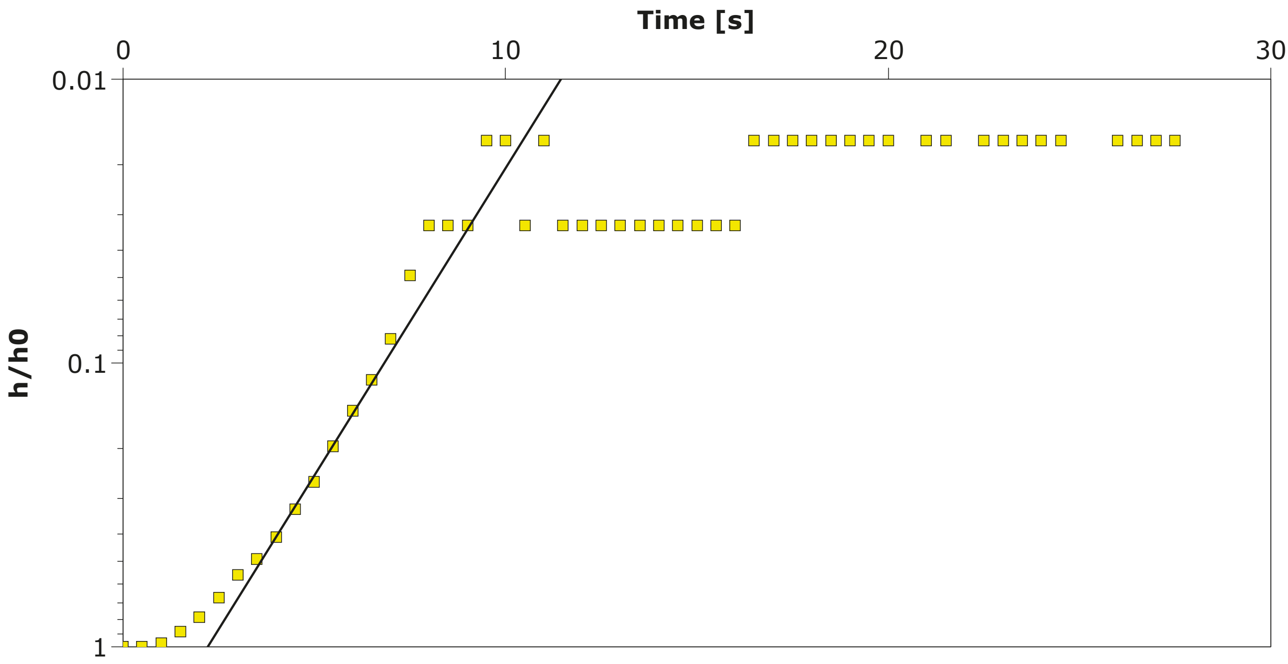
Calculation using Bouwer & Rice

Observation Well	Hydraulic Conductivity [m/d]	
ELSMB06S	1.80×10^{-1}	

AGE Consultants
Level 2/15 Mallon St
Bowen Hills, QLD, 4006

Slug Test Analysis Report
Project: Gemco
Number: G1663
Client: Hansen Bailey

Location: Groote Eylandt, NT	Slug Test: ELSMB07D: falling head	Test Well: ELSMB07D
Test Conducted by: H. McCarthy		Test Date: 27/05/2014
Analysis Performed by: H. McCarthy	Hvorslev	Analysis Date: 1/07/2014
Aquifer Thickness: 21.00 m		

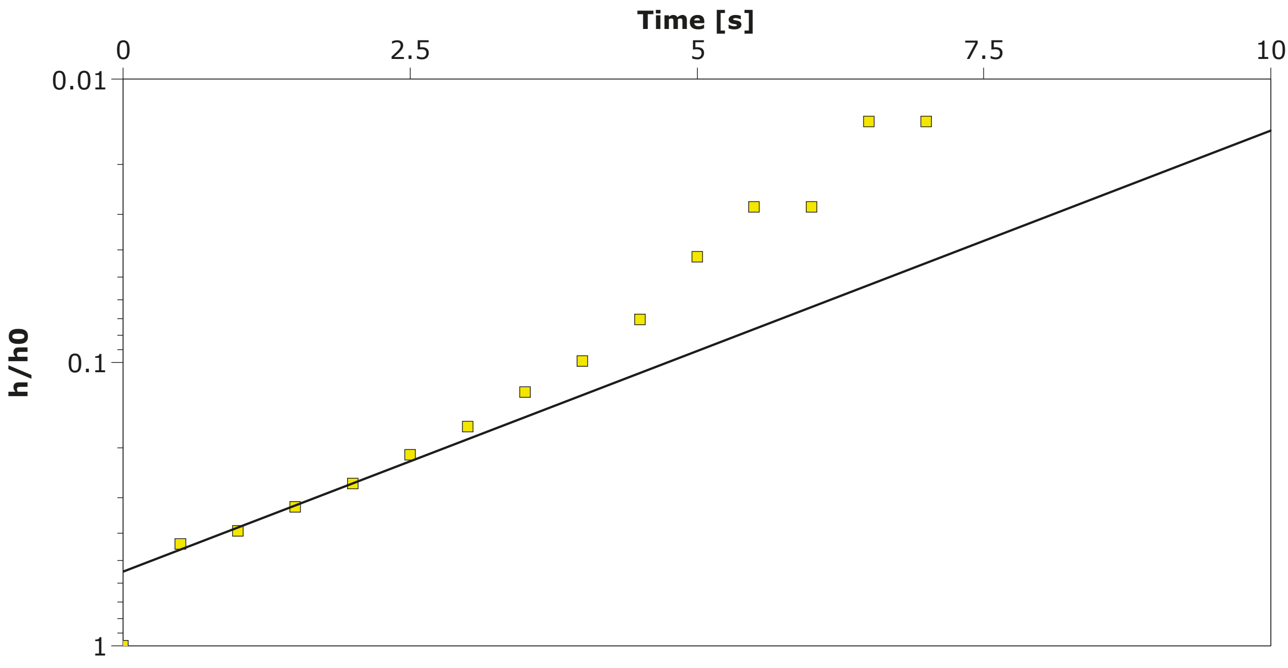


Calculation using Hvorslev

Observation Well	Hydraulic Conductivity [m/d]
ELSMB07D	8.86×10^{0}

AGE Consultants **Level 2/15 Mallon St** **Bowen Hills, QLD, 4006**	**Slug Test Analysis Report** Project: Gemco Number: G1663 Client: Hansen Bailey

Location: Groote Eylandt, NT	Slug Test: ELSMB07S: rising head	Test Well: ELSMB07S
Test Conducted by: H. McCarthy		Test Date: 22/05/2014
Analysis Performed by: H. McCarthy	Bouwer & Rice	Analysis Date: 30/06/2014
Aquifer Thickness: 5.00 m		



Calculation using Bouwer & Rice

Observation Well	Hydraulic Conductivity [m/d]	
ELSMB07S	1.20×10^{1}	

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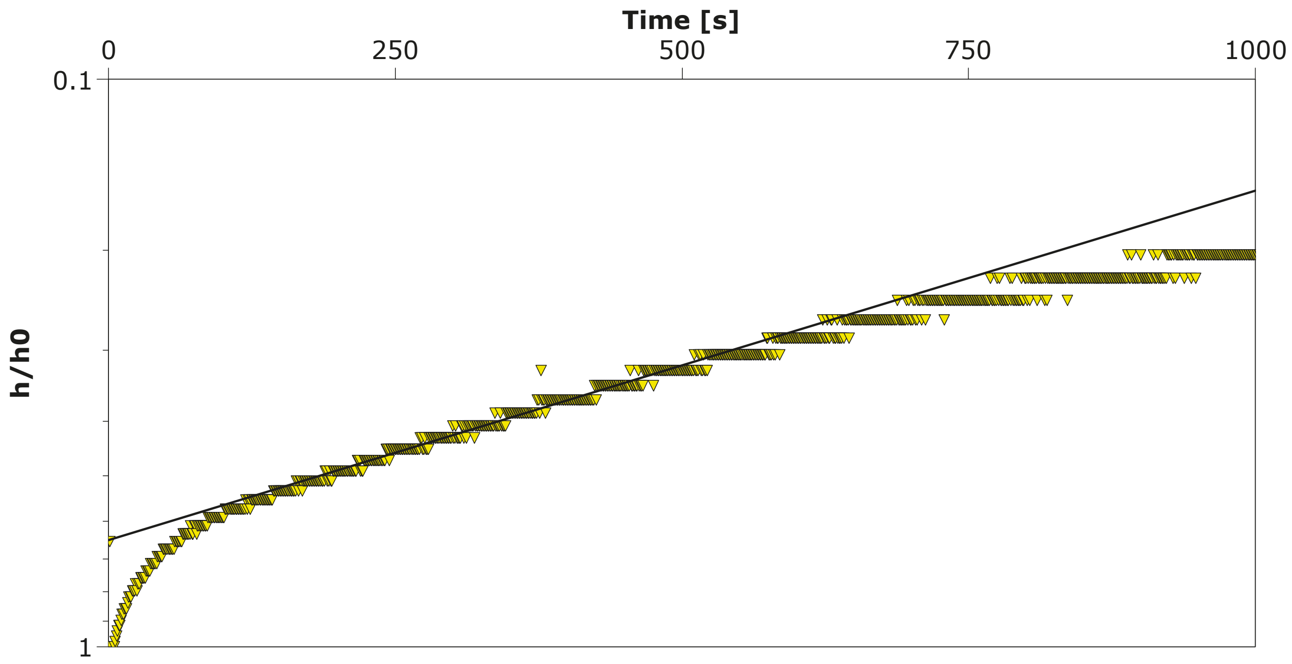
Bowen Hills, QLD, 4006

Slug Test Analysis Report		
Project: Gemco		
Number: G1663		
Client: Hansen Bailey		
Location: Groote Eylandt, NT	Slug Test: ELSMB08D: falling head	Test Well: ELSMB08D
Test Conducted by: H. McCarthy		Test Date: 29/05/2014
Analysis Performed by: H. McCarthy	Hvorslev	Analysis Date: 30/06/2014
Aquifer Thickness: 6.00 m		

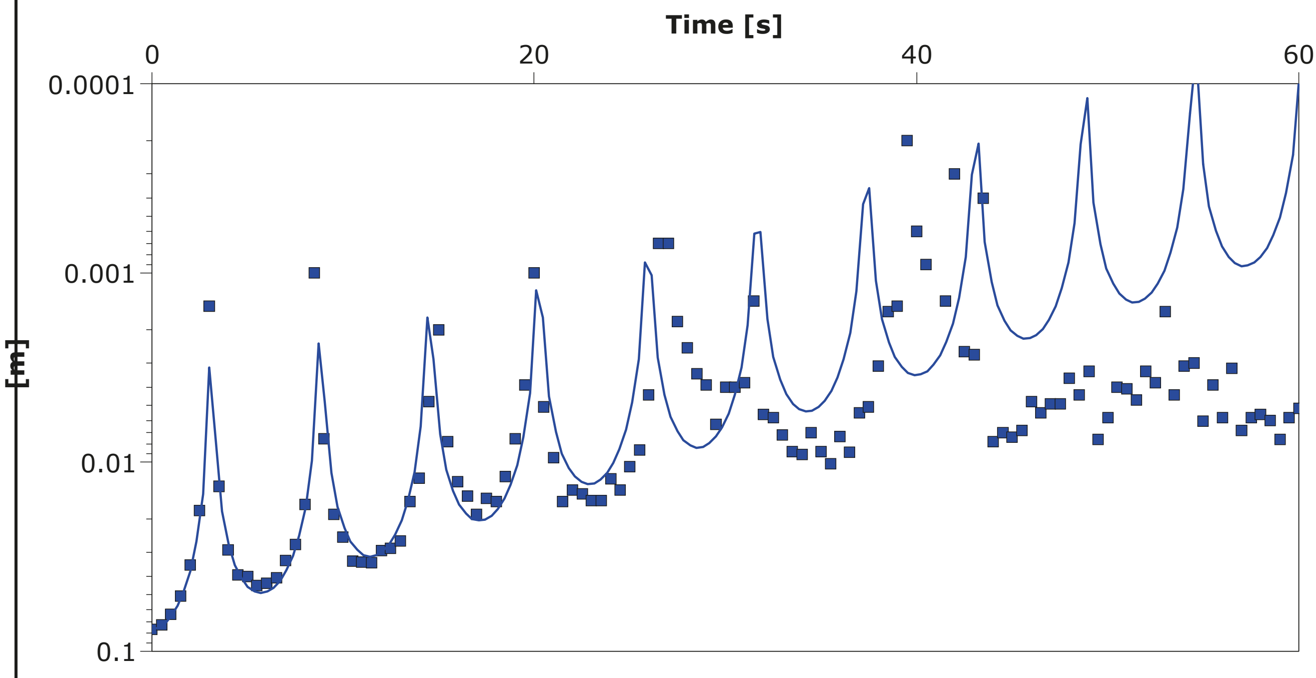


Calculation using Hvorslev

Observation Well	Hydraulic Conductivity [m/d]
ELSMB08D	6.15×10^{-2}

AGE Consultants **Level 2/15 Mallon St** **Bowen Hills, QLD, 4006**	**Slug Test Analysis Report** Project: Gemco Number: G1663 Client: Hansen Bailey

Location: Groote Eylandt, NT	Slug Test: ELSMB09D: falling head	Test Well: ELSMB09D
Test Conducted by: H. McCarthy		Test Date: 25/05/2014
Analysis Performed by: H. McCarthy	Butler High K	Analysis Date: 30/06/2014
Aquifer Thickness: 25.00 m		

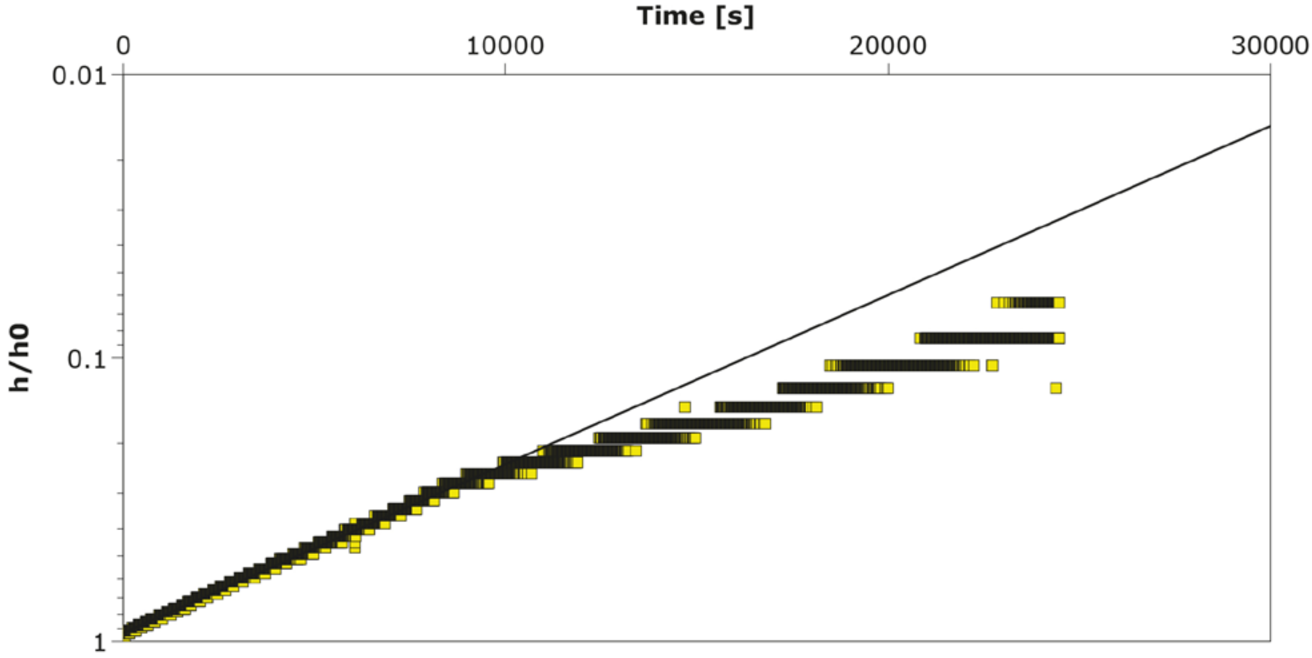


Calculation using Butler High-K

Observation Well	tD/t	Hydraulic Conductivity m/d	CD	
ELSMB09D	5.55×10^{-1}	3.52×10^{1}	2.79×10^{-1}	

AGE Consultants **Level 2/15 Mallon St** **Bowen Hills, QLD, 4006**	**Slug Test Analysis Report**
	Project: Gemco
	Number: G1663
	Client: Hansen Bailey

Location: Groote Eylandt, NT	Slug Test: ELSMB09S: falling head	Test Well: ELSMB09S
Test Conducted by: H. McCarthy		Test Date: 17/06/2014
Analysis Performed by: H. McCarthy	Bouwer & Rice	Analysis Date: 30/06/2014
Aquifer Thickness: 8.50 m		



Calculation using Bouwer & Rice

Observation Well	Hydraulic Conductivity [m/d]
ELSMB09S	4.60×10^{-3}

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Bowen Hills, QLD, 4006

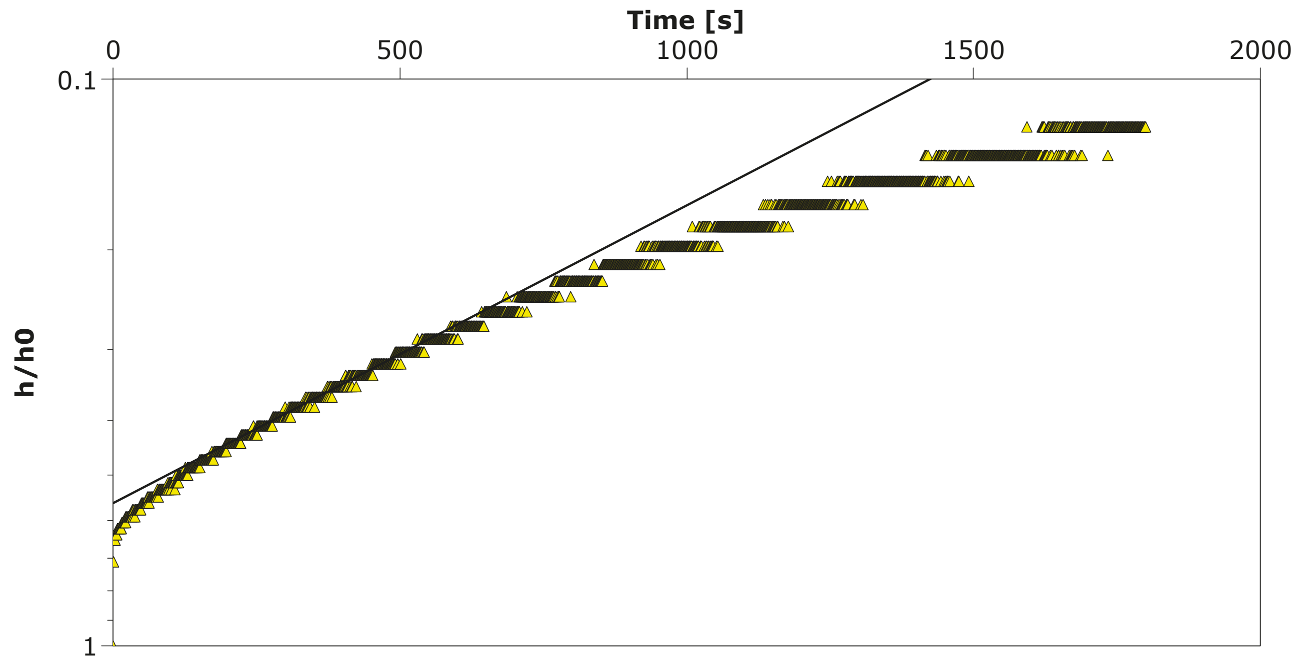
Slug Test Analysis Report

Project: Gemco

Number: G1663

Client: Hansen Bailey

Location: Groote Eylandt, NT	Slug Test: ELSMB10D: rising head	Test Well: ELSMB10D
Test Conducted by: H. McCarthy		Test Date: 29/05/2014
Analysis Performed by: H. McCarthy	Hvorslev	Analysis Date: 30/06/2014
Aquifer Thickness: 8.60 m		

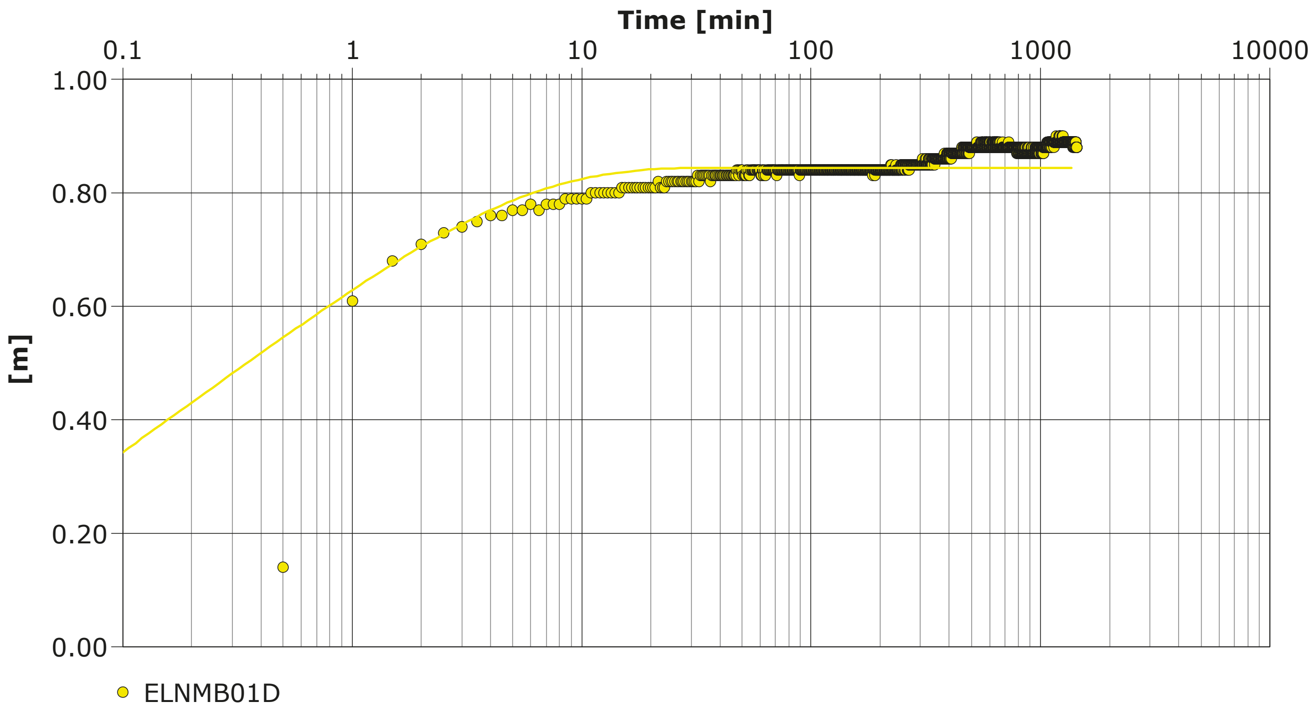


Calculation using Hvorslev

Observation Well	Hydraulic Conductivity [m/d]	
ELSMB10D	3.00×10^{-2}	

AGE Consultants Level 2/15 Mallon St Bowen Hills, QLD, 4006	**Pumping Test Analysis Report**
	Project: Gemco
	Number: G1663
	Client: Hansen Bailey

Location: Groote Eylandt, NT	Pumping Test: 24 hr constant rate	Pumping Well: ELNPB01
Test Conducted by: Gemco / J & S Drilling		Test Date: 22/06/2014
Analysis Performed by: H. McCarthy		Analysis Date: 3/07/2014
Aquifer Thickness: 12.00 m	Discharge Rate: 12.3 [l/s]	



Calculation using Hantush

Observation Well	Transmissivity [m²/d]	Hydraulic Conductivity [m/d]	Storage coefficient	Hydr. resistance [min]	Leakage factor [m]	Radial Distance to PW [m]
ELNMB01D	6.40×10^{2}	5.33×10^{1}	7.40×10^{-5}	1.10×10^{5}	2.21×10^{2}	10.2

AGE Consultants
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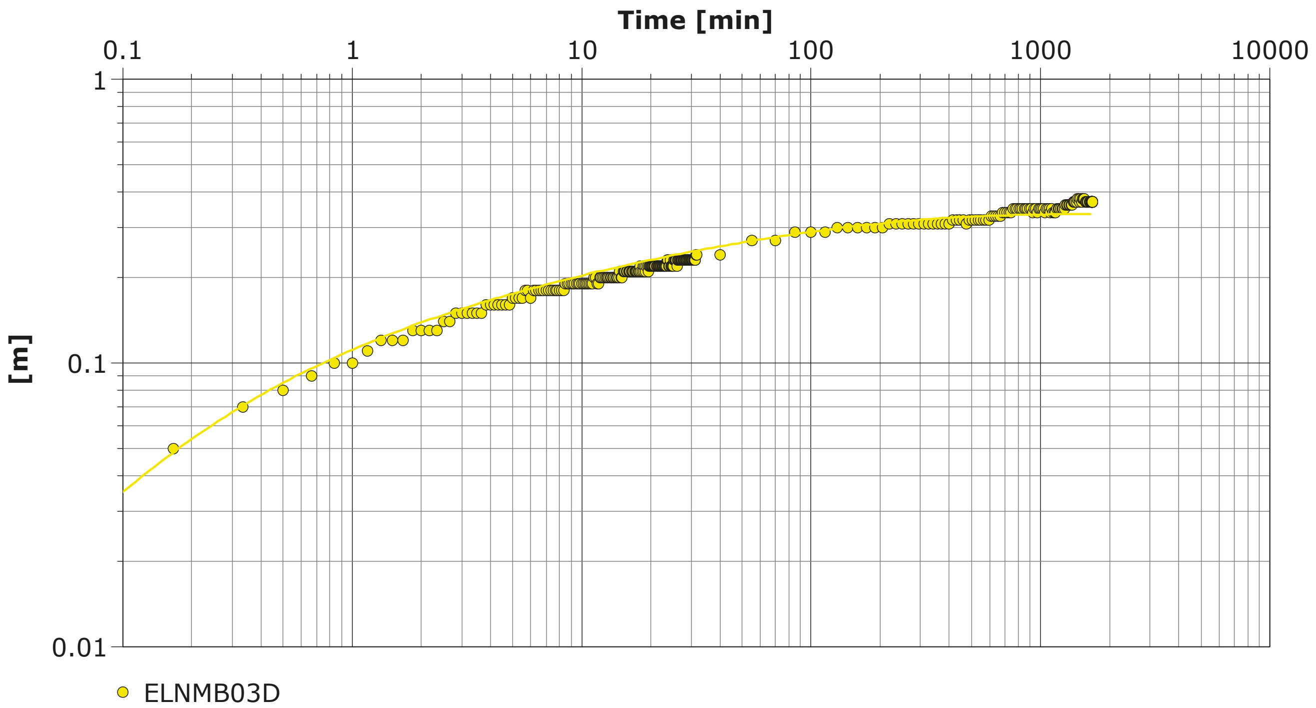
Bowen Hills, QLD, 4006

Pumping Test Analysis Report	
Project: Gemco	
Number: G1663	
Client: Hansen Bailey	

Location: Groote Eylandt, NT	Pumping Test: 24 hr constant rate	Pumping Well: ELNPB03
Test Conducted by: H. McCarthy (AGE)		Test Date: 24/05/2014
Analysis Performed by: H. McCarthy	Hantush	Analysis Date: 2/07/2014
Aquifer Thickness: 20.00 m	Discharge Rate: 5.1 [l/s]	

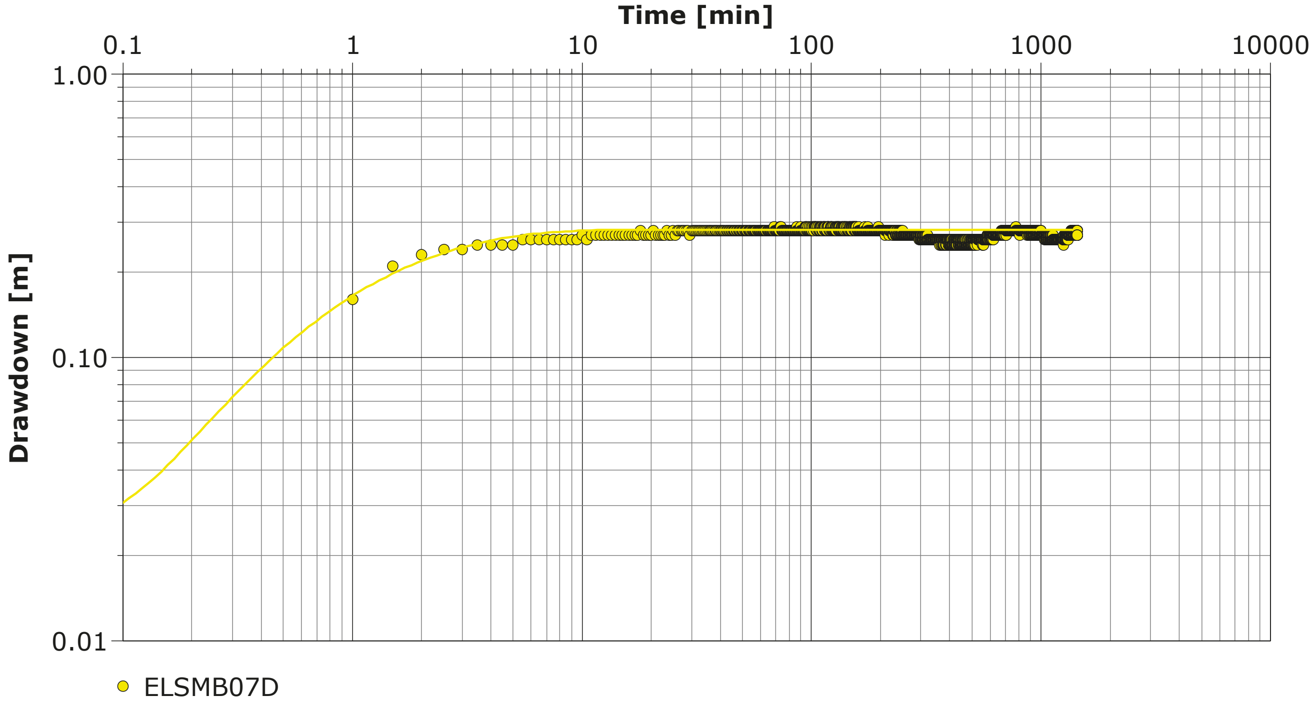


Calculation using Hantush

Observation Well	Transmissivity [m²/d]	Hydraulic Conductivity [m/d]	Storage coefficient	Hydr. resistance [min]	Leakage factor [m]	Radial Distance to PW [m]
ELNMB03D	8.50×10^{2}	4.25×10^{1}	1.14×10^{-3}	3.75×10^{5}	4.70×10^{2}	11.0

AGE Consultants **Level 2/15 Mallon St** **Bowen Hills, QLD, 4006**	**Pumping Test Analysis Report** Project: Gemco Number: G1663 Client: Hansen Bailey

Location: Groote Eylandt, NT	Pumping Test: 24 hr constant rate	Pumping Well: ELSPB07
Test Conducted by: Gemco / J & S Drilling		Test Date: 26/06/2014
Analysis Performed by: H. McCarthy	Hantush	Analysis Date: 2/07/2014
Aquifer Thickness: 21.00 m	Discharge Rate: 12.3 [l/s]	



Calculation using Hantush

Observation Well	Transmissivity [m²/d]	Hydraulic Conductivity [m/d]	Storage coefficient	Hydr. resistance [min]	Leakage factor [m]	Radial Distance to PW [m]
ELSMB07D	6.20×10^{2}	2.95×10^{1}	2.00×10^{-3}	1.80×10^{3}	2.78×10^{1}	13.6

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Bowen Hills, QLD, 4006

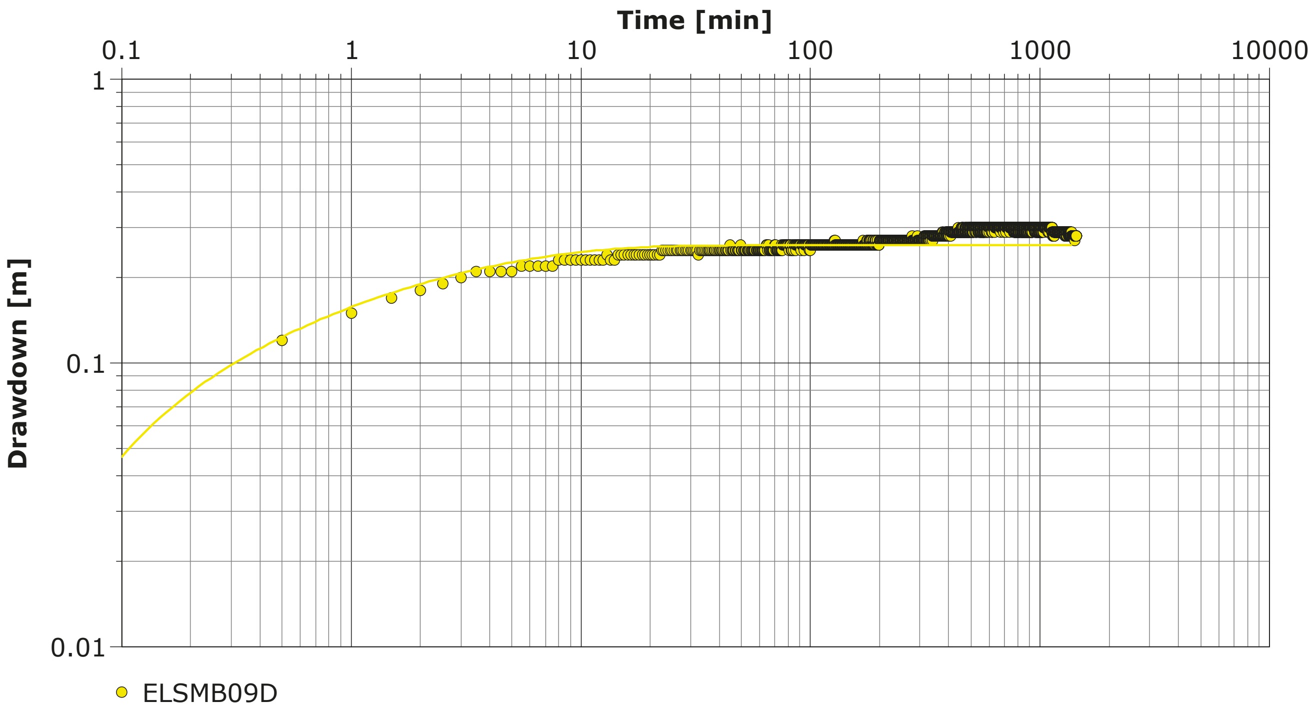
Pumping Test Analysis Report

Project: Gemco

Number: G1663

Client: Hansen Bailey

Location: Groote Eylandt, NT	Pumping Test: 24 hr constant rate	Pumping Well: ELSPB09
Test Conducted by: Gemco / J & S Drilling		Test Date: 30/06/2014
Analysis Performed by: H. McCarthy	Hantush	Analysis Date: 7/07/2014
Aquifer Thickness: 25.00 m	Discharge Rate: 13.3 [l/s]	



Calculation using Hantush

Observation Well	Transmissivity [m²/d]	Hydraulic Conductivity [m/d]	Storage coefficient	Hydr. resistance [min]	Leakage factor [m]	Radial Distance to PW [m]
ELSMB09D	1.70×10^{3}	6.80×10^{1}	7.59×10^{-4}	1.46×10^{4}	1.31×10^{2}	11.0

Appendix A 3

Water quality data

G1663 (GEMCO)
Groundwater Quality Results
Sample Date: January 2014

APPENDIX A 3
Page 1 / 6

Analyte	Units	LOR	Fresh Water Aquatic	Drinking Water	ELNMB01 S	ELNMB03 S	ELNMB03 D	ELNMB04 D	ELSMB06 S	ELSMB06 D	BLANK 2	ELNMB01 D	ELNMB01 D DUPLICATE	Relative Percentage Difference
EA025: Suspended Solids														
Susoended Solids (SS)	mg/L	5	-	-	-	-	-	-	-	-	-	-	-	-
EA065: Total Hardness as CaCO3														
Total Hardness as CaCO3	mg/L	1	-	-	78	7	<1	13	22	22	<1	7	7	0%
ED037P: Alkalinity by PC Titrator														
Bicarbonate Alkalinity as CaCO3	`	1	-	-	95	26	8	26	36	28	5	13	14	7%
Carbonate Alkalinity as CaCO3	mg/L	1	-	-	<1	<1	<1	<1	<1	<1	<1	<1	<1	0%
Hydroxide Alkalinity as CaCO3	mg/L	1	-	-	<1	<1	<1	<1	<1	<1	<1	<1	<1	0%
Total Alkalinity as CaCO3	mg/L	1	-	-	95	26	8	26	36	28	5	13	14	7%
ED041G: Sulfate (Turbidimetric) as SO4 2- by DA														
Sulfate as SO4 - Turbidimetric	mg/L	1	-	500	35	2	1	1	3	9	<1	1	1	0%
ED045G: Chloride Discrete analyser														
Chloride	mg/L	1	-	250[b]	**314**	14	12	6	11	14	1	10	10	0%
ED093F: Dissolved Major Cations														
Calcium	mg/L	1	-	-	10	1	<1	2	4	4	<1	1	1	0%
Magnesium	mg/L	1	-	-	13	1	<1	2	3	3	<1	1	1	0%
Potassium	mg/L	1	-	-	2	<1	<1	<1	<1	<1	<1	<1	<1	0%
Sodium	mg/L	1	-	-	210	18	8	6	11	12	<1	8	8	0%
EG020F: Dissolved Metals by ICP-MS														
Aluminium	mg/L	0.01	0.055	0.2[b]	<0.01	0.02	<0.01	<0.01	<0.01	0.02	<0.01	0.03	0.02	**40%**
Arsenic	mg/L	0.001	0.013	0.01	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0%
Barium	mg/L	0.001	-	2	0.084	0.016	0.035	0.037	0.016	0.031	<0.001	0.022	0.022	0%
Beryllium	mg/L	0.001	0.004	0.09	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0%
Boron	mg/L	0.05	0.37	4	0.06	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0%
Cadmium	mg/L	0.0001	0.0002	0.002	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0%
Chromium	mg/L	0.001	0.01	0.05	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0%
Cobalt	mg/L	0.001	-	-	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0%
Copper	mg/L	0.001	0.0014	2	**0.007**	0.001	**0.032**	**0.008**	**0.002**	**0.01**	<0.001	**0.003**	**0.003**	0%
Iron	mg/L	0.05	-	0.3[b]	0.06	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0%
Lead	mg/L	0.001	0.0034	0.01	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0%
Manganese	mg/L	0.001	1.9	0.5	**0.978**	0.029	0.388	**4.32**	0.074	**0.73**	<0.001	0.139	0.138	1%
Nickel	mg/L	0.001	0.011	0.02	**0.014**	<0.001	0.003	0.001	0.001	0.005	<0.001	0.003	0.003	0%
Selenium	mg/L	0.01	0.005	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0%
Uranium	mg/L	0.001	-	0.017	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0%
Vanadium	mg/L	0.01	-	-	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0%
Zinc	mg/L	0.005	0.008	3[b]	**0.013**	0.007	**0.025**	0.006	<0.005	**0.02**	<0.005	**0.012**	**0.013**	8%
EG020T: Total Metals by ICP-MS														
Aluminium	mg/L	0.01	-	-	0.06	0.15	<0.01	0.06	1.44	0.12	<0.01	0.21	0.19	10%
Arsenic	mg/L	0.001	-	-	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0%
Barium	mg/L	0.001	-	-	0.079	0.017	0.036	0.037	0.038	0.031	<0.001	0.03	0.031	3%
Beryllium	mg/L	0.001	-	-	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0%
Boron	mg/L	0.05	-	-	0.18	<0.05	<0.05	<0.05	<0.05	<0.05	0.06	<0.05	<0.05	0%
Cadmium	mg/L	0.0001	-	-	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0%
Chromium	mg/L	0.001	-	-	<0.001	<0.001	0.003	<0.001	0.002	<0.001	<0.001	0.001	0.001	0%
Cobalt	mg/L	0.001	-	-	0.001	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	0%
Copper	mg/L	0.001	-	-	0.01	0.002	0.028	0.003	0.004	0.008	<0.001	0.006	0.006	0%
Iron	mg/L	0.05	-	-	0.18	0.12	<0.05	0.13	1.9	0.11	<0.05	0.3	0.27	11%
Lead	mg/L	0.001	-	-	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0%
Manganese	mg/L	0.001	-	-	0.945	0.033	0.41	4.29	0.19	0.762	<0.001	0.253	0.247	2%
Nickel	mg/L	0.001	-	-	0.013	0.001	0.004	0.002	0.003	0.005	<0.001	0.004	0.004	0%
Selenium	mg/L	0.01	-	-	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0%
Uranium	mg/L	0.001	-	-	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0%
Vanadium	mg/L	0.01	-	-	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0%
Zinc	mg/L	0.005	-	-	0.014	0.007	0.03	0.066	0.012	0.019	<0.005	0.015	0.017	13%
EG035F: Dissolved Mercury by FIMS														
Mercury	mg/L	0.0001	-	-	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0%
EG035T: Total Recoverable Mercury by FIMS														
Mercury	mg/L	0.0001	-	-	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0%
Nutrients by Discrete Analyser														
Nitrite + Nitrate as N	mg/L	0.01	-	-	0.14	0.15	0.04	0.03	<0.01	<0.01	<0.01	0.03	0.03	0%
Total Kjeldahl Nitrogen as N	mg/L	0.1	-	-	0.2	<0.1	<0.1	0.2	<0.1	<0.1	<0.1	<0.1	<0.1	0%
Total Nitrogen as N	mg/L	0.1	-	-	0.3	0.2	<0.1	0.2	<0.1	<0.1	<0.1	<0.1	<0.1	0%
Total Phosphorus as P	mg/L	0.01	-	-	0.02	<0.01	<0.01	<0.01	0.02	<0.01	<0.01	0.02	0.03	**40%**
EN055: Ionic Balance*														
Ionic Balance*	%	0.01	-	-	3.3	-	-	-	-	-	-	-	-	0%
Total Anions	meq/L	0.01	-	-	11.5	0.96	0.52	0.71	1.09	1.14	0.13	0.56	0.58	4%
Total Cations	meq/L	0.01	-	-	10.8	0.92	0.35	0.53	0.92	0.97	<0.01	0.48	0.48	0%
EP080/071: Total Petroleum Hydrocarbons														
C10 - C14 Fraction	µg/L	50	-	-	<50	<50	<50	<50	<50	<50	<50	<50	<50	0%
C10 - C36 Fraction (sum)	µg/L	50	-	-	<50	<50	<50	<50	<50	<50	<50	<50	<50	0%
C15 - C28 Fraction	µg/L	100	-	-	<100	<100	<100	<100	<100	<100	<100	<100	<100	0%
C29 - C36 Fraction	µg/L	50	-	-	<50	<50	<50	<50	<50	<50	<50	<50	<50	0%
EP080/071: Total Recoverable Hydrocarbons - NEPM 2013														
>C10 - C16 Fraction	µg/L	100	-	-	<100	<100	<100	<100	<100	<100	<100	<100	<100	0%
>C10 - C40 Fraction (sum)	µg/L	100	-	-	100	<100	<100	<100	<100	<100	<100	<100	<100	0%
>C16 - C34 Fraction	µg/L	100	-	-	100	<100	<100	<100	<100	<100	<100	<100	<100	0%
>C34 - C40 Fraction	µg/L	100	-	-	<100	<100	<100	<100	<100	<100	<100	<100	<100	0%

Notes:

LOR	Limit of reporting
200	Detected concentration above Aquatic Guideline for Fresh Water
100	Detected concentration above Long Term Irrigation purposes
3	Detected concentration above Drinking Water Guidelines
0.01	LOR is higher than the guideline trigger
60%	RPDs above 50% criteria
40%	Where one sample is below detectable levels, evaluated as equivalent to detection limit
-	No value
b	Aesthetic

G1663 (GEMCO)
Groundwater Quality Results
Sample Date: February, 2014

APPENDIX A 3
Page 2 / 6

Analyte	Units	LOR	Fresh Water Aquatic	Drinking Water	ELNMB01 S	ELNMB03 S	ELNMB03 D	ELNMB04 D	ELSMB06 S	ELSMB06 D	BLANK 2	ELNMB01 D	ELNMB01 D DUPLICATE	Relative Percentage Difference
EA025: Suspended Solids														
Susoended Solids (SS)	mg/L	5	-	-	<5	20	<5	<5	<5	<5	<5	<5	<5	0%
EA065: Total Hardness as CaCO3														
Total Hardness as CaCO3	mg/L	1	-	-	22	<1	<1	5	<1	11	<1	4	4	0%
ED037P: Alkalinity by PC Titrator														
Bicarbonate Alkalinity as CaCO3	`	1	-	-	48	9	5	22	10	11	5	11	11	0%
Carbonate Alkalinity as CaCO3	mg/L	1	-	-	<1	<1	<1	<1	<1	<1	<1	<1	<1	0%
Hydroxide Alkalinity as CaCO3	mg/L	1	-	-	<1	<1	<1	<1	<1	<1	<1	<1	<1	0%
Total Alkalinity as CaCO3	mg/L	1	-	-	48	9	5	22	10	11	5	11	11	0%
ED041G: Sulfate (Turbidimetric) as SO4 2- by DA														
Sulfate as SO4 - Turbidimetric	mg/L	1	-	500	42	<1	<1	1	1	2	<1	<1	<1	0%
ED045G: Chloride Discrete analyser														
Chloride	mg/L	1	-	250[b]	74	7	12	6	8	10	1	10	10	0%
ED093F: Dissolved Major Cations														
Calcium	mg/L	1	-	-	4	<1	<1	2	<1	1	<1	<1	<1	0%
Magnesium	mg/L	1	-	-	3	<1	<1	<1	<1	2	<1	1	1	0%
Potassium	mg/L	1	-	-	1	<1	<1	<1	<1	<1	<1	<1	<1	0%
Sodium	mg/L	1	-	-	82	6	7	4	7	6	<1	6	6	0%
EG020F: Dissolved Metals by ICP-MS														
Aluminium	mg/L	0.01	0.055	0.2[b]	0.02	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0%
Arsenic	mg/L	0.001	0.013	0.01	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0%
Barium	mg/L	0.001	-	2	0.026	0.006	0.028	0.044	0.009	0.035	<0.001	0.023	0.022	4%
Beryllium	mg/L	0.001	0.004	0.09	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0%
Boron	mg/L	0.05	0.37	4	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.08	<0.05	<0.05	0%
Cadmium	mg/L	0.0001	0.0002	0.002	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0%
Chromium	mg/L	0.001	0.01	0.05	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0%
Cobalt	mg/L	0.001	-	-	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	0%
Copper	mg/L	0.001	0.0014	2	0.005	0.005	0.021	0.005	0.001	0.016	<0.001	0.005	0.005	0%
Iron	mg/L	0.05	-	0.3[b]	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0%
Lead	mg/L	0.001	0.0034	0.01	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0%
Manganese	mg/L	0.001	1.9	0.5	0.254	0.018	0.206	5.8	0.034	1.2	<0.001	0.154	0.155	1%
Nickel	mg/L	0.001	0.011	0.02	0.002	<0.001	0.003	0.003	<0.001	0.004	<0.001	0.002	0.002	0%
Selenium	mg/L	0.01	0.005	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0%
Uranium	mg/L	0.001	-	0.017	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0%
Vanadium	mg/L	0.01	-	-	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0%
Zinc	mg/L	0.005	0.008	3[b]	0.007	<0.005	0.029	0.014	<0.005	0.009	<0.005	0.01	0.008	22%
EG020T: Total Metals by ICP-MS														
Aluminium	mg/L	0.01	-	-	0.71	0.64	0.01	0.02	0.5	0.08	<0.01	0.06	0.06	0%
Arsenic	mg/L	0.001	-	-	0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0%
Barium	mg/L	0.001	-	-	0.031	0.014	0.029	0.043	0.014	0.038	<0.001	0.024	0.025	4%
Beryllium	mg/L	0.001	-	-	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0%
Boron	mg/L	0.05	-	-	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.07	<0.05	<0.05	0%
Cadmium	mg/L	0.0001	-	-	<0.0001	<0.0001	<0.0001	0.0001	<0.0001	0.0001	<0.0001	<0.0001	<0.0001	0%
Chromium	mg/L	0.001	-	-	0.002	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0%
Cobalt	mg/L	0.001	-	-	<0.001	<0.001	<0.001	<0.001	<0.001	0.002	<0.001	<0.001	<0.001	0%
Copper	mg/L	0.001	-	-	0.02	0.016	0.025	0.009	0.001	0.02	<0.001	0.012	0.006	67%
Iron	mg/L	0.05	-	-	0.77	0.56	<0.05	0.1	0.62	0.05	<0.05	0.06	0.06	0%
Lead	mg/L	0.001	-	-	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0%
Manganese	mg/L	0.001	-	-	0.31	0.042	0.224	6.1	0.053	0.94	<0.001	0.185	0.184	1%
Nickel	mg/L	0.001	-	-	0.004	0.002	0.003	0.003	0.001	0.005	<0.001	0.002	0.002	0%
Selenium	mg/L	0.01	-	-	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0%
Uranium	mg/L	0.001	-	-	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0%
Vanadium	mg/L	0.01	-	-	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0%
Zinc	mg/L	0.005	-	-	0.014	0.01	0.025	0.016	<0.005	0.009	<0.005	0.008	0.008	0%
EG035F: Dissolved Mercury by FIMS														
Mercury	mg/L	0.0001	-	-	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0%
EG035T: Total Recoverable Mercury by FIMS														
Mercury	mg/L	0.0001	-	-	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0%
Nutrients by Discrete Analyser														
Nitrite + Nitrate as N	mg/L	0.01	-	-	0.21	0.04	0.02	0.07	0.03	0.01	<0.01	0.02	0.03	40%
Total Kjeldahl Nitrogen as N	mg/L	0.1	-	-	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0%
Total Nitrogen as N	mg/L	0.1	-	-	0.3	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0%
Total Phosphorus as P	mg/L	0.01	-	-	0.04	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0%
EN055: Ionic Balance*														
Ionic Balance*	%	0.01	-	-	1.45	-	-	-	-	-	-	-	-	0%
Total Anions	meq/L	0.01	-	-	3.92	0.38	0.44	0.63	0.45	0.54	0.13	0.5	0.5	0%
Total Cations	meq/L	0.01	-	-	4.04	0.26	0.3	0.48	0.3	0.48	<0.01	0.34	0.34	0%
EP080/071: Total Petroleum Hydrocarbons														
C10 - C14 Fraction	µg/L	50	-	-	<50	<50	<50	<50	<50	<50	<50	<50	<50	0%
C10 - C36 Fraction (sum)	µg/L	50	-	-	<50	<50	<50	<50	<50	<50	<50	<50	<50	0%
C15 - C28 Fraction	µg/L	100	-	-	<100	<100	<100	<100	<100	<100	<100	<100	<100	0%
C29 - C36 Fraction	µg/L	50	-	-	<50	<50	<50	<50	<50	<50	<50	<50	<50	0%
EP080/071: Total Recoverable Hydrocarbons - NEPM 2013														
>C10 - C16 Fraction	µg/L	100	-	-	<100	<100	<100	<100	<100	<100	<100	<100	<100	0%
>C10 - C40 Fraction (sum)	µg/L	100	-	-	<100	<100	<100	<100	<100	<100	<100	<100	<100	0%
>C16 - C34 Fraction	µg/L	100	-	-	<100	<100	<100	<100	<100	<100	<100	<100	<100	0%
>C34 - C40 Fraction	µg/L	100	-	-	<100	<100	<100	<100	<100	<100	<100	<100	<100	0%

Notes:

LOR	Limit of reporting
200	Detected concentration above Aquatic Guideline for Fresh Water
100	Detected concentration above Long Term Irrigation purposes
3	Detected concentration above Drinking Water Guidelines
0.01	LOR is higher than the guideline trigger
60%	RPDs above 50% criteria
40%	Where one sample is below detectable levels, evaluated as equivalent to detection limit
-	No value
b	Aesthetic

G1663 (GEMCO)
Groundwater Quality Results
Sample Date: March, 2014

APPENDIX A 3
Page 3 / 6

Analyte	Units	LOR	Fresh Water Aquatic	Drinking Water	ELNMB01 S	ELNMB02D	ELNMB03 S	ELNMB03 D	ELNMB04 D	ELSMB06 S	ELSMB06 D	BLANK 2	ELNMB01 D	ELNMB01 D DUPLICATE	Relative Percentage Difference
EA025: Suspended Solids															
Susoended Solids (SS)	mg/L	5	-	-	<5	1560	<5	<5	16	7	<5	<5	<5	<5	0%
EA065: Total Hardness as CaCO3															
Total Hardness as CaCO3	mg/L	1	-	-	16	<1	<1	<1	<1	<1	4	<1	<1	<1	0%
ED037P: Alkalinity by PC Titrator															
Bicarbonate Alkalinity as CaCO3	`	1	-	-	30	33	11	3	12	7	5	6	6	6	0%
Carbonate Alkalinity as CaCO3	mg/L	1	-	-	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	0%
Hydroxide Alkalinity as CaCO3	mg/L	1	-	-	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	0%
Total Alkalinity as CaCO3	mg/L	1	-	-	30	33	11	3	12	7	5	6	6	6	0%
ED041G: Sulfate (Turbidimetric) as SO4 2- by DA															
Sulfate as SO4 - Turbidimetric	mg/L	1	-	500	45	10	2	2	2	2	2	1	2	2	0%
ED045G: Chloride Discrete analyser															
Chloride	mg/L	1	-	250[b]	53	10	6	10	5	8	10	<1	9	9	0%
ED093F: Dissolved Major Cations															
Calcium	mg/L	1	-	-	3	<1	<1	<1	<1	<1	<1	<1	<1	<1	0%
Magnesium	mg/L	1	-	-	2	<1	<1	<1	<1	<1	1	<1	<1	<1	0%
Potassium	mg/L	1	-	-	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	0%
Sodium	mg/L	1	-	-	60	25	7	8	4	6	6	<1	6	6	0%
EG020F: Dissolved Metals by ICP-MS															
Aluminium	mg/L	0.01	0.055	0.2[b]	0.1	-	0.03	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0%
Arsenic	mg/L	0.001	0.013	0.01	<0.001	-	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0%
Barium	mg/L	0.001	-	2	0.029	-	0.008	0.034	0.028	0.013	0.039	<0.001	0.021	0.02	5%
Beryllium	mg/L	0.001	0.004	0.09	<0.001	-	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0%
Boron	mg/L	0.05	0.37	4	<0.05	-	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0%
Cadmium	mg/L	0.0001	0.0002	0.002	<0.0001	-	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0%
Chromium	mg/L	0.001	0.01	0.05	<0.001	-	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0%
Cobalt	mg/L	0.001	-	-	<0.001	-	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	0%
Copper	mg/L	0.001	0.0014	2	0.054	-	0.009	0.017	0.008	0.001	0.032	<0.001	0.005	0.005	0%
Iron	mg/L	0.05	-	0.3[b]	<0.05	-	<0.05	<0.05	0.06	<0.05	<0.05	<0.05	<0.05	<0.05	0%
Lead	mg/L	0.001	0.0034	0.01	<0.001	-	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0%
Manganese	mg/L	0.001	1.9	0.5	0.228	-	0.021	0.29	2.57	0.054	0.716	<0.001	0.116	0.116	0%
Nickel	mg/L	0.001	0.011	0.02	0.001	-	<0.001	0.002	0.002	<0.001	0.004	<0.001	0.002	0.001	67%
Selenium	mg/L	0.01	0.005	0.01	<0.01	-	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0%
Uranium	mg/L	0.001	-	0.017	<0.001	-	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0%
Vanadium	mg/L	0.01	-	-	<0.01	-	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0%
Zinc	mg/L	0.005	0.008	3[b]	0.009	-	0.005	0.016	0.017	<0.005	0.016	<0.005	0.011	0.01	10%
EG020T: Total Metals by ICP-MS															
Aluminium	mg/L	0.01	-	-	0.23	13.4	0.13	0.08	0.03	0.14	0.05	<0.01	0.05	0.06	18%
Arsenic	mg/L	0.001	-	-	<0.001	0.004	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0%
Barium	mg/L	0.001	-	-	0.032	0.344	0.009	0.039	0.033	0.017	0.037	<0.001	0.022	0.022	0%
Beryllium	mg/L	0.001	-	-	<0.001	0.005	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0%
Boron	mg/L	0.05	-	-	<0.05	0.07	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0%
Cadmium	mg/L	0.0001	-	-	<0.0001	0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0%
Chromium	mg/L	0.001	-	-	0.001	0.005	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0%
Cobalt	mg/L	0.001	-	-	<0.001	0.005	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	0%
Copper	mg/L	0.001	-	-	0.067	0.016	0.012	0.014	0.01	0.002	0.029	<0.001	0.006	0.006	0%
Iron	mg/L	0.05	-	-	0.22	13.6	0.1	0.1	0.19	0.16	0.08	<0.05	0.06	0.08	29%
Lead	mg/L	0.001	-	-	<0.001	0.04	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0%
Manganese	mg/L	0.001	-	-	0.25	0.511	0.028	0.323	2.88	0.074	0.656	<0.001	0.137	0.135	1%
Nickel	mg/L	0.001	-	-	0.003	0.014	0.001	0.002	0.002	0.001	0.005	<0.001	0.003	0.002	40%
Selenium	mg/L	0.01	-	-	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0%
Uranium	mg/L	0.001	-	-	<0.001	0.02	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0%
Vanadium	mg/L	0.01	-	-	<0.01	0.02	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0%
Zinc	mg/L	0.005	-	-	0.012	0.064	0.006	0.015	0.023	0.006	0.016	<0.005	0.011	0.012	9%
EG035F: Dissolved Mercury by FIMS															
Mercury	mg/L	0.0001	-	-	<0.0001	-	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0%
EG035T: Total Recoverable Mercury by FIMS															
Mercury	mg/L	0.0001	-	-	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0%
Nutrients by Discrete Analyser															
Nitrite + Nitrate as N	mg/L	0.01	-	-	0.17	0.05	0.03	0.02	0.06	<0.01	0.04	<0.01	0.02	0.03	40%
Total Kjeldahl Nitrogen as N	mg/L	0.1	-	-	0.2	0.2	0.2	0.1	0.2	0.2	0.1	<0.1	0.2	0.1	67%
Total Nitrogen as N	mg/L	0.1	-	-	0.4	0.2	0.2	0.1	0.3	0.2	0.1	<0.1	0.2	0.1	67%
Total Phosphorus as P	mg/L	0.01	-	-	0.05	0.29	0.02	0.02	0.02	0.03	0.04	0.03	0.03	0.04	29%
EN055: Ionic Balance*															
Ionic Balance*	%	0.01	-	-	1.83	-	-	-	-	-	-	-	-	-	0%
Total Anions	meq/L	0.01	-	-	3.03	1.15	0.43	0.38	0.42	0.41	0.42	0.14	0.42	0.42	0%
Total Cations	meq/L	0.01	-	-	2.92	1.09	0.3	0.35	0.26	0.26	0.34	<0.01	0.26	0.26	0%
EP080/071: Total Petroleum Hydrocarbons															
C10 - C14 Fraction	µg/L	50	-	-	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	0%
C10 - C36 Fraction (sum)	µg/L	50	-	-	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	0%
C15 - C28 Fraction	µg/L	100	-	-	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	0%
C29 - C36 Fraction	µg/L	50	-	-	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	0%
EP080/071: Total Recoverable Hydrocarbons - NEPM 2013															
>C10 - C16 Fraction	µg/L	100	-	-	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	0%
>C10 - C40 Fraction (sum)	µg/L	100	-	-	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	0%
>C16 - C34 Fraction	µg/L	100	-	-	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	0%
>C34 - C40 Fraction	µg/L	100	-	-	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	0%

Notes:

LOR	Limit of reporting
200	Detected concentration above Aquatic Guideline for Fresh Water
100	Detected concentration above Long Term Irrigation purposes
3	Detected concentration above Drinking Water Guidelines
0.01	LOR is higher than the guideline trigger
60%	RPDs above 50% criteria
40%	Where one sample is below detectable levels, evaluated as equivalent to detection limit
-	No value
b	Aesthetic

G1663 (GEMCO)
Groundwater Quality Results
Sample Date: May 2014

APPENDIX A 3
Page 4 / 6

Analyte	Units	LOR	Fresh Water Aquatic	Drinking Water	ELNMB01 S	ELNMB03 S	ELNMB03 D	ELNMB04 D	ELSMB06 S	ELSMB06 D	BLANK 2	ELNMB01 D	ELNMB01 D DUPLICATE	Relative Percentage Difference
EA025: Suspended Solids														
Susoended Solids (SS)	mg/L	5	-	-	-	-	-	-	-	-	-	-	-	0%
EA065: Total Hardness as CaCO3														
Total Hardness as CaCO3	mg/L	1	-	-	13	<5	<5	<5	<5	<5	<5	<5	<5	0%
ED037P: Alkalinity by PC Titrator														
Bicarbonate Alkalinity as CaCO3	`	1	-	-	26	8	3	6	5	4	<1	6	8	29%
Carbonate Alkalinity as CaCO3	mg/L	1	-	-	<1	<1	<1	<1	<1	<1	<1	<1	<1	0%
Hydroxide Alkalinity as CaCO3	mg/L	1	-	-	<1	<1	<1	<1	<1	<1	<1	<1	<1	0%
Total Alkalinity as CaCO3	mg/L	1	-	-	26	8	3	6	5	4	<1	6	8	29%
ED041G: Sulfate (Turbidimetric) as SO4 2- by DA														
Sulfate as SO4 - Turbidimetric	mg/L	1	-	500	42	<1	<1	1	<1	<1	<1	<1	<1	0%
ED045G: Chloride Discrete analyser														
Chloride	mg/L	1	-	250[b]	38	8	12	5	9	11	<1	9	10	11%
ED093F: Dissolved Major Cations														
Calcium	mg/L	1	-	-	2	<1	<1	<1	<1	<1	<1	<1	<1	0%
Magnesium	mg/L	1	-	-	2	<1	<1	<1	<1	<1	<1	<1	<1	0%
Potassium	mg/L	1	-	-	<1	<1	<1	<1	<1	<1	<1	<1	<1	0%
Sodium	mg/L	1	-	-	51	7	7	3	5	5	<1	6	6	0%
EG020F: Dissolved Metals by ICP-MS														
Aluminium	mg/L	0.01	0.055	0.2[b]	0.1	0.12	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0%
Arsenic	mg/L	0.001	0.013	0.01	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0%
Barium	mg/L	0.001	-	2	0.028	0.014	0.022	0.018	0.013	0.032	<0.001	0.021	0.021	0%
Beryllium	mg/L	0.001	0.004	0.09	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0%
Boron	mg/L	0.05	0.37	4	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0%
Cadmium	mg/L	0.0001	0.0002	0.002	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0%
Chromium	mg/L	0.001	0.01	0.05	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0%
Cobalt	mg/L	0.001	-	-	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0%
Copper	mg/L	0.001	0.0014	2	0.009	0.009	0.016	0.025	0.002	0.041	<0.001	0.008	0.008	0%
Iron	mg/L	0.05	-	0.3[b]	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0%
Lead	mg/L	0.001	0.0034	0.01	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0%
Manganese	mg/L	0.001	1.9	0.5	0.184	0.04	0.102	0.671	0.049	0.37	<0.001	0.109	0.109	0%
Nickel	mg/L	0.001	0.011	0.02	0.014	0.008	0.01	0.02	0.004	0.007	<0.001	0.009	0.009	0%
Selenium	mg/L	0.01	0.005	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0%
Uranium	mg/L	0.001	-	0.017	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0%
Vanadium	mg/L	0.01	-	-	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0%
Zinc	mg/L	0.005	0.008	3[b]	0.031	0.017	0.015	0.017	0.01	0.018	<0.005	0.016	0.013	21%
EG020T: Total Metals by ICP-MS														
Aluminium	mg/L	0.01	-	-	0.35	0.17	0.01	0.03	0.13	0.03	<0.01	0.07	0.08	13%
Arsenic	mg/L	0.001	-	-	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0%
Barium	mg/L	0.001	-	-	0.03	0.016	0.024	0.022	0.014	0.033	<0.001	0.022	0.025	13%
Beryllium	mg/L	0.001	-	-	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0%
Boron	mg/L	0.05	-	-	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0%
Cadmium	mg/L	0.0001	-	-	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0%
Chromium	mg/L	0.001	-	-	0.01	0.004	0.002	0.002	<0.001	<0.001	<0.001	<0.001	0.002	0%
Cobalt	mg/L	0.001	-	-	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0%
Copper	mg/L	0.001	-	-	0.013	0.009	0.014	0.027	0.002	0.037	<0.001	0.008	0.012	40%
Iron	mg/L	0.05	-	-	0.36	0.11	<0.05	0.15	0.14	0.1	<0.05	0.07	0.11	44%
Lead	mg/L	0.001	-	-	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0%
Manganese	mg/L	0.001	-	-	0.199	0.044	0.111	0.766	0.052	0.361	<0.001	0.121	0.149	21%
Nickel	mg/L	0.001	-	-	0.018	0.009	0.01	0.02	0.005	0.007	<0.001	0.009	0.01	11%
Selenium	mg/L	0.01	-	-	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0%
Uranium	mg/L	0.001	-	-	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0%
Vanadium	mg/L	0.01	-	-	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0%
Zinc	mg/L	0.005	-	-	0.038	0.013	0.012	0.022	0.009	0.016	<0.005	0.013	0.016	21%
EG035F: Dissolved Mercury by FIMS														
Mercury	mg/L	0.0001	-	-	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0%
EG035T: Total Recoverable Mercury by FIMS														
Mercury	mg/L	0.0001	-	-	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0%
Nutrients by Discrete Analyser														
Nitrite + Nitrate as N	mg/L	0.01	-	-	0.18	0.07	0.02	0.03	0.04	0.02	<0.01	0.03	0.02	40%
Total Kjeldahl Nitrogen as N	mg/L	0.1	-	-	0.3	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0%
Total Nitrogen as N	mg/L	0.1	-	-	0.5	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0%
Total Phosphorus as P	mg/L	0.01	-	-	0.04	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.02	<0.01	0%
EN055: Ionic Balance*														
Ionic Balance*	%	0.01	-	-	-	-	-	-	-	-	-	-	-	0%
Total Anions	meq/L	0.01	-	-	2.47	0.39	0.4	0.28	0.35	0.39	<0.01	0.37	0.44	17%
Total Cations	meq/L	0.01	-	-	2.48	0.3	0.3	0.13	0.22	0.22	<0.01	0.26	0.26	0%
EP080/071: Total Petroleum Hydrocarbons														
C10 - C14 Fraction	µg/L	50	-	-	<50	<50	<50	<50	<50	<50	<50	<50	<50	0%
C10 - C36 Fraction (sum)	µg/L	50	-	-	<50	<50	<50	<50	<50	<50	<50	<50	<50	0%
C15 - C28 Fraction	µg/L	100	-	-	<100	<100	<100	<100	<100	<100	<100	<100	<100	0%
C29 - C36 Fraction	µg/L	50	-	-	<50	<50	<50	<50	<50	<50	<50	<50	<50	0%
EP080/071: Total Recoverable Hydrocarbons - NEPM 2013														
>C10 - C16 Fraction	µg/L	100	-	-	<100	<100	<100	<100	<100	<100	<100	<100	<100	0%
>C10 - C40 Fraction (sum)	µg/L	100	-	-	<100	<100	<100	<100	<100	<100	<100	<100	<100	0%
>C16 - C34 Fraction	µg/L	100	-	-	<100	<100	<100	<100	<100	<100	<100	<100	<100	0%
>C34 - C40 Fraction	µg/L	100	-	-	<100	<100	<100	<100	<100	<100	<100	<100	<100	0%

Notes:

LOR	Limit of reporting
200	Detected concentration above Aquatic Guideline for Fresh Water
100	Detected concentration above Long Term Irrigation purposes
3	Detected concentration above Drinking Water Guidelines
0.01	LOR is higher than the guideline trigger
60%	RPDs above 50% criteria
40%	Where one sample is below detectable levels, evaluated as equivalent to detection limit
-	No value
b	Aesthetic

G1663 (GEMCO)
Groundwater Quality Results
Sample Date: June 2014

APPENDIX A 3
Page 5 / 6

Analyte	Units	LOR	Fresh Water Aquatic	Drinking Water	ELNMB01 S	ELNMB03 S	ELNMB03 D	ELNMB04 D	ELNMB05	ELSMB06 S	ELSMB06 D	ELSMB07D	ELSMB08D	BLANK 2	ELNMB01 D	ELNMB01 D DUPLICATE	Relative Percentage Difference
EA025: Suspended Solids																	
Susoended Solids (SS)	mg/L	5	-	-	-	-	-	-		-	-			-	-	-	0%
EA065: Total Hardness as CaCO3																	
Total Hardness as CaCO3	mg/L	1	-	-	9	<1	<1	<1	<1	<1	<1	67	26	<1	<1	<1	0%
ED037P: Alkalinity by PC Titrator																	
Bicarbonate Alkalinity as CaCO3	`	1	-	-	22	10	3	5	30	5	4	136	50	2	3	6	67%
Carbonate Alkalinity as CaCO3	mg/L	1	-	-	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	0%
Hydroxide Alkalinity as CaCO3	mg/L	1	-	-	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	0%
Total Alkalinity as CaCO3	mg/L	1	-	-	22	10	3	5	30	5	4	136	50	2	3	6	67%
ED041G: Sulfate (Turbidimetric) as SO4 2- by DA																	
Sulfate as SO4 - Turbidimetric	mg/L	1	-	500	50	<1	<1	1	<1	<1	<1	8	6	<1	<1	<1	0%
ED045G: Chloride Discrete analyser																	
Chloride	mg/L	1	-	250[b]	39	7	12	5	17	9	11	47	22	<1	10	10	0%
ED093F: Dissolved Major Cations																	
Calcium	mg/L	1	-	-	2	<1	<1	<1	<1	<1	<1	12	4	<1	<1	<1	0%
Magnesium	mg/L	1	-	-	1	<1	<1	<1	<1	<1	<1	9	4	<1	<1	<1	0%
Potassium	mg/L	1	-	-	<1	<1	<1	<1	1	<1	<1	3	2	<1	<1	<1	0%
Sodium	mg/L	1	-	-	54	8	8	4	25	7	7	68	26	<1	7	7	0%
EG020F: Dissolved Metals by ICP-MS																	
Aluminium	mg/L	0.01	0.055	0.2[b]	**0.32**	<0.01	<0.01	<0.01	0.04	<0.01	<0.01	-	0.02	<0.01	<0.01	<0.01	0%
Arsenic	mg/L	0.001	0.013	0.01	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	-	<0.001	<0.001	<0.001	<0.001	0%
Barium	mg/L	0.001	-	2	0.027	0.014	0.002	0.018	0.002	0.011	0.031	-	0.08	<0.001	0.022	0.021	5%
Beryllium	mg/L	0.001	0.004	0.09	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	-	<0.001	<0.001	<0.001	<0.001	0%
Boron	mg/L	0.05	0.37	4	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	-	<0.05	<0.05	<0.05	<0.05	0%
Cadmium	mg/L	0.0001	0.0002	0.002	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	-	<0.0001	<0.0001	<0.0001	<0.0001	0%
Chromium	mg/L	0.001	0.01	0.05	<0.001	<0.001	<0.001	<0.001	0.003	<0.001	<0.001	-	<0.001	<0.001	<0.001	<0.001	0%
Cobalt	mg/L	0.001	-	-	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	-	0.006	<0.001	<0.001	<0.001	0%
Copper	mg/L	0.001	0.0014	2	**0.082**	**0.01**	<0.001	**0.027**	**0.002**	**0.003**	**0.036**	-	**0.001**	<0.001	**0.009**	**0.009**	0%
Iron	mg/L	0.05	-	0.3[b]	0.1	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	-	0.06	<0.05	<0.05	<0.05	0%
Lead	mg/L	0.001	0.0034	0.01	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	-	<0.001	<0.001	<0.001	<0.001	0%
Manganese	mg/L	0.001	1.9	0.5	0.195	0.037	<0.001	0.431	0.009	0.056	0.3	-	**6.01**	<0.001	0.093	0.091	2%
Nickel	mg/L	0.001	0.011	0.02	0.005	0.002	<0.001	0.003	0.004	0.001	0.008	-	**0.013**	<0.001	0.008	0.009	12%
Selenium	mg/L	0.01	0.005	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	-	<0.01	<0.01	<0.01	<0.01	0%
Uranium	mg/L	0.001	-	0.017	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	-	<0.001	<0.001	<0.001	<0.001	0%
Vanadium	mg/L	0.01	-	-	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	-	<0.01	<0.01	<0.01	<0.01	0%
Zinc	mg/L	0.005	0.008	3[b]	**0.047**	**0.013**	0.007	**0.019**	**0.015**	0.006	**0.021**	-	**0.018**	<0.005	**0.027**	**0.027**	0%
EG020T: Total Metals by ICP-MS																	
Aluminium	mg/L	0.01	-	-	0.5	0.08	<0.01	<0.01	0.19	0.92	0.06	4.74	0.22	<0.01	<0.01	<0.01	0%
Arsenic	mg/L	0.001	-	-	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.003	<0.001	<0.001	<0.001	<0.001	0%
Barium	mg/L	0.001	-	-	0.032	0.015	0.048	0.021	0.003	0.035	0.033	0.243	0.089	<0.001	0.023	0.022	4%
Beryllium	mg/L	0.001	-	-	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0%
Boron	mg/L	0.05	-	-	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0%
Cadmium	mg/L	0.0001	-	-	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0002	<0.0001	<0.0001	<0.0001	<0.0001	0%
Chromium	mg/L	0.001	-	-	0.004	<0.001	<0.001	<0.001	0.004	<0.001	<0.001	0.008	<0.001	<0.001	<0.001	<0.001	0%
Cobalt	mg/L	0.001	-	-	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.022	0.006	<0.001	<0.001	<0.001	0%
Copper	mg/L	0.001	-	-	0.098	0.007	0.022	0.029	0.002	0.006	0.033	0.037	0.005	<0.001	0.009	0.008	12%
Iron	mg/L	0.05	-	-	0.55	<0.05	<0.05	<0.05	0.2	1.22	0.11	9.84	0.19	<0.05	<0.05	<0.05	0%
Lead	mg/L	0.001	-	-	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.009	<0.001	<0.001	<0.001	<0.001	0%
Manganese	mg/L	0.001	-	-	0.223	0.046	0.304	0.524	0.026	0.22	0.318	13.6	6.12	<0.001	0.101	0.101	0%
Nickel	mg/L	0.001	-	-	0.006	0.002	0.006	0.003	0.004	0.003	0.009	0.036	0.012	<0.001	0.008	0.008	0%
Selenium	mg/L	0.01	-	-	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0%
Uranium	mg/L	0.001	-	-	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0%
Vanadium	mg/L	0.01	-	-	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	<0.01	<0.01	<0.01	<0.01	0%
Zinc	mg/L	0.005	-	-	0.052	0.014	0.025	0.016	0.018	0.014	0.024	0.061	0.019	<0.005	0.024	0.024	0%
EG035F: Dissolved Mercury by FIMS																	
Mercury	mg/L	0.0001	-	-	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	-	<0.0001	<0.0001	<0.0001	<0.0001	0%
EG035T: Total Recoverable Mercury by FIMS																	
Mercury	mg/L	0.0001	-	-	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0%
Nutrients by Discrete Analyser																	
Nitrite + Nitrate as N	mg/L	0.01	-	-	0.14	0.06	0.01	0.03	0.05	<0.01	0.02	<0.01	<0.01	<0.01	0.02	0.02	0%
Total Kjeldahl Nitrogen as N	mg/L	0.1	-	-	<0.1	<0.1	<0.1	0.6	<0.1	<0.1	0.5	1.5	0.2	<0.1	<0.1	<0.1	0%
Total Nitrogen as N	mg/L	0.1	-	-	0.1	<0.1	<0.1	0.6	<0.1	<0.1	0.5	1.5	0.2	<0.1	<0.1	<0.1	0%
Total Phosphorus as P	mg/L	0.01	-	-	0.04	<0.01	<0.01	0.56	0.22	0.08	0.19	0.4	0.15	<0.01	<0.01	<0.01	0%
EN055: Ionic Balance*																	
Ionic Balance*	%	0.01	-	-	-	-	-	-	-	-	-	1.88	-	-	-	-	0%
Total Anions	meq/L	0.01	-	-	2.58	0.4	0.4	0.26	1.08	0.35	0.39	4.21	1.74	0.04	0.34	0.4	16%
Total Cations	meq/L	0.01	-	-	2.53	0.35	0.35	0.17	1.11	0.3	0.3	4.37	1.71	<0.01	0.3	0.3	0%
EP080/071: Total Petroleum Hydrocarbons																	
C10 - C14 Fraction	µg/L	50	-	-	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	0%
C10 - C36 Fraction (sum)	µg/L	50	-	-	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	0%
C15 - C28 Fraction	µg/L	100	-	-	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	0%
C29 - C36 Fraction	µg/L	50	-	-	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	0%
EP080/071: Total Recoverable Hydrocarbons - NEPM 2013																	
>C10 - C16 Fraction	µg/L	100	-	-	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	0%
>C10 - C16 Fraction minus Napthalene	µg/L	100	-	-	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	0%
>C10 - C40 Fraction (sum)	µg/L	100	-	-	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	0%
>C16 - C34 Fraction	µg/L	100	-	-	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	0%
>C34 - C40 Fraction	µg/L	101	-	-	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	0%

Notes:

LOR	Limit of reporting
200	Detected concentration above Aquatic Guideline for Fresh Water
100	Detected concentration above Long Term Irrigation purposes
3	Detected concentration above Drinking Water Guidelines
0.01	LOR is higher than the guideline trigger
60%	RPDs above 50% criteria
40%	Where one sample is below detectable levels, evaluated as equivalent to detection limit
-	No value
[b]	Aesthetic

G1663 (GEMCO)
Groundwater Quality Results
Sample Date: July 2014

Analyte	Units	LOR	Fresh Water Aquatic	Drinking Water	ELNMB01S	ELNMB03S	ELNMB03D	ELNMB04D	ELSMB05D	ELSMB06S	ELSMB06D	ELSMB07S	ELSMB07D	ELSMB08S	ELSMB08D	ELSMB09S	ELSMB09D	ELSMB10S	ELSMB10D	BLANK 2	ELNMB01D	DUPLICATE ELNMB01D	Relative Percentage Difference
EA025: Suspended Solids																							
Susoended Solids (SS)	mg/L	5	-	-																			n/a
EA065: Total Hardness as CaCO3																							
Total Hardness as CaCO3	mg/L	1	-	-	7	<1	<1	<1	4	<1	<1	<1	33	114	16	91	14	81	36	<1	<1	<1	n/a
ED037P: Alkalinity by PC Titrator																							
Bicarbonate Alkalinity as CaCO3	`	1	-	-	25	13	5	4	30	4	5	4	69	216	27	33	14	116	59	4	4	5	22%
Carbonate Alkalinity as CaCO3	mg/L	1	-	-	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	n/a
Hydroxide Alkalinity as CaCO3	mg/L	1	-	-	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	n/a
Total Alkalinity as CaCO3	mg/L	1	-	-	25	13	5	4	30	4	5	4	69	216	27	33	14	116	59	4	4	5	22%
ED041G: Sulfate (Turbidimetric) as SO4 2- by DA																							
Sulfate as SO4 - Turbidimetric	mg/L	1	-	500	41	<1	<1	2	1	<1	<1	<1	9	5	10	3	<1	15	20	<1	<1	<1	n/a
ED045G: Chloride Discrete analyser																							
Chloride	mg/L	1	-	250[b]	42	11	11	6	15	9	10	7	24	221	15	177	12	20	26	<1	9	9	0%
ED093F: Dissolved Major Cations																							
Calcium	mg/L	1	-	-	1	<1	<1	<1	<1	<1	<1	<1	5	26	3	10	4	21	6	<1	<1	<1	n/a
Magnesium	mg/L	1	-	-	1	<1	<1	<1	1	<1	<1	<1	5	12	2	16	1	7	5	<1	<1	<1	n/a
Potassium	mg/L	1	-	-	<1	<1	<1	<1	1	<1	<1	<1	2	6	1	1	<1	4	2	<1	<1	<1	n/a
Sodium	mg/L	1	-	-	59	10	10	4	22	7	7	5	28	174	15	85	8	36	37	<1	5	6	18%
EG020F: Dissolved Metals by ICP-MS																							
Aluminium	mg/L	0.01	0.055	0.2[b]	0.41	0.02	<0.01	<0.01	0.04	0.03	<0.01	0.02	0.09	0.15	0.02	0.08	0.04	0.13	0.57	<0.01	<0.01	<0.01	n/a
Arsenic	mg/L	0.001	0.013	0.01	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	0.002	<0.001	<0.001	<0.001	0.002	0.002	<0.001	<0.001	<0.001	n/a
Barium	mg/L	0.001	-	2	0.029	0.028	0.04	0.018	0.003	0.018	0.033	0.007	0.109	1.01	0.105	0.056	0.024	0.122	0.036	<0.001	0.014	0.015	7%
Beryllium	mg/L	0.001	0.004	0.09	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	n/a
Boron	mg/L	0.05	0.37	4	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.09	<0.05	0.07	<0.05	0.07	0.06	<0.05	<0.05	<0.05	n/a
Cadmium	mg/L	0.0001	0.0002	0.002	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0001	<0.0001	<0.0001	<0.0001	n/a
Chromium	mg/L	0.001	0.01	0.05	<0.001	<0.001	<0.001	<0.001	0.003	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	0.005	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	n/a
Cobalt	mg/L	0.001	-	-	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.007	0.009	0.005	0.002	<0.001	0.002	0.003	<0.001	<0.001	<0.001	n/a
Copper	mg/L	0.001	0.0014	2	0.048	0.041	0.02	0.02	0.002	0.01	0.05	0.004	0.001	0.004	0.002	0.007	0.004	0.002	0.003	<0.001	0.009	0.01	11%
Iron	mg/L	0.05	-	0.3[b]	0.14	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.07	11	0.29	0.06	0.08	0.42	0.38	<0.05	<0.05	<0.05	n/a
Lead	mg/L	0.001	0.0034	0.01	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.002	<0.001	<0.001	<0.001	n/a
Manganese	mg/L	0.001	1.9	0.5	0.208	0.067	0.164	0.302	0.012	0.094	0.365	0.085	5.4	15.3	4.51	1.19	0.328	1.83	4.17	<0.001	0.054	0.052	4%
Nickel	mg/L	0.001	0.011	0.02	0.01	0.006	0.004	0.004	0.003	0.003	0.016	0.003	0.012	0.038	0.015	0.053	0.008	0.01	0.014	<0.001	0.004	0.004	0%
Selenium	mg/L	0.01	0.005	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	n/a
Uranium	mg/L	0.001	-	0.017	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	n/a
Vanadium	mg/L	0.01	-	-	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	n/a
Zinc	mg/L	0.005	0.008	3[b]	0.062	0.022	0.025	0.038	0.017	0.008	0.068	0.025	0.03	0.023	0.032	0.359	0.037	0.015	0.028	<0.005	0.034	0.033	3%
EG020T: Total Metals by ICP-MS																							
Aluminium	mg/L	0.01	-	-	0.56	0.42	0.08	0.04	0.43	3.53	0.01	0.05	1.44	0.77	0.08	2.63	0.16	0.39	1.3	<0.01	0.04	0.05	22%
Arsenic	mg/L	0.001	-	-	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	0.002	0.002	<0.001	0.001	<0.001	0.002	0.002	<0.001	<0.001	<0.001	n/a
Barium	mg/L	0.001	-	-	0.034	0.036	0.045	0.021	0.006	0.102	0.033	0.007	0.135	1.05	0.107	0.07	0.028	0.13	0.044	<0.001	0.016	0.016	0%
Beryllium	mg/L	0.001	-	-	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	n/a
Boron	mg/L	0.05	-	-	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.11	<0.05	0.06	<0.05	0.09	0.06	<0.05	<0.05	<0.05	n/a
Cadmium	mg/L	0.0001	-	-	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0002	<0.0001	<0.0001	<0.0001	<0.0001	0.0001	<0.0001	<0.0001	<0.0001	n/a
Chromium	mg/L	0.001	-	-	0.001	<0.001	<0.001	<0.001	0.004	0.003	<0.001	<0.001	0.003	0.004	<0.001	0.023	<0.001	0.001	0.004	<0.001	<0.001	<0.001	n/a
Cobalt	mg/L	0.001	-	-	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	0.009	0.014	0.006	0.002	<0.001	0.003	0.005	<0.001	<0.001	<0.001	n/a
Copper	mg/L	0.001	-	-	0.067	0.043	0.021	0.025	0.004	0.027	0.054	0.005	0.008	0.025	0.007	0.018	0.007	0.01	0.015	<0.001	0.01	0.01	0%
Iron	mg/L	0.05	-	-	0.59	0.36	0.15	0.08	0.45	4.96	0.06	<0.05	2.45	12.5	0.33	2.71	0.16	0.87	0.9	<0.05	0.06	<0.05	n/a
Lead	mg/L	0.001	-	-	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	0.002	0.003	<0.001	0.002	0.003	<0.001	0.004	<0.001	<0.001	<0.001	n/a
Manganese	mg/L	0.001	-	-	0.237	0.089	0.235	0.392	0.1	0.695	0.356	0.096	7.17	16.2	4.48	1.53	0.487	2	4.88	<0.001	0.067	0.065	3%
Nickel	mg/L	0.001	-	-	0.016	0.01	0.005	0.005	0.006	0.012	0.015	0.003	0.018	0.059	0.017	0.065	0.01	0.01	0.02	<0.001	0.005	0.004	22%
Selenium	mg/L	0.01	-	-	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	n/a
Uranium	mg/L	0.001	-	-	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	n/a
Vanadium	mg/L	0.01	-	-	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.02	<0.01	<0.01	<0.01	n/a
Zinc	mg/L	0.005	-	-	0.082	0.03	0.028	0.034	0.031	0.03	0.063	0.03	0.05	0.022	0.038	0.43	0.044	0.022	0.048	<0.005	0.04	0.035	13%
EG035F: Dissolved Mercury by FIMS																							
Mercury	mg/L	0.0001	-	-	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	n/a
EG035T: Total Recoverable Mercury by FIMS																							
Mercury	mg/L	0.0001	-	-	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	n/a
Nutrients by Discrete Analyser																							
Nitrite + Nitrate as N	mg/L	0.01	-	-	0.13	0.04	<0.01	0.04	0.05	0.01	0.02	<0.01	<0.01	<0.01	<0.01	0.03	0.02	<0.01	0.02	<0.01	0.01	0.01	0%
Total Kjeldahl Nitrogen as N	mg/L	0.1	-	-	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.3	1.2	<0.1	0.4	<0.1	0.5	0.2	<0.1	<0.1	<0.1	n/a
Total Nitrogen as N	mg/L	0.1	-	-	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.3	1.2	<0.1	0.4	<0.1	0.5	0.2	<0.1	<0.1	<0.1	n/a
Total Phosphorus as P	mg/L	0.01	-	-	0.04	<0.01	<0.01	<0.01	0.23	0.06	<0.01	<0.01	0.07	0.17	<0.01	0.06	0.03	0.06	0.42	<0.01	<0.01	<0.01	n/a
EN055: Ionic Balance*																							
Ionic Balance*	%	0.01	-	-	-	-	-	-	-	-	-	-	-	3.15	-	1.58	-	1.5	-	-	-	-	n/a
Total Anions	meq/L	0.01	-	-	2.54	0.57	0.41	0.29	1.04	0.33	0.38	0.28	2.24	10.6	1.17	5.71	0.62	3.19	2.33	0.08	0.33	0.35	6%
Total Cations	meq/L	0.01	-	-	2.7	0.43	0.43	0.17	1.06	0.3	0.3	0.22	2.12	10	0.99	5.54	0.63	3.29	2.37	<0.01	0.22	0.26	17%
EP080/071: Total Petroleum Hydrocarbons																							
C10 - C14 Fraction	µg/L	50	-	-	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	60	<50	70	<50	<50	<50	<50	n/a
C10 - C36 Fraction (sum)	µg/L	50	-	-	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	60	<50	380	<50	<50	<50	<50	n/a
C15 - C28 Fraction	µg/L	100	-	-	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	250	<100	<100	<100	<100	n/a
C29 - C36 Fraction	µg/L	50	-	-	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	60	<50	<50	<50	<50	n/a
EP080/071: Total Recoverable Hydrocarbons - NEPM 2013																							
>C10 - C16 Fraction	µg/L	100	-	-	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	n/a
>C10 - C40 Fraction (sum)	µg/L	100	-	-	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	250	<100	<100	<100	<100	n/a
>C16 - C34 Fraction	µg/L	100	-	-	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	250	<100	<100	<100	<100	n/a
>C34 - C40 Fraction	µg/L	100	-	-	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	n/a

Notes:

LOR	Limit of reporting
200	Detected concentration above Aquatic Guideline for Fresh Water
100	Detected concentration above Long Term Irrigation purposes
3	Detected concentration above Drinking Water Guidelines
0.01	LOR is higher than the guideline trigger
60%	RPDs above 50% criteria
40%	Where one sample is below detectable levels, evaluated as equivalent to detection limit
-	No value
b	Aesthetic

Appendix B

Numerical Modelling Report

B1 Groundwater modelling

B1.1 Overview of groundwater modelling

Predictive numerical modelling was undertaken to assess the impact of the project on the groundwater regime. The objectives of the predictive modelling were to:

- estimate the groundwater seepage flux into the active mining areas over the life of mine;
- simulate and predict the area of influence of the seepage and the level and rate of drawdown at specific locations;
- predict the impact of drawdown on groundwater flows to creeks and other groundwater users, both human and the environment; and
- provide mitigation/control strategies if adverse impacts are identified.

The key to the success of any modelling exercise is to provide an understanding of the groundwater regime and the key processes. This is known as a conceptual model of the groundwater system. The conceptual model describes the groundwater system and how it operates given the available data, and represents the natural system as an idealised and simplified way.

The conceptual groundwater model of the project site was developed based on geological and topographical maps, geological information from exploration bores drilled across the project site, level and quality data from the monitoring bores, results from previous hydrogeological investigations and relevant data from the Department of Land Resources Management (DLRM) Water Portal. Section 7 of the main report describes the conceptual model. The following sections outline the numerical groundwater model developed based on the conceptual model.

B1.2 Groundwater model

B1.2.1 Model code

The modelling code was selected to meet the model objectives outlined above. Numerical simulation of groundwater flow for the project was undertaken using the MODFLOW-SURFACT code (referred to as SURFACT for the remainder of the report). A commercial derivative of the standard MODFLOW code, SURFACT is distributed by HGL and has some distinct advantages over MODFLOW; advantages that are critical for the simulation of groundwater flow for the project.

The MODFLOW code (on which SURFACT is based) is the most widely used code for groundwater modelling and is presently considered an industry standard. Use of the SURFACT modelling package is becoming increasingly widespread, particularly in mining applications where groundwater dewatering and recovery are simulated.

SURFACT is capable of simulating unsaturated conditions. This is critical for the requirements of the project, where geology units will be progressively dewatered during active mine operations, and rewet following the cessation of mining. SURFACT is also supplied with more robust numerical solution schemes to handle the more complex numerical problem resulting from the unsaturated flow formulation. Added to the more robust numerical solution schemes is an adaptive time-stepping function that aides the progression of the solution past difficult and complex numerical situations such as oscillations.

The input files for the SURFACT model were created using customised Fortran code and a special SURFACT edition of the Groundwater Data Utilities (Watermark Numerical Computing, 2012).

B1.2.2 Model geometry

The model domain was discretised into rectangular cells arranged into eight layers comprising 255 columns and 364 rows, and rotated 27.2° anticlockwise. There are 86,294 active cells in each layer with the dimensions of the cells varying from a maximum of 400 m by 400 m, to 120 m by 120 m within the existing mining area, and down to 40 m by 40 m at the eastern mining leases. The model boundary extends 28.2 km laterally, and 32.0 km vertically, covering the potentially impacted drainage catchments of the eastern mining leases. The model covers a total area of approximately 734.7 km^2. Figure B.1 shows the model grid.

The numerical model represented the following key hydrostratigraphic layers identified while developing the conceptual groundwater model of the area:

- Quaternary sediments;
- Tertiary laterite and underlying lateritic clay;
- Marine claystone which hosts the manganese orebody;
- Cretaceous sandstone (comprising marine sandstone and reworked basement); and
- Proterozoic basement.

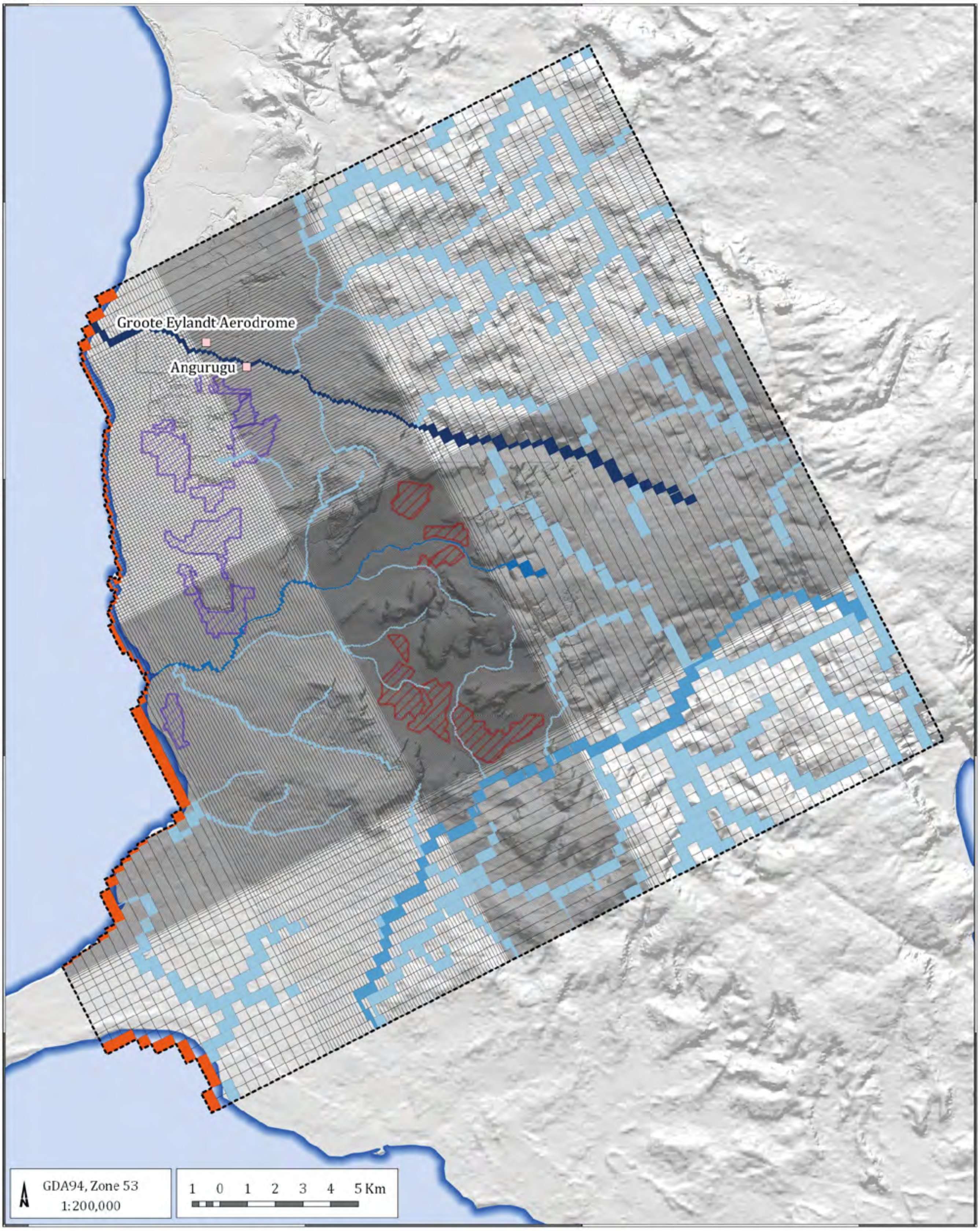
Table B 1 summarises the hydrostratigraphic layers represented in the model.

Table B 1 Model layers

Ground water model layer	GEMCO geological model surface	Geological age	Geological unit	Status
1	100 - 200	Quaternary	Quaternary sediments	Ephemeral groundwater present
2	200 - 300	Tertiary	Laterite	Unconfined aquifer
3	300 - 400	Tertiary	Lateritic clay	Aquitard / Confining unit
4	400 - 900	Cretaceous	Manganese orebody	Aquitard / Confining unit
5	900 - 1000	Cretaceous	Marine claystone	Aquitard / Confining unit
6	1000 +	Cretaceous	Cretaceous sandstone	Confined aquifer
7	n/a	Proterozoic	Weathered basement	Confined aquifer
8	n/a	Proterozoic	Basement	Aquitard

The elevation of each layer in the model was based on data provided by GEMCO's geological model. Detailed structure contours were available for the GEMCO mine and the Eastern Leases. Outside of these areas, the surfaces were extrapolated based on the Eastern Leases groundwater drilling program and DLRM registered bores.

The extent of the Quaternary sediments was defined based on the 1:250,000 scale surface geology map. The thickness of the Quaternary sediments layer varied in the model between 0 m to 3 m based on data in the GEMCO geological model and field investigation data. The thickness of the remaining Tertiary and Cretaceous sediments (i.e model layers 2 to 6) was based on data in, and extrapolated from, the GEMCO geological model, Eastern Leases groundwater drilling program and DLRM registered bores.



LEGEND

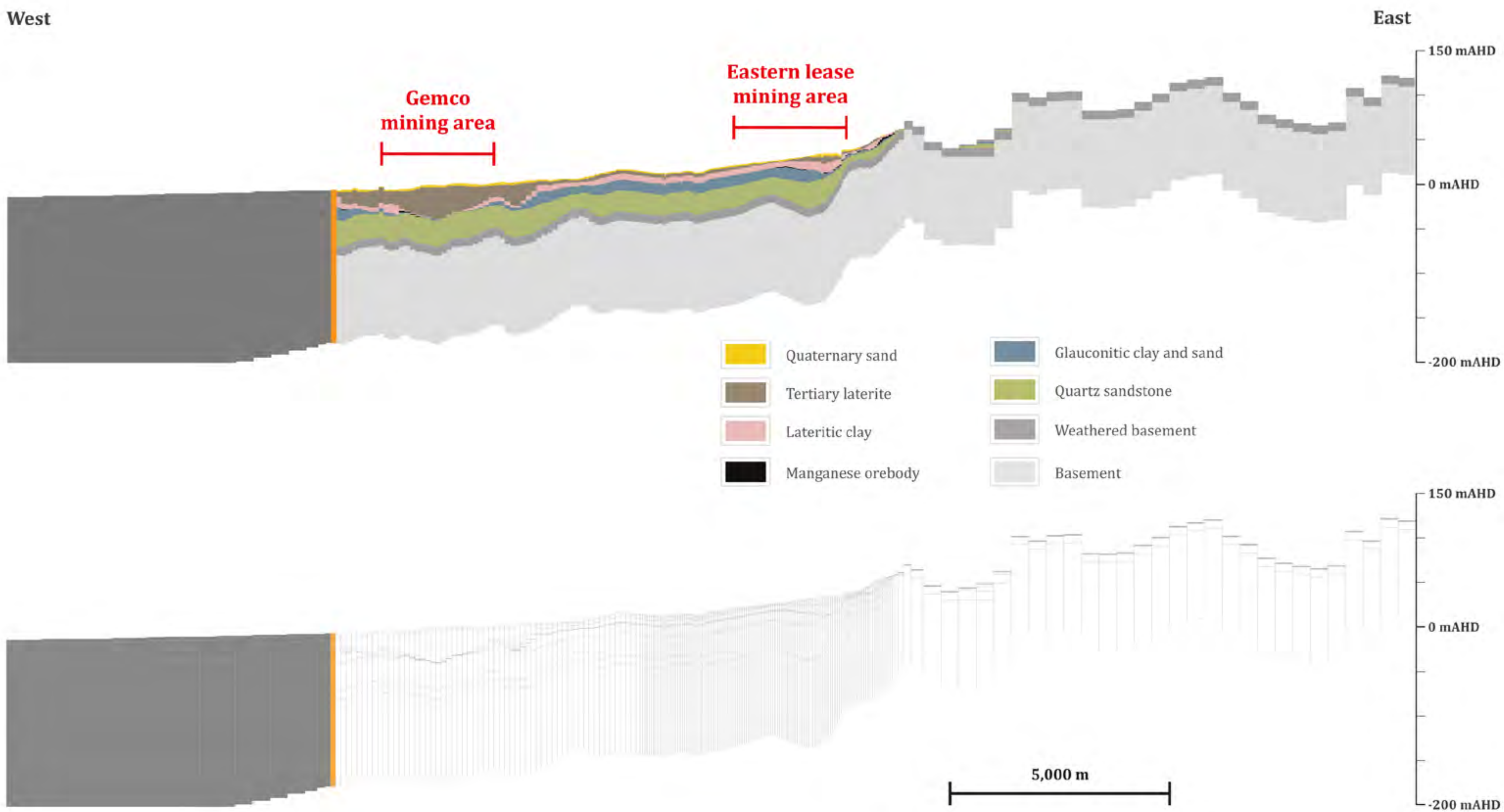
- Place name
- Existing pit area
- Proposed pit area
- Watercourse
- Model boundary
- Mode grid
- Fixed head
- Angurugu River
- Emerald River
- Amagulu River
- Minor creek

GEMCO (G1663)

Model grid

DATE 22/8/2014

FIGURE No: **B.1**



Model grid cross section - west - east

Figure B.2

GEMCO (G1663)

Where the Quaternary, Tertiary and Cretaceous sediments were not present (i.e. basement outcrops), model layers 1 to 6 were thinned to 1 m and to represent a weathered basement regolith layer.

The Tertiary sediments are represented by an upper laterite layer (layer 2) which forms a shallow aquifer, and a lower lateritic clay (layer 3) horizon which forms an aquitard. Layer 4 represents the manganese orebody, and the base of mining in quarries. Layer 5 represents the marine claystone horizon which forms a confining layer above the high yielding Cretaceous sandstone aquifer. Layer 6 represents the confined Cretaceous sandstone aquifer. Layer 7 represents a ubiquitous weathered basement profile across the Proterozoic basement (layer 8). Figure B.2 shows a cross-section through the model grid and shows the relative vertical distribution of the model layers.

B1.2.3 Modelling approach

The methodology for predicting project impacts involved constructing and calibrating a robust and justifiable groundwater model. The calibrated model was then used to predict the future changes to the existing groundwater regime. The predictive scenarios simulated the:

- cumulative impacts from the nearby existing mine operations;
- dewatering of the shallow laterite and sandstone aquifers; and
- impacts on nearby rivers and creeks.

Mining in the Eastern Leases would take place concurrently with the operation of the existing GEMCO mine. According to current planning, construction in the Northern EL would commence in 2017 (Project Year 1) and mining activities would commence in the second half of 2018 (Project Year 2). Construction in the Southern EL is scheduled to commence approximately 4 years later in 2022 (Project Year 6) and mining would then take place in both of the tenements until approximately 2031 (Project Year 15). This equates to a total of 13 years of mining operations (i.e. mining of ore).

The model included proposed mining in the Eastern leases and also represented the approved mining in the GEMCO mine. Mining north of the Angurugu River was not represented in the model as it was sufficiently distant from the Eastern Leases that no cumulative impacts would occur.

B1.2.4 Boundary conditions

Boundary conditions govern the simulation of water entering and leaving the model domain. The sections below outline the boundary conditions adopted in the model.

B1.2.4.1 Model boundaries

The model boundaries were placed at a significant distance from the project so that predicted groundwater impacts do not interact with these boundaries. The coast line was set as the western boundary and assigned with a constant 'fixed head' representing sea level. The eastern boundary approximately follows catchment divides and is assigned a no flow boundary condition. The northern and southern boundaries were aligned to be parallel to the groundwater flow direction and also assigned as no flow. The base of the model was also assumed to be a no flow boundary condition.

B1.2.4.2 Recharge and evaporation

The model represented diffuse recharge from rainfall using the SURFACT recharge (RCH) package. Recharge was applied in Layer 1 across zones representing the outcropping geological units. The rainfall recharge rate was derived during calibration as a percentage of the annual rainfall rate of 1364.1 mm.

B1.2.4.3 Surface drainage

The model represented discharge from the aquifers to rivers and creeks with the SURFACT River package (RIV). The bed level for each river or creek was estimated using Digital Elevation Model (DEM) data. The riverbed conductance was calculated from the width, thickness and vertical hydraulic conductivity of the riverbed material. Table B.2 summaries the parameters used to represent the rivers in the model.

Table B.2 River bed parameters

ID	Width (m)	Depth (m)	Perennial stage height (m) steady state	Perennial stage height (m) transient	Ephemeral stage height (m) transient	Thickness (m)	Zone
Angurugu River	10	5	1.75	1.65 – 1.93	0-0.5	1	1
Emerald River	5	5	2.13	2.01 – 2.31	0-0.5	1	2
Amagulu River	20	5	1.02	1.41 – 2.01	-	1	3
Minor Creeks	2	1	0	0	-	1	4

The key rivers and streams in the Eastern Leases were inspected to determine where the streams changed from ephemeral to perennial flow. The model assigned a zero stage height for the ephemeral reaches based on this data. Where perennial flow was identified, the river stage heights were based upon historic averages at gauging stations. The perennial reaches occurred as follows:

- two along the Angurugu River - Gauging stations G9290006 and G9290120;
- one along the Emerald River - Gauging station G9290211; and
- one along the Amagula River - Gauging station G9290005.

B1.2.4.4 Mine drainage

The model represented mine dewatering with the SUFACT drain (DRN) package. Section B2.2 details the approach to representing the mining process.

B1.3 Model calibration

The objective of model calibration was to reproduce measured groundwater levels and construct the starting head water levels for the predictive transient model.

B1.3.1 Calibration approach

The groundwater model was calibrated to both steady state and transient conditions to ensure the seasonal response to stresses (e.g. rainfall, surface water flow) was replicated. This was particularly important where the rainfall is highly seasonal with contrasting wet and dry periods. The steady state model was calibrated by adjusting aquifer parameters and stresses to produce the best match between the observed and simulated water levels. A further detailed transient condition was calibrated to reproduce the transient water level fluctuations measured in the monitoring bore network installed for the project. The transient model adopted weekly stress periods from December 2013 to June 2014 which was sufficient to provide a robust transient calibration result.

B1.3.2 Calibration targets

Available groundwater level data was used to calibrate the model. This data included site specific monitoring data from the Eastern Leases and GEMCO mine, and data from DLRM registered bores in the vicinity of the Eastern Leases.

A total of 92 water level data were used for the steady state calibration. This represents a significant set of calibration targets and provides the basis for a robust calibration. Table B 3 presents the bores used in the calibration process, the measured and model predicted water levels, and the difference between these levels.

During the calibration processes some of the bores were weighted to focus the calibration on matching water levels at these sites. The weighting focussed on water levels in bores around the Eastern Leases. This ensured that the vertical gradient and groundwater levels adjacent to the Eastern Leases were replicated by the model.

Table B 3 Steady state calibration targets

BORE ID	Easting GDA94 (m)	Northing GDA94 (m)	Model layer	Observed water level (mAHD)	Calculated water level (mAHD)	Residual (m)	Weight
DPW010A	656,983	8,444,894	2	6.86	10.97	-4.11	1
DQMB1	656,984	8,444,902	2	7.59	10.19	-2.60	1
DQMB3	656,979	8,444,888	2	7.79	8.85	-1.06	1
DQMW1	656,689.3	8,444,637	2	6.47	11.02	-4.55	1
DQMW2	657,410.3	8,445,614	2	6.77	10.93	-4.16	1
DQMW3	655,868.2	8,445,303	2	6.94	8.38	-1.44	1
DQMW4	655,720.2	8,447,852	2	9.57	16.46	-6.89	1
DTMW1	658,263.7	8,452,420	4	8.18	4.54	3.64	1
DTMW2	658,685.4	8,452,450	4	9.00	11.72	-2.72	1
DTMW3A	658,748.3	8,451,890	3	21.49	21.89	-0.40	1
DTMW3B	658,738	8,451,890	4	24.63	21.59	3.04	1
FCMW1B	658,572.5	8,454,348	2	30.19	20.71	9.48	1
FCMW3	659,327.8	8,455,977	3	24.15	20.85	3.30	1
FCMW4	655,634.2	8,456,412	2	26.55	25.44	1.11	1

BORE ID	Easting GDA94 (m)	Northing GDA94 (m)	Model layer	Observed water level (mAHD)	Calculated water level (mAHD)	Residual (m)	Weight
FCMW6	659,384	8,456,968	5	38.00	33.90	4.10	1
FP10	656,006.4	8,454,156	6	42.35	26.44	15.91	1
FP11	656,073.5	8,454,155	6	29.55	27.50	2.05	1
FP1A	656,020.7	8,454,052	6	45.70	39.56	6.14	1
FP2	656,008.4	8,454,068	6	31.90	30.72	1.18	1
FP3	656,020.1	8,454,078	6	22.26	27.32	-5.06	1
FP4	656,021	8,454,022	6	19.31	21.11	-1.80	1
FP5	655,975	8,454,078	6	32.31	32.15	0.16	1
FP6	656,003.7	8,454,125	6	21.58	23.17	-1.59	1
FP8	656,028.6	8,454,120	6	33.76	34.53	-0.77	1
FP9	655,962.8	8,454,162	6	34.51	32.64	1.87	1
MW8567	657,916	8,454,946	2	37.38	37.88	-0.50	1
MW8569	657,450	8,454,456	2	22.03	23.65	-1.62	1
MW8570	655,950	8,454,880	2	25.50	27.49	-1.99	1
MW8579	657,294	8,444,564	2	38.18	38.75	-0.57	1
MW8582	653,883.9	8,455,017	2	53.30	46.32	6.98	1
NFMW1	655,899	8,454,290	2	6.27	9.27	-3.00	1
NFMW2	655,883	8,454,290	2	12.85	18.06	-5.21	1
NFMW3	655,861	8,454,280	2	6.13	8.66	-2.53	1
NFMW4	655,887	8,454,252	2	23.58	19.94	3.64	1
NFMW5	656,023	8,454,066	2	6.59	6.64	-0.05	1
SPMW1	655,948.1	8,453,801	5	5.19	6.81	-1.62	1
SPMW2	655,959.5	8,453,842	5	8.30	6.69	1.61	1
SPMW3	656,018	8,453,776	5	7.82	6.65	1.17	1
TDFMW1	656,905.1	8,449,243	2	7.31	6.68	0.63	1
TDFMW2A	654,513.4	8,451,430	2	6.96	6.69	0.27	1
TDFMW6	657,016.1	8,453,244	5	6.93	6.56	0.37	1
TDFMW8	657,010.9	8,453,868	3	7.20	6.63	0.57	1
TDMW1	654,083.4	8,455,005	2	6.80	6.70	0.10	1
TDMW10	654,031.0	8,455,429	2	6.71	6.52	0.19	1
TDMW2	653,900.7	8,453,849	2	8.63	12.93	-4.30	1
TDMW23	654,309.2	8,452,782	2	5.27	6.79	-1.52	1
TDMW24	654,309.1	8,452,779	2	9.03	6.76	2.27	1

BORE ID	Easting GDA94 (m)	Northing GDA94 (m)	Model layer	Observed water level (mAHD)	Calculated water level (mAHD)	Residual (m)	Weight
TDMW25	654,313.5	8,452,521	2	9.21	14.48	-5.27	1
TDMW26	654,313.5	8,452,523	2	17.92	13.24	4.68	1
TDMW27	654,316.2	8,452,358	2	2.92	1.91	1.01	1
TDMW28	654,316.1	8,452,356	2	7.64	5.31	2.33	1
TDMW3	654,368.7	8,453,827	2	8.74	11.86	-3.12	1
TDMW7	654,093	8,455,148	2	4.64	9.52	-4.88	1
TDMW8	654,067.2	8,455,181	2	2.65	4.83	-2.18	1
TDMW9	655,439.2	8,454,883	6	7.67	15.11	-7.44	1
DPW012A	656,784	8,444,902	2	2.55	4.18	-1.63	1
DPW013A	656,584	8,444,910	2	5.28	5.22	0.06	1
MW4269	656,907	8,457,748	2	5.91	8.63	-2.72	1
MW7656	656,330	8,445,148	2	5.51	8.65	-3.14	1
MW7657	656,326	8,445,148	2	3.93	1.17	2.76	1
MW7658	655,636	8,450,914	2	8.01	7.38	0.63	1
MW7660	657,505	8,447,636	2	8.45	7.39	1.06	1
MW7661	653,255	8,451,766	2	7.89	7.45	0.44	1
MW8565	654,945.5	8,448,732	2	8.14	7.48	0.66	1
MW8574	656,860	8,448,006	2	8.34	7.17	1.17	1
MW8575	655,385	8,446,238	2	10.07	6.57	3.50	1
MW8576	654,943	8,448,736	2	9.15	6.55	2.60	1
MW8578	657,297	8,444,560	2	9.84	6.85	2.99	1
TDMW20	654,603.2	8,453,867	2	14.35	12.80	1.55	1
TDMW21	654,767.2	8,454,954	2	5.69	8.19	-2.50	1
TDMW22	653,889.5	8,454,918	2	8.39	11.82	-3.43	1
TDMW6	654,086	8,454,968	2	6.78	9.88	-3.10	1
ELNMB01D	664,017	8,447,502	6	3.07	1.66	1.41	2
ELNMB01S	664,017	8,447,503	2	0.90	-0.03	0.93	2
ELNMB02D	664,120	8,448,622	2	3.16	1.72	1.44	2
ELNMB03D	664,986	8,447,703	6	4.80	3.06	1.74	2
ELNMB03S	664,986	8,447,701	2	4.89	3.87	1.02	2
ELNMB04D	665,744	8,449,493	6	2.24	1.26	0.98	2
ELSMB05	664,483	8,442,764	5	2.39	3.97	-1.58	2
ELSMB06D	663,556	8,442,620	6	2.35	3.98	-1.63	2

BORE ID	Easting GDA94 (m)	Northing GDA94 (m)	Model layer	Observed water level (mAHD)	Calculated water level (mAHD)	Residual (m)	Weight
ELSMB06S	663,563	8,442,620	2	2.07	4.86	-2.79	2
ELSMB07D	665,208	8,441,009	6	2.05	4.85	-2.80	2
ELSMB07S	665,211	8,441,009	2	1.60	5.29	-3.69	2
ELSMB08D	667,491	8,440,495	5	1.61	5.29	-3.68	2
ELSMB08S	667,491	8,440,495	3	3.55	2.57	0.98	2
ELSMB09D	665,821	8,440,249	6	4.04	1.72	2.32	2
ELSMB09S	665,823	8,440,247	3	2.21	1.21	1.00	2
ELSMB10D	668,228	8,441,997	5	2.46	0.98	1.48	2
ELSMB10S	668,227	8,441,994	2	3.48	5.36	-1.88	2
YEDIKBA	657,343	8,443,132	6	1.98	5.86	-3.88	1
RN027979	664,025	8,436,467	6	14.51	13.44	1.07	1

B1.3.3 Steady state calibration results

An objective method to evaluate the calibration of the model is to examine the statistical parameters associated with the calibration. One such method is by measurement of the error between the modelled and observed (measured) water levels. A root mean square (RMS) expressed as:

$$RMS = \left[1/n\sum(h_o - h_m)_i^{\,2}\right]^{0.5}$$

where: n = number of measurements

h_o = observed water level

h_m = simulated water level

RMS is considered to be the best measure of error, if errors are normally distributed. The RMS error calculated for the calibrated model is 3.4 m.

Figure B.3 compares graphically the observed and calculated water levels, with Table B.4 presenting statistics from the calibration process.

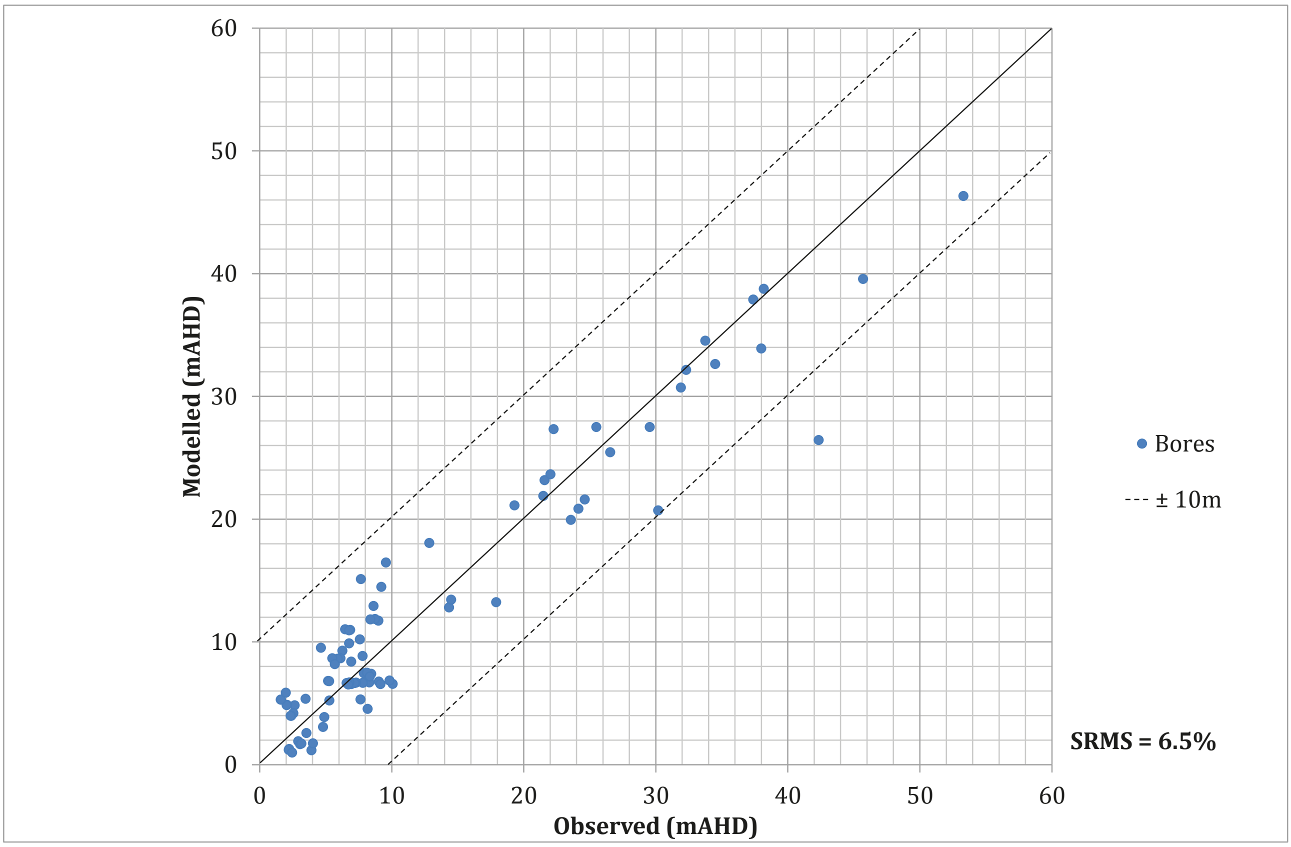


Figure B.3 Steady state calibration – modelled vs observed groundwater levels

Table B.4 Calibration statistics – steady state

Calibration performance measure	Value
Sum of residuals (SR) (m)	-11.83
Mean sum of residuals (MSR) (m)	-0.13
Scaled mean sum of residuals (SMSR) (%)	-0.25
Sum of squares (SSQ) (m2)	1064.47
Mean sum of squares (MSSQ) (m2)	11.70
Root mean square (RMS) (m)	3.42
Root mean fraction square (RMFS) (%)	34.84
Scaled RMFS (SRMFS) (%)	8.17
Scaled RMS (SRMS) (%)	6.53

The maximum acceptable value for the calibration criterion depends on the magnitude of the change in heads over the model domain. If the ratio of the RMS error to the total head loss in the system is small, the errors are only a small part of the overall model response. The total observed head loss within the model domain is 52.4 m; therefore, the ratio of RMS to the total head loss (SMRS) is 6.5 %. This indicates a good calibration and is within the Australian guidelines (Barnett et al, 2012) of 10 % Scaled RMS.

The model was calibrated to multi-level monitoring bores to ensure the observed vertical groundwater gradients were replicated by the model. Figure B.4 shows graphically how the model reproduced the vertical hydraulic gradients observed. The results indicate the vertical gradient is replicated by the model.

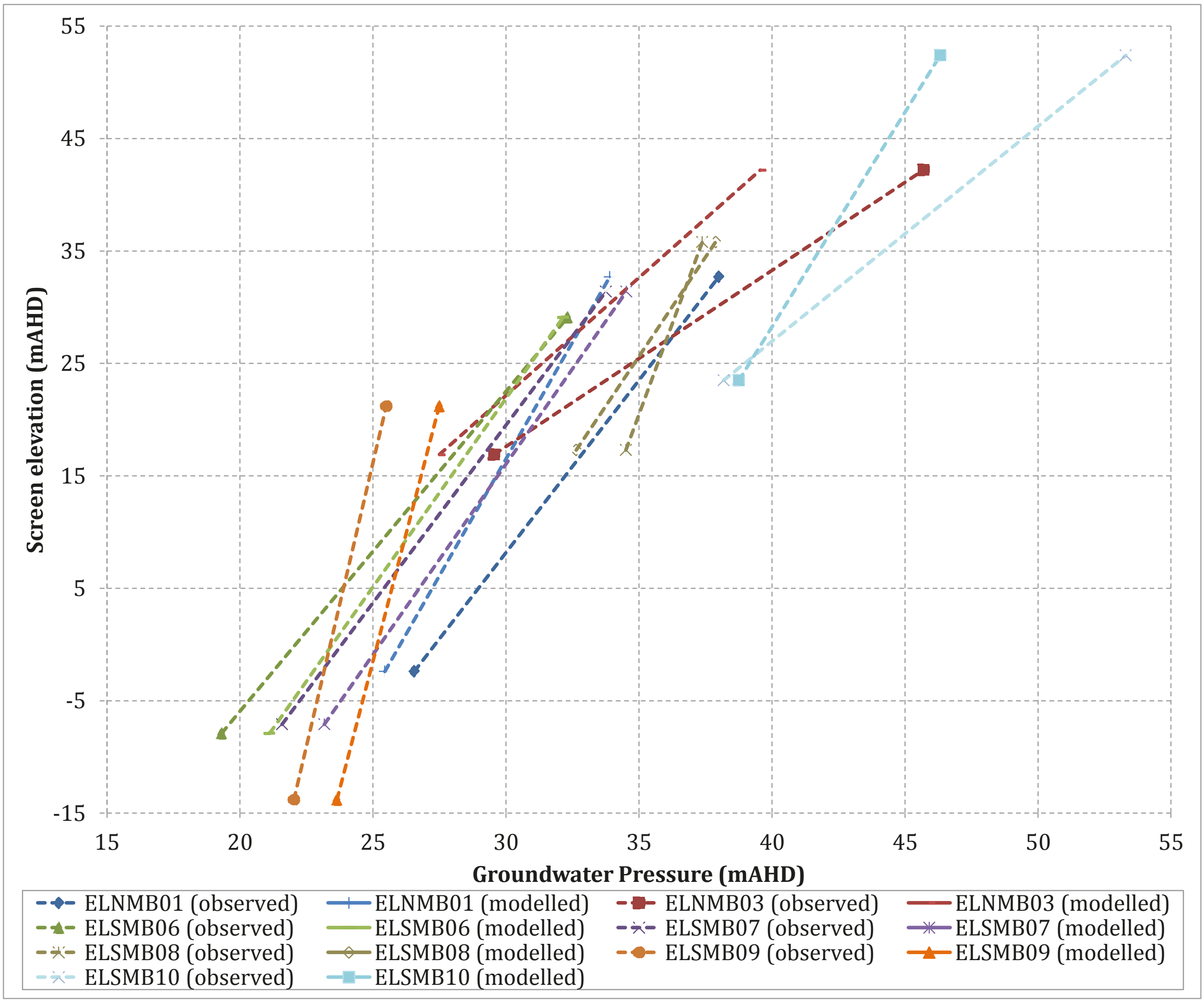


Figure B.4 Steady state vertical pressure gradient – observed vs measured

B1.3.4 Transient calibration results

Water level records from a total of 38 bores were used to calibrate the transient model over the period December 2013 to June 2014.

Figure B 5 compares the observed and calculated water levels from the transient model graphically with Table B 5 presenting statistics from the calibration process. Appendix B-1 provides hydrographs for each bore comparing the observed and simulated groundwater levels from the transient model. As the number of calibration data points varied at each location, the residuals were weighted according to the number of measurements at each location to prevent skewing of the model statistics.

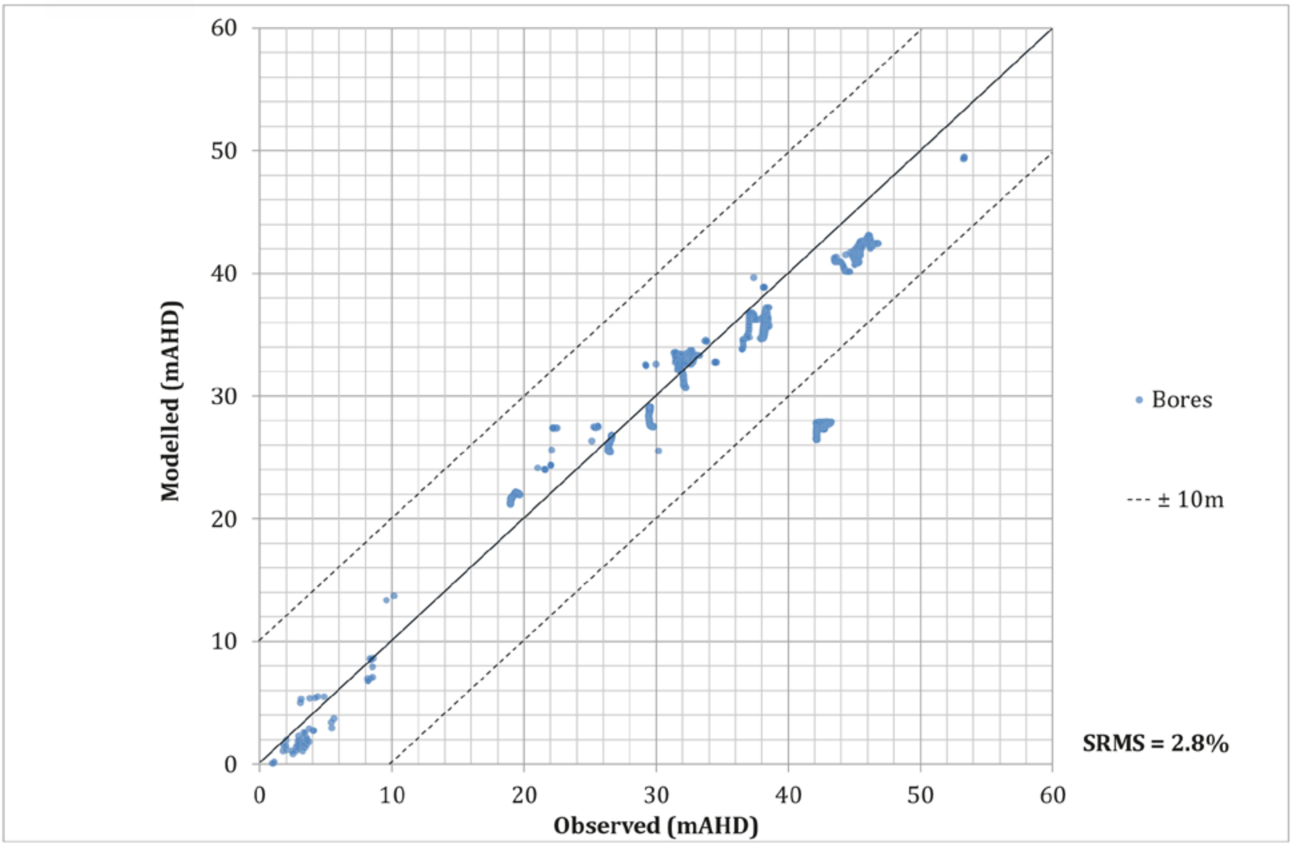


Figure B 5 Transient calibration – modelled vs observed groundwater levels

Table B 5 Calibration statistics – transient model

Calibration performance measure	Weighted value
Sum of residuals (SR) (m)	3172.89
Mean sum of residuals (MSR) (m)	83.50
Scaled mean sum of residuals (SMSR) (%)	159.25
Sum of squares (SSQ) (m2)	83.18
Mean sum of squares (MSSQ) (m2)	2.19
Root mean square (RMS) (m)	1.48
Root mean fraction square (RMFS) (%)	107.10
Scaled RMFS (SRMFS) (%)	65.37
Scaled RMS (SRMS) (%)	2.82

The RMS error calculated for the calibrated model is 1.5 m. The total observed head loss within the model domain is 52.4 m; therefore, the ratio of RMS to the total head loss (SMRS) is 2.8 %. This indicates a good calibration and is within the Australian guidelines (Barnett et al, 2012) of 10 % Scaled RMS.

The transient calibration model has a higher level of accuracy compared to the steady state model. This is because the model encapsulates seasonal variability not represented by the steady state model. Hydrographs presented in Appendix B-1 indicate the model replicates the seasonal response to rainfall in the laterite aquifer, as well as the more muted and lagging response to rainfall recorded in the Cretaceous sandstone aquifer.

B1.3.5 Calibrated heads

Calibrated heads were derived for the following layers:

- Layer 2 – Laterite aquifer– Steady state (pre-mining);
- Layer 6 – Cretaceous sandstone aquifer– Steady state (pre-mining);
- Layer 2 – Laterite aquifer – Transient (July 2014); and
- Layer 6 – Cretaceous sandstone aquifer – Transient (July 2014).

B1.3.6 Hydraulic properties

Table B.6 summaries the calibration hydraulic conductivity of the hydrostratigraphic units in the model.

Table B.6 Model layer hydraulic parameters

Model layer	Lithology	Horizontal hydraulic conductivity (m/day)	Vertical hydraulic conductivity (m/day)	Specific yield Sy (%)	Specific storage Ss (m^{-1})
1	Sand	1.00E+00	1.41E-01	3.8	7.09E-04
2	Laterite / ferricrete	3.24E-02	6.57E-03	1.3	7.34E-05
3	Lateritic clay / concretionary manganese	1.00E-02	1.11E-03	1.0	1.84E-05
4	Manganese orebody	4.11E-01	2.05E-01	0.9	1.12E-04
5	Cretaceous clay / claystone	1.62E-04	1.76E-06	0.6	5.13E-05
6	Quartz sandstone	2.00E+01	3.36E+00	1.0	3.32E-04
7	Weathered basement	2.23E+01	1.30E+00	1.0	3.43E-04
8	Basement	3.87E-02	2.01E-03	0.2	2.17E-04

***Note**: Parameters used in the model are conservative estimates using a combination of field data, hydrogeological expertise and knowledge of the region.*

Figure B.6 shows the distribution of modelled hydraulic conductivity (horizontal) compared to field data and parameters used for the previous modelling assessments undertaken on Groote Eylandt. The geometric mean for the model parameters is shown, which gives a good indication of the fit of the model to real data.

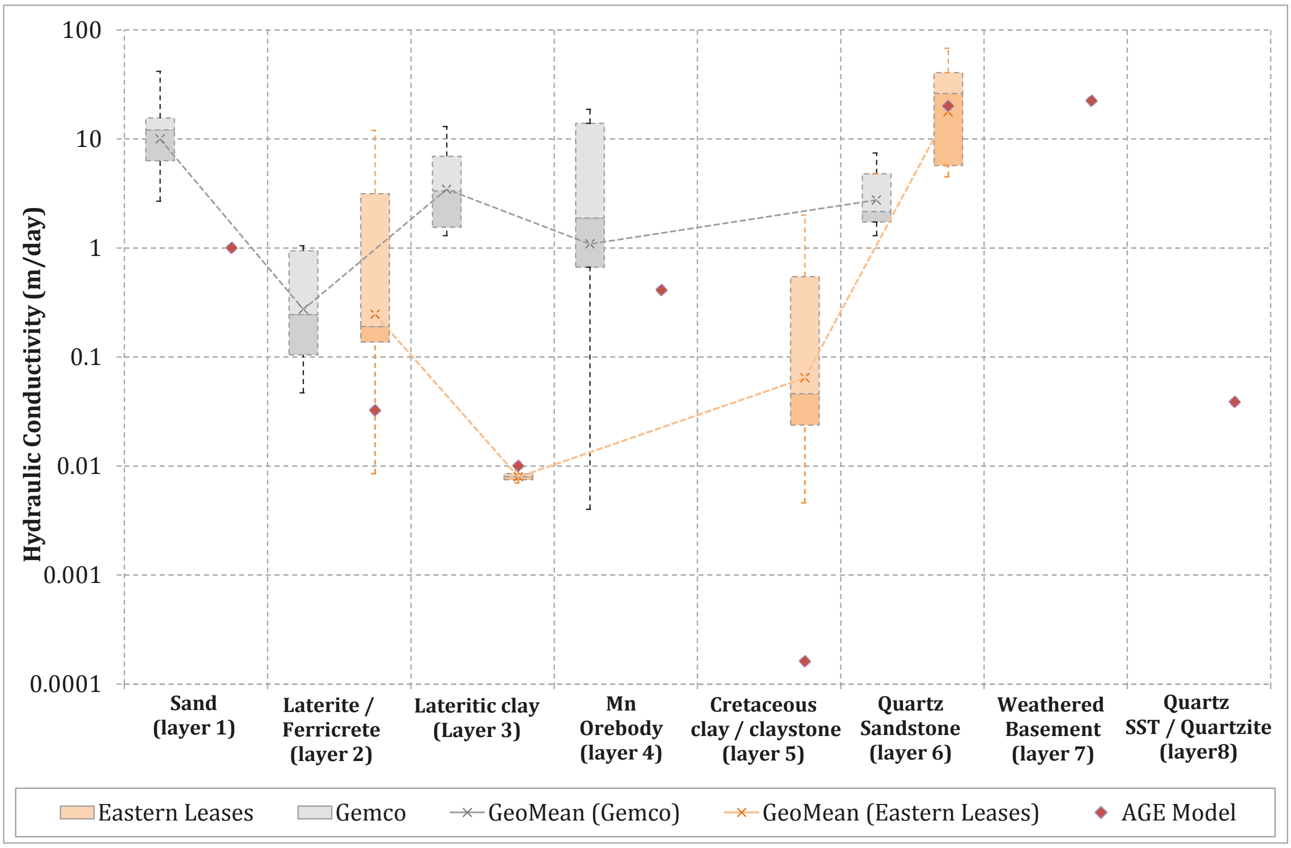


Figure B.6 Distribution of horizontal hydraulic conductivity

All values for the Quaternary sediments (predominantly sands), Tertiary laterite and lateritic clay and the Cretaceous sandstone units fall within the range of field data results. Field data is not available for the weathered basement and basement as they are located at depth or beyond the immediate mineable quarry areas. For these units, the model derived the values that provided the most robust calibration result based on field observations. The robust calibration statistic (discussed in the previous section) confirms that the adopted values are suitable.

The model value for the marine claystone unit is lower than the measured values from the in-situ permeability tests. The bores used in the permeability tests target discrete horizons which yielded water and therefore showed a higher permeability. These values do not therefore reflect the lower bulk hydraulic conductivity of the unit. The model value is at the higher end of the typical permeability range for claystone and therefore represents a conservative value for the purposes of this assessment.

Riverbed vertical conductivity of each river system was calibrated in the steady state and transient models (see Table B.7). The calibrated value for the river beds was close to the vertical hydraulic conductivity of the Quaternary sediments (predominantly sands) and lateritic sediments in the model. This agreed with the conceptual model, which the surface water and groundwater system are locally connected.

Table B.7 Calibrated river bed vertical hydraulic conductivity

ID	Width (m)	Depth (m)	Thickness (m)	Kz (m/day)
Angurugu River	10	5	1	0.09
Emerald River	5	5	1	0.02
Amagula River	20	5	1	0.06
Minor Creeks	2	1	1	1.00

B1.3.7 Calibrated recharge

Table B.8 summaries the calibrated rate of recharge for each unit. The rate of diffuse recharge (ML/day) was calculated based on the area of outcrop for each unit, as it is represented in the numerical model. The steady state model assumed a percentage of the total daily rainfall rate, whereas the transient model assumed a percentage of the measured average weekly rainfall amount.

Table B.8 Model recharge rates

Unit	Recharge (%)	Recharge (ML/day)
Quaternary sediments	1.92	28.96
Weathered basement outcrops	3.71	40.94
Break of slope at outcrops	4.93	5.04
Total		**74.94**

Annual rainfall is reported in Section 3.3 of the main report. Table B.8 shows that 1.9 % of annual rainfall (i.e. 25.2 mm) enters the basin sediments as recharge. The unit with the highest rate of recharge is the break of slope, with a rate of approximately 4.9 % of annual rainfall (65 mm).

Evapotranspiration was applied to Layer 1 in the model domain using the EVT package, with an extinction depth of 2 m. The rate of evapotranspiration was taken from the Bureau of Meteorology evapotranspiration map of Australia, which was approximately 2,154 mm/year over the model domain. These rates used in the model simulation were scaled back to 10 % of evapotranspiration rates, for numerical stability.

B1.3.8 Calibration baseflow

Table B.9 compares simulated river baseflow rates from the calibration process with measured baseflow. The model replication of baseflow is considered to be within an appropriate range for the purposes of this assessment.

Table B.9 Model baseflow rates

River	Simulated baseflow (ML/day)	Adopted daily baseflow (ML/day)[1]
	Steady state	
Angurugu River	4.4	8.6
Emerald River	0.5	5.2
Amagula River	5.6	4.3

River	Simulated baseflow (ML/day)	Adopted daily baseflow (ML/day)[1]
	Transient average	
Angurugu River	4.1	8.6
Emerald River	0.6	5.2
Amagula River	8.0	4.3

Note: *1 - (Source: Aquaterra 2001-2002)*

B1.3.9 Water budget

The steady state mass balance error, that is, the difference between calculated model inflows and outflows at the completion of the steady state calibration was -0.13 %. This value confirms that the model is stable and achieves an accurate numerical solution. Table B 10 summarises the water budget for the steady state model.

Table B 10 Steady state model budget

Parameter	IN (KL/day)	OUT (KL/day)	IN (ML/day)	OUT (ML/day)
Fixed head	3831	35614	3.8	35.6
Recharge	74943	-	74.9	0.0
River	4955	28249	5.0	28.2
EVT	-	19980	0.0	20.0
Total	**83730**	**83842**	**83.7**	**83.8**

The water budget indicates that recharge to the groundwater system within the model averages 75 ML/day with approximately 28 ML/day discharged via surface drainage, and 20 ML/day lost to evapotranspiration in areas where the water table is within 2 m of the land surface. A total of 36 ML/day leaves the system as it flows to the ocean to the west of the model domain.

The transient model mass balance error, that is, the difference between calculated model inflows and outflows at any time step in the simulation was less than ±0.01 %. This value confirms that the model is stable and achieves an accurate numerical solution. Figure B.7 summarises the water budget for the transient model.

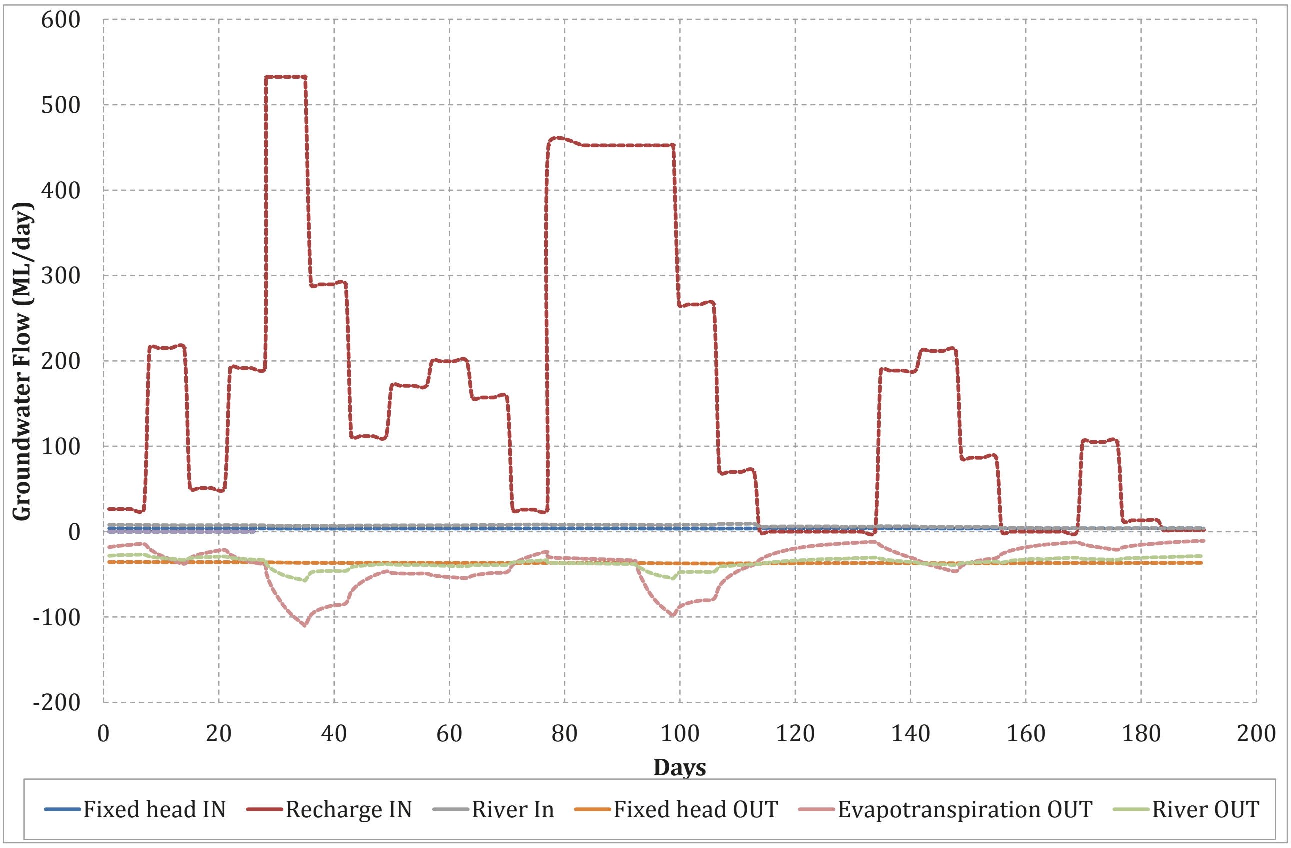


Figure B.7 Transient model budget

B1.3.10 Calibration Sensitivity

Sensitivity analysis evaluates the effect of changing individual model parameters on model results and indicates the uncertainty in the estimates of model parameters. The sensitivity of simulated heads to parameters was assessed to aid model calibration. The relative composite sensitivity (RCS) was calculated as outlined by Doherty (2010):

$$s_i = (J^tQJ)^{0.5}b_i/m$$

where: J = Jacobian matrix, derivatives of simulated heads at observations with respect to the ith parameter in vector b.

Q = cofactor matrix, a diagonal matrix with the elements being the squared observation weights.

b_i = ith parameter value in vector b.

m number of observations that have non-zero weights.

The composite sensitivity values were calculated during the PEST calibration process for the steady-state/transient models and were converted to RCS as shown in Figure B.8.

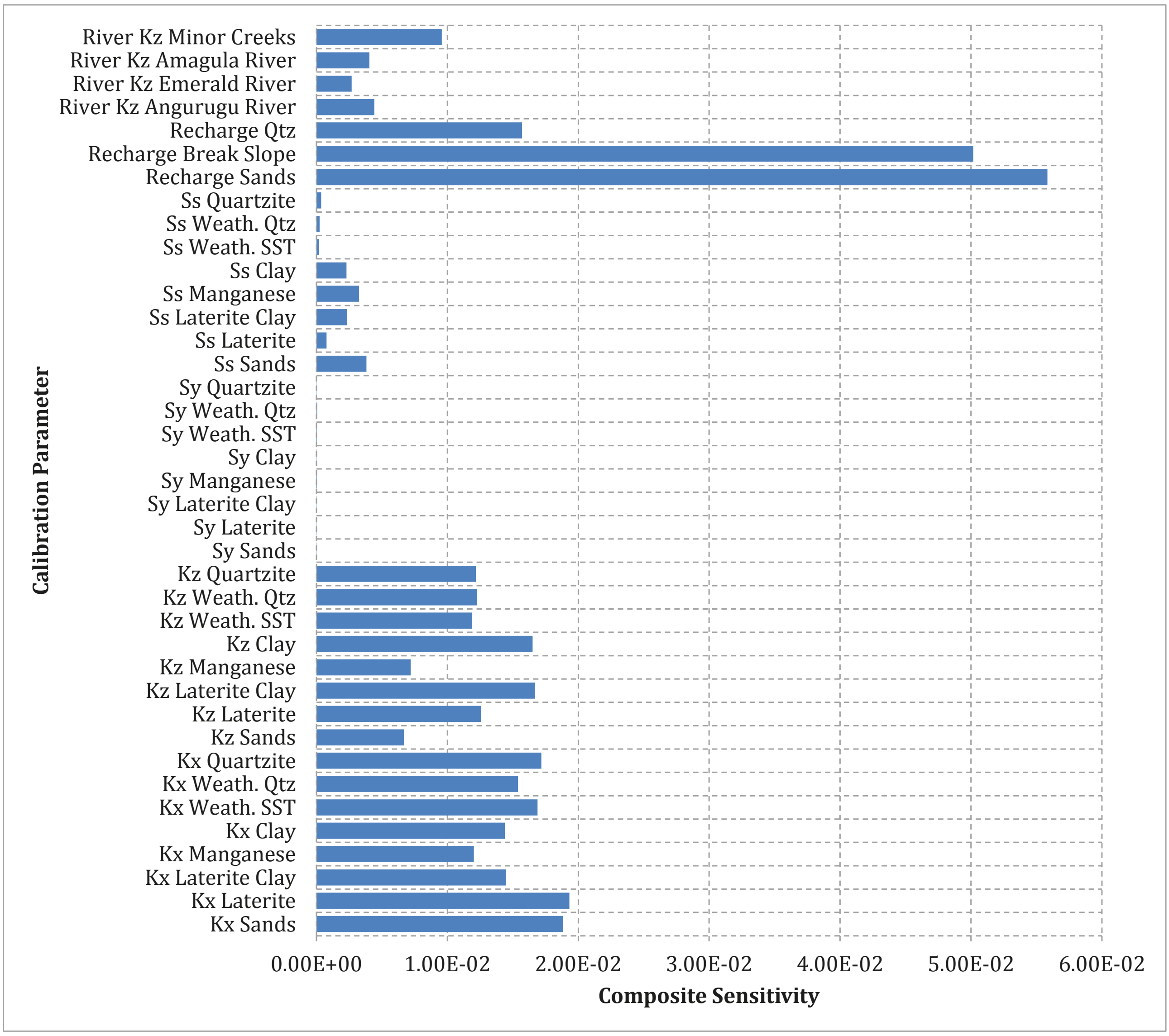


Figure B.8 Model composite sensitivity

RCS is a measure of the composite changes in model outputs that have incurred by a change in the value of the parameter (Hill and Tiedeman, 2007). That is, whether the model calibration is sensitive to an input parameter such as hydraulic conductivity or recharge. This statistic can be used to assess the relative sensitivity of model parameters given the set of observations used in the model.

Generally, if the RCS of a parameter is greater than one, the model is sensitive to this parameter and the model observations have provided enough information to estimate the parameter with greater certainty. Where parameters have a low RCS, the model calibration is less sensitive to these, yet there is greater uncertainty associated with them and they are likely to contribute more to the uncertainty of the model predictions. In this case, the predictive uncertainty has been guided by this sensitivity analysis within the constraints of the model calibration statistics.

For the current model, the RCS of all calibration parameters is less than one. This demonstrates that the model has a relatively low sensitivity to parameter changes.

B1.3.11 Model classification

Barnett *et al* (2012) developed a system to classify the confidence-level for groundwater models. Models are classified as either Class 1, Class 2 or Class 3 in order of increasing confidence (i.e. Class 3 has the highest level of confidence). Several factors are considered in determining the model confidence level:

- available data;
- calibration procedures;
- consistency between calibration and predictive analysis; and
- level of stresses.

The model has achieved and generally exceeded the criteria considered for a Class 1 model. The following aspects of the model support a Class 2 classification:

- a transient calibration has been undertaken and seasonal fluctuations are replicated;
- streamflow data and baseflow estimates have been used to verify calibration; and
- mass balance closure is less than 1 % of total.

The model is considered to be fit-for-purpose as an impact assessment model.

B2 Predictive simulations

B2.1 Time slices

An iterative modelling approach was applied. This involved running the model in short time frames (time "slices" of three months) to represent the mining process and changes in hydraulic conductivity that occurs. The mine life was subdivided into three month stages. At the end of each stage, the model was stopped and the last predicted groundwater levels for the simulation were used as starting points for the next simulation stage. At this point in time, changes in aquifer parameters resulting from the effects of the emplacement of reworked material into the mined area were applied on a quarterly basis. A Fortran computer program was written to undertake the "stop-start" nature of the staged simulation. This program defined the active cell drains on a quarterly basis and applied pre-defined rules for the changes in aquifer parameters and finally generated each of the time slices. This approach has been used successfully for a large number of impact assessment flow models.

B2.2 Mine drainage

This involved setting a reference elevation for the base of the drain, and a conductance term. Groundwater levels in the model are compared to the reference elevation in the drain cells, and when the groundwater level are above the reference level, water is removed from the model domain at a rate determined by the head difference and the conductance term. The proposed mining was represented by introducing drains at three monthly intervals. The advancing drain cells remained active for three monthly intervals, before being turned off and the parameters of the mined units changed to represent the increased permeability and recharge through the re-worked waste rock material. A nominally high drain conductance of 100 m^2/day was applied to the drain cells and the elevation of the mined floor was used as the drain level.

The model assumes active mining areas are unsaturated and there is no seepage from the pits to the in pit overburden emplacements. Recharge to the in pit overburden emplacements includes direct rainfall.

B2.3 In pit overburden emplacements properties

Table B.11 shows the aquifer parameters adopted for the in pit overburden emplacements.

Table B.11 Hydraulic/recharge parameters

Geology Type	Parameter	Value
Overburden materials	Horizontal hydraulic conductivity Kx	1 m/day
	Vertical hydraulic conductivity Kz	0.1 m/day
	Specific yield Sy	10 %
	Specific storage Ss	5 x 10^{-3} m^{-1}
	Recharge	5.0 %

B2.4 Sensitivity analysis

A sensitivity analysis was carried out to assess the response of the model to varying input parameters. The objective of the sensitivity analysis was to rank the input parameters in terms of their influence on the predicted results. The following perturbations were assessed in the sensitivity analysis:

- ±1 order of magnitude change in horizontal and vertical hydraulic conductivity of the laterite, manganese orebody and basement aquifer units (Layers 1-5, & 8);
- ±30 to 50 % change in the horizontal and vertical hydraulic conductivity of the Cretaceous sandstone aquifer units (Layers 6 & 7);
- ± 50 % change in the horizontal and vertical hydraulic conductivity of the in pit overburden emplacement;
- ±50 % change in the specific yield of all units in the model;
- ±50 % change in the specific storage of all units in the model; and
- ±50 % change in the rainfall recharge rate across the model domain.

The following sections detail results of these sensitivity analyses.

B2.4.1 Mining area seepage

Figure B.9 shows the sensitivity of the predicted seepage rate to changing the parameters in the model.

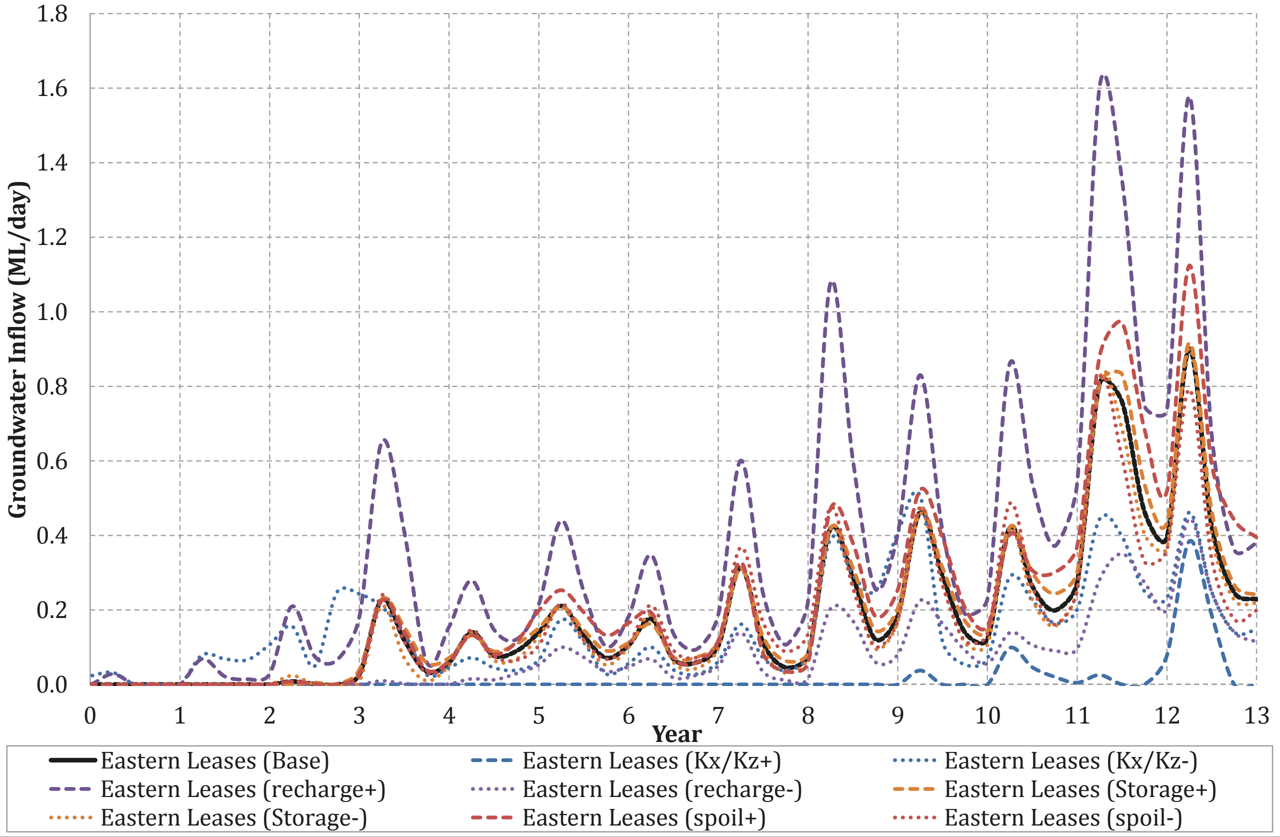


Figure B.9 Sensitivity of quarry inflows

The predicted seepage is most sensitive to changes in the recharge rate. Increasing the recharge rate by 50 % doubles the maximum predicted seepage peaks from 0.8 ML/day to 1.6 ML/day. Reducing the recharge rate by 50 % effectively halves the maximum predicted seepage peak. Hydraulic conductivity of the overburden emplacement was the second most sensitive parameter to mining area seepage, with a 50 % increase, resulting in an increase above the base seepage rate of about 0.2 ML/day.

Table B 12 shows how changing the model parameters influences the overall model error (as represented by the SRMS and the mine seepage). It shows that changes to the hydraulic conductivity result in the model falling out of calibration and these changes are therefore unrealistic extremes.

Maximum yearly inflow rates from the sensitivity scenarios suggest that mine inflow can increase by 100 % of the predicted base case and remain relatively low.

Table B 12 Summary results of sensitivity analysis

Parameter	Steady state SRMS (%)	Transient SRMS (%)	Maximum mine seepage (ML/a)
Basecase	6.5	2.8	221
Kx/Kz+	23.8	5.2	52
Kx/Kz-	10.5	4.8	123
Storage+	-	3.0	238
Storage -	-	2.8	208
Recharge+	7.1	3.7	406
Recharge-	5.8	3.3	101
waste rock+	-	-	279
waste rock-	-	-	193

B2.4.2 Interaction with surface water system

When the modelled groundwater level adjacent to a surface water feature falls in response to mining, the model simulates a reduced rate of baseflow. Conversely, when the modelled groundwater levels increase, the flow from the aquifer to the river also increases. This is shown the charts below as positive and negative flow.

During mining, the model predicts a negligible change in baseflow to the Amagula, Emerald and Angurugu rivers.

Table B.13 shows how changing a model parameter influences the model error and the groundwater interaction with water courses.

Table B.13 Summary results of sensitivity analysis

Parameter	Steady state SRMS (%)	Transient SRMS (%)	Modelled total flow change over mine life					
			Angurugu River		Emerald River		Amagulu River	
			(ML)	(%)	(ML)	(%)	(ML)	(%)
Base case	6.5	2.8	64.6	-0.2	-39.4	1.5	3.2	-0.004
Kx/Kz+	23.8	5.2	28.6	-0.1	0	0	57	-0.1
Kx/Kz-	10.5	4.8	9.3	-0.03	-2.6	0.1	-6.6	0.01
Storage+	-	3.0	41.8	-0.1	-12.4	0.5	-8.1	0.01
Storage -	-	2.8	107	-0.3	-11.7	0.4	69.7	-0.1
Recharge+	7.1	3.7	4.1	-0.01	-23.5	0.9	-66.5	0.1
Recharge-	5.8	3.3	67.2	-0.2	-0.4	0.0	42	-0.06
Overburden+	-	-	108.4	-0.3	-12.2	0.5	39	-0.05
Overburden-	-	-	41	-0.1	-7.3	0.3	3.3	-0.004

The sensitivity analysis indicates that changing model parameters does not impact significantly on the predicted loss in river baseflow. The loss remains low of all scenarios and would be undetectable.

B2.4.3 Zone of depressurisation

The sensitivity analysis assessed the changes to the zone of depressurisation in the laterite and manganese ore body. Drawdown is most sensitive to changes in the storage and recharge. The extent of drawdown varies little, extending to a maximum of ±200 m from the base case.

B2.4.4 Sensitivity classification

The Murray Darling Basin Modelling Guidelines (MDBC, 2000) recommends classifying sensitivity by the resultant changes to the model calibration and predictions. The four sensitivity types are as follows:

- Type I: Insignificant changes to calibration and prediction;
- Type II: Significant changes to calibration – insignificant changes to predictions;
- Type III: Significant changes to calibration –significant changes to predictions; and
- Type IV: Insignificant changes to calibration –significant changes to predictions.

Types I-III are of no concern as these Types have an insignificant impact on model predications, and the model is a calibrated, high complexity model. Type IV is classed as 'a cause for concern' as non-uniqueness in a model input model input might allow a range of valid calibrations but the choice of value impacts significantly on a prediction (Middlemis, 2000).

Using the data presented in Section 0, the model input parameters are classified as:

- Hydraulic conductivity: Type II – III
- Storage: Type I – III
- Recharge: Type II – III

There are no type IV parameters in the model and therefore we can be confident in the range of predictions.

B3 References

Barnett *et al*, (2012) *"Australian Groundwater Modelling Guidelines".*

Doherty, J. (2010) "*PEST: Model-Independent Parameter Estimation, User Manual":* 5th Edition, Watermark Numerical Computing.

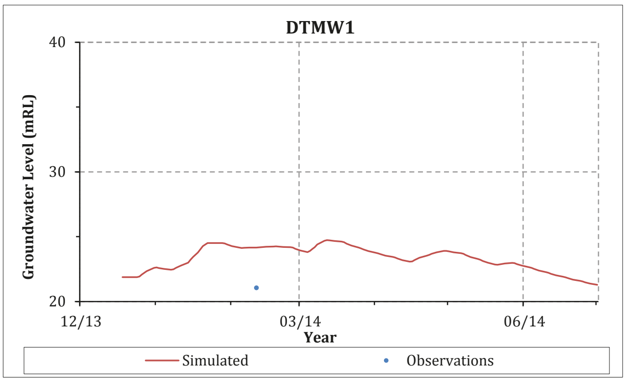
Hill and Tiedeman (2007) *"Effective Groundwater Model Calibration, with Analysis of Data, Sensitivities, Predictions, and Uncertainty"* By Mary C. Hill and Claire R. Tiedeman Published by John Wiley and Sons, New York, in 2007.

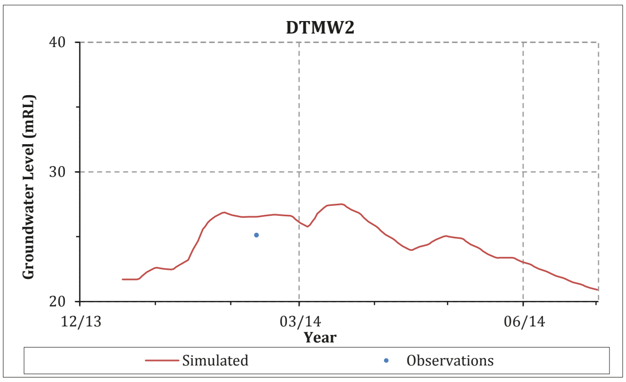
Middlemis et al (2000), "*Murray Darling Basin Commission Groundwater Modelling Guidelines*". November 2000, Project No. 125, Final guideline issue January 2001.

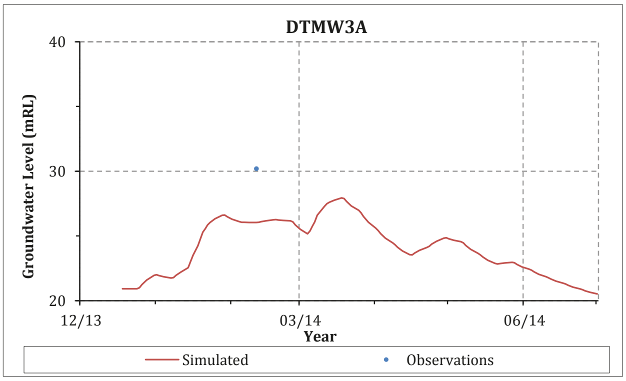
Appendix B-1

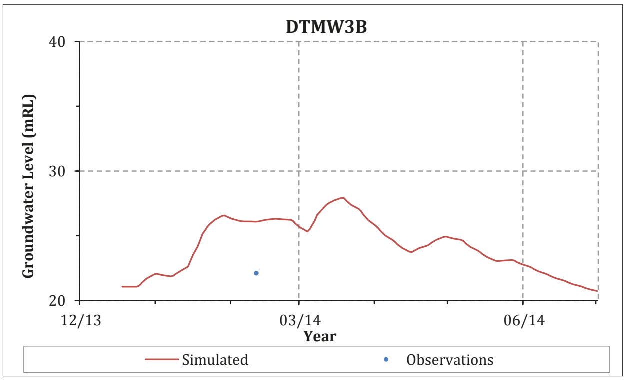
Calibration Hydrographs

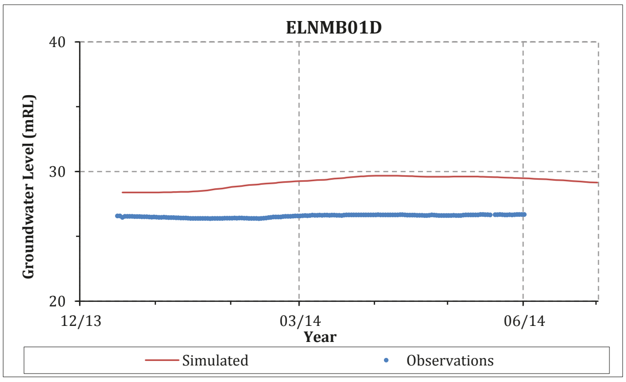
Calibration Hydrographs

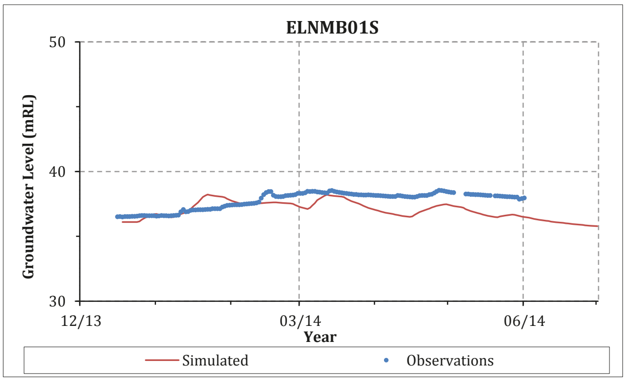


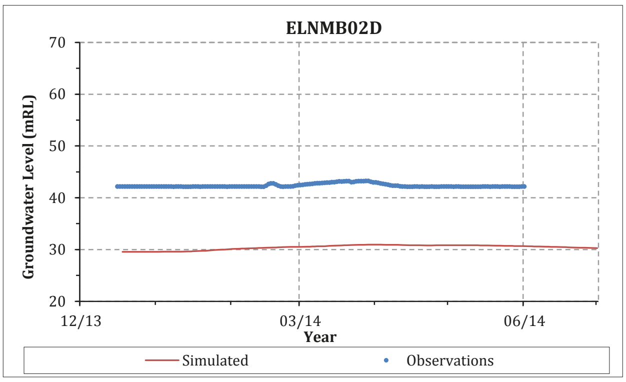


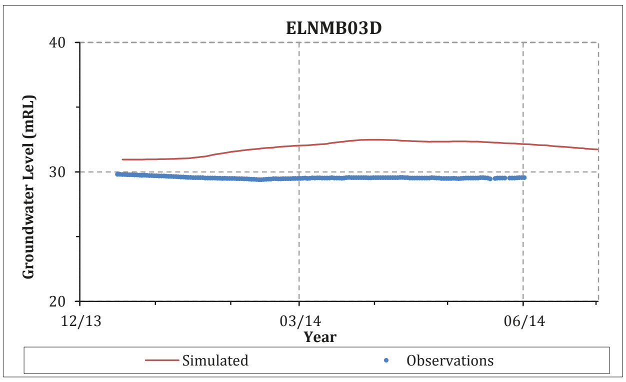




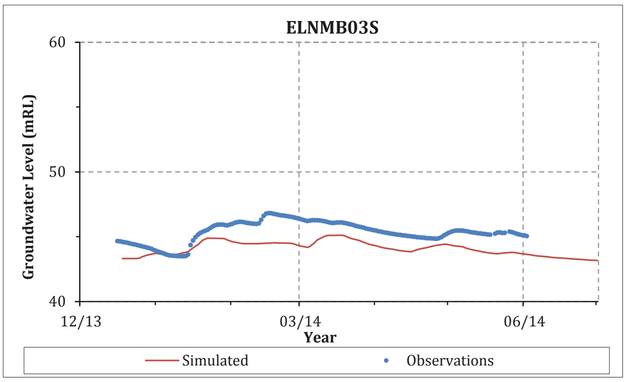


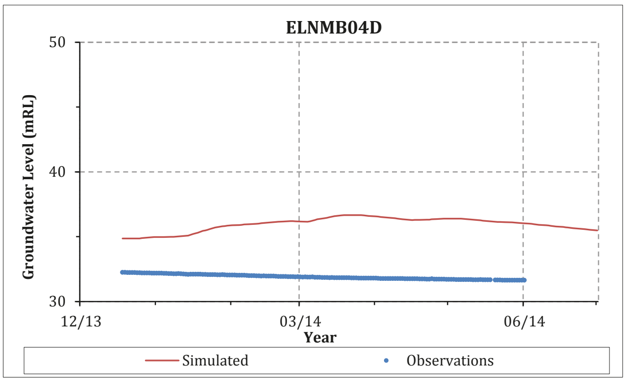


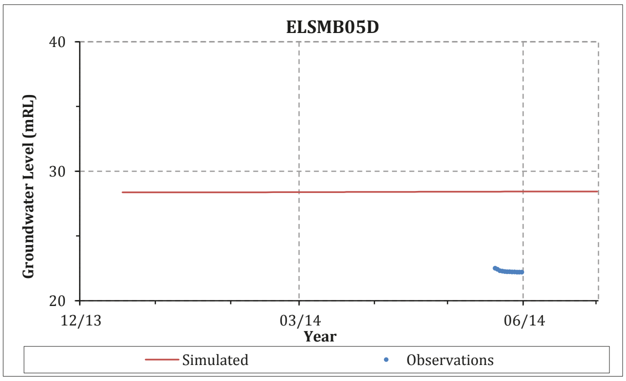


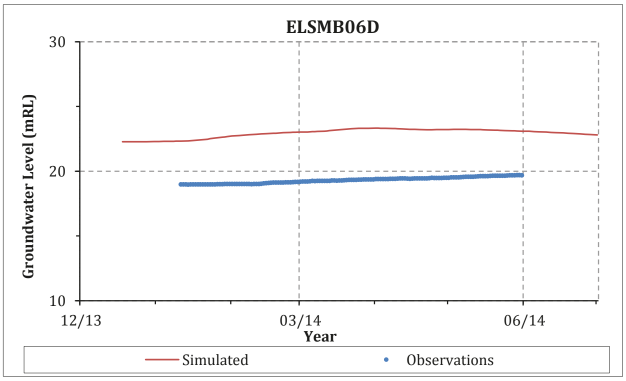


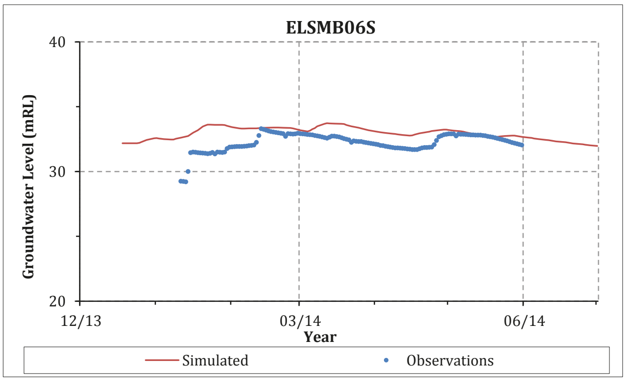
Calibration Hydrographs

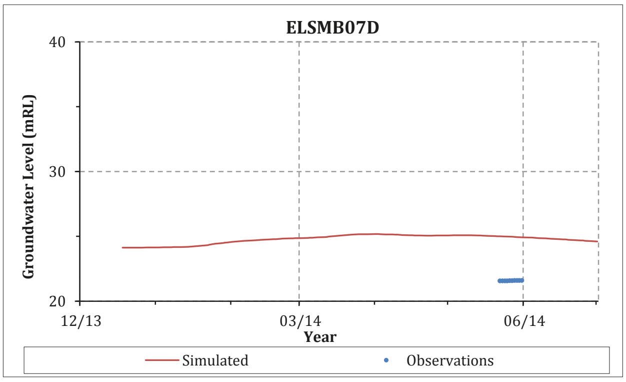


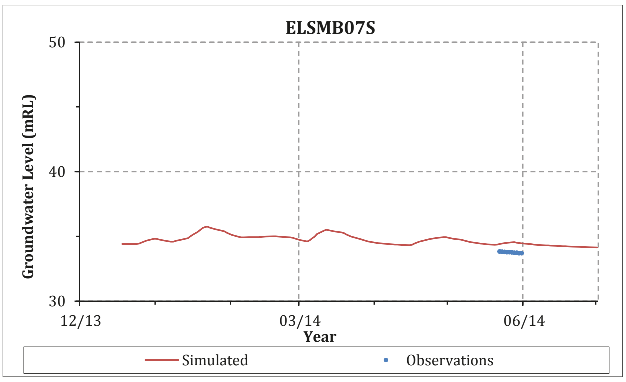


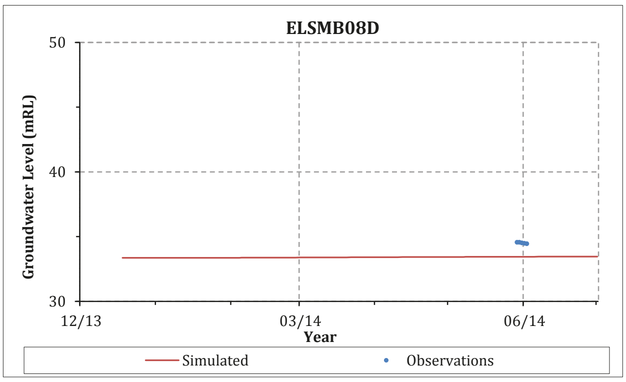




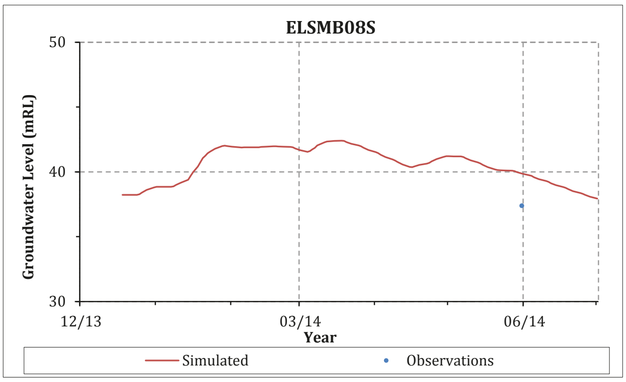


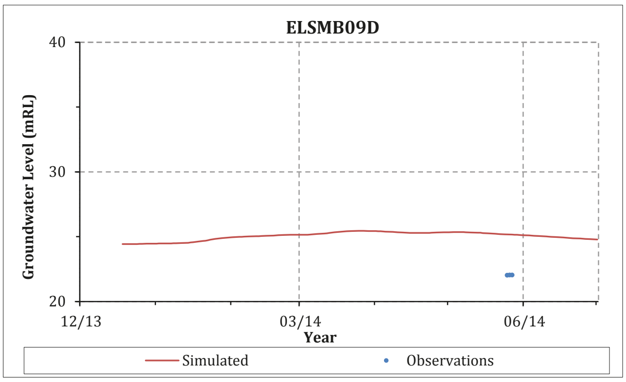


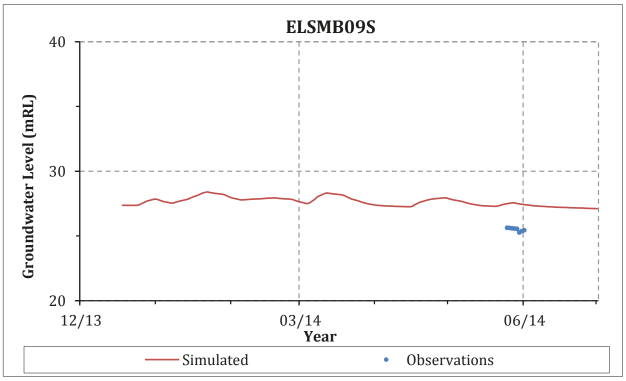


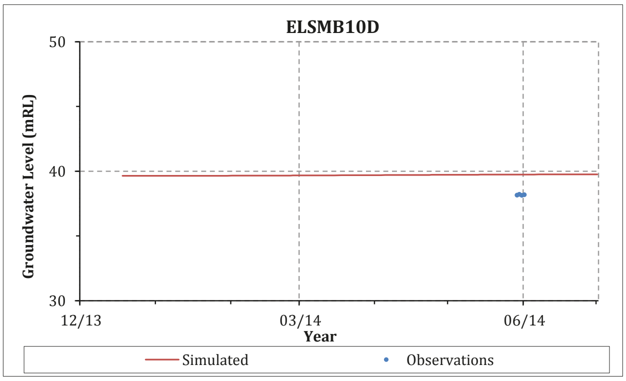


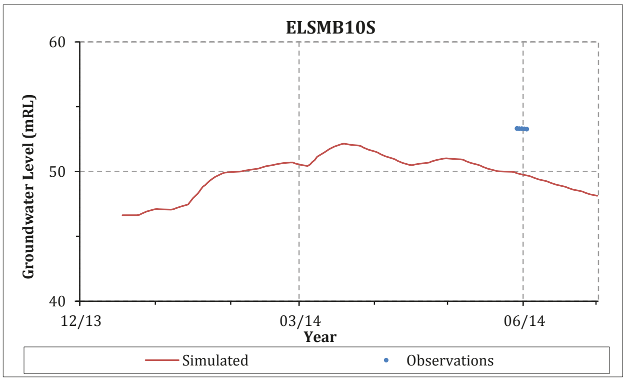
Calibration Hydrographs

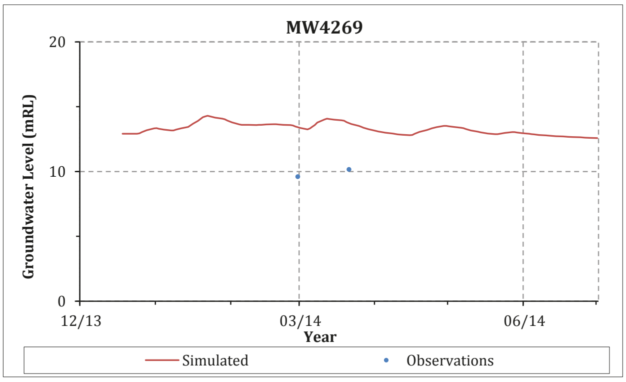


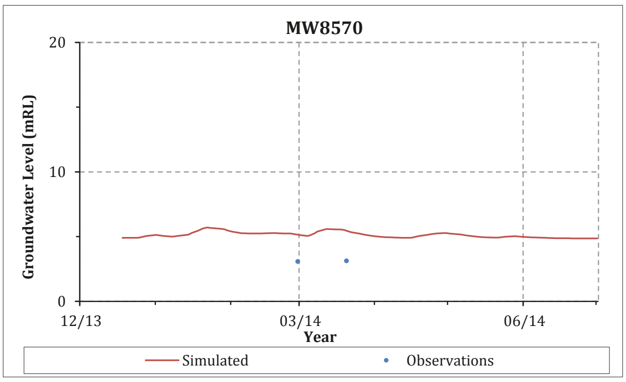


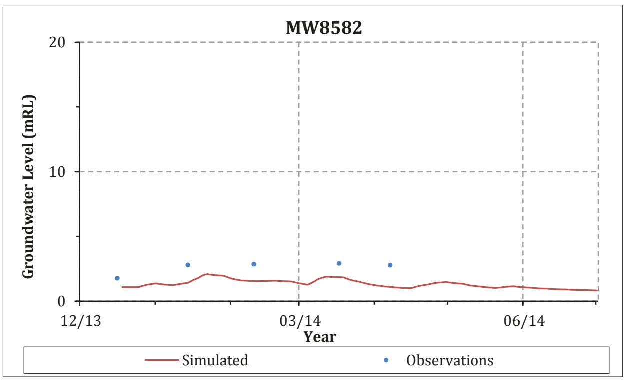




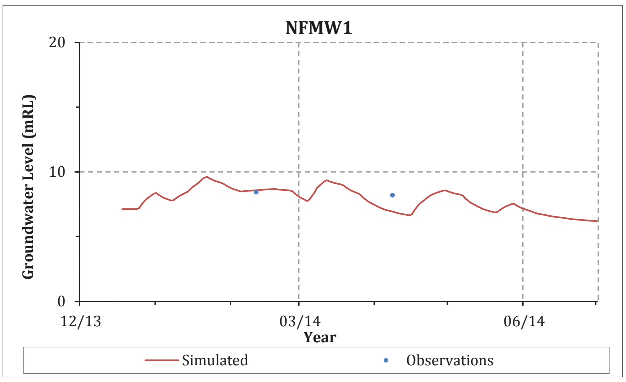


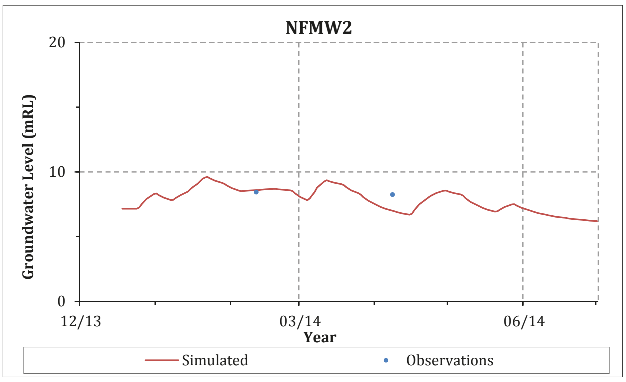


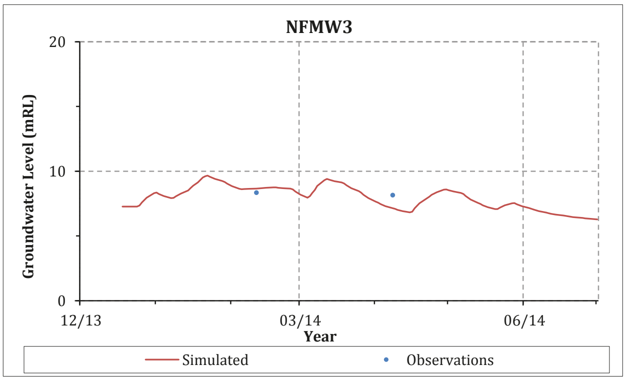


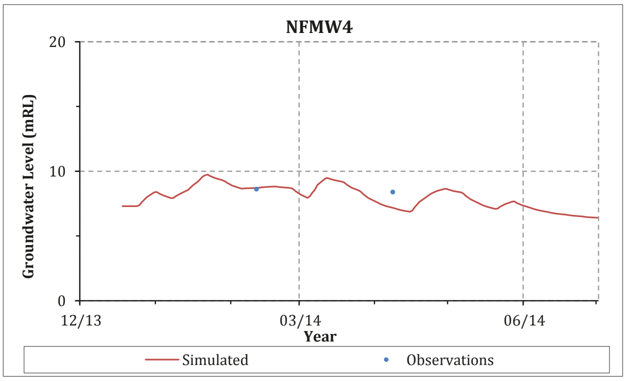


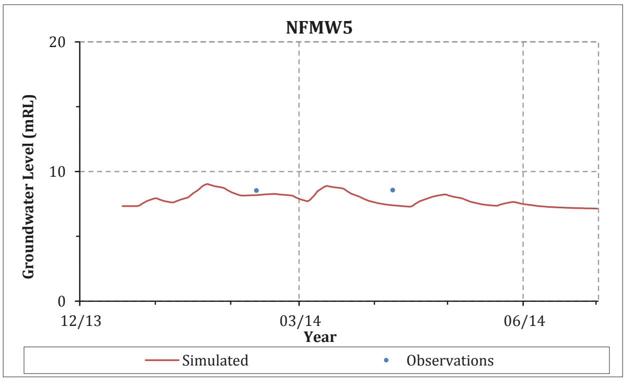
Calibration Hydrographs

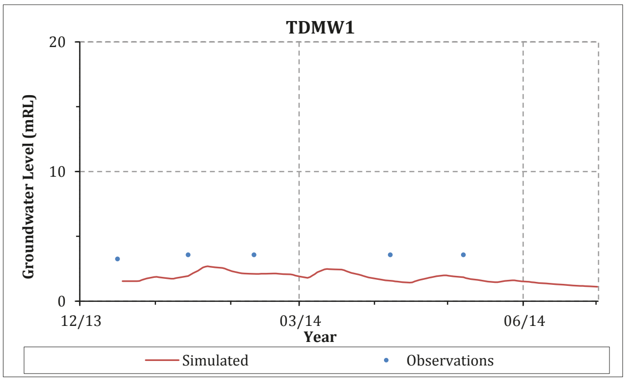


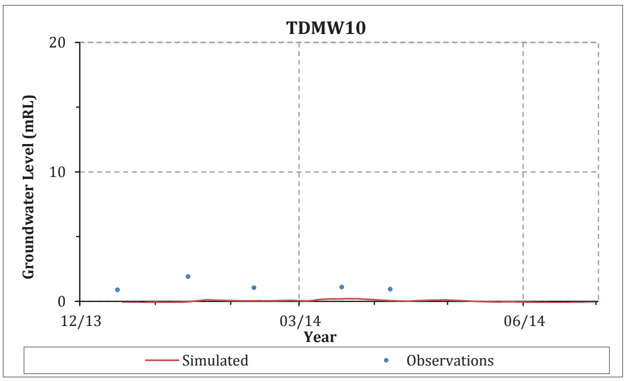


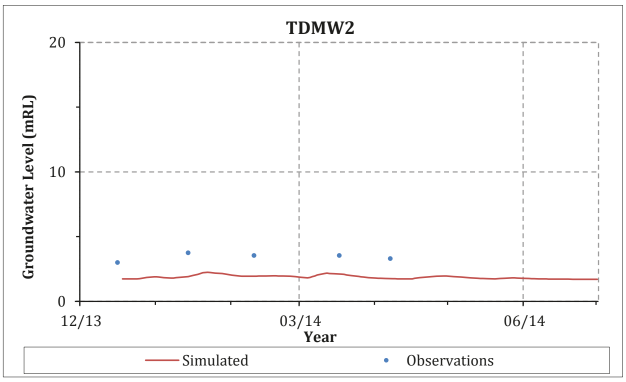












Calibration Hydrographs