APPENDIX

B1

GROUNDWATER TECHNICAL REPORT



Wesfarmers Resources Pty Ltd

Curragh Extension Project - Groundwater Technical Report

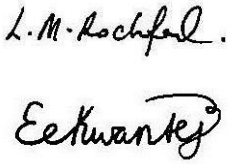
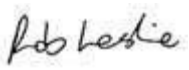
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Glossary

Alkaline	Having the properties of any of various bases, the hydroxides of the alkali metals and of ammonium, which neutralise acids to form salts.
Alluvial	Sediments deposited by flowing water.
Alluvium	General term for unconsolidated deposits of inorganic materials (clay, silt, sand, gravel, boulders) deposited by flowing water.
Alluvium aquifer	An aquifer formed within alluvium. See *Alluvium.*
ANZECC guidelines	*Australian and New Zealand Guidelines for Fresh and Marine Water Quality* (2000).
Aquifer	Rock or sediment in a formation, group of formations or part of a formation that is saturated and sufficiently permeable to transmit economic quantities of water to wells and springs.
Aquitard	Saturated geological unit with a relatively low permeability that can store large volumes of water but does not readily transmit or yield significant quantities of water to bores or springs. An aquitard can sometimes, if completely impermeable, be called an aquiclude.
Australian Height Datum (AHD)	A level datum, uniform throughout Australia, that generally approximates mean sea level.
Authority to prospect (ATP)	A petroleum tenure granted under the *Petroleum Gas (Production and Safety) Act 2004* (Qld) allowing the holder to undertake petroleum exploration activities and studies to evaluate the development potential of a defined resource.
Baseflow	The component of river or stream flow that is derived from groundwater discharge to the river or stream.
Baseline	A basic standard or level, usually regarded as a reference point for comparison.
Beneficial use	An alternative reuse for a material such as coal seam water or salt residues that changes the status of the material from a waste to a resource that can be used for a beneficial purpose.
Bore	Artificially constructed or improved groundwater cavity used for the purpose of accessing or recharging water from an aquifer. Interchangeable with borehole, piezometer.
Borehole	Includes a well, excavation, or other artificially constructed or improved groundwater cavity which can be used for the purpose of intercepting, collecting or storing water from an aquifer; observing or collecting data and information on water in an aquifer; or recharging an aquifer. Interchangeable with bores, wells, piezometers.

Brackish	Water that contains between 500 and 10,000 milligrams per litre of dissolved solids according to National Water Commission.
Clay	Deposit of particles with a diameter less than 0.002 mm, typically contain variable amounts of water within the mineral structure, and exhibit high plasticity.
Coal	Carbon-based sedimentary rock formed by the accumulation and decomposition of plant material in layers, which can be used as a combustible fuel. Main types, in order of highest rank to lowest rank, are black coal (anthracite, bituminous, sub-bituminous), brown coal (lignite) and peat (considered to be a precursor of coal).
Confined aquifer	An aquifer bounded above and below by impervious (confining) layers. In a confined aquifer, the water is under sufficient pressure so that when wells are drilled into the aquifer, measured water levels rise above the top of the aquifer.
Cumulative impact	The combined impact to one or more environmental values delivered by multiple projects being undertaken simultaneously within the same sphere of physical influence.
Dam	An engineered land-based structure that is designed to contain, divert or control liquid. A dam does not mean a fabricated or manufactured tank or container, designed and constructed to an Australian Standard that deals with strength and structural integrity of that tank or container.
Depressurisation	Reduction in groundwater pore pressure (pressure head) in a confined groundwater system due to extraction of groundwater.
Dewatering	Draining, permanently or temporarily, a wet area of land or an aquifer.
Dissolved solids	Minerals and organic matter dissolved in water; a measure of salinity.
Drawdown	The change in groundwater level in a bore, or the change in water table elevation in an unconfined groundwater system, due to the extraction of groundwater.
Ecosystem	An organic community of plants, animals and bacteria and the physical and chemical environment they inhabit.
Environmental authority (EA)	A licence to operate, issued in accordance with the *Environmental Protection Act 1994* (Qld), that imposes conditions on authorised activities to reduce or avoid potential environmental impacts; used by Queensland Department of Environment and Heritage Protection to assess and administer regulatory environmental compliance of the project.
Environmental management plan (EMP)	Document that provides operational detail of how environmental management measures identified in the environmental impact statement will be implemented.
Environmental values	Desirable characteristics, properties and behaviours or an aspect of the environment.

Ephemeral	Relates to the amount of time that surface water persists in a watercourse or wetland; ephemeral watercourses flow only during significant rainfall events and for a short-time following rainfall events.
Erosion	Wearing away of rock or soil caused by physical or chemical processes.
Fault	Zone of displacement in rock formations resulting from forces of tension or compression in the earth's crust.
Formation	General term used to describe a sequence of rock layers.
Fracture	Break in a rock including cracks, joints, and faults.
Groundwater	Water found in the subsurface in the saturated zone below the water table or piezometric surface i.e. the water table marks the upper surface of groundwater systems.
Groundwater flow	The movement of water through openings and pore spaces in rocks below the water table i.e. in the saturated zone.
Groundwater resource	Groundwater available for beneficial use, including human usage, aquatic ecosystems and the greater environment.
Hydraulic conductivity	Measure of the ease with which water will pass through earth material; defined as the rate of flow through a cross-section of one square metre under a unit hydraulic gradient at right angles to the direction of flow (metres per day).
Hydraulic gradient	Change in the hydraulic head over a certain distance.
(Hydraulic) head	Elevation to which water will rise in a borehole connected to a point in an aquifer.
Hydrogeology	The study of the interrelationships of geological materials and processes with water, especially groundwater.
Hydrograph	Graph that shows groundwater or surface water properties as a function of time.
Impact	An event that disrupts ecosystem, community, or population structure and alters the physical environment, directly or indirectly.
Infiltration	The downward movement of water from the atmosphere into the ground; not to be confused with percolation.
Landholder	The owner, occupier, manager, or controller of land or water, including anyone acting on their behalf.
Lithology	The physical character of rocks.
Modelling	The creation of a computerised model that simulates natural environment, allows simulations to project future outcomes.
Monitoring bore	A bore used to monitor groundwater levels or quality.

Mudstone	A clayey rock of nearly uniform texture throughout, with little or no lamination.
Natural resource	Resource that occurs naturally, such as sunlight, wind, soil, or water.
Palaeochannel	Buried stream channel.
Permeability	The ease with which a fluid can pass through a porous medium and is defined as the volume of fluid discharged from a unit area of an aquifer under unit hydraulic gradient in unit time (metres per day).
pH	Absolute value of the decimal logarithm of the hydrogen-ion concentration (activity). Used as an indicator of acidity (pH < 7) or alkalinity (pH > 7).
Recharge	Recharge is defined as the process by which water is added from outside to the zone of saturation of an aquifer, either directly into a formation, or indirectly by way of another formation.
Recovery	Rise of the water level in a bore or an aquifer after the pumping rate has been reduced or the pump has been shut off or when mining has ceased. Also known as rebound.
Riparian	Situated along or near the bank of a waterway.
Runoff	All surface and subsurface flow from a catchment, but in practice refers to the flow in a river i.e. excludes groundwater not discharged into a river.
Salinity	The concentration of dissolved salts in water, usually expressed in electrical conductivity (EC) units (µS/cm) or total dissolved solids (TDS) units (mg/L TDS).
Sediment	Particles derived from rocks or biological materials that have been transported by air or water.
Seep	A diffuse wetland area where interflow and groundwater emerges, usually at a slow rate or small volume, to become surface flow.
Semi-confined aquifer	An aquifer that is partly confined by layers of lower permeability material through which recharge and discharge may occur, also referred to as a leaky aquifer.
Shallow groundwater	In the context of the study, shallow groundwater has been recognised as groundwater resources not deeper than 100 m below ground surface.
Siltstone	Consolidated silt; fine-grained sedimentary rock.

Spring	Natural discharges of groundwater at the surface or within stream beds. Spring vents are a single point in the landscape where groundwater is discharged at the surface. Recharge (reject) springs occur where rates of recharge are greater than rates of water infiltration; thus, 'rejection' of water causes seepage of water at the surface from exposed formations. Recharge springs are commonly an ephemeral feature in a local aquifer and not necessarily connected to the water table aquifer. Discharge springs occur where faulting or rapid thinning occur against basement highs disrupting lateral through-flow of groundwater or where water-bearing zones approach the ground surface and pressurised groundwater breaks through fractures in thin confining beds. Watercourse springs are a section of a watercourse where groundwater enters the stream from an aquifer through the streambed. These springs occur where an outcropping aquifer has been eroded to create a depression in the surface of sufficient depth to reach the water table.
Strata	Single bed of sedimentary rock, generally consisting of one kind of matter representing continuous deposition.
Stratigraphy	Branch of geology dealing with the classification, nomenclature, correlation, and interpretation of stratified rocks.
Terrestrial	Relating to, consisting of, or representing the Earth; relating to the land as distinct from the water.
Trigger level	The point at which some form of action is begun, such as exceedance of guidelines.
Water table	The surface in an unconfined aquifer or confining bed at which the pore water pressure is atmospheric; it can be measured by installing shallow wells extending a few feet into the zone of saturation and then measuring the water level in those wells.
Watercourse	A river, creek or other stream, including a stream in the form of an anabranch or a tributary, in which water flows permanently or intermittently, regardless of the frequency of flow events: ■ in a natural channel, whether artificially modified or not ■ in an artificial channel that has changed the course of the stream ■ it also includes weirs, lakes and dams.
Well	A structure that is designed to bore through the earth's surface in order to extract resources.

Wetland	Numerous definitions of wetland exist. Under the Queensland Wetland Strategy, wetland is defined as 'areas of permanent or periodic/ intermittent inundation, whether natural or artificial, with water that is static of flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed 6 m'. Three types of freshwater wetland (excluding aquifers) are recognised: Riverine wetlands, which are analogous to 'watercourses' used in this report. Palustrine wetlands, which are vegetated swamps. Many springs are also considered to be similar to palustrine wetlands. Lacustrine wetlands, which are areas of relatively deep, non-flowing water. Lakes, farm dams and large billabongs on floodplains are examples of lacustrine wetlands. As 'watercourse' is used to refer to 'riverine wetlands', use of the term 'wetland' more specifically refers to palustrine and lacustrine wetlands.
Yield	The quantity of water removed from a water resource e.g. yield of a borehole.

Abbreviations

ADWG	Australian Drinking Water Guidelines
AHD	Australian Height Datum
ALS	Australian Laboratory Service
AMTD	Adopted middle thread distance
ANZECC	Australian and New Zealand Environment Conservation Council
ATP	Authority to Prospect
AWS	Automatic weather station
BOM	Bureau of Meteorology
CHPP	Coal Handling and Preparation Plant
CMB	Chloride mass balance
DEHP	Department of Environment and Heritage Protection (Queensland)
CDFM	Cumulative deviation from mean
DNRM	Department of Natural Resources and Mines
DoE	Department of the Environment
EA	Environmental Authority
EC	Electrical conductivity
EMP	Environmental Management Plan
EMS	Environmental Management System
EPBC Act	*Environment Protection and Biodiversity Conservation Act 1999* (Commonwealth)
EPP (Water)	Environmental Protection (Water) Policy 2009 (Queensland)
ESP	Exchangeable sodium percentage
EVs	Environmental values
GDE	Groundwater dependent ecosystem
GL	Gigalitres
GMP	Groundwater monitoring program
ha	hectare
IESC	Independent Expert Scientific Committee
Kh	Horizontal hydraulic conductivity
km	kilometre
Kv	Vertical hydraulic conductivity
L/s	Litre per second
m	metre
mAHD	metres Australian Height Datum

mbgl	metres below ground level
MDL	Mineral Development Licence
MIA	Mine infrastructure area
Ml	megalitre
ML	Mining Lease
mm	millimetre
MNES	Matters of national environmental significance
Mtpa	million tonnes per annum
NATA	National Association of Testing Authorities
NHMRC	National Health and Medical Research Council
PCI	Pulverised coal injected
PL	Petroleum lease
RE	Regional ecosystem
ROM	Run-of-mine
S_s	Specific storage
STP	Sewage treatment plant
S_y	Specific yield
TEC	Threatened Ecological Community
The Project	Curragh Extension Project
TPH	Total petroleum hydrocarbons
TSF	Tailings storage facility
VM Act	*Vegetation Management Act 1999* (Queensland)
WCPL	Wesfarmers Curragh Pty Ltd
WQOs	Water quality objectives

Executive summary

Wesfarmers Curragh Pty Ltd (WCPL) operates the existing Curragh Mine Project under Environmental Authority (EA) EPML00643713. The Curragh Mine commenced operation in 1983 and is an open cut coal mining operation located approximately 6 kilometres (km) north of the township of Blackwater in Central Queensland.

The proposed action is the Curragh Extension Project (the Project) for the extension of open cut coal mining operations at Curragh Mine in four adjacent Mining Lease (ML) areas. The addition of the Project to the Curragh Mine operation is not planned to increase the annual production but rather extend the life of mine by 8 years to approximately 2038.

Project description

Early planning works for the Project have considered environmental constraints, including groundwater related constraints, and implemented avoidance strategies to minimise impacts. The Project will utilise existing infrastructure within the adjacent Curragh Mine minimising the need for new infrastructure requirements. All coal processing, coal stockpiling, tailings storage, sewage treatment and train loading will occur at the existing Curragh Mine.

The Project will involve open cut coal mining in four pit areas (Pit X, Pit D extension, Pit J extension and Pit Z), run of mine (ROM) stockpiles, basic mine infrastructure areas (MIA) and fuel storage facilities near proposed Pit X and Pit Z, mine water storage near proposed Pit X and Pit Z, in-pit and out-of-pit spoil dumps and residual voids. Mining in Pit X, Pit J extension and Pit Z is not proposed to commence until after 2022 allowing adequate time for WCPL to obtain baseline groundwater information and confirm the findings of this impact assessment.

Physical setting

The topography of the study area (the groundwater model domain) is generally flat. Land use is predominantly livestock grazing, coal mining, dryland cropping and urban/residential in the town of Blackwater. Annual rainfall in the region is variable and quite low at 563 millimetres (mm) per year on average. Most rainfall occurs in the summer months. Evaporation is almost four times greater than average annual rainfall.

The study area is in the Fitzroy Basin. Mackenzie River, located 760 metres (m) to the north of proposed Pit X, has permanent flow with regular releases made from Bedford Weir to supply downstream water users. Blackwater Creek, a tributary of Mackenzie River, is a braided system which is located to the east of proposed Pit X, Pit D extension and Pit J extension. The creek has been subject to a 10 km diversion around Curragh Mine and is significantly altered. The creek receives a constant low flow from Blackwater Wastewater Treatment Plant; however the creek is dry downstream near proposed Pit X. Minnie Creek, a tributary of Blackwater Creek, flows through the proposed Pit X area and a 5.3 km reach of this creek, near its confluence with Blackwater Creek, will be diverted along with a 2.9 km reach of one of its unnamed tributaries. Bonnie Doon Creek, a tributary of Burngrove Creek to the west of proposed Pit Z, will be subject to a diversion (a 580 m reach of Bonnie Doon Creek at proposed Pit Z, and approximately 700 m of its secondary flood channels). Both creeks are ephemeral with their channels drying out for long periods.

The study area is underlain by Permian sediments within a gently folded and faulted sequence of the Bowen Basin. The sediments dip to the east and have been affected by thrust faulting. Coal will be mined from the Cancer, Aries, Castor, Pollux, Orion and Pisces seams of the Rangal Coal Measures. The Triassic Rewan

Formation overlies the Permian sediments in the east of the study area. Permo-Triassic strata are overlain by unconsolidated Quaternary and Tertiary alluvium associated with creeks, rivers and floodplain, and poorly consolidated Tertiary sediments of the Duaringa and Emerald formations. The Rangal Coal Measures are underlain by the Burngrove Formation and the Fair Hill Formation. The Back Creek Group forms the basement of the study area The Jellinbah Fault is located approximately 4 km to the east of proposed Pit X and has an approximate vertical displacement of 120 m.

Hydrogeology

The major water bearing units in the study area (the groundwater model domain) are the sand and gravel layers in alluvium associated with the Mackenzie River and the coal seams of the Rangal Coal Measures, Burngrove Formation and Fair Hill Formation. Water bearing zones may occur in weathered rock, the unconsolidated Duaringa and Emerald formations and faulted interburden of the Rangal Coal Measures and Burngrove Formation. Aquitard units include silt/clay layers in alluvium, the Rewan Formation, interburden of the Rangal Coal Measures, Burngrove Formation and Fair Hill Formation and the Back Creek Group.

Investigations at Curragh North prior to mining have indicated the alluvium is dry in many areas, and where water is present, it occurs within palaeochannels in deeper sections of alluvium. Alluvium near proposed Pit X is less than 12 m thick and comprises clay with occasional channel sand lenses and gravels at depth. The meandering system of Mackenzie River has created a depositional sequence that displays significant lateral variability in grain size and permeability and this is interpreted to control groundwater flow and interaction with Mackenzie River and Blackwater Creek. Alluvium near proposed Pit D extension, Pit J extension and Pit Z is less than 2 m thick, comprises clay with occasional channel sand lenses and is unlikely to be significantly water bearing. Coal seams within the Rangal Coal Measures are fractured rock aquifers and groundwater flow is along joints, cleats and possibly fault lineaments. Faulting of the coal seams and interburden may restrict flow due to the lateral discontinuity of water bearing coal seams. The aquifer is confined by interburden layers, except in sub crop zones, and has variable hydraulic conductivity with low to moderate permeability within discrete fracture systems.

Groundwater in alluvium generally occurs at the base of the alluvial profile, although perched groundwater may occur within the mid-section of alluvium at some isolated locations. Depth to groundwater in Permian sequences varies from 5 to 48 metres below ground level (mbgl) due to aspects of aquifer connectivity, confining conditions, topography and mining influence. Groundwater flow direction in the alluvium follows topography and drainage lines, but is affected locally where alluvium has been intersected during mining, (e.g. at Curragh North). Groundwater flow direction in Permian strata is to the north-east, but is influenced locally by dewatering in active pit areas of Curragh Mine.

Groundwater quality at Curragh Mine is similar for all formations and distinct from surface water. Groundwater is brackish to saline with neutral pH and a major ion composition dominated by sodium, chloride, magnesium and sulphate. Dissolved metal concentrations are generally low. Groundwater monitoring bores at Curragh Mine are mostly in disturbed areas. WCPL has recently installed reference bores to establish a baseline of undisturbed groundwater conditions near the mine.

Recharge of alluvial aquifers occurs through rainfall infiltration and via stream flow, particularly during periods of overbank flooding. Observations of limited seepage from Mackenzie River to alluvium at Curragh North suggest the stream bed and upper sections of the alluvial profile comprise low permeability materials and are a limited source of recharge to the alluvial groundwater system. Recharge of fractured aquifers within the Rangal Coal Measures and Burngrove Formation occurs through rainfall infiltration, stream flow where formations outcrop and vertical leakage, particularly where coal seams subcrop beneath alluvium.

The predominant discharge processes from the alluvium are by evapotranspiration where the water table is shallow, downward leakage into underlying geological units and dewatering of mine pits where alluvium is intersected. The predominant discharge processes from Rangal Coal Measures are dewatering of mine pits and regional aquifer through-flow. Some minor discharge occurs from registered bores.

The Bureau of Meteorology (BOM) groundwater dependent ecosystem (GDE) Atlas indicates Mackenzie River, Blackwater Creek and Cooroora Creek have a moderate potential for groundwater interaction. The Queensland GDE mapping identifies Blackwater Creek near the town of Blackwater as having potential for groundwater interaction. A review of depth to groundwater information indicates that groundwater levels in alluvium are generally more than 3 m below the stream bed and streams are unlikely to receive baseflow from groundwater.

Environmental values

The environmental values for groundwater adopted by the Queensland government for the Fitzroy Basin include aquatic ecosystems, irrigation, farm supply/use, stock water, human consumption, primary recreation, drinking water and cultural and spiritual values. A review of groundwater quality and availability (yield) indicates the beneficial use of groundwater is limited to livestock usage due to elevated salinity and relatively low yields (generally less than 1 litre per second (L/s)).

There are 15 registered landholder bores within the study area. Two bores are installed in alluvium associated with Mackenzie River and are located 1.8 and 3 km to the west of proposed Pit X. The closest of these bores is used by Central Highlands Regional Council to irrigate grass and supply water to the toilet block at the campground near Bedford Weir. Six bores are located 1.8 km or more to the west and south-west of proposed Pit Z. There are also a number of bores located more than 5 km to the south of proposed Pit J. Surface water allocation holders that take supplemented water from the Nogoa-Mackenzie Water Supply Scheme and unsupplemented water from natural Mackenzie River flows are located on Mackenzie River near proposed Pit X and downstream. There are three surface water licences in the study area associated with the diversion and impoundment of water for Blackwater Mine to the south of the Project.

The BOM GDE Atlas identifies numerous streams, riverine wetlands and palustrine wetlands that may rely on the surface expression of groundwater (“surface expression GDEs”). Depth to groundwater information indicates that watercourses in the study area are unlikely to receive baseflow from groundwater, and are more likely to be losing streams that are disconnected from groundwater. Depth to groundwater information also indicates that groundwater levels in alluvium are generally more than 4 m below wetlands, so even if wetlands are incised they are unlikely to be connected to groundwater. Swamps underlain by alluvium may be fed by perched groundwater in some areas.

GDEs reliant on the subsurface expression of groundwater (“subsurface GDEs”) have been mapped using data from the GDE Atlas, Queensland Government regional ecosystem (RE) mapping and field surveys to verify REs. The likelihood of groundwater dependence has been assessed based on the dominant species, reliance on water (groundwater or surface water), underlying geology and estimated base case depth to groundwater. Likely subsurface GDEs are associated with treed REs dominated by either *Eucalyptus* spp. (*Eucalyptus tereticornis* and/or *E. coolabah*) with or without *Melaleuca bracteata* (when fringing the drainage channel) or Brigalow (*Acacia harpophylla*) on alluvium.

Impacts associated with existing mine

A review of the impacts of existing Curragh Mine on groundwater has been undertaken to provide an indication of the impacts that may be expected for the Curragh Extension Project.

The review indicates inflows of 0.5 to 0.6 megalitre (Ml)/day/pit for the pits at Curragh East and 0.6 to 5.6 Ml/day/pit at Curragh North. Inflows at Curragh East are from Rangal Coal Measures whereas inflows at Curragh North are from alluvium and Rangal Coal Measures. Inflows generally increase with pit depth, but this varies at Curragh North where an underlying palaeochannel system with significant lateral variability in grain size and permeability is controlling groundwater flow. Site observations of mining in Pit S, 300 m from Mackenzie River, indicate the alluvium has been dewatered but Mackenzie River maintains flow.

Available groundwater level data in the vicinity of active pits suggests that drawdown associated with existing mining operations is localised and does not extend more than 2 km from mine pits. Water level recovery of 15 m was observed in one bore in the vicinity of a pit over an 18 year period.

Groundwater monitoring at Curragh Mine targeting in-pit and out-of-pit spoil dumps, tailings storage facilities and mine water storage dams indicate spoil and tailings are not acid generating and tailings and mine water storage dams are fresh compared to groundwater. Hydrocarbons detected in groundwater near mine infrastructure areas and fuel storage facilities have not been detected in subsequent sampling events suggesting the source may be localised spills or leaks.

Numerical groundwater modelling

The primary objective of the groundwater modelling was to quantify impacts to groundwater resources and associated environmental values in response to the proposed mining for the Curragh Extension Project. The modelling also aimed to quantify cumulative impacts associated with mining at the existing Curragh Mine, neighbouring mines and for the Curragh Extension Project. Development of the model has followed the Australian groundwater modelling guidelines (Barnett et al. 2012) and an independent peer review has been undertaken by Dr Stuart Brown of Hydrosimulations.

Modelling was carried out using MODFLOW USG and the Groundwater Vistas user interface. The model domain is 20.6 km by 45.2 km. A model cell size of 100 m x 100 m has been used, resulting in 206 columns and 452 rows and a total of 931,120 cells over the 10 model layers. The model domain covers all historical and future mining operations at Curragh Mine and extends far enough to allow the effects of cumulative impacts from neighbouring mines to be assessed. Model boundaries are located approximately 5 km from historical and proposed pits to prevent boundary effects on model outcomes.

The model conceptualisation was simplified into ten layers representing the key hydrogeological units including the alluvium, weathered rock, Rewan Formation and overlying/interburden units, coal seams of the Rangal Coal Measures, the Burngrove Formation and the Fair Hill Formation. The coal seams of the Rangal Coal Measures were aggregated into upper, middle and lower layers. A conservative approach was adopted and mining was assumed to occur from the base of the lowest seam in each group. The elevations and thicknesses of the model layers were developed using data from the Curragh Mine VULCAN database.

Mackenzie River was represented at a constant level using the river package. Blackwater Creek and other drainage lines were represented using the drain package. Recharge rates have been estimated using the steady state chloride mass balance method and applied in zones based on surface geology type. Evapotranspiration was applied using the EVT package based on Bureau of Meteorology (BOM) data with an extinction depth of 3 m. General head boundaries were applied to the north, south, east and west boundaries of the model. Hydraulic properties were assigned based on site field results and inferred estimates from previous studies.

The model was run for a steady state stress period of 100 years duration representing pre-development at Curragh Mine, followed by 12 transient stress periods of three years duration representing historical development at Curragh Mine from 1983 to 2015 (calibration run). Two predictive scenarios were run:

- Base case run: transient stress periods of annual duration representing future mining activities at Curragh Mine and neighbouring mines that have already been approved by government or are in advanced stages of approval.
- Cumulative run: transient stress periods of annual duration representing future mining activities at Curragh Mine and neighbouring mines as well as proposed mining activities for the Curragh Extension Project.

The difference between these two runs provided the impacts of the Curragh Extension Project.

The recovery period included two transient stress periods of annual duration and one stress period of 750 years duration representing the period following completion of mining.

Mining was simulated using the drain package with staged mine progression following the planned mine schedule. Simulation of in-pit backfilling was undertaken by altering the hydraulic conductivity, storage properties and recharge of each model cell in the stress period following simulation of mining.

Manual calibration methods were applied to improve the ability of the model to match observed water level and pit inflow behaviour. The calibrated model has a mass balance error of 0.0%, which is below the accepted threshold of 1% to 2%. The model reported an unweighted scaled RMS error of 13% and a weighted scaled RMS error of 5.8% for the transient calibration period. Sensitivity analysis was undertaken for the parameters expected to be most sensitive based on the conceptual hydrogeological model. The results indicate the most sensitive parameters to be increased horizontal hydraulic conductivity of the alluvium near Curragh North and Pit X, increased horizontal and vertical hydraulic conductivity of the uppermost coal seams and increased recharge. Predictive uncertainty analysis was undertaken for these parameters for the period of mining and the results showed that pit inflow rates predicted for the uncertainty runs were lower than pit inflow rates predicted for the cumulative run and were generally within 30% of the cumulative run predictions. Water table drawdown predictions for the uncertainty runs were generally the same or slightly higher.

Potential impacts

Potential impacts to groundwater have been assessed through a review of impacts associated with existing Curragh Mine operations and numerical groundwater modelling. Numerical groundwater modelling included assessment of cumulative impacts associated with existing Curragh Mine operations, neighbouring mines and the proposed Curragh Extension Project.

Project components with potential to impact on groundwater levels include dewatering of pits during mining and residual voids. Project activities with potential to impact on groundwater quality include fuel spills during construction, operation and rehabilitation, in-pit and out-of-pit spoil dumps, ROM stockpiles, MIAs, mine water storage dams, fuel storage facilities and residual mine voids.

Drawdown and recovery

Dewatering of pits is integral to the extraction of coal and will result in localised drawdown of groundwater systems (including depressurisation of confined hydrostratigraphic units). The results of groundwater modelling show that groundwater level drawdown due to the Project will generally be less than 2 m at a distance of 2 km from mine pits. This is consistent with observations of impacts due to mining at the current operation (Curragh Mine).

Water users

Numerical groundwater modelling has indicated that drawdown at registered bores in the study area will be less than 0.51 m due to mining for the Curragh Extension Project. Cumulative impacts to registered bores due to mining at Curragh Mine, neighbouring mines and for the Curragh Extension Project will be less than 0.7 m at all bores.

Streams and GDEs reliant on the surface expression of groundwater

Watercourses in the study area are losing streams that are disconnected from groundwater. The model predicts that losses due to the Curragh Extension Project will be less than 0.01 Ml/year from each stream reach, including Mackenzie River, for the simulated period of mining and recovery. Therefore there are no predicted impacts to the supplemented and unsupplemented water allocation holders on Mackenzie River due to the Project.

Based on depth to groundwater for the base case, wetlands and swamps in the study area are unlikely to be reliant on the surface expression of groundwater, and are unlikely to be impacted by groundwater drawdown.

Recharge

Minor increases in flood levels during large flood events as a result of Project related activities could potentially increase groundwater recharge in the Project area.

GDEs reliant on the subsurface expression of groundwater

Direct impacts to potential subsurface GDEs mapped within the Project footprint has been calculated based on the area of likely and possible subsurface GDEs, and associated regional ecosystems, impacted within the Project footprint. Approximately 46.7 ha of likely and potential subsurface, <0.02% of the total area of likely and potential subsurface GDEs in the study area, will be directly impacted by the Project within and surrounding Pit X. Of the potential subsurface GDEs directly impacted by the Project, 0.6 ha is mapped in association with the 'Brigalow (*Acacia harpophylla* dominant and co-dominant) Threatened Ecological Community (Brigalow TEC).

The results indicate a total of 167.8 ha of likely and potential subsurface GDEs, less than 1% of the total area of likely and potential subsurface GDEs within the study area, may be indirectly impacted as a result of drawdown associated with the Project. Of the 167.8 ha, 122.7 ha is considered to be associated with regional ecosystems that are likely to be associated with subsurface GDEs, and 45.1 ha is associated only with potential regional ecosystems associated with subsurface GDEs. The main areas likely to be affected by drawdown are the areas along Blackwater Creek to the east of Pit D and J and the area of regional ecosystems on alluvium to the North of Pit X (Figure 8.2). A few small areas of potential subsurface GDEs mapped along Minnie Creek outside the Project footprint may be affected by drawdown.

Groundwater quality

Spoil material will be placed in dedicated in-pit and out-of-pit spoil dumps. Spoil characterisation studies indicate spoil has low acid forming potential and groundwater quality monitoring at Curragh Mine indicates there are no acid mine drainage issues. Water quality analyses for mine water storage dams at Curragh Mine indicate mine water is not a source of acidity and salinity is comparable to or fresher than groundwater. Hydrocarbons have been detected in groundwater near the MIA and fuel storage facilities at Curragh Mine; however the impacts have been short-term and localised suggesting the source is spills and leaks from vehicles servicing the area.

Residual voids

Mine pits will be mostly backfilled, however four residual voids will remain following completion of mining. These voids may be a source or sink to groundwater. If voids are a source to groundwater, there is potential to increase the salinity of groundwater resources. If voids are a sink to groundwater, there is potential for drawdown of pre-mining groundwater levels over the long term.

Mitigation and management

Pit dewatering

Groundwater in the Project area is part of the Highlands Groundwater Management Area and in accordance with the requirements of the Fitzroy Basin water resource plan, WCPL will obtain water licences for mine dewatering purposes to account for any water taken from groundwater systems during mining.

Numerical groundwater modelling and assessment of potential impacts indicates there will be no impacts to surface water resources in Mackenzie River or its tributaries, and therefore water allocations from the Nogoa-Mackenzie Water Supply Scheme and the Upper Mackenzie Water Management Area are not required.

Groundwater users

Numerical groundwater modelling has predicted less than 51 cm impact at registered bore 84221 and less than 3 cm impact at other registered bores in the study area. An impact of 51 cm is within the range of natural variation and will not impact on the utility of the bore.

To confirm the results of the modelling, a groundwater monitoring bore will be installed between Pit Z and registered bore 84221. The bore will be monitored two years prior to the commencement of mining to establish baseline conditions and drawdown trigger levels, and then throughout mining to confirm there is no potential for impacts. If the early warning/investigation trigger level is exceeded, further investigations will be undertaken to assess the potential for impact, including a bore census survey and consultation with the landholder if required.

Surface water users

There are no predicted impacts to the supplemented and unsupplemented water allocation holders on Mackenzie River or water licence holder on Burngrove Creek.

To confirm the results of the modelling, a groundwater monitoring bores will be installed between Pit X and Mackenzie River. The bore will be monitored two years prior to the commencement of mining to establish baseline conditions and drawdown trigger levels, and then throughout mining to confirm there is no potential for impacts. If the early warning/investigation trigger level is exceeded, further investigations will be undertaken to assess the potential for impact, including consultation with the Nogoa-Mackenzie Water Supply Scheme operator and water allocation holders if required.

GDEs

Field verification studies of GDEs in the Pit X area will be undertaken prior to the commencement of works in 2023 to confirm whether GDEs exist in the area, characterise the nature groundwater dependence and assess potential risks associated with mining. Diversion of Minnie Creek is scheduled for 2023 and mining within ML700007 and ML700008 (Pit X) is scheduled for 2025, providing adequate time for completion of this assessment. Details of the field verification studies may potentially be included in the Matters of National Environmental Significance (MNES) Environmental Management Plan for the Project and Groundwater Monitoring Program (GMP) for Curragh Mine.

Nested groundwater monitoring bores will be installed in proximity of potential GDE areas to characterise seasonal water level variations and improve understanding of the interaction between alluvial groundwater systems, GDEs and streams. The monitoring bores will be located within and outside the area of predicted drawdown influence from pit development and will be monitored prior to and during mining to assess water level trends and plant health.

Monitoring potential GDEs within and outside expected drawdown areas, under the same management regime, will assist in determining the reliance of these REs on groundwater for future assessments, and will indicate any indirect impacts that may occur (i.e. canopy die back) as a result of drawdown. If there is a significant difference in vegetation parameters observed between the GDEs within and outside drawdown areas (i.e. canopy die back), albeit unlikely, then WCPL will investigate rehabilitation management activities and/or potentially provide offsets in accordance with the applicable *Environment Protection and Biodiversity Conservation Act 1999* Environmental Offsets Policy.

Groundwater quality

The handling, management and disposal of all hazardous substances, including fuels and chemicals, will be undertaken in accordance with the Curragh Mine Waste Management Plan (EM PLAN 3.0), which references Australian Standards. Spills will be handled as detailed in the Curragh Mine Spill Response Procedure (EMS PROC 3.3). All regulated wastes generated from a spill will be managed as per Curragh Mine Regulated Waste Management Procedure (EMS PROC 3.2). Tailings and mine water storage dams will be constructed and operated in accordance with the *Manual for Assessing Consequence Categories and Hydraulic Performance of Structures* (DEHP 2013) and WCPL regulated structure operational plans.

Residual voids

Management of residual voids will meet condition G13 of the EA, which requires that residual voids must not cause any serious harm to any recognised groundwater aquifer, and condition G14, which requires that residual void investigation reports be prepared and submitted to Queensland government six months prior to the commencement of mining activities in the area. Residual void outcomes in residual void investigation reports must be reviewed every three years.

Monitoring and reporting

WCPL has prepared a Groundwater Monitoring Program (GMP) for Curragh Mine to meet condition C53 of the EA. As part of the GMP, WCPL are undertaking groundwater monitoring at reference bores to establish natural background groundwater conditions for the area. The GMP will be updated to include the monitoring for the Curragh Extension Project area following Project approval. The existing Curragh Mine groundwater monitoring bore network will be augmented to include bores in the Curragh Extension Project area. The additional bores have been selected to:

- establish baseline conditions prior to commencement of mining
- provide for early warning of potential impacts to sensitive receptors, including water users, streams and GDEs, during mining
- detect changes in groundwater conditions due to seepage from site infrastructure, including ROM and MIA areas and mine water storage dams.

Ideally bores would be installed at least three years prior to the commencement of development and monitored for at least two years to provide adequate time to establish pre-mining baseline conditions.

Drawdown trigger values and water quality trigger values and contaminant limits will be established using reference bores and/or pre-mining data for the Project area.

In accordance with the EA, WCPL will notify the Queensland government of any exceedances of trigger levels or contaminant limits within 28 days of receiving results. WCPL will report to State and Commonwealth governments in compliance with the terms of environmental approvals issued by Queensland Department of Environment and Heritage Protection (DEHP) and Commonwealth Department of the Environment (DoE).

1. Introduction

1.1 Proposed action

Wesfarmers Curragh Pty Ltd (WCPL) operates the existing Curragh Mine Project (Curragh Mine) under Environmental Authority (EA) EPML00643713. The Curragh Mine commenced operation in 1983 and is an open cut coal mining operation located approximately 6 kilometres (km) north of the township of Blackwater in Central Queensland. The Curragh Mine produces a variety of coking, pulverised coal injected (PCI) and streaming coal products for both export and domestic markets.

The proposed action is the Curragh Extension Project (the Project) for the extension of open cut coal mining operations at Curragh Mine in four adjacent Mining Lease (ML) areas within Mineral Development Licence (MDL) 162 tenement (Figure 1.1). The addition of the Project to the Curragh Mine operation is not planned to increase the annual production but rather extend the life of mine. Based on existing approvals for the Curragh Mine, the life of mine is to 2030. The Project is likely to extend the life of the Curragh Mine to approximately 2038.

1.2 Project location

The Project is located approximately 6 km north of the township of Blackwater in Central Queensland, approximately 200 km west of Rockhampton and 350 km west-northwest of the Port of Gladstone. The Project is within the Central Highlands Regional Council local government area. The local area is a well-established grazing, farming and coal mining region. Figure 1.1 shows the Project location in the context of the State of Queensland and the local area.

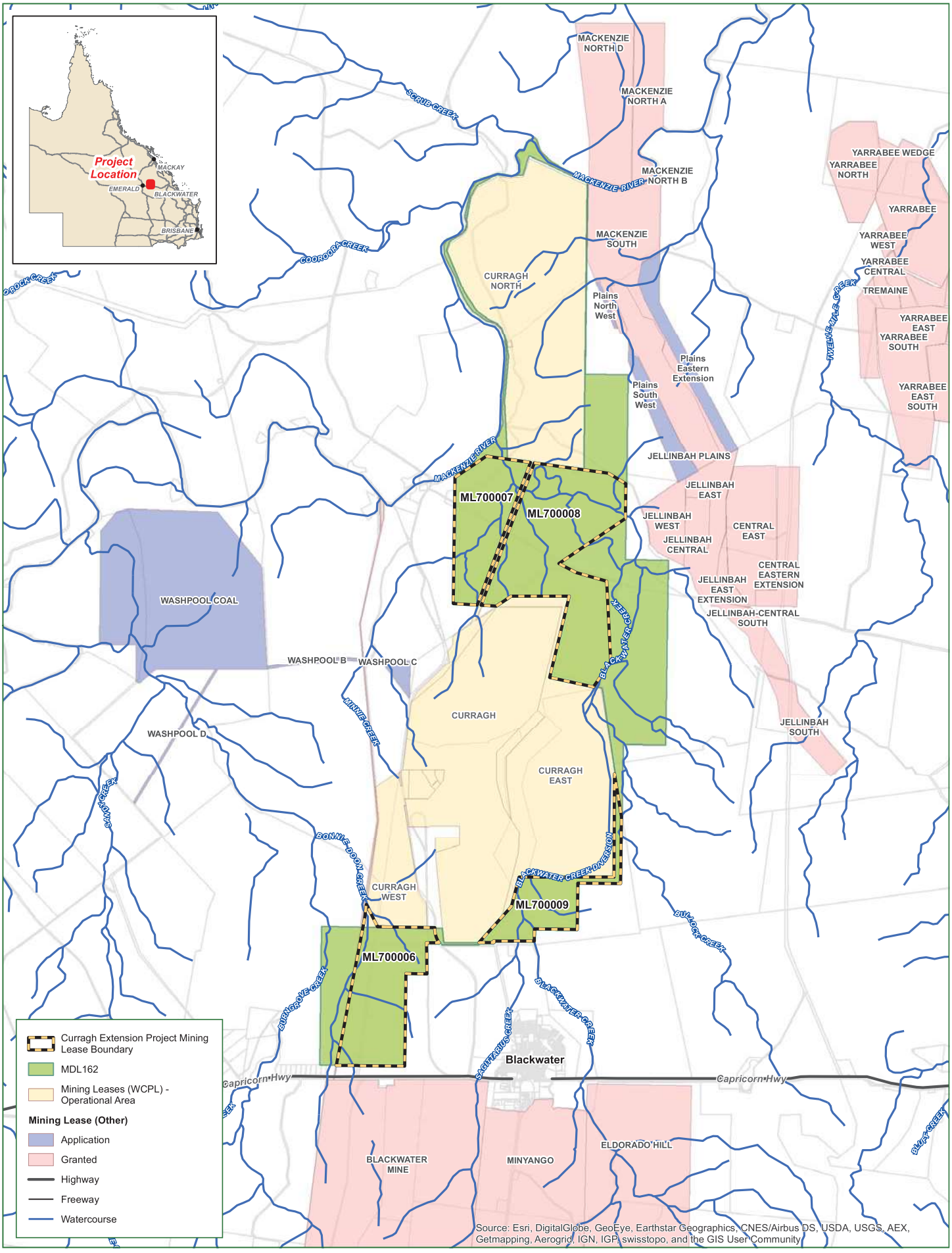
Several mining and petroleum (coal seam gas) tenements have been identified on the Queensland government's Queensland Globe mapping as occurring within and adjacent to MDL 162 (Table 1.1). Figure 1.1 shows the location of these tenements in relation to the Project. The nearest coal mine neighbours are Blackwater Mine located approximately 1.8 km south, Mackenzie South located approximately 2.5 km east and Jellinbah Central located approximately 5.5 km east. There are three authorities to prospect for petroleum (ATP) that overlap the Curragh Extension Project ML areas. There are no petroleum leases (PL) overlapping or directly adjacent to MDL 162.

Table 1.1 Neighbouring mines

Owner	Operation	Mining Lease	Status	Type of operation
Jellinbah Group Pty Ltd	Jellinbah Central and Jellinbah Plains	ML2418, ML6992, ML80018, ML80053, ML80068, ML80108, ML80140, ML80165, ML80184	Operational (mining commenced in 1989)	Open cut
	Jellinbah Plains Central North, Eastern Extension and Western Extension	ML700011, ML700013	Proposed (application)	Open cut
	Mackenzie South	ML80129	Operational (mining commenced in 2004)	Open cut
	Mackenzie North	ML70445, ML70446, ML70448, ML70449	Proposed (approved)	Open cut

Owner	Operation	Mining Lease	Status	Type of operation
BHP Coal Pty Ltd	Blackwater Mine	ML1759, ML1761	Operational (mining commenced in 1967)	Open cut
Blackwater Coal Pty Ltd	Minyango	ML80173	Proposed (approved)	Underground
Cook Resource Mining Pty Ltd	Eldorado Hill	ML1768, ML1769, ML1779, ML1799, ML7357	No information is available about operations at this mine. Review of Landsat imagery indicated a CHPP at the surface, suggesting mining is operational.	Underground
Washpool Coal Pty Ltd	Washpool Coal	ML80164, ML80176, ML80177	Proposed (application)	Open cut
BOW CSG Pty Ltd	Blackwater and Comet CSG Fields	ATP1025	Granted	Coal seam gas
OME Resources Australia Pty Ltd	N/a	ATP806	Granted	Coal seam gas
BNG (Surat) Pty Ltd	N/a	ATP684	Granted	Coal seam gas

N/a – not available



0 0.5 1 2 3 4 km

Scale 1:140,000

Scale correct when printed at A3 Portrait

Projection: Transverse Mercator
Coordinate System: GDA 1994 MGA Zone 55

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Data Source:
Cadastre from DNRM (2014)
Imagery from Wesfarmers (2014)

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Groundwater impact assessment
Curragh Extension Project
Figure 1.1
Project location

MXD Number: 2172652H_GIS_SW_F020_A2
Date: 20/06/2016
Author: GL
Approved by:AOK

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1.3 Existing Curragh Mine

The Curragh Mine operation produces a variety of export coals (coking, semi-soft and PCI) for international steel production and steaming coal for domestic power generation (WCPL has a long-term domestic coal supply contract with Stanwell Corporation). The mine is designed to produce up to 15 million tonnes per annum (Mtpa) of saleable product. Total coal production levels are currently at 13.5 Mtpa. These production levels are forecast to be maintained through to 2025, with the end of life of the Curragh Mine currently forecast to be 2030.

Curragh Mine currently operates within 10 mining leases (MLs) comprising a total area of approximately 13,655 hectares (ha). Mining operations first commenced in 1983 on ML1878. Mining activities at the Curragh East Mine on ML80086 and Curragh North Mine on ML80010 commenced in 2001 and 2004, respectively. Mining lease approval for the Curragh West Mine (ML80171) was granted on 15 July 2015.

The Curragh Mine project areas are listed in Table 1.2 and shown on Figure 1.2. Mining no longer occurs in the Curragh and Curragh Extended project areas. These areas are used for coal processing, coal stockpiling, train loading, landfill and tailings storage facilities. Mining is currently occurring at Curragh East in pits C, D, E, F and H and at Curragh North in pits S, T and U. Active pit areas for 2015 as well as life of mine footprints are shown on Figure 1.2.

Table 1.2 Curragh Mine project areas

Project areas	Mining leases	Size (ha)	Active pits
Curragh	ML1878, ML80112, ML1990	4,738	
Curragh Extended (No. 1, 2 and 3)	ML80010, ML80011, ML80012	73	
Curragh East	ML80086	3,026	C, D, E, F, H
Curragh North	ML80110, ML80123	4,864	S, T, U
Curragh West	ML80171	954	
Curragh Central Extended	ML700008	2,643	
Curragh Extended	ML700009	797	

At completion of mining, residual voids will remain in Pit T at Curragh North and Pits K and L at Curragh East. Mining at Curragh West is not proposed at this stage.

Existing facilities and infrastructure at the Curragh Mine that will be used by the Curragh Extension Project include the following:

- administration buildings
- bulk fuel storage tanks
- chemical storage tanks
- conveyor
- electrical equipment for dragline operations
- electrical transmission lines
- haul roads
- hydrocarbon storage areas/bunding
- landfill
- living quarters/camp
- pipelines
- potable water treatment plants
- preparation plants
- railing and loading facilities
- retention dams

- run of mine (ROM) pads
- security fencing
- sewage treatment plants
- stockpile areas
- vehicle parking areas
- vehicle wash down pads
- warehouse and yards
- workshop areas.

1.4 Project description

The Curragh Extension Project is the mining of additional open cut pits within four new proposed ML areas to extend the life of Curragh Mine by 8 years, moving the end of life forecast to approximately 2038. The Project will not increase annual production.

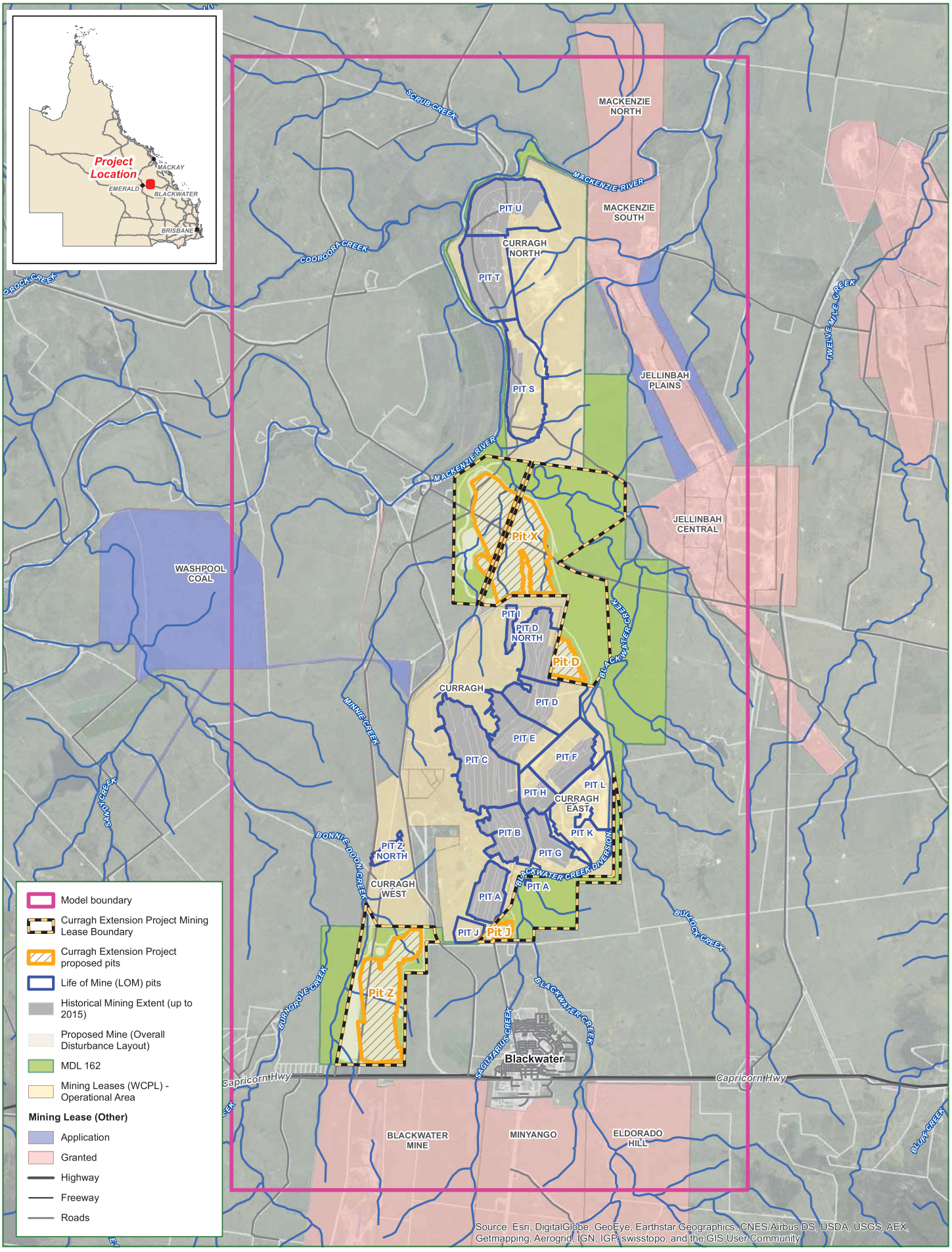
The MDL 162 tenement is an irregular shaped tenement covering approximately 9,185 ha. Mining is proposed to occur within four proposed ML areas which include ML700006, ML700007, ML700008 and ML700009 covering a footprint of 5,996 ha (Figure 1.2). The Project will utilise existing infrastructure within the adjacent Curragh Mine and will minimise the need for new infrastructure requirements. All coal processing, coal stockpiling and train loading will occur at the existing Curragh Mine.

1.4.1 Mining

The Project is located within the Early Permian to Middle Triassic Bowen Basin, one of the most important coal basins in Australia. The coal is to be mined from the Cancer, Aries, Castor, Pollux, Orion and Pisces seams of the Rangal Coal Measures.

Coal mining in the Project area is planned to commence in ML700008 (Pit D) in 2018, however, larger scale mining is currently scheduled to commence in Pit X in 2025. Mine scheduling within the four ML areas will depend on market conditions, but is currently planned as follows:

- **ML700006** Curragh South (Pit Z) – is located in the southern portion of MDL 162 and includes the south-west corner of MDL 328, to the south-west of the current Curragh Mine operations. It is proposed that construction of this mining area will commence in 2023 and become operational in 2027.
- **ML700007** Curragh Central (Pit X (west)) – is located in the northern portion of the Project between the current Curragh and Curragh North operations. The existing overland conveyor (part of ML80110) and central access road connecting Curragh North with Curragh, traverses through the Curragh Central and Curragh Central Extended. The development of Curragh Central is not proposed to start until all mining operations at Curragh North for which the overland conveyor and central access road are required have ceased. Construction of this mining area is proposed to commence in 2022 and operations in 2025 and will be developed as a single mining development with Curragh Central Extended.
- **ML700008 (granted)** Curragh Central Extended (Pit X (east) and Pit D) – Pit D extension is located in the central portion of the Project, to the east of the existing Curragh operation. Pit D is the northern extension of the Curragh Mine Pit D which operates under existing ML 80086. Construction of this mining area is proposed to commence in 2017 and operation in 2018. It is proposed that Pit X will commence construction in 2022 and operation in 2025 to coincide with the development of Curragh Central.
- **ML700009 (granted)** Curragh Extended (Pit J) – is located in the southern portion of the Project, immediately west of Sagittarius Creek. It is an extension of the existing Curragh Mine (Pit J) to the south. It is proposed that construction of this mining area will commence in 2029 and operations in 2030.



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0 0.5 1 2 3 4 km

Scale 1:140,000

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Projection: Transverse Mercator
Coordinate System: GDA 1994 MGA Zone 55

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Data Source:
Cadastre from DNRM (2014)
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Groundwater impact assessment
Curragh Extension Project
Figure 1.2
Curragh Mine layout and study area

MXD Number: 2172652H_GIS_SW_F021_A3
Date: 15/06/2016
Author: GL
Approved by:AOK

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Mining techniques at the Project are proposed to be similar to the existing Curragh Mine operation and involve the following sequence of events:

- The mining strip (typically 60–80 m wide) is marked out. Vegetation is pushed into piles using bulldozers and/or graders and also utilised in new rehabilitated areas.
- Topsoil, which on average runs to a depth of 0.3 m on the site, is stripped to the required depth using scrapers or bulldozers. Where possible, the topsoil is directly spread onto areas of reshaped spoil for rehabilitation. When direct spreading is not achievable, topsoil is placed in stockpiles at strategic locations for later use in the rehabilitation process.
- Overburden is drilled and blasted where required with overburden removal undertaken using draglines, shovels, bulldozers or large excavators and trucks. Overburden blasting activities are conducted using a rotary drill rig and contractor bulk-explosive manufacturing trucks.
- The removed spoil material is transported to dedicated in-pit and out-of-pit spoil dumps using either draglines or truck and shovel.
- The exposed coal seam is then ripped by dozers where required and mined by a hydraulic excavator or front-end loader and loaded into haul trucks.
- Profiling, topsoil placement and revegetation complete rehabilitation post-mining.

1.4.2 Infrastructure

The Project will utilise existing infrastructure within the adjacent Curragh Mine and therefore will require minimal infrastructure being located in the four new ML areas. All coal processing and waste facilities, coal stockpiling and train loading for the Project will occur at the existing Curragh Mine.

New infrastructure required to support the development of the Project is summarised in Table 1.3.

Table 1.3 Curragh Extension Project infrastructure requirements

Key infrastructure requirements	ML700008 Curragh Central Extended (Pit D)	ML700009 Curragh Extended (Pit J)	ML700007 Curragh Central and Curragh Central Extended (Pit X)	ML700006 Curragh South (Pit Z)
ROM/Pads/Hardstand (m^2)	--	--	66,370	106,100
HV Roads (km)	--	--	9.1	12.5
LV Roads (km)	--	3.0	5.8	10.5
Levee (m)	--	730	11,100	850
Diversion (km)	--	--	5.3 km (+2.9 km long reach of one of its unnamed tributaries)	580 m (+700 m of its secondary flood channels)
Water Management Dams (number required)	--	--	1	2
Water Pipeline (m)	--	--	2,600	2,600
Powerlines (km)	8.1	--	11.9	37.3
Fuel facility (number required)	--	--	1	1
Truck fill (number required)	--	--	1	1
Crib facility (number required)	--	--	1	1

New infrastructure for the Project which has potential to impact on groundwater resources includes:

- run of mine stockpiles
- mine infrastructure areas
- water storage dams.

Details of the proposed new infrastructure are provided below.

1.4.2.1 ROM pad

New ROM stockpiles are proposed at the south western corner of Curragh Central Extended near the Pit D extension and to the north of Curragh South near Pit Z. Coal will be hauled, via haul trucks, from Curragh South (Pit Z) and Curragh Central and Curragh Central Extended (Pit X) to the new ROM areas where it will be transferred to road trains and transported to the existing Curragh coal handling and preparation plant (CHPP).

1.4.2.2 Mine infrastructure area

A new mine infrastructure area (MIA) is not required to support Curragh Central Extended (Pit D) or Curragh Extended (Pit J) as the existing Curragh MIA will be used.

A basic MIA is proposed to be located adjacent to the new ROM areas utilised by both the Curragh Central ML and Curragh South ML. The MIA will include a fuel facility, crib facilities and a water truck fill. Existing Curragh Mine infrastructure will be utilised (major maintenance facilities, administration etc.) to reduce the infrastructure requirements of the Curragh Extension Project.

1.4.2.3 Water management

A water management network of pipes and pumps currently exists within the Curragh Mine. This network collects and transfers water between water storage dams on both the Curragh and Curragh North mines. This water management network for the Project will incorporate new dams within the Curragh Central and Curragh South development areas, and provide supply to the newly constructed facilities.

For Curragh Central and Curragh Central Extended (Pit X), one new water management dam is proposed to be located on the western boundary to service the western section of the pit. Water will be managed with a new pump and pipe infrastructure network.

For Curragh South, two new water management dams are proposed to store mine affected water. One is proposed to be located on the eastern side of the ROM and one located on the western boundary of the pit area.

No new water management infrastructure is required to support the development of Curragh Extended (Pit J) or Curragh Central Extended (Pit D). Water supply, reticulation and storage will be via existing water management infrastructure.

1.4.3 Waste management

Waste generation and waste management requirements and procedures for the Project are expected to be the same to those observed and planned for the existing Curragh Mine operation.

Spoil material will be transported to dedicated in-pit and out-of-pit spoil dumps. All tailings and coarse rejects will be managed in existing Curragh Mine facilities, which are registered structures certified on an annual basis.

Coarse rejects are conveyed from the coal handling and preparation plants (CHPPs) into a rejects storage bin for transport via truck to in-spoil locations. Coarse rejects are also collected and buried with spoil as part of the rehabilitation process. This process will remain the same for the Curragh Extension Project.

Existing Curragh Mine sewage treatment plants (STPs) are expected to have capacity to treat the additional sewage generated as a result of the Project.

1.4.4 Water supply

Water supply and management at the Curragh Extension Project is expected to be as per the Water Management System currently in place at Curragh Mine.

Curragh Mine has raw water allocations from Mackenzie River totalling approximately 3,220 Ml/annum purchased through Sunwater. This is supplied to the mine via a pipeline from Bedford Weir, and direct pumping from the river adjacent to operations at Curragh North. No new water supply volume is required to support the Curragh Extension Project. To reduce the amount of purchased water required for Curragh Mine, water is recycled from the tailings facility and retention dams for use in the CHPPs and for dust management.

No new water management infrastructure is required to support the development of Curragh Central Extended (Pit D) or Curragh Extended (Pit J). New dams within the Curragh Central and Curragh South development areas will be required to provide supply to the newly constructed facilities.

1.4.5 Rehabilitation and residual voids

1.4.5.1 Rehabilitation and post mining land use

Rehabilitation requirements and management practices for the Project are expected to be generally consistent with those observed and planned for the existing Curragh Mine operation, which are detailed in Curragh Mine's Environmental Management System (EMS).

Rehabilitation of completed in-pit spoil and profiled out-of-pit dumps would be undertaken using various heavy earthmoving equipment including dozers, excavators, trucks, graders and scrapers. Once a spoil dump is re-contoured, the completed landforms are topsoiled and seeded or planted with selected tube stock as appropriate.

Final rehabilitation land-use varies across the Curragh Mine site, however the predominantly proposed post-mine land use for areas disturbed for the Project will be a native woodland/open forest (flora and fauna habitat) using appropriate native tree, shrub and grass species.

1.4.5.2 Residual voids

Residual voids will remain in Pit X and Pit Z following completion of mining. EA EPML00643713 contains conditions (G13 and G14) relating to residual voids, including 'rehabilitation outcomes'.

1.5 Scope of this assessment

The scope of this assessment has been developed to address the potential impacts to groundwater resources and associated environmental values due to the Project. Advice from the Independent Expert Scientific Committee (IESC) to the Department of the Environment (DoE) dated 4 November 2015 has been considered and key issues raised are addressed in this assessment (refer Table 1.4). Cumulative impacts of the existing Curragh Mine, neighbouring mines and the Project have been assessed.

Table 1.4 Key issues raised by IESC addressed in this report

Key issues	Section
Update the groundwater model to include: ■ cumulative impacts from all Curragh Extension Project pits, existing pits and other nearby mines ■ appropriately detailed parameterisation of stratigraphy ■ paleochannels, faults and other structural features ■ the losing/gaining nature of Mackenzie River. Undertake calibration, sensitivity analysis and uncertainty analysis.	7
Identification of the water requirements of potentially groundwater-dependent vegetation communities and assessment of potential impacts to these communities	5.2.3
Conceptualisation of surface water-groundwater interaction and potential impact pathways for GDEs reliant on the surface expression of water	4.6
Residual voids	7.1.3

Dewatering of pits is integral to the extraction of coal and, based on experience at the existing Curragh Mine, will result in localised drawdown of groundwater systems (including depressurisation of confined hydrostratigraphic units). Drawdown of groundwater systems has the potential to result in:

- decrease in groundwater levels in bores and reduced supply to groundwater users
- loss or degradation of groundwater dependent ecosystems (GDEs) reliant on the subsurface expression of groundwater
- reduced stream flow and loss or degradation of aquatic ecosystems reliant on the surface expression of groundwater
- loss or reduction of supply to surface water users.

A number of Project activities have the potential to contaminate groundwater resources, including:

- excavation activities during construction and operation
- migration of leachate from spoil, rejects or tailings
- mine water storage
- coal processing at the mine infrastructure area; hydrocarbon leaks from fuel storage facilities
- increased salinity in residual voids due to evaporative processes.

Degradation of groundwater quality can lead to degradation of the beneficial use of groundwater supplies or loss or degradation of GDEs reliant on affected aquifers.

To investigate and assess the potential impacts and cumulative impacts to groundwater resources and associated environmental values, the scope of this assessment includes:

- characterisation of the physical setting of the Project and surrounding area (Chapter 2)
- review of available information for the Project and surrounding areas (Chapter 3)
- development of a conceptual hydrogeological model for the Project and surrounding area (Chapter 4)
- identification of groundwater related values and assets, including groundwater users, surface water users and GDEs (Chapter 5)
- review of impacts associated with existing operations (Chapter 6)
- numerical groundwater modelling to quantitatively assess drawdown impacts associated with the Project, stream losses and the cumulative impacts of the existing Curragh Mine, neighbouring mines and the Project (Chapter 7)
- qualitative assessment of the risks to groundwater quality (Chapter 8)
- assessment of the significance of potential impacts to groundwater related values and assets (Chapter 8)
- identification of mitigation and management measures for the potential impacts and assessment of residual impacts remaining after application of the mitigation and management measures (Chapter 9)

- development of a monitoring program to improve information about the hydrogeology of the Project area prior to the commencement of mining and provide a mechanism for early identification of potential impacts due to mining (Chapter 9).

The numerical groundwater model developed for this assessment includes simple representation of the residual voids that will remain at the end of mining. More detailed assessment of the residual voids will be undertaken in accordance with Condition G14 of EA EPML00643713, which requires preparation of a residual void investigation report. The report will address whether the residual voids at Curragh Mine will behave as a sink or source to groundwater. Further details of the residual void investigation report are provided in Section 9.1.6.

1.6 Study area

To allow for assessment of potential impacts to groundwater resources associated with the Project, as well as cumulative impacts of the existing Curragh Mine, neighbouring mines and the Project, the study area includes:

- historical and future mining operations at the existing Curragh Mine
- historical and future mining operations at neighbouring mines
- proposed mining operations for the Curragh Extension Project.

The study area referred to in this report is the model boundary shown on Figure 1.2. The Project area referred to in this report is the Curragh Extension Project area.

1.6.1 Coordinate system

Curragh Mine use their own local coordinate system. Spatial data presented in this report is in the Curragh Grid.

While the same parameters as AMG 84 are used for the site datum definition, the control is closer aligned to AMG 66, which is approximately 3 m difference in position to AMG 84. The conversion between AMG 84 and the Curragh Grid is as follows:

- From AMG 84 to Curragh Grid:
  - Easting – Add 1.065
  - Northing – Add 2.845
  - RL – Add 0.240.
- From Curragh Grid to AMG 84
  - Easting – Subtract 1.065
  - Northing – Subtract 2.845
  - RL – Subtract 0.240.

To convert from AMG 84 to MGA 94, the GDay v2.1 software available through the Queensland Department of Natural Resources and Mines website and NTv2 ‘QLD_0900’ deformation grid can be used.

2. Physical setting

2.1 Topography and land use

The topography of the Project area is generally flat, including gently undulating plains, rises associated with weathered sedimentary outcrop and floodplains in the vicinity of Mackenzie River to the north. The dominant topographic features of the area are drainage depressions, creek lines, Mackenzie River and the open cut pits and spoil dumps of Curragh Mine and neighbouring mines. Topography and drainage near the Project area is shown on Figure 2.1.

Outside of the towns of Clermont, Emerald, Springsure and Blackwater, the catchment is sparsely populated. Land use is typically rural with substantial areas cleared for livestock grazing. Other nearby land uses include coal mining, dryland cropping and urban/residential in the town of Blackwater. There is some minor irrigated cropping adjacent to Mackenzie River, which is understood to be irrigated with surface water from the Nogoa-Mackenzie Water Supply Scheme.

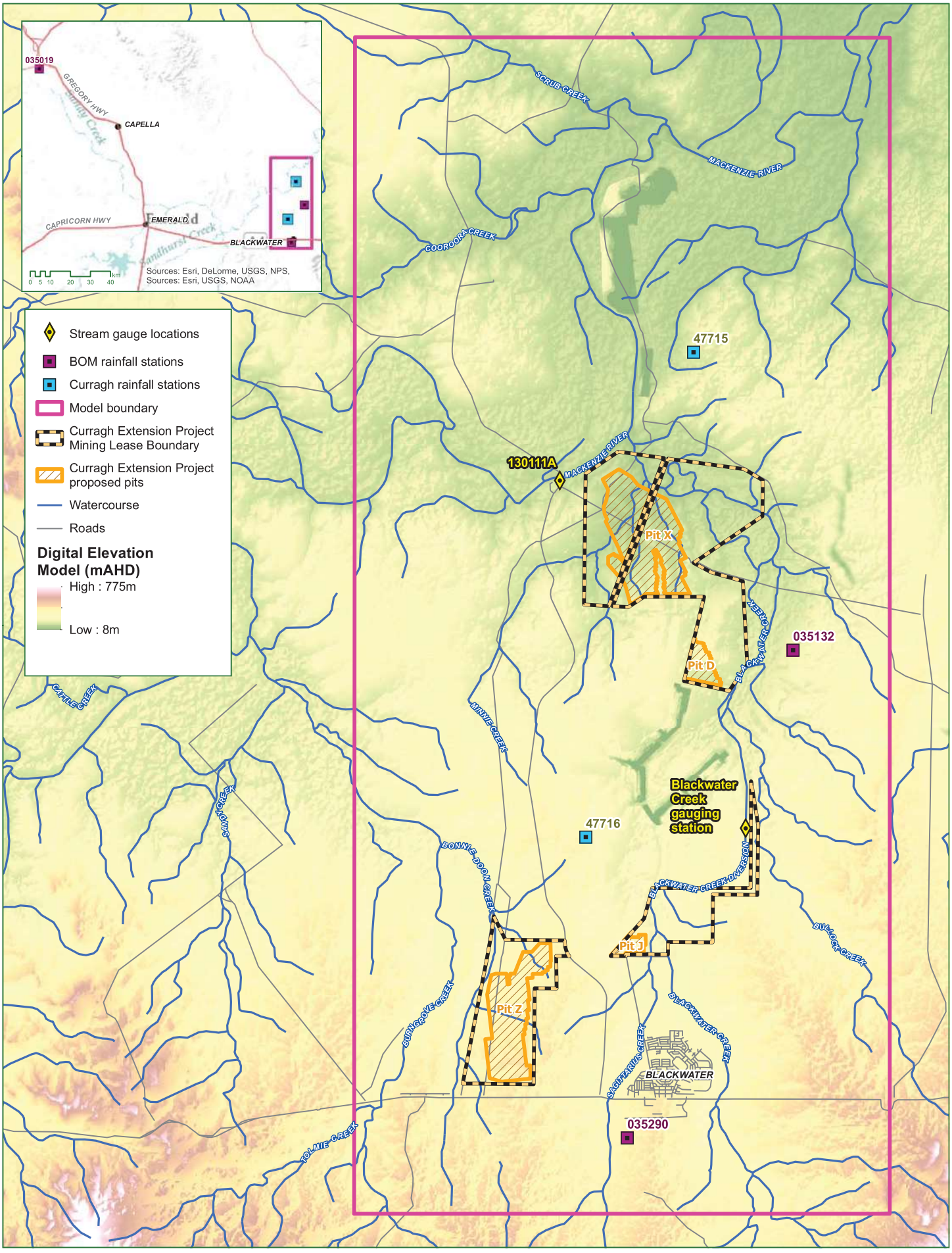
Meteorological data were obtained from the closest Bureau of Meteorology (BOM) weather stations to the Project. The closest BOM weather station with rainfall data is located at Blackwater Water Treatment Plant (site number 035290). The closest BOM weather station with evaporation data is located at Clermont Post Office (site number 035019). Two automatic weather stations (AWSs) which collect rainfall and evaporation data are operated by WCPL; one at Curragh (47716) and another at Curragh North (47715).

The locations of the weather stations are shown on Figure 2.1. Details of the stations, including the available data and period of record, are provided in Table 2.1.

Table 2.1 BOM and Curragh Mine weather stations

Station	Station number	Easting	Northing	Elevation (mAHD)	Distance from Project (km)	Available data	Period of record
Blackwater Water Treatment Plant	035290	690806	7388811	187	4.2	Rainfall	Aug 1995–Feb 2010
Clermont Post Office	035019	697183	7407557	273	137.7	Evaporation	1979–2011
New Caledonia	035132	565671	7475157	152	1.8	Rainfall	1968–current
Curragh	47716	689210	7400366	173	n/a	Rainfall (Temp, solar radiation, wind velocity since 2015)	Mar 2006–current[#]
Curragh North	47715	693352	7419009	141	n/a	Rainfall (Temp, solar radiation, wind velocity since 2015)	May 2010–current*

[#] Data gaps exist between March 2009 – May 2010 and June 2013 – January 2015
* Data gaps exist between June 2013 – January 2015



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Data Source:
Roads, watercourse from DNRM (2014)
Mining data from WSP/PB (2016)

Groundwater impact assessment
Curragh Extension Project
Figure 2.1
Topography and drainage

MXD Number: 2172652H_GIS_SW_F026_A2
Date: 15/06/2016
Author: GL
Approved by: LR
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2.2 Climate

2.2.1 Rainfall

Rainfall data used in this report has been collected at the BOM weather station at New Caledonia (035132), which has the longest continuous period of record.

Annual rainfall in the region is variable and generally quite low. Most rainfall occurs in the summer months. July, August and September have the lowest total rainfalls. Figure 2.2 presents monthly rainfall data for the four stations in Table 2.1. Historical data shows that the region receives on average approximately 563 mm per year based on rainfall data from 1968 to 2015 (BOM 2015a).

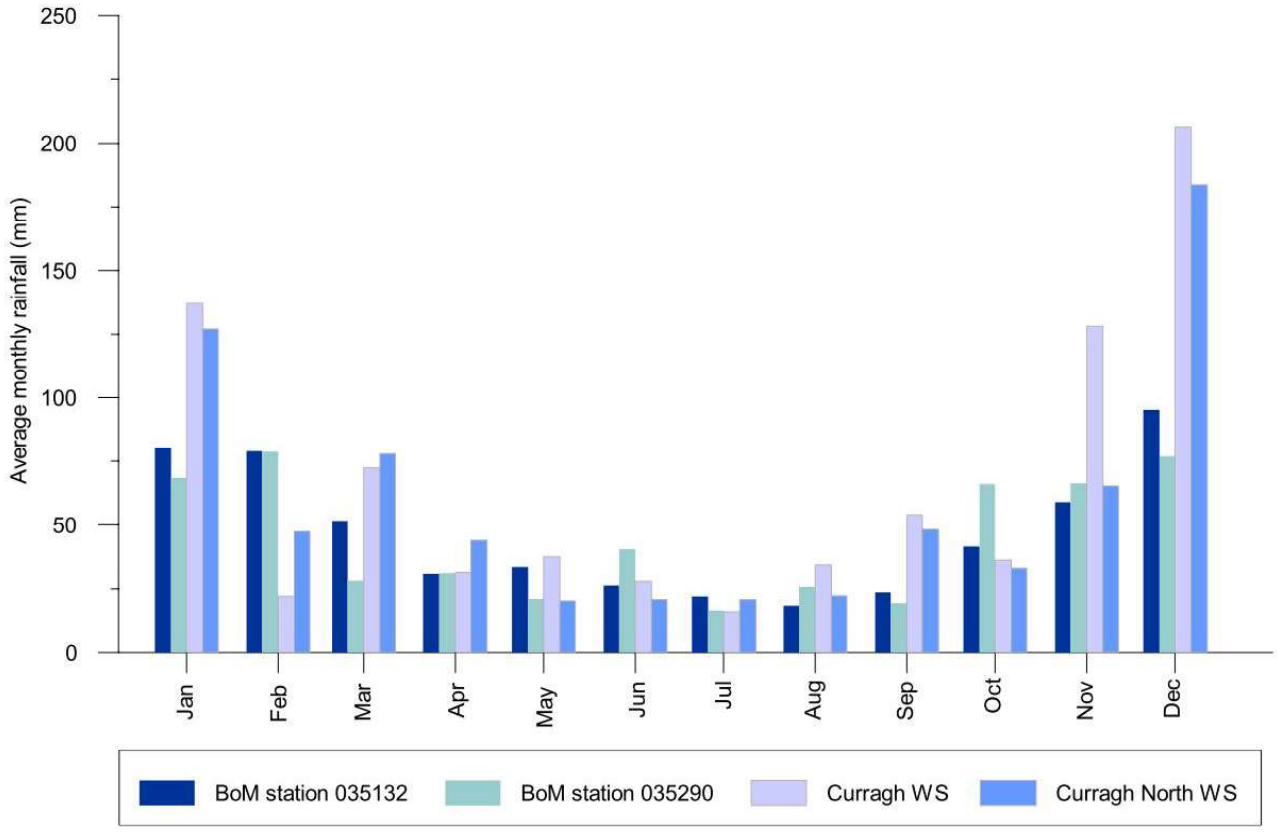


Figure 2.2 Average monthly rainfall data

The long-term, monthly cumulative deviation from mean (CDFM) rainfall for the period 1969 to 2015 is plotted in Figure 2.3. The long-term cumulative rainfall residual plots are formulated by subtracting the average monthly rainfall for the recorded period from the actual monthly rainfall and then accumulating these residuals over the assessment period. Periods of below average rainfall are represented as downward trending slopes while periods of above average rainfall are represented as upward trending slopes.

The cumulative deviation plot shows a drier period between 1997 and 2010, as well as 2013 and 2015, as indicated by the downwards sloping cumulative deviation trend. Monthly rainfall in this period was typically below the mean rainfall of 563 mm per year, with the exception of 2011 to 2013.

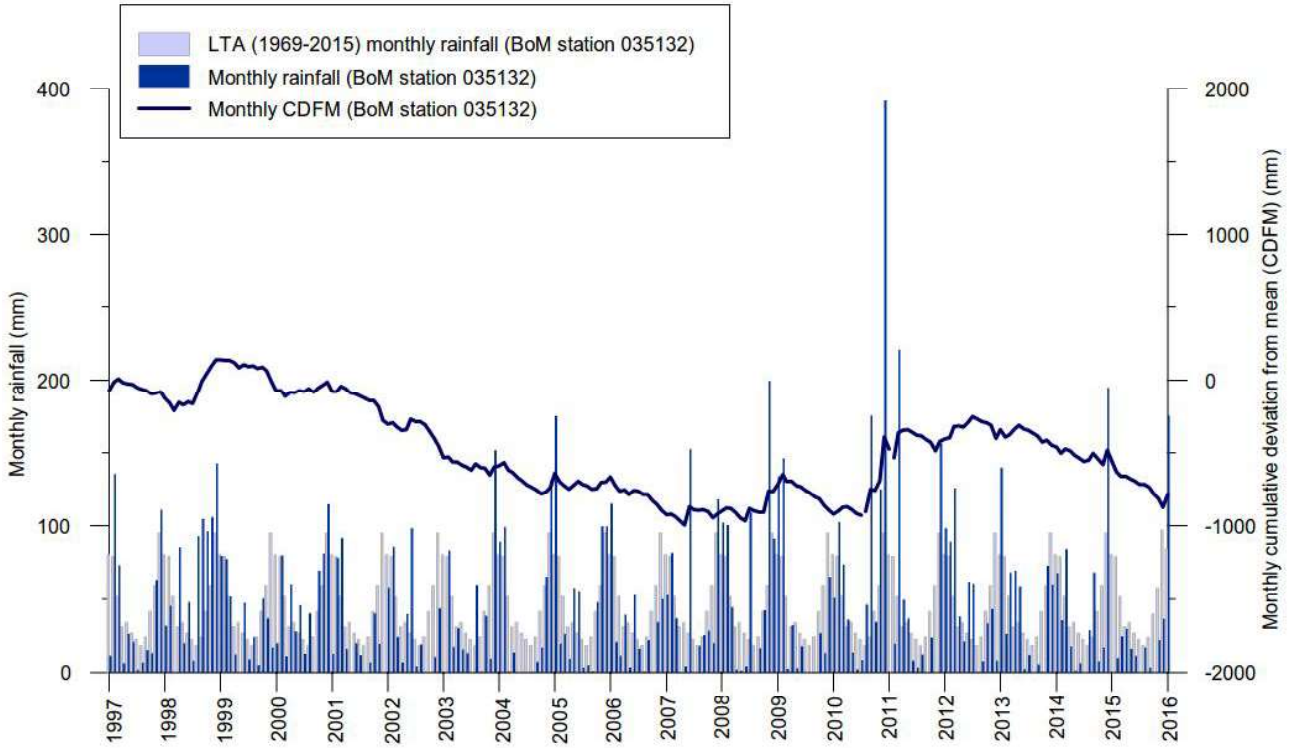


Figure 2.3 Long-term monthly rainfall

2.2.2 Evaporation

The coldest months in the Project area are generally June and July, with warmer temperatures occurring in December and January.

Evaporation data collected at Clermont Post Office indicates the average annual evaporation for the period 1979 to 2011 is more than 2,000 mm, which is almost four times greater than average annual rainfall.

BOM evapotranspiration maps indicate that actual annual evapotranspiration, the water lost to atmosphere which would occur under average rainfall conditions, in the Project area is 600–700 mm per year.

2.3 Hydrology

The main hydrological systems in the study area are shown in Figure 2.1 and discussed in Sections 2.3.1 to 2.3.3.

2.3.1 Mackenzie River

The main drainage in the study area is Mackenzie River. Mackenzie River is a major tributary of the Fitzroy River which flows to the Coral Sea at Rockhampton. Mackenzie River forms at the confluence of the Nogoa and Comet rivers, approximately 66 km upstream of the Project area. The total catchment area of Mackenzie River to Bingegang Weir, just downstream of the study area, is approximately 50,960 km^2.

Within the study area, Mackenzie River forms a large floodplain with buried meanders (palaeochannels) evident on aerial photographs. The river floodplain is a relatively flat, broad alluvial tract about 4 to 5 km wide. A number of semi-permanent waterholes are associated with the floodplain.

Within the study area, Mackenzie River is a regulated river system located between Bedford and Bingegang weirs. Fairbairn Dam is located upstream and stores 1,300 gigalitres (GL) when full. Releases from the dam deliver supplies to downstream riparian water users and maintain levels in Bedford and Bingegang weirs so that various towns, mines and irrigators can be supplied.

The regulation of Mackenzie River has altered the natural flow regime. Mackenzie River in the study area is a permanently wetted system (Figure 2.4). Flow in the river occurs when releases from Bedford Weir are made to deliver water to customers or maintain levels in Bingegang Weir, or associated with a large natural flood. Stream hydrographs for Bedford Weir and Bingegang Weir are provided in Attachment A.

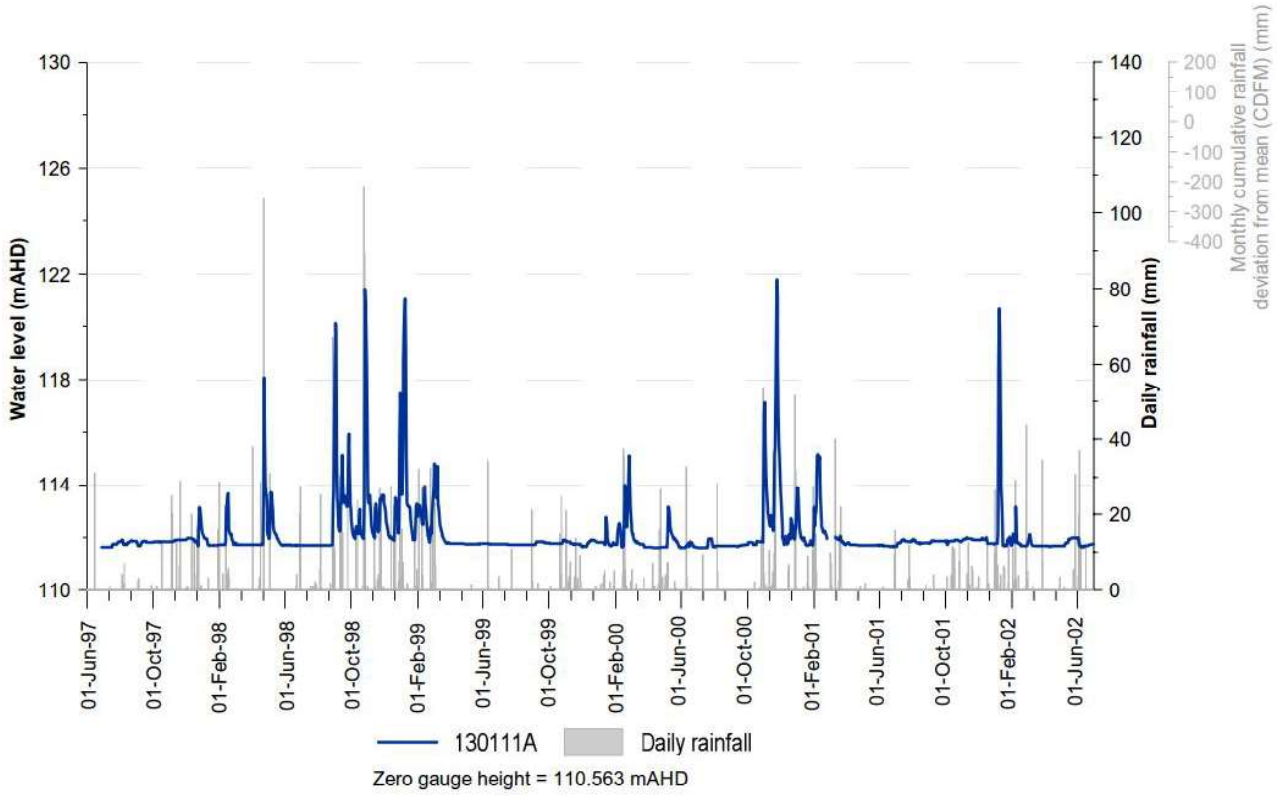


Figure 2.4 Mackenzie River water levels

Local land uses, including cattle grazing, have led to bank erosion, sedimentation and eutrophication in Mackenzie River (AGE, 2006). Photo 2.1 shows Mackenzie River at Curragh North.

The main tributaries of Mackenzie River in the study area include Blackwater Creek, Burngrove Creek, Cooroora Creek and Scrub Creek.



Photo 2.1 Mackenzie River near Pit S at Curragh North

2.3.2 Blackwater Creek and tributaries

The main tributary of Mackenzie River in the study area is Blackwater Creek, which flows in a northerly direction to the east of proposed Pit J extension, Pit D extension and Pit X.

Blackwater Creek is naturally ephemeral; however at its upstream end, it has a constant low flow (Photo 2.2) due to discharge of treated effluent from Blackwater Wastewater Treatment Plant (WTP) via Sagittarius Creek.



Photo 2.2 Constant low flow in southern section of Blackwater Creek

Downstream of the confluence with Sagittarius Creek, Blackwater Creek is a highly modified system having been diverted on three previous occasions for the Curragh East mine workings. The latest alteration involved the diversion of a 9.4 km length of the creek in 2010. The Blackwater Creek diversion is a large engineered drainage structure made of compacted earth and vegetated with grasses and shrubs (Photo 2.3).



Photo 2.3 Blackwater Creek diversion

The discharge from Blackwater WTP is observed along the extent of the diversion as shown by stream gauge data for Blackwater Creek (Figure 2.5), but flow is not observed north of the diversion.

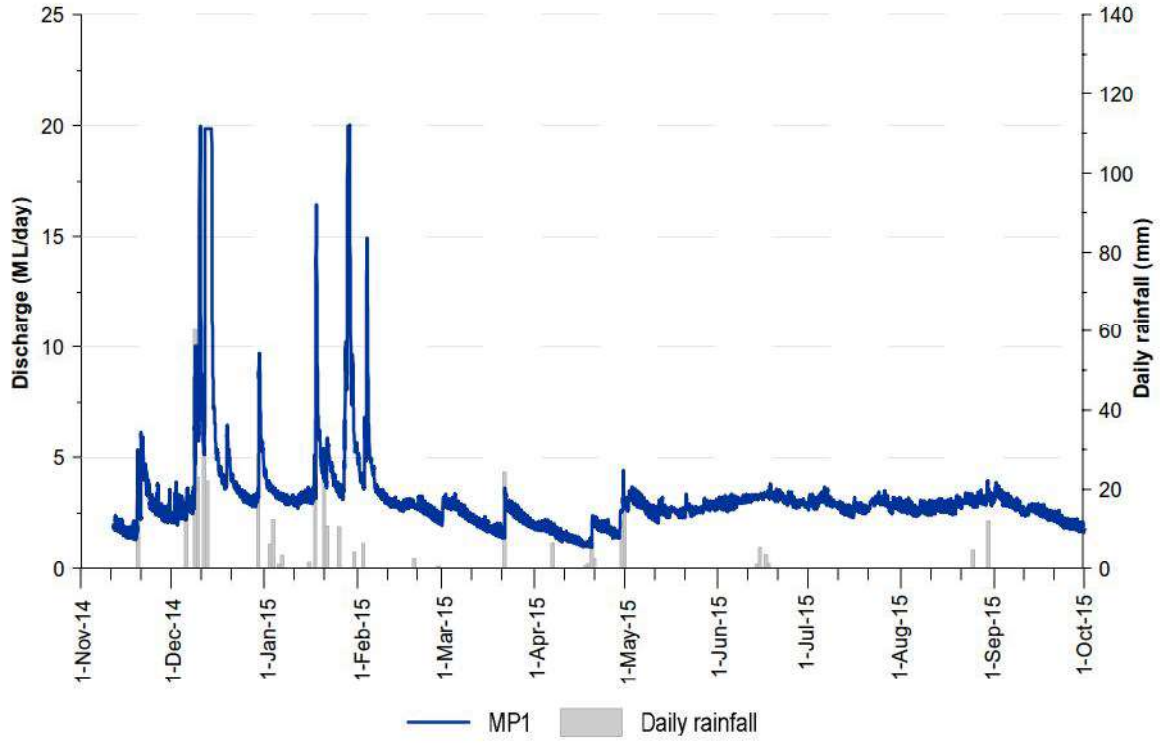


Figure 2.5 Blackwater Creek stream hydrograph

Blackwater Creek is a braided system near proposed Pit X where it comprises numerous channels that split off and re-join each other. The northern part of Blackwater Creek, near proposed Pit X, is observed to be dry except following rainfall, indicating the creek does not receive natural baseflow from groundwater (Photo 2.4).



Photo 2.4 Blackwater Creek north of the diversion

Tributaries of Blackwater Creek in the Project area include Taurus Creek, Sagittarius Creek, Minnie Creek and Bullock Creek, which are all ephemeral. Minnie Creek flows through the proposed Pit X area and will be subject to a 5.3 km diversion near its confluence with Blackwater Creek plus a 2.9 km diversion of one of its unnamed tributaries around the western side of the pit prior to the commencement of mining.

2.3.3 Burngrove Creek and tributaries

Other tributaries of Mackenzie River in the Project area include Burngrove Creek. A tributary of Burngrove Creek is Bonnie Doon Creek, which flows in a northerly direction to the west of proposed Pit Z and will be subject to a diversion (580 m long reach plus approximately 700 m of secondary flood channels). Burngrove Creek and Bonnie Doon Creek are ephemeral, with their channels drying out for long periods.

2.4 Geology

2.4.1 Regional geology

The study area is underlain by Permian to Quaternary fluvial and deltaic sediments located within a gently folded and faulted sequence of the Bowen Basin, one of the most important coal basins in Australia.

The consolidated Permo-Triassic sediments of the Bowen Basin sequence include the Triassic Rewan Formation and the underlying Permian Blackwater Group, which includes the Rangal Coal Measures, Burngrove Formation and Fair Hill Formation. The Triassic strata are overlain by unconsolidated Quaternary alluvium associated with creeks, rivers and floodplains and the poorly consolidated Tertiary sediments of the Duaringa and Emerald formations. The Back Creek Group underlies the Blackwater Group and forms the basement of the area. The stratigraphic sequence of Permian age units is shown in Figure 2.6.

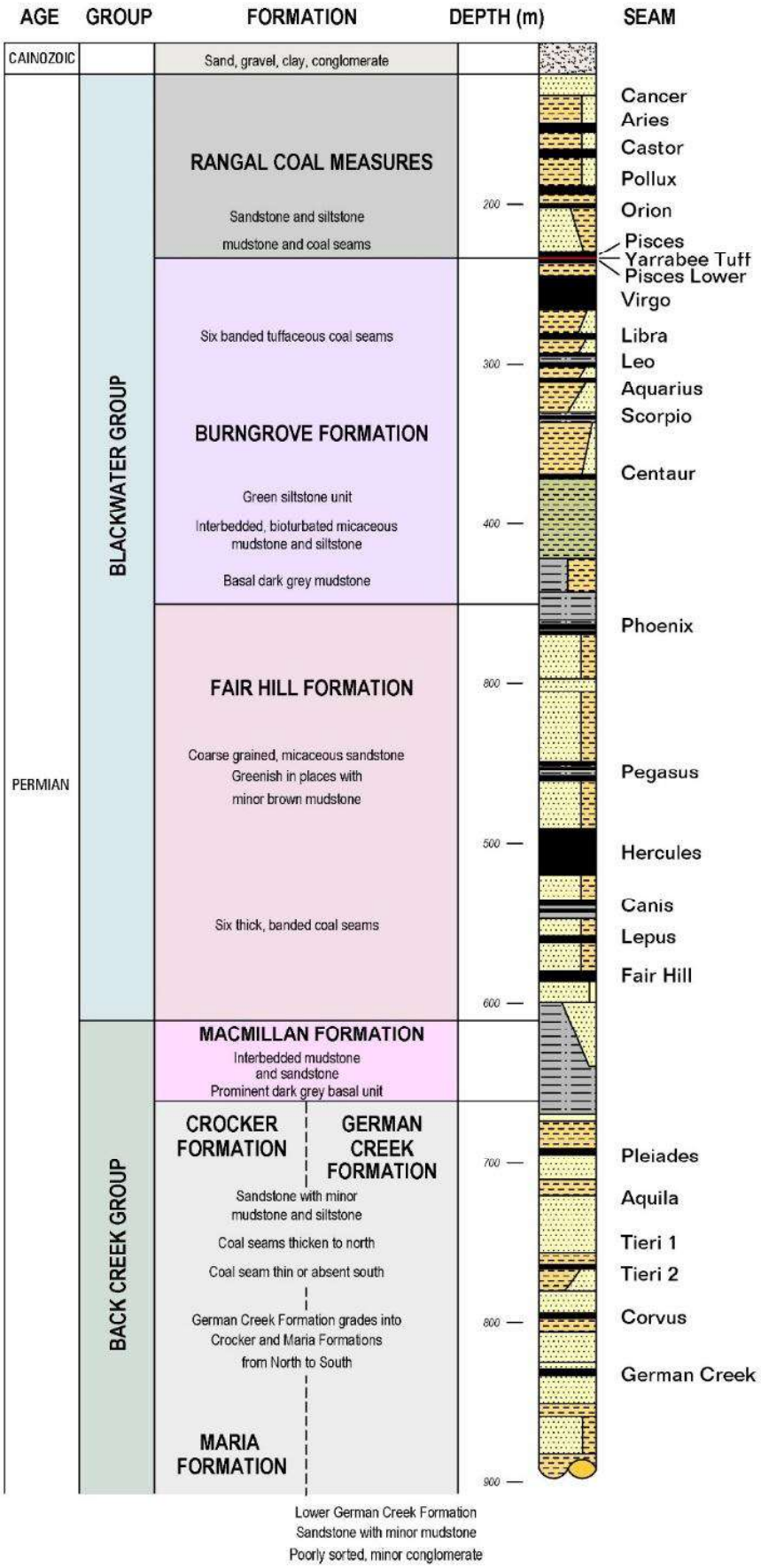


Figure 2.6 Blackwater Coalfield stratigraphic column

2.4.2 Geology of the study area

A map of the surface geology in the study area based on the latest 1:100,000 scale geology map sheets (Cooroorah, Comet, Strathconan and Dingo) is shown in Figure 2.7.

Drilling programs conducted since the mine was commissioned have resulted in over 11,000 drill holes being drilled at Curragh Mine and over 400 drill holes being drilled in the proposed Curragh Extension Project area. The majority are open drill holes with downhole geophysical log data. The drilling data is maintained in VULCAN databases at the mine site. Drill hole data and grid files of geological layers exported from the VULCAN databases have been used to develop a detailed understanding of the geology of the Curragh Mine area.

Exploration data for neighbouring mines is available from the Queensland Globe. This data has been downloaded and assessed together with the Curragh Mine data to develop a detailed understanding of the geology of the broader study area.

The stratigraphic sequence underlying the study area is presented in Table 2.2 and summarised below.

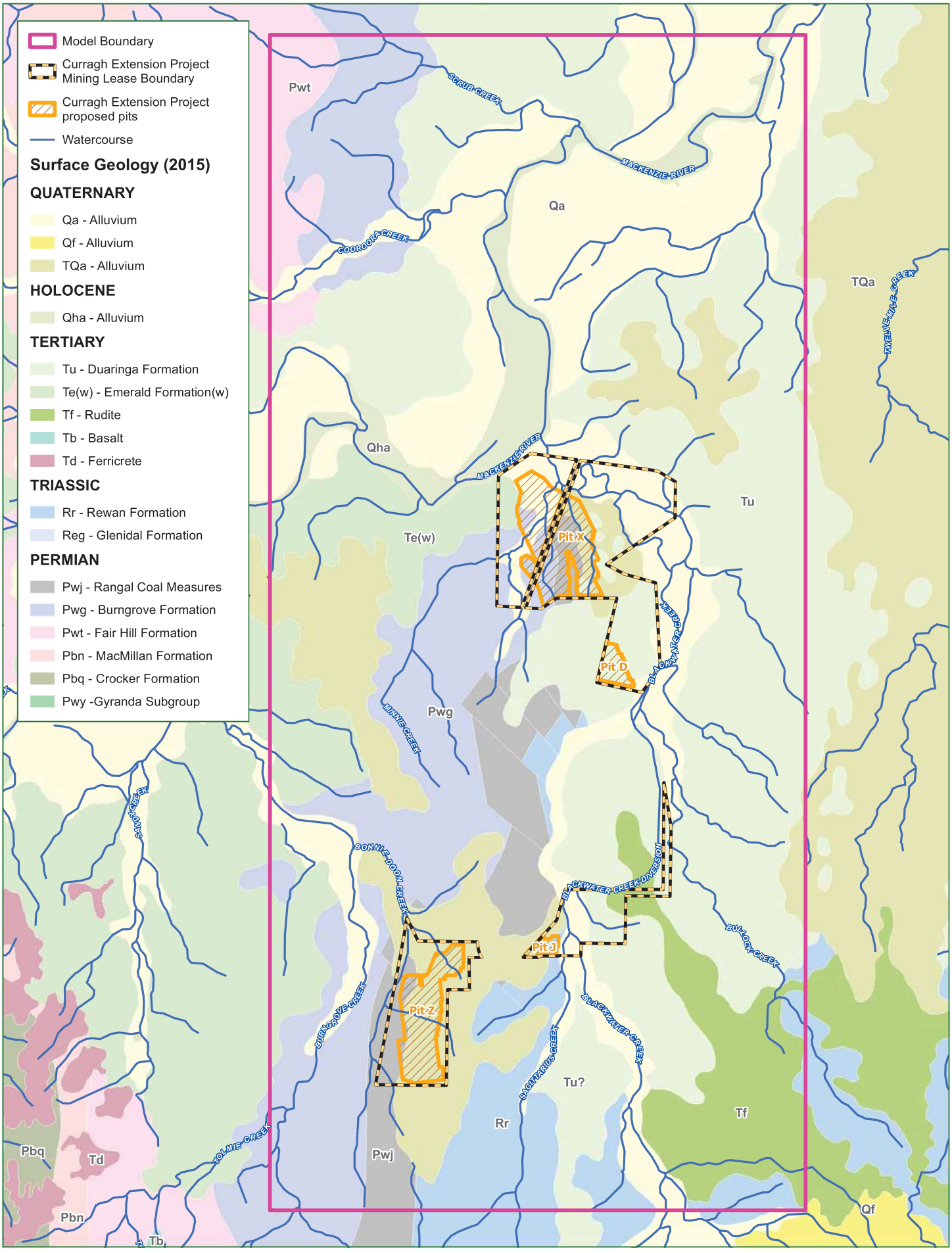
Table 2.2 Stratigraphy

Age	Group	Stratigraphic unit	Lithology
Quaternary and Tertiary		Alluvium	Alluvial sand, silt and gravel.
Tertiary		Duaringa Formation/Emerald Formation	Mudstone, sandstone, conglomerate, siltstone, oil shale, lignite and basalt. Sediments are weakly consolidated in parts.
Triassic	Mimosa Group	Rewan Formation	Mudstone, interbeds of lithic sandstone.
Late Permian	Blackwater Group	Rangal Coal Measures (including the Bandanna Formation and Baralaba Coal Measures)	Carbonaceous mudstone, siltstone, coal, feldspathic and lithic sandstone, calcareous in places, tuff.
		Burngrove Formation	Carbonaceous mudstone, thinly interbedded mudstone and fine lithic sandstone, siliceous siltstone, calcareous lithic and feldspathic sandstone.
		Fair Hill Formation	Lithic and feldspathic labile sandstone, quartzose sublabile sandstone, siltstone, mudstone, calcareous and tuffaceous sandstone, volcanic conglomerate, carbonaceous mudstone, coal.
Permian	Back Creek Group	Macmillan Formation	Interbedded mudstone and sandstone, prominent dark grey basal unit.

2.4.2.1 Quaternary and Tertiary alluvium

Alluvium covers most of the mineable resource in the Curragh Extension Project area.

In the proposed Pit X area, the alluvium is floodplain sediments associated with Mackenzie River and Blackwater Creek. A review of lithology logs from the exploration drilling program indicates the alluvium in the proposed Pit X area is typically less than 12 m thick and predominantly comprised of clay with occasional channel sand and gravel lenses at depth.



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Scale 1:135,073

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Projection: Transverse Mercator
Coordinate System: AGD 1984 AMG Zone 55

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Data Source:
Geology from GSQ (2015)
Watercourse from DNRM (2016)
Mining data from WSP/PB (2016)

Groundwater impact assessment
Curragh Extension Project
Figure 2.7
Surface geology

MXD Number: 2172652H_GIS_SW_F027_A3
Date: 15/06/2016
Author: GL
Approved by: LR

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Alluvium in the vicinity of proposed Pit J extension and proposed Pit Z is generally thin (generally 2 m; but can be up to 4 m) and comprised of clay and silt. Alluvium occurs in the south east corner of proposed Pit D extension and is typically less than 2 m (but can be up to 10 m) and comprised of clay and sand.

Alluvium occurs extensively at Curragh North and neighbouring mine Mackenzie South. Alluvium in this area is floodplain sediments associated with Mackenzie River. The sediments display an overall fining upwards sequence and significant lateral variability typical of fluvial channel fill depositional environments (Parsons Brinckerhoff 2003).

The average thickness of alluvial sediments in the Curragh North and Mackenzie South areas is 18 to 20 m (Parsons Brinckerhoff 2003; AGE 2006). Drilling data indicates the alluvium may be up to 35 m thick and the base of the alluvium is deepest close to Mackenzie River (AGE 2006).

The composition and thickness of alluvium in the study area is further discussed in Section 4.1.1.

2.4.2.1 Tertiary sediments

Tertiary aged sediments of the Duaringa Formation occur in the proposed Pit X and Pit D extension areas and outcrop extensively in the north, east and south of the study area. In the north of the study area the Tertiary sediments have been eroded by the anastomosing channel of the Mackenzie River (Parsons Brinckerhoff 2003).

Tertiary aged sediments of the Emerald Formation occur in the western section of the proposed Pit X area and outcrop in the west of the study area.

The Tertiary sequence consists of interbedded stiff to hard clay rich sands, gravels and thick beds of ferruginous clays of medium to high plasticity. The sand beds of the Tertiary strata are similar to those of the Quaternary sequence (Minserve, 1998, cited in Parsons Brinckerhoff 2003).

The Tertiary deposits are remnant channel (fluvial) or valley fill (colluvial), which are partially cemented. The sequence unconformably overlies Permian coal measures with an indistinct boundary due to the clay rich and ferruginous composition of both horizons caused by the in-situ weathering of these dominantly fluvial sediments (Minserve 1998, cited in Parsons Brinckerhoff 2003).

2.4.2.2 Triassic sediments

Sediments of the Rewan Formation occur in the proposed Pit J extension area and outcrop in the south of the study area near the Minyango project.

The Triassic sediments of the Rewan Formation comprise thinly interbedded mudstones, lithic sandstones and siltstones deposited in shallow, freshwater environs. Drilling in the Minyango project area found the thickness of Rewan Formation to be up to 350 m and the depth of weathering to be between 30 and 70 m (AGE 2013a).

2.4.2.3 Permian sediments

The Rangal Coal Measures is the uppermost sequence in the Blackwater Group and is the most commercially mined coal measure sequence in the Bowen Basin. The Rangal Coal Measures comprise light grey, predominantly fine grained to occasionally medium grained lithic sandstone; grey to dark grey siltstone and mudstone, with sporadic very strong siderite bands; and carbonaceous mudstone and coal.

The Rangal Coal Measures contain seams of high quality PCI coal, high quality medium-to-low ash coals suitable for prime coking coal, anthracite and semi-anthracite, and high energy thermal coals. The Cancer, Aries, Castor, Pollux, Orion and Pisces seams are present within the Curragh Extension Project area. The

seams generally dip to the east at less than 3°, with steeper dips occurring locally in fault and deformation zones. The Rangal Coal Measures outcrop in the proposed Pit X and Pit Z areas and subcrop in the proposed Pit Z and Curragh North areas. The Rangal Coal Measures also subcrop to the east of the Jellinbah Fault where Jellinbah Mine is located.

The upper boundary of the Burngrove Formation is interpreted to be the top of the Yarrabee Tuff Bed, which is a distinctive marker horizon. The tuff bed lies between the target Pisces seam and the Pisces lower seam. The strata underlying the Yarrabee Tuff Bed and the Pisces lower seam in the upper part of the Burngrove Formation comprise dark grey to grey mudstones grading to siltstones. The Burngrove Formation outcrops in the proposed Pit X area and to the west of Curragh Mine. The Burngrove Formation hosts the Scorpio seam, which is the target coal seam at Washpool Mine.

The Fair Hill Formation underlies the Burngrove Formation and outcrops in the north west of the study area. The formation comprises lithic sandstone, conglomerate, mudstone, carbonaceous shale, coal, tuff and tuffaceous (cherty) mudstone and includes the Fort Cooper Coal Measures.

The upper Permian sediments are weathered. The depth of weathering in the study area is approximately 14 metres below ground level (mbgl), except where Quaternary erosion and deposition has resulted in the replacement of Permian sediments by Quaternary alluvium. Where this occurs deeper weathering up to 35 mbgl is noted. The degree of weathering varies from high to slight. Highly weathered rocks are reduced to soil strength and do not retain any rock structure. Slightly weathered rocks are discoloured only along joints and fractures (WCPL 2015a).

2.4.3 Structural geology

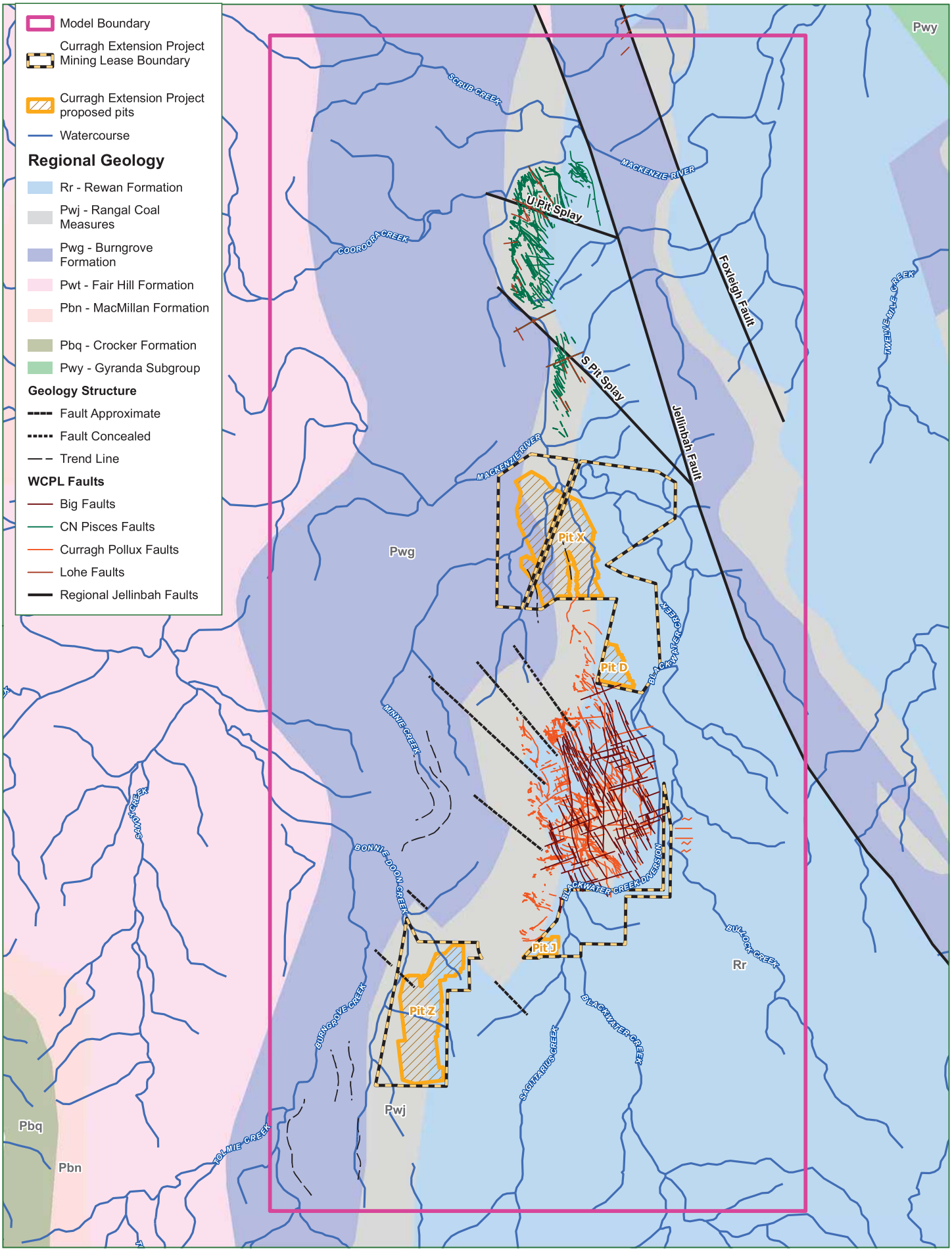
The structural geology of the study area is shown in Figure 2.8.

The study area is located within gently folded and faulted sedimentary sequences of the Bowen Basin. The study area lies on the eastern limb of the Comet Ridge, adjacent to the Folded Zone within the Bowen Basin. This ridge was formed over an existing basement platform, creating a regional anticlinal structure with low amplitude and gentle folds (Ishaq 1985, cited in Parsons Brinckerhoff 2003). The Jellinbah Thrust Belt, a north west trending zone of thrust faults with throws (slip displacement) in the order of 100 to 500 m (URS 2012) occurs approximately 75 km to the west of the Project. Individual faults are typically 10 to 80 km long.

The Jellinbah Fault is located approximately 4 km to the east of proposed Pit X and approximately 1 km to the east of the current Curragh North pit workings. The fault has a north west to south east orientation and is the major fault structure in the Curragh Mine region. The fault has an approximate vertical displacement of 120 m. The throw of this fault allows the Jellinbah Coal operations which target the Rangal Coal Measures to the west to be mined.

The Permian sediments in the Curragh Extension Project area have been affected by thrust faulting in a similar manner to those at Curragh Mine. The thrusting is low angle from the north east and results in seam displacements up to 20 m vertically. Fault deformation has resulted in seam thinning, seam repetitions and absenting occurring throughout the Curragh Extension Project areas. There was common evidence of faulting observed in the cuttings and core samples observed during the drilling program. The regional dip is approximately 3° to the east so where bedding dips are observed at greater than 10°, structural disturbance is inferred.

Only minor instances of intrusive material have been intercepted in drill holes or mined during production at Curragh Mine.



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0 0.5 1 2 3 4 km

Scale 1:135,000
Scale correct when printed at A3 Portrait
Projection: Transverse Mercator
Coordinate System: AGD 1984 AMG Zone 55

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Data Source:
Geology from GSQ (2015)
Faults from WCPL (2016)
Watercourse from DNRM (2016)
All other data from WSP/PB (2016)

Groundwater impact assessment
Curragh Extension Project
Figure 2.8
Structural geology
MXD Number: 2172652H_GIS_SW_F028_A4
Date: 15/06/2016
Author: VD
Approved by: LR
\\APBNEFIL03\proj\W\wesfarmers_resources\2172652H_Curragh_Extension_Phase_2\10_GIS\Projects\Maps\SufaceWater_Modeling\2172652H_GIS_SW_F028_A4.mxd

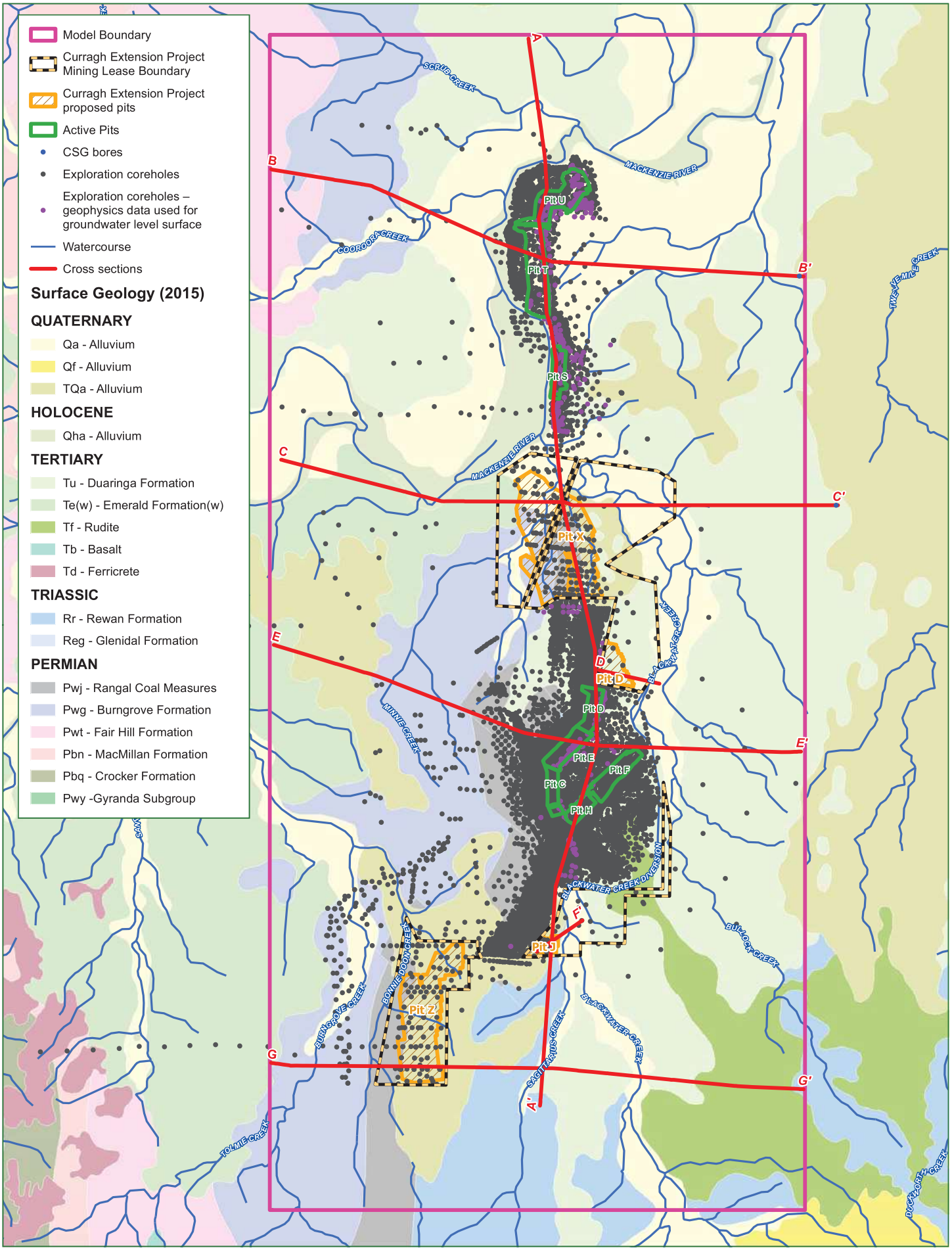
2.4.4 Cross-sections

Conceptual cross-sections have been prepared for the study area to aid in conceptualising the hydrogeology and developing the numerical groundwater model. The cross-sections show the geology of the study area and the progression of mining at August 2015.

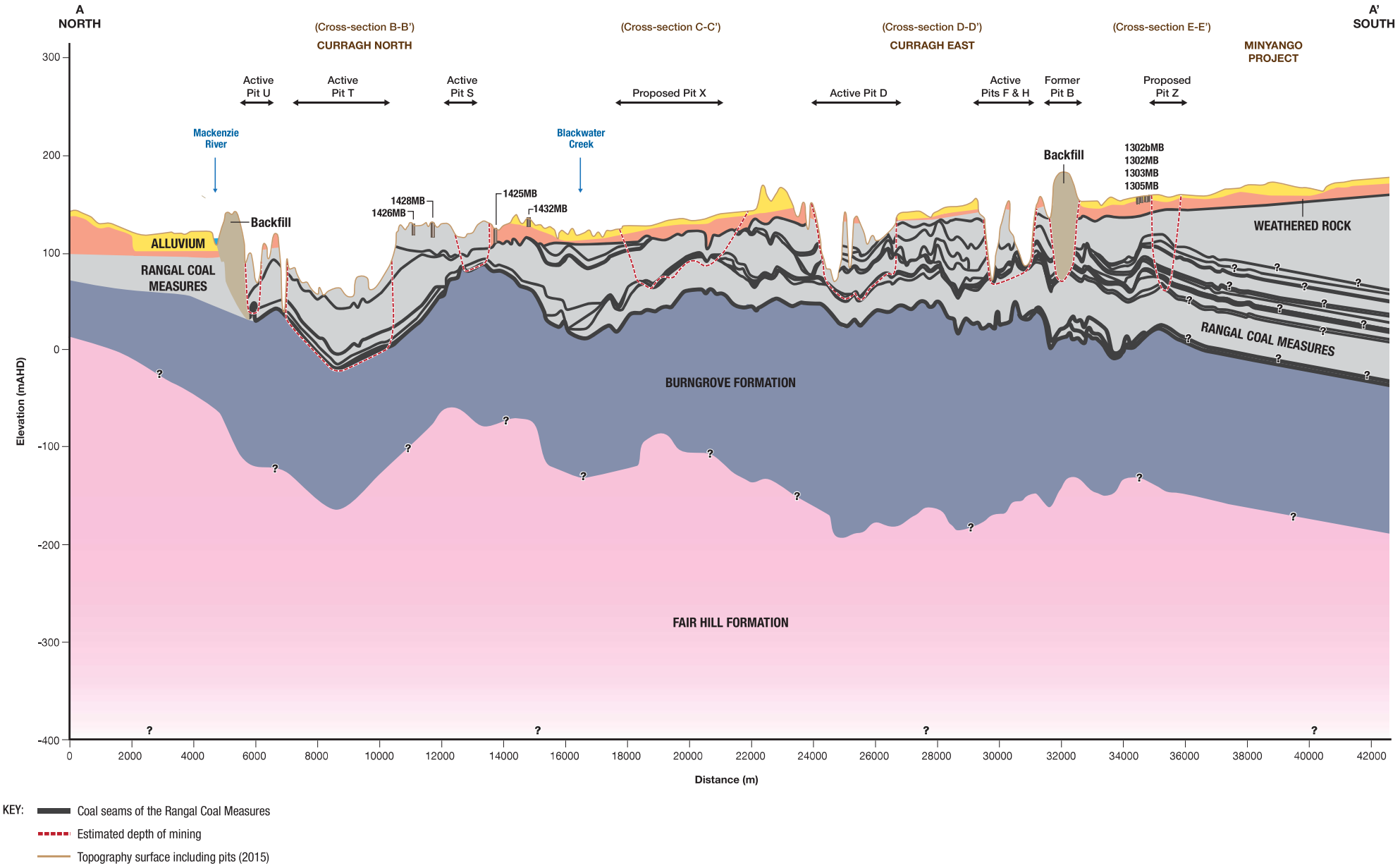
The locations of the cross-sections are shown on Figure 2.9 and include:

- one north-south long section A-A' (Figure 2.10)
- four west-east long sections B-B', C-C', E-E' and G-G' (Figures 2.11, 2.12, 2.14 and 2.16)
- two short sections through the proposed Pit D and Pit J extension areas (Figures 2.13 and 2.15).

The cross sections have been developed using LiDAR of active pit areas from August 2015 and drill hole data (Figure 2.9) and grid files of geological layers exported from the Curragh Mine VULCAN databases. Exploration data for neighbouring mines from the Queensland Globe has also been used (Figure 2.9).

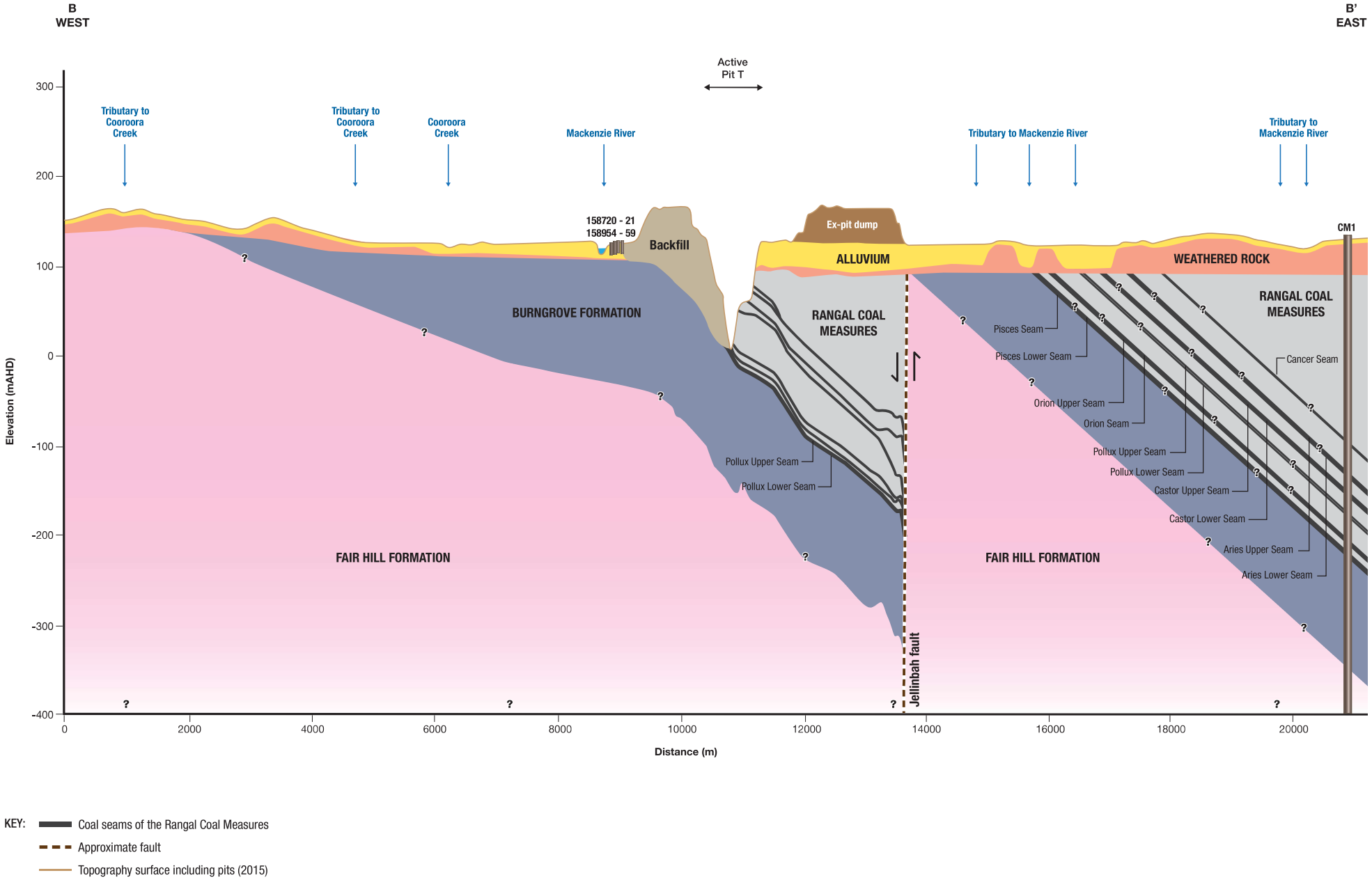


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\\APBNEFIL03\proj\W\wesfarmers_resources\2172652H_Curragh_Extension_Phase_2\10_GIS\Projects\Maps\SufaceWater_Modeling\2172652H_GIS_SW_F029_A2.mxd



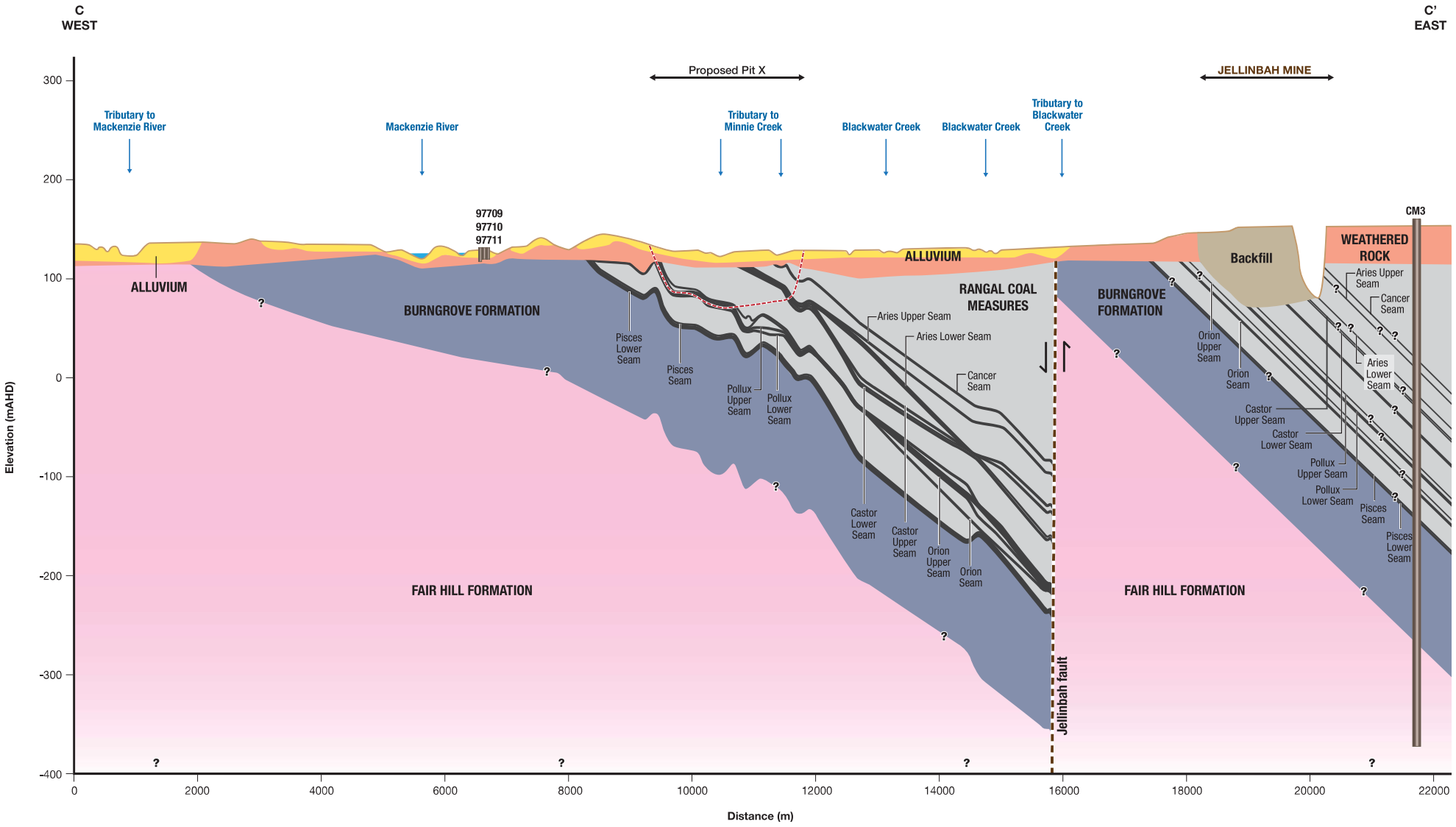
Note: Rangal Coal Measures and Burngrove Formation are faulted, but faults are not shown.

Figure 2.10 Conceptual cross-section A-A' (N-S)



Note: Rangal Coal Measures and Burngrove Formation are faulted, but faults other than Jellinbah Fault are not shown.

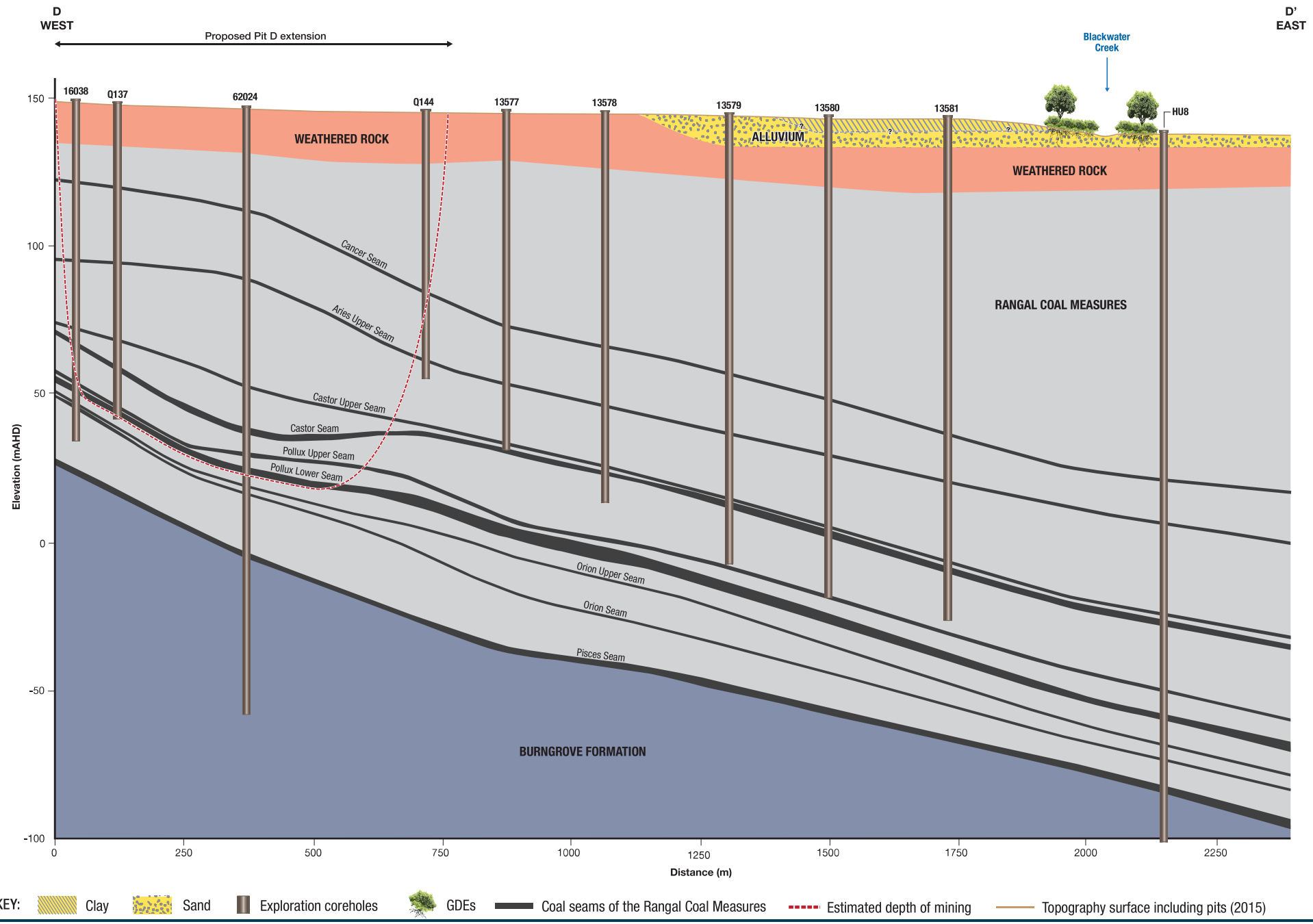
Figure 2.11 Conceptual cross-section B-B' (Pit T W-E)



KEY:
- Coal seams of the Rangal Coal Measures
- Estimated depth of mining
- Approximate fault
- Topography surface including pits (2015)

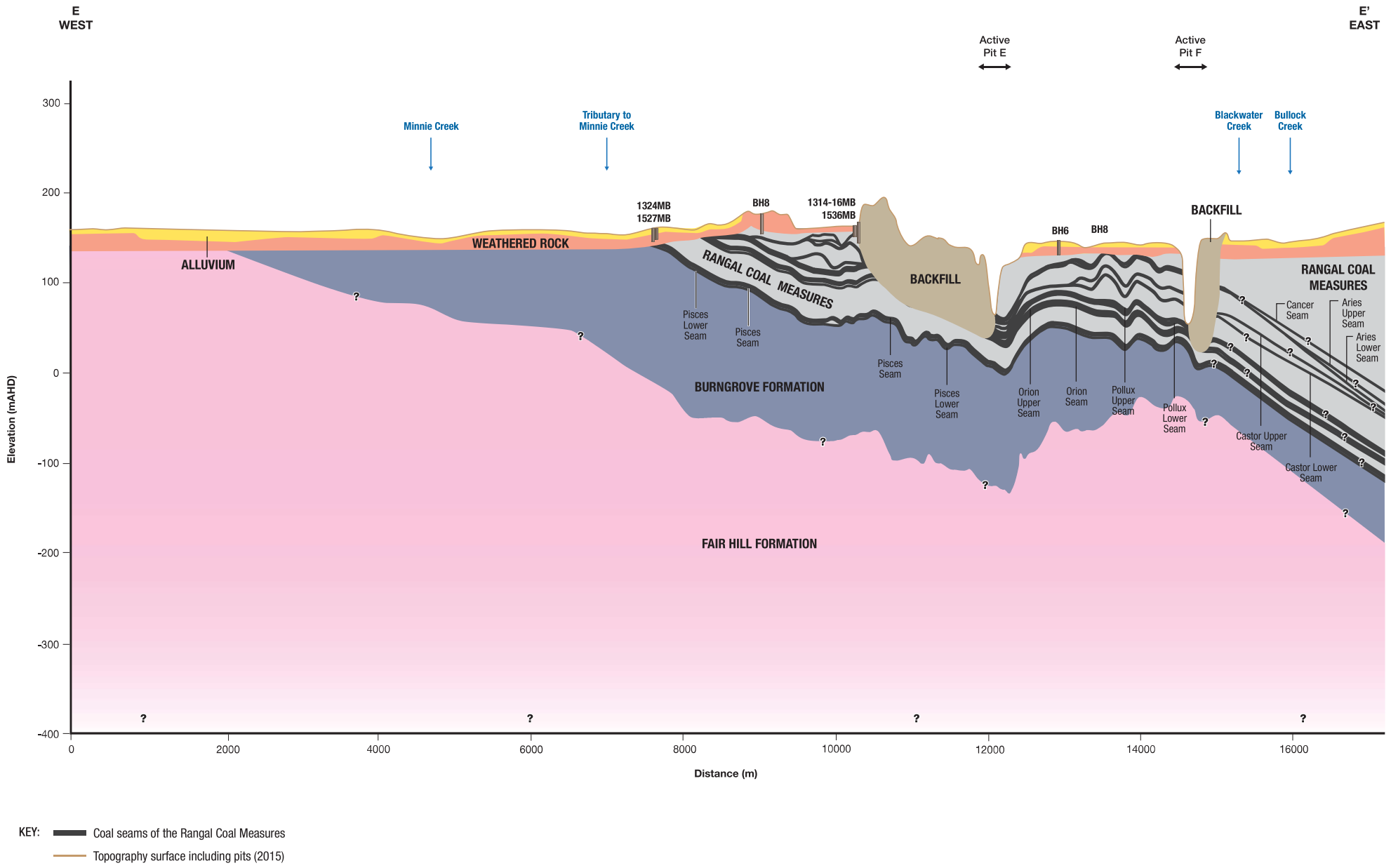
Note: Rangal Coal Measures and Burngrove Formation are faulted, but faults other than Jellinbah Fault are not shown.

Figure 2.12 Conceptual cross-section C-C' (Pit X W-E)



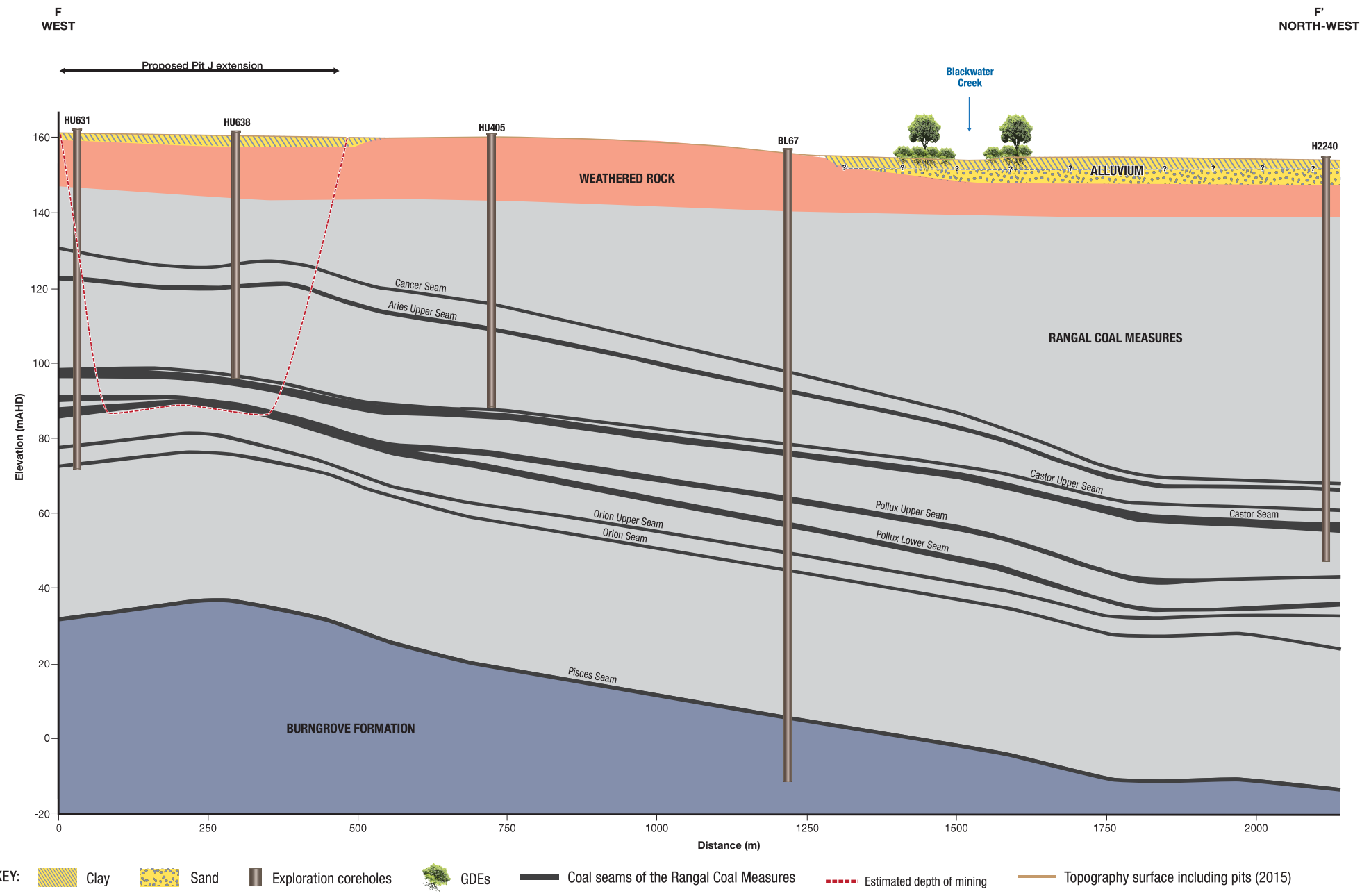
Note: Rangal Coal Measures and Burngrove Formation are faulted, but faults are not shown.

Figure 2.13 Conceptual cross-section D-D' (Pit D extension W-E)



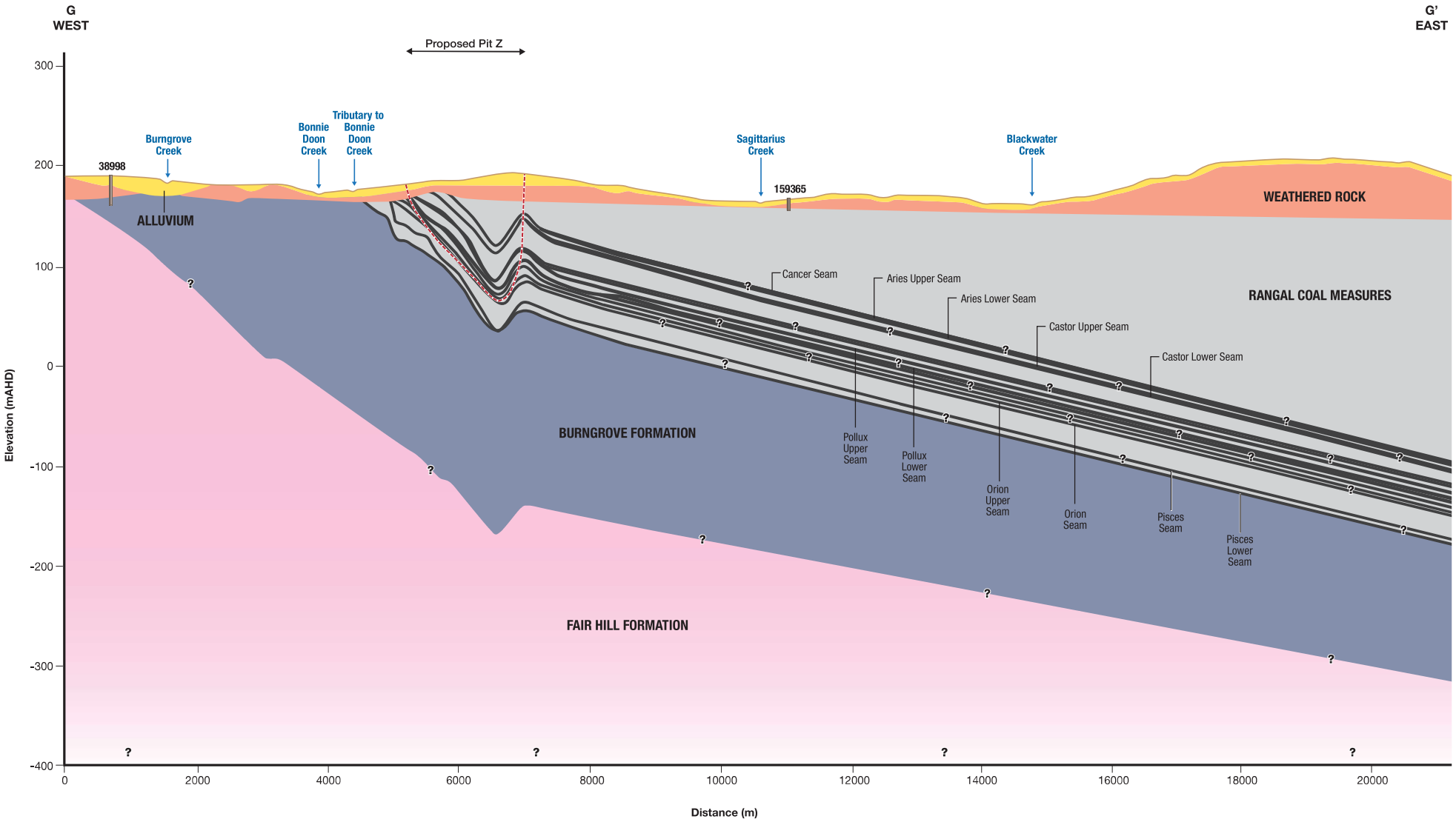
Note: Rangal Coal Measures and Burngrove Formation are faulted, but faults are not shown.

Figure 2.14 Conceptual cross-section E-E' (Pits E and F W-E)



Note: Rangal Coal Measures and Burngrove Formation are faulted, but faults are not shown.

Figure 2.15 Conceptual cross-section F-F' (Pit J extension W-E)



KEY:
- Coal seams of the Rangal Coal Measures
- Estimated depth of mining
- Topography surface including pits (2015)

Note: Rangal Coal Measures and Burngrove Formation are faulted, but faults are not shown.

Figure 2.16 Conceptual cross-section G-G' (Pit Z W-E)

3. Groundwater monitoring data

3.1 Groundwater monitoring

Condition C53 of Curragh Mine's EA EPML00643713 requires implementation of a groundwater monitoring program (GMP) to detect significant changes to groundwater levels and groundwater quality values, consistent with the current suitability of the groundwater for domestic and agricultural use, due to activities that are part of the mine. WCPL recently commissioned WSP | Parsons Brinckerhoff to prepare a GMP for Curragh Mine. The GMP provides details of:

- the groundwater monitoring network
- the frequency of groundwater monitoring
- parameters for groundwater quality assessment
- groundwater monitoring procedures
- a methodology for development of trigger values for key parameters which will trigger the need for further investigation and implementation of management responses.

The GMP does not currently include the Curragh Extension Project area. Groundwater monitoring requirements for the Curragh Extension Project area will be included in the GMP following Project approval. Details of the GMP for Curragh Mine are provided below.

3.1.1 Groundwater monitoring bores

A dedicated groundwater monitoring network has been progressively installed at Curragh Mine since the 1990s. The bore network comprises 46 groundwater monitoring bores located within the Curragh, Curragh, Curragh East and Curragh North project areas and is shown on Figure 3.1. This network has recently been rationalised as part of development of the GMP. Details of the monitoring bores, including bore construction, target formation and date of installation, are provided in Table 3.1.

The groundwater monitoring bores at Curragh Mine target the alluvium, Duaringa Formation, Rewan Formation, Rangal Coal Measures and Burngrove Formation, with emphasis on water bearing units. Nested monitoring bores have been installed at some locations to provide an assessment of vertical hydraulic gradients and connectivity.

The groundwater monitoring network at Curragh Mine has been designed to improve conceptual understanding of the hydrogeological conditions in the area surrounding Curragh Mine and identify impacts associated within mining operations. Monitoring bore locations have been chosen to:

- provide spatial coverage across the area
- investigate a range of hydrogeological environments
- identify impacts to sensitive features including potential groundwater dependent ecosystems (GDEs) and areas of potential surface water-groundwater interaction
- detect changes in groundwater conditions due to seepage from site infrastructure, including old and new tailings storage facilities (TSFs), landfills, fuel farms and water storage dams
- establish a baseline of undisturbed groundwater conditions so that trigger levels representative of the local conditions and able to detect impacts associated with mining can be developed.

The GMP identifies groundwater monitoring bores as:

- compliance bores, monitored to assess potential impacts on sensitive receptors due to mining activities
- reference bores, monitored to establish a baseline of undisturbed groundwater conditions so that trigger levels representative of the local conditions and able to detect impacts associated with mining can be developed
- observation bores, monitored to improve conceptual understanding of the hydrogeological conditions in the area surrounding the Curragh Mine project.

There are currently no groundwater monitoring bores in the Curragh Extension Project area. Groundwater levels in the Project area have been interpreted from downhole density logs taken during exploration drilling. As Curragh Mine is immediately adjacent to the Curragh Extension Project area and has a comparable hydrogeological environment, the groundwater monitoring network at Curragh Mine has been used to conceptualise groundwater systems in the Curragh Extension Project area and assess potential impacts. WCPL is progressively adding to the groundwater monitoring network and plan to install groundwater monitoring bores in the Curragh Extension Project area in the near future to allow establishment of baseline conditions prior to commencement of mining. Details of the proposed monitoring bore network for the Project are provided in Section 9.2.

3.1.2 Groundwater monitoring

Groundwater monitoring at Curragh Mine is undertaken in accordance with:

- the Curragh Mine Groundwater Monitoring Procedure (EMS PROC 2.4) (WCPL 2015b)
- Australian Standard AS 5667:1998 – Water Quality Sampling
- Queensland government Monitoring and Sampling Manual (DEHP 2009 Version 2 September 2010 – July 2013 format edits).

The monitoring frequency and sampling locations are in accordance with the GMP (Parsons Brinckerhoff 2015a) and the Curragh Mine Environmental Monitoring Management Procedure (EMS PROC 0.1) (WCPL 2015c).

Groundwater level monitoring is currently undertaken every two months at reference bores, and every six months at compliance bores. Historically, groundwater levels have been measured less frequently. Groundwater levels are measured from the top of the bore casing with a manual water level dipper.

Groundwater samples are analysed by NATA certified laboratory Australian Laboratory Service (ALS) Environmental Pty Ltd. The groundwater quality parameters monitored have been selected to protect environmental values and beneficial uses of groundwater from potentially contaminating activities at Curragh Mine. The parameters are in accordance with Table C13 of the EA and include:

- physical parameters
- major ions
- nutrients
- metals
- hydrocarbons.

The Curragh Mine EMS Procedures 2.4 and 0.1 detail the procedures for groundwater level and quality data analysis and record keeping.

Table 3.1 Groundwater monitoring bores

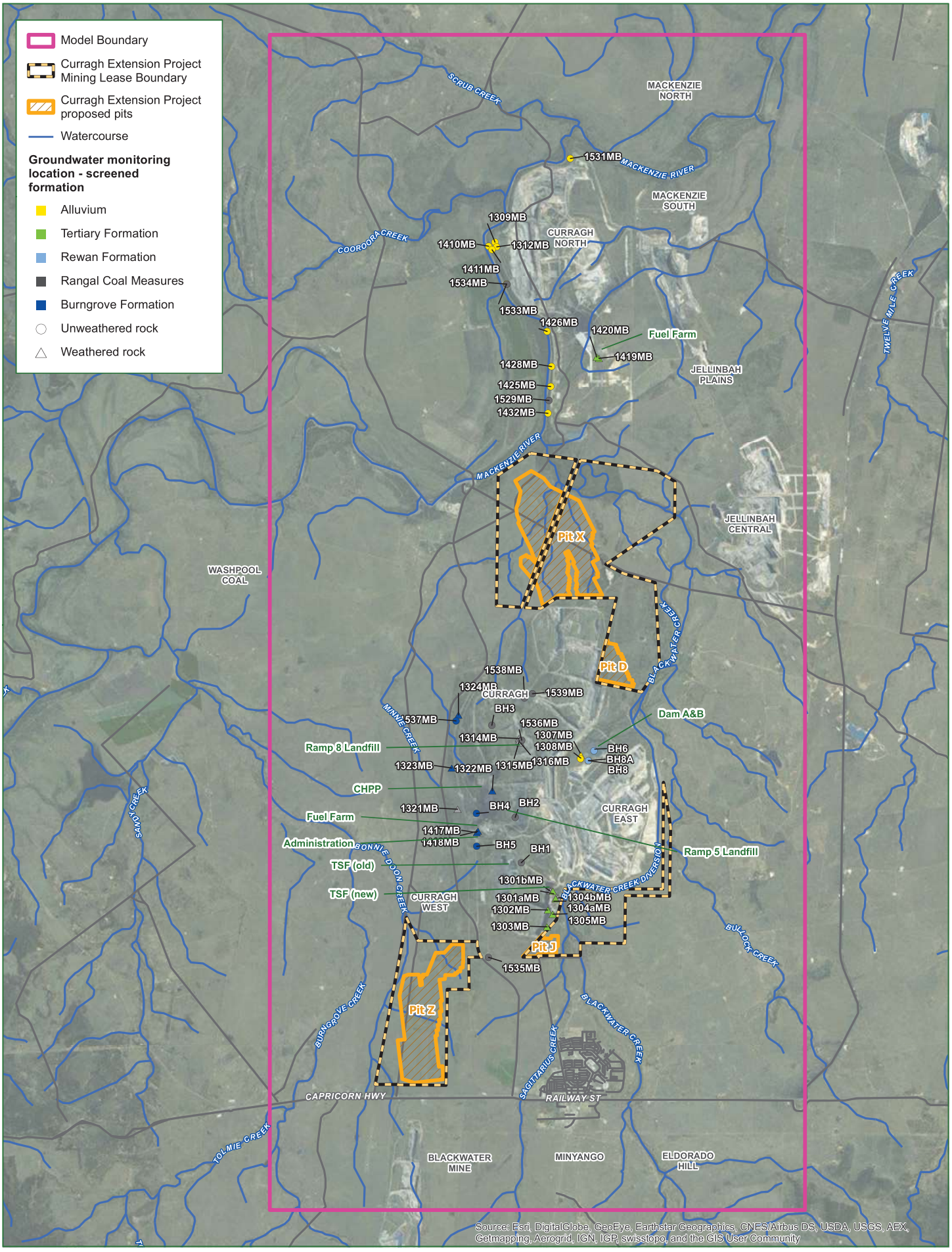
Bore ID	Site ID	Easting*	Northing*	Ground level (mAHD)	Top of casing (mAHD)	Total depth (mbgl)	Screened interval (mbgl)	Target formation	Date installed	Location	Type of bore in GMP
BH1	BH1	689978	7399250	157.70	158.23	18.0	n/a	RCM	n/a	Crib hut 3	Compliance
BH2	BH2	689746	7400993	169.821	169.92	70.0	n/a	RCM	n/a	Ramp 5 Landfill	Compliance
BH3	BH3	688846	7404539	176.517	177.11	43.0	n/a	RCM	n/a	Ramp 8 Landfill	Compliance
BH4	BH4	688260	7401147	170.19	170.66	33.0	n/a	Burngrove Fm	n/a	CHPP Landfill	Compliance
BH5	BH5	688268	7399885	176.607	177.24	62.0	n/a	Burngrove Fm	n/a	Admin Building	Observation
BH6	BH6	692902	7403743	141.978	142.21	30.0	n/a	Rewan Fm	n/a	Dam A and B	Observation
BH8	BH8	692678	7403357	142.90	143.36	15.0	n/a	Rewan Fm	n/a	Dam A	Observation
BH8A	BH8A	692678	7403356	142.90	143.06	7.1	n/a	Alluvium	n/a	Dam A	Observation
1301aMB	MB1A	691313	7398339	151.83	152.65*	11.0	4–11	Weathered rock (Tertiary)	6/07/2013	New TSF (formally Pit A Ramp 2)	Observation
1301bMB	MB1B	691308	7398335	151.69	152.49*	18.0	14–18	Weathered rock (RCM)	6/07/2013	New TSF (formally Pit A Ramp 2)	Observation
1302MB	MB2	691118	7397611	153.64	154.46	6.0	3–6	Weathered rock (Tertiary)	5/07/2013	New TSF (formally Pit A Ramp 2)	Observation
1303MB	MB3	691086	7396966	156.90	157.67	6.0	3–6	Weathered rock (Tertiary)	5/07/2013	New TSF (formally Pit A Ramp 2)	Observation
1304aMB	MB4A	691481	7398090	153.35	154.33	9.0	6–9	Weathered rock (Tertiary)	4/07/2013	New TSF (formally Pit A Ramp 2)	Compliance
1304bMB	MB4B	691481	7398084	153.33	154.21	17.0	14–17	Weathered rock (RCM)	2/07/2013	New TSF (formally Pit A Ramp 2)	Observation

Bore ID	Site ID	Easting*	Northing*	Ground level (mAHD)	Top of casing (mAHD)	Total depth (mbgl)	Screened interval (mbgl)	Target formation	Date installed	Location	Type of bore in GMP
1305MB	MB5	691303	7397452	156.30	157.08	6.6	3.6–6.6	Weathered rock (Tertiary)	4/07/2013	New TSF (formally Pit A Ramp 2)	Observation
1307MB	MB6	692378	7403433	143.16	143.99	7.0	4–7	Alluvium	8/07/2013	Dam A	Observation
1308MB	MB6A	692387	7403452	143.30	144.12	14.0	10–14	Alluvium/weathered rock (Tertiary Duaringa Fm)	9/07/2013	Dam A	Observation
1309MB	MB7	689082	7423302	124.43	125.18*	18.0	12–18	Alluvium	10/07/2013	CN3 (Between Pit and Mackenzie River)	Compliance
1312MB	MB10	689148	7423118	125.93	126.76*	17.0	11–17	Alluvium	11/07/2013	CN3 (Between Pit and Mackenzie River)	Observation
1314MB	MB11A	690010	7404210	146.48	147.25	5.0	2–5	Weathered rock (RCM)	12/07/2013	Landfill	Observation
1315MB	MB11B	690027	7404125	147.73	148.43	8.0	5–8	Weathered rock (RCM)	13/07/2013	Landfill	Observation
1316MB	MB11C	690067	7404049	148.03	148.75	9.0	6–9	Weathered rock (RCM)	12/07/2013	Landfill	Observation
1321MB	NMB05	687647	7401486	172.42	173.22	25.0	2–25	Weathered rock (RCM)	24/07/2013	Upgradient of industrial/ process area	Observation
1322MB	NMB04	688976	7402204	162.69	163.56*	25.0	2–25	Weathered rock (Burngrove Fm)	26/07/2013	Downgradient of industrial/ process area	Observation
1323MB	NMB08	687417	7403078	164.44	165.24*	25.0	16–25	Weathered rock (Burngrove Fm)	25/07/2013	Upgradient mining ops	Reference

Bore ID	Site ID	Easting*	Northing*	Ground level (mAHD)	Top of casing (mAHD)	Total depth (mbgl)	Screened interval (mbgl)	Target formation	Date installed	Location	Type of bore in GMP
1324MB	NMB07	687673	7405113	158.60	159.46	25.0	2–25	Weathered rock (Burngrove Fm)	25/07/2013	Upgradient mining ops	Observation
1410MB	MB8	688842	7423144	126.05	126.69*	18.0	10–18	Alluvium	27/11/2014	CN3	Compliance
1411MB	MB9	688974	7423011	128.23	128.84	20.0	9–20	Alluvium	21/11/2014	CN3 (strong hydrocarbon/chemical smell in topsoil)	Compliance
1417MB	FF1 Curragh	688376	7400592	175.56	176.06*	15.0	1.2–15	Weathered rock (Burngrove Fm)	18/11/2014	Curragh fuel farm	Reference
1418MB	FF2 Curragh	688428	7400647	175.56	176.06	21.0	1.2–16	Weathered rock (Burngrove Fm)	18/11/2014	Curragh fuel farm (backfilled 16–21 below 3 m clay layer)	Compliance
1419MB	FF3 CN	693083	7418830	137.96	138.46	15.0	1.2–15	Weathered rock (Tertiary Duaringa Fm)	19/11/2014	Curragh North Fuel Farm	Reference
1420MB	FF4 CN	693004	7418881	138.43	138.43	15.0	1.2–15	Weathered rock (Tertiary Duaringa Fm)	20/11/2014	Curragh North Fuel Farm	Compliance
1425MB	SMB1	691229	7417747	125.12	n/a	21.0	16–19	Alluvium	24/11/2014	S Pit west – below levee south	
1426MB	SMB2	691085	7419864	128.79	129.29*	26.0	12–26	Alluvium	25/11/2014	S Pit west – below levee north	Compliance
1428MB	SMB4	691266	7418518	127.90	127.90	26.0	13–26	Alluvium	26/11/2014	S Pit west – below levee central (palaeochannel/ failure)	Observation

Bore ID	Site ID	Easting*	Northing*	Ground level (mAHD)	Top of casing (mAHD)	Total depth (mbgl)	Screened interval (mbgl)	Target formation	Date installed	Location	Type of bore in GMP
1430MB^	TMB1	691169	7422399	127.56	n/a	27.0	22–27	Alluvium	21/11/2014	T Pit – East (palaeochannel)	Observation
1432MB	SMB6	691123	7416724	134.75	n/a	12.0	2–5	Alluvium	25/11/2014	S Pit Tertiary Ridge	Observation
1529MB	PMB07	691161	7417212	123.81	n/a	39.0	33–39	RCM	17/07/2015	S Pit west – below levee south	Compliance
1531MB	PMB01	691987	7426518	125.53	126.35	27.0	21–27	Alluvium	16/07/2015	U Pit Extension – North near levee	Observation
1533MB	PMB03	689529	7421689	132.36	133.16	27.0	21–27	Alluvium	15/07/2015	T Pit – West levee	Compliance
1534MB	PMB04	689540	7421687	132.52	132.52	33.0	27–33	RCM	13/07/2015	T Pit – West levee	Reference
1535MB	PMB05	688828	7395788	180.241	n/a	45.5	39.5–45.5	RCM	25/06/2015	J Pit substation	Reference
1536MB	PMB08	690116	7404141	148.504	149.27	41.5	35.5–41.5	RCM	2/07/2015	Landfill – east	Compliance
1537MB	PMB09	687589	7404885	157.71	157.71	36.5	30.5–36.5	Burngrove Fm (coal seam)	27/06/2015	SAR	Reference
1538MB	PMB06	690217	7405768	153.18	n/a	79.0	73–79	RCM	29/06/2015	Ramp 10/11	Reference
1539MB	PMB06A	690523	7405931	152.20	152.20	59.0	53–59	RCM	3/07/2015	Ramp 10/11 – second site	Observation

mAHD metres Australian Height Datum
mbgl metres below ground level
RCM Rangal Coal Measures
Fm Formation
n/a not available
* Alternative stickup recorded for May 2015 monitoring round
^ Destroyed June 2015



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Data Source:
Roads and watercourse from DNRM (2016)
All other from WSP/PB unless otherwise stated (2016)

Groundwater impact assessment
Curragh Extension Project
Figure 3.1
Groundwater monitoring network

MXD Number: 2172652H_GIS_SW_F024_A2
Date: 15/06/2016
Author: VD
Approved by: LR

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3.2 Surface water monitoring

Surface water monitoring data from Curragh Mine and two stream gauging stations on Mackenzie River has been used to conceptualise surface water-groundwater interaction in the Project area, assess risks to GDEs and assess risks to groundwater quality associated with water storage in onsite dams and residual voids. Curragh Mine is immediately adjacent to Curragh Extension Project area and has a comparable surface water environment.

The EA for Curragh Mine requires monitoring to assess potential impacts associated with mine affected water releases. This includes monitoring of stream flow and surface water quality in receiving streams and onsite water storages and pits.

3.2.1 Stream gauging

Stream flow is monitored at three gauge stations in the vicinity of the Project area:

- two stations on Mackenzie River, one upstream of the Project area at Bedford Weir (130111A) and one downstream of the Project area at Bingegang Weir (130106A)
- one station on the Blackwater Creek diversion (Blackwater Creek gauging station).

Stream water levels are recorded every 15 minutes.

The locations of the stream flow gauges are shown on Figure 3.2. Details of the stream gauges are provided in Table 3.2.

Table 3.2 Stream gauges

Stream gauge ID	Location	Easting*	Northing*	Zero gauge elevation (mAHD)	Monitoring commenced	Monitoring end
130111A	Mackenzie River at Bedford Weir Tailwater	688214	7414081	110.536	27/06/1997	01/07/2002
130106A	Mackenzie River at Bingegang	708267	7446600	95.466	13/08/1971	Ongoing
Blackwater Creek gauging station	Blackwater Creek Diversion	695361	7400717	149.53	11/11/2014	Ongoing

mAHD – metres Australian Height Datum
* MGA 94, Zone 55

3.2.2 Surface water quality monitoring

Surface water quality is monitored in receiving streams in accordance with the EA and the Curragh Mine Receiving Environment Monitoring Program (EMS PROC 2.1) (WCPL 2014a).

Surface water quality monitoring of receiving streams is undertaken during releases and every two months.

The locations of the receiving environment monitoring locations are shown on Figure 3.2. Details of the receiving environment monitoring locations are provided in Table 3.3.

Table 3.3 Receiving environment surface water quality monitoring locations

Surface water quality monitoring location ID	Location	Easting*	Northing*
MP1	Blackwater Creek 0.54 km upstream of RP1	691628	7397782
MP4	Blackwater Creek ~14 km downstream of RP1	695764	7410231
MP6	Blackwater Creek crossing 1.85 km upstream of RP4 on Mackenzie River	691800	7413935
MP7	Mackenzie River downstream of Bedford Weir but upstream of Blackwater Creek confluence	690629	7415710
MP8	Mackenzie River 0.5 km downstream of the confluence with Blackwater Creek and 8.5 km upstream of RP3	691040	7416480
MP11	Mackenzie River ~8.5 km downstream of RP3	694557	7426048

* MGA 94, Zone 55

Surface water quality is monitored in onsite water storage dams and pits in accordance with the EA and the Curragh Mine EMS Water Management Plan (EM PLAN 2.0) (WCPL 2015d).

Surface water quality monitoring of onsite water storages and pits is undertaken during releases and every four months. Details of the onsite surface water monitoring locations are provided in Table 3.4.

Table 3.4 Onsite surface water quality monitoring locations

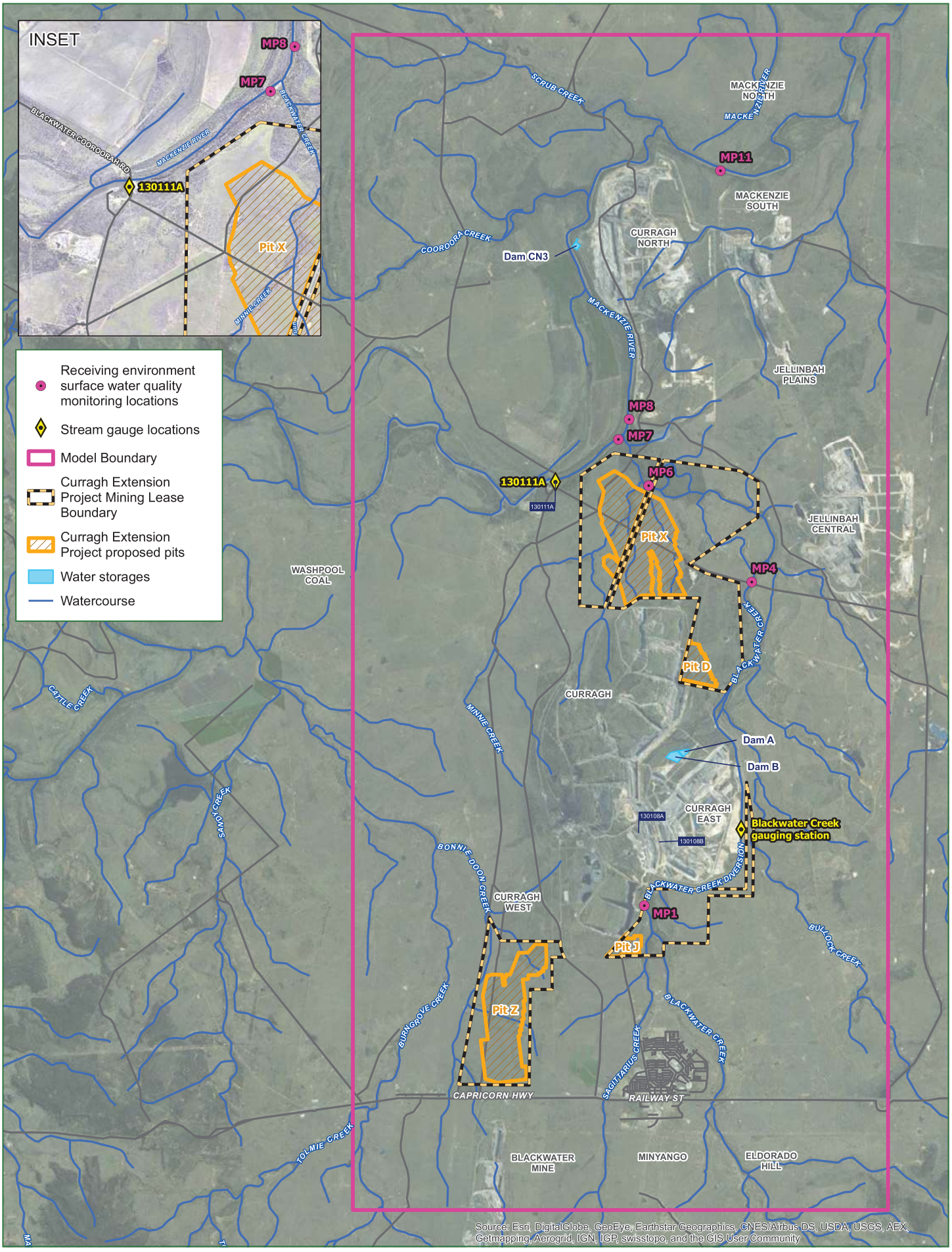
Surface water quality monitoring location ID	Location	Purpose	Easting*	Northing*
Dam A	Curragh East	Mine water storage	693178	7403675
Dam B	Curragh East	Mine water storage	692827	7403513
I Pit	Curragh	Residual void	689028	7423151
CN3	Curragh North near Mackenzie River	Mine water storage and release	693178	7403675
T Pit	Curragh North	Active pit	690615	7422321

* MGA 94, Zone 55

Surface water samples are analysed by NATA certified laboratory Australian Laboratory Service (ALS) Environmental Pty Ltd. The parameters analysed include:

- physical parameters
- major ions
- nutrients
- metals
- hydrocarbons.

The Curragh Mine EMS Groundwater Monitoring Procedure (EMS PROC 2.4) and Environmental Monitoring Management Procedure (EMS PROC 0.1) detail the procedures for surface water flow and quality data analysis and record keeping.



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Data Source:
Roads and watercourse from DNRM (2016)
All other data from WSP/PB unless otherwise stated

Groundwater impact assessment
Curragh Extension Project
Figure 3.2
Surface water monitoring network

MXD Number: 2172652H_GIS_SW_F025_A2
Date: 15/06/2016
Author: VD
Approved by: LR

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4. Hydrogeology

This section presents the conceptual hydrogeological model for the study area. The conceptual model is used as the basis for the numerical groundwater model discussed in Section 7.

4.1 Hydrostratigraphy

The hydrostratigraphy of the Curragh Extension Project area is summarised in Table 4.1. The main water bearing units in the study area are discussed in more detail in Sections 4.1.1 to 4.1.3.

Table 4.1 Hydrostratigraphy

Hydrostratigraphic unit	Occurrence	Aquifer characteristics
Quaternary and Tertiary alluvium	Alluvium is up to 12 m thick near proposed Pit X and comprises clay, sand and gravel units. Alluvium is relatively thin (~2 m thick) near proposed Pit D extension, proposed Pit J extension and proposed Pit Z. Alluvium predominantly comprises clay and silt at proposed Pit Z and sand and clay at proposed Pit D extension and Pit J extension.	Alluvium is dry in many areas. Unconfined water bearing sand and gravel units may occur at the base of the alluvium near proposed Pit X. Alluvium is unlikely to be significantly water bearing near proposed Pit D extension, Pit J extension and Pit Z.
Weathered rock	Occurs across the Project area at thicknesses between 5 and 15 m. Includes weathered residual rocks of the Duaringa and Emerald formations, Rewan Formation, Rangal Coal Measures and Burngrove Formation in areas of outcrop and underlying alluvium.	Variable permeability with water bearing zones in more permeable or fractured layers and low permeability zones where rock has weathered to clay.
Tertiary Duaringa and Emerald formations	Occurs in Curragh Central and Curragh Central Extended near proposed Pit X and Pit D extension. Comprises cemented sands and gravels and sandstones, siltstones and mudstones.	Water bearing zones may occur in more permeable layers, unconfined to semi-confined.
Triassic Rewan Formation	Occurs in Curragh Extended near proposed Pit J extension. Comprises mudstone and interbeds of lithic sandstone.	Aquitard.
Permian Rangal Coal Measures	Occurs extensively across the Project area at thicknesses up to 100 m. Coal seams and interburden have been affected by thrust faulting. Interburden layers have very low primary porosity and void spacing in the sandstones is typically cemented by clay providing poor interconnection of void space.	Water bearing cleated coal seams and faulted interburden, confined to unconfined fractured rock aquifer. Faulting restricts flow due to lateral discontinuity of water bearing coal seams. Interburden forms aquitards.
Permian Burngrove Formation	Occurs in the proposed Pit X and Pit Z areas. Comprises fractured coal seams and sandstone units.	Water bearing cleated coal seams, confined to unconfined fractured rock aquifer.
Permian Fair Hill Formation	Underlies Burngrove Formation	Water bearing cleated coal seams, confined to unconfined fractured rock aquifer.
Permian Back Creek Group	Underlies Fair Hill Formation	Aquitard.

4.1.1 Alluvium

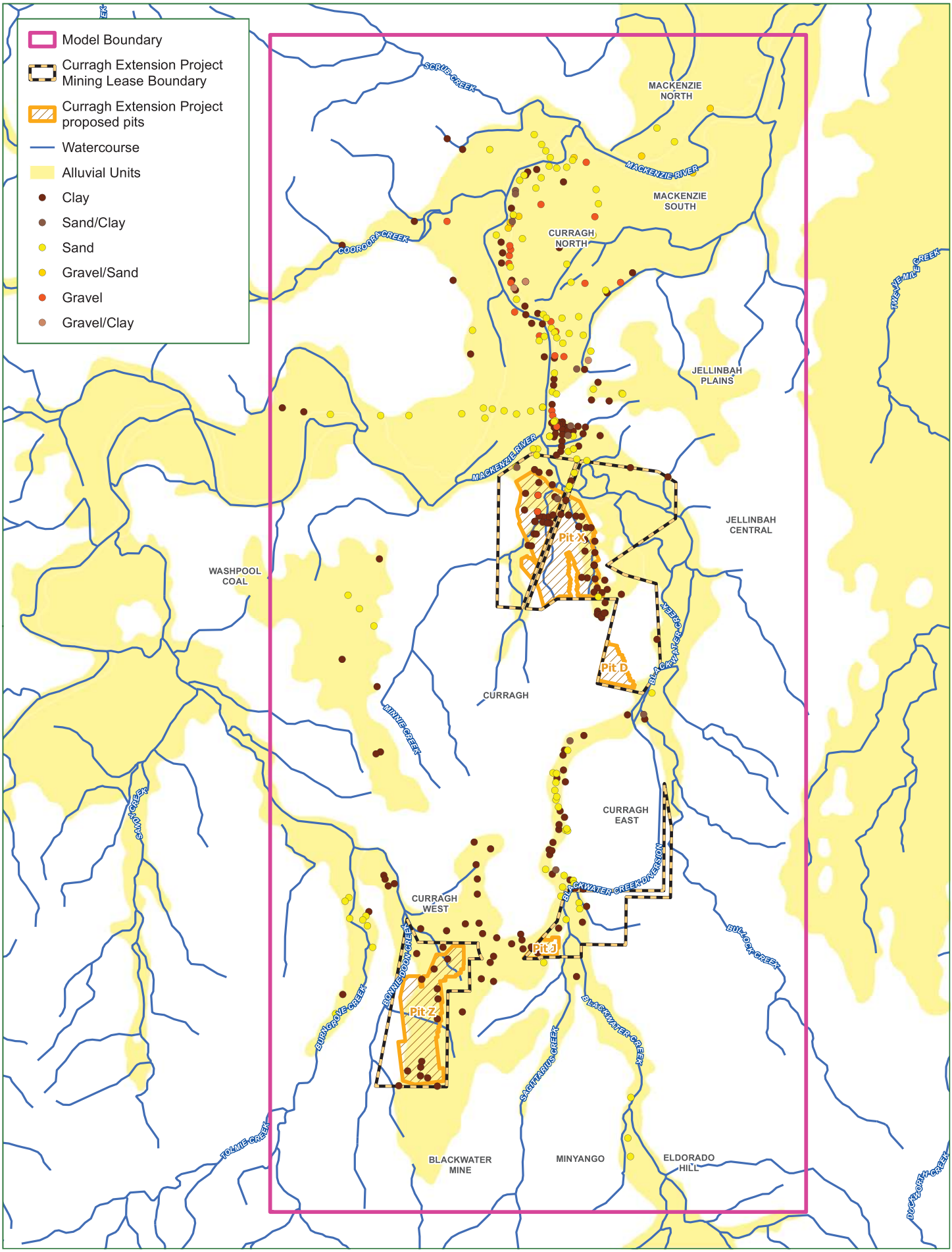
The alluvium is comprised of coarse sediments (sands and gravels) which are considered to be water bearing zones and fine sediments comprising silt and clay. The groundwater is considered to be unconfined with storage in its primary porosity. The alluvium occurs extensively across Curragh North and the northern part of the Curragh Extension Project near proposed Pit X and is typically floodplain sediments associated with Mackenzie River and associated streams, including Blackwater Creek.

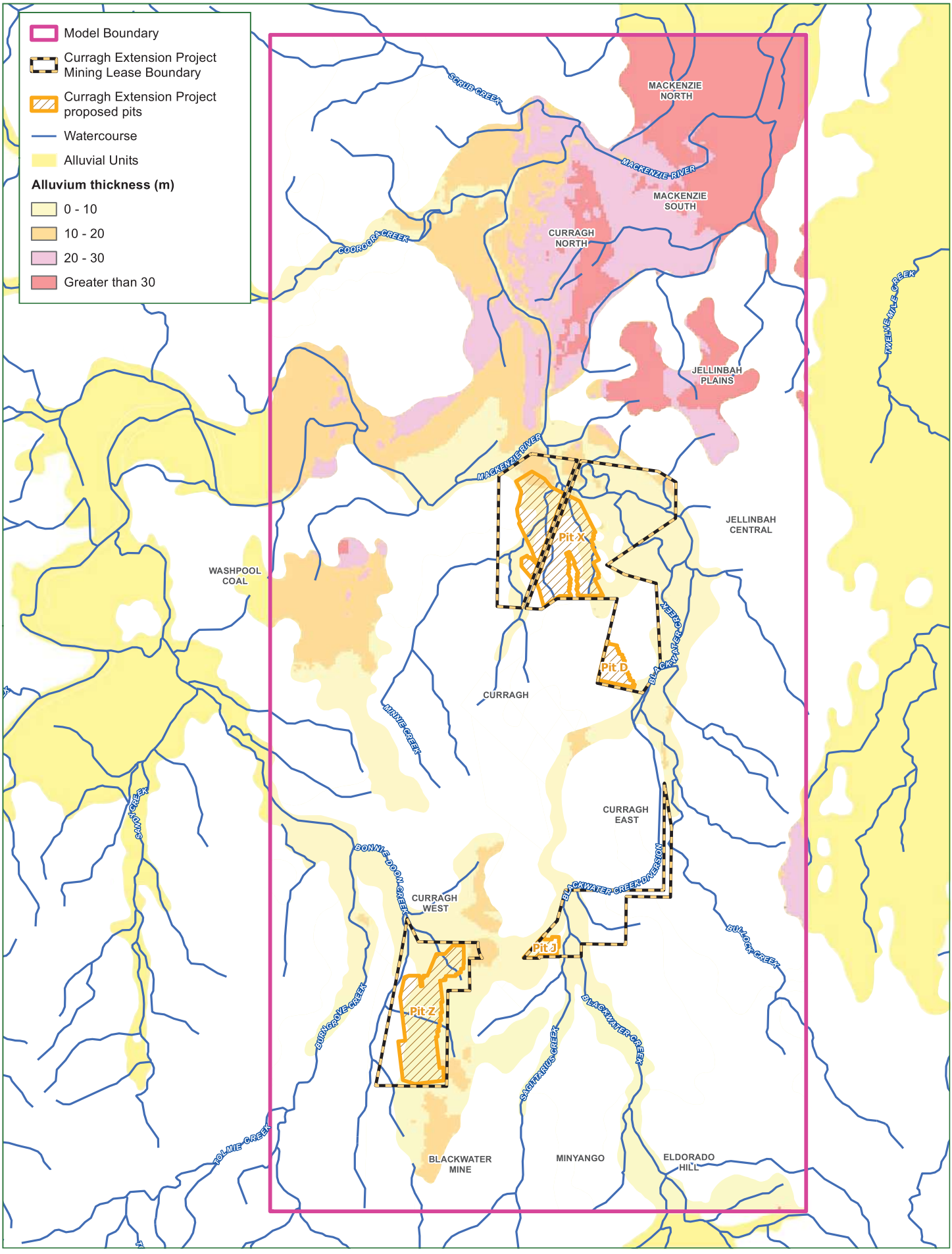
A review of lithology logs from the exploration drilling program indicates that Curragh North is underlain by a palaeochannel system that comprises sand and gravel units and forms a significant thickness of alluvium (between 12 m and 30 m). The northern part of the Curragh Extension Project is underlain by a less developed sequence of alluvium (typically less than 12 m) which predominantly comprises clay with occasional channel sand lenses and gravels, typically occurring at depth (Parsons Brinckerhoff 2003). The alluvium in other parts of the Project area is generally thin (less than 2 m) and unlikely to be water bearing being comprised predominantly of clay and silt. The dominant (>60%) alluvium composition at drill hole locations in the study area is shown on Figure 4.1. The thickness of alluvium in the study area is shown on Figure 4.2.

Mackenzie River is part of a meandering system whose channel has migrated across the floodplain over time. This has resulted in coarse sediments (sands and gravels) being deposited as point bar/channel lenses with overlying finer floodplain sediments. The channel fill deposition of this material has created a sequence that displays significant lateral variability in grain size and permeability and this is interpreted to control groundwater flow and interaction with Mackenzie River and probably Blackwater Creek. The coarse point bar and channel deposits may not necessarily be continuous over long distances due to the process of channel migration.

Groundwater studies undertaken at Curragh North prior to the commencement of mining found the majority of monitoring bores installed in alluvium were dry (Parsons Brinckerhoff 2003). Where water was present in monitoring bores, it occurred within the basal channel lag gravels and coarse sands. This indicated the alluvium was variably saturated, and where water was present in alluvium, it occurred in the deeper sections, such as where palaeochannels were present.

The sands and gravels within the alluvium aquifer are expected to have variable permeability which depends on interstitial fines (silt/clay) content. The clay layers are expected to retard groundwater interaction between pits and nearby watercourses and the main risk for groundwater impacts may be associated with the lateral extent and connectivity of the channel sand/gravel deposits between the pits, streams or sensitive receptors such as landholder bores and GDEs.


Model Boundary
Curragh Extension Project Mining Lease Boundary
Curragh Extension Project proposed pits
Watercourse
Alluvial Units
Clay
Sand/Clay
Sand
Gravel/Sand
Gravel
Gravel/Clay
SCRUB CREEK
MACKENZIE NORTH
MACKENZIE RIVER
MACKENZIE SOUTH
COOROORA CREEK
CURRAGH NORTH
TWELVE MILE CREEK
JELLINBAH PLAINS
MACKENZIE RIVER
JELLINBAH CENTRAL
Pit X
WASHPOOL COAL
Pit D
BLACKWATER CREEK
CURRAGH
MINNIE CREEK
SMOKY CREEK
CURRAGH EAST
BLACKWATER CREEK DIVERSION
CURRAGH WEST
BULLOO CREEK
Pit J
BOUNDARY CREEK
Pit Z
BURNGROVE CREEK
BLACKWATER CREEK
SAGITTARIUS CREEK
TOLMIE CREEK
BLACKWATER MINE
MINYANGO
ELDORADO HILL
DUCKWORTH CREEK
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Data Source:
Geology from GSQ (2015)
Watercourse from DNRM (2016)
Mining data from WSP/PB (2016)
Groundwater impact assessment
Curragh Extension Project
Figure 4.1
Alluvium composition
MXD Number: 2172652H_GIS_SW_F032_A4
Date: 15/06/2016
Author: SH
Approved by: LR
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Data Source:
Geology from GSQ (2015)
Watercourse from DNRM (2016)
Mining data from WSP/PB (2016)

Groundwater impact assessment
Curragh Extension Project
Figure 4.2
Thickness of alluvium

MXD Number: 2172652H_GIS_SW_F033_A5
Date: 15/06/2016
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4.1.2 Rangal Coal Measures

Coal seams within the Rangal Coal Measures are considered fractured rock aquifers with groundwater flow along joints and cleats. The coal seams and interburden have also been affected by thrust faulting.

Faulting of the coal seams and interburden may restrict flow due to the lateral discontinuity of water bearing coal seams. Fault lineaments may also form pathways for groundwater flow.

At depth the coal seam aquifers are confined by the overlying Rewan Formation (where it exists) and interburden layers of impermeable shale, siltstone and mudstone. The fractured rock aquifer is heterogeneous in properties and distribution over a spatial extent.

4.1.3 Burngrove Formation

This unit comprises a fractured rock aquifer system with water bearing units located within fractured or weathered sandstone and coal joints/cleats. Interlayers comprise impermeable siltstone, mudstone and tuff. The fractured aquifer at depth is confined by interburden and the overlying Rangal Coal Measures. The fractured rock aquifers are heterogeneous in properties and distribution over their spatial extent.

4.2 Groundwater levels and flow direction

Groundwater level hydrographs for monitoring bores with more than two data points are presented in Attachment B. Available water level data for groundwater monitoring bores in the study area are presented in Attachment C. Groundwater levels and flow direction in the main water bearing units in the study area are discussed below.

4.2.1 Alluvium

The alluvium associated with Mackenzie River is dry in many areas. Where water is present, it generally occurs in palaeochannels at the base of the alluvial profile. The presence of perched groundwater within the mid-section of alluvium was noted in some isolated locations (Parsons Brinckerhoff 2003).

Pre-mining groundwater levels in the alluvium at Curragh North were generally 18 to 22 mbgl. Groundwater levels recorded in alluvium at Curragh North since commencement of mining are presented in Figure 4.3. The groundwater levels recorded range from approximately 16 to 26 mbgl.

The alluvium associated with Blackwater Creek is dry in many areas. Pre-mining groundwater levels in the alluvium near the Minyango project were approximately 10 mbgl (AGE 2013a). Groundwater levels recorded in BH8A and 1307MB since commencement of mining at Curragh East are 3.6 to 7.6 mbgl, although these levels may be affected by mine water storage dams A and B nearby.

Groundwater flow direction in the alluvium is presented in Figure 4.4. Groundwater flow follows topography and drainage lines to the north and north east and is affected locally by open cut pits where alluvium has been intersected during mining.

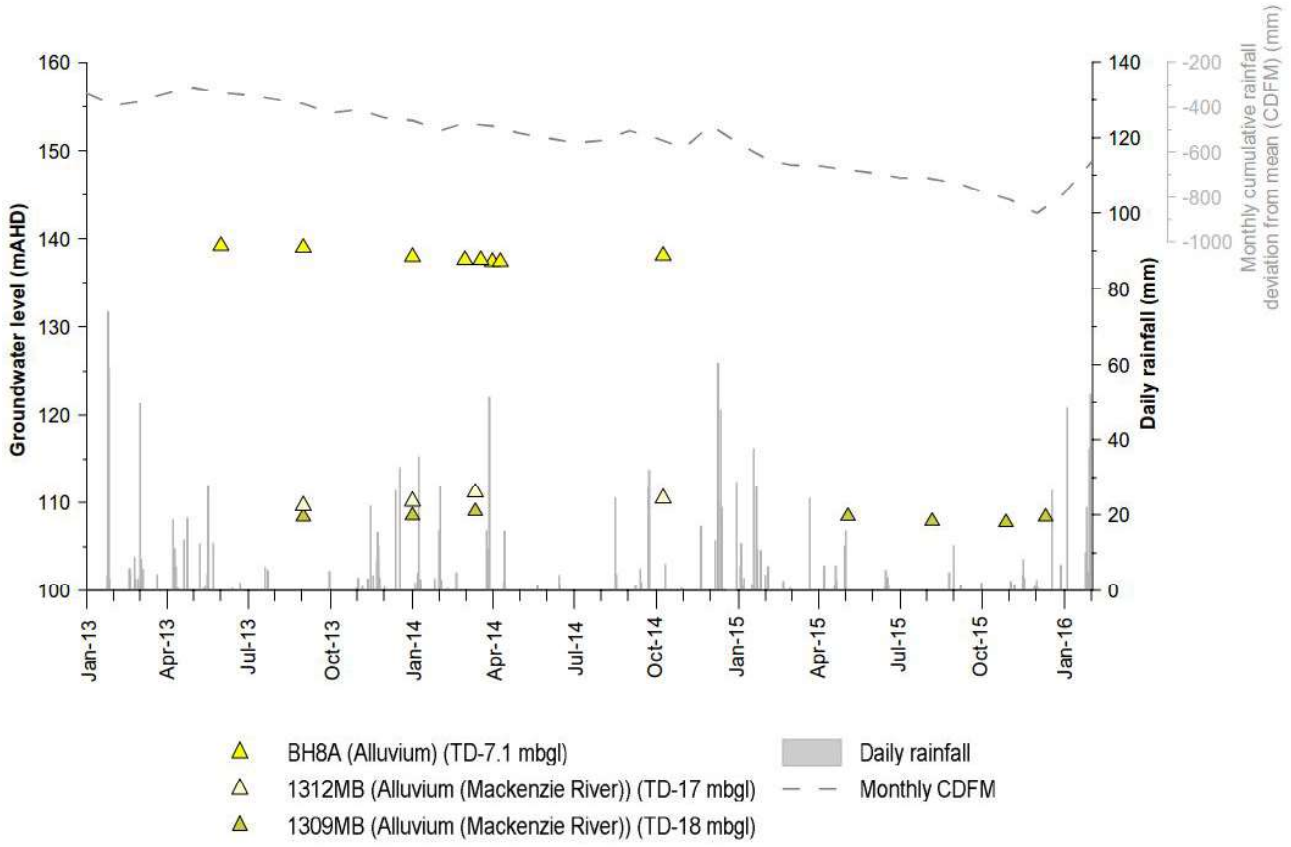
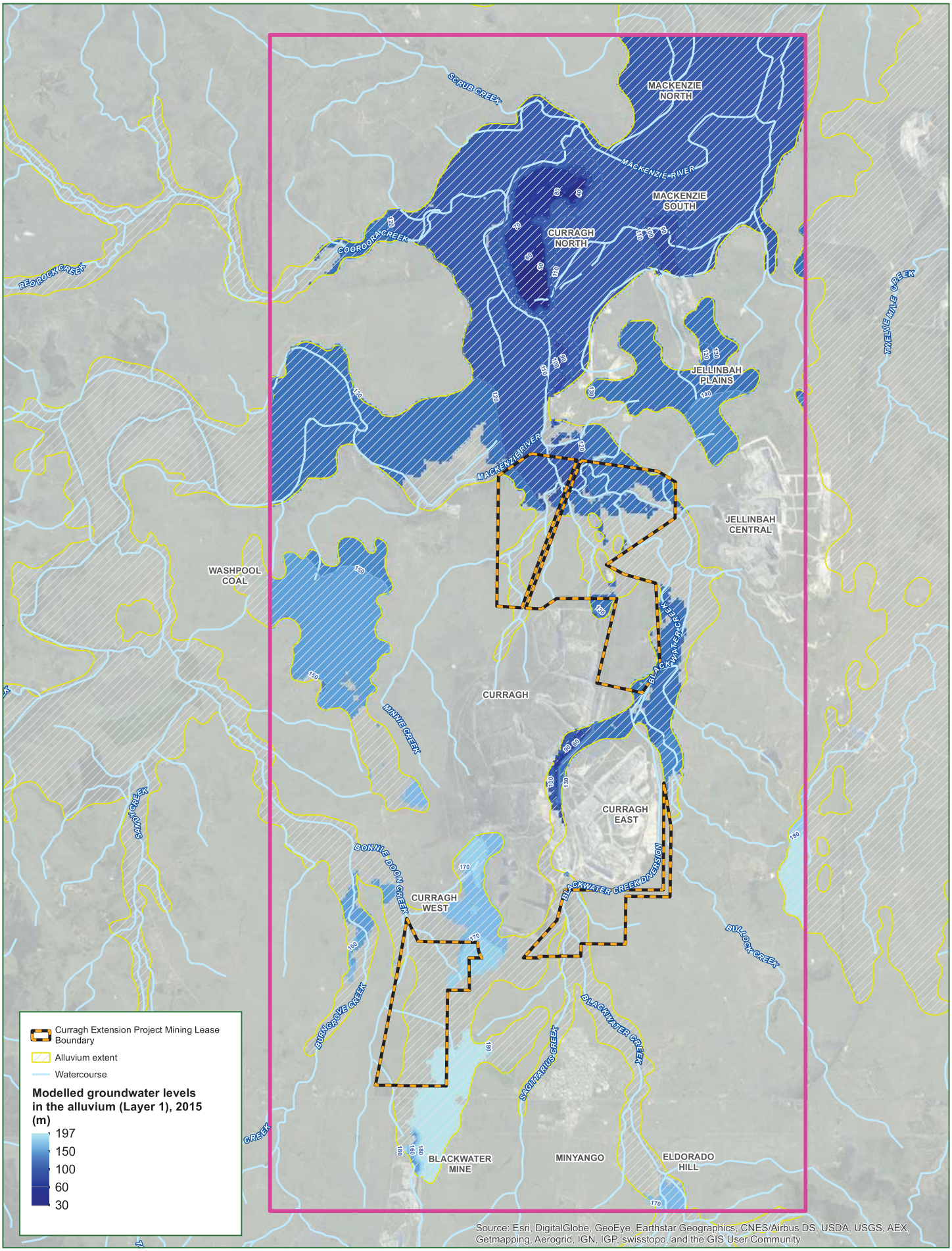


Figure 4.3 Groundwater levels – Alluvium



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Data Source:
All data from WSP/PB (2016)

Groundwater impact assessment
Curragh Extension Project
Figure 4.4
Groundwater flow direction - Alluvium (2015)

MXD Number: 2172652H_GIS_SW_F009_A2
Date: 15/06/2016
Author: VD
Approved by: LR

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4.2.2 Rangal Coal Measures

Monitoring of the Pisces seam at Curragh North prior to the commencement of mining indicated pressure heads of 0 to 78 m above the seam. Unconfined conditions occurred east of Mackenzie River where the Pisces seam subcropped and confined conditions occurred where coal seams were deeper (Parsons Brinckerhoff 2003).

Groundwater levels recorded in Rangal Coal Measures at Curragh Mine since commencement of mining are presented in Figure 4.5. Depths to groundwater range from approximately 5 to 48 mbgl. The depth to groundwater in the Permian sequences varies due to aspects of aquifer connectivity, confining conditions, topography and mining influence.

Groundwater levels in BH1, where Rangal Coal Measures outcrop, follow the CDFM, indicating groundwater levels in this bore follow long term rainfall trends. Groundwater levels in BH2 increase over the period of monitoring showing recovery of groundwater levels as mining progresses away from the bore.

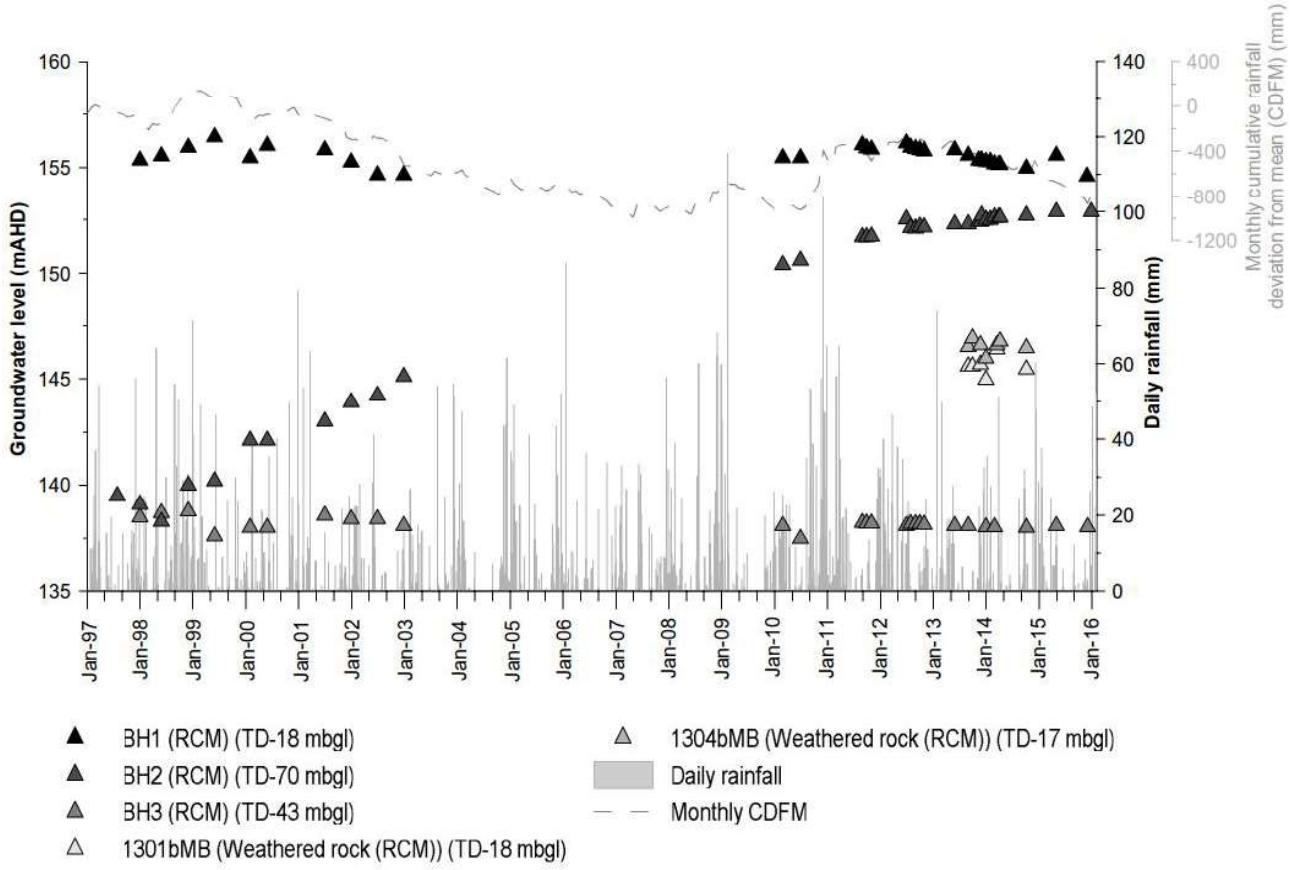


Figure 4.5 Groundwater levels – Rangal Coal Measures

Prior to mining, groundwater flow direction in the Permian strata was to the north east at a gradient of 1 in 400 (Douglas Partners 2014). Since commencement of mining, groundwater flow direction in the Permian strata has been influenced locally by dewatering in the active pit areas of Curragh and Jellinbah mines.

4.2.3 Burngrove Formation

Monitoring of the Virgo seam at Curragh North prior to the commencement of mining indicated confined conditions in this area, with a pressure head of 156 m above the seam recorded (Parsons Brinckerhoff 2003). In the west of the study area where the Burngrove Formation outcrops and subcrops, unconfined conditions occur.

Groundwater levels recorded in Burngrove Formation since commencement of mining are presented in Figure 4.6. Depths to groundwater range from approximately 6 to 29 mbgl. The depth to groundwater in the Burngrove Formation varies due to aspects of aquifer connectivity, confining conditions, topography and mining influence.

Groundwater levels in BH4 and BH5, where the Burngrove Formation outcrops, follow the CDFM, indicating groundwater levels in these bores follow long term rainfall trends.

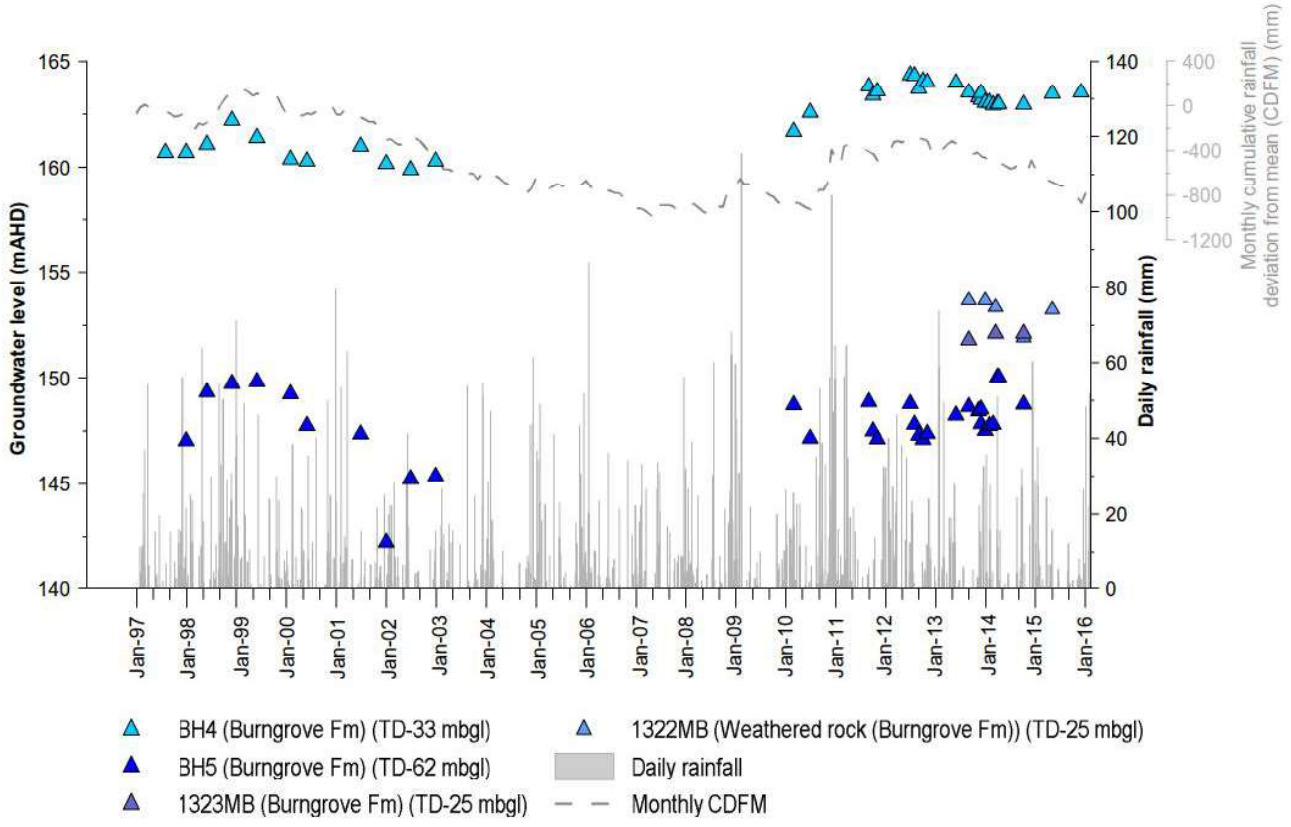


Figure 4.6 Groundwater levels – Burngrove Formation

4.3 Hydraulic properties

Field hydraulic testing of alluvium and Rangal Coal Measures was undertaken by GHD at Curragh North (Minserve 1998). Falling head tests and packer tests were completed. The results are presented in Table 4.2.

Field hydraulic testing of alluvium, Rewan Formation, Rangal Coal Measures and Fair Hill Formation was also undertaken for nearby projects Mackenzie South, Minyango and Cook Colliery. The tests undertaken include falling head tests, rising head tests, constant rate pumping tests, drill stem tests and injection/fall-off tests with packers. The results are presented in Table 4.2.

Table 4.2 also presents hydraulic data for other studies in the Bowen Basin. The data presented includes calibrated parameters used in other groundwater models

As shown in Table 4.2, the sands and gravels within the alluvium have variable permeability which depends on the interstitial fines (silt/clay) content. The coal seams within the Rangal Coal Measures and Burngrove Formation also have variable permeability with low to moderate permeability within discrete fracture systems as characterised by fractured rock aquifer systems.

Table 4.2 Hydraulic properties

Geological age	Formation	Lithology	Kh (m/d)	Kv (m/d)	Ss (m^{-1})	Sy	Data source	Project	Source
Quaternary	Alluvium	Mackenzie River alluvium - silty clay	0.0009 – 0.001				Falling head tests	Curragh North	1
		Mackenzie River alluvium - sand	0.09 – 9				Falling head tests	Curragh North	1
		Mackenzie River alluvium - sand/gravel	0.9 – 9				Falling head tests	Curragh North	1
		Mackenzie River alluvium - gravel	10				Constant rate pumping test	Mackenzie South	2
		Blackwater Creek alluvium	0.4				Rising head test	Minyango	3
		Blackwater Creek alluvium	0.6	0.018			Calibrated model parameters	Minyango	3
		Floodplain/ river alluvium	1 – 40	0.1 – 2	0.0005	0.05 – 0.18	Calibrated model parameters	Arrow Energy	7
		Not specified	100	10	0.001	0.25	Unknown	Ensham Central	6
		Not specified	0.7 – 1.5				Unknown	Baralaba North	13
		Not specified	10	1	0.0001	0.2	Calibrated model parameters	Millennium expansion	8
		Not specified	0.088 – 0.38				Unknown	Caval Ridge	9
		Not specified	10	1	0.00001	0.1	Unknown	Springsure Creek	11
Tertiary	Duaringa Formation	Sedimentary rocks	0.05	0.005	0.00005	0.12	Calibrated model parameters	Arrow Energy	7
			0.6	0.018			Calibrated model parameters	Minyango	3
	Weathered rock	Sandy gravels	0.9				Unknown	Curragh North	1

Geological age	Formation	Lithology	Kh (m/d)	Kv (m/d)	Ss (m^{-1})	Sy	Data source	Project	Source
	Weathered rock	Claystone/other cemented strata	0.43				Unknown	Curragh North	1
Triassic	Rewan Formation	Sedimentary rocks	0.00075	0.0000001	0.00005	0.05	Calibrated model parameters	Arrow Energy	7
			0.00015 – 0.055				Falling and rising head tests	Minyango	3
			0.0009	0.000054			Calibrated model parameters	Minyango	3
			0.00001 – 0.0001	0.000001 – 0.00001	0.000001	0.005	Unknown	Ensham Central	6
			0.1		0.000005	0.05	Unknown	Daunia	10
			0.0001	0.00001	0.00001	0.01	Unknown	Springsure Creek	11
			0.000007	0.0000007			Calibrated model parameters	Carmichael	12
Permian	Rangal Coal Measures	Overlying units (intact)	0.004	0.001			Packer tests	Curragh North	1
		Sheared/ fractured coal	0.009 to 0.09				Packer tests	Curragh North	1
		Intact coals	0.017				Packer tests	Curragh North	1
		Aries coal seam	0.003				Falling head test	Minyango	3
			0.14				Drill stem testing	Minyango	4
		Aries/Castor coal seam	0.00014				Injection/fall-off tests with packers	Cook Colliery	5
		Castor coal seam	0.06				Drill stem testing	Minyango	4
		Pollux coal seam	0.017				Drill stem testing	Minyango	4
			0.9				Constant rate pumping test	Mackenzie South	2

Geological age	Formation	Lithology	Kh (m/d)	Kv (m/d)	Ss (m^{-1})	Sy	Data source	Project	Source
		Pisces coal seam	0.003				Drill stem testing	Minyango	4
		Interburden	0.0001	0.00000001	0.0000085	0.05	Calibrated model parameters	Arrow Energy	7
			0.00009	0.0000018			Calibrated model parameters	Minyango	3
			0.1		0.000005	0.05	Unknown	Daunia	10
			0.001	0.00001	0.00001	0.01	Unknown	Springsure Creek	11
	Burngrove Formation	Coal and interburden	0.00044	0.0000088	0.00005	0.12	Calibrated model parameters	Arrow Energy	7
			0.000009	0.00000099			Calibrated model parameters	Minyango	3
	Fair Hill Formation	Fort Cooper coal seams (Virgo/ Leo/ Aquarius)	0.000017				Injection/fall-off tests with packers	Cook Colliery	5

1 Minserve (1998), cited in Parsons Brinckerhoff (2003)

2 ERM (2002), cited in AGE (2006)

3 AGE (2013a)

4 Polymetra (2009), cited in AGE (2013a)

5 North Queensland Energy (1993), cited in AGE (2013a)

6 AGE (2006), cited in HydroSimulations (2014)

7 Ausenco-Norwest (2012)

8 Matrix Plus (2010/)

9 URS (2009), cited in HydroSimulations (2014)

10 BHP Billiton Mitsubishi Alliance, cited in HydroSimulations (2014)

11 CDM Smith (2013), cited in HydroSimulations (2014)

12 GHD (2013)

13 JBT (2012), cited in HydroSimulations (2014)

4.4 Groundwater chemistry

The groundwater quality sampling program is summarised in Section 3.1.2. Groundwater samples were analysed for electrical conductivity (EC), pH, major ions, nutrients, dissolved metals and hydrocarbons. Historically, groundwater quality monitoring has been undertaken infrequently since 1997. However, from 2012 groundwater sampling has occurred more frequently. According to the Environmental Monitoring Management Procedure (EM PROC 0.1), groundwater is currently sampled six monthly in April and October. Table 4.3 shows the groundwater quality data available for bores in each screened stratigraphy.

Table 4.3 Available groundwater chemistry data

Screened stratigraphy	Bore ID	Sampling period	Total number of samples	Colour on graphs	Potential influences on groundwater quality
Blackwater Creek alluvium	BH8A	2012–2014	9	Yellow	Dams A and B (mine water storage)
Mackenzie River alluvium	1309MB, 1312MB	2013–2014	7	Pink/orange	Dam CN3 (mine water storage)
Duaringa Formation	1301aMB, 1304aMB, 1308MB	2013–2014	15	Green	Tailings storage facility (TSF)
Rewan Formation	BH6, BH8	2012–2014	19	Purple	Dams A and B (mine water storage)
Rangal Coal Measures	BH1, BH2, BH3	1999–2015	84	Grey/black	Old TSF (BH1), Landfills (BH2, BH3)
	1301bMB, 1304bMB	2013–2014	14		Tailings storage facility (TSF)
	1534MB, 1539MB	2015	2		Pit T (1534MB), Pit D (1539MB)
Burngrove Formation	BH4, BH5	1999–2015	73	Blue	Landfill (BH4), Admin building (BH5)
	1322MB, 1323MB	2013–2014	8		Industrial/process area (1322MB), Upgradient of operations (1323MB)
	1417MB	2015	1		Fuel farm

Groundwater quality data are presented in Figures 4.7 to 4.10. Figure 4.7 presents the available EC data and Figure 4.8 presents the available pH data. Figure 4.9 presents time series of EC and pH. Major ion chemistry for all groundwater samples is shown on the piper diagram in Figure 4.10. A piper diagram is a graphical representation of the chemistry of a water sample, used to show the relative concentrations of major ions (Ca^{2+}, Mg^{2+}, Na^{2+}, K^{+}, Cl^{-}, HCO^{3-} and SO_4^{2-}).

Most monitoring bores in the current network are in disturbed areas of Curragh Mine. WCPL has recently installed reference bores in locations upgradient of Curragh Mine to establish a baseline of undisturbed groundwater conditions (Parsons Brinckerhoff 2015a).

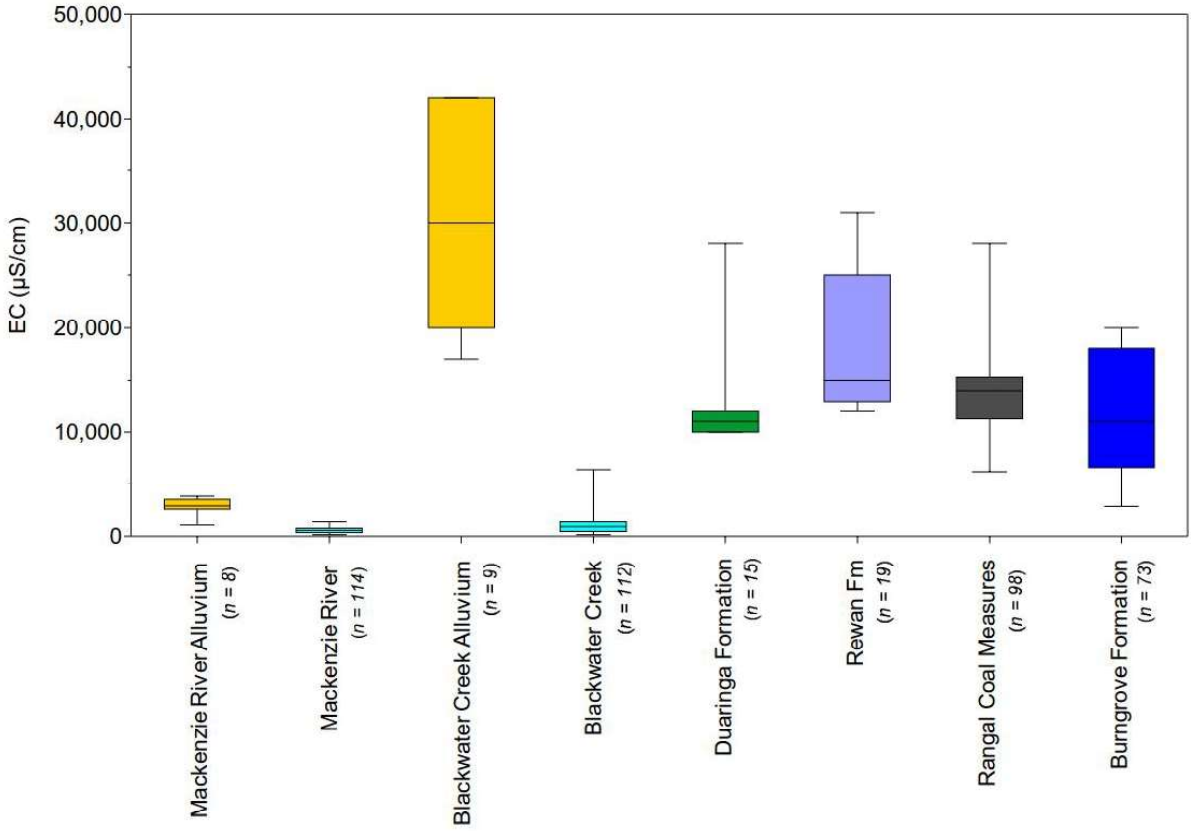


Figure 4.7 Groundwater EC

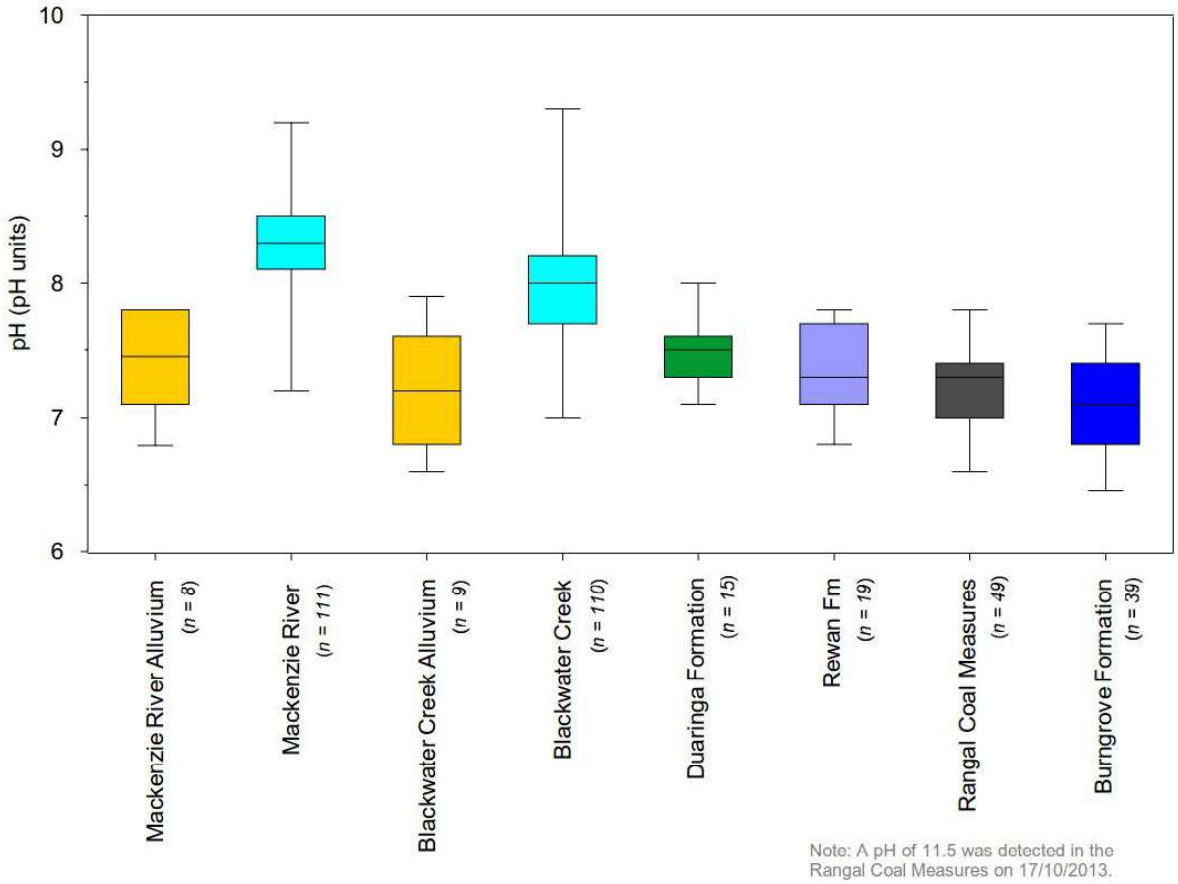


Figure 4.8 Groundwater pH

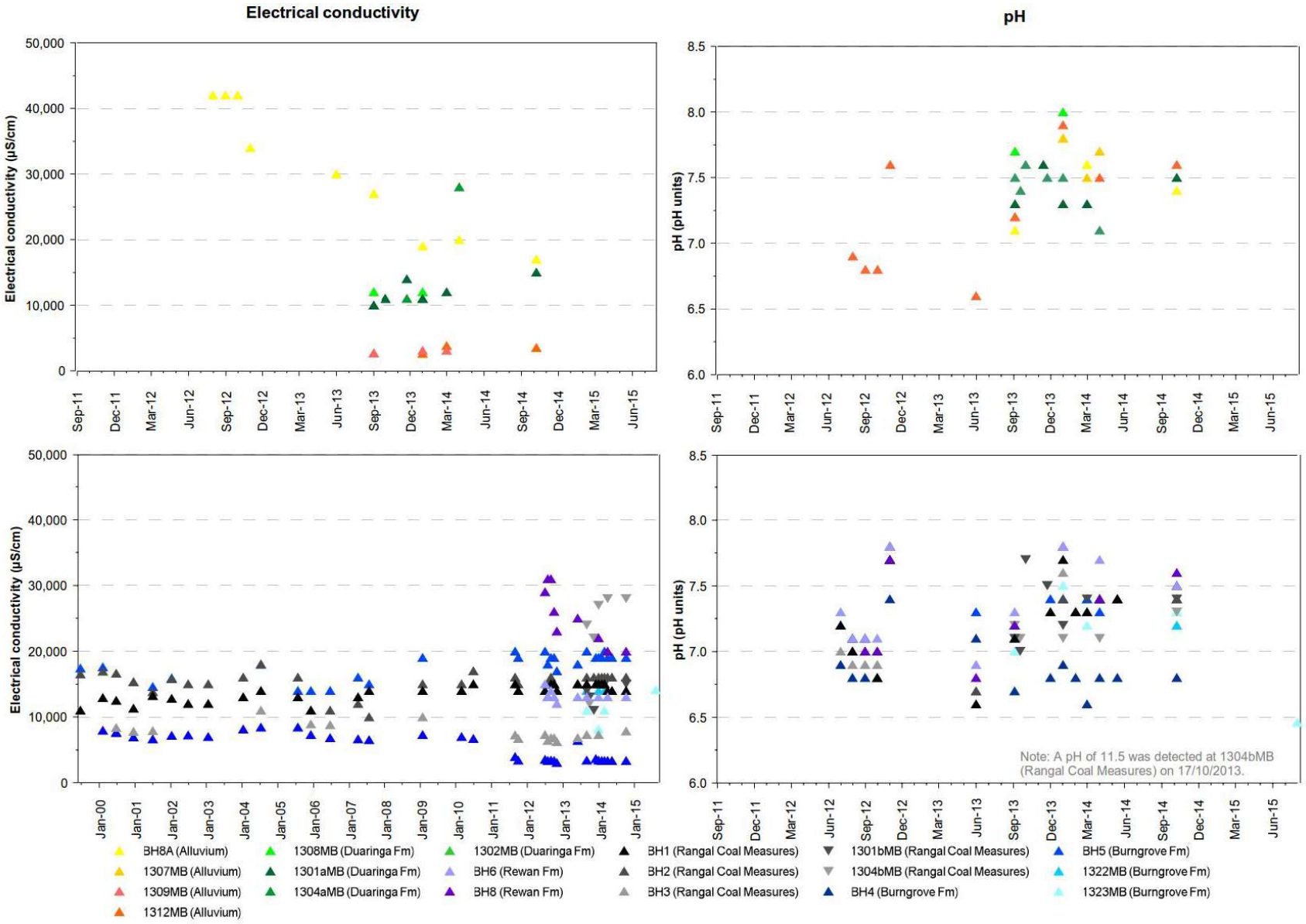


Figure 4.9 EC and pH time series

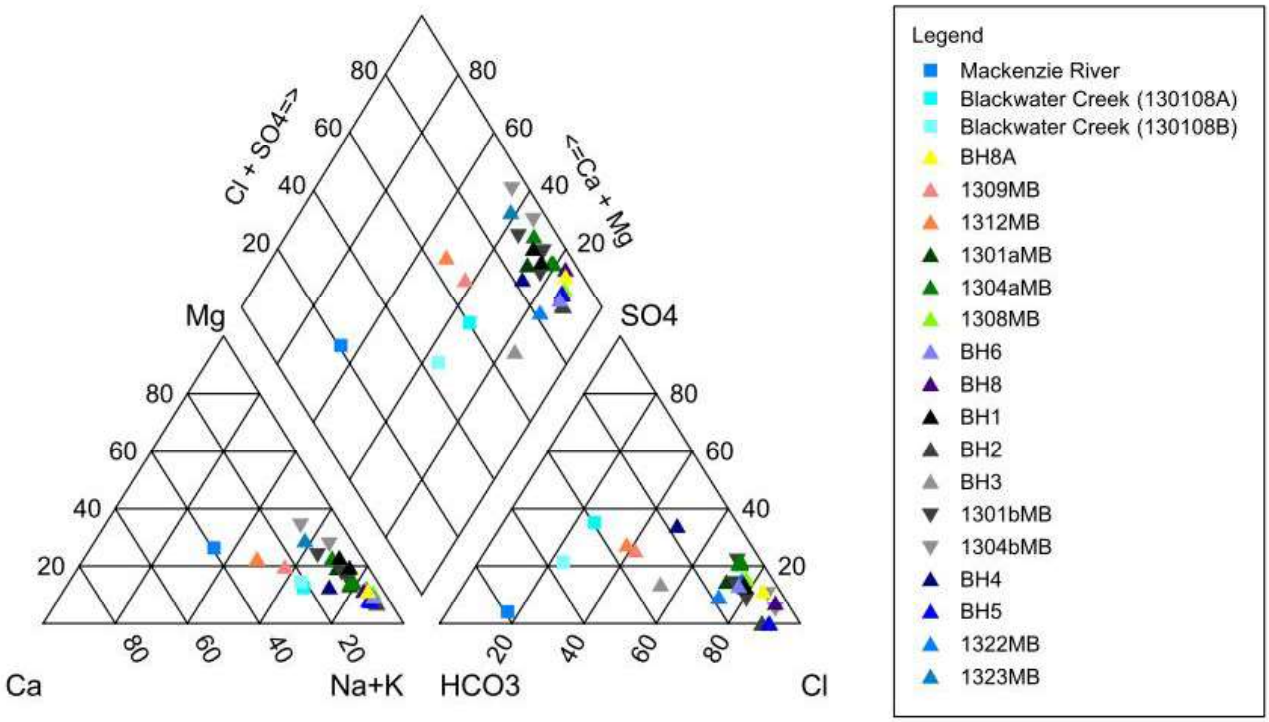


Figure 4.10 Piper plot

4.4.1 Alluvium

Groundwater in the Blackwater Creek alluvium is highly saline with spatial and temporal variability (generally 20,000–42,000 µS/cm). The pH is mostly neutral (6.6–7.9) and appears to have slightly increased over the monitoring period, while the EC has decreased. Groundwater in the Mackenzie River alluvium is generally of brackish quality (<4,000 µS/cm) and neutral pH (6.8–7.8). The values are not unexpected as Blackwater Creek is an ephemeral stream and Mackenzie River has a constant influx of water from dam releases upstream. Both surface water streams generally have fresh water (<800 µS/cm) of slightly alkaline nature (pH 8–8.5).

Groundwater in the alluvium associated with Blackwater Creek is in most cases dominated by sodium, chloride and magnesium, as opposed to the surface water which is dominated by sodium and bicarbonate and to a lesser extent calcium, magnesium and sulphate. Groundwater in the alluvium associated with Mackenzie River is typically dominated by sodium and chloride and to a lesser extent calcium, magnesium, bicarbonate and sulphate, as opposed to the surface water which is dominated by calcium and bicarbonate and to a lesser extent sodium and magnesium.

Dissolved metal concentrations that have been detected in the alluvium are presented in Attachment D. Most concentrations are low with only boron and iron detected at concentrations above 1 mg/L.

Nitrate-N concentrations ranged between 0.073 and 2.9 mg/L and total phosphorous concentrations ranged from 0.086 to 0.28 mg/L.

Hydrocarbon compounds were detected on one occasion at the Blackwater Creek alluvium monitoring location BH8A on 27 September 2012. As hydrocarbons have not been detected at this location since, the detection is assumed to be cross-contamination in the field or laboratory (Parsons Brinckerhoff 2015b).

4.4.2 Duaringa Formation

Groundwater in the Duaringa Formation is moderately saline (generally 10,000–28,000 µS/cm) and the pH is neutral to slightly alkaline (7.5–8). No pH or EC trends are observed during the monitoring period.

Groundwater in the Duaringa Formation is in most cases dominated by sodium, chloride and sulphate.

Dissolved metal concentrations that have been detected in the Duaringa Formation are presented in Attachment D. Most concentrations are low with only iron and manganese detected at concentrations above 1 mg/L.

An ammonia-N concentration of 0.41 mg/L was detected in the Duaringa Formation. Nitrate-N concentrations ranged between 0.02 and 1.2 mg/L and total phosphorous concentrations ranged from 0.007 to 0.039 mg/L.

Hydrocarbons were detected at low concentrations in BH4 and BH5 during sampling rounds in 2003, 2004 and 2012 and have not been detected since. These detections are likely the result of cross-contamination in the field or laboratory (Parsons Brinckerhoff 2015b).

4.4.3 Rewan Formation

Groundwater in the Rewan Formation is saline (12,000–31,000 µS/cm) and the pH is neutral to slightly alkaline (6.8–7.8). The pH is appears to have slightly increased over the monitoring period, while the EC has decreased.

Groundwater in the Rewan Formation is typically dominated by sodium, chloride, magnesium and sulphate.

Dissolved metal concentrations that have been detected in the Rewan Formation are presented in Attachment D. Most concentrations are low with only boron and iron detected at concentrations above 1 mg/L.

Ammonia-N concentrations ranged between 0.73 and 0.93 mg/L, nitrate-N concentrations ranged between 0.02 and 2.7 mg/L and total phosphorous concentrations ranged from 0.009 to 0.036 mg/L.

Hydrocarbons were detected on one occasion in July 2012. This detection is likely the result of cross contamination in the field or laboratory (Parsons Brinckerhoff 2015b).

4.4.4 Rangal Coal Measures

Groundwater in the Rangal Coal Measures is moderately saline (generally 10,000–15,000 µS/cm) and the pH is neutral (approximately 7.5). One pH value of 11.5 was recorded at 1304b on 17 October 2013. This pH value is uncharacteristic of groundwater and notably higher than TSF water, and is likely to be due to a measuring or laboratory reporting error (Parsons Brinckerhoff 2015b). Since monitoring began in 1999, the EC has been fairly stable at most monitoring locations and below 20,000 µS/cm with exception of 1304b (near Blackwater Creek), where the EC values consistently range between 20,000 and 30,000 µS/cm.

Groundwater in the Rangal Coal Measures is typically dominated by sodium, chloride, magnesium and sulphate.

Dissolved metal concentrations that have been detected in the Rangal Coal Measures are presented in Attachment D. Most concentrations are low with only boron, iron and manganese detected at concentrations above 1 mg/L.

Ammonia-N concentrations ranged between 0.25 and 4.5 mg/L, nitrate-N concentrations ranged between 0.01 and 1.1 mg/L and total phosphorous concentrations ranged from 0.012 to 0.041 mg/L.

Hydrocarbons were detected at low concentrations in BH1 and BH2 during sampling rounds in 2003, 2004 and 2012 and have not been detected since. These detections are likely the result of cross-contamination in the field or laboratory (Parsons Brinckerhoff 2015b). Hydrocarbons (were detected at BH3 in 2012 and 2014. The source of this TPH detection at BH3 may be a result of landfill leachate, a localised spill or leak from vehicles servicing the area near BH3, naturally occurring TPH associated with coal or peat in the Rangal Coal Measures (Volk et. al. 2011) or cross-contamination in the laboratory (Parsons Brinckerhoff 2015b). Ongoing sampling is underway to confirm these detections are localised and do not present a risk to groundwater quality.

4.4.5 Burngrove Formation

Groundwater in the Burngrove Formation is of variable water quality with EC ranging from 7,000 to 18,000 µS/cm for the majority of samples. The pH is neutral and ranges from 6.7 to 7.4 for the majority of samples.

Groundwater in the Burngrove Formation is in most cases dominated by sodium and chloride.

Dissolved metal concentrations that have been detected in the Burngrove Formation are presented in Attachment D. Most concentrations are low with only boron and iron detected at concentrations above 1 mg/L.

Ammonia-N concentrations ranged between 0.06 and 4.3 mg/L, nitrate-N concentrations ranged between 0.01 and 0.7 mg/L and total phosphorous concentrations ranged from 0.008 to 0.06 mg/L.

Hydrocarbons were detected at BH5 in 2012) and have not been detected since. This detection is likely the result of cross-contamination in the field or laboratory (Parsons Brinckerhoff 2015b). TPH was detected in groundwater at BH4 in 2014. The source of this detection may be a localised spill or leak from vehicles servicing the area near BH4, naturally occurring TPH associated with coal or peat in the Rangal Coal Measures (Volk et. al. 2011) or cross-contamination in the laboratory (Parsons Brinckerhoff 2015b). Ongoing sampling is underway to confirm these detections are localised and do not present a risk to groundwater quality.

4.5 Recharge and discharge

4.5.1 Recharge

Recharge of alluvial aquifers and weathered rock occurs via stream flow, particularly during periods of high flow and flooding, as well as via rainfall infiltration. Although most streams in the region are ephemeral, the Mackenzie River is a supplemented river system and Blackwater Creek near proposed Pit D extension and proposed Pit J extension has a constant low flow due to discharge from the Blackwater Wastewater Treatment Plant. These streams may provide a constant source of recharge to the underlying alluvial and weathered rock groundwater systems. Groundwater studies undertaken at Curragh North prior to the commencement of mining found the alluvium was dry in many areas (Parsons Brinckerhoff 2003). This may be related to low permeability clays and silts occurring in the upper part of the alluvial profile restricting recharge via streamflow or rainfall infiltration (Parsons Brinckerhoff 2003).

In the initial phases of mining at Pit S at Curragh North in late 2014, conceptual understanding was that Mackenzie River may provide recharge to the alluvium with the hydraulic gradient towards Pit S (Douglas and Partners, 2014). However, site observations have indicated very minor inflow from alluvium in the wall buttress on the Mackenzie River side of the pit and no change in water levels in Mackenzie River during mining. This may be due to intervening lateral clay conditions reducing permeability and flow between the river and alluvium, and dewatering of alluvium adjacent to the pit, suggesting Mackenzie River may not provide a major source of recharge to alluvium. Parsons Brinckerhoff (2003) also point out from review of

monitoring data that the response of groundwater levels to rainfall events and subsequent river level rise is lacking and may be due to the occurrence of perched systems in the alluvium and high content of fines (silt/clay) within sand or gravel lenses along Mackenzie River. A review of lithology logs for bores drilled in alluvium between Mackenzie River and proposed Pit X and Blackwater Creek and proposed Pit D extension and proposed Pit J extension indicates a relatively high proportion of clay and suggests recharge to alluvium may be limited.

Recharge of fractured aquifers within the Rangal Coal Measures and Burngrove Formation is understood to occur predominantly through rainfall infiltration of formation outcrops and vertical leakage, particularly where coal seams subcrop beneath relatively permeable alluvium and soils. A high proportion of recharge would follow fracture/joint orientation down dip along strata beds. Some recharge may also occur via stream flow where formations outcrop, for example where Rangal Coal Measures outcrop beneath Bonnie Doon Creek flows.

4.5.2 Discharge

The major discharge from Rangal Coal Measures in the study area is inflow to mine pits. Regional aquifer through-flow is also considered a discharge mechanism for groundwater systems in the study area, with groundwater flow toward the north-east.

Evapotranspiration from the water table is considered one of the major discharge mechanisms in the study area. The evapotranspiration rate depends on land use and depth to groundwater. In areas where the water table is shallow and within the rooting depth of vegetation, evapotranspiration can be a significant component of the water balance.

Extraction of groundwater through the use of existing bores in the area may also be considered a mechanism of discharge from groundwater systems in the study area. This is further discussed in Section 5.

The BOM GDE Atlas indicates that Mackenzie River, Blackwater Creek and Cooroora Creek have a moderate potential for groundwater interaction. There is potential that groundwater in alluvium may discharge to Mackenzie River at times, particularly during the wet season when groundwater levels may rise. This is discussed further in Section 4.6.

Other streams in the study area, including Blackwater Creek, Minnie Creek, Sagittarius Creek and Bonnie Doon Creek, are not identified in the BOM GDE atlas and are considered unlikely to receive baseflow from groundwater. This is consistent with site observations which indicate these streams are dry during the dry season and only flow following rainfall runoff during the wet season.

4.6 Surface water-groundwater interaction

4.6.1 Classification

Hydraulic connection between surface water and groundwater exists where the river is in direct contact with the underlying aquifer via a zone of saturated material or where the river is separated from the aquifer by a narrow unsaturated zone, generally less than twice the stream width (Bouwer and Maddock 1997). Where the groundwater level is much deeper than the base of the river, reductions in the water table will have little or no effect on the stream.

Streams can be classified as either ‘gaining’ or ‘losing’ (Evans 2007):

- A ‘gaining’ stream exists where the water table or groundwater level in an aquifer is higher than the running level in a stream. Groundwater will flow or discharge to the stream, contributing to ‘baseflow’.

- A 'losing' stream exists where the water table or groundwater level is lower than the running level in a stream. Water will flow from the stream and recharge groundwater, called 'stream leakage'.

Whether a stream is losing or gaining can change along the course of a stream and over time. Streams can also be either 'disconnected' or 'connected' to the groundwater in the aquifer (Evans 2007):

- A 'connected' stream occurs when the water table level intersects the surface water body.
- A 'disconnected' stream occurs when the water table level in the aquifer is below the base of the surface water body or a zone of unsaturated material exists between the surface water body and the water table.

This results in three possible types of groundwater surface water interaction which are shown in Figure 4.11:

- Gaining and connected (A)
- Losing and connected (B)
- Losing and disconnected (C).

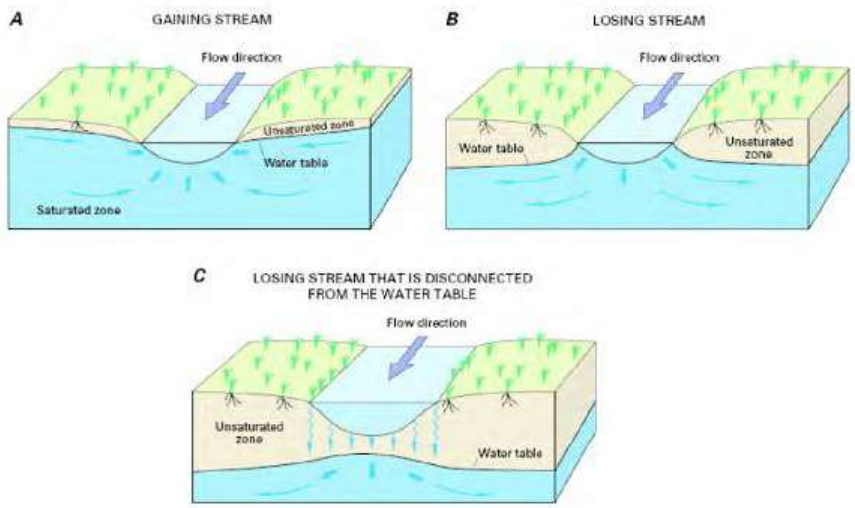


Figure 4.11 Types of surface water – groundwater interaction (after Winter et al. 1998)

4.6.2 GDE Atlas mapping

The Bureau of Meteorology (BOM) groundwater dependent ecosystems (GDE) atlas has been reviewed to identify streams in the study area that may potentially be connected to groundwater. It is important to note that the GDE Atlas mapping (BOM 2015) is an indicative regional scale map. Desktop methods generally tend to overestimate the extent of GDEs (Richardson et al. 2011).

The GDE Atlas identifies three watercourses in the study area that may rely on the surface expression of groundwater (Figure 5.3):

- Mackenzie River
- Cooroora Creek, a tributary of Mackenzie River
- Blackwater Creek.

The GDE Atlas also identifies numerous wetlands that may rely on the surface expression of groundwater, which are discussed further in Section 5.2.3.

The GDE Atlas indicates these watercourses and wetlands have a moderate potential for groundwater interaction.

4.6.3 Mackenzie River (including Cooroora Creek)

Mackenzie River is the main drainage in the study area. The regulation of Mackenzie River has altered the natural flow regime. Cooroora Creek is a tributary of Mackenzie River to the west of the Curragh North project area.

4.6.3.1 Occurrence of groundwater in alluvium

Groundwater studies undertaken by Parsons Brinckerhoff (2003) at Curragh North prior to the commencement of mining found the majority of monitoring bores installed in alluvium were dry. Where water was present in monitoring bores, it occurred within the basal channel lag gravels and coarse sands. This indicated the alluvium was variably saturated, and where water was present in alluvium, it occurred in the deeper sections, such as where palaeochannels were present.

4.6.3.2 Pre-mining groundwater levels

Groundwater studies undertaken by Parsons Brinckerhoff (2003) at Curragh North prior to the commencement of mining included installation of a groundwater monitoring network in the Mackenzie River alluvium and monitoring of groundwater levels and Mackenzie River levels using data loggers. Monitoring was undertaken from November 2001 to May 2003 at three alluvial bores located immediately adjacent to Mackenzie River (near current Pit U and Pit T). Hydrographs for the monitoring bores and the Mackenzie River gauge are shown on Figure 4.12.

The monitoring indicated that groundwater levels in the alluvium were typically between 3 and 5 m below the water level in Mackenzie River. The monitoring also showed that fluctuations in water level in Mackenzie River were not reflected in water levels in the monitoring bores. The data indicates that prior to mining at Curragh North, there was no or very minimal leakage from the river to the alluvium, and there was no discharge of groundwater from the alluvium to the river.

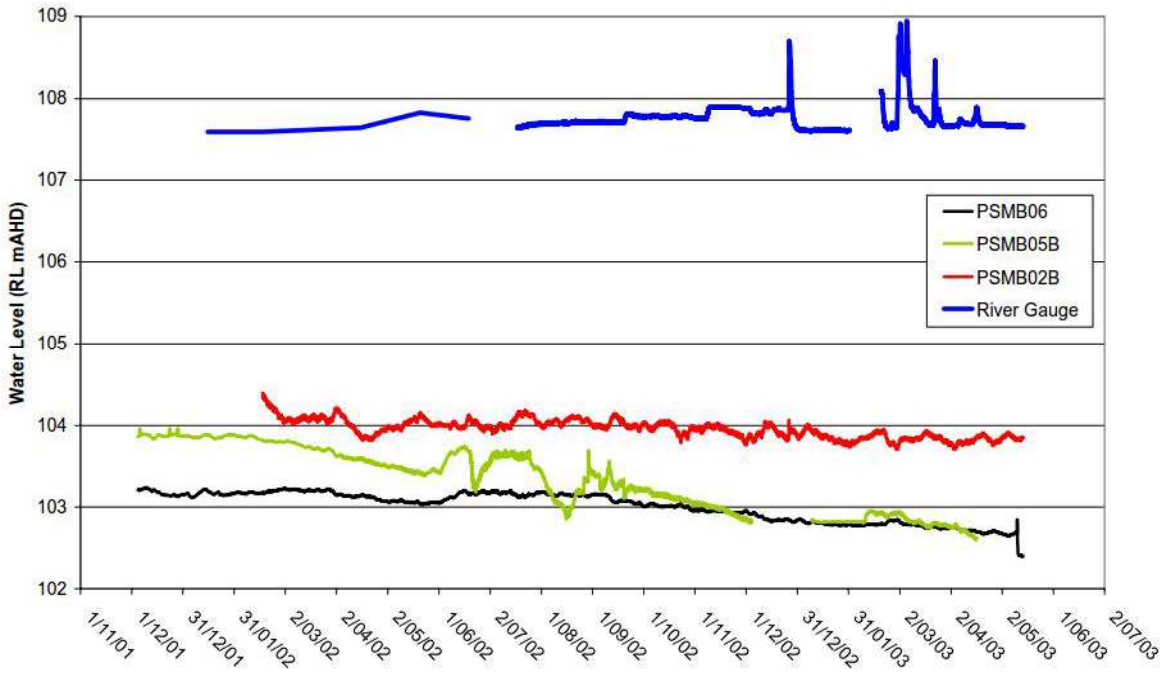


Figure 4.12 Mackenzie River stream levels compared to alluvium groundwater levels (reproduced from AGE, 2006)

Groundwater monitoring undertaken for the Mackenzie South Project had similar findings with water levels in alluvial bore MSP0203 immediately adjacent to the Mackenzie River measured at 4.2 m below the level in the Mackenzie River prior to the commencement of mining (AGE, 2006). It is noted that the monitoring undertaken for the Curragh North and Mackenzie South projects was undertaken during a period of low rainfall.

4.6.3.1 Observations of mining adjacent to the River

The Curragh North pits (S, T and U) experience inflows from the alluvium, which is thick and comprised of sand and gravel in this area. Average daily pit inflow data provided by Curragh Mine is presented in Section 6.1.

A review of inflows to Pit S by Douglas Partners (2014) indicated that at commencement of mining in late 2014, inflows were occurring from a water bearing sand and gravel unit at the base of the alluvium. Curragh Mine personnel have reported that saturated alluvium was encountered in Pit S at approximately 5 to 10 mbgl and initial dewatering rates for alluvium were 6.5 Ml/day.

After two months of mining in Pit S, the alluvium on the western pit wall face adjacent to Mackenzie River was dewatered and the majority of inflows were coming from the eastern pit wall face (pers. comm., Curragh Mine, September 2015). Monitoring bores screened to the base of the alluvium located between Mackenzie River and Pit S were dry or had water levels near the base.

Site observations of limited seepage in the western buttress wall suggest there is limited hydraulic connection between Mackenzie River and Pit S via the alluvium. This may be due to the low permeability of Mackenzie River stream bed materials or intervening low permeability silt and clay rich sediments between the river and pit. Curragh Mine personnel have observed that Mackenzie River has maintained flow throughout mining and pit inflows have not changed in relation to changing water levels in Mackenzie River or wet season rainfall conditions.

4.6.3.2 Stream bed materials

Inspection of stream bed materials in the Mackenzie River by AGE (2006) for the Mackenzie South Project, immediately downstream of Curragh North, found the material exposed in the banks to be clay bound gravels. This suggests the Mackenzie River stream bed is of low permeability, limiting seepage of water from the river to the alluvium.

Comparable stream bed materials were observed in the Nogoa River upstream, where a detailed study of connectivity between the river and underlying alluvium was undertaken for Ensham Mine (AGE, 2006). The study involved installation of 23 monitoring bores in alluvium along both sides of the Nogoa River and excavation of pits in the stream bed and showed that there was no connection between the alluvium and river (AGE, 2006). Results from a similar study for Baralaba Mine on the Dawson River also demonstrated no connection between the river and underlying alluvium. The results of these studies were supported by investigations undertaken by the Queensland government which involved drilling bores across the Nogoa River floodplain. The government study concluded '*it is unlikely that there is any connection between the river system and groundwater. Groundwater is restricted to the deeper section of the alluvium and there are large tracts of dry alluvium*' (Lloyd 1995, cited in AGE 2006).

4.6.3.3 Water quality

Water quality data for alluvial monitoring bores 1309MB and 1312MB and surface water in Mackenzie River are presented in Section 4.4.

Groundwater in alluvium is distinctly different from surface water in Mackenzie River. Groundwater in alluvium is brackish (<4,000 µS/cm) with neutral pH (6.8–7.8), compared to surface water in Mackenzie River which is fresh (<800 µS/cm) and slightly alkaline (pH 8–8.5). Groundwater in alluvium is dominated by sodium and chloride, compared to surface water which is dominated by calcium and bicarbonate.

Time series water quality data for the monitoring bores indicates that EC is stable and pH is increasing. Monitoring bores 1309MB and 1312MB are targeting mine water storage dam CN3, which stores pit inflow water from alluvium and Rangal Coal Measures. The increasing trend in pH is likely to reflect the water in Rangal Coal Measures, which has a median pH of approximately 7.5.

4.6.3.4 Conceptual model

The hydraulic connection between Mackenzie River and the underlying alluvium is of interest for the proposed mining at Pit X, which is located 760 m from Mackenzie River.

Groundwater investigations for the Curragh North project indicated that large sections of the alluvium are dry, and where water is present, it occurs within deeper sections of alluvium, including palaeochannels. Pre-mining water level data for the Curragh North and Mackenzie South projects indicates the river and alluvium are disconnected, with the water table occurring 3 to 5 m below the river; although Parsons Brinckerhoff (2003) note that monitoring was undertaken during a relatively dry period and groundwater levels may be higher during wetter periods.

Observations of mining through alluvium approximately 100 m from the Mackenzie River at Curragh North indicated large initial inflows when saturated alluvium was encountered followed by limited seepage in the pit wall face once alluvium was dewatered. This, combined with observations that Mackenzie River maintained flow throughout mining (pers. comm., Curragh Mine, September 2015), indicates seepage from the river to alluvium is not significant enough to compromise flow in the river or produce seepage to the pit. The limited seepage from the river is explained by the low permeability of the stream bed, which comprises clay bound gravels, and the low permeability of the upper sections of the alluvial profile, which comprises silt and clay.

A conceptual model of the interaction between surface water in Mackenzie River and groundwater in the underlying alluvium is presented in Figure 4.13. As shown in the figure, Mackenzie River is conceptualised to be a losing stream that is disconnected from the water table. During wetter times, Mackenzie River may be losing and connected.

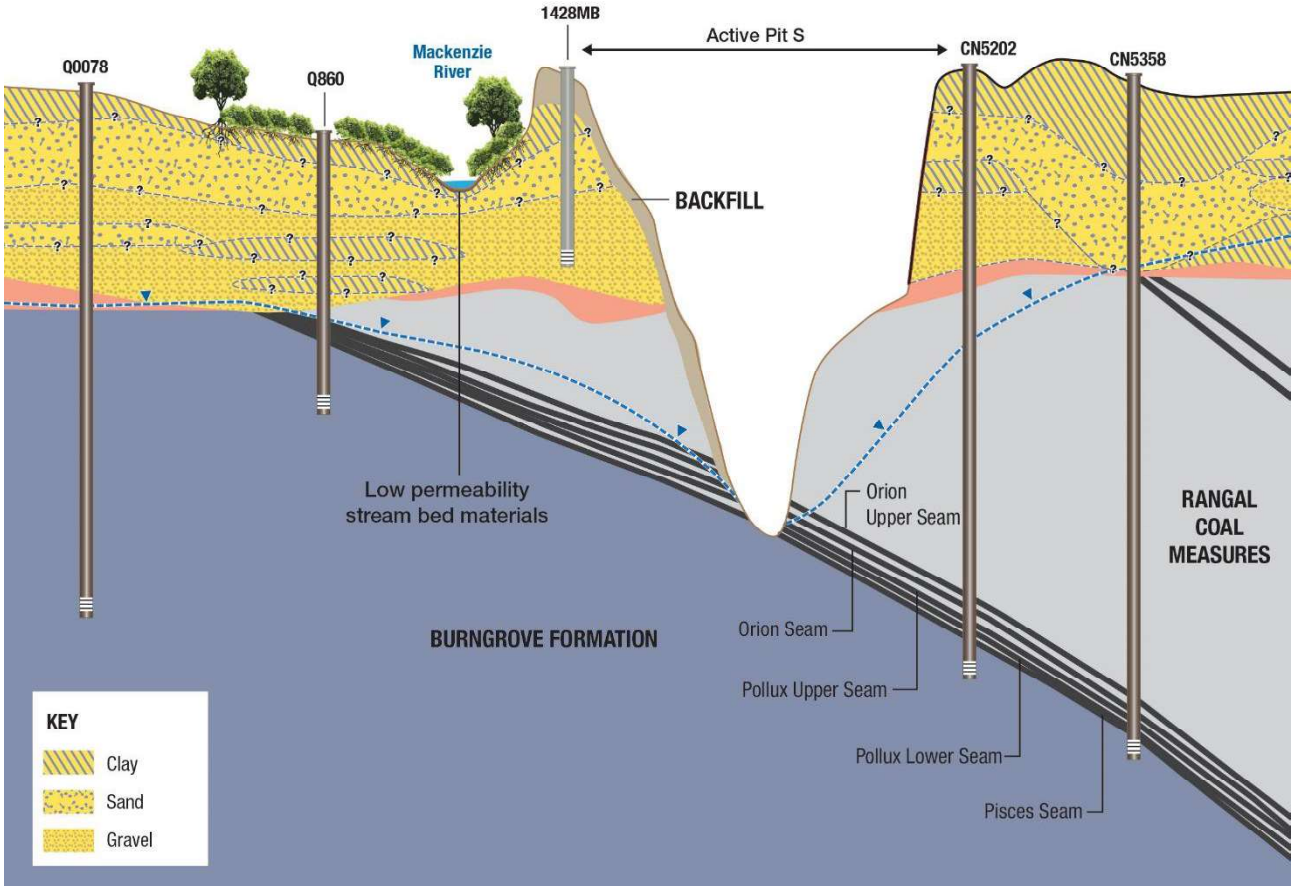


Figure 4.13 Conceptual model of surface water – groundwater interaction for Mackenzie River and underlying alluvium near Pit S

4.6.4 Blackwater Creek

Blackwater Creek is a tributary of Mackenzie River. It is a highly modified system having undergone three previous channel alterations due to Curragh Mine workings. The latest alteration involved the diversion of a 9.4 km length of Blackwater Creek in 2010.

The GDE Atlas suggests there is moderate potential for Blackwater Creek to interact with groundwater in two areas within the model domain:

- the upstream section of Blackwater Creek near Blackwater and the proposed Pit J extension
- the main channel of Blackwater Creek at its downstream end near proposed Pit X.

4.6.4.1 Upstream section

The upstream section of Blackwater Creek is conceptualised to be a losing stream that is disconnected from the water table.

The field investigation program for the Minyango project found the Blackwater Creek alluvium was only saturated in areas where there is a significant thickness of deeper alluvial sediment (AGE 2013). Within the study area, the Blackwater Creek alluvium forms a relatively thin heterogeneous system, with lenses of poorly connected clean sand separated by lower permeability clayey facies and bedrock highs. The constant flow in the upstream section of Blackwater Creek is understood to be from the Blackwater Wastewater Treatment Plant (WTP) which discharges effluent via Sagittarius Creek.

Current depth to groundwater (based on 2015 water levels from the calibrated numerical groundwater model) indicates the downstream section of Blackwater Creek is unlikely to receive baseflow from groundwater, with groundwater levels more than 3 m below the stream bed (Table 4.4).

Table 4.4 Depth to water table, Blackwater Creek upstream (2015)

Stream section (GDE Atlas ID)	Underlying formation	Depth to water table (2015) (mbgl)
2680623	Alluvium	3.12
2680633	Alluvium	3.55
2680705	Alluvium	4.21
2680729	Alluvium	4.49

mbgl – metres below ground level

4.6.4.2 Downstream section

The downstream section of Blackwater Creek is conceptualised to be a losing stream that is disconnected from the water table.

Current depth to groundwater (based on 2015 water levels from the calibrated numerical groundwater model) indicates the downstream section of Blackwater Creek is unlikely to receive baseflow from groundwater, with groundwater levels more than three metres below the stream bed (Table 4.5). This is supported by observations which indicate the downstream end of Blackwater Creek is observed to be dry except following rainfall.

A trend in groundwater quality within the Blackwater Creek alluvium (BH8A) whereby pH is increasing and electrical conductivity is decreasing suggests there may be increasing surface water input to the aquifer over time; although it is noted that BH8A is adjacent to Dams A and B which store mine water.

Table 4.5 Depth to water table, Blackwater Creek downstream (2015)

Stream section (GDE Atlas ID)	Underlying formation	Depth to water table (2015) (mbgl)
2680302	Alluvium	4.37
2680309	Alluvium	3.32
2680326	Alluvium	2.78
2680330	Alluvium	3.27
2680335	Alluvium	3.67
2680336	Alluvium	3.59
2680337	Alluvium	3.04
2680343	Alluvium	3.04
2680348	Alluvium	3.26
2680371	Alluvium	3.36
2680376	Alluvium	7.41
2680411	Alluvium	3.17
2680448	Alluvium	4.10
2680467	Alluvium	3.59
2680486	Alluvium	3.73

mbgl – metres below ground level

5. Water-related values and assets

5.1 Water-related environmental values

The Environmental Protection (Water) Policy 2009 (EPP Water) has been established to protect Queensland waters while allowing for ecologically sustainable development. It sets the broad environmental protection measures for the protection of Queensland waters and provides a framework for identifying environmental values (EVs) for aquatic ecosystems and human uses, and determining water quality guidelines and objectives (WQOs) to enhance or protect the EVs.

The study area is located within the Mackenzie River sub-basin of the Fitzroy River Basin, specifically within the Mackenzie main channel. Final EVs and WQOs have been adopted by the Queensland Government for this sub-basin and are included in *Mackenzie River Sub-basin Environmental Values and Water Quality Objectives* (DERM 2011) listed under Schedule 1 of the EPP Water.

The Receiving Environment Monitoring Program (Wesfarmers Curragh Pty Ltd 2014a) for Curragh Mine identifies the EVs that are relevant to groundwater and surface water systems in the study area. The EVs for Mackenzie River are relevant as mining may potentially impact on flows in the river. The EVs are presented in Table 5.1.

Table 5.1 Environmental values of Curragh Mine receiving environment (Wesfarmers Curragh Pty Ltd 2014a)

Environmental values	Fitzroy groundwaters	Mackenzie River
Aquatic ecosystems	✓	✓
Irrigation	✓	
Farm supply/use	✓	
Stock water	✓	✓
Aquaculture		
Human consumer	✓	✓
Primary recreation	✓	✓
Secondary recreation		
Visual recreation		
Drinking water	✓	✓
Industrial use		
Cultural and spiritual values	✓	✓

✓Means the EV is selected for protection
Blank indicates that the EV is not chosen for protection

5.2 Water-related assets

The water-related values in the study area are:

- bores used to extract groundwater for water supply
- works (including pumps and storages) used to extract surface water for water supply
- riverine wetlands and swamps along Blackwater Creek, Mackenzie River and Burngrove Creek
- terrestrial vegetation along Blackwater Creek, Mackenzie River and Minnie Creek.

Further details are provided below. Potential risks to water-related assets associated with the Project are discussed in Section 8.

5.2.1 Groundwater extractive use

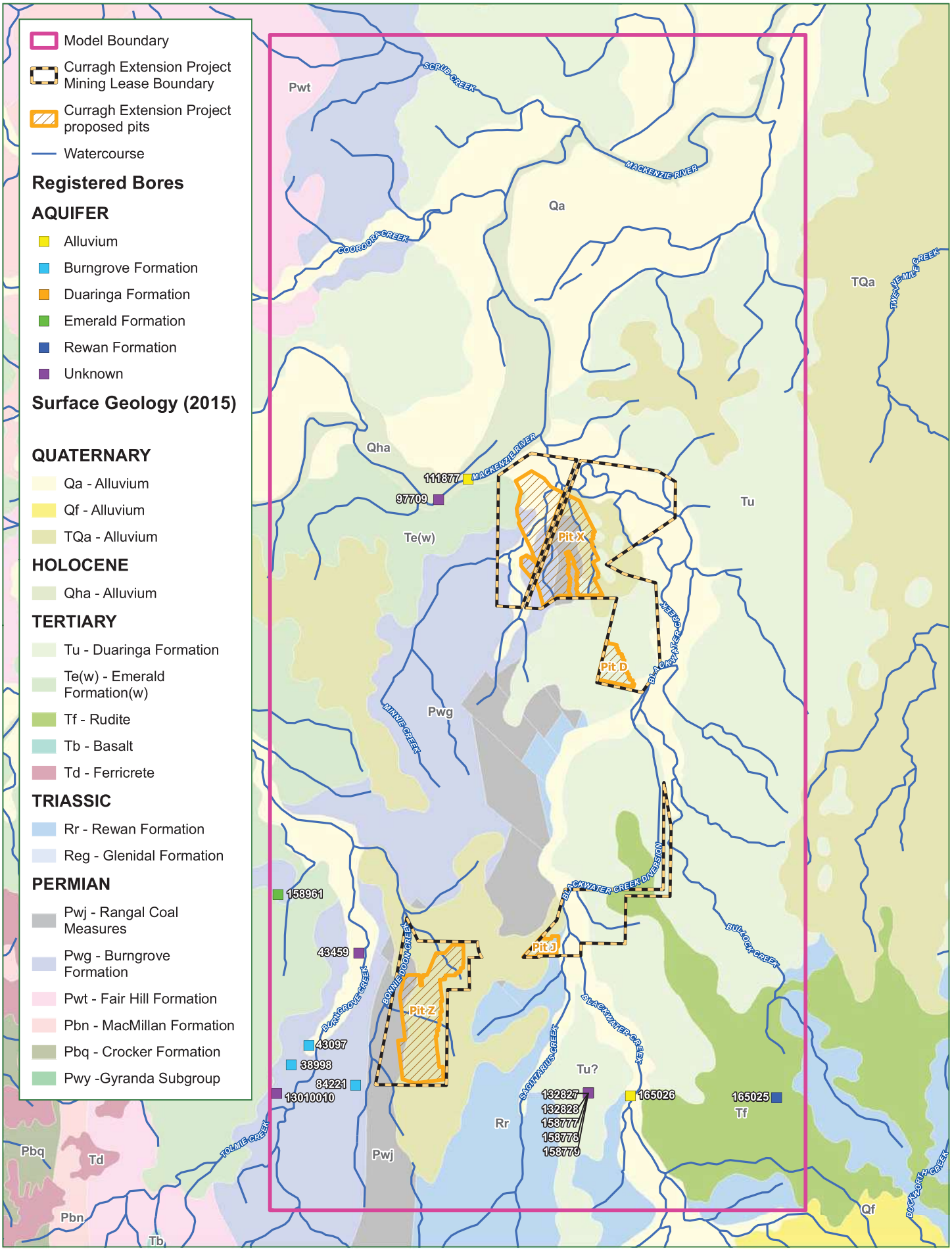
5.2.1.1 Registered bores

Groundwater bores in Queensland are registered in the DNRM groundwater database. There are 15 registered bores located within the study area (Table 5.2). The locations of registered bores within the study area are shown on Figure 5.1.

Table 5.2 Registered bores

RN	Hydrogeological unit	Depth (m)	Standing water level (mbgl)	Water quality	Yield (L/s)	Year installed	Distance from CEP pits (km)
38998	Burngrove Formation	28	9	Brackish	0.69	1972	4.2
43097	Burngrove Formation	20	9	Brackish	0.75	1972	3.4
43459	Burngrove Formation*	–	–	–	–	1900	2.0
84221	Burngrove Formation*	31	30	Salty	0.12	1988	1.8
97709^	Alluvium*	57	13	Fresh	3.2	1998	3.0
111877	Mackenzie River Alluvium	23	15	–	–	2002	1.8
132827	Duaringa Formation	–	4	–	–	2012	5.5
132828	Duaringa Formation*	–	–	–	–	2012	5.5
158777	Duaringa Formation*	–	–	–	–	2014	5.5
158778	Duaringa Formation*	–	–	–	–	2014	5.5
158779	Duaringa Formation*	–	–	–	–	2014	5.5
158961	Emerald Formation	–	36	Brackish	0.13	2014	5.8
165025	Rewan Formation	–	–	Salty	–	2015	10.1
165026	Alluvium	15	7	Salty	–	2015	6.1
13010010	Burngrove Formation	52	19	Brackish	–	2004	4.9

mbgl – metres below ground level
– not available
* Target formation not available, inferred based on underlying geology
^ Bore is abandoned but useable


Model Boundary
Curragh Extension Project Mining Lease Boundary
Curragh Extension Project proposed pits
Watercourse
Registered Bores
AQUIFER
Alluvium
Burngrove Formation
Duaringa Formation
Emerald Formation
Rewan Formation
Unknown
Surface Geology (2015)
QUATERNARY
Qa - Alluvium
Qf - Alluvium
TQa - Alluvium
HOLOCENE
Qha - Alluvium
TERTIARY
Tu - Duaringa Formation
Te(w) - Emerald Formation(w)
Tf - Rudite
Tb - Basalt
Td - Ferricrete
TRIASSIC
Rr - Rewan Formation
Reg - Glenidal Formation
PERMIAN
Pwj - Rangal Coal Measures
Pwg - Burngrove Formation
Pwt - Fair Hill Formation
Pbn - MacMillan Formation
Pbq - Crocker Formation
Pwy -Gyranda Subgroup
SCRUB CREEK
MACKENZIE RIVER
COOROORA CREEK
TWELVE MILE CREEK
MACKENZIE RIVER
BLACKWATER CREEK
MINNIE CREEK
BLACKWATER CREEK DIVERSION
BULLOCK CREEK
BOWIE BOOM CREEK
BURNGROVE CREEK
SAGITTARIUS CREEK
BLACKWATER CREEK
TOLMIE CREEK
DUCKWORTH CREEK
Pit X
Pit D
Pit J
Pit Z
111877
97709
158961
43459
43097
38998
84221
13010010
132827
132828
158777
158778
158779
165026
165025
Pwt
Qa
Qha
Te(w)
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Projection: Transverse Mercator
Coordinate System: AGD 1984 AMG Zone 55
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Data Source:
Geology from GSQ (2015)
Watercourse from DNRM (2016)
Mining data from WSP/PB (2016)
Groundwater impact assessment
Curragh Extension Project
Figure 5.1
Groundwater users
MXD Number: 2172652H_GIS_SW_F036_A3
Date: 15/06/2016
Author: SH
Approved by: LR
\\APBNEFIL03\proj\W\wesfarmers_resources\2172652H_Curragh_Extension_Phase_2\10_GIS\Projects\Maps\SufaceWater_Modeling\2172652H_GIS_SW_F036_A3.mxd

RN111877 is owned by Central Highlands Regional Council (Photo 5.1). The bore is screened in Mackenzie River alluvium and is located at the campground approximately 150 m south of Bedford Weir on Mackenzie River.

Central Highlands Regional Council have indicated the bore is used to irrigate grass near the playground at Bedford Weir and in the toilet block at the campground and that the groundwater is relatively saline. The bore pumps into a 45,000 L tank, which is filled 2 to 3 times each week.



Photo 5.1 Council bore at campground near Bedford Weir

5.2.1.2 Groundwater licences

The take of groundwater in the Project area is regulated by the Fitzroy Basin water resource plan (listed under the *Water Act 2000*) and resource operations plan. The water resource plan provides the management framework for groundwater resources in the Fitzroy Basin and the resource operations plan specifies the day-to-day rules and management arrangements for water users.

Groundwater in the study area is part of the Highlands Groundwater Management Area. The take of groundwater in this area requires a water licence. A search of the Queensland Government Water Entitlements website indicates there are no groundwater licences within the study area.

5.2.1.3 Beneficial use of groundwater

The beneficial use of groundwater is the suitability (quality) and availability (resource yield or level/pressure) of groundwater for consumptive use (e.g. domestic or agricultural use) and to support GDE.

A high level assessment of the beneficial use of groundwater for land use applications in the region has been undertaken. The assessment indicates the beneficial use of groundwater is limited to livestock usage due to poor water quality and relatively low yields. This is discussed below.

Water quality

An assessment of beneficial use with respect to water quality was undertaken by comparing key indicators of water quality (total dissolved solids and pH) with the relevant guideline values for different beneficial uses. The relevant guidelines include:

- Australian and New Zealand Environment Conservation Council (ANZECC) (2000) Guidelines for Fresh and Marine Water Quality.
- National Health and Medical Research Council (NHMRC) (2011) Australian Drinking Water Guidelines (ADWG).
- Queensland Water Quality Guidelines (DERM 2009).

The assessment indicates that groundwater in alluvium has quality suitable for livestock watering, and groundwater in Rangal Coal Measures and Burngrove Formation may be suitable for livestock usage in some areas but not in other areas due to elevated salinity levels.

Groundwater in the area is unfit for human consumption; up to 2500 µs/cm can be tolerated for human use although below 800 µs/cm is considered good water. The brackish to saline nature of groundwater is unsuitable for drinking water or irrigation; however groundwater resources may be suitable for industrial use, such as mining purposes including mineral/coal processing or dust suppression.

Resource yield

An assessment of registered bores within 30 km of the Curragh Mine project by Douglas and Partners (2012) indicated groundwater yields of up to 4 L/s and an average yield of 1 L/s. These yields are relatively low and although able to provide restricted beneficial use for watering stock or domestic use, they would not be suitable for high quantity uses such as irrigation or mineral/coal processing.

Yield data for registered bores within 5 km of the Project area is presented in Table 5.2. The data indicates that aquifers in the vicinity of the Project are generally low yielding, with bores producing less than 1 L/s.

5.2.2 Surface water extractive use

Consumptive surface water use in the Fitzroy Basin includes stock and domestic, agricultural, industrial, and town water supply.

The take of surface water in the study area is regulated by the Fitzroy Basin water resource plan (listed under the *Water Act 2000*) and resource operations plan. The water resource plan provides the management framework for surface water resources in the Fitzroy Basin and the resource operations plan specifies the day-to-day rules and management arrangements for water users and infrastructure operators.

Mackenzie River is part of the Nogoa-Mackenzie Water Supply Scheme. Surface water users in this scheme hold tradable water allocations to take supplemented water which is delivered from Fairbairn Dam via a series of weirs. Other surface water users on Mackenzie River hold unsupplemented water allocations to take water from the Nogoa Mackenzie Water Management Area during high flow conditions.

Tributaries of Mackenzie River located within the study area are part of the Upper Mackenzie subcatchment. Surface water users hold water licences to take water from these tributaries.

5.2.2.1 Supplemented water allocations

Supplemented water allocations in the study area are taken from the following zones on the Mackenzie River:

- Mackenzie 'H' – 513.0 - 548.8 km AMTD being the effective upstream limit of Bingegang Weir to Bedford Weir
- Mackenzie 'I' - 548.8 - 585.8 km Adopted Middle Thread Distance (AMTD) being Bedford Weir to the effective upstream limit of Bedford Weir.

Details of supplemented water allocation holders in these zones are provided in Table 5.3. The data is from the Department of Natural Resources and Mines (DNRM) Water Entitlements database (2016) and Fitzroy Basin resource operations plan 2004.

Table 5.3 Supplemented water allocations in the study area

Authorisation number	Converting authorisation*	Authorised purpose	Nominal Entitlement (Ml/water year)	Priority*
Mackenzie 'H'				
296AP6829	38974F	Agriculture	519	Medium
289AP6829	33113F	Agriculture	200	Medium
298AP6829	52676F	Agriculture	100	Medium
814AP6829	171191	Any	220	High
294AP6829	103088	Any	70	High
295AP6829	057826F	Agriculture	309	Medium
Mackenzie 'I'				
380AP6829	103026	Any	309	High
483AP6829	na	Agriculture	100	na
899AP6829	174792	Any	1500	High
300AP6829	52669F, 52675F	Any	1828	Medium
306AP6829	103072	Any	2800	High
307AP6829	103074	Any	1603	High
308AP6829	29241F	Any	245	Medium
379AP6829	103025	Any	1155	High
5297AP6829	na	Any	533	na
302AP6829	103087	Any	1333	High
305AP6829	103081	Any	678	High
311AP6829	52647F, 52660F	Agriculture	1100	Medium

Authorisation number	Converting authorisation*	Authorised purpose	Nominal Entitlement (Ml/water year)	Priority*
377AP6829	103011	Any	300	High
378AP6829	103013	Any	200	High
5296AP6829	na	Any	800	na
303AP6829	103080	Any	1500	High
304AP6829	103076	Any	1595	High
627AP6829	na	Agriculture	25	na
929AP6829	103027	Distribution Loss	313	High

(1) * Fitzroy Basin ROP 2004
(2) na – not available

5.2.2.2 Unsupplemented water allocations

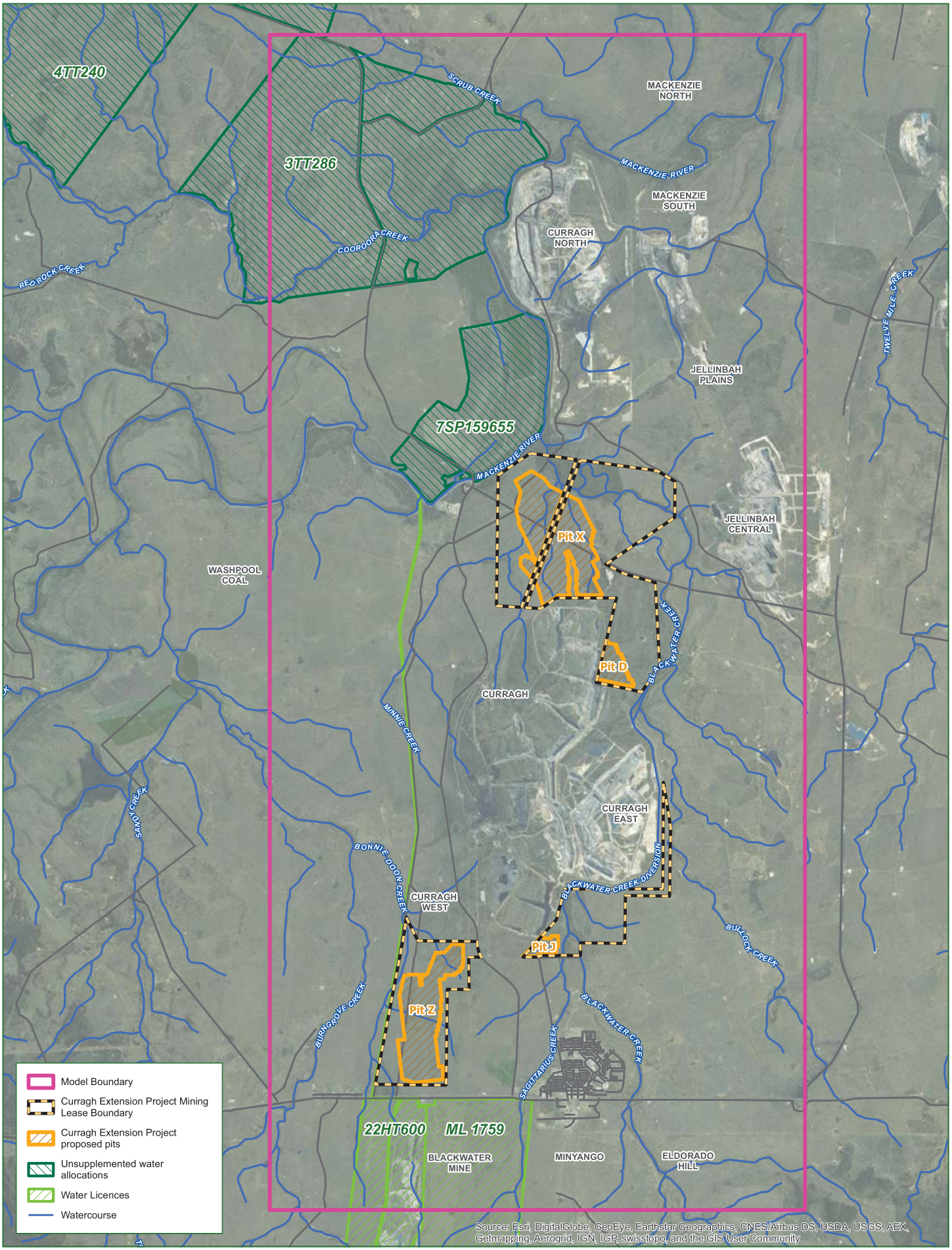
Unsupplemented water allocations in the study area are taken from the Mackenzie 'H' and Mackenzie 'I' zones on Mackenzie River.

Details of unsupplemented water allocations in the study area are provided in Table 5.4. The data is from the Department of Natural Resources and Mines (DNRM) Water Entitlements database (2016) and Fitzroy Basin resource operations plan 2013. The locations of the unsupplemented water allocations is shown on Figure 5.2.

Table 5.4 Unsupplemented water allocations and water licences in the study area

Lot Plan	Authorisation number (converting authorisation in brackets)	Location and WAG	NV (Ml/ water year)	VL (Ml/ water year)	Max rate (L/s)	Passing flow condition (Ml/ day passing flow)	Purpose
3TT286	299 (104986)	Mackenzie H Class 2A	902	1236	650	2592	Agriculture
7SP159655	327 (57831F)	Mackenzie I Class 2B	1,622	2,350	1,600	4,320	Agriculture
	310 (57830F)	Mackenzie I Class 2B	1622	2350	1600	4320	Agriculture
	329 (57832WF)	Mackenzie I Class 2B	1622	2350	1600	4320	Agriculture
	333 (57832WF)	Mackenzie I Class 2B	1622	2350	1600	4320	Agriculture
	301 (52675F)	Mackenzie I Class 2A	416	570	300	2592	Agriculture
	301 (105195)	Mackenzie I Class 2A	416	570	300	2592	Agriculture

WAG – Water allocation group
NV – Nominal volume
VL – Volumetric limit



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0 0.5 1 2 3 4 km

Scale 1:135,000

Scale correct when printed at A3 Portrait

Projection: Transverse Mercator
Coordinate System: GDA 1994 MGA Zone 55

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Data Source:
Cadastre, ML, watercourses, streets from DNRM (2015)

Groundwater impact assessment
Curragh Extension Project
Figure 5.2
Surface water users

MXD Number: 2172652H_GIS_SW_F039_A2
Date: 20/06/2016
Author: VD
Approved by: LR

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5.2.2.3 Water licences

There are three water licences in the study area (Table 5.5). All three licences are associated with Blackwater Mine to the south of the Project. Two of the licences of to divert streams around mine workings. One licence is to impound water on Burngrove Creek outside the study area.

Table 5.5 Water licences in the study area

Lot Plan	Authorisation number	Location	Purpose	Licence type
ML1759 (Blackwater Mine)	609051	Sagittarius Creek	Divert the course of flow	Licence to interfere by diversion – Channel
22HT600 (Blackwater Mine)	40137F	Burngrove Creek	Divert the course of flow	Licence to interfere by diversion – Other
	51464F	Burngrove Creek	Impound water	Licence to interfere by impounding – Embankment or wall

5.2.3 Groundwater dependent ecosystems

The purpose of this section is to provide an overview of the likely extent and location of potential groundwater dependent ecosystems (GDEs) within the study area potentially affected by groundwater drawdown as a result of the Project. The study area has been set as the maximum extent of groundwater drawdown expected based on water level information from existing operations (Section 6) and the numerical groundwater model (Section 7).

Groundwater dependent ecosystems are defined as "*ecosystems which require access to groundwater on a permanent or intermittent basis to meet all or some of their water requirements so as to maintain their communities of plants and animals, ecological processes and ecosystem services* (DSITIA 2013a)."

Under this definition: The ecosystem must have access to groundwater; and the ecosystem must use groundwater (e.g. must utilise groundwater during the dry season or during drought periods). It is important to understand that groundwater dependence is only an attribute of an ecosystem and must be combined with other attributes to characterise the ecosystem. For example, there may be terrestrial systems, some of which are GDEs while others are non-GDEs. The 'Queensland Groundwater Dependent Ecosystem Mapping and Classification Method (DSITIA 2012)' lists the types of GDEs that may occur within landscapes in Queensland and further describes their defining characteristics (refer Table 5.6).

Table 5.6 Groundwater dependent ecosystem sub-types and their defining characteristics (DSITIA 2013a)

GDE type	GDE sub-type	Defining characteristic(s)
Ecosystems dependent on the surface expression of groundwater ('surface expression GDEs')	Wetland – Lacustrine (large open water dominated systems)	▪ lakes with gaining or variable gaining/losing aquifer connectivity ▪ indicated by maintained lake water availability regardless of surface water availability
	Wetland – Palustrine (inland non tidal characterised by trees, shrubs and emergent vegetation – e.g. swamps, bogs, floodplain)	▪ palustrine wetlands with gaining or variable gaining/losing aquifer connectivity
	Wetland – Riverine water body	▪ streams with gaining or variable gaining/losing aquifer connectivity

GDE type	GDE sub-type	Defining characteristic(s)
		■ indicated by maintained river water availability regardless of surface water availability
	Wetland – Springs	■ springs have inherent gaining aquifer connectivity
Ecosystems dependent on the sub-surface presence of groundwater ('terrestrial GDEs')	Terrestrial ecosystems	■ groundwater presence within the root zone ■ indicated by vegetation vigour regardless of surface water availability
	Wetland – Riverine regional ecosystem	■ riverine regional ecosystems with groundwater connectivity
Subterranean aquatic ecosystems ('subterranean GDEs')	Aquifer ecosystems	■ aquifer ecosystems are innately groundwater dependent ■ it is assumed that stygofauna are potentially present in all aquifers where suitable habitat occurs ■ measured by stygofauna surveys.
	Cave ecosystems	■ caves with some degree of groundwater connectivity ■ indicated by cave ecosystems, moisture levels and presence of stygofauna.

5.2.3.1 Groundwater dependent ecosystem assessment methods

A number of datasets have been used to classify and map the potential GDEs within the study area including:

- Groundwater Dependent Ecosystems Atlas (GDE Atlas) (Bureau of Meteorology 2015).
- Groundwater Dependent Ecosystems (GDEs) Terrestrial (DSITIA Terrestrial GDEs) Area Features Version 1.4 (DSITIA 2015).
- Regional Ecosystem (RE) Mapping Version 8.1 (Queensland Herbarium 2015).
- Curragh Expansion Project field verified RE mapping (Appendix C1: Terrestrial Biodiversity Report of the Preliminary Documentation 2015).
- Curragh Extension Project groundwater conceptualisation, saturated and unsaturated alluvium (Section 4), and modelled depressurisation zone (Section 7).
- Groundwater Dependent Ecosystems (GDEs) Surface Expression Lines and Point Features (DSITIA Surface Expression GDEs) Version 1.4 (DSITIA 2015).

It is important to note that both the GDE Atlas mapping (BOM 2015b) and DSITIA (2015) terrestrial and surface expression GDE mapping layers are indicative regional scale mapping layers based on regional scale data sets. Because desktop methods are based on regional scale data they generally tend to overestimate the extent of GDEs (Richardson et al. 2011). Given this potential, a more detailed assessment of potential GDEs within the study area has been prepared based on a conceptualised groundwater model and an assessment of the potential field verified and Queensland Herbarium mapped regional ecosystems (REs) within the study area that are more likely to rely on the presence of groundwater and/or surface water for their survival.

In addition to assessing areas of surface expression and subsurface GDEs in the study area, an assessment of stygofauna (subterranean aquifer ecosystems) has also been conducted and presented in Appendix B3 to the Supplementary Information.

5.2.3.2 GDEs reliant on the surface expression of groundwater

Several areas of GDEs reliant on the surface expression of groundwater (referred to as “surface expression GDEs” in this report) were returned from the BOM GDE atlas mapping with potential to occur within the study area (Figure 5.3).

The BOM GDE atlas mapping identified three watercourses in the study area with potential to rely on the surface expression of groundwater:

- Mackenzie River
- Cooroora Creek, a tributary of Mackenzie River
- Blackwater Creek.

The Queensland Government DSITIA (2015) surface expression GDE mapping only identified a small section of Blackwater Creek, near the township of Blackwater, as a moderate confidence surface expression GDE (Figure 5.4).

As discussed in Section 4.6, watercourses in the study area are unlikely to receive baseflow from groundwater, and are more likely to be losing streams that are disconnected from groundwater. Information on the instream aquatic ecosystems associated with these streams is provided in Appendix C2: Aquatic Ecology Assessment Report of the Preliminary Documentation.

The BOM GDE atlas also identifies a number of wetlands in the study area that may rely on the surface expression of groundwater (refer Figure 5.3):

- Riverine wetlands
- Palustrine wetland (floodplain grass, sedge and herb swamps)
- Palustrine wetlands (floodplain tree swamps).

An initial assessment of the likelihood of occurrence of wetlands within the study area was conducted based on the predicted depth to the water table at the location of the wetland. The depth to the water table is based on groundwater levels predicted by the numerical groundwater model for the ‘base case’ simulation. The ‘base case’ simulation is all development likely to occur excluding the proposed Curragh Extension Project. The results of this assessment are presented below.

Information on the instream aquatic ecosystems associated with these wetlands is provided in Appendix C2: Aquatic Ecology Assessment Report of the Preliminary Documentation (October 2015) and Appendix B3 to the Supplementary Information.

Riverine wetlands

The GDE Atlas identified potential riverine wetlands within the study area as listed in Table 5.7 and shown on Figure 5.3. The riverine wetlands in the study area, associated with tributaries of Mackenzie River and Blackwater Creek, are however conceptualised as losing and disconnected systems. Results from the calibrated numerical groundwater model indicate the depth to the water table at the location of the GDE Atlas wetlands is more than 4 metres (Table 5.7). Wetlands underlain by alluvium may however be fed by perched groundwater in some localised areas where clay layers in the alluvium prevent the downward movement of water.

Table 5.7 Depth to water table, riverine wetlands

Stream	Wetland ID (BOM GDE Atlas)	Wetland area (ha)	Depth to water table (base case) (mbgl)	Location
Scrub Creek	3798601	1679	5.2	Outside mining areas
Tributary of Mackenzie River	3798803	1.00	17	Located within Mackenzie North project area
	3798833	1.56	57	
	3798851	2.26	120	
	3798865	4.13	27	
	3798877	2.64	23	
Tributary of Mackenzie River	3798955	6.87	15	Located within Mackenzie South project area
Minnie Creek	3799151	6.07	4.0	Located within Pit X area

(1) mbgl – metres below ground level

Palustrine wetland (floodplain grass, sedge and herb swamps)

Floodplain grass, sedge and herb swamps in the study area are listed in Table 5.8 and shown in association with Palustrine wetlands on Figure 5.3.

The swamps are located on floodplains of Mackenzie River and its tributaries, which are conceptualised as losing and disconnected systems. Results from the calibrated numerical groundwater model indicate the depth to the water table at the location of the swamps is more than 8.9 metres (Table 5.8), so even if swamps are incised 5 mbgl they are unlikely to be connected to groundwater. Swamps underlain by alluvium may be fed by perched groundwater in some areas.

Table 5.8 Depth to water table, floodplain grass, sedge and herb swamps

Location	Wetland ID (BOM GDE Atlas)	Wetland area (ha)	Depth to water table (base case) (mbgl)
Floodplain of Mackenzie River near Scrub Creek	3798876	1.74	16
	3798885	1.86	17
	3798870	6.87	17
Floodplain of tributary of Mackenzie River	3799020	18.5	8.9
	3799021	7.33	9.2
	3799028	2.64	7.2

(1) mbgl – metres below ground level

Palustrine wetlands (floodplain tree swamps)

Floodplain tree swamps (Melaleuca and Eucalypt) in the study area are listed in Table 5.9 and shown in association with Palustrine wetlands on Figure 5.3. A number of the swamps are located within existing or proposed mining areas and will experience direct impacts due to excavation of pits.

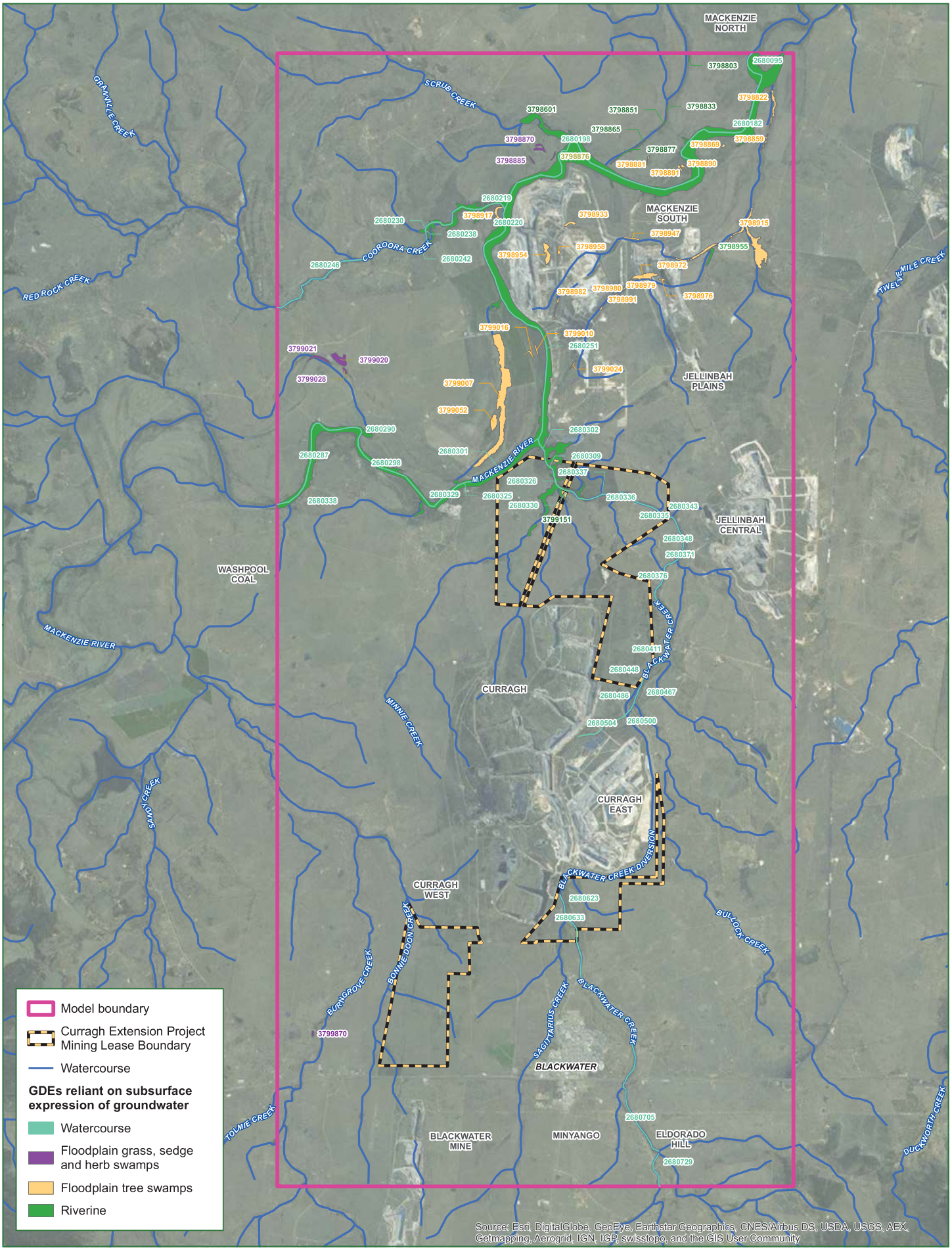
The swamps are located on floodplains of Mackenzie River and its tributaries, which are conceptualised as losing and disconnected systems. Results from the calibrated numerical groundwater model indicate the

depth to the water table at the location of the swamps is generally more than 8 metres (Table 5.9), so even if swamps are incised 5 m below ground level they are unlikely to be connected to groundwater. The depth to the water table is 4.1 metres at one swamp near Burngrove Creek (3799870). Swamps underlain by alluvium may be fed by perched groundwater in some areas.

Table 5.9 Depth to water table, floodplain tree swamps

Closest stream	Wetland ID (BOM GDE Atlas)	Wetland area (ha)	Depth to water table (base case) (mbgl)	Location
Mackenzie River	3798881	1.45	27	Within Mackenzie North project area
	3798890	1.75	18	
	3798891	2.16	21	
Tributaries of Mackenzie River	3798822	11.4	11	East of Mackenzie North project
	3798859	3.07	11	
	3798869	1.48	12	
Mackenzie River	3798933	4.39	135	Within Curragh North project area
	3798954	14.4	146	
	3798958	1.64	47	
Tributaries of Mackenzie River	3798982	3.71	139	
	3799024	1.94	110	
	3798980	1.44	18	
	3798991	1.25	20	
	3798979	1.44	17	
Cooroora Creek	3798917	6.72	7.2	West of Mackenzie River near Pit U
Tributary of Mackenzie River	3799007	147.4	16	West of Mackenzie River near Pit S
	3799052	13.7	8.3	
Mackenzie River	3799010	2.47	21	
	3799016	2.64	22	
Tributaries of Mackenzie River	3798947	3.87	22	Within Mackenzie South project area
	3798972	19.3	23	
	3798976	2.12	32	
Tributary of Mackenzie River	3798915	78.0	19	East of Mackenzie South project
Burngrove Creek	3799870	1.56	4.1	West of Burngrove Creek near proposed Pit Z

(1) mbgl – metres below ground level



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0 0.5 1 2 3 4 km

Scale 1:140,000

Scale correct when printed at A3 Portrait

Projection: Transverse Mercator
Coordinate System: AGD 1984 AMG Zone 55

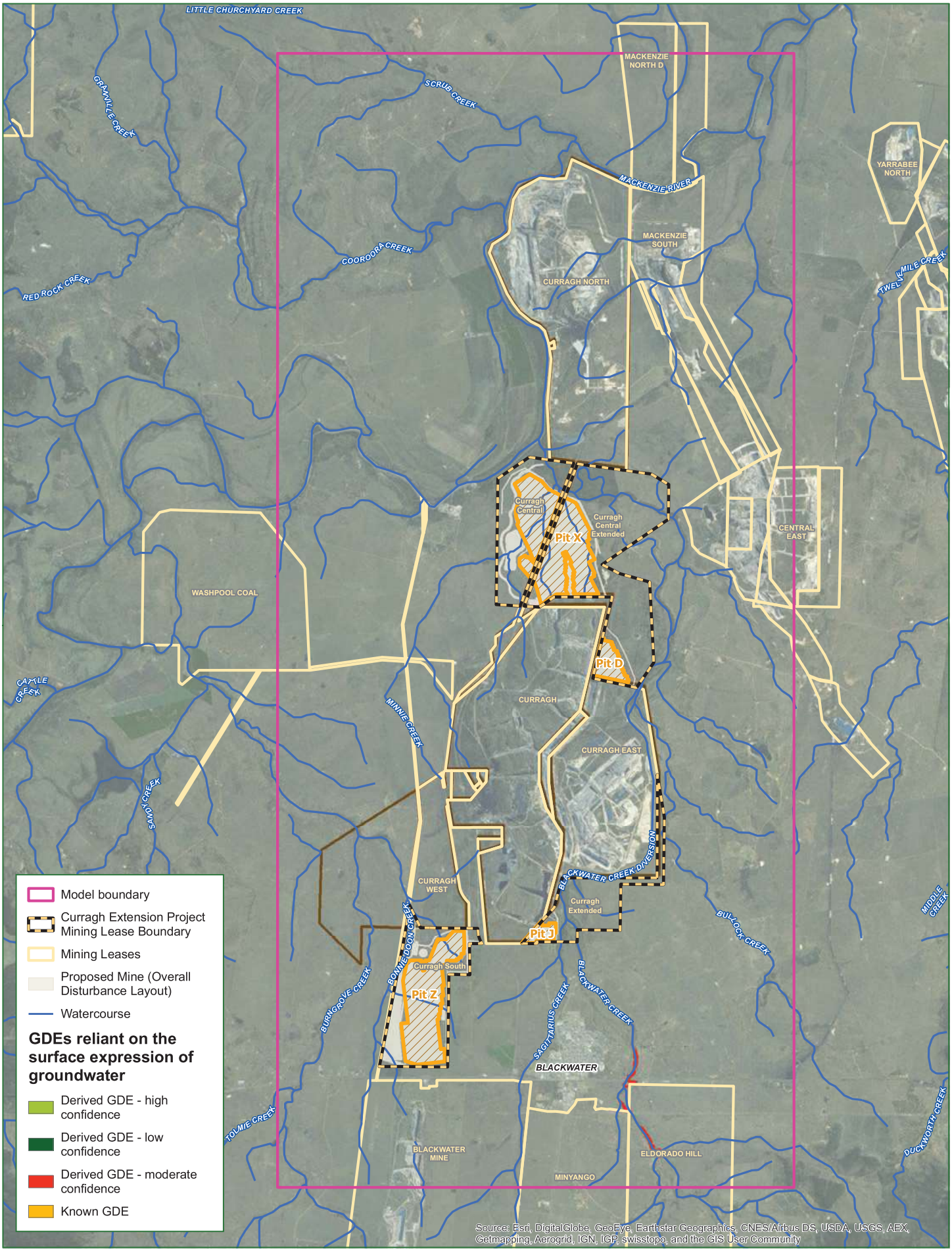
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Groundwater impact assessment
Curragh Extension Project
Figure 5.3
BOM Atlas GDEs reliant on the surface expression of groundwater

MXD Number: 2172652H_GIS_SW_F046_A5
Date: 16/06/2016
Author: AM
Approved by: LR

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Groundwater impact assessment
Curragh Extension Project
Figure 5.4
DSITIA GDEs reliant on the surface expression of groundwater

MXD Number: 2172652H_GIS_SW_F050_A1
Date: 20/06/2016
Author: AM
Approved by: LR

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5.2.3.3 GDEs reliant on the subsurface expression of groundwater

Several areas of terrestrial GDEs reliant on the presence of subsurface groundwater (referred to as "subsurface GDEs" in this report) were returned from the GDE Atlas (BOM 2015) (Figure 5.5) and the DSITIA (2015) terrestrial GDE mapping (Figure 5.6) with potential to occur in the study area.

It is important to note that both the subsurface GDE Atlas mapping (Figure 5.5) and the DSITIA (2015) terrestrial GDE mapping (Figure 5.6) are based on regional scale data sets and have the potential to overestimate the area of potential subsurface GDEs. Given this potential a more detailed assessment of the potential occurrence of subsurface GDEs within the study area has been prepared based on a combination of:

- the conceptualised groundwater model (Section 4)
- areas of saturated alluvium based on numerical groundwater modelling for the 'base case' simulation. The 'base case' simulation is all development likely to occur excluding the proposed Curragh Extension Project (Figure 5.7)
- the field verified and Queensland Herbarium mapped regional ecosystems considered likely to be reliant on the presence of water (surface water or groundwater) for their survival
- the Queensland Groundwater Dependent Ecosystem Mapping and Classification Method (DSITIA 2012) (baseline mapping).

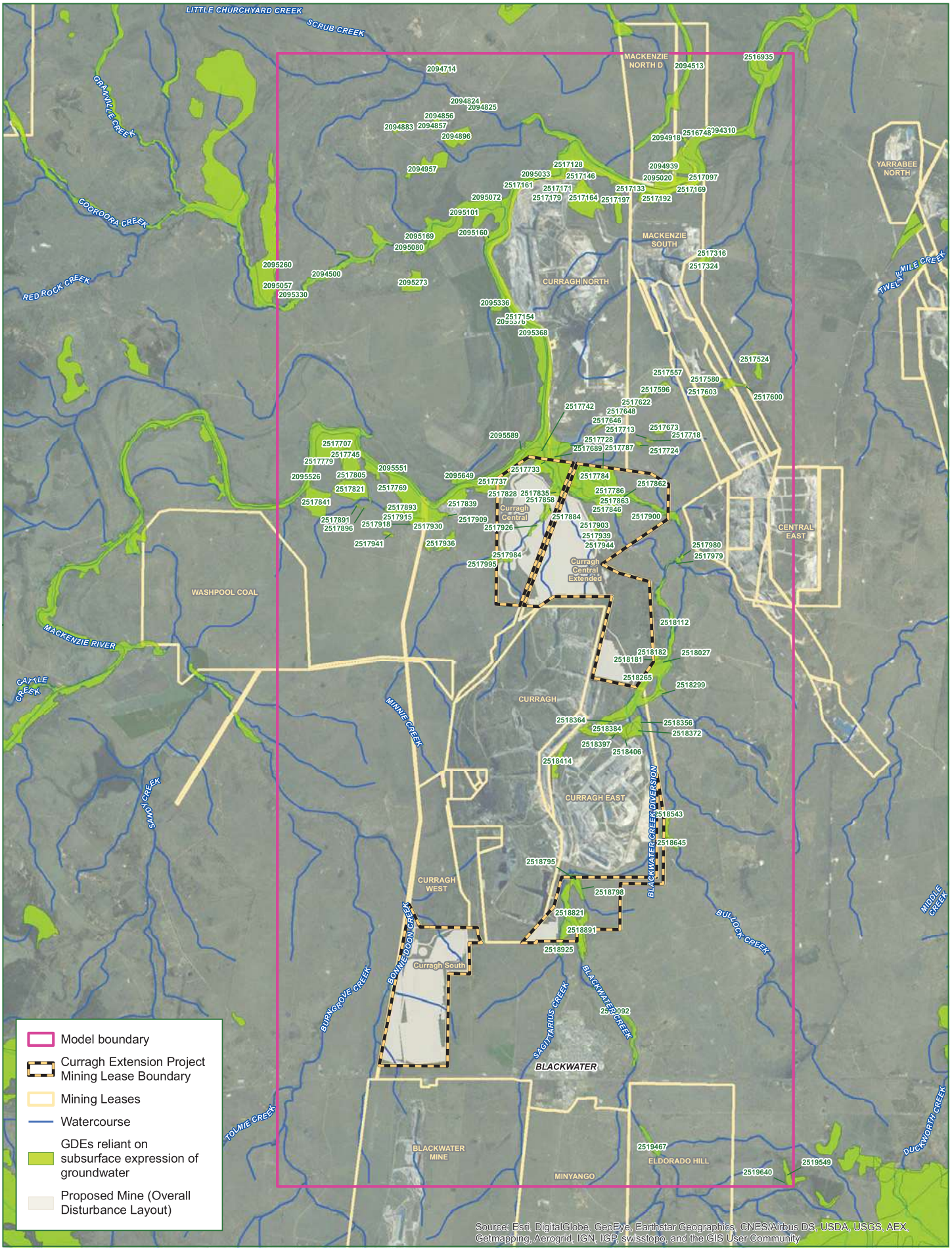
The detailed method is primarily desktop based and is consistent with following methods used to classify and map subsurface GDEs:

- Australian groundwater-dependent ecosystems toolbox part 1 and part 2: assessment framework (Richardson et al. 2011).
- Groundwater Dependent Ecosystem Mapping and Classification Method: a method for providing baseline mapping and classification of GDEs in Queensland (DSITIA 2012) (classification).
- Queensland Groundwater Dependent Ecosystem Mapping Technical Mapping Specifications (DSITIA (2013a).
- Desktop assessment of groundwater dependent ecological assets (GDEAs) associated with the Central Condamine Alluvium Area, Strategic Water Policy, Department of Environment and Resource Management, Queensland (Tomlinson 2009).

The likelihood of the regional ecosystems within the study area relying on groundwater has been assessed based on the following:

- an assessment of the watering requirements for each RE based on the presence/absence of ecological dominant species reliant on groundwater
- the underlying geology and geomorphology in which the REs occur (land zones)
- groundwater modelled areas of saturated alluvium and depth to groundwater within saturated alluvium.

It should be noted that the groundwater modelled areas of saturated alluvium is likely to be overestimated. Field investigations at Curragh North prior to mining found the alluvium to be variably saturated, with many areas dry.



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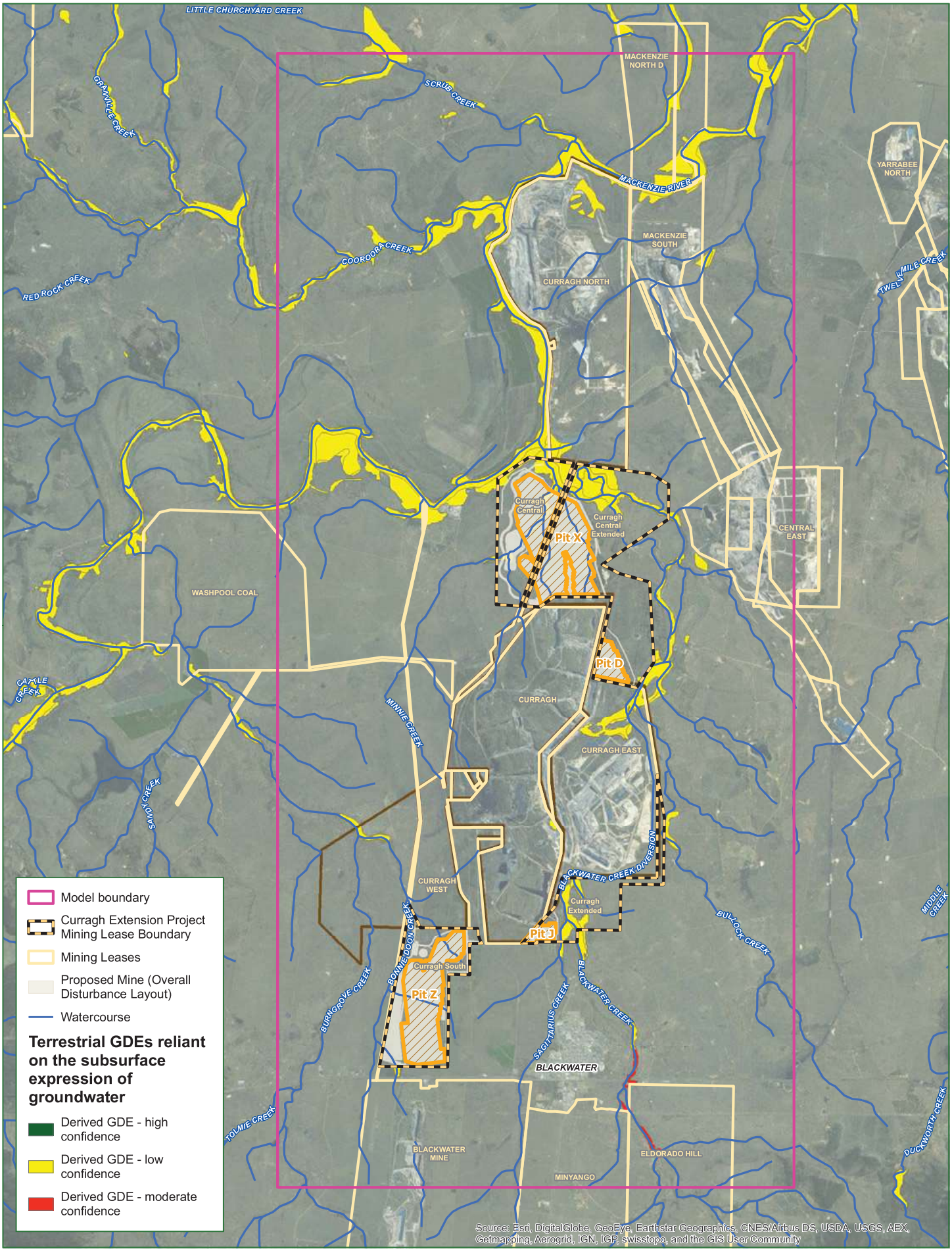
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Groundwater impact assessment
Curragh Extension Project
Figure 5.5
BOM Atlas GDEs reliant on the subsurface presence of groundwater

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Groundwater impact assessment
Curragh Extension Project
Figure 5.6
DSITIA Terrestrial GDEs reliant on the subsurface presence of groundwater

MXD Number: 2172652H_GIS_SW_F051_A1
Date: 20/06/2016
Author: AM
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Watering requirements for regional ecosystems within the study area

The regional ecosystems in the study area determined likely to be dependent on the supply of water (surface or groundwater) include those with *Eucalyptus* spp. (i.e. *E. tereticornis/ E. coolabah*) and/or *Melaleuca* spp. restricted to Quaternary alluvium, fringing riparian channels (land zone 3) and/or older Tertiary alluvium (land zone 5), including but not limited to:

- *Eucalyptus tereticornis* and *Melaleuca bracteata* (associated with RE 11.3.25)
- *E. coolabah* (associated with RE 11.3.3 and RE 11.3.3a).

The groundwater dependence for other regional ecosystems within the study area dominated by other *Eucalyptus* spp. (i.e. *E. populnea*) and/ or *Acacia* spp. (*A. harpophylla*), is not considered as likely given these species occur on a variety of geologies and land zones that are known to be disconnected to surface and/or groundwater systems.

The level of reliance upon water (surface and/or groundwater) by these plants within likely subsurface GDEs is however poorly understood (Holloway et al. 2013). The watering requirements of vegetation species is thought to vary depending upon the hydrological characteristics of the soils, the availability of surface water and sub-surface water and the intrinsic water requirements each of the plant species (Holloway et al. 2013).

Eucalyptus spp. *and Melaleuca* spp.*,* like many Australian trees, have a dimorphic root system, with lateral roots that are close to the surface, and a taproot that penetrates deep into the soil up to 9 to 10 m (Holloway et al. 2013). The dimorphic root system allows the trees to take advantage of both surface and groundwater resources (most likely when within less than 10 m depth to water table).

Table 5.10 provides a list of the likely, potential and unlikely groundwater dependent REs within the study area based on the species present within the ecological dominant layer of the ecosystem and the underlying geology or land zone in which they occur.

Table 5.10 GDE likelihood table for REs mapped within the study area

Regional Ecosystem (RE)	Data source	RE Description	VM Status	EPBC Act Status	Likelihood of groundwater dependence
11.3.1	DEHP and Field Verified RE	*Acacia harpophylla* and/or *Casuarina cristata* open forest on alluvial plains	Endangered	Endangered	Potential
11.3.1x	Field Verified RE	*Acacia harpophylla, Terminalia oblongata* and *Eucalyptus coolabah* on alluvial plains and channels	Endangered	Endangered	Potential
11.3.2	DEHP	*Eucalyptus populnea* woodland on alluvial plains	Of Concern	NA	Potential
11.3.2/ 11.3.25	DEHP	Mixed polygon see full descriptions for each individual RE in this table.	Of Concern/ Least Concern	NA	Potential/ Likely
11.3.25	DEHP and Field Verified RE	*Eucalyptus tereticornis* or *E. camaldulensis* woodland fringing drainage lines	Least Concern	NA	Likely
11.3.2/ 11.3.25/ 11.3.3/ 11.3.1	DEHP	Mixed polygon see full descriptions for each individual RE in this table.	Of Concern/ Least Concern/ Of Concern/ Endangered	Endangered (RE 11.3.1)	Potential/ Likely/ Likely/ Potential

Regional Ecosystem (RE)	Data source	RE Description	VM Status	EPBC Act Status	Likelihood of groundwater dependence
11.3.2/ 11.3.1/ 11.3.3/ 11.3.25	DEHP	Mixed polygon see full descriptions for each individual RE in this table.	Of Concern/ Endangered/ Of Concern/ Least Concern	Endangered (RE 11.3.1)	Potential/ Potential/ Likely/ Likely
11.3.25/ 11.3.3	DEHP	Mixed polygon see full descriptions for each individual RE in this table.	Least Concern	NA	Likely
11.3.25/ 11.3.3a	DEHP and Field Verified RE	Mixed polygon see full descriptions for each individual RE in this table.	Least Concern/ Of Concern	NA	Likely
11.3.25/ 11.3.3/ 11.3.3c	DEHP	Mixed polygon see full descriptions for each individual RE in this table/ Palustrine wetland (e.g. vegetated swamp). *Eucalyptus coolabah* woodland to open woodland (to scattered trees) with a sedge or grass understorey in back swamps and old channels.	Least Concern/ Of Concern/ Of Concern	NA	Likely/ Likely/ Likely
11.3.3	DNRM and Field Verified RE	Coolibah (*Eucalyptus coolabah*) woodland on alluvial plains	Of Concern	NA	Likely
11.3.3a	Field Verified RE	Riverine wetland or fringing riverine wetland. *Melaleuca bracteata* woodland. On alluvial plains.	Of Concern	NA	Likely
11.3.3/11.3.1	DEHP	Mixed polygon see full descriptions for each individual RE in this table.	Of Concern/ Endangered	Endangered (RE 11.3.1)	Likely/Potential
11.3.3/ 11.3.1/ 11.3.2	DEHP	Mixed polygon see full descriptions for each individual RE in this table.	Of Concern/ Endangered / Of Concern	Endangered (RE 11.3.1)	Likely/ Potential/ Potential
11.3.6/ 11.3.3	DEHP	Mixed polygon see full descriptions for each individual RE in this table.	Least Concern	NA	Potential/ Likely
11.3.3/ 11.3.25/ 11.9.1	DEHP	Mixed polygon see full descriptions for each individual RE in this table.	Least Concern/ Of Concern/ Endangered	NA/ NA/ Endangered	Likely/ Likely/ Unlikely - RE 11.9.1
11.3.3.c	DEHP	Palustrine wetland (e.g. vegetated swamp). *Eucalyptus coolabah* woodland to open woodland (to scattered trees) with a sedge or grass understorey in back swamps and old channels.	Of Concern	NA	Likely
11.3.6	DEHP	*Eucalyptus melanophloia* woodland on alluvial plains	Least Concern	NA	Potential

Regional Ecosystem (RE)	Data source	RE Description	VM Status	EPBC Act Status	Likelihood of groundwater dependence
11.4.2	DEHP	*Eucalyptus* spp. and/or *Corymbia* spp. grassy or shrubby woodland on Cainozoic clay plains	Of Concern	NA	Unlikely
11.4.2/11.3.4	DEHP	*Eucalyptus* spp. and/or *Corymbia* spp. grassy or shrubby woodland on Cainozoic clay plains/ *Eucalyptus tereticornis* and/or *Eucalyptus* spp. woodland on alluvial plains	Of Concern/ Of Concern	NA	Unlikely/Likely
11.4.7	Field Verified RE	*Eucalyptus populnea* with *Acacia harpophylla* and/or *Casuarina cristata* open forest to woodland on Cainozoic clay plains	Endangered	Endangered	Unlikely
11.4.8	Field Verified RE	*Eucalyptus cambageana* woodland to open forest with *Acacia harpophylla* or *A. argyrodendron* on Cainozoic clay plains	Endangered	Endangered	Unlikely
11.4.9	DEHP and Field Verified RE	*Acacia harpophylla* shrubby woodland with *Terminalia oblongata* on Cainozoic clay plains	Endangered	Endangered	Unlikely
11.4.9a	DEHP	*Acacia harpophylla, Lysiphyllum carronii +/- Casuarina cristata* open forest to woodland. (BVG1M: 25a)	Endangered	Endangered	Unlikely
11.5.3	Field Verified RE	*Eucalyptus populnea* open forest woodland with a layered understory containing *Cassia brewsteri, Eremophila mitchellii* and grassy ground layer on weathered remnant tertiary surface	Least Concern	NA	Unlikely
11.7.1	Field Verified RE	*Acacia harpophylla* and/or *Casuarina cristata* and *Eucalyptus thozetiana* or *E. microcarpa* woodland on lower scarp slopes on Cainozoic lateritic duricrust	Least Concern	NA	Unlikely
11.7.2	DEHP	*Acacia spp.* woodland on Cainozoic lateritic duricrust. Scarp retreat zone	Least Concern	NA	Unlikely
11.9.1	DEHP	*Acacia harpophylla-Eucalyptus cambageana* woodland to open forest on fine-grained sedimentary rocks	Endangered	Endangered	Unlikely
11.9.2	DEHP	*Eucalyptus melanophloia +/- E. orgadophila* woodland on fine-grained sedimentary rocks	Least Concern	NA	Unlikely
11.9.1/ 11.9.2	DEHP	Mixed polygon see full descriptions for each individual RE in this table.	Endangered/ Endangered	Endangered/ Endangered	Unlikely/ Unlikely

Regional Ecosystem (RE)	Data source	RE Description	VM Status	EPBC Act Status	Likelihood of groundwater dependence
11.9.5	DEHP	*Acacia harpophylla* and/or *Casuarina cristata* open forest on fine-grained sedimentary rocks	Endangered	Endangered	Unlikely
HVR 11.3.1	Field Verified RE	High value regrowth *Acacia harpophylla* and/or *Casuarina cristata* open forest on alluvial plains	Non-remnant	Endangered	Potential
HVR 11.3.25	Field Verified RE	High value regrowth *Eucalyptus tereticornis* or *E. camaldulensis* woodland fringing drainage lines	Non-remnant	NA	Likely
HVR 11.4.8	Field Verified RE	High value regrowth *Eucalyptus cambageana* woodland to open forest with *Acacia harpophylla* or *A. argyrodendron* on Cainozoic clay plains	Non-remnant	Endangered	Unlikely
HVR 11.4.9	Field Verified RE	High value regrowth *Acacia harpophylla* shrubby woodland with *Terminalia oblongata* on Cainozoic clay plains	Non-remnant	Endangered	Unlikely
Non-remnant	DEHP and Field Verified RE	Cleared non-remnant vegetation	Non-remnant	NA	Unlikely

(1) Field verified RE relates to vegetation communities and regional ecosystems mapped within the project area as a result surveys undertaken by suitably qualified ecologists from WSP | Parsons Brinckerhoff

(2) DEHP indicates the regional ecosystems mapped by the Department of Environment and Heritage Protection within the study area outside the area of field verified regional ecosystem mapping. Where there are multiple REs the initial likelihood rating has been applied to the likelihood mapping Figure 5.8 given this RE has the largest mapped percentage.

Underlying geology and land zones

The broader classification and mapping rules for 'terrestrial GDEs' (subsurface GDEs) in Queensland suggest that all treed REs, riverine REs and non-riverine wetland REs on land zone 3 (Quaternary alluvium) from Queensland regional ecosystems mapping are potentially groundwater dependent (DSITIA 2013). The reliance on groundwater use of treed REs on other geological land zones in the study area is however largely unknown. Subsequent conversations with staff from the Queensland Herbarium and other groundwater specialists indicate that some regional ecosystems on older Tertiary alluvium (land zone 5) may also be groundwater dependent, however groundwater reliance of alluvial communities is likely to be species specific (A. Biggs DNRM, pers. comm. 2014).

Groundwater modelled areas of saturated alluvium and depth to groundwater

The area of potential subsurface GDEs in the AOI has been assumed to be restricted to areas of saturated alluvium based on the depth to groundwater results from the numerical groundwater modelling for the 'base case' simulation (Figure 5.7).

It is also widely assumed that within areas of saturated alluvium the groundwater dependence is also related to depth to water table and vegetation rooting depth (DSITIA 2013; Richardson et al. 2011) whereby the following criteria can be applied:

- High – depth to water table 0–10 m
- Possible – depth to water table 10–20 m
- Unlikely – depth to water table > 20 m.

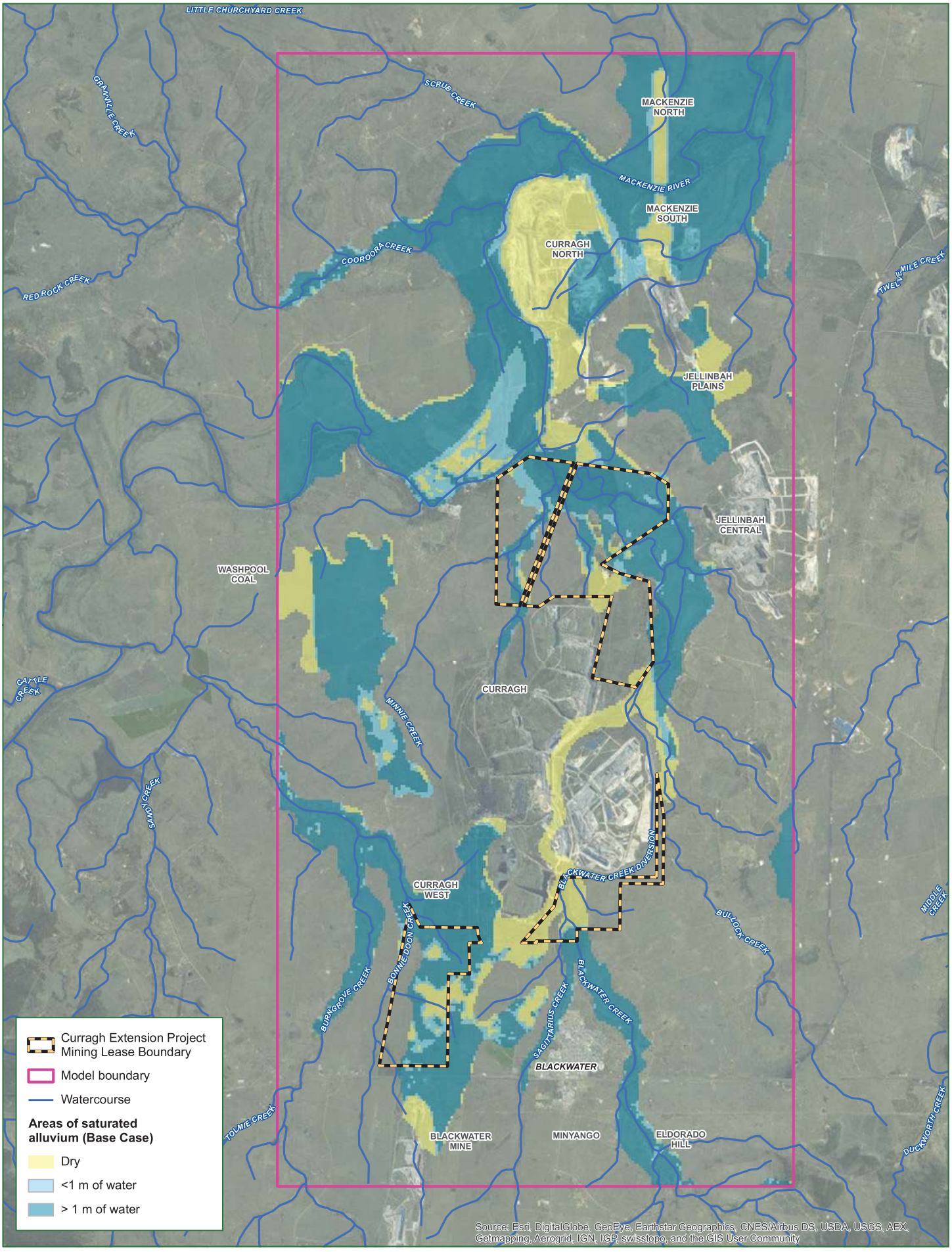
Likely and potential subsurface GDE mapping criteria

The areas of likely and potential subsurface GDEs within the study area have been mapped (refer Figure 5.8) based on the following criteria:

- intersecting the field verified and Queensland Herbarium mapped regional ecosystems associated with likely and potential GDEs (Table 5.10) within the modelled base case areas of saturated alluvium (refer Figure 5.7)
- determining the likelihood of groundwater dependence for the potential and likely subsurface GDEs within the area of saturated alluvium as:
  - High – depth to groundwater within saturated alluvium greater than 10 m
  - Moderate – depth to groundwater within saturated alluvium between 10 and 20 m
  - Low – depth to groundwater within saturated alluvium greater than 20 m.

5.2.3.4 Subterranean GDEs

Desktop assessment of subterranean GDEs (i.e. stygofauna) is presented in Appendix B3 to the Supplementary Information.



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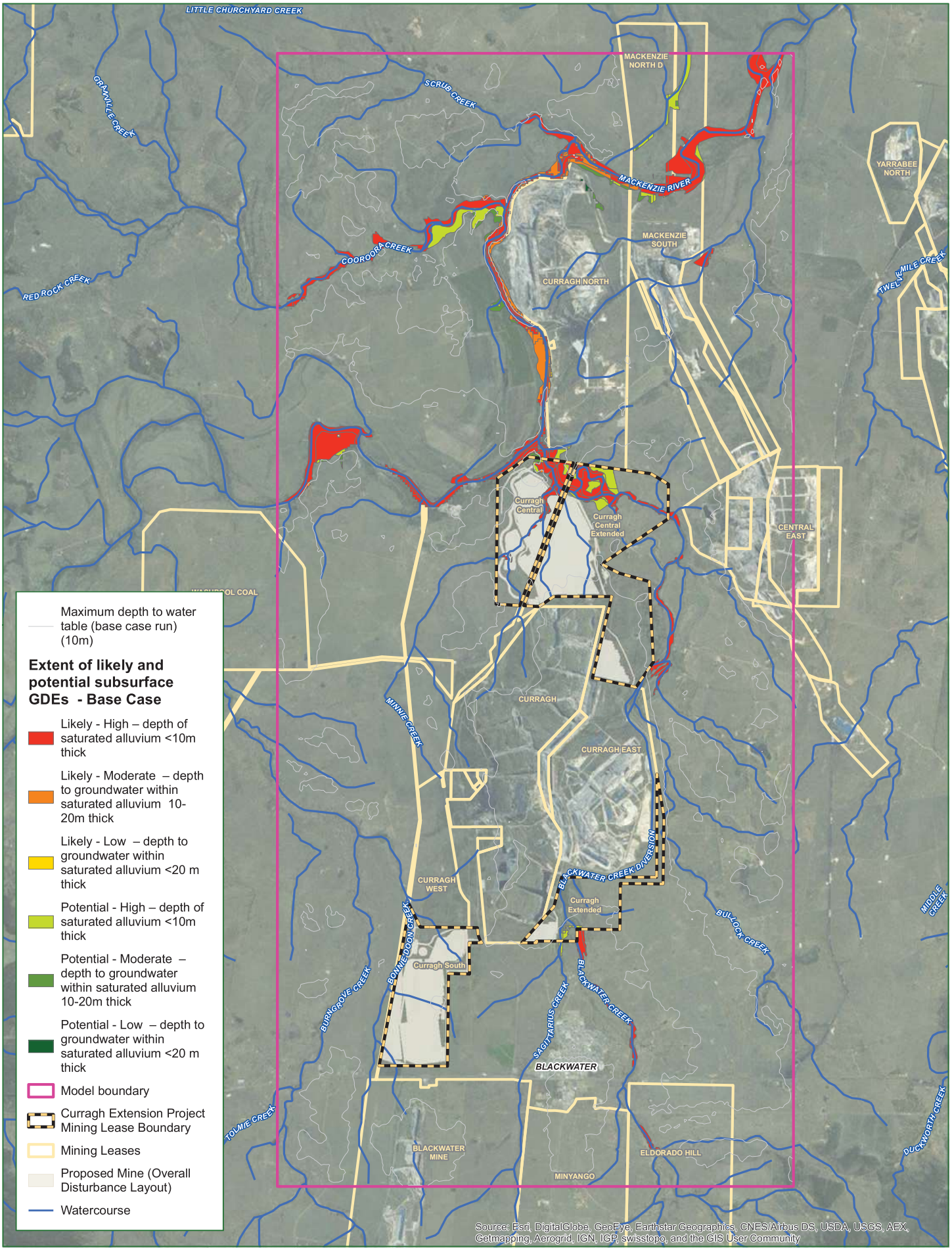
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Groundwater impact assessment
Curragh Extension Project
Figure 5.7
Areas of saturated alluvium, base case run

MXD Number: 2172652H_GIS_SW_F048_A4
Date: 15/06/2016
Author: AM
Approved by: LR

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Groundwater impact assessment
Curragh Extension Project
Figure 5.8
Extent of likely and potential subsurface GDEs in study area

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6. Review of existing operations

A review of the impacts of existing operations at Curragh North and Curragh East on groundwater has been undertaken to provide an indication of the impacts that may be expected for the Curragh Extension Project.

Impacts are expected to be similar where the geological and hydrogeological environments are similar.

The geological and hydrogeological environment near proposed Pit X is similar to Curragh North, however the following differences should be noted:

- The thickness of alluvium near proposed Pit X (up to 12 m) is one third the thickness of alluvium at Curragh North (up to 30 m at Pit S and Pit U).
- The composition of alluvium near proposed Pit X is predominantly clay with sand at depth, whereas the composition of alluvium at Pit S is predominantly sand and gravel and the composition at Pit U is predominantly sand.
- Proposed Pit X will come within 760 m of Mackenzie River, whereas Pit S is 160 m from the river and Pit U is 400 m from the river.

The geological and hydrogeological environments near proposed Pit D extension, Pit J extension and Pit Z are similar to Curragh East, with alluvium less than 2 m thick and predominantly comprised of clay.

6.1 Pit inflows

Average daily pit inflow data was provided by Curragh Mine pump personnel, who are responsible for pit dewatering and water management on site. The data is average daily pumping hours for each active pit in September 2015 and pumping rates measured using ultrasound flow meters in December 2015.

Table 6.1 also presents the volume of open pit and pit depth calculated using LiDAR data from August 2015. The pit dimensions provide context for the inflow data as pit inflows will increase with increasing open area of excavation. The active pit areas are shown on Table 6.1. Pits are backfilled as mining progresses.

The Curragh North pits (S, T and U) experience inflows from the alluvium, which is thick and comprised of sand and gravel in this area, and the Rangal Coal Measures. At Curragh East, alluvium is less than 2 m thick and comprised of clay, and inflows are predominantly from Rangal Coal Measures.

Table 6.1 Estimated pit inflows at Curragh Mine

Mining area	Curragh North			Curragh East				
Pit	**S**	**T**	**U**	**C**	**D**	**E**	**F**	**H**
Volume of pit (Ml)	23,305	143,050	95,278	25,921	25,752	17,977	17,727	19,794
Pit depth (m)	68	120	105	87	81	104	95	75
Inflows from alluvium								
Pump hours	nd	3	6 – 8	0	0	0	0	0
Pump rate (L/s)	nd	40	70	n/a	n/a	n/a	n/a	n/a
Daily volume (Ml)	0.1*	0.4	3.0	0.0	0.0	0.0	0.0	0.0

Mining area	Curragh North			Curragh East				
Pit	S	T	U	C	D	E	F	H
Inflows from Rangal Coal Measures								
Pump hours	4	4	24	2	3	3 - 4	4 - 5	4 - 5
Pump rate (L/s)	40	40	40	40	40	40	40	40
Daily volume (Ml)	0.5*	0.6	2.6	0.3	0.4	0.4	0.6	0.6
Total inflows								
Daily total (Ml)	0.6	1.0	5.6	0.3	0.4	0.4	0.6	0.6
Annual volume (GL)	0.2	0.4	2.0	0.1	0.2	0.2	0.2	0.2

n/a – not applicable
nd – no data
* alluvium inflows estimated to be 10% of inflows to pit

The highest pit inflows occur in Pit U at Curragh North. This pit is larger and deeper than the other active mine pits, with the exception of Pit T. Approximately half the inflows at Pit U are from alluvium. Comparison to the inflows at Pit S, which has a similar thickness and composition of alluvium, indicates significantly lower inflow volumes. The differences in inflows from alluvium is understood to be related to the palaeochannel system that underlies Curragh North. The channel fill deposition of this material has created a sequence that displays significant lateral variability in grain size and permeability and this is interpreted to control groundwater flow and interaction with Mackenzie River.

Inflows to Pit U from Rangal Coal Measures are also higher than inflows to Pit T from Rangal Coal Measures, despite Pit T being deeper and larger than Pit U. Although site observations do not indicate that geological fault structures provide noticeable flow conduits into pits at Curragh Mine, the differences may be related to differences in fault and fracture controlled flow within the Rangal Coal Measures. Fractured rock formations typically have variable hydraulic properties.

A review of inflows to Pit S by Douglas Partners (2014) indicated that at the commencement of mining in late 2014, inflows were occurring from a water bearing sand and gravel unit at the base of the alluvium and were up to 4 L/s after mining two blocks approximately 150 m in length, increasing to 9 L/s during wet periods. Curragh Mine pump personnel have reported that saturated alluvium was encountered in Pit S at approximately 5 to 10 mbgl and initial dewatering rates for alluvium were 6.5 Ml/day.

Site observations have indicated that after two months of mining in Pit S, the alluvium on the western side of the pit wall face adjacent to Mackenzie River was dewatered and the majority of inflows from alluvium were coming from the eastern pit wall face at a rate of approximately 0.1 to 0.2 Ml/day (pers. comm., Curragh Mine, September 2015). Monitoring bores screened to the base of the alluvium located between Mackenzie River and Pit S are dry or have water levels near the base which supports the current observation of minimal seepage from alluvium on the western side pit wall.

Site observations of limited seepage in the western buttress wall suggest there is limited hydraulic connection between Mackenzie River and Pit S via the alluvium which maybe largely due to intervening low permeability silt and clay rich sediments and pit dewatering (pers. comm., Curragh Mine, September 2015). Curragh Mine pump personnel have not observed any change in pit inflows related to changing water levels in Mackenzie River or wet season rainfall conditions.

Pit inflows at Curragh Mine are within ranges reported and predicted for other coal mines in the Bowen Basin. A summary of pit inflow data for other mines is provided in Table 6.2.

Table 6.2 Daily pit inflows, Bowen Basin mines

Mine	Inflow sources	Number of pits	Inflow (Ml/d)	Reference	Reference
Open cut mines					
Mackenzie South	Alluvium and Pollux seam	1	0.4	Analytical model prediction	AGE 2006
Newlands	Tertiary sediments, basalts and coal seams	4	0.3^	AGE groundwater model	AGE 2012
Rolleston (existing)		5	6.5*	Site data	
Rolleston West (proposed)	Basalts, coal seams	2	3.7*	Numerical model prediction	
Rolleston South (proposed)	Tertiary sediments, basalts and coal seams	5	5.8*	Numerical model prediction	
Underground mines					
Newlands		n/a	1.2*	Numerical model prediction	AGE 2012
Minyango (bord and pillar)	Aries seam	n/a	1.5*	Numerical model prediction	AGE 2013
Minyango (longwall)	Aries seam	n/a	0.3*	Numerical model prediction	AGE 2013
Minyango	Pollux seam	n/a	1.0*	Numerical model prediction	AGE 2013

^ Inflows generally less than
* Peak inflow

6.2 Drawdown and recovery

Drawdown associated with existing operations at Curragh North and Curragh East has been assessed using recent groundwater level data in the vicinity of active pits.

Groundwater levels indicate that drawdown impacts associated with existing mining operations are localised and do not extend more than 1 to 2 km from mine pits. A number of groundwater monitoring bores in close proximity to operational pits, including 1425MB, 1428MB and 1432MB in alluvium, are dry. However groundwater levels in monitoring bores located approximately 1.5 km from pits, including BH1 in Rangal Coal Measures, show little variation over time indicating drawdown impacts associated with mining operations are relatively localised.

Monitoring bore BH2, screened in Rangal Coal Measures, was located 560 m from Pit C in 1997 when monitoring commenced. Since 1997, mining has progressed away from BH2 and Pit C has been progressively backfilled. As shown in the hydrograph for BH2 in Attachment B, groundwater levels have recovered by 15 m over this 18 year period. Mining in Pit C is currently 1,350 m from BH2.

6.3 Groundwater quality

The groundwater monitoring network at Curragh Mine has been designed to detect changes in groundwater quality due to seepage from site infrastructure, including old and new TSFs, landfills, fuel farms and water storage dams.

Activities and infrastructure for the Curragh Extension Project which have potential to impact on groundwater quality includes spoil material, tailings, mine water storage dams, run of mine stockpiles and mine infrastructure areas, and fuel storage facilities. A review of groundwater quality data for groundwater monitoring bores targeting these areas at Curragh Mine and data for tailings dams and mine water storage dams has been undertaken to identify:

- potential impacts associated with the Project
- whether existing mitigation and management measures at Curragh Mine have been effective in managing potential impacts groundwater quality and therefore would be suitable for managing potential impacts associated with the Project.

Existing mitigation and management measures at Curragh Mine include:

- constructing and operating tailings dams and mine water storage dams in accordance with the Manual for Assessing Consequence Categories and Hydraulic Performance of Structures (DEHP 2013) and WCPL regulated structure operational plans
- handling, managing and disposing of all hazardous substances, including fuels and chemicals, in accordance Australian Standards AS 1940:2004 The Storage and Handling of flammable and combustible liquids and AS 3833:2007 The storage and handling of mixed classes of dangerous goods, in packages, and intermediate bulk containers and SOP-005 Hazardous Substances (Standards Australia 2004)
- handling spills in accordance with the Spill Response Procedure (EMS PROC 3.3) and managing regulated wastes generated from a spill in accordance with the Regulated Waste Management Procedure (EMS PROC 3.2)
- managing residual voids in accordance with residual void investigation reports prepared under condition G13 of the EA EPML00643713.

As part of the GMP, WCPL is also undertaking groundwater monitoring at reference bores to establish natural background groundwater conditions for the area. This information will be used to further assess potential groundwater quality impacts associated with operations at Curragh Mine.

6.3.1 Spoil material

Spoil material is transported to dedicated in-pit and out-of-pit spoil dumps.

Spoil characterisation studies indicate the spoil at Curragh Mine has low acid forming potential (WCPL 2012). Groundwater quality monitoring indicates the pH of groundwater is neutral (6.5 to 7.8) (Section 4.4) and that Curragh Mine has not experienced acid mine drainage issues.

6.3.2 Tailings

All tailings and coarse rejects from the Project will be managed in existing Curragh Mine facilities. Water quality analyses for the tailings dam and down gradient groundwater monitoring bores (1301a, 1301b, 1302, 1303, 1304a, 1304b and 1305) at Curragh Mine indicate:

- pH of water in the tailings dam ranges from 8.3 to 8.6, indicating tailings are not acid generating and not a source of acidity to groundwater.
- EC of water in the tailings dam ranges from 5000 to 5500 µS/cm and is fresher than the EC of groundwater which ranges from 10,000 to 28,000 µS/cm.
- Tailings dam waters have low concentrations of dissolved and total metals which are comparable with concentrations in groundwater and lower than the guidelines for livestock, with the exception of selenium. Concentrations of total selenium in the tailings dam are up to 38 µg/L compared to the guideline for livestock of 20 µg/L. The concentrations of total selenium in the tailings dam are elevated compared to down gradient monitoring bores (4 µg/L), but within the range of concentrations in groundwater across the site (1 µg/L to 210 µg/L).
- Tailings dam waters have total recoverable hydrocarbon (TRH) concentrations below laboratory detection limits.

6.3.3 Water storage dams

A number of groundwater monitoring bores target mine water storage dams at Curragh Mine:

- BH8A (alluvium), 1308 (alluvium/Duaringa Formation), BH6 (Burngrove Formation) and BH8 (Burngrove Formation) target Dams A and B at Curragh East
- 1309 (alluvium) and 1312 (alluvium) target mine water storage dam CN3 at Curragh North.

The EC of water in storage dams and pits at Curragh Mine has been compared with the EC of groundwater for adjacent bores. The results indicate the EC of water in dams and pits ranges from 2,800 to 14,000 µS/cm and is generally comparable to or fresher than groundwater in adjacent bores.

Other water quality analyses for the storage dams at Curragh Mine indicate:

- pH of water in dams ranges from 8.8 to 9.6, indicating dams are not a source of acidity to groundwater
- dam waters have low concentrations of dissolved and total metals which are comparable with concentrations in groundwater and lower than the guidelines for livestock, with the exception of selenium. Concentrations of selenium in the water storage dams are up to 51 µg/L compared to the guideline for livestock of 20 µg/L. The concentrations of total selenium in the tailings dam are low compared to down gradient monitoring bores (up to 190 µg/L) and within the range of concentrations in groundwater across the site (1 µg/L to 210 µg/L)
- dam waters have total recoverable hydrocarbon concentrations below laboratory detection limits.

6.3.4 Run of mine and MIA

Monitoring bore BH4 targets the CHPP within the MIA at Curragh Mine. Groundwater quality analyses for BH4 indicate:

- pH of groundwater is neutral and ranges between 6.6 and 7.4
- EC ranges from 3,000 to 8,400 µS/cm
- hydrocarbons were detected during sampling events in 2003, 2004, 2012 and 2014, but not in more recent sampling events. The source of hydrocarbons is assumed to be from localised spills or leaks from vehicles servicing the area near BH4 rather than an ongoing source.

6.3.5 Fuel storage facilities

The nearest groundwater monitoring bores to the Curragh Mine fuel storage facilities are BH4, BH5 and 1321MB.

Hydrocarbons were detected in BH4 during sampling events in 2003, 2004, 2012 and 2014, and in BH5 during a sampling event in 2012, but not in recent sampling events. The source of hydrocarbons is assumed to be from localised spills or leaks from vehicles servicing the area rather than leaking tanks which would be indicated by ongoing concentrations in groundwater.

7. Numerical groundwater modelling

7.1 Modelling objectives

The primary objective of the groundwater modelling was to quantify impacts to groundwater resources and associated environmental values in response to the proposed mining for the Curragh Extension Project. The modelling also aimed to quantify cumulative impacts associated with mining at the existing Curragh Mine, neighbouring mines and for the Curragh Extension Project.

The design, construction and calibration of the model was tailored to meet the modelling objectives. The model is consistent with the conceptual hydrogeological model in Section 4 and was calibrated to broadly replicate groundwater levels, flow directions and inflows. Following calibration, the model was used to simulate the impacts of the Project on groundwater resources and associated environmental values.

7.2 Compliance with modelling guidelines

The Australian groundwater modelling guidelines (Barnett et al, 2012) provide guiding principles and minimum standards of numerical groundwater models. The guidelines recommend that the overall reliability, complexity and confidence level of the model should be assessed and agreed prior to construction of the model, and if possible re-assessed at a later stage in the modelling project. The confidence level classification comprises three classes; class 1, class 2 and class 3, in order of increasing confidence level. The level of confidence typically depends on the available data, calibration procedures, consistency between the calibration conditions and predictive analysis scenario, and the level or severity of stresses being simulated. A table of quantifiable indicators with which to assess a models confidence level based on those attributes is included in the modelling guidelines.

Typically in impact assessments for mining projects, the paucity of time series and spatial data for calibration compared with the proposed development timeframe is such that a class 2 confidence level is the highest feasible. The numerical model developed for this assessment is class 2.

Independent peer review of the numerical groundwater model has been undertaken by Dr Stuart Brown of HydroSimulations. The findings of the review are provided in Attachment E.

7.3 Model design

7.3.1 Model code

Numerical modelling was carried out using MODFLOW USG and the Groundwater Vistas user interface. MODFLOW (McDonald and Harbaugh 1988) utilises a finite difference approach, and is well suited to impact assessment modelling in which water source interactions and precise water balance estimates are important. MODFLOW USG allows for unstructured grids and variable saturated flow conditions.

The MODFLOW-USG BETA version of MODFLOW was used. MODFLOW-USG incorporates the xMD solver (Ibaraki, 2011) for asymmetric matrices generated by use of Newton Raphson linearization using the upstream weighted formulation.

MODFLOW-USG treats unsaturated conditions (dry cells) as inactive, meaning recharge and evapotranspiration (ET) will apply to the uppermost active cell (layer) and the model will calculate the water level from the first active cell.

7.3.2 Model geometry

The model domain is 20.6 km by 45.2 km. A model cell size of 100 m x 100 m has been used, resulting in 206 columns and 452 rows and a total of 931,120 cells over the 10 model layers.

The model domain covers all historical and future mining operations at Curragh Mine. Model boundaries are located approximately 5 km from historical and proposed pits to prevent boundary effects on model outcomes. The model domain is shown on Figure 7.1.

The model domain extends far enough to allow the effects of cumulative impacts from neighbouring mines to be assessed. Mining operations in the vicinity of the project are listed in Table 1.1 and shown on Figure 7.1. Gas production at petroleum leases overlapping or directly adjacent to the project is not proposed prior to 2045 (OGIA, 2016) and has not been included in this assessment.

7.3.3 Model layers

Model layer discretisation aimed to find a balance between having sufficient layers to represent detail in the geology, whilst limiting the number of cells to ensure model run time was manageable. To achieve this, geological units with similar hydraulic properties were grouped into single layers.

The model conceptualisation was simplified into ten layers representing the key hydrogeological units as summarised in Table 7.1. The elevations and thicknesses of the model layers were developed using grid files of geological layers exported from the Curragh Mine VULCAN database. Model layers were extended outside the Curragh Mine area using exploration data from the Queensland Globe.

The coal seams of the Rangal Coal Measures were aggregated into upper, middle and lower layers. A conservative approach was adopted and mining was assumed to occur from the base of the lowest seam in each group.

Layers 4 to 8 (Rangal Coal Measures) are not present across the whole of the model domain due to dipping geological strata and are absent in the west where the older Burngrove Formation outcrops and in the east where the Jellinbah Fault has thrust Burngrove Formation to the surface.

Table 7.1 Model layers

Layer	Formation	Lithology
1	Alluvium	Silty clay, sand and gravel
2	Weathered rock	Tertiary and weathered Permian sediments
3	Rewan Formation and overlying/interburden units of the Rangal Coal Measures	Sandstone/siltstone/mudstone
4	Rangal Coal Measures – upper coal seams	Aggregate thickness of Cancer, Aries, Castor seams
5	Rangal Coal Measures – interburden	Sandstone/siltstone
6	Rangal Coal Measures – middle coal seams	Aggregate thickness of Pollux (upper and lower) and Orion (upper and lower)
7	Rangal Coal Measures – interburden	Sandstone/siltstone
8	Rangal Coal Measures – lower coal seam	Aggregate thickness of Pisces seam
9	Burngrove Formation	Sandstone/siltstone/mudstone/coal seams
10	Fair Hill Formation	Sandstone/mudstone/coal seams

7.3.3.1 Geological faults

Geological faults have been incorporated into the groundwater flow model as follows:

- Faults from regional scale geological mapping, in particular the Jellinbah Fault, have been incorporated into geological model surfaces. Flow barrier boundary conditions or zones of enhanced permeability have not been used to simulate these structures. Layers have been assumed to be continuous across the faults, providing for a conservative estimate of potential impacts.
- Faults from local scale geological mapping have been incorporated through parameterisation of model layers. The Permian sediments in the study area have been affected by thrust faulting and deformation resulting in seam displacements up to 20 m vertically, seam thinning and absenting. Faulting of the coal seams and interburden may restrict flow due to the lateral discontinuity of water bearing coal seams or form pathways for groundwater flow. Faulting is incorporated in the bulk permeability of the Permian sediments.

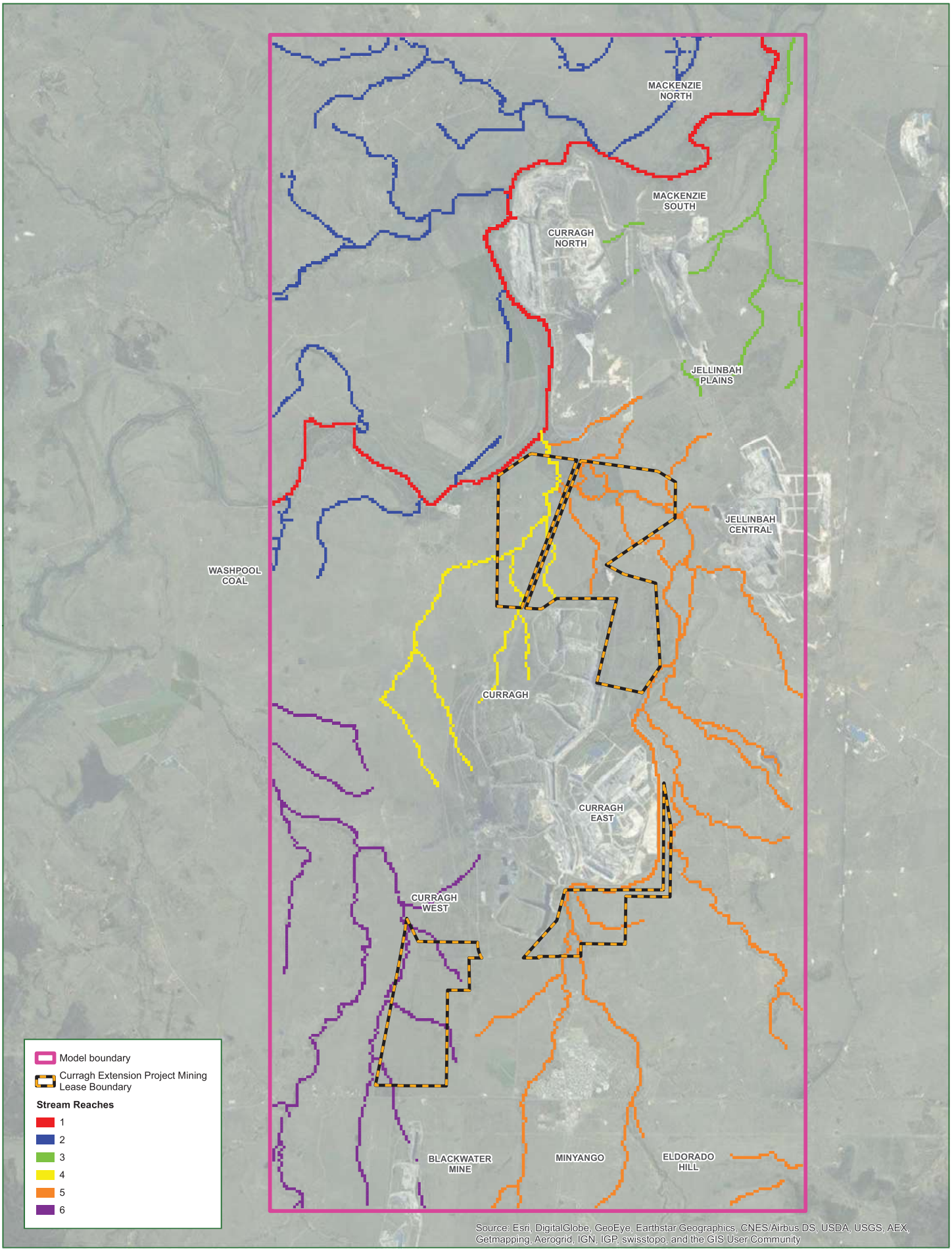
7.3.4 Boundary conditions

7.3.4.1 Surface drainage

Mackenzie River is a regulated river. Regular releases of water are made from Bedford Weir, located upstream of Curragh Mine, to maintain levels at Bingegang Weir, located downstream of Curragh Mine.

The Mackenzie River was represented in the model with a constant level using the MODFLOW river package (RIV). The river package allows exchange in either direction between the river and groundwater system. River stage elevations were based on Curragh Mine LiDAR data across the model domain. The minimum LiDAR value within a 100 m model cell was assumed to represent the water level in Mackenzie River. The river bottom elevation was set to 1.5 m below the river stage. The river bed conductance is based on the hydraulic conductivity of clay, as this is the dominant lithology in the stream bed and the alluvial sequence underlying Mackenzie River.

Tributaries of Mackenzie River, including Blackwater Creek, are ephemeral with channels drying out for long periods. Blackwater Creek and other drainage lines have been represented in the model using the MODFLOW drain package (DRN). The drain package will accept baseflow when the water table reaches the stage of the drain cells, but will never provide a source of water to the groundwater system. Drain stage elevations were based on Curragh Mine LiDAR data across the model domain. The minimum LiDAR value within a 100 m model cell was assumed to represent the elevation of the drainage lines. The drain conductance of the tributaries is based on the hydraulic conductivity of sandy clay, as this is the dominant lithology in the stream bed and the alluvium at the surface.



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Data Source:
All data from WSP/PB (2016)

Groundwater impact assessment
Curragh Extension Project
Figure 7.1
Stream reaches

MXD Number: 2172652H_GIS_SW_F045_A2
Date: 15/06/2016
Author: VD
Approved by: LR

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7.3.4.2 Recharge and evapotranspiration

A small proportion of total rainfall recharges the groundwater system via infiltration through the unsaturated zone. The remainder is lost as surface runoff via rivers and streams, and as evapotranspiration. The rate of recharge to the alluvial sediments differs from to the rate of recharge to weathered rock due to the difference in thickness and permeability of the unsaturated zone.

Recharge rates have been estimated using the steady state chloride mass balance of groundwater method (CMB); this is the most widely used method for estimating recharge in Australia (Crosbie et al. 2010).

The CMB method can be described using the following equation:

$$R = \frac{D}{C_{gw}}$$

where:

- R = recharge (LT^{-1})
- D = chloride deposition rate ($ML^{-2}T^{-1}$)
- C_{gw} (ML^{-3}) = the chloride concentration in groundwater.

The chloride deposition rate (D) is often estimated as the chloride concentration of rainfall multiplied by the average annual rainfall.

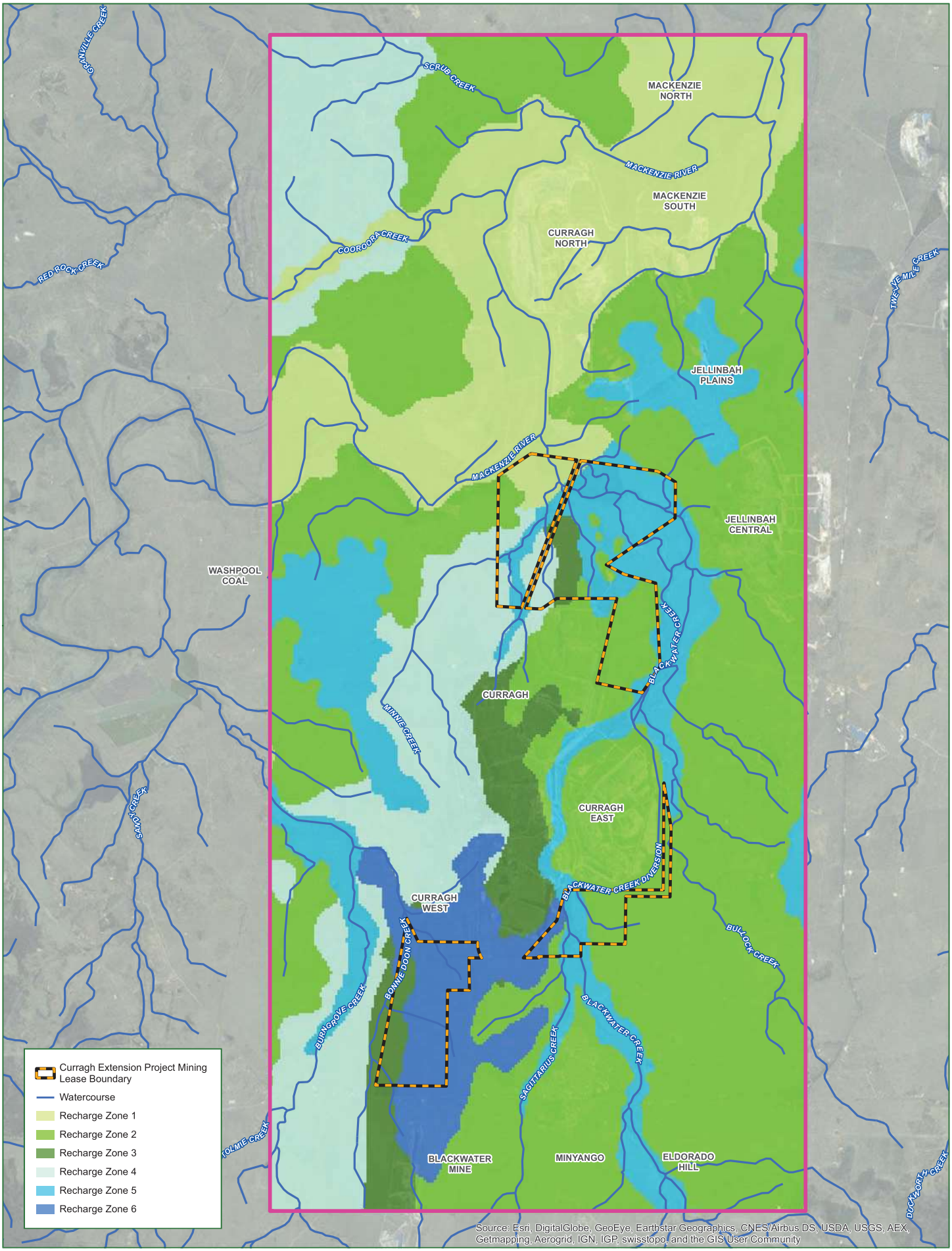
As there was no local available data for chloride concentrations in rainfall, the approximate chloride concentration in rainwater was based on published data (Crosbie et al. 2012). There is a well-established relationship between chloride concentration in rainwater and distance from the ocean. Therefore the average concentration of chloride in rainwater at Clermont of 1 mg/L was used. The township of Clermont is located a similar distance from the ocean as the Curragh Mine is from the ocean.

Average annual rainfall of 569 mm/year is assumed, based on long-term (1969–2015) average annual rainfall at BOM station 035132. The median concentrations of chloride from Curragh Mine groundwater monitoring bores screened in alluvium, Duaringa Formation, Rangal Coal Measures and Burngrove Formation are shown in Table 7.2.

The implied recharge rates as a percentage of rainfall are show in Table 7.2. Aquifer recharge was applied to the model using the MODFLOW recharge package (RCH). Recharge was applied in zones based on the surface geology as shown in Figure 7.2. Chloride concentrations in groundwater for the Emerald Formation (Zone 2) were not available, therefore a recharge rate of 0.02% was assumed to be consistent with the recharge rates to the weathered rock (including the Duaringa Formation).

Table 7.2 Estimates of recharge using the chloride (Cl) mass balance

Component	Units	Alluvium	Duaringa Formation	Rangal Coal Measures	Burngrove Formation
		Zones 1, 5 and 6	Zone 2	Zone 3	Zone 4
Rainfall [Cl]	mg/L	1	1	1	1
Median groundwater [Cl]	mg/L	445	5700	4300	3250
Annual rainfall	mm/yr	569	569	569	569
Recharge	mm/yr	1.3	0.1	0.1	0.2
Recharge	% Rainfall	0.22	0.02	0.02	0.03



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Data Source:
All data from WSP/PB (2016)

Groundwater impact assessment
Curragh Extension Project
Figure 7.2
Recharge zones

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Date: 15/06/2016
Author: VD
Approved by: LR

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Evapotranspiration was applied using the MODFLOW EVT package. The average annual evapotranspiration at Curragh Mine is 650 mm; this was obtained from the average, areal, actual evapotranspiration maps created by the BOM data collected between 1961 and 1990 (BOM 2015a). Evapotranspiration was set at 50% of the annual actual rate with an extinction depth of 3 m across the model domain.

7.3.4.3 General head boundaries

A MODFLOW general head boundary was applied to the north, south, east and west boundaries of the model. Groundwater levels at the boundaries of the model domain were set at 4.5 m below the topographic surface to reflect the effects of neighbouring mines. The conductance of the general head boundaries is based on the hydraulic conductivity of the alluvium and the weathered rock.

7.3.5 Simulation period and temporal discretisation

The time periods adopted for the model runs were as follows:

1. A steady state stress period of 100 years duration (stress period 1) representing pre-development at Curragh Mine.
2. Transient stress periods of three years duration (stress periods 2 to 12) representing historical development at Curragh Mine from 1983 to 2015 (**calibration run**).
3. Transient stress periods of annual duration (stress periods 13 to 36) representing future mining activities at Curragh Mine and neighbouring mines that have already been approved by government or are in advanced stages of approval (**base case run**).
4. Transient stress periods of annual duration (stress periods 13 to 36) representing future mining activities at Curragh Mine and neighbouring mines as well as proposed mining activities for the Curragh Extension Project (**cumulative run** or **CEP run**).
5. Two transient stress periods of annual duration (stress periods 37 and 38) and one stress period of 750 years duration (stress period 39) representing the period following completion of mining (**recovery period**).

7.4 Model calibration

7.4.1 Calibration approach

Calibration of the groundwater model has focussed on historical matching of groundwater levels. A total of 328 groundwater level observations were available at 39 sites for the period 1997 to 2015. The sites are located across the model domain within the Curragh, Curragh East and Curragh North mining areas. Groundwater level observations were available for all model layers except 6, 8 and 10.

Calibration of the groundwater model has also considered average daily pit inflow data provided by the Curragh Mine pump personnel for September 2015.

As there are no reliable pre-mining groundwater level data available, transient calibration of the model was undertaken by simulating historical mining operations at Curragh Mine and neighbouring mines. An initial steady state run was undertaken to establish initial heads and allow the model to stabilise prior to simulation of mining. Historical mining operations were then simulated from 1983 to 2015. The historical mine schedule used for the calibration run is presented in Section 7.4.1.

Manual calibration methods were applied to improve the ability of the model to match observed water level and pit inflow behaviour. A summary of model performance in relation to observed water levels and pit

inflows is presented in Section 7.4.2. The calibrated model has a mass balance error of 0.0%, which is below the accepted threshold of 1 to 2%.

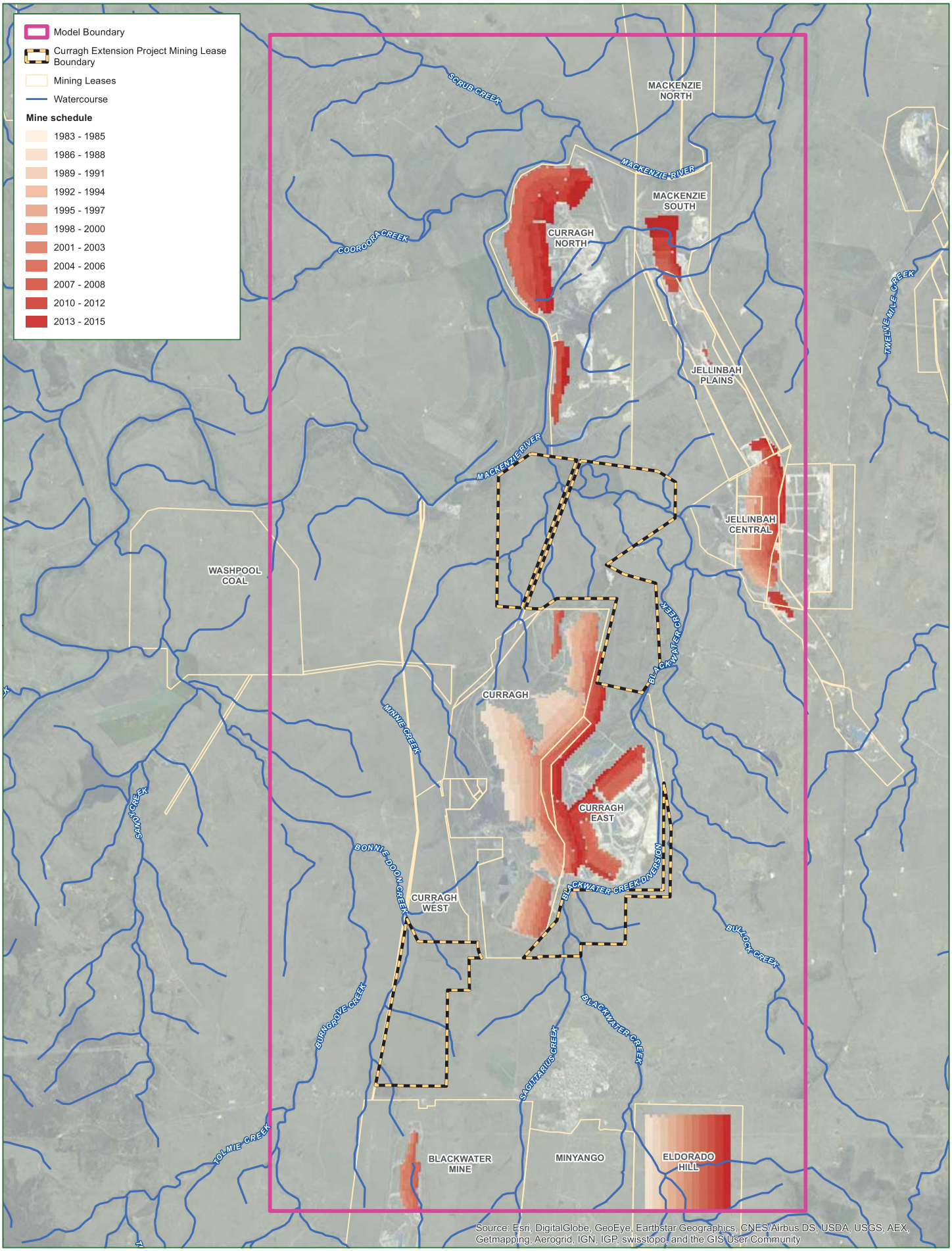
7.4.1.1 Historical mining schedule

The historical mining schedule is shown in Figure 7.3. Historical mining at Curragh, Curragh East and Curragh North was simulated based on the following information provided by WCPL:

- pit outlines for the period 1983–1993
- annual pit footprints provided for the period 1994–2015
- lowest mineable seam.

Historical mining at neighbouring open cut mines was simulated based on monthly Landsat imagery available from the USGS website. Historical mining at neighbouring underground mine Eldorado Hill was estimated based on the mining depth and mining lease footprint in the absence of mine plan information. Details of the approach to simulating historical mining in at neighbouring mines is provided in Table 7.3.

Active open cut pits and underground voids were simulated using the MODFLOW drain package (DRN). The elevation of the drain cells was set to the base of the lowest mineable coal seam in each area. This is considered a conservative approach as mining will occur from the shallower coal seams initially, instead of immediately from the base of the lowest mineable seam. The drain cell conductance was set to 1000 m/day.



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Data Source:
Geology from GSQ (2015)
Watercourse from DNRM (2016)
Mining data from WSP/PB (2016)

Groundwater impact assessment
Curragh Extension Project
Figure 7.3
Mine schedule – transient calibration

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Table 7.3 Neighbouring mines

Owner	Operation	Status	Period of operation	Type of operation	Target seam	Groundwater information available	Calibration period (1983–2015)	Predictive scenarios (2016–2039)
Jellinbah Group Pty Ltd	Jellinbah Central and Jellinbah Plains	Operational	Mine has been operational since 1989. Landsat imagery has been used to provide historical extent of open pit areas. The imagery suggests that mining is progressing in an easterly direction.	Open cut coal mine	Assumed to be Pollux seam of the Rangal Coal Measures (Layer 6)	None available.	Simulated mining from 1989 to 2015 based on Landsat Imagery	Simulated mining from west to east in the areas that have not been mined historically.
Jellinbah Group Pty Ltd	Jellinbah Plains Central North, Eastern Extension and Western Extension	Proposed (application only)	The IDP indicates that mining will occur in Central North commencing in 2023 and the Eastern Extension commencing in 2028 for a period of approximately 20 years. The Western Extension will be used for placement of overburden spoil and topsoil.	Open cut coal mine	Pollux seam of the Rangal Coal Measures (Layer 6), although it is noted the Pollux seam occurs at 270 m depth in the north which is beyond the limit of open cut mining.	No groundwater modelling undertaken. EA Amendment supporting information concluded that pit developments associated with Jellinbah Mine have encountered negligible groundwater resources and the alluvium is a poor aquifer with low long term yield.	Not included. Mine area not operational during this period.	Simulated mining from 2023 to 2039 in a west to east direction according to the plans in the Initial Development Plan.

Owner	Operation	Status	Period of operation	Type of operation	Target seam	Groundwater information available	Calibration period (1983–2015)	Predictive scenarios (2016–2039)
Jellinbah Group Pty Ltd	Mackenzie South	Operational	Mining commenced in 2004 Landsat imagery has been used to provide historical extent of open pit areas. The IDP indicates that mining would commence in 2006 and be completed in 2022.	Open cut coal mine	Pollux seam of the Rangal Coal Measures (Layer 6)	AGE developed an analytical model for Mackenzie South in 2006. The cone of depression was assumed to be 1 km based on experience at other mines in the Bowen Basin.	Simulated mining from 1989 to 2015 based on Landsat Imagery.	Simulated mining from 2016 to 2021 in a south to north direction according to the plans in the IDP.
Jellinbah Group Pty Ltd	Mackenzie North	Proposed (approved on 16 April 2015)	Assumed to be an extension of operations at Mackenzie South.	Open cut coal mine	Assumed to be Pollux seam of the Rangal Coal Measures (Layer 6)	None available.	Not included. Mine not operational during this period.	Simulated mining from 2022 to 2039 in a south to north direction.
BHP Coal Pty Ltd	Blackwater Mine	Operational	Mining commenced in 1967. The main area of the mine is located south of the model domain. Landsat imagery indicated mining occurred within the model domain between approximately 1998 and 2006.	Open cut coal mine	Aries, Castor, Pollux and Orion seams of the Rangal Coal Measures (Layers 4 and 6)	Groundwater modelling undertaken by AGE in 2013 for the Minyango EIS included Blackwater Mine to assess cumulative impacts. Drawdown at Blackwater Mine was predicted to be 0.1 m or less.	Simulated mining from 1998 to 2006 based on Landsat imagery.	Not included. Future mining within the model domain is not anticipated. The main area of the mine is located south of the model domain.

Owner	Operation	Status	Period of operation	Type of operation	Target seam	Groundwater information available	Calibration period (1983–2015)	Predictive scenarios (2016–2039)
Blackwater Coal Pty Ltd	Minyango	Proposed (approved on 1 December 2015)		Underground coal mine (combination of bord and pillar and longwall)	Aries seam and Pollux seam of the Rangal Coal Measures (Layers 4 and 6)	Groundwater modelling was undertaken by AGE in 2013 for the EIS. Results indicate depressurisation in the Aries seams would be less than 1 m within approximately 2 km of the project site, and depressurisation in the Pollux seam would be less than 1 m within approximately 5 m of the site. Rapid recovery of groundwater levels to within 80% of pre-mining levels is predicted within 30 years. The potential for significant impacts to groundwater resources in alluvium and Rewan Formation was predicted to be very low.	Not included. Mine not operational during this period.	Simulated mining from 2016 to 2038 in the Aries and Pollux seams in accordance with the mine plans in the AGE (2013) report.
Cook Resource Mining Pty Ltd	Eldorado Hill	Operational	No information is available about operations at this mine. Review of Landsat imagery indicated a CHPP at the surface, suggesting mining is operational.	Underground coal mine (method unknown)	Assumed to be Aries seam and Pollux seam of the Rangal Coal Measures (Layers 4 and 6)	None available.	Simulated mining from 1983 to 2015 in the Aries seam from west to east (down dip).	Simulated mining from 2016 to 2039 in the Pollux seam in a west to east direction (down dip).

Owner	Operation	Status	Period of operation	Type of operation	Target seam	Groundwater information available	Calibration period (1983–2015)	Predictive scenarios (2016–2039)
Washpool Coal Pty Ltd	Washpool Coal	Proposed (application only)	Review of Landsat imagery indicates construction of the mine has not commenced. Once commenced, the project will have a 15 to 20 year life.	Open cut Two pits, west and east, that would eventually merge	Scorpio seam of the Burngrove Formation (Layer 9)	EIS dated 2012 –report not available. DNRM and IESC assessment reports provide information about the EIS. An analytical model was developed to assess groundwater impacts. Groundwater modelling indicated the maximum drawdown would extend 1.4 km from mine pits and drawdown in the alluvial aquifer may potentially increase leakage from Mackenzie River up to 11 Ml/a. The IESC state that due to the lack of surface–groundwater characterisations, the estimated loss of stream flow in Mackenzie River could be underestimated.	Not included. Mine not operational during this period.	Simulated mining from 2017 to 2021 in the Burngrove Formation (at the elevation of the Scorpio seam) in an east to west direction.

Owner	Operation	Status	Period of operation	Type of operation	Target seam	Groundwater information available	Calibration period (1983–2015)	Predictive scenarios (2016–2039)
Arrow Energy	Arrow Bowen Gas Project	Proposed	The draft UWIR 2016 indicates no gas production is proposed in this area before 2045.	Coal seam gas field	Rangal Coal Measures (Leichhardt and Vermont seams) and Moranbah Coal Measures	A groundwater model was developed for the EIS. The gas field is located within the Surat Cumulative Management Area and was considered in the draft Surat UWIR 2016	Not included. Gas field not operational during this period.	Not included. The draft UWIR 2016 indicates no gas production is proposed in this area before 2045.

(1) UWIR – Underground water impact report

(2) IDP – Initial development plan

7.4.1.2 Spoil emplacement

Simulation of in pit backfilling was undertaken by altering the hydraulic conductivity, storage properties and recharge of each model cell in the stress period following simulation of mining.

Spoil used for in pit backfilling is highly heterogeneous which can result in variable hydraulic properties. Hydraulic properties for spoil have been adopted from Mackie (2009) and are presented in Table 7.4. The higher permeability of the spoil compared to the host formation was altered using MODFLOW-USGs Time-Variant Materials (TVM) package.

The higher infiltration properties of the spoil were accommodated by increasing rainfall recharge to 5% of rainfall. Topography was not altered to reflect landform changes and evapotranspiration was not altered to reflect changed vegetation.

Table 7.4 Hydraulic properties applied to spoil

Kh (m/d)	Kv (m/d)	Ss (m^{-1})	Sy	Recharge	ET
1	1	0.1	5.0×10^{-3}	5% rainfall	No change

7.4.2 Calibration results

7.4.2.1 Hydraulic properties

Calibrated model hydraulic properties for each layer are presented in Table 7.5. The modelled zonation for layer 1 alluvium is shown in Figure 7.4. The higher hydraulic conductivities in zone 1 of layer 1 (Curragh North and Pit X) reflect the palaeochannels that exist in the alluvium in these areas. Single values for hydraulic conductivity were used for other layers.

Table 7.5 Calibrated model hydraulic properties

Layer	Formation	Zone	Kh (m/day)	Kv (m/day)	S_s (m^{-1})	S_y
1	Alluvium – Sand and gravel	1	1	0.1	0.00001	0.15
	Weathered rock – Tertiary and Rewan formations	11	0.01	0.001	0.00001	0.05
	Weathered rock – Rangal Coal Measures	12	0.01	0.001	0.00001	0.05
	Weathered rock – Burngrove and Fair Hill formations	13	0.01	0.001	0.00001	0.05
	Alluvium – Sand and clay	14	0.1	0.01	0.00001	0.1
	Alluvium – Clay	15	0.01	0.001	0.00001	0.02
2	Weathered rock		0.01	0.001	0.00001	0.05
3	Rewan Formation and overlying/interburden units of the Rangal Coal Measures		0.0005	0.00005	0.00001	0.05
4	Rangal Coal Measures – upper coal seams		0.006	0.0006	0.00001	0.05
5	Rangal Coal Measures – interburden		0.00001	0.000001	0.00001	0.05

Layer	Formation	Zone	Kh (m/day)	Kv (m/day)	S_s (m^{-1})	S_y
6	Rangal Coal Measures – middle coal seams		0.005	0.0005	0.00001	0.05
7	Rangal Coal Measures – interburden		0.00001	0.000001	0.00001	0.05
8	Rangal Coal Measures – lower coal seam		0.004	0.0004	0.00001	0.05
9	Burngrove Formation		0.0001	0.00001	0.00001	0.05
10	Fair Hill Formation		0.00005	0.000005	0.00001	0.05

The calibrated model parameters are in good agreement with the field and literature hydraulic properties compiled in Section 4.3. Key points to note are:

- alluvium permeability reflects the alluvium composition as shown in Figure 4.1, with higher permeabilities for sand and gravel in zone 1, and lower permeabilities for sand and clay in zone 14 and clay in zone 15
- coal seam permeability is one to two orders of magnitude greater than interburden
- coal seam permeability decreases with depth reflecting the increased loading of overburden
- Rewan Formation permeability is low consistent with available data.



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Data Source:
All data from WSP/PB (2016)

Groundwater impact assessment
Curragh Extension Project
Figure 7.4
Calibrated hydraulic parameter distribution – Layer 1

MXD Number: 2172652H_GIS_SW_F038_A3
Date: 15/06/2016
Author: VD
Approved by: LR

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7.4.2.2 Hydraulic heads

Figure 7.5 presents a summary of the groundwater level calibration, comparing observed (measured) versus modelled heads for the transient calibration period. Overall, there is good correlation between observed and modelled water levels. Water levels are over predicted in some areas of the Burngrove Formation and under predicted in layer 4 of the Rangal Coal Measures.

The model reported an unweighted RMS error of 8.6 m and a weighted RMS error of 3.8 m for the transient calibration period. RMS error is a statistic similar to standard deviation which measures the variation in observed and modelled water levels. Observations are weighted prior to calibration based on the reliability of data. A weighting of 0.5 was applied to monitoring bores BH1, BH3 and BH4 and a weighting of 0.1 was applied to monitoring bores BH2 and BH5 as historical data for these bores is considered to be unreliable.

The ratio of RMS to the total head change across the calibration targets is the scaled RMS. The model reported an unweighted scaled RMS error of 13% and a weighted scaled RMS error of 5.8% for the transient calibration period.

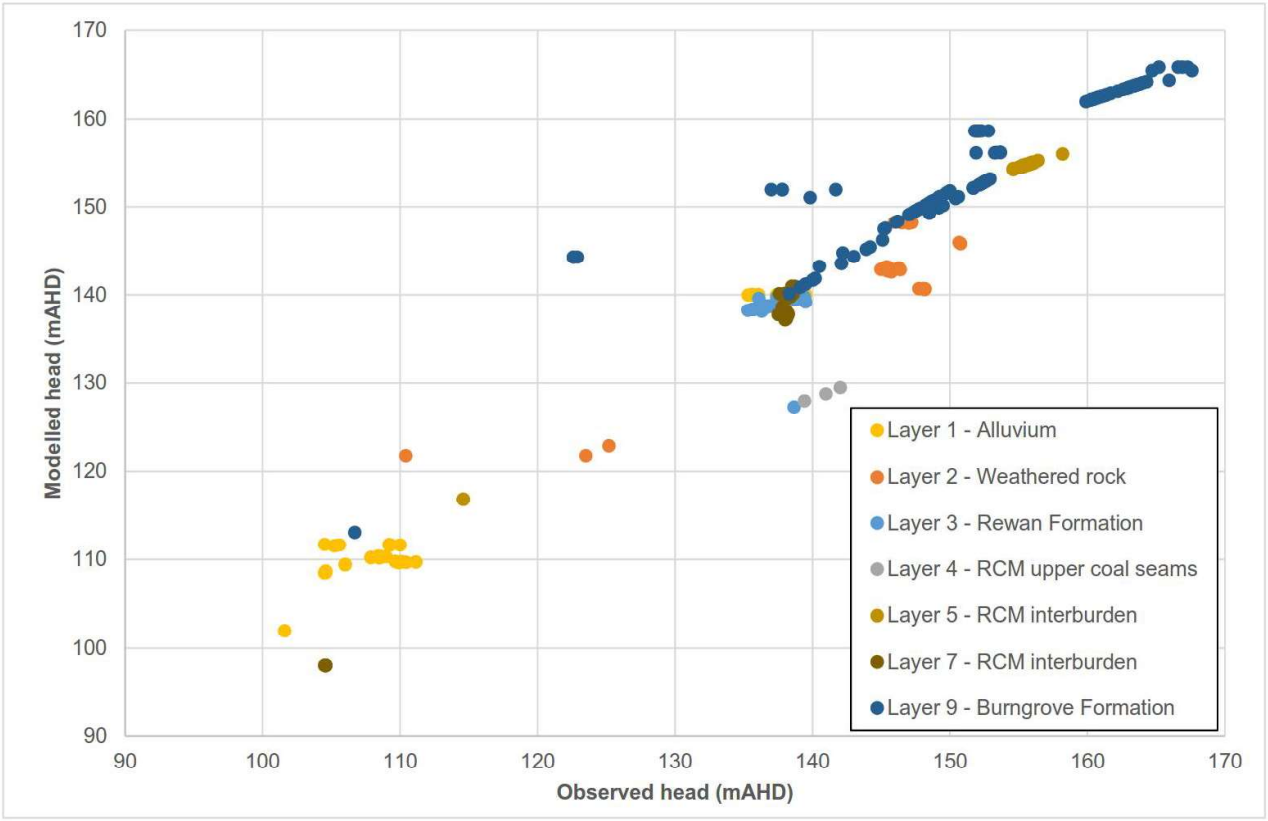
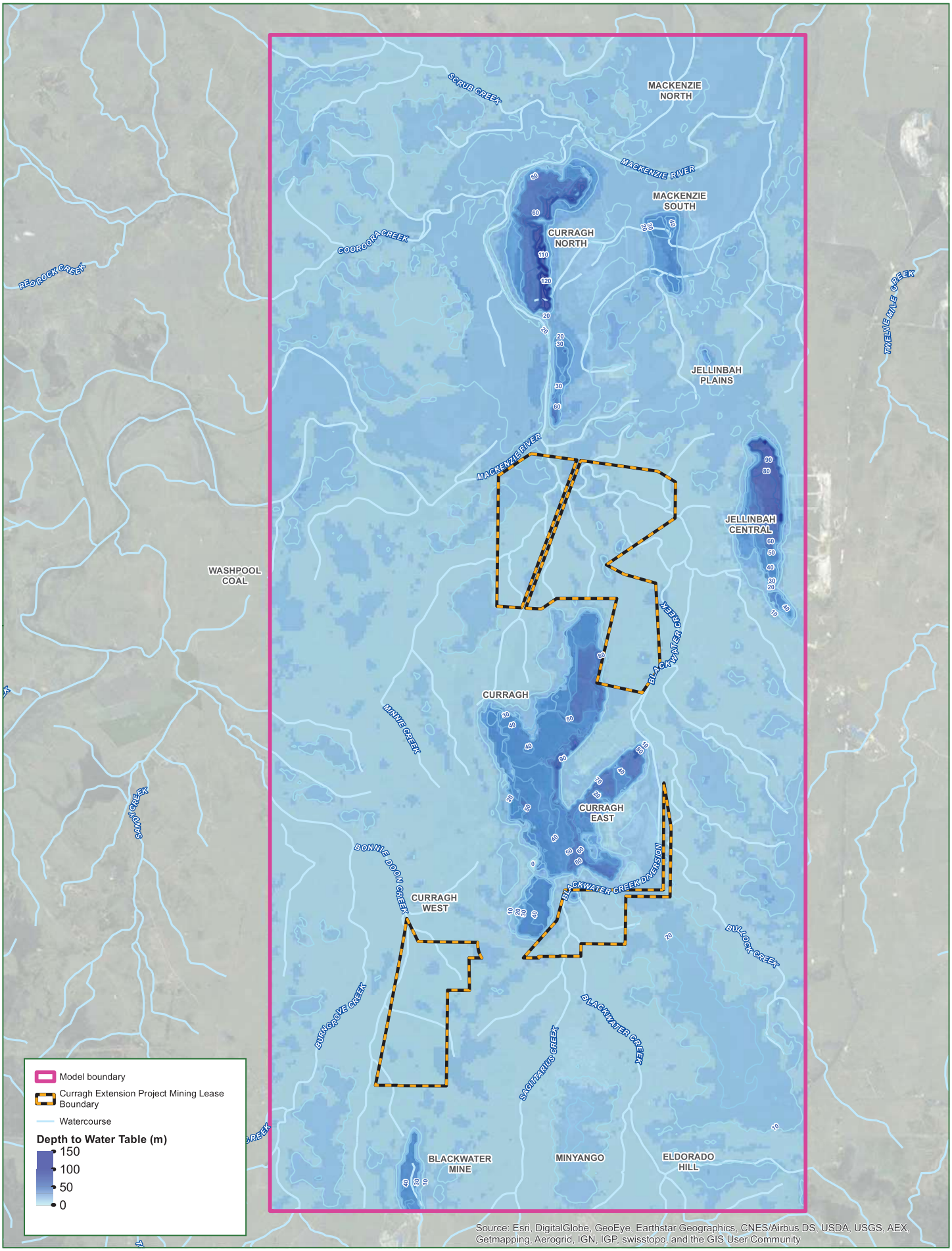


Figure 7.5 Observed vs modelled heads

Figure 7.6 shows the modelled water table in 2015 and Figure 7.7 shows the modelled heads for layer 6 in 2015. Layer 6 is the Pollux and Orion seams of the Rangal Coal Measures, the main target seams in the study area.



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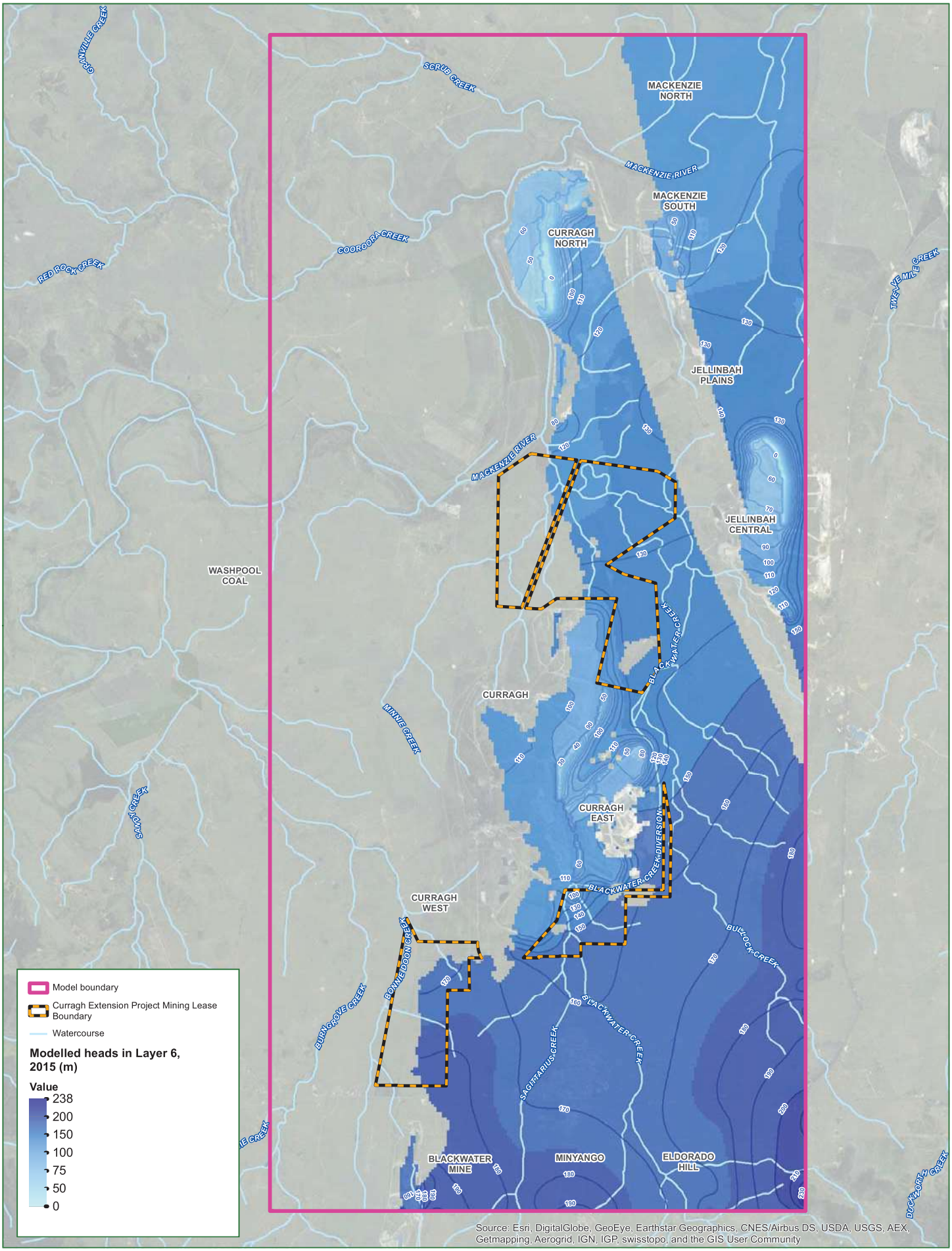
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Data Source:
Watercourse from DNRM (2016)
All other data from WSP/PB

Groundwater impact assessment
Curragh Extension Project
Figure 7.6
Depth to water table, 2015

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Date: 15/06/2016
Author: VD
Approved by: LR

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Projection: Transverse Mercator
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Data Source:
All data from WSP/PB (2016)

Groundwater impact assessment
Curragh Extension Project
Figure 7.7
Modelled heads Layer 6 (2015)

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Author: VD
Approved by: LR

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7.4.2.3 Water balance

The mass balance for the calibrated model across the model domain is summarised in Table 7.6. The modelled mass balance error is low at 0.0%.

Recharge (11%) and losses from Mackenzie River (0.4%) are a small proportion of inflows. Groundwater outflow is dominated by dewatering of mine pits (51%), with evapotranspiration providing 9% of groundwater outflow.

Table 7.6 Water balance, calibration run (1983–2015)

Component	Groundwater inflow (recharge) (Ml/d)	Groundwater outflow (discharge) (Ml/d)	Net (Ml/d)
Recharge	1.65	–	1.65
Evapotranspiration	–	-1.22	-1.22
Rivers (Mackenzie River)	0.05	-0.03	0.02
Drains (tributaries)	–	0.00	0.00
Drains (mine pits)	–	-7.14	-7.14
General head boundary	0.63	-0.09	0.54
Storage	11.54	-5.39	6.15
TOTAL	13.87	-13.87	0.00

7.4.2.4 Mine inflows

Modelled pit inflows for the calibration period are summarised in Table 7.7. These are groundwater figures only and do not include ingress to pits from runoff or flooding or evaporation from pit walls or floor.

Pit inflows predicted by the model for 2015 have been compared with pit inflows measured by Curragh Mine pump personnel in August 2015 (Table 7.7). Overall the model provides good replication of pit inflows. Inflows are under predicted for Pit U at Curragh North.

Table 7.7 Observed vs modelled daily pit inflows (2015)

Mining area	Pit	Measured inflows (Ml/d)	Modelled inflows (Ml/d)
Curragh East	C, D, E, F, H	2.3	1.7
Curragh North	U	5.6	1.5
	T	1.0	1.0
	S	0.6	0.6

7.4.3 Sensitivity analysis

A sensitivity analysis assessed the response of the model calibration to changes in the model input parameters. The objective of the sensitivity analysis was to rank the input parameters in terms of their influence on the results. The most sensitive parameters were selected for predictive uncertainty analysis. The results of the uncertainty analysis are presented in Section 7.6.

Sensitivity analysis was undertaken for the parameters expected to be most sensitive based on the conceptual hydrogeological model. The sensitivity analysis assessed the impact of:

- increasing/decreasing the horizontal and vertical hydraulic conductivity and specific yield of the alluvial zones by a factor of +/-10
- increasing/decreasing the horizontal and vertical hydraulic conductivity and specific storage of coal seams (layers 4, 6 and 8) by a factor of +/- 10
- increasing/decreasing the streambed conductance of Mackenzie River by a factor of +/- 10.

The results indicate the most sensitive parameters to be:

- increased horizontal hydraulic conductivity of the alluvium (zone 1)
- increased horizontal and vertical hydraulic conductivity of the uppermost coal seams (Layer 4)
- increased recharge (all zones in layer 1).

7.5 Model predictions

7.5.1 Approach

Two main predictive model scenarios were run:

1. A **base case run**, representing future mining activities at Curragh Mine and neighbouring mines that have been approved by government or are in advanced stages of approval.
2. A **cumulative run**, representing future mining activities at Curragh Mine and neighbouring mines as well as proposed mining activities for the Curragh Extension Project.

The difference between these two runs provided the impacts of the Curragh Extension Project.

Both models used the calibrated historic period as a precursor to the predictive simulation period and included a recovery period of 750 years.

7.5.1.1 Mining schedule

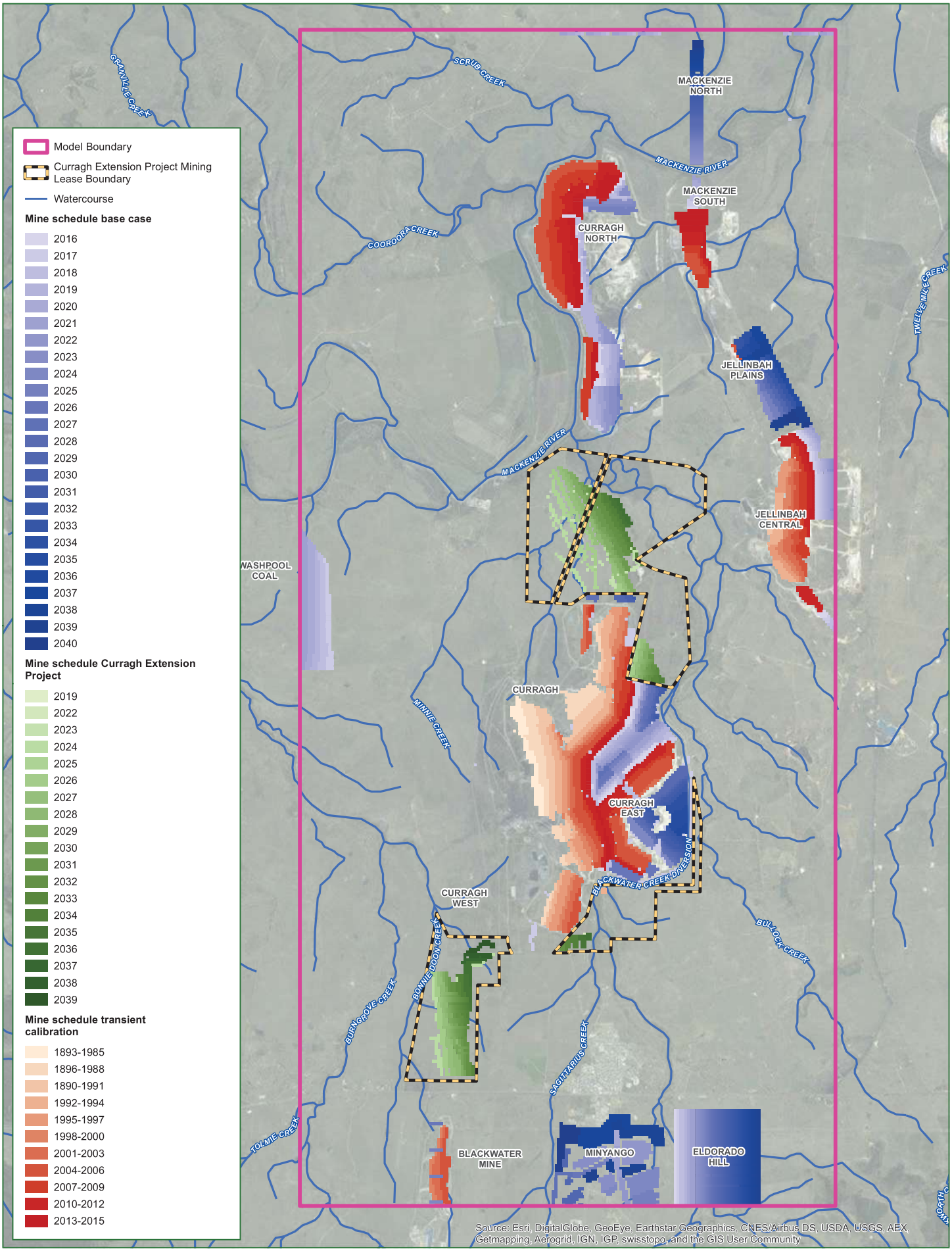
The mining schedule for the base case and cumulative runs is shown in Figure 7.8.

Future mining at Curragh Mine was simulated based on pit shell elevation surfaces provided by WCPL. The pit shells were provided for each year from 2017 to 2039. The location and depth of mining in 2016 was estimated based on mining in 2015 and 2017.

Active open cut pits at Curragh Mine were simulated using the MODFLOW drain package (DRN). The location and elevation of drain cells was determined by intersecting the pit shell elevation surfaces with the model layers in each model cell.

Future mining at neighbouring mines was simulated based on information in initial development plans or environmental impact assessment documents, or was estimated based on the progression of historical mining. Details of the approach to simulating future mining at neighbouring mines is provided in Table 7.3.

Active open cut pits and underground voids at neighbouring mines were simulated using the MODFLOW drain package (DRN). The elevation of the drain cells was set to the base of the lowest mineable coal seam in each area. This is considered a conservative approach as mining will occur from the shallower coal seams initially, instead of immediately from the base of the lowest mineable seam.



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Data Source:
Geology from GSQ (2015)
Watercourse from DNRM (2016)
Mining data from WSP/PB (2016)

Groundwater impact assessment
Curragh Extension Project
Figure 7.8
Mining schedule – base case and Curragh Extension Project

MXD Number: 2172652H_GIS_SW_F042_A4
Date: 20/06/2016
Author: SH
Approved by: LR

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7.5.1.2 Spoil emplacement

Simulation of in pit backfilling was undertaken by altering the hydraulic conductivity, storage properties and recharge of each model cell in the stress period following simulation of mining.

Spoil used for in pit backfilling is highly heterogeneous which can result in variable hydraulic properties. Hydraulic properties for spoil have been adopted from Mackie (2009) and are presented in Table 7.8. The higher permeability of the spoil compared to the host formation was altered using MODFLOW-USGs Time Variant Materials (TVM) package.

The higher infiltration properties of the spoil were accommodated by increasing rainfall recharge to 5% of rainfall. Topography was not altered to reflect landform changes and evapotranspiration was not altered to reflect changed vegetation.

Table 7.8 Hydraulic properties applied to spoil

Kh (m/d)	Kv (m/d)	Ss (m^{-1})	Sy	Recharge	ET
1	1	0.1	5.0×10^{-3}	5% rainfall	No change

7.5.1.3 Residual voids

Four residual voids will remain following completion of mining at Curragh Mine:

- Pit T (Curragh North)
- Pit X (Curragh Extension Project)
- Pits K and L (Curragh East)
- Pit Z (Curragh Extension Project).

Residual voids may be a source or sink to groundwater, depending on the equilibrium water level in the voids compared to the natural water table. Climatic conditions in the study area suggest the residual voids will be a groundwater sink and will not be a source of salinity to groundwater. If residual voids are a sink, groundwater levels local to the voids may be drawn down below pre-mining levels over the long term.

Detailed assessment of residual voids is not included in this report. Condition G14 of EA EPML00643713 requires preparation of a residual void investigation report, which will assess the residual voids at Curragh Mine in detail, including consideration of whether the voids will behave as a sink or source to groundwater. Section 9.1.3 provides an outline of the contents of the residual void investigation report.

A simple representation of the four residual voids has been included in the numerical groundwater model as follows:

- At completion of mining, pit drain cells were deactivated and replaced with spoil, with the exception of residual void cells
- The hydraulic properties of residual void cells were altered using the TMP package. Kh and Kv were set to 1000 m/day and Sy was set to 1
- Recharge for residual void cells was modified to 100% of rainfall and the ET surface was set to the elevation of the drain cells in the last year of mining.

7.5.2 Water balance

The model water balance reports the inflows, outflows and change in storage for the model domain. The water balance for the cumulative run has been compared to the water balance for the base case run to provide the incremental change in the water balance due to the Curragh Extension Project (Table 7.9). The water balances have been averaged over the 24 years of future mining from 2016 to 2039.

The results for the two scenarios are relatively similar, with the main difference being an increase in pit inflows due to the excavation of additional mine pits for the Curragh Extension Project. The water balance is consistent with the model conceptualisation.

Table 7.9 Average simulated water balances (2016 – 2039)

Component	Base case run		Incremental change due to CEP	
	Inflows (Ml/day)	Outflows (Ml/day)	Inflows (Ml/day)	Outflows (Ml/day)
Recharge	4.62	–	0.17	–
Evapotranspiration	–	-1.95	–	-0.07
Rivers (Mackenzie River)	0.01	-0.02	0.00	0.00
Drains (tributaries)	–	0.00	–	0.00
Drains (mining)	–	-30.64	–	-2.01
General head boundary	11.44	-0.14	0.00	0.00
Storage	64.90	-48.32	7.27	-5.50

7.5.3 Predicted pit inflows

Groundwater inflows to operational pits at Curragh Mine for the period 2016 to 2039 are presented in Figure 7.9. The inflows presented are cumulative inflows for Curragh Mine (in grey) and do not include inflows to residual voids. Inflows to Curragh Extension Project pits are shown in blue.

Cumulative inflows to Curragh Mine pits are predicted to range from 0.18 to 4.51 Gl/year, with an average of 2.65 Gl/year. Peak inflows predicted to occur in 2019.

Inflows to Curragh Extension Project pits for the period 2019 to 2039 are predicted to range from 0.01 to 1.26 Gl/year, with an average of 0.57 Gl/year. Peak inflows predicted to occur in 2032.

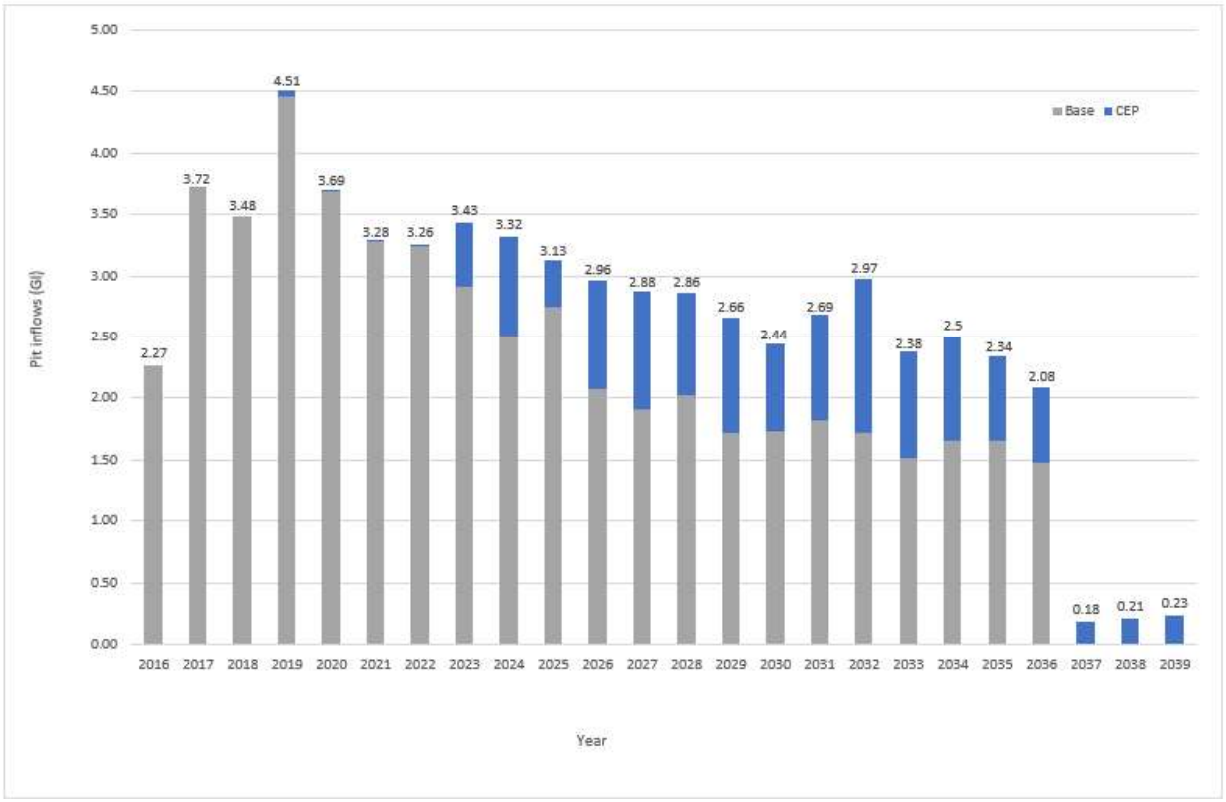


Figure 7.9 Predicted pit inflows

7.5.4 Predicted drawdown and recovery

Dewatering of pits is integral to the extraction of coal and will result in localised drawdown of groundwater systems (including depressurisation of confined hydrostratigraphic units). The extent of drawdown will depend on the hydraulic properties of the coal seams and other stratigraphic units. Drawdown is greatest in the working areas of the mine and gradually reduces with distance from the mine.

Groundwater level recovery will occur throughout the mining process as pits are progressively backfilled following mining of target seams.

7.5.4.1 Curragh Extension Project

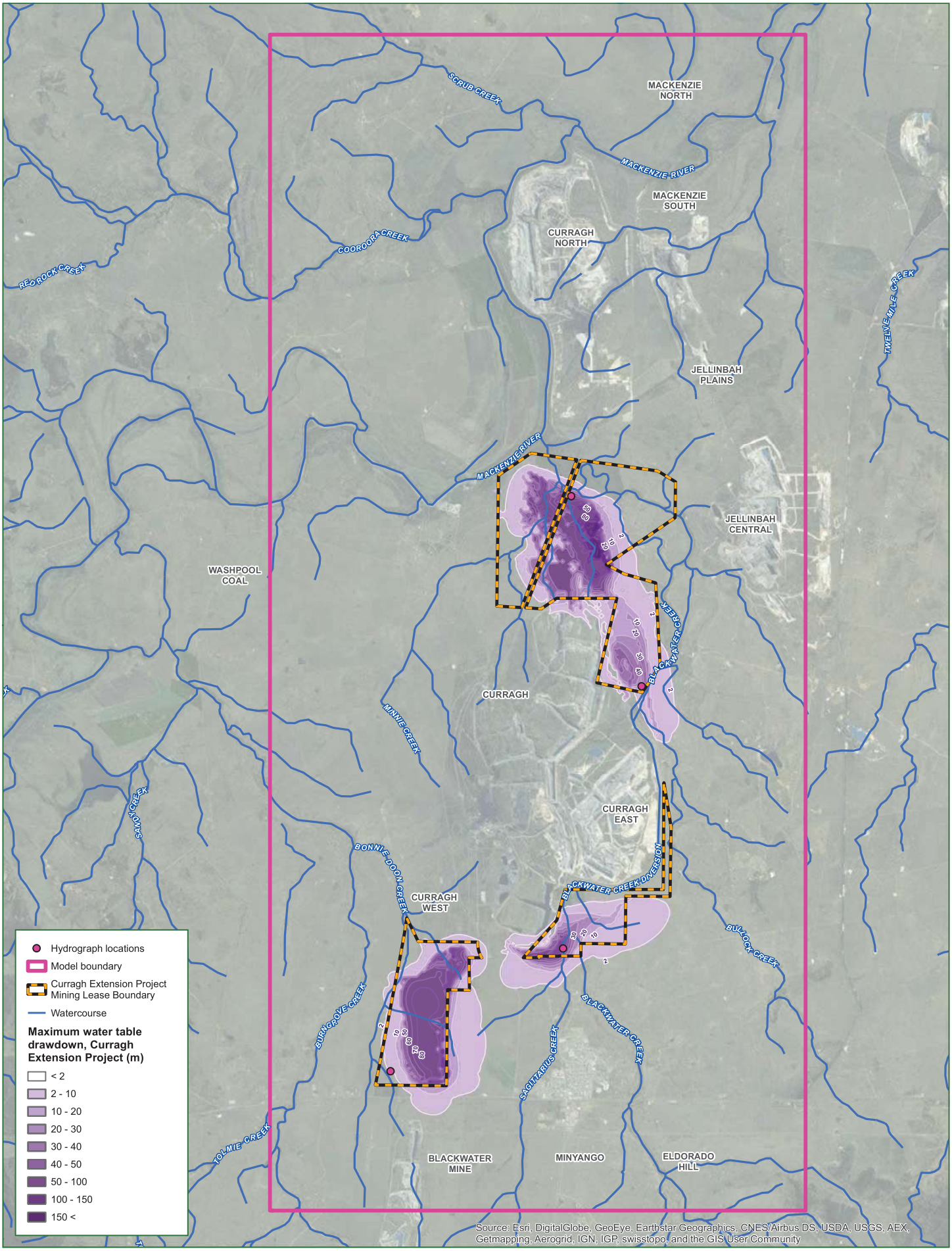
Predicted maximum water table drawdown due to the Curragh Extension Project is presented in Figure 7.10. Predicted maximum drawdown in the Pollux and Orion seams (layer 6) is presented in Figure 7.11. Predicted maximum drawdown in the Pisces Seam (layer 8) and Burngrove Formation (layer 9) are presented in the figures in Attachment F.

The results show that groundwater level drawdown due to the Project will generally be less than 2 m at a distance of 2 km from mine pits. This is consistent with groundwater level observations at groundwater monitoring bores located at the current operation (Curragh Mine).

Groundwater level hydrographs showing drawdown and recovery near the Curragh Extension Project pits are presented in Figures 7.12 (Pit X), 7.13 (Pit D extension), 7.14 (Pit J extension) and 7.15 (Pit Z). Less recovery is observed where residual voids will remain (Pit X and Pit Z). The locations of the hydrographs are shown in Figure 7.10.

7.5.4.2 Cumulative

Predicted maximum water table drawdown due to all proposed development in the model domain is presented in Figure 7.16. Predicted maximum drawdown in the Pollux and Orion seams (layer 6) is presented in Figure 7.17. Predicted maximum drawdown in the Pisces Seam (layer 8) and Burngrove Formation (layer 9) are presented in the figures in Attachment G.



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Data Source:
Cadastre from DNRM (2014)
Imagery from Wesfarmers (2014)

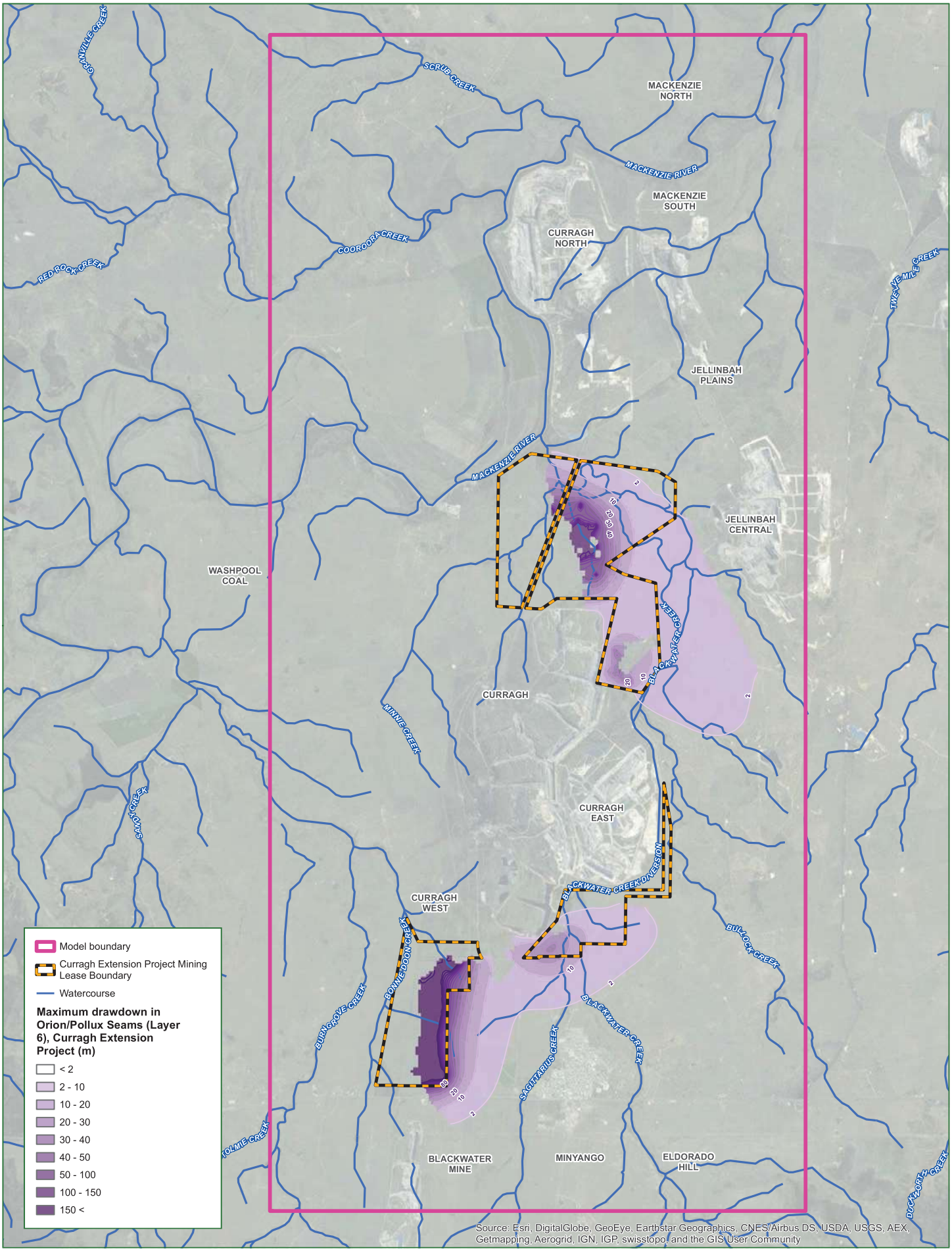
Groundwater impact assessment
Curragh Extension Project

Figure 7.10

Maximum water table drawdown - Curragh Extension Project

MXD Number: 2172652H_GIS_SW_F006_A8
Date: 15/06/2016
Author: VD
Approved by: LR

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0 0.5 1 2 3 4 km

Scale 1:135,000

Scale correct when printed at A3 Portrait

Projection: Transverse Mercator
Coordinate System: GDA 1994 MGA Zone 55

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Data Source:
All data from WSP/PB (2016)

Groundwater impact assessment
Curragh Extension Project

Figure 7.11

Maximum drawdown in Orion/Pollux Seams (Layer 6), Curragh Extension Project

MXD Number: 2172652H_GIS_SW_F017_A5
Date: 15/06/2016
Author: VD
Approved by: LR

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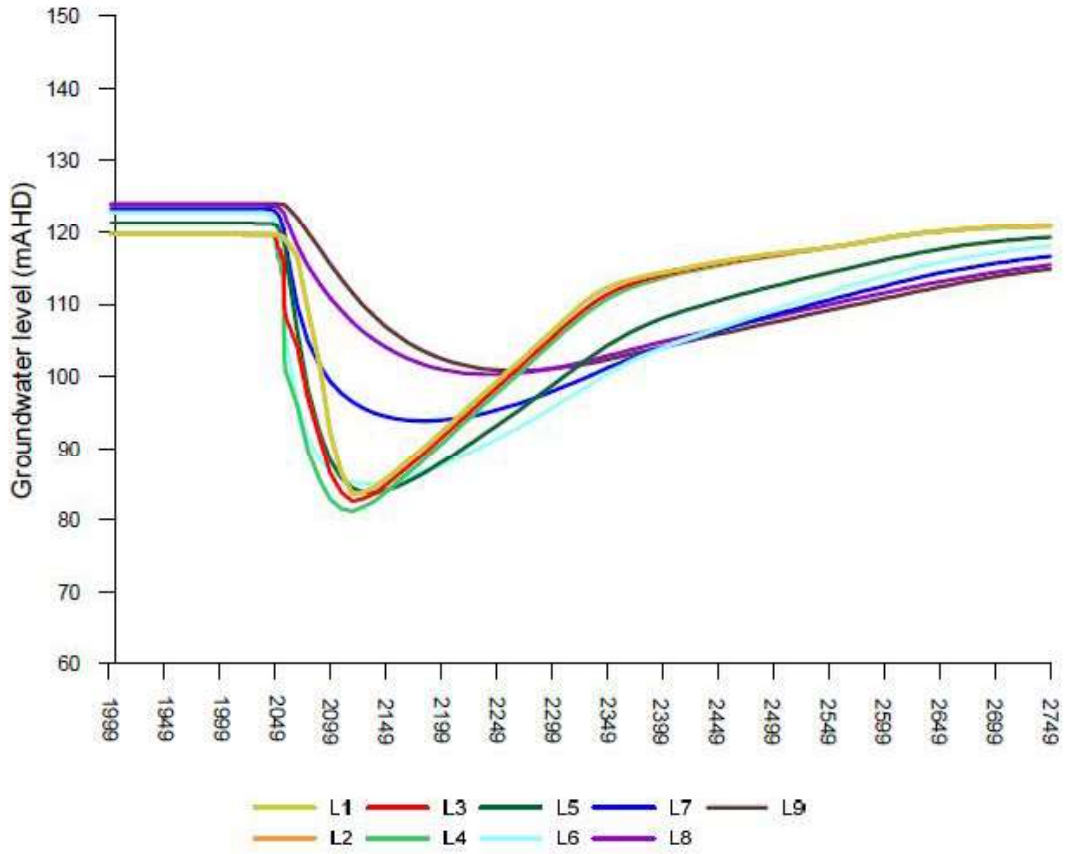


Figure 7.12 Drawdown hydrograph (near Pit X)

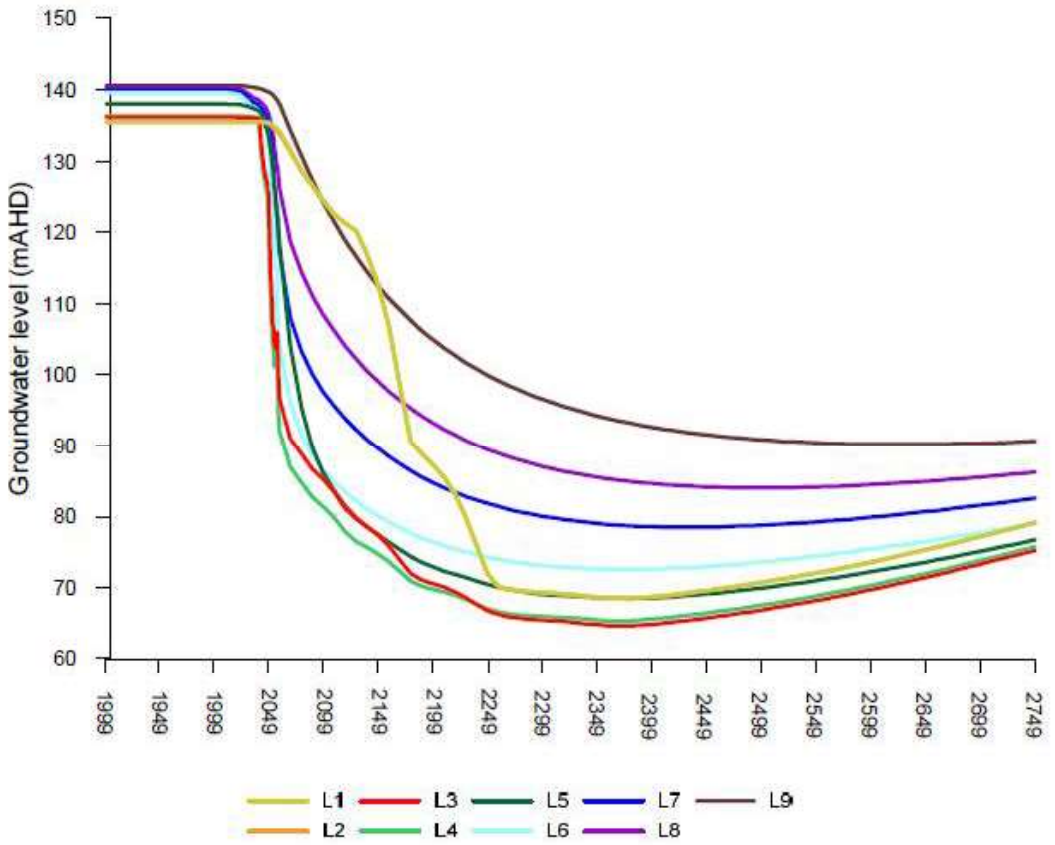


Figure 7.13 Drawdown hydrographs (near Pit D extension)

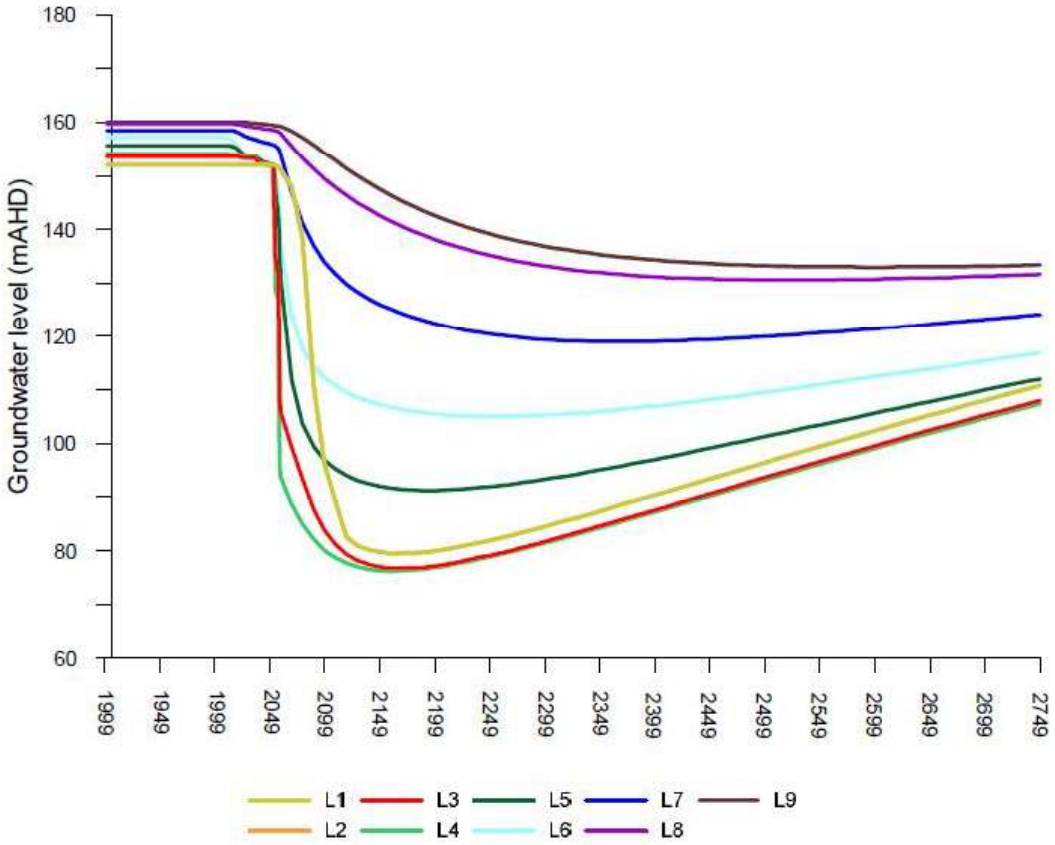


Figure 7.14 Drawdown hydrograph (near Pit J extension)

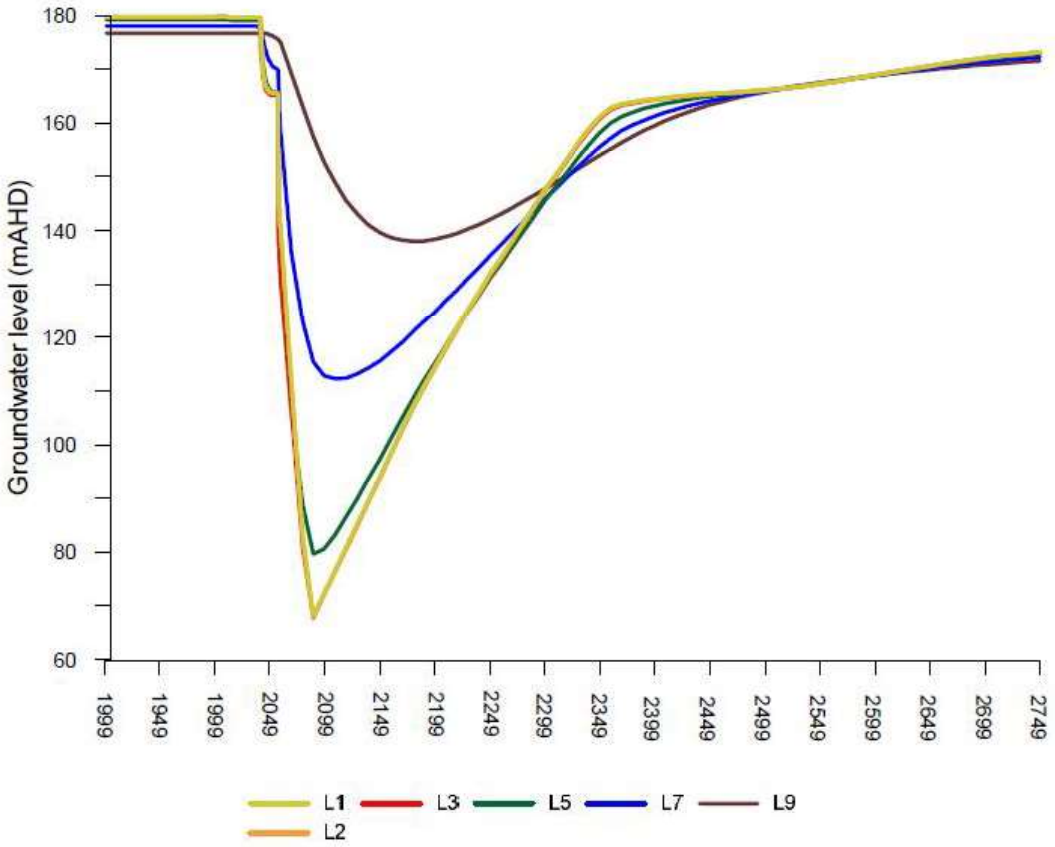
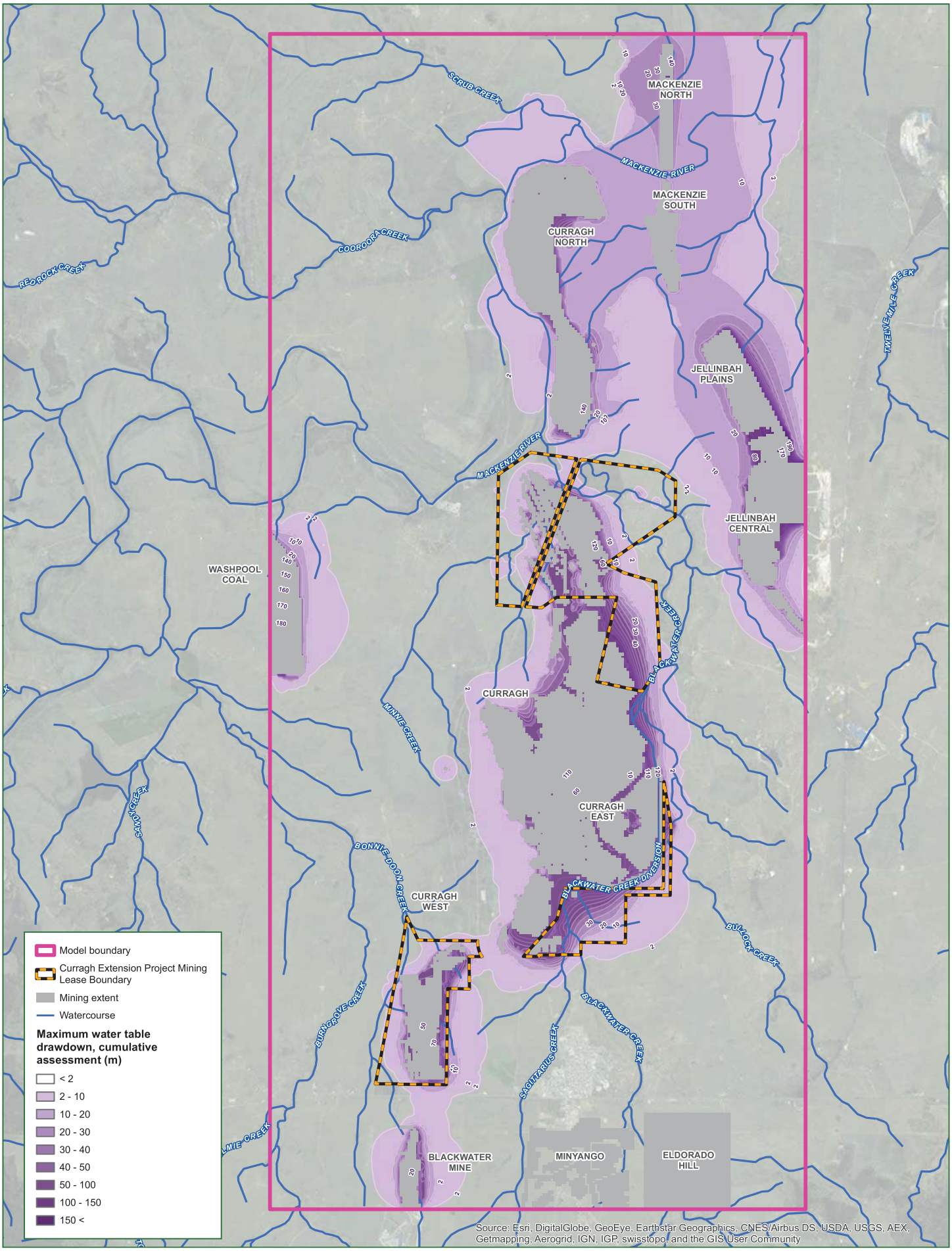


Figure 7.15 Drawdown hydrograph (near Pit Z)



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0 0.5 1 2 3 4 km

Scale 1:135,000

Scale correct when printed at A3 Portrait

Projection: Transverse Mercator
Coordinate System: GDA 1994 MGA Zone 55

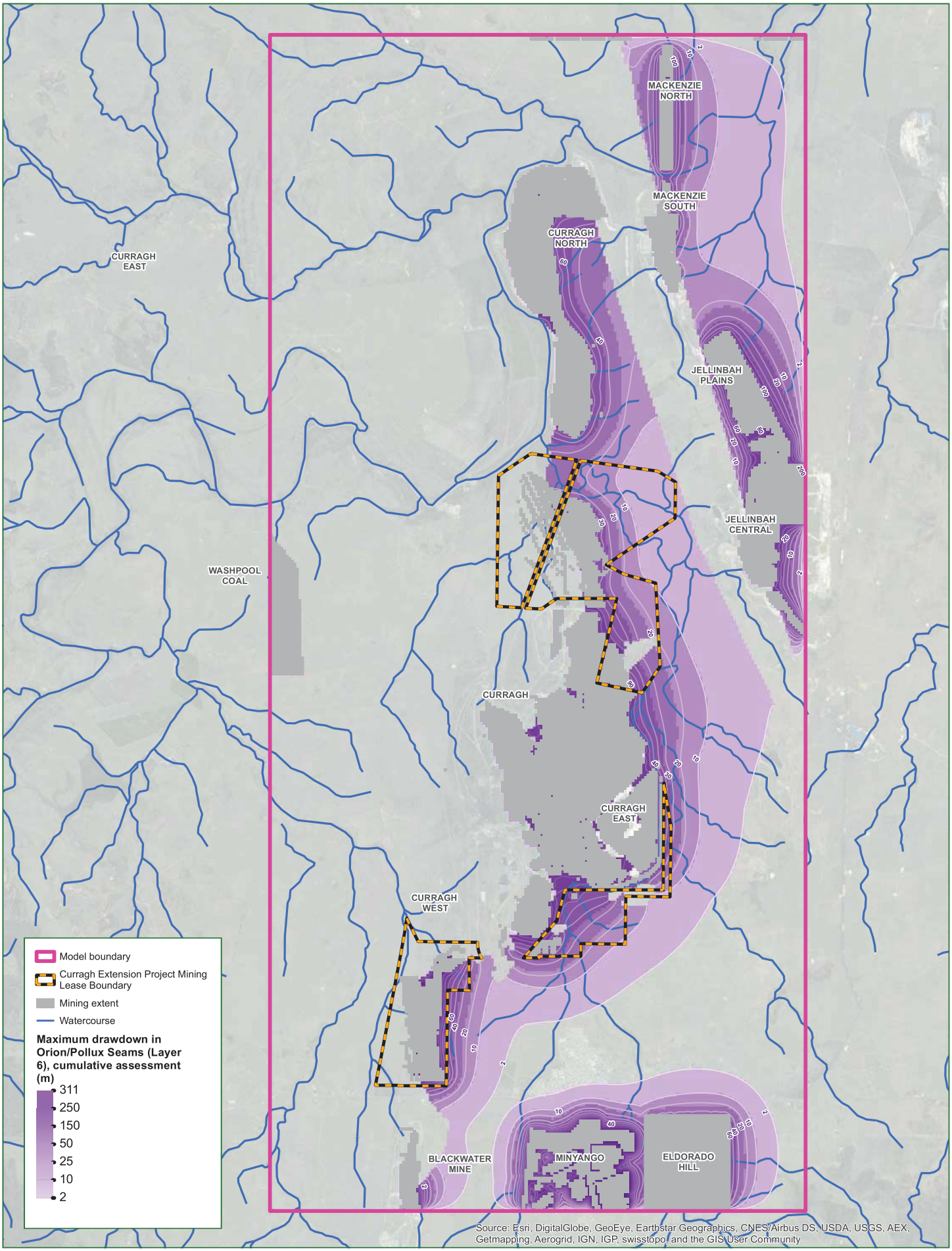
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Data Source:
Cadastre from DNRM (2014)
Imagery from Wesfarmers (2014)

Groundwater impact assessment
Curragh Extension Project
Figure 7.16
Maximum water table drawdown – cumulative assessment

MXD Number: 2172652H_GIS_SW_F005_A9
Date: 15/06/2016
Author: VD
Approved by: LR

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Wesfarmers

PARSONS BRINCKERHOFF

0 0.5 1 2 3 4 km

Scale 1:135,000

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Projection: Transverse Mercator
Coordinate System: GDA 1994 MGA Zone 55

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Data Source:
All data from WSP/PB (2016)

Groundwater impact assessment
Curragh Extension Project
Figure 7.17
Maximum drawdown Layer 6 – cumulative assessment

MXD Number: 2172652H_GIS_SW_F013_A9
Date: 15/06/2016
Author: VD
Approved by: LR

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7.6 Uncertainty analysis

The sensitivity analysis indicated the calibration was most sensitive to:

- increased horizontal and vertical hydraulic conductivity of the alluvium (zone 1)
- increased horizontal and vertical hydraulic conductivity of the uppermost coal seams (Layer 4)
- increased recharge (all zones).

Predictive uncertainty analysis was undertaken for these parameters for the period of mining. The following uncertainty runs were undertaken:

- increased horizontal hydraulic conductivity of zone 1 of the alluvium by a factor of 10 (Kh = 10 m/day) and increased vertical hydraulic conductivity of zone 1 of the alluvium by a factor of 100 (Kv = 10 m/day)
- increased horizontal and vertical hydraulic conductivity of the uppermost coal seams (Layer 4) by a factor of 10 (Kh = 0.06 m/day and Kv = 0.006 m/day)
- increased recharge by a factor of 1.5 for all zones.

The results of the uncertainty analysis are presented in Tables 7.10 and 7.11. Table 7.10 presents a comparison of maximum pit inflow rates for the cumulative run with the uncertainty runs.

Table 7.10 Pit inflows – uncertainty analysis

Maximum pit inflow rate (Ml/day)	Pit X	Pit D extension	Pit J extension	Pit Z
Cumulative run	5.1	0.8	0.9	5.4
Increased K alluvium	4.9	0.5	0.7	5.2
Increased K upper coal seams	5.1	0.7	0.6	5.2
Increased recharge	5.0	0.5	0.9	5.3

Table 7.11 presents a comparison of maximum water table drawdown at the hydrograph locations shown in Figure 7.10.

Table 7.11 Maximum water table drawdown at hydrograph locations – uncertainty analysis

Maximum water table drawdown (m)	Pit X hydrograph location	Pit D extension hydrograph location	Pit J extension hydrograph location	Pit Z hydrograph location
Cumulative run	1	1	1	40
Increased K alluvium	1	2	1	44
Increased K upper coal seams	26	11	1	36
Increased recharge	1	1	1	47

The results show that pit inflow rates predicted for the uncertainty runs were lower than pit inflow rates predicted for the cumulative run and were generally within 30% of the cumulative run predictions. Although maximum rates were lower for the uncertainty runs, total inflows are expected to be similar over the period of mining.

Water table drawdown predictions for the uncertainty runs were the same or slightly greater, except the water table drawdown predictions for the coal seam uncertainty run, which were substantially greater than the cumulative run for Pit X and Pit D extension (Table 7.11).

7.7 Model assumptions and limitations

The groundwater flow model simulates a simplified version of a complex geological and hydrogeological system. This simplification is required to allow the model to be run and utilised within a reasonable timeframe. Further, the model assumptions that were incorporated were deemed appropriate and acceptable given the purpose of the model (i.e. to develop a model to simulate changes in groundwater levels in response to the proposed mining). In this context, the assumptions made are considered to be conservative in respect of the scale of the groundwater impacts that are predicted (i.e. the assumptions, when compounded, would tend to overestimate the scale of the impact).

A summary of the assumptions incorporated into the model, and their resulting limitations, include:

- The model is based on the conceptual hydrogeological model in Section 4.
- Groundwater level and hydraulic property data is not available for the Curragh Extension Project area. The groundwater model has drawn on groundwater level and hydraulic property data available for Curragh Mine and neighbouring mines, which is considered to provide a good indication of values as these mines are located in the same hydrogeological environment. The model has been calibrated to available groundwater level and pit inflow data and hydraulic properties are within reasonable ranges. Groundwater level and hydraulic property data will be gathered for the Project area prior to commencement of mining and the current model will be recalibrated.
- The number of layers within the model has been limited to ten. The coal seams have been aggregated into three layers. This represents the mined coal in the model, and is considered a conservative approach as mining is assumed to occur from the base of the aggregated seams. Vertical discretisation of the model layers is deemed appropriate and reasonable for the purpose of determining the likely impact to groundwater from proposed mining in the study area.
- The alluvium has been assigned a minimum thickness of 5 m for the purposes of modelling however in some parts of the Project area, including near the Pit D extension and Pit J extension, the alluvium is less than 5 m thick. Also, the model was unable to replicate the variably saturated nature of the alluvium. Drawdown impacts to alluvium are therefore likely to be over-predicted.
- The numerical groundwater model includes simple representation of the residual voids that will remain at the end of mining. The model may not accurately replicate whether the voids will act as a source or sink to groundwater.

8. Impact assessment

Construction, operation and rehabilitation of the Project, if undertaken without adequate management controls in place, has the potential to impact on the identified groundwater resources and environmental values through changes in groundwater levels and groundwater quality. Section 7 of this report presents the results of the numerical groundwater modelling undertaken to quantitatively assess the magnitude and extent of drawdown associated with the Project and neighbouring projects. Quantitative assessment of drawdown impacts on registered bores and GDEs in the study area are presented in Section 8.2. Other potential impacts to groundwater resources are discussed qualitatively in Section 8.3.

8.1 Project activities with potential to impact groundwater resources

The Project will utilise existing infrastructure within the adjacent Curragh Mine and will minimise the need for new infrastructure requirements. All coal processing, coal stockpiling and train loading will occur at the existing Curragh Mine. All tailings and coarse rejects will be managed in existing Curragh Mine facilities, and existing Curragh Mine STPs are expected to have capacity to treat the additional sewage generated as a result of the Project.

Early planning works for the Project have considered environmental constraints, including groundwater related constraints, and implemented avoidance strategies to minimise impacts. Proposed Pit X has been located at a distance of 760 m from Mackenzie River (compared to 100 m at Curragh North).This has led to a reduction in the scale of environmental impacts that need to be considered in the approval process.

Project activities with the potential to impact on groundwater levels have been assessed *quantitatively* using numerical groundwater modelling (Section 7) and include:

- dewatering of proposed Pit X, Pit D extension, Pit J extension and Pit Z during the extraction of coal
- backfilling of pits and associated changes in recharge
- residual voids (preliminary consideration only).

Risks to environmental values associated with the potential impacts to groundwater levels are discussed in Section 8.2.

Project activities with the potential to impact on groundwater quality have been assessed *qualitatively* in Section 8.3 and include:

- construction activities for roads, stream diversions, water pipelines and mine water management dams
- ROM stockpiles at the south western corner of Curragh Central Extended and to the north of Curragh South
- a basic mine infrastructure area adjacent to the new ROM facilities
- a water storage dam within the Curragh Central development area and two within the Curragh South area
- fuel and truck fill facilities
- in-pit and out-of-pit spoil dumps, including burial of coarse rejects with spoil
- residual voids.

Tailings from the Project will be managed in existing Curragh Mine facilities. Potential impacts associated with the tailings storage facility at Curragh Mine are discussed in Section 8.2.3.3.

8.2 Drawdown impacts

Dewatering of pits is integral to the extraction of coal and will result in localised drawdown of groundwater systems (including depressurisation of confined hydrostratigraphic units). Drawdown of groundwater systems has the potential to result in:

- decrease in groundwater levels in bores and reduced supply to groundwater users
- decrease in groundwater levels and loss or degradation of GDEs
- reduced flow in Mackenzie River and loss or degradation of dependent aquatic ecosystems
- loss or reduction of supply to surface water users on Mackenzie River and Bonnie Doon Creek.

Drawdown due to the Curragh Extension Project and nearby operations has been quantitatively assessed using numerical groundwater modelling (Section 7). Risks to environmental values associated with predicted drawdown are discussed below.

8.2.1 Groundwater users

There are 15 registered bores in the study area. The locations of the bores are shown on Figure 5.1. One of the bores is abandoned but useable (97709).

Numerical groundwater modelling has indicated that drawdown at registered bores in the study area will be less than 0.51 m due to mining for the Curragh Extension Project (Table 8.1). Cumulative impacts to registered bores due to mining at Curragh Mine, neighbouring mines and for the Curragh Extension Project will be less than 0.7 m at all bores (Table 8.1).

Table 8.1 Predicted drawdown at registered bores

RN	Model layer	Modelled water level (2015) (mbgl)	Drawdown (base case run) (m)	Drawdown (cumulative run) (m)	Drawdown due to CEP (m)
38998	9	6.45	0.09	0.09	0.00
43097	9	0.31	0.07	0.08	0.02
43459	9*	2.90	0.08	0.08	0.00
84221	9*	9.57	0.10	0.61	0.51
97709^	1*	3.05	0.02	0.02	0.00
111877	1	3.93	0.02	0.02	0.00
132827	2	16.5	0.28	0.31	0.03
132828	2*	16.5	0.28	0.31	0.03
158777	2*	16.5	0.29	0.31	0.03
158778	2*	16.7	0.29	0.31	0.03
158779	2*	16.8	0.29	0.31	0.03
158961	2	3.81	0.08	0.08	0.00
165025	3	20.1	0.69	0.69	0.00
165026	1	3.37	0.11	0.11	0.00
13010010	9	3.25	0.05	0.05	0.00

mbgl – metres below ground level
* Target formation not available, inferred based on underlying geology
^ Bore is abandoned but useable

8.2.2 Streams

Stream losses for the Project were calculated as the difference in the river flux (Mackenzie River) or the difference in the drain flux (other streams) between the base case and cumulative scenario runs.

The model predicts that losses due to the Curragh Extension Project will be less than 0.01 Ml/year from each stream reach (Figure 7.1), including Mackenzie River, for the simulated period of mining and recovery.

8.2.3 Surface water users

Numerical modelling has predicted negligible impact to stream flow in Mackenzie River due to the Curragh Extension Project and therefore there are no predicted impacts to the supplemented and unsupplemented water allocation holders on Mackenzie River (Figure 5.2).

Blackwater Mine hold a water licence to impound water on Burngrove Creek (Figure 5.2). There are no predicted impacts to stream flow in Burngrove Creek due to the Project.

8.2.4 Groundwater dependent ecosystems

Potential impacts to potential surface expression GDEs are discussed in Section 8.2.4.1.

Potential impacts to areas of potential subsurface GDEs are discussed in Section 8.3.4.2.

8.2.4.1 Impacts to GDEs reliant on the surface expression of groundwater

The GDE atlas (BOM 2015) identifies a number of watercourses, wetlands and swamps in the study area as potentially reliant on the surface expression of groundwater (Figure 5.3).

The DSITIA (2015) surface expression GDE mapping did not return any known or high likelihood surface expression GDEs in the study area. A small section of moderate confidence surface expression GDE was returned from the DSITIA surface expression GDE mapping within the within the study area, outside the project footprint, along Blackwater Creek adjacent to the township of Blackwater (Figure 5.4).

It is important to note that the GDE atlas mapping (BOM 2015) and the DSITIA (2015) surface expression GDE mapping are indicative regional scale mapping layers. Desktop methods, such as those used to create the atlas, generally tend to overestimate the extent of GDEs (Richardson et al. 2011).

An assessment of the likelihood of reliance of watercourses, wetlands and swamps on groundwater was conducted based on the predicted depth to the water table at the location of the wetland. The depth to the water table was based on groundwater levels predicted by the numerical groundwater model for the ‘base case’ simulation. The ‘base case’ simulation is all development likely to occur excluding the proposed Curragh Extension Project.

The results from the calibrated numerical groundwater model indicate the watercourses in the study area are unlikely to receive baseflow from groundwater, and are more likely to be losing streams that are disconnected from groundwater. In addition, the depth to groundwater at the wetlands and swamps in the study area also indicated that these features are unlikely to receive baseflow from groundwater (refer Section 5.2.3.2). Wetlands and swamps underlain by alluvium may be fed by perched groundwater in some areas at certain times.

As watercourses, wetlands and swamps in the study area are unlikely to be reliant on the surface expression of groundwater, assessment of potential impacts associated with water table drawdown is not required.

8.2.4.2 Potential impacts to subsurface GDEs

Direct impacts to potential subsurface GDEs within Project footprint

Direct impacts to subsurface GDEs within the Project footprint (Figure 5.8) have been discussed and calculated based on the area of likely and potential subsurface GDEs, and associated regional ecosystems, occurring within the Project footprint (Figure 5.8).

Approximately 46.7 ha of likely and potential subsurface GDEs will be directly impacted by the Project within and surrounding Pit X (Table 8.2). Of the area of likely subsurface GDEs directly impacted within the footprint 45.7 are considered with a high likelihood of being groundwater dependent and 0.4 ha are considered with a moderate chance of being groundwater dependent.

Approximately 0.6 ha of potential subsurface GDEs will be directly impacted by the Project within and surrounding Pit X (Table 8.2). Of the area of potential subsurface directly impacted within the footprint 0.6 ha are considered with a high likelihood of being groundwater dependent.

An impact rating of high, medium and low has also been provided in Table 8.2 based on determining the percentage of each regional ecosystem directly impacted within the Project footprint compared with the amount mapped within the study area using the following criteria:

- High >30% of the subsurface GDE regional ecosystem within the study area impacted by the Project
- Medium 10–30% of the subsurface GDE regional ecosystem within the study area impacted by the Project
- Low <10% of the subsurface GDE regional ecosystem within the study area impacted by the Project.

Overall 0.02 percent of the entire are of likely and potential GDEs within the study area (refer to Figure 5.8) will be directly impacted within the project footprint (refer Table 8.2). In addition less than 1% of the regional ecosystems associated with likely and potential subsurface GDEs will be impacted within the project footprint, apart for RE 11.3.3a which constitutes an 11% medium level impact. Regional ecosystems 11.3.3a were however only mappable at the project scale (i.e. within the project area), it is therefore highly likely that this RE occurs more broadly throughout the study area (i.e. outside the area of detailed field verified mapping) and would therefore reduce the level of impact to low.

Of the potential subsurface GDEs directly impacted by the Project, 0.6 ha is mapped in association with the 'Brigalow (*Acacia harpophylla* dominant and co-dominant) Threatened Ecological Community (Brigalow TEC). The significance of impact to the Brigalow TEC within the Project footprint is low in terms of percentage within the study area however impacts to the Brigalow Tec within the project footprint have been discussed in more detail in Appendix C1: Terrestrial Biodiversity Report of the Preliminary Documentation (WSP | Parsons Brinckerhoff October 2015).

Table 8.2 Direct impact to potential subsurface GDEs in Project footprint

Regional Ecosystem (RE)	Data source	RE Description	VM Status	EPBC Act Status	BOM atlas subsurface GDE ID	DSITIA (2015) Terrestrial GDE confidence	Likelihood of groundwater dependence	Impact area (ha)	Study area (ha)	Impact percent (%)
11.3.1	Field verified RE and DEHP	*Acacia harpophylla* and/or *Casuarina cristata* open forest on alluvial plains	Endangered	Endangered	2517742	Low	Potential - High	0.6	398.7	<0.01
11.3.3	Field Verified RE	Coolibah (*Eucalyptus coolabah*) woodland on alluvial plains	Of Concern	NA	2517733 2517835 2517926 2517984 2517858 2517884 2517742	Low	Likely – High Likely – Moderate	42.5 0.4	712.5	0.05 <0.01
11.3.3a	Field Verified RE	Coolibah (*Eucalyptus coolabah*) woodland on alluvial plains	Of Concern	NA	2517733 2517858	Low	Likely – High	3.2	29.3	11
Total								**46.7**	**1853**	**0.02**

Field verified RE relates to vegetation communities and regional ecosystems mapped within the project area as a result surveys undertaken by suitably qualified ecologists from WSP | Parsons Brinckerhoff
DEHP indicates the regional ecosystems mapped by the Department of Environment and Heritage Protection within the study area outside the area of field verified regional ecosystem mapping.

Indirect impacts to GDEs reliant on the subsurface expression of groundwater

The area of subsurface GDEs that may potentially be indirectly impacted by the Project as a result of drawdown has been identified by comparing the area of likely subsurface GDEs mapped within the saturated alluvium in the base case run (Figure 5.7) with the area of likely subsurface GDEs mapped within saturated alluvium in the cumulative run (Figure 8.1). The subsurface GDEs associated with areas of alluvium that were saturated in the base case run but unsaturated in the cumulative run identified as being potentially indirectly impacted by the Project are listed in Table 8.3 and shown on Figure 8.2.

The results indicate a total of 167.8 ha of likely and potential subsurface GDEs, less than 1% of the total area of likely and potential subsurface GDEs within the study area, may be indirectly impacted as a result of drawdown associated with the Project. Of the 167.8 ha, 122.7 ha is considered to be associated with regional ecosystems that are likely to be associated with subsurface GDEs, and 45.1 ha is associated only with potential regional ecosystems associated with subsurface GDEs. The main areas likely to be affected by drawdown are the areas along Blackwater Creek to the east of Pit D and J and the area of regional ecosystems on alluvium to the North of Pit X (Figure 8.2). A few small areas of potential subsurface GDEs mapped along Minnie Creek outside the Project footprint may be affected by drawdown.

It is important to note that the potential impact area is based on the assumptions of the groundwater model. The alluvium has been assigned a minimum thickness of 5 m for the purposes of modelling; however in some parts of the Project area, including near the Pit D extension and Pit J extension, the alluvium is less than 5 m thick and less likely to be water bearing prior to the commencement of mining. Also, the model was unable to replicate the variably saturated nature of the alluvium and a more conservative approach was taken with alluvium assumed to be water bearing prior to the commencement of mining. Drawdown impacts to alluvium are therefore likely to be over-predicted. Groundwater investigations are required to understand whether alluvium is saturated in these areas so the potential use of groundwater by the ecosystems in these areas can be understood (refer Section 9.1.4).

It is also important to note that the DSITIA (2015) Terrestrial GDE mapping only indicates a low to moderate likelihood of subsurface GDEs occurring within the study area (Figure 5.6). The DSITIA Terrestrial GDE mapping is based largely on regional scale data sets and expert opinion.

The subsurface GDEs that may be potentially impacted as a result of drawdown mapped along the Mackenzie River and Blackwater Creek floodplains and upstream along Minnie Creek (Figure 8.2) are associated with treed regional ecosystems dominated by either *Eucalyptus* spp. (*Eucalyptus tereticornis* and/or *E. coolabah*) or Brigalow (*Acacia harpophylla)*. Like many Australian trees, *Eucalyptus* spp. have a dual (dimorphic) root system, with lateral roots that are close to the surface, and a taproot or ‘sinker’ that penetrates deep into the soil (up to 9 m for River Red Gum (*E. camaldulensis*)) (Holloway et al. 2013). *Eucalypt*us spp. are therefore able to source water from multiple sources (i.e. surface water, soil moisture after flooding and rainfall, and/or groundwater). Their reliance and use of groundwater is therefore facultative (optional) (DSITIA 2013b). In addition most *Eucalyptus* spp. rely on flooding for regeneration, not base flow (Holloway et al. 2013).

Acacia spp. (i.e. Brigalow) are somewhat drought resistant and can withstand prolonged periods of dry. Their root systems may be both deep and shallow, enabling the plant to tap the moisture and the accumulation of minerals held below the surface as well as taking advantage of lighter rainfalls and shallower nutrient supplies with the shallow root system. For this reason regional ecosystems dominated by Brigalow have only be listed as potential GDEs (Table 5.10) and would be unlikely to be significantly impacted as a result of drawdown.

In addition indirect impacts to the potential subsurface GDEs lining the Blackwater Creek drainage channel near the Pit D and Pit J extensions are unlikely to be significant given the degree of water discharge into this system from the Blackwater Wastewater Treatment Plant, providing a constant source of recharge to groundwater. Also, it is unlikely that seasonal surface flows and flooding are going to be significantly different

from longer term patterns for Blackwater Creek as a result of the Project (Appendix B3: Surface Water Impact Assessment Report of the Preliminary Documentation (October 2015)).

Indirect impacts to potential subsurface GDEs mapped in association with the Mackenzie River are also unlikely to be significant given the amount of surface flow maintained within the system as a result of releases from Fairbairn Dam and Bedford Weir, providing a constant source of water in this area.

Further assessment of the depth to groundwater in areas mapped as containing likely and potential subsurface GDEs that may be affected by drawdown (refer Figure 8.2) will assist in refining potential indirect impact assessments to subsurface GDEs as a result of the Project. Subsequent ongoing ecological condition monitoring within these refined areas of subsurface GDEs that may be indirectly impacted as a result of drawdown will assist with establishing a knowledge base as to the potential effect of drawdown and reliance on groundwater of these associated subsurface GDEs. Further discussion on monitoring for subsurface GDEs that may be indirectly affected as a result of drawdown from the Project has been provided in Section 9.1.4.

An impact rating of high, medium and low has also been provided in Table 8.3 based on determining the percentage of each regional ecosystem potentially indirectly impacted within the potential drawdown area in the saturated alluvium (Figure 8.2) compared with the amount mapped within the study area using the following criteria:

- High >30% of the subsurface GDE regional ecosystem within the study area impacted by the Project
- Medium 10–30% of the subsurface GDE regional ecosystem within the study area impacted by the Project
- Low <10% of the subsurface GDE regional ecosystem within the study area impacted by the Project.

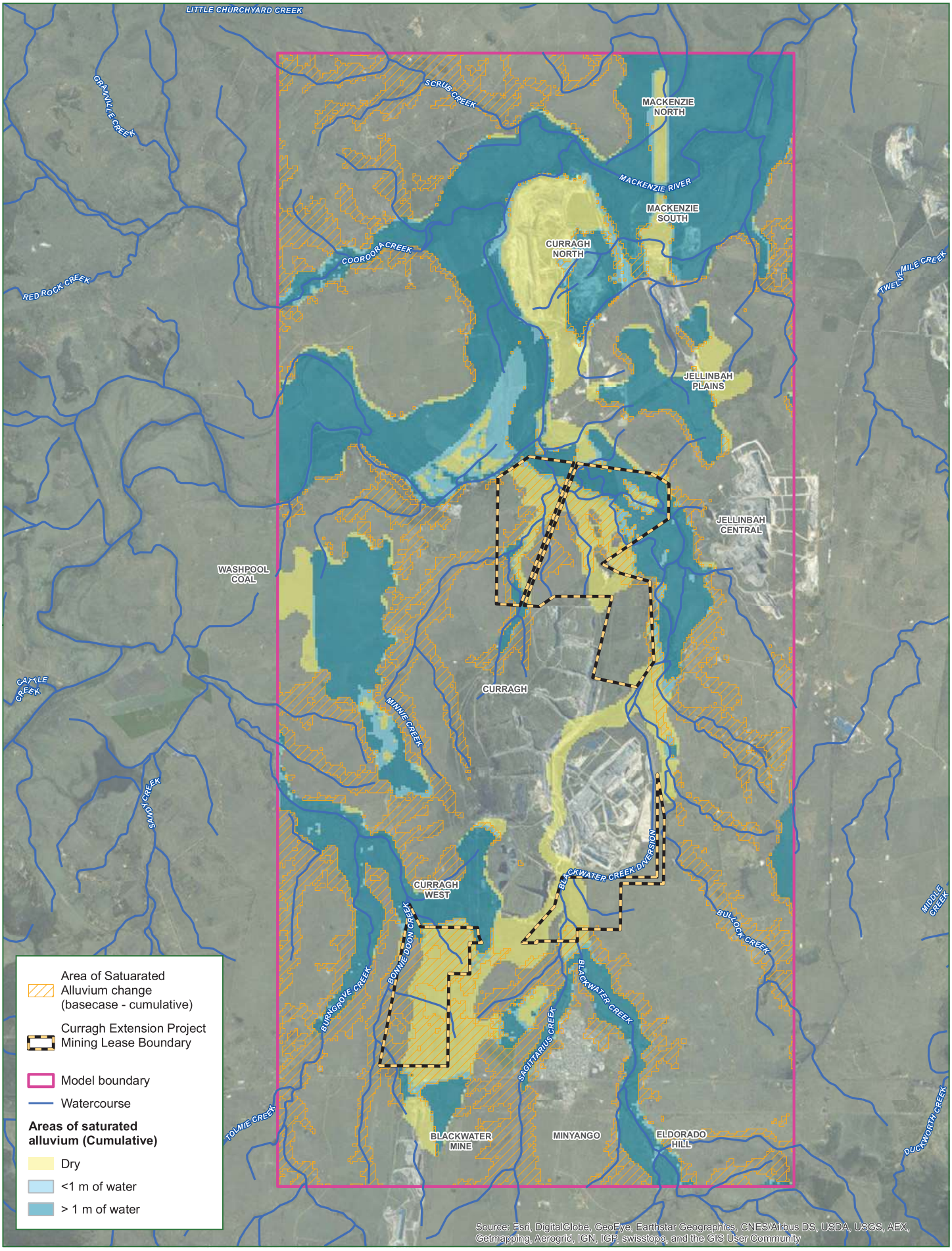
Of the potential subsurface GDEs directly impacted by the Project, 45.1 ha is mapped in association with the 'Brigalow (*Acacia harpophylla* dominant and co-dominant) Threatened Ecological Community (Brigalow TEC). The significance of impact to the Brigalow TEC within the Project footprint has been discussed in Appendix C1: Terrestrial Biodiversity Report of the Preliminary Documentation (WSP | Parsons Brinckerhoff October 2015).

Table 8.3 Area of likely and potential subsurface GDEs potentially impacted as a result of base case plus Curragh Extension Project groundwater drawdown in alluvium

Regional Ecosystem (RE)	Data source	RE Description	VM Status	EPBC Act Status	BOM atlas subsurface GDE ID	DSITIA (2015) Terrestrial GDE confidence	Likelihood of groundwater dependence	Impact area (ha)	Study area (ha)	Impact percent (%)
11.3.1	DEHP	*Acacia harpophylla* and/or Casuarina cristata open forest on alluvial plains	Endangered	Endangered	2517786 2517846 2517835 2518925 2517728	Low	Potential - High	28.9	377.5	0.08
11.3.1x	Field Verified RE	*Acacia harpophylla, Terminalia oblongata and Eucalyptus coolabah on alluvial plains and channels*	Endangered	Endangered	2518821 2518925 2518891	Low	Potential- High	16.1	19.1	0.84
11.3.25	Field Verified	*Eucalyptus tereticornis* or *E. camaldulensis* woodland fringing drainage lines	Least Concern	NA	2518821 2518925 2517733	Low	Likely- High	9.6	93.8	0.10
11.3.25/ 11.3.3a	Field Verified RE	Mixed polygon see full descriptions for each individual RE in this table.	Least Concern/ Of Concern	NA	2517786 2517863 2517784 2517846	Low	Likely- High/ Likely - High	30.5	64.8	0.47
11.3.3	DEHP and Field Verified RE	Coolibah (*Eucalyptus coolabah*) woodland on alluvial plains	Of Concern	NA	2517733 2517835 2517728 2517742 2517784 2517786 2517846 2517984 2518027 2517737 2518891	Low	Likely - High	66.4	712.5	0.09

Regional Ecosystem (RE)	Data source	RE Description	VM Status	EPBC Act Status	BOM atlas subsurface GDE ID	DSITIA (2015) Terrestrial GDE confidence	Likelihood of groundwater dependence	Impact area (ha)	Study area (ha)	Impact percent (%)
11.3.3a	Field Verified RE	Riverine wetland or fringing riverine wetland. *Melaleuca bracteata* woodland. On alluvial plains.	Of Concern	NA	2517733	Low	Likely - High	0.2	3.4	0.06
11.3.3/ 11.3.1	DEHP	Mixed polygon see full descriptions for each individual RE in this table.	Of Concern/ Endangered	Endangered (RE 11.3.1)	2517689	Low	Likely – High/ Potential - High	1	149.4	0.01
11.3.25/11.3.3/ 11.3.3c	DEHP	Mixed polygon see full descriptions for each individual RE in this table/ Palustrine wetland (e.g. vegetated swamp). *Eucalyptus coolabah* woodland to open woodland (to scattered trees) with a sedge or grass understorey in back swamps and old channels.	Least Concern/ Of Concern/ Of Concern	NA	2517733 2518821	Low	Likely- High/ Likely - High/ Likely - High	15	1255.8	0.01
HVR 11.3.1	Field Verified RE	High value regrowth *Acacia harpophylla* and/or *Casuarina cristata* open forest on alluvial plains	Non-remnant	Endangered	2517742	Low	Potential – Moderate	0.1	15.6	0.01
TOTAL								**167.8**	**2691.9**	**0.06**

Field verified RE relates to vegetation communities and regional ecosystems mapped within the project area as a result surveys undertaken by suitably qualified ecologists from WSP | Parsons Brinckerhoff
DEHP indicates the regional ecosystems mapped by the Department of Environment and Heritage Protection within the study area outside the area of field verified regional ecosystem mapping.



Wesfarmers
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0 0.5 1 2 3 4 km

Scale 1:140,000

Scale correct when printed at A3 Portrait

Projection: Transverse Mercator
Coordinate System: AGD 1984 AMG Zone 55

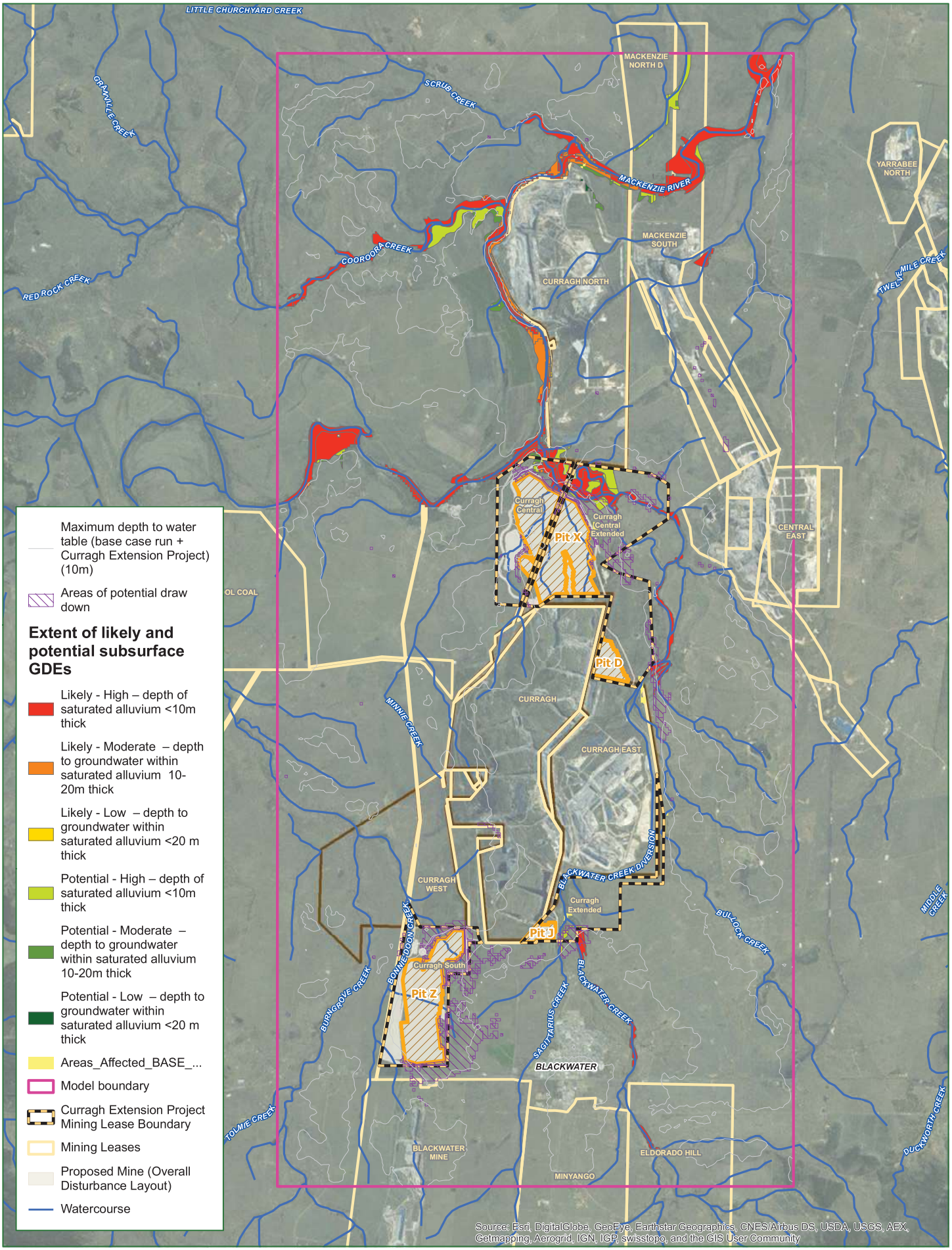
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Data Source:
Cadastre, ML, watercourses, streets from DNRM (2015)
Imagery from Wesfarmers (2014)

Groundwater impact assessment
Curragh Extension Project
Figure 8.1
Areas of saturated alluvium, cumulative run

MXD Number: 2172652H_GIS_SW_F049_A4
Date: 15/06/2016
Author: AM
Approved by: LR

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Coordinate System: GDA 1994 MGA Zone 55

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Data Source:
Cadastre, ML, watercourses, streets from DNRM (2016)

Groundwater impact assessment
Curragh Extension Project
Figure 8.2
Potential subsurface GDEs study area post-mining drawdown

MXD Number: 2172652H_GIS_SW_F008_A8
Date: 16/06/2016
Author: AM
Approved by: LR

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8.3 Recharge

Recharge of alluvial aquifers may occur during periods of high flow and flooding, as well as via rainfall infiltration. Recharge of fractured aquifers within the Rangal Coal Measures may occur via stream flow where formations outcrop under streams (e.g. where Bonnie Doon Creek is underlain by weathered Rangal Coal Measures, and where these formations outcrop).

Minor increases in flood levels during large flood events as a result of the Project (Appendix B2: Flood Assessment Report of the Preliminary Documentation) could potentially increase groundwater recharge in the Project area. Increased recharge has been simulated for the uncertainty analysis (Section 7,6).

Groundwater recharge may also increase where in-pit soil dumps and spoil heaps are located. Spoil dumps have increased hydraulic conductivity compared to the natural landscape, increasing the infiltration of rainfall in these areas. Increased recharge in backfilled areas been simulated in the numerical groundwater model.

8.4 Water quality impacts

Project activities have the potential to contaminate groundwater resources through:

- surface and shallow excavation activities during construction and operation
- migration of leachate from spoil, rejects or tailings
- mine water storage
- coal processing at the mine infrastructure area
- hydrocarbon leaks from fuel storage facilities
- increased salinity in residual voids due to evaporative processes.

Degradation of groundwater quality can lead to:

- degradation of the beneficial use of groundwater supplies
- degradation of the beneficial use of surface water supplies in Mackenzie River, which may receive baseflow from alluvium near proposed Pit X
- loss or degradation of GDEs dependent on affected aquifers.

8.4.1 Surface and shallow subsurface activities

Fuel spills during construction and decommissioning activities can leak into the underlying hydrogeological unit and impact the water quality of shallow aquifers. Hydrocarbon and other chemical spills may also occur during servicing and maintenance activities during operation of the mine.

Potential impacts may occur in areas where groundwater is shallow or the water table is intersected, and will be short-term and localised.

8.4.2 Spoil material

Spoil material will be placed in dedicated in-pit and out-of-pit spoil dumps.

Groundwater quality monitoring at Curragh Mine indicates the pH of groundwater is neutral (6.5 to 7.8) and that Curragh Mine has not experienced acid mine drainage issues.

Spoil characterisation studies indicate that the spoil at Curragh Mine has low acid forming potential (WCPL 2012). The physiochemical results of the overburden analysis indicate that the pH for the overburden is alkaline; with exchangeable sodium percentage (ESP) values indicating sodic conditions. Based on the sodicity and associated tendency of the overburden to be dispersive, Tertiary material and much of the fine-

grained Permian material will not be desirable as subsoil. All overburden samples analysed were non-saline, while the pH and Net Acid Producing Potential results have indicated that the overburden is characterised by a low propensity for acid generation.

8.4.3 Tailings

All tailings and coarse rejects from the Project will be managed in existing Curragh Mine facilities.

Water quality analyses for the tailings dam at Curragh Mine (Section 6.3.2) indicate that tailings are not acid generating or a source of salinity to groundwater. Concentrations of selenium in the tailings dam at Curragh Mine are elevated compared to the guideline for livestock of 20 µg/L but are within the range of concentrations in groundwater across the site, suggesting background concentrations of selenium exist in the area. This will be further considered as part of the GMP which will establish natural background groundwater conditions for the area using data from reference bores.

8.4.4 Mine water storage dams

Comparison of the water quality of mine water storage dams with groundwater quality at Curragh Mine (Section 6.3.3) indicates mine water storage dams are not a source of acidity and the EC of water in the dams is generally comparable to or fresher than groundwater.

8.4.5 Mine infrastructure area

All coal stockpiling and processing will occur at the existing Curragh Mine.

Groundwater quality data for the MIA at Curragh Mine indicates that run of mine stockpiles and other MIA activities are not a source of acidity or salinity to groundwater (Section 6.3.4). Hydrocarbons have been detected in groundwater near the MIA; however the impacts have been short-term and localised suggesting the source is spills and leaks from vehicles servicing the area (Section 6.3.4).

8.4.6 Fuel storage facilities

Hydrocarbons have been detected in groundwater near fuel storage facilities at Curragh Mine; however the impacts have been short-term and localised suggesting the source is spills and leaks from vehicles servicing the area rather than leaking fuel tanks (Section 6.3.5).

Risks to environmental values associated with the proposed fuel storage facilities near proposed Pit X and Pit Z are considered low as the facilities will be constructed and operated in the same manner as those at the existing Curragh Mine.

8.4.7 Summary of risks

Risks to groundwater quality associated with the Project are low, with only short-term localised impacts associated with hydrocarbon and other chemical spills identified as risks to groundwater quality in the Project area. These risks are managed through Curragh Mine's Waste Management Plan (EM PLAN 3.0), which requires that spills be handled as detailed in the Spill Response Procedure (EMS PROC 3.3) and regulated wastes generated from a spill be managed as per Regulated Waste Management Procedure (EMS PROC 3.2).

9. Mitigation and management

The mitigation and management measures identified for reducing the significance of potential impacts on groundwater resources and environmental values are based on the existing measures contained within the EMS that WCPL has previously developed and implemented for Curragh Mine. Applying the same mitigation and management measures for the Curragh Mine operations to the Curragh Extension Project will ensure a consistent approach by construction and operational personnel and a common understanding for both regulators and the community of the measures to be applied and that the required outcomes are achieved.

The EMS for Curragh Mine addresses the conditions of EA EPML00643713 issued by the Queensland Government. On approval of the Curragh Extension Project, WCPL will update its EMS to include the mitigation, management and monitoring commitments in this section and the requirements of State and Commonwealth approvals for the Project.

9.1 Mitigation measures

Mitigation and management measures will be implemented to reduce the significance of the potential impacts identified in Chapter 8 on groundwater environmental values. Details are provided below.

9.1.1 Pit dewatering

Although the Project is not expected to increase annual dewatering volumes, it will extend the duration of dewatering by eight years.

The take of groundwater and surface water in the vicinity of the Project area is regulated by the Fitzroy Basin water resource plan (listed under the *Water Act 2000*) and resource operations plan. The water resource plan provides the management framework for groundwater and surface water resources in the Fitzroy Basin and the resource operations plan specifies the day-to-day rules and management arrangements for water users and infrastructure operators. The objective of the plans is to provide for the sustainable allocation and management of water in the Fitzroy Basin, balancing the needs of the environment with consumptive use. Water entitlements are required to take water, including for dewatering purposes, so the take of water in the catchment can be managed within sustainable levels.

Groundwater in the Project area is part of the Highlands Groundwater Management Area. The take of groundwater in this area requires a water licence. In accordance with the requirements of the Fitzroy Basin water resource plan, WCPL will obtain water licences for mine dewatering purposes to account for any water taken from groundwater systems during mining.

The Mackenzie River located to the north of the Project area is part of the Nogoa-Mackenzie Water Supply Scheme. Surface water users in this scheme hold tradable water allocations to take supplemented water which is delivered from Fairbairn Dam via a series of weirs. Tributaries of Mackenzie River located within the Project area are part of the Upper Mackenzie subcatchment. Surface water users in this area hold tradeable water allocations to take unsupplemented water or water licences.

Numerical groundwater modelling in Section 7, and assessment of potential impacts in Section 8, indicates there will be no impacts to surface water resources in Mackenzie River or its tributaries, and therefore water allocations from the Nogoa-Mackenzie Water Supply Scheme and the Upper Mackenzie Water Management Area are not required.

9.1.2 Groundwater users

Numerical groundwater modelling has predicted less than 51 cm impact at registered bore 84221 and no impact at other registered bores in the study area. An impact of 51 cm is within the range of natural variation and will not impact on the utility of the bore.

To confirm the results of the modelling, a groundwater monitoring bore will be installed between Pit Z and registered bore 84221. The bore will be monitored two years prior to the commencement of mining to establish baseline conditions and drawdown trigger levels, and then throughout mining to confirm there is no potential for impacts. If the early warning/investigation trigger level, set out in the approved Management Plan, is exceeded, further investigations will be undertaken to assess the potential for impact, including a bore census survey and consultation with the landholder if required.

9.1.3 Surface water users

Numerical groundwater modelling has predicted stream losses from Mackenzie River will be less than 0.01 Ml/year due to the Curragh Extension Project. Losses from other streams in the study area are also predicted to be less than 0.01 Ml/year. As such, there are no predicted impacts to the supplemented and unsupplemented water allocation holders on Mackenzie River or water licence holder on Burngrove Creek.

To confirm the results of the modelling, two groundwater monitoring bores will be installed: one between Pit X and Mackenzie River and one between Pit X and Blackwater Creek. The bores will be monitored two years prior to the commencement of mining to establish baseline conditions and drawdown trigger levels, and then throughout mining to confirm there is no potential for impacts. If the early warning/investigation trigger level, set out in the approved Management Plan, is exceeded, further investigations will be undertaken to assess the potential for impact, including consultation with the Nogoa-Mackenzie Water Supply Scheme operator and water allocation holders if required.

9.1.4 Groundwater dependent ecosystems

Field verification studies of GDEs in the Pit X area will be undertaken prior to the commencement of works in 2023 to confirm whether GDEs exist in the area, characterise the nature groundwater dependence and assess potential risks associated with mining. Diversion of Minnie Creek is scheduled for 2023 and mining within ML700007 and ML700008 (Pit X) is scheduled for 2025, providing adequate time for completion of this assessment. An overview of the field studies is provided below. Details of the field verification studies may potentially be included in the MNES Environmental Management Plan for the Project and Groundwater Monitoring Program (GMP) for Curragh Mine.

Nested groundwater monitoring bores will be installed in proximity of potential GDE areas to characterise seasonal water level variations and improve understanding of the interaction between alluvial groundwater systems, GDEs and streams. The monitoring bores will be located within and outside the area of predicted drawdown influence from pit development and will be monitored prior to and during mining to assess water level trends and plant health.

Monitoring potential GDEs within and outside expected drawdown areas, under the same management regime, will assist in determining the reliance of these REs on groundwater for future assessments, and will indicate any indirect impacts that may occur (i.e. canopy die back) as a result of drawdown. If there is a significant difference in vegetation parameters observed between the GDEs within and outside drawdown areas (i.e. canopy die back), albeit unlikely, then WCPL will investigate rehabilitation management activities and/or potentially provide offsets in accordance with *Environment Protection and Biodiversity Conservation Act 1999* Environmental Offsets Policy.

9.1.5 Groundwater quality

9.1.5.1 Surface operations

The Curragh Mine Waste Management Plan (EM PLAN 3.0) outlines the measures to minimise the potential risk of impacts of surface operations on shallow groundwater resources. The Plan requires that the handling, management and disposal of all hazardous substances, including fuels and chemicals, be undertaken in accordance Australian Standards AS 1940:2004 *The Storage and Handling of flammable and combustible liquids* and AS 3833:2007 *The storage and handling of mixed classes of dangerous goods, in packages, and intermediate bulk containers* and SOP-005 Hazardous Substances (Standards Australia 2004).

Any spills are to be handled as detailed in the Spill Response Procedure (EMS PROC 3.3) (referenced in WCPL 2014b). The general response will be to contain the released material, stabilise and neutralise spilt material, clean up released materials, evaluate and document the incident and investigate and remediate if necessary.

All regulated wastes generated from a spill will be managed as per Regulated Waste Management Procedure (EMS PROC 3.2) (referenced in WCPL 2014b).

9.1.5.2 Tailings storage

Seepage from tailings storage dams has the potential to impact on water quality in underlying aquifers. The potential for seepage is limited as the tailings storage facility at Curragh Mine is constructed and operated in accordance with the *Manual for Assessing Consequence Categories and Hydraulic Performance of Structures* (DEHP 2013) and WCPL regulated structure operational plans. Seepage into groundwater is controlled using measures such as geosynthetic liners to limit the migration of fluids.

Seepage monitoring is undertaken at Curragh Mine in accordance with the GMP to ensure effectiveness of the control measures. In accordance with the requirements of EA EPML00643713, WCPL are required to develop trigger levels for groundwater and report to the Queensland Government on exceedances of the trigger values.

9.1.5.3 Mine water storage

Mine water has the potential to impact on water quality in underlying aquifers through seepage or overflow from storage dams. The potential for seepage is limited as mine water storage dams will be constructed and operated in accordance with the *Manual for Assessing Consequence Categories and Hydraulic Performance of Structures* (DEHP 2013) and WCPL regulated structure operational plans. Seepage into groundwater is controlled using measures such as geosynthetic liners to limit the migration of fluids.

Mine water management will be undertaken in accordance with WCPL's Water Management Plan (EM PLAN 2.0). This includes ensuring dam levels are managed in accordance with the operating requirements for regulated dams.

Seepage monitoring will be undertaken to ensure effectiveness of the control measures (Section 9.2). In accordance with the requirements of the EA EPML00643713, WCPL are required to develop trigger levels for groundwater and report to the Queensland Government on exceedances of the trigger values.

9.1.6 Residual voids

Mine pits will be mostly backfilled; however four residual voids will remain following completion of mining. These voids may be a source or sink to groundwater. If voids are a source to groundwater, there is potential

to increase the salinity of groundwater resources. If voids are a sink to groundwater, there is potential for drawdown of pre-mining groundwater levels over the long term.

The numerical groundwater model developed for this assessment included simple representation of the residual voids that will remain at the end of mining. More detailed assessment of residual voids will be undertaken to meet the conditions of the EA. This assessment will investigate whether the voids will act as a source or sink to groundwater. The numerical groundwater model can be revised at this time if required.

Management of residual voids will meet condition G13 of the EA, which requires that residual voids must not cause any serious harm to any recognised groundwater aquifer, and condition G14, which requires that residual void investigation reports be prepared and submitted to Queensland Government six months prior to the commencement of mining activities in the area. Residual void outcomes in residual void investigation reports must be reviewed every three years.

The residual void investigation reports prepared for the Curragh Extension Project area will assess whether residual voids will behave as a sink or source to groundwater.

9.2 Monitoring

Groundwater monitoring in the Project area will provide a mechanism for early identification of potential drawdown and groundwater quality impacts due to mining and will inform the measures required to be implemented to avoid or minimise adverse impacts on environmental values, including water users, streams and GDEs.

Groundwater monitoring will also provide improved information about groundwater systems and surface water-groundwater connectivity in the Project area and will allow the results of the numerical groundwater modelling to be verified.

9.2.1 Groundwater monitoring bores

WCPL has prepared a groundwater monitoring program (GMP) for Curragh Mine to meet condition C53 of the Environmental Authority. As part of the GMP, WCPL are undertaking groundwater monitoring at reference bores to establish natural background groundwater conditions for the area. The GMP will be updated to include the monitoring for the Curragh Extension Project area following Project approval.

The existing Curragh Mine groundwater monitoring bore network will be augmented to include bores in the Curragh Extension Project area. The additional bores have been selected to:

- establish baseline conditions prior to commencement of mining
- provide for early warning of potential impacts to sensitive receptors, including water users, streams and GDEs, during mining
- detect changes in groundwater conditions due to seepage from site infrastructure, including ROM and MIA areas and mine water storage dams.

Details of the additional bores proposed for the Project area are provided in Table 9.1 and in Sections 0, 9.2.1.2 and 9.2.1.3. Ideally bores would be installed at least three years prior to the commencement of development and monitored for at least two years to provide adequate time to establish pre-mining baseline conditions.

Table 9.1 Potential future monitoring bores

Bore ID	Target formation	Location	Objective/purpose
PMB14A/ PMB14B (nested bores)*	Alluvium/ Rangal Coal Measures	Between proposed Pit X and Mackenzie River and nearby GDEs	■ establish baseline conditions prior to commencement of mining ■ provide an early warning of potential drawdown impacts to GDEs ■ conceptualise connection between alluvium and Rangal Coal Measures
PMB03 (PMB_A1)*	Alluvium	Between proposed Pit X and Blackwater Creek and nearby GDEs	■ establish baseline conditions prior to commencement of mining ■ provide an early warning of potential drawdown impacts to GDEs
PMB04A/ PMB04B (nested bores) (PMB_A2)*	Alluvium/ Rangal Coal Measures	Between proposed Pit X and Blackwater Creek and associated GDEs	■ establish baseline conditions prior to commencement of mining ■ provide an early warning of potential drawdown impacts to GDEs ■ conceptualise connection between alluvium and Rangal Coal Measures
PMB15*	Alluvium	Near Blackwater Creek and GDEs outside areas of predicted drawdown	■ provide groundwater level information to support the GDE assessment
PMB05 (PMB_C1)	Burngrove Formation	Between proposed Pit Z and registered bore 84221	■ establish baseline conditions prior to commencement of mining ■ provide an early warning of potential drawdown impacts to GDEs
PMB13 (PMB_B2)	Burngrove Formation	Between proposed Pit Z and Bonnie Doon Creek	■ establish baseline conditions prior to commencement of mining ■ provide an early warning of potential drawdown impacts to Bonnie Doon Creek and registered bores
PMB16 (multiple bores)	Water bearing zone underlying dam	Targeting mine water dams in Project area	■ establish baseline conditions prior to commencement of mining ■ identify potential groundwater quality impacts due to seepage from site infrastructure
PMB17 (multiple bores)	Water bearing zone underlying ROM/MIA/fuel storage facility	Targeting ROM/MIA and fuel storage facilities in Project area	■ establish baseline conditions prior to commencement of mining ■ identify potential groundwater quality impacts due to seepage from site infrastructure

* Bores located within area of affected drawdown surrounding Pit X

9.2.1.1 Water users

Two groundwater monitoring bores are proposed to be installed between proposed Pit Z and the registered bores to the west and south-west: PMB05 and PMB13 (Table 9.1).

One groundwater monitoring bore (PMB14) is proposed to be installed between proposed Pit X and the surface water allocation holder on Mackenzie River to assess water level drawdown in proximity to Mackenzie River; although it is noted that risks to surface water allocation holders on Mackenzie River are

assessed to be negligible. Monitoring of this bore will enable adaptive management measures to be implemented if required.

9.2.1.2 Groundwater dependent ecosystems

As discussed in Section 9.1.4, field verification studies and monitoring of GDEs in the Pit X area will be undertaken to:

- confirm whether GDEs exist in the area
- characterise the nature groundwater dependence
- monitor impacts during mining.

Based on current mine planning, diversion of Minnie Creek is scheduled for 2023 and mining within Pit X is scheduled for 2025, providing adequate time to install groundwater monitoring bores and establish pre-mining conditions before undertaking impact monitoring. The GMP will be updated to include the monitoring for the Curragh Extension Project area following Project approval.

GDEs reliant on the surface expression of groundwater

Groundwater monitoring bores PMB03 and PMB04A/PMB04B will be installed between proposed Pit X and the potential GDEs along Blackwater Creek, and PMB14A/PMB14B will be installed between proposed Pit X and the potential GDEs along Mackenzie River. Another monitoring bore, PMB15, is proposed to be installed in proximity to GDEs along Blackwater Creek outside the area of predicted drawdown (Table 9.1). The bores will be monitored prior to mining to characterise baseline seasonal water level variations and improve understanding of the interaction between alluvial groundwater systems, GDEs and streams. The bores will also be monitored during mining to assess potential impacts and after mining to understand recovery.

Ecological monitoring of potential surface expression GDEs will only be required if groundwater monitoring indicates there are areas of potential surface expression GDEs that are likely to be impacted by drawdown.

If surface expression GDEs do occur the ecological monitoring would be required to determine if mining causses significant difference in vegetation parameters between the GDEs within and outside drawdown areas. If obvious impacts do occur to areas of surface expression GDEs, then WCPL will investigate rehabilitation management activities and/or potentially provide offsets in accordance with *Environment Protection and Biodiversity Conservation Act 1999* Environmental Offsets Policy (refer Section 9.1.4).

GDEs reliant on the subsurface expression of groundwater

Classification and mapping of potential subsurface GDEs within the study area was based on the ‘root depth and morphology’ method as described in (Richardson et al 2011). This method assumes that, where plant roots are deep enough to interact with groundwater (in terrestrial vegetation communities, wetlands and/or riparian vegetation along base flow streams), there may be some reliance on groundwater by the vegetation. This method provides a good first-pass indication of potential for groundwater dependence, however it is highly dependent on the adequacy and quality of the vegetation mapping and the depth to water table model. In addition, the rooting depths of most tree species are poorly known, and vary between sites. Based on this method a number of potential subsurface GDEs initially mapped in the study area may have been overestimated.

To improve the knowledge of the extent and level of impact on potential subsurface GDEs within the area affected by drawdown as a result of the Project, a combination of monitoring methods is required.

Additional groundwater monitoring bores will be located within potential subsurface GDEs within and outside the area of predicted drawdown influence from pit development (PMB03, PMB04A/PMB04B and PMB15). The data gathered through the monitoring bores will be used to update the digital elevation model (DEM) required to translate the water table elevation into a depth-to-water table, and to monitor the effects of

drawdown pre, during and post mining. The updated model will also be used to revise the assessment of potential subsurface GDEs within the area affected by drawdown.

Potential subsurface GDEs within and outside expected drawdown areas under the same management regime will be monitored to assist in determining the reliance of vegetation species on groundwater, and to indicate any indirect impacts that may occur (i.e. canopy die back) as a result of drawdown.

If there is a significant difference in vegetation parameters observed between the GDEs within and outside drawdown areas (i.e. canopy dieback), then WCPL will investigate rehabilitation management activities and/or potentially provide offsets in accordance with *Environment Protection and Biodiversity Conservation Act 1999* Environmental Offsets Policy (refer Section 9.1.4).

A modified Before After Control Impact (BACI) monitoring plan will be developed for potential subsurface GDEs, identified as a result of revised assessments, within and outside the area of predicted drawdown influence from pit development. The monitoring plan would be based on recording observations of a systems response to change over time due to anthropogenic influences. Monitoring will include observations of climate, extent and condition of the GDE, groundwater regime and the human activities and other impacts that potentially influence the GDE and its groundwater regime (Richardson et al. 2011).

9.2.1.3 Infrastructure with potential for seepage

Groundwater monitoring bores will be installed in the Project area to detect potential changes in groundwater conditions due to seepage from site infrastructure. Groundwater monitoring bores will be installed down hydraulic gradient of:

- ROM stockpiles, MIAs and fuel storage facilities at the south western corner of Curragh Central Extended and to the north of Curragh South
- the mine water storage dam within the Curragh Central development area and the two mine water storage dams within the Curragh South area.

Groundwater monitoring bores are already installed for existing infrastructure at Curragh Mine, including the tailings storage facility.

9.2.2 Groundwater monitoring approach

Groundwater monitoring will be undertaken in accordance with the GMP (Parsons Brinckerhoff 2015a) and the Curragh Mine Environmental Monitoring Management Procedure (EMS PROC 0.1) (WCPL 2015c).

Groundwater level monitoring is proposed to be undertaken every month and groundwater quality monitoring undertaken every second month for the first two years to establish pre-mining baseline conditions. Where groundwater level trigger values and contaminant limits are established and included in the GMP, groundwater level and quality monitoring will be undertaken every six months to assess compliance with the triggers.

Groundwater quality parameters will be selected to protect environmental values and beneficial uses of groundwater from potentially contaminating activities at Curragh Mine. The parameters include:

- physical parameters
- major ions
- nutrients
- metals
- hydrocarbons.

Groundwater level and quality data analysis and record keeping will be undertaken in accordance with the Curragh Mine Groundwater Monitoring Procedure (EMS PROC 2.4) and the Environmental Monitoring Management Procedure (EMS PROC 0.1).

9.3 Trigger levels and exceedance response

Drawdown trigger values and water quality trigger values and contaminant limits will be established using reference bores and/or pre-mining data for the Project area.

The GMP for Curragh Mine identifies reference bores that will be used to establish a baseline of undisturbed groundwater conditions so that trigger levels representative of the local conditions and able to detect impacts associated with mining can be developed. There are three reference bores in alluvium, three in Rangal Coal Measures and three in the Burngrove Formation.

9.3.1 Drawdown impacts

Drawdown trigger levels will be established for compliance monitoring bores PMB05, PMB03 and PMB04 to provide an early warning of potential impacts to registered bore 84221 and the potential GDEs along Blackwater Creek. Drawdown trigger levels will be developed as part of the update to the GMP for the Curragh Extension Project. The GMP is a requirement of condition C53 of the Environmental Authority.

In the event that a drawdown trigger level is exceeded, WCPL will conduct an investigation into the potential for environmental harm. If the investigation indicates potential for environmental harm, a suitably qualified person will develop an action plan to mitigate potential harm.

9.3.2 Water quality impacts

Water quality trigger levels and contaminant limits will be established for the compliance monitoring bores targeting site infrastructure with potential for seepage. Water quality trigger levels will be developed as part of the update to the GMP for the Curragh Extension Project. The GMP is a requirement of condition C53 of the Environmental Authority.

The trigger levels will be developed in accordance with the methodology in the ANZECC (2000) guidelines and Queensland water quality guidelines. In the event that a water quality trigger level is exceeded, WCPL will conduct an investigation into the potential for environmental harm. If the investigation indicates potential for environmental harm, a suitably qualified person will develop an action plan to mitigate potential harm.

9.4 Reporting

Condition C56 of the Environmental Authority requires that WCPL notify the Queensland government of any exceedances of trigger levels or contaminant limits. The results of investigations into the potential for environmental harm and action plans to mitigate harm will also be submitted to the Queensland government.

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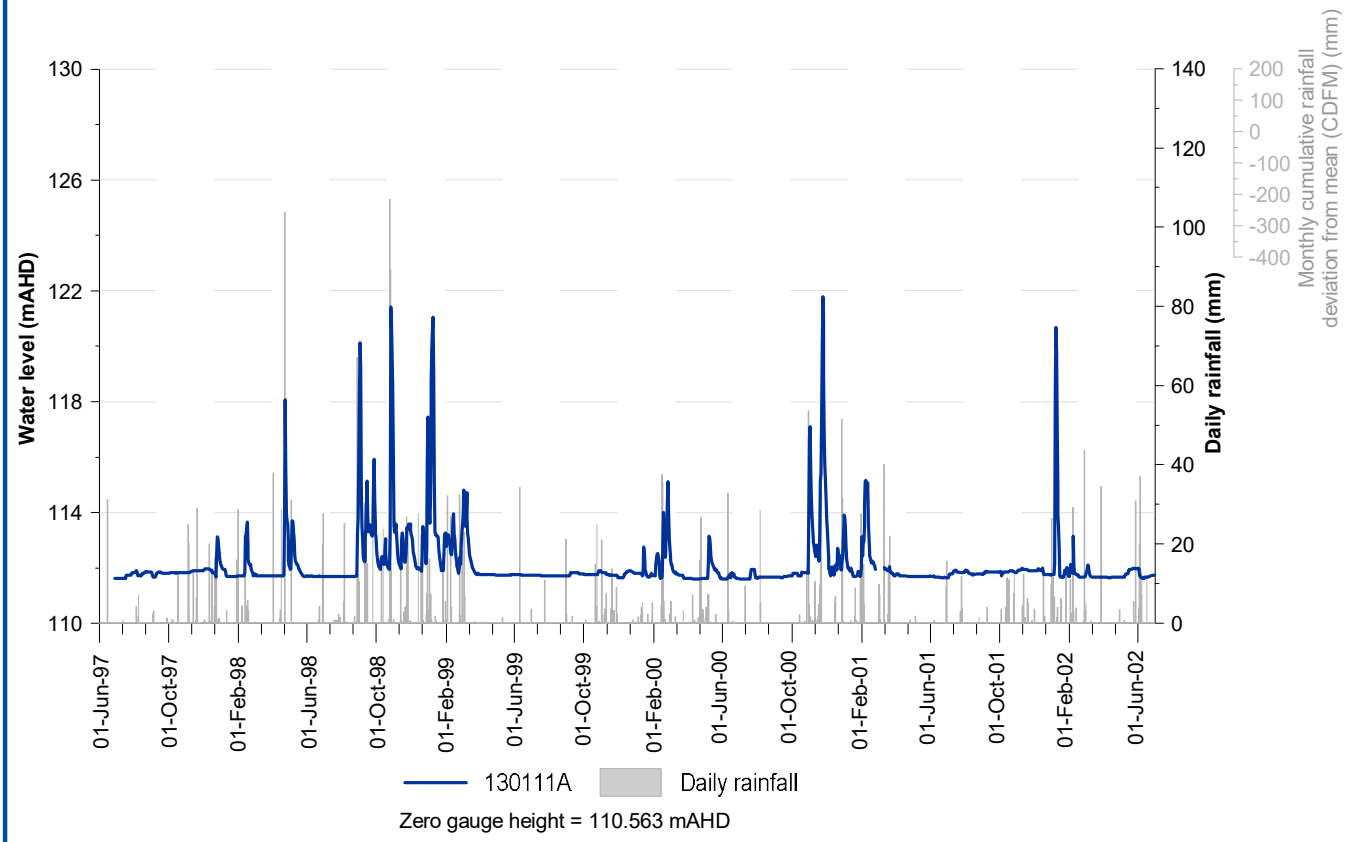
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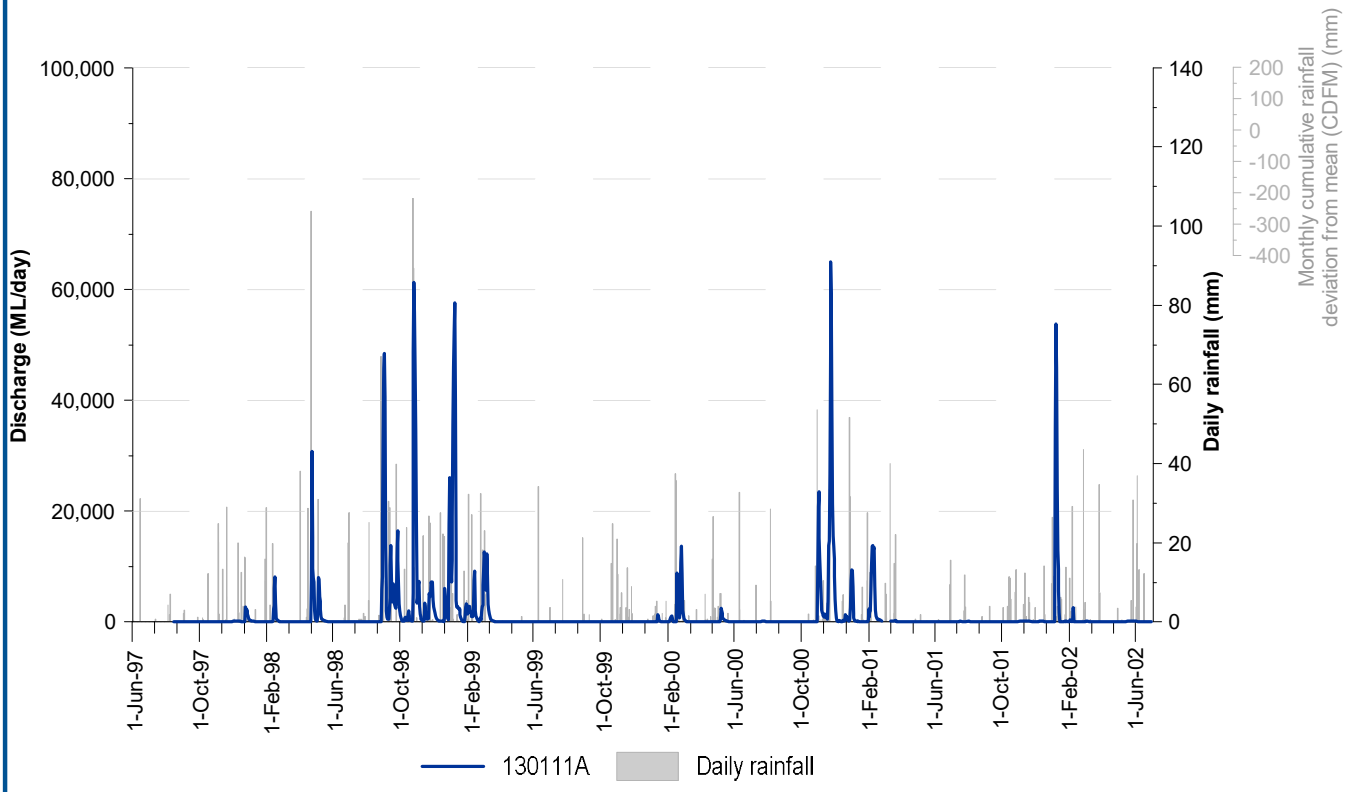
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Attachment A

Surface water hydrographs

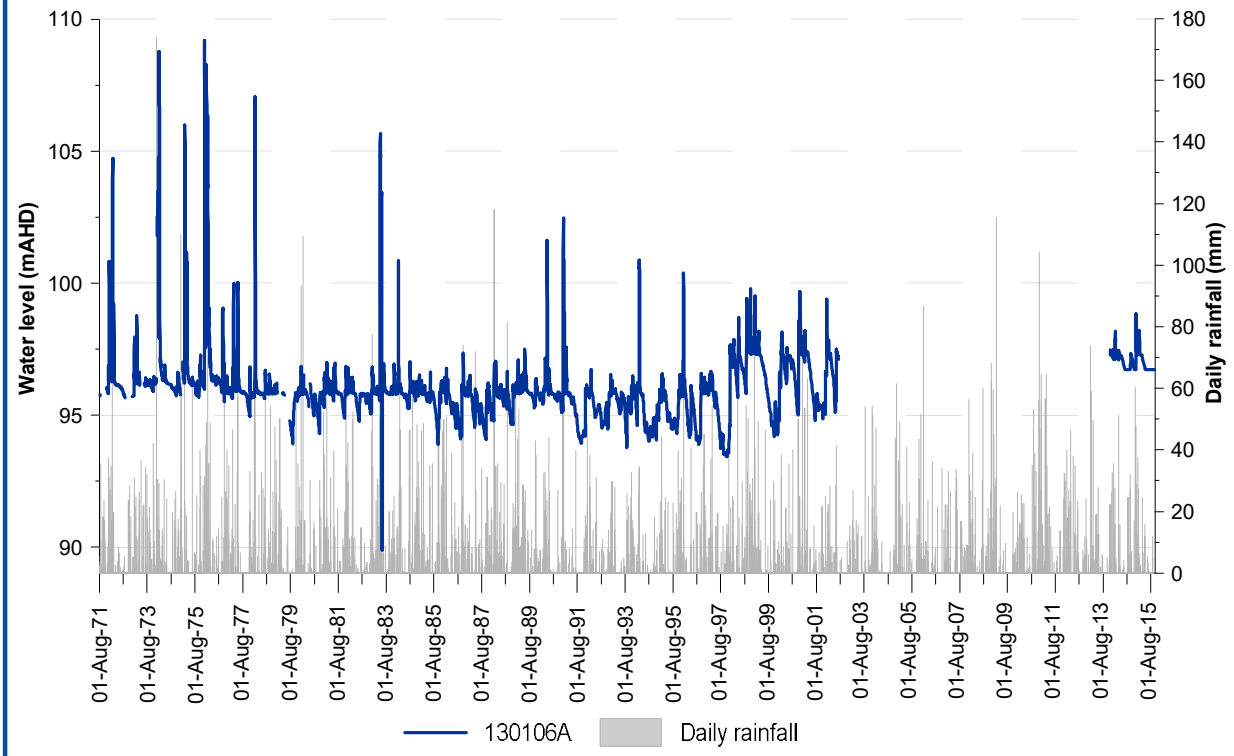




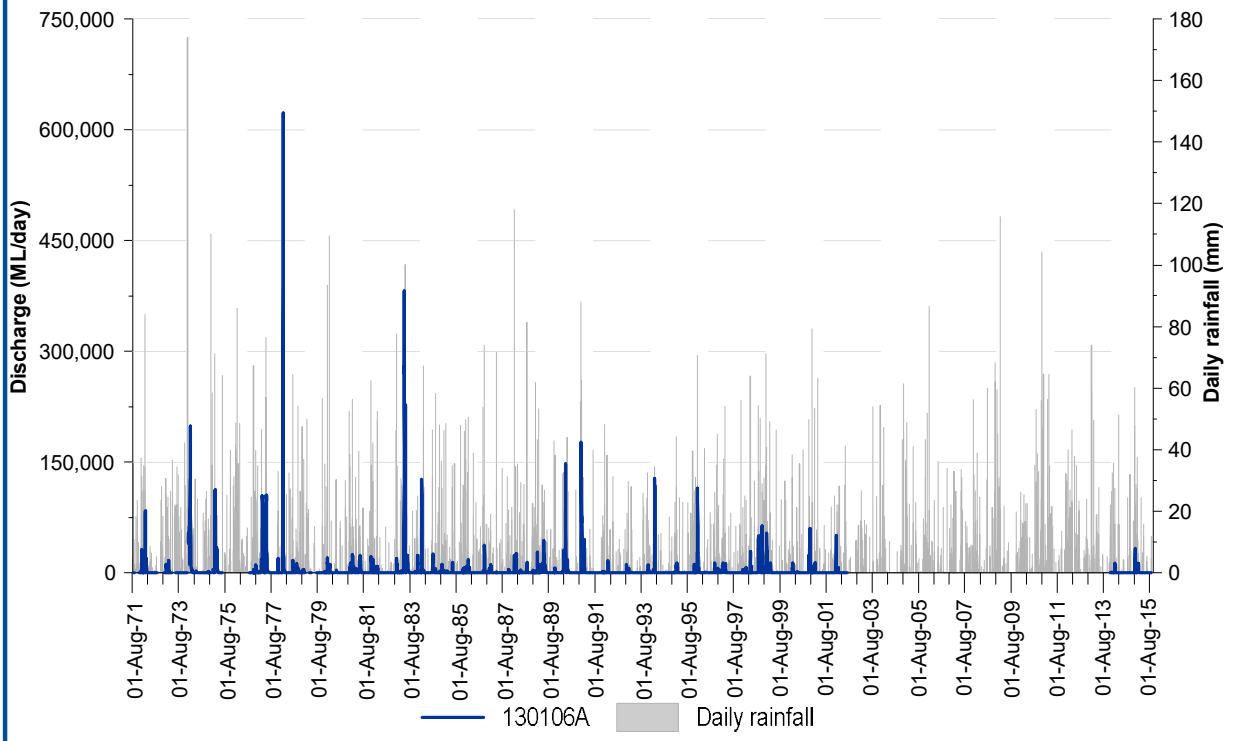


Note: Rainfall data for October 2015 was not available at the time of writing

Figure A.1: Surface water monitoring - Mackenzie River at Bedford

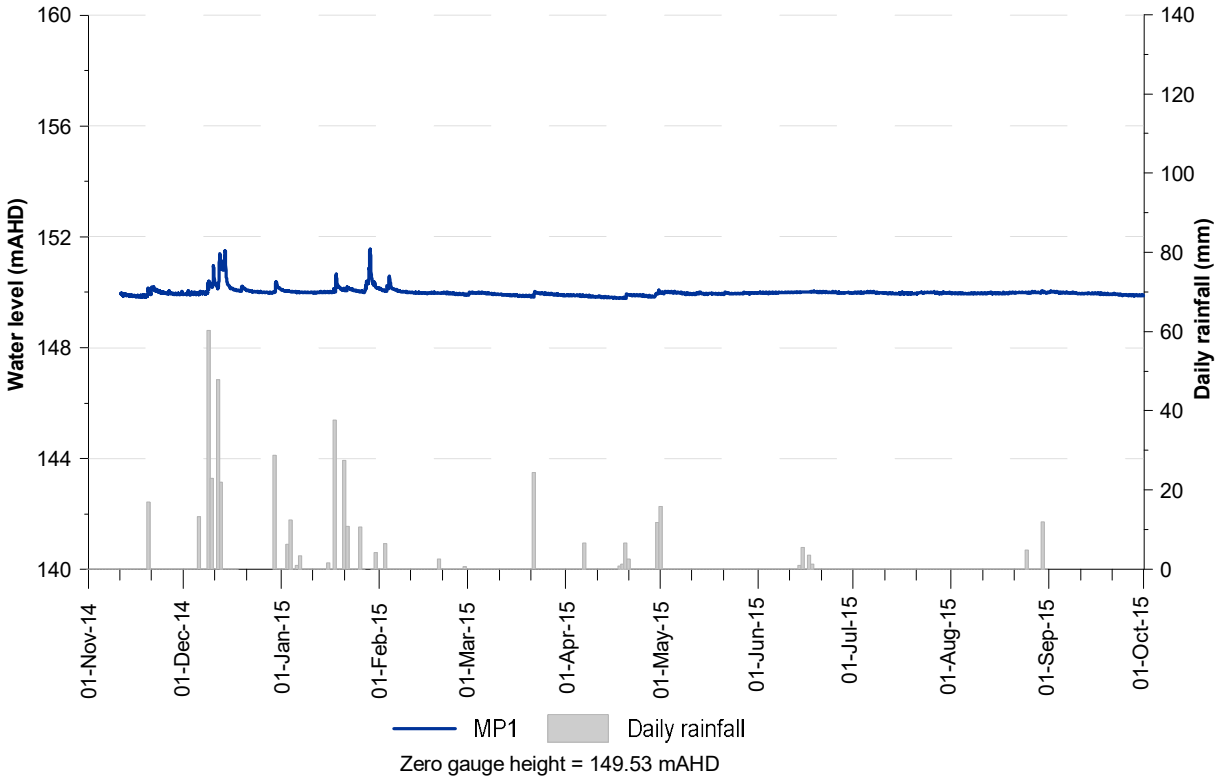


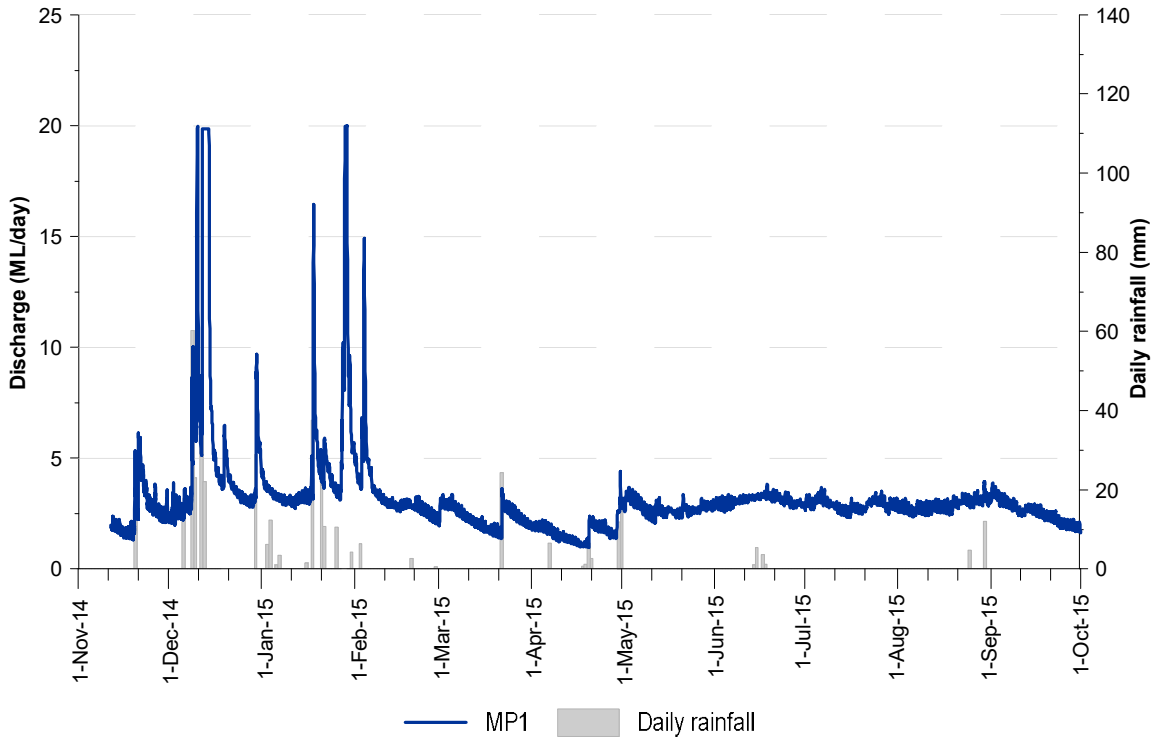
Zero gauge height = 95.466 mAHD until 27/10/1976
Zero gauge height = 101.066 mAHD from 28/10/1976 onwards
Values have been corrected to the applicable zero gauge datum.



Note: Rainfall data for October 2015 was not available at the time of writing

Figure A.2: Surface water monitoring - Mackenzie River at Bingegang





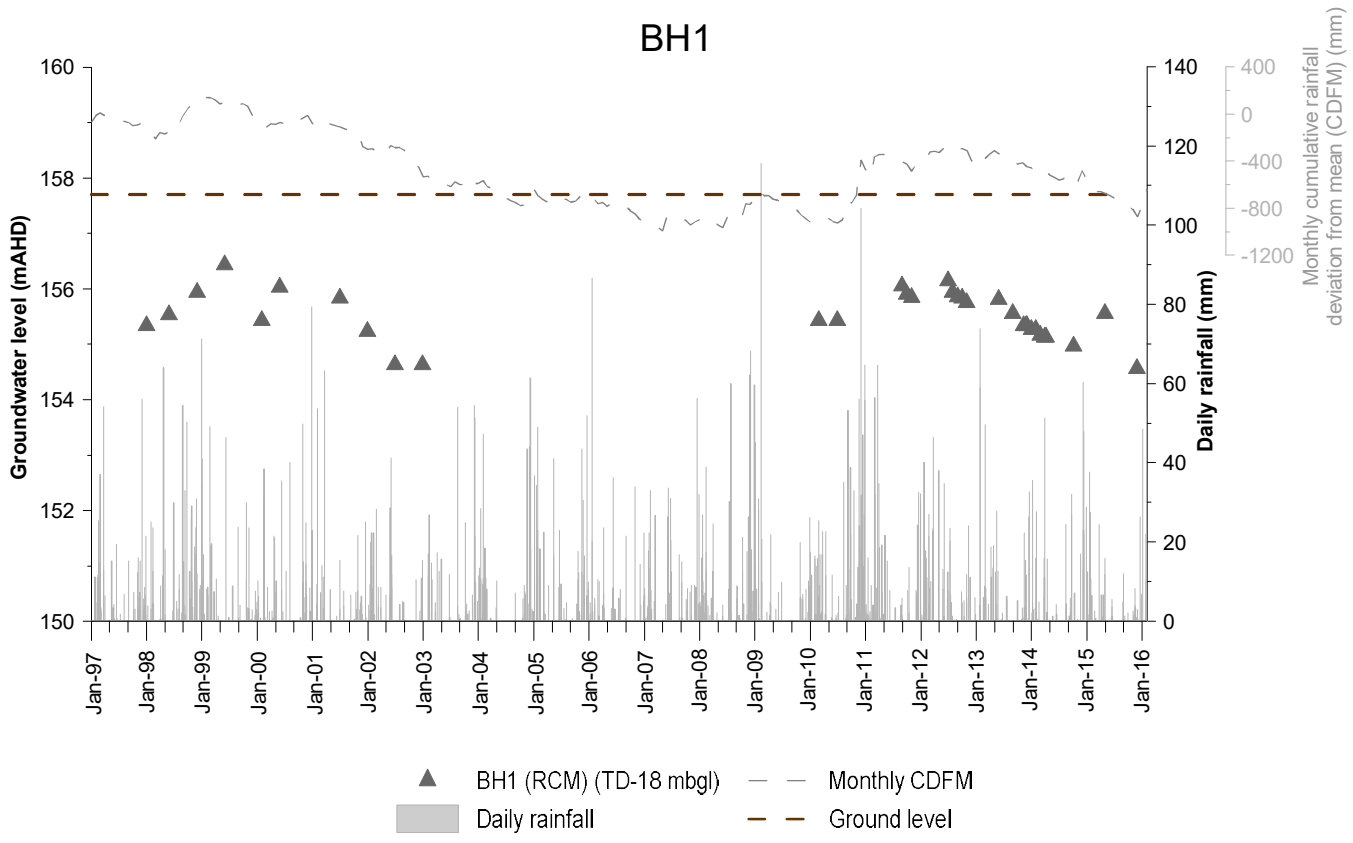
Note: Rainfall data for October 2015 was not available at the time of writing

Figure A.3: Surface water monitoring - Blackwater Creek Diversion

Attachment B

Groundwater hydrographs





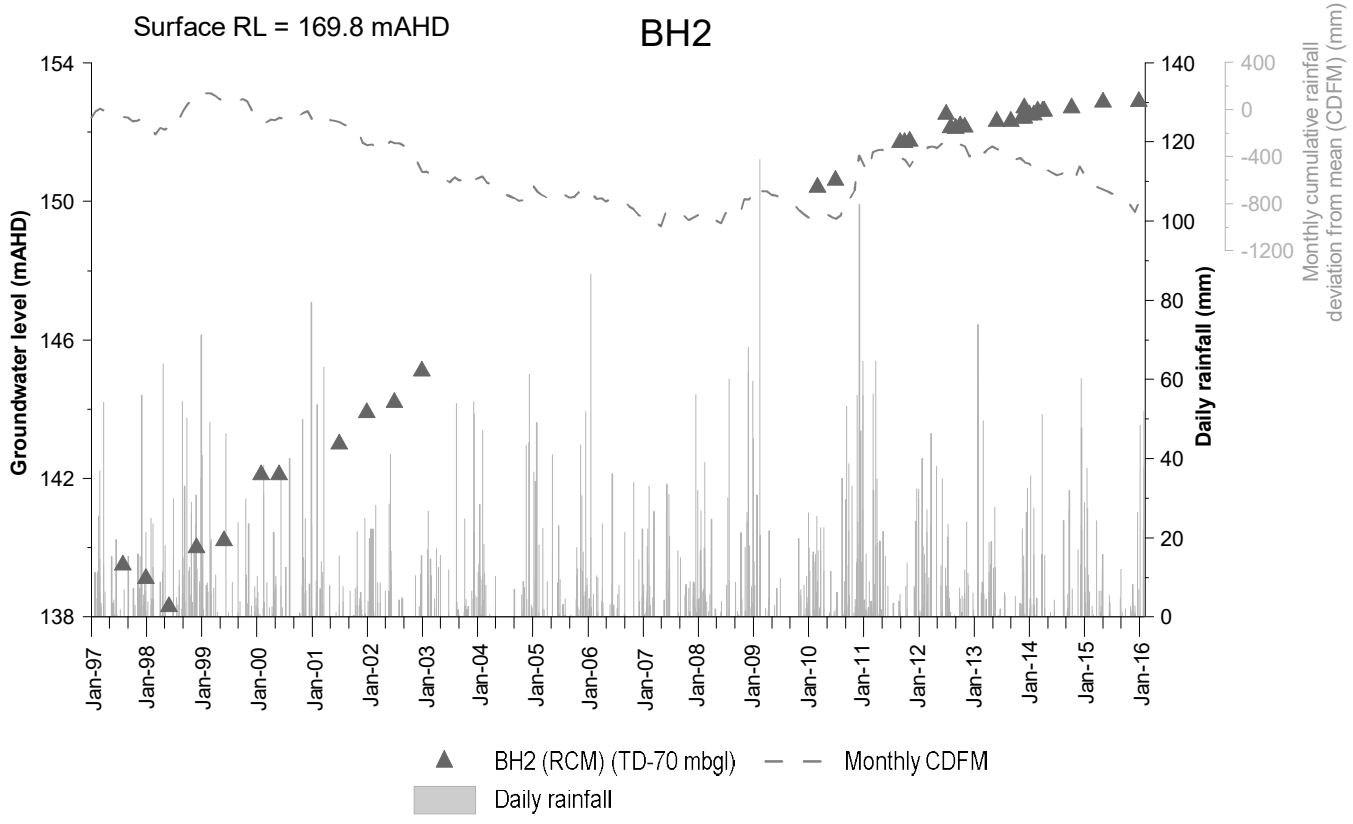
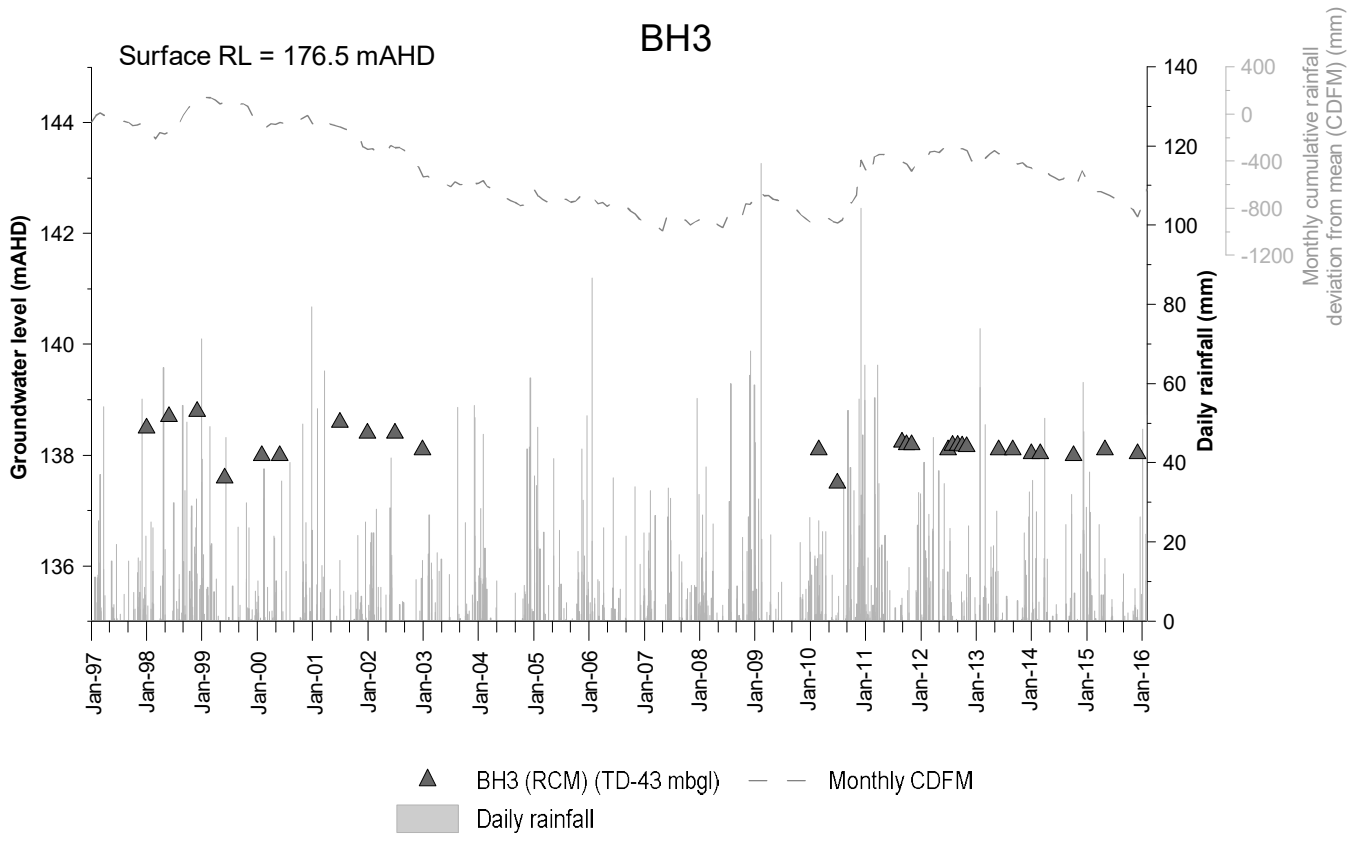


Figure B.1: Monitoring bores BH1 and BH2



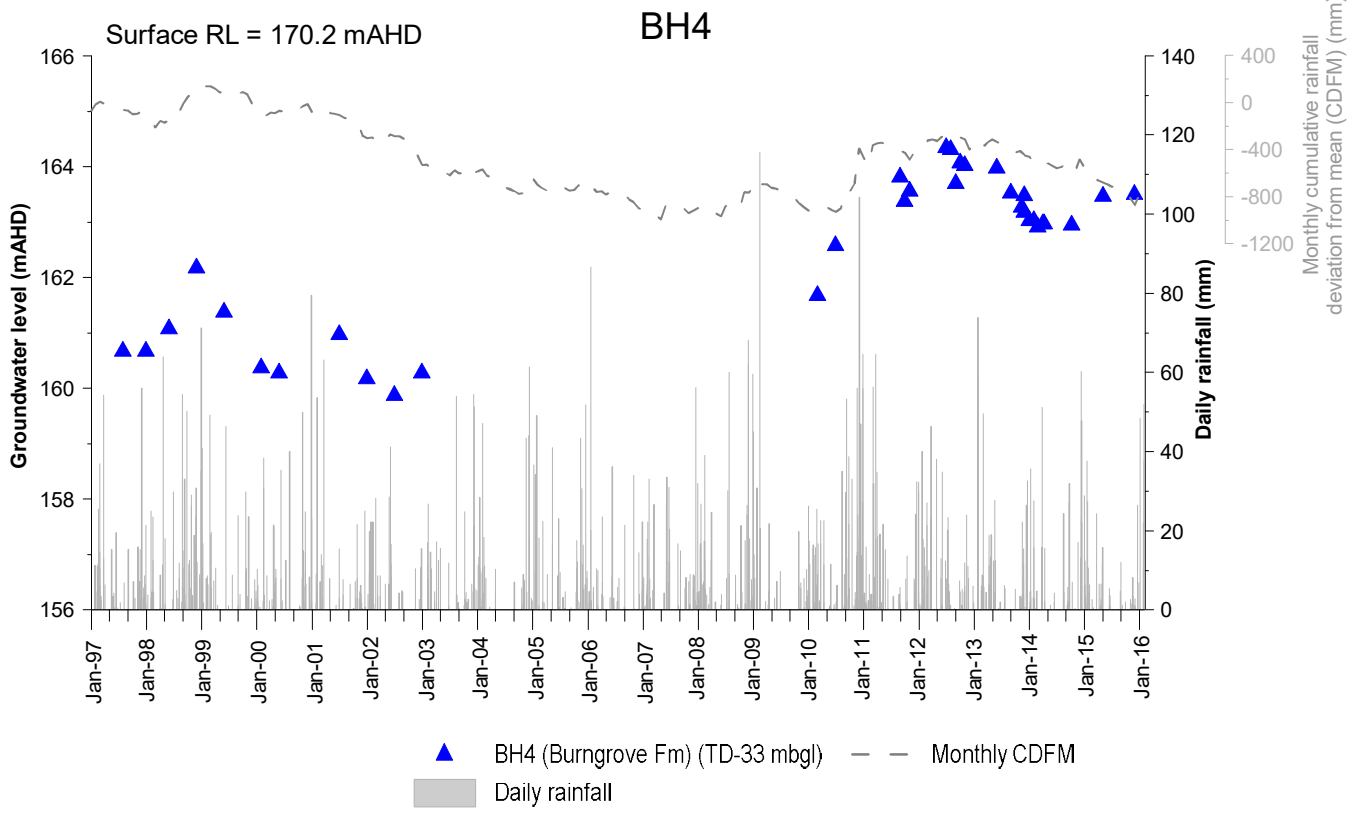
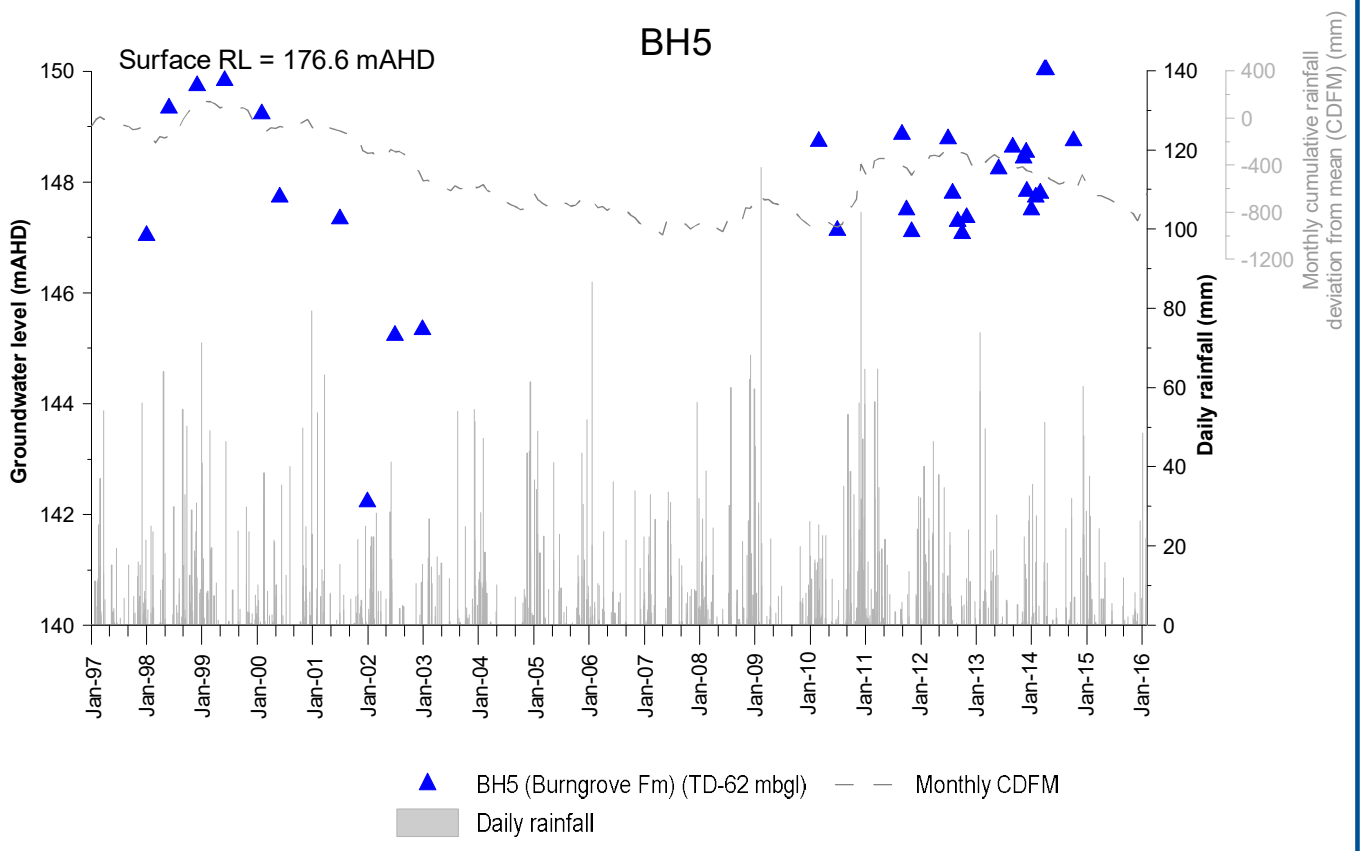


Figure B.2: Monitoring bores BH3 and BH4



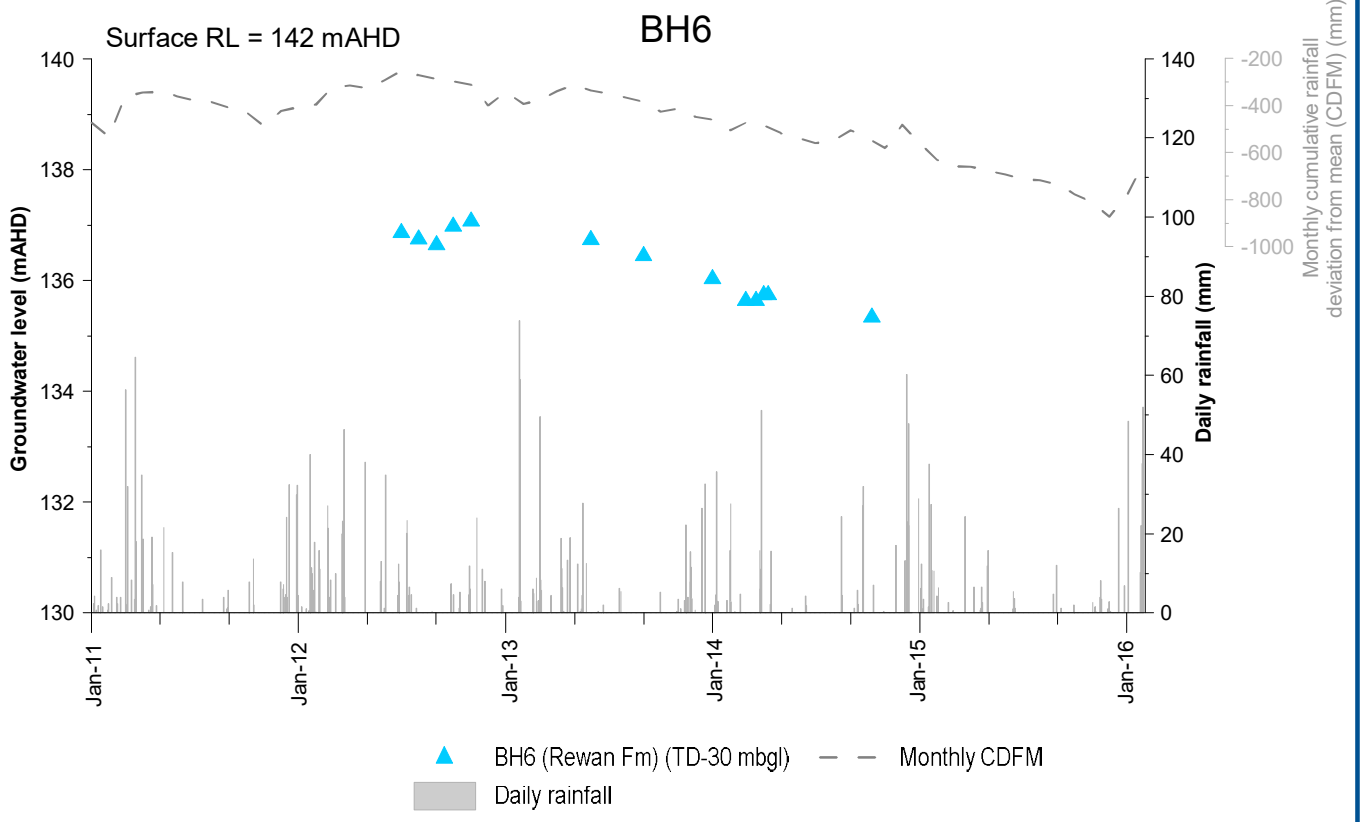


Figure B.3: Monitoring bores BH5 and BH6

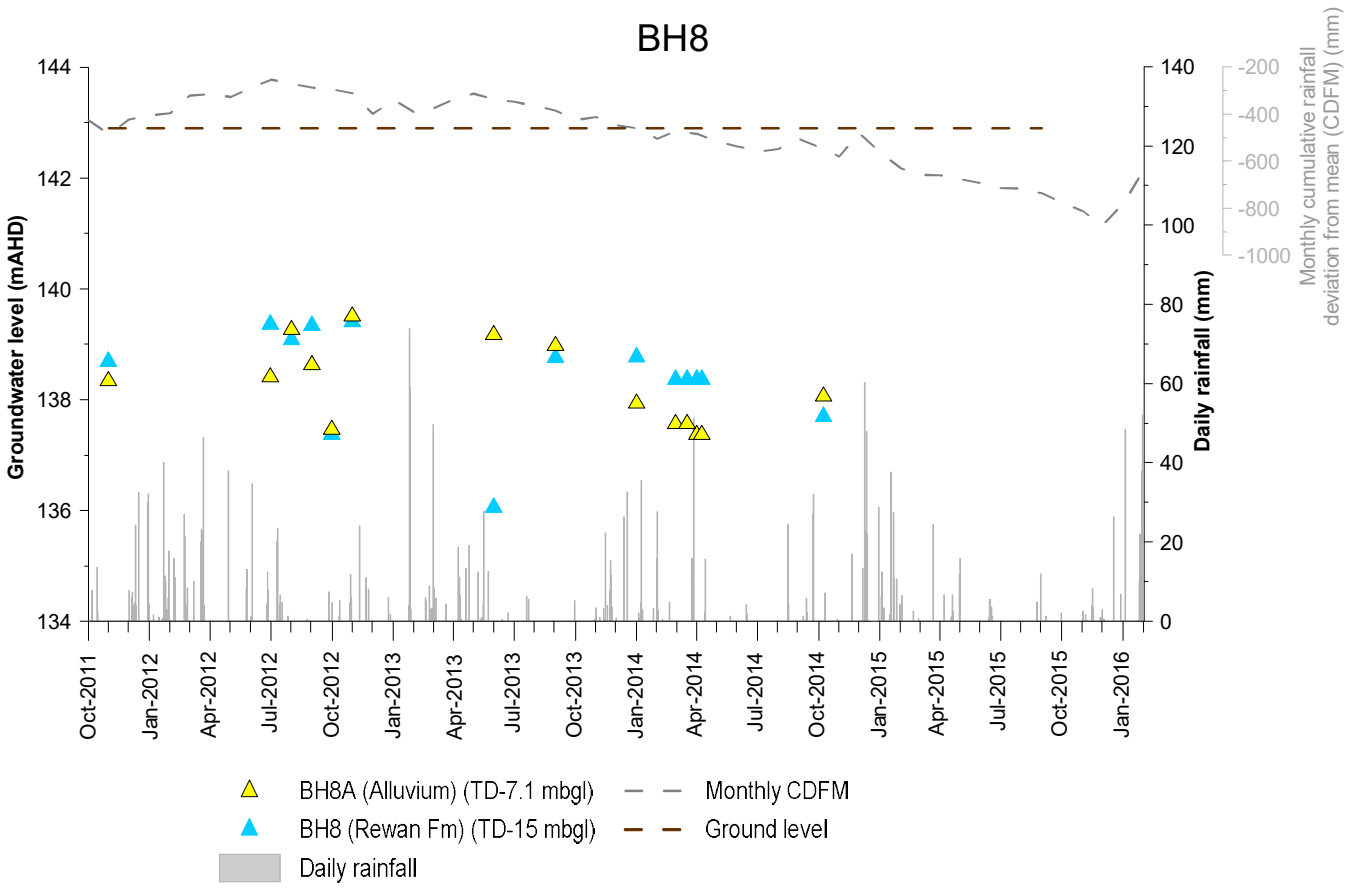
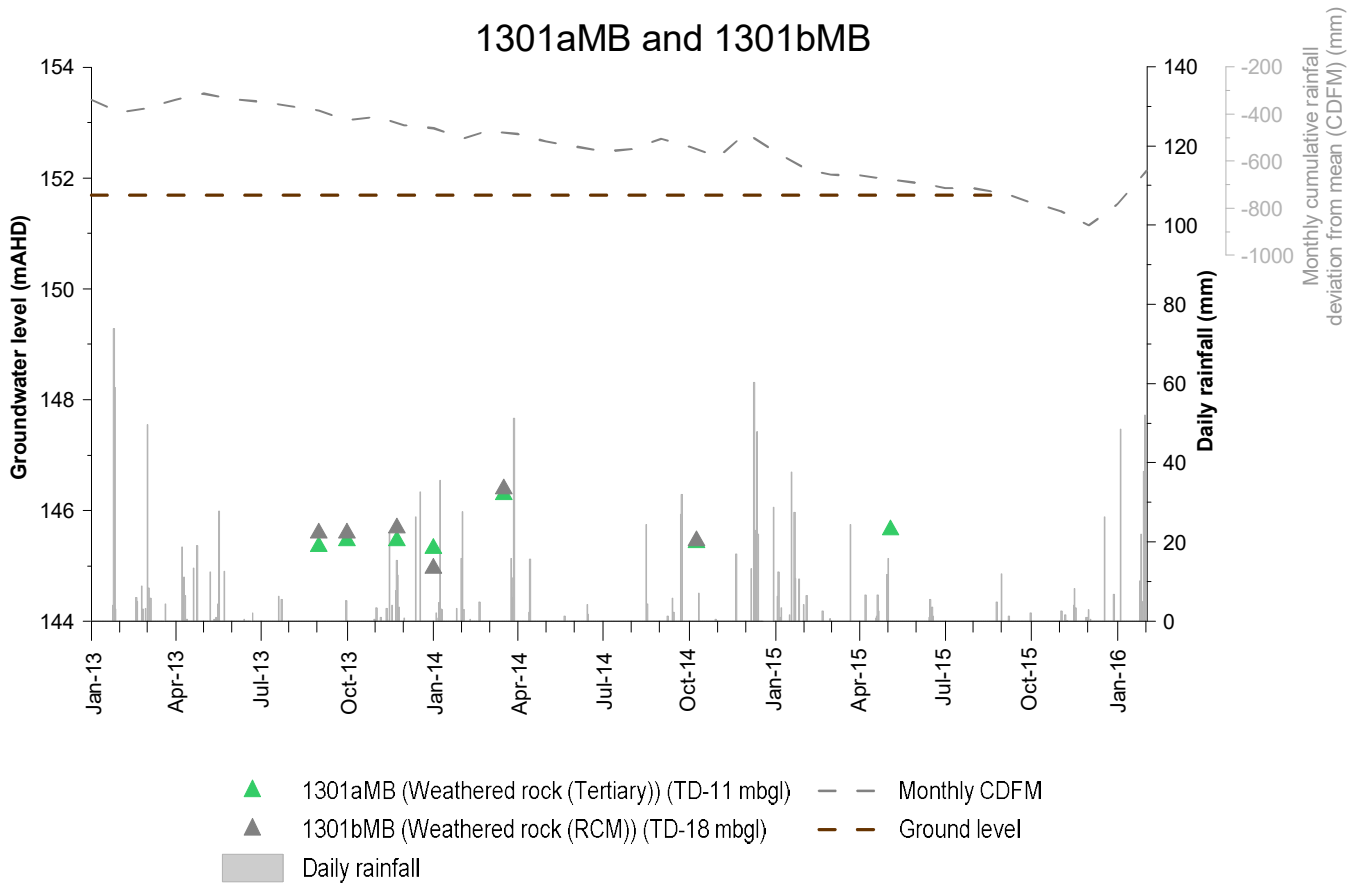


Figure B.4: Monitoring bores BH8 and BH8A



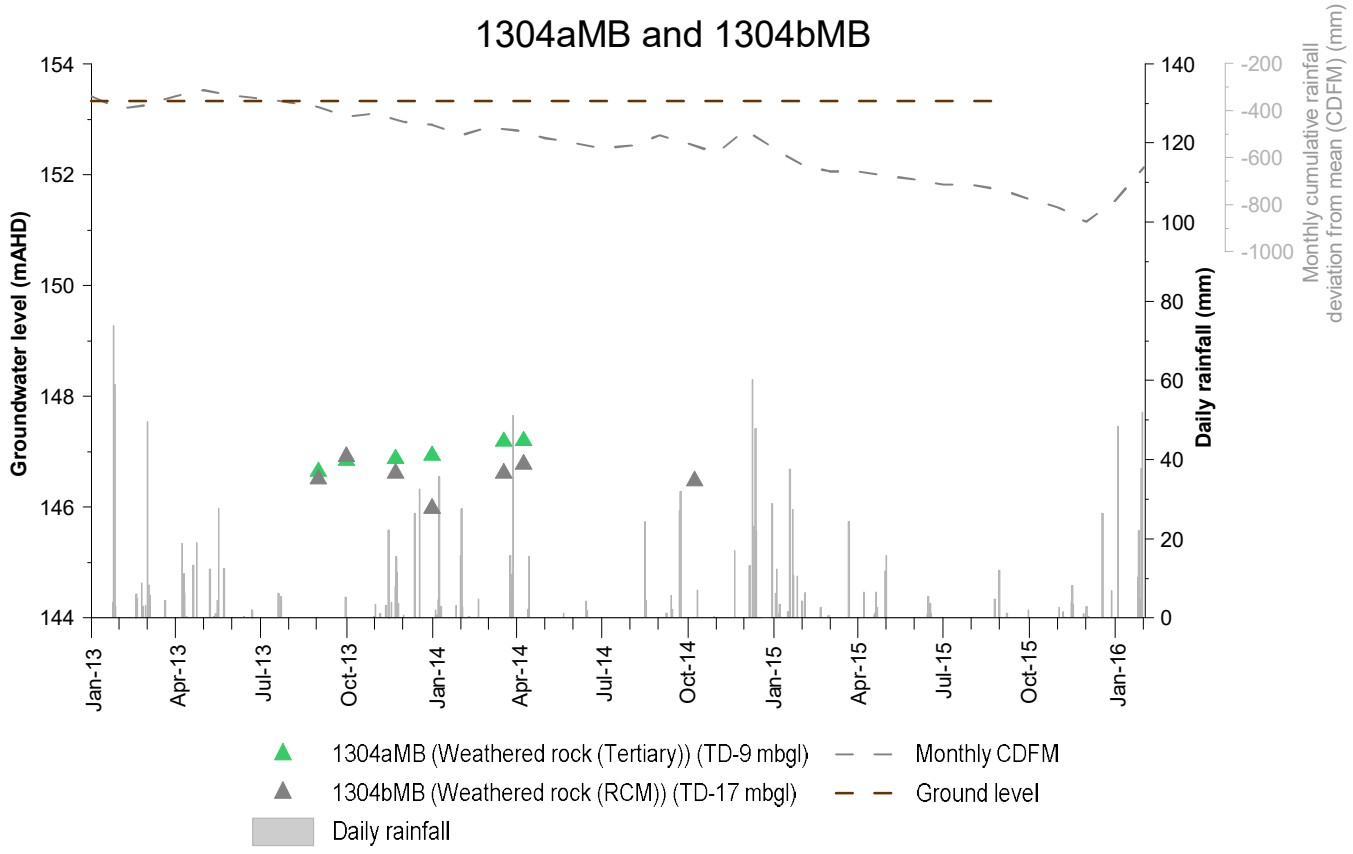
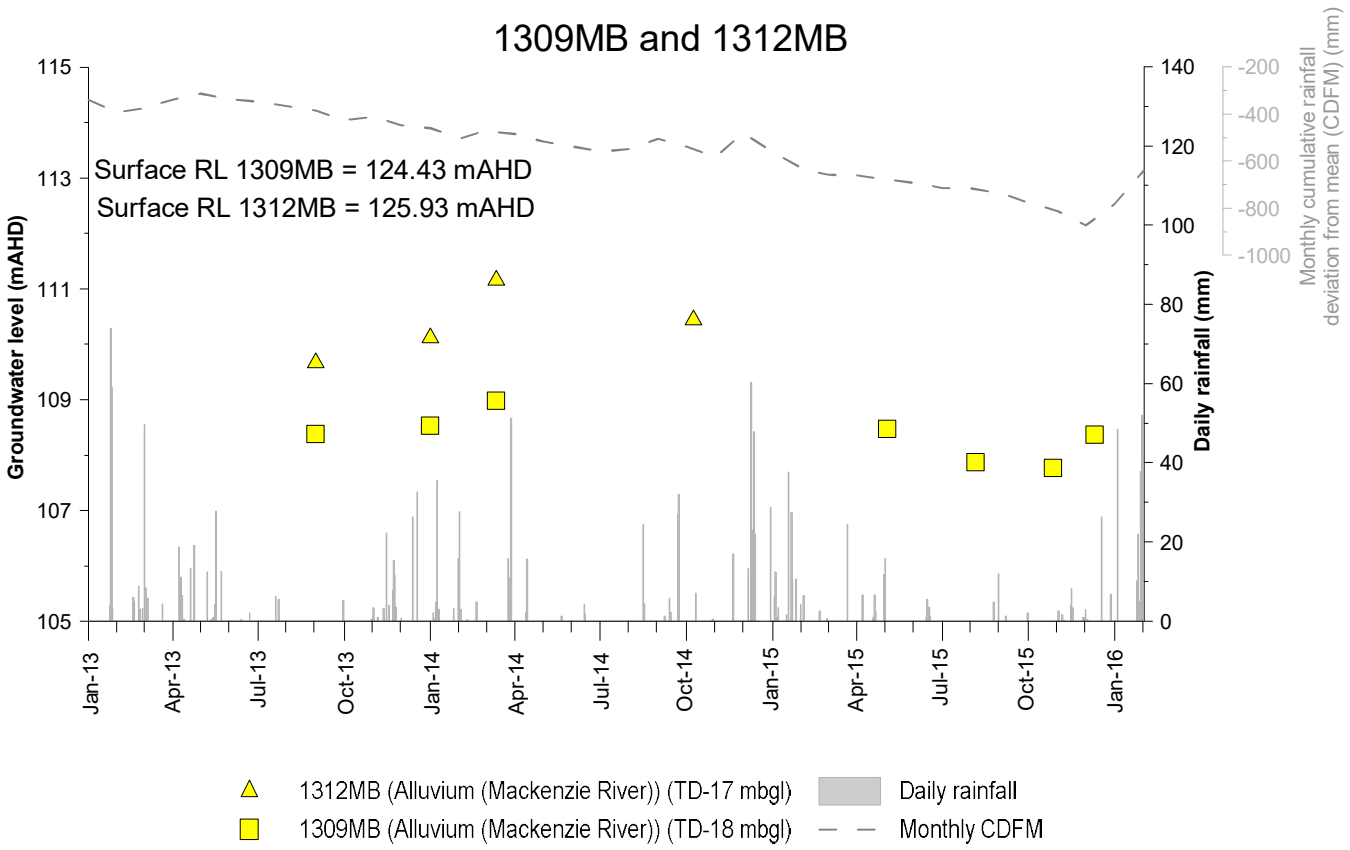


Figure B.5: Monitoring bores 1301MB and 1304MB



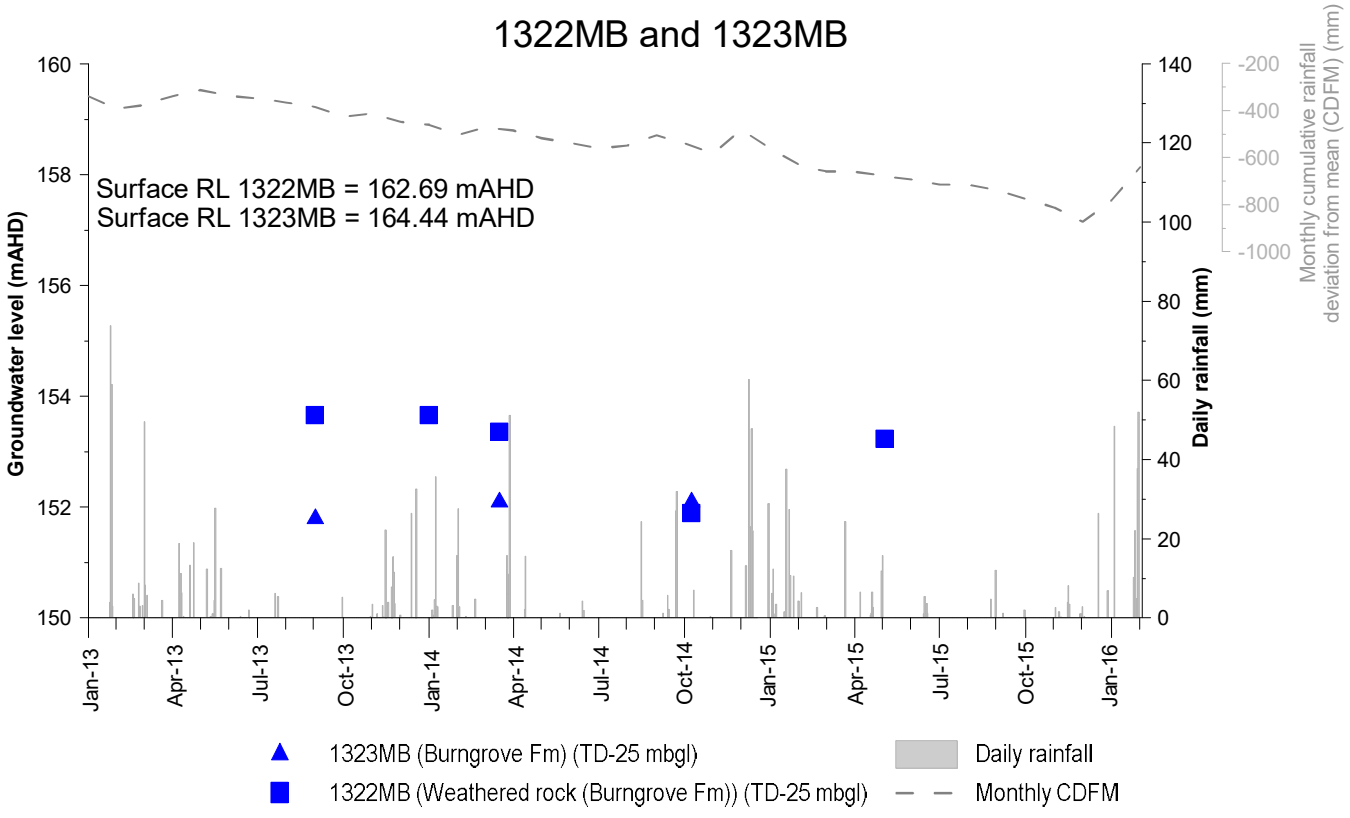


Figure B.6: Monitoring bores 1309MB, 1312MB, 1322MB and 1323MB

Attachment C

Water level data



Table C1: Groundwater levels (mbTOC)

Site	Screened formation	Total depth (m)	Casing height (m)	Surface RL (m)	TOC* (mAHD)	1/8/1997	1/1/1998	1/6/1998	1/12/1998	1/6/1999	1/2/2000	1/6/2000	1/7/2001	1/1/2002	1/7/2002	1/1/2003	19/06/2006	3/04/2007	20/12/2007	1/3/2010	1/7/2010	1/9/2011	1/10/2011	1/11/2011	1/7/2012	1/8/2012	1/9/2012
BH1	Rangal Coal Measures	18.0	0.53	157.7	158.2		2.9	2.7	2.3	1.8	2.8	2.2	2.4	3	3.6	3.6	3.2	2.44	2.69	2.8	2.8	2.2	2.3	2.4	2.09	2.29	2.37
BH2	Rangal Coal Measures	70.0	0.10	169.8	169.9	30.4	30.8	31.6	29.9	29.7	27.8	27.8	26.9	26	25.7	24.8	21.4	20.67	20.38	19.5	19.3	18.2	18.2	18.2	17.38	17.77	17.80
BH3	Rangal Coal Measures	43.0	0.59	176.5	177.1	dry	38.6	38.4	38.3	39.5	39.1	39.1	38.5	38.7	38.7	39	39.25			39	39.6	38.9	38.9	38.9	38.99	38.92	38.92
BH4	Burngrove Fm	33.0	0.47	170.2	170.7	10	10	9.6	8.5	9.3	10.3	10.4	9.7	10.5	10.8	10.4	10.2	9.41	9.85	9	8.1	6.9	7.3	7.1	6.33	6.36	6.98
BH5	Burngrove Fm	62.0	0.63	176.6	177.2	28	30.2	27.9	27.5	27.4	28	29.5	29.9	35	32	31.9	36.71	31.17	31.07	28.5	30.1	28.4	29.7	30.1	28.45	29.44	29.94
BH6	Rewan Fm	30.0	0.23	142.0	142.2																			19.50	5.38	5.49	5.60
BH8	Rewan Fm	15.0	0.46	142.9	143.4																			4.67	4.00	4.28	4.02
BH8A	Alluvium	7.1	0.16	142.9	143.1																			4.73	4.66	3.81	4.45
1307MB	Alluvium	7.0	0.83	143.16	144.0																						
1308MB	Alluvium/weathered rock (Tertiary Duaringa Fm)	14.0	0.82	143.30	144.1																						
1309MB	Alluvium	18.0	0.75	124.43	125.2																						
1312MB	Alluvium	17.0	0.83	125.93	126.8																						
1314MB	Weathered rock (Rangal Coal Measures)	5.0	0.77	146.48	147.3																						
1315MB	Weathered rock (Rangal Coal Measures)	8.0	0.70	147.73	148.4																						
1316MB	Weathered rock (Rangal Coal Measures)	9.0	0.72	148.03	148.7																						
1321MB	Weathered rock (Rangal Coal Measures)	25.0	0.80	172.42	173.2																						
1322MB	Weathered rock (Burngrove Fm)	25.0	0.87	162.69	163.6																						
1323MB	Weathered rock (Burngrove Fm)	25.0	0.80	164.44	165.2																						
1324MB	Weathered rock (Burngrove Fm)	25.0	0.86	158.60	159.5																						
1301aMB	Weathered rock (Tertiary)	11.0	0.82	151.83	152.7																						
1301bMB	Weathered rock (Rangal Coal Measures)	18.0	0.80	151.69	152.5																						
1302MB	Weathered rock (Tertiary)	6.0	0.82	153.64	154.5																						
1303MB	Weathered rock (Tertiary)	6.0	0.77	156.90	157.7																						
1304aMB	Weathered rock (Tertiary)	9.0	0.98	153.35	154.3																						
1304bMB	Weathered rock (Rangal Coal Measures)	17.0	0.88	153.33	154.2																						
1305MB	Weathered rock (Tertiary)	6.6	0.78	156.30	157.1																						
1410MB	Alluvium	18.0	0.64	126.05	126.7																						
1411MB	Alluvium	20.0		128.23																							
1417MB	Weathered rock (Burngrove Fm)	15.0	0.61	175.56	176.2																						
1418MB	Weathered rock (Burngrove Fm)	21.0	0.50	175.56	176.1																						
1419MB	Weathered rock (Tertiary Duaringa Fm)	15.0	0.50	137.96	138.5																						
1420MB	Weathered rock (Tertiary Duaringa Fm)	15.0	0.50	138.43	138.9																						
1425MB#	Alluvium	21.0		125.12																							
1426MB	Alluvium	26.0	0.78	128.79	129.6																						
1428MB	Alluvium	26.0	0.5	127.90	128.4																						
1430MB#	Alluvium	27.0		127.56																							
1432MB#	Alluvium	12.0		134.75																							
1529MB#	Rangal Coal Measures	39.0		123.81																							
1531MB	Alluvium	27.0	0.75	125.53	126.3																						
1533MB	Alluvium	27.0	0.82	132.36	133.2																						
1534MB	Rangal Coal Measures	33.0	0.8	132.52	133.3																						
1535MB#	Rangal Coal Measures	45.5		180.241																							
1536MB	Rangal Coal Measures	41.5	0.66	148.504	149.2																						
1537MB	Burngrove Fm (coal seam)	36.5	0.77	157.71	158.5																						
1538MB#	Rangal Coal Measures	79.0		153.18																							
1539MB	Rangal Coal Measures	59.0	0.67	152.20	152.9																						

*Top of casing

No water level data currently available

PARSONS BRINCKERHOFF

Table C1: Groundwater levels (mbTOC) Cont.

Site	Screened formation	Total depth (m)	Casing height (m)	Surface RL (m)	TOC* (mAHD)	1/10/2012	1/11/2012	1/6/2013	1/9/2013	1/10/2013	13/11/2013	23/11/2013	29/11/2013	1/12/2013	1/1/2014	1/2/2014	1/3/2014	1/4/2014	12/3/2014	17/3/2014	18/3/2014	8/4/2014	9/4/2014	8/10/2014	4/5/2015	6/8/2015
BH1	Rangal Coal Measures	18.0	0.53	157.7	158.2	2.40	2.48	2.42	2.68		2.90		2.90	2.90	2.96	2.96	3.07	3.10					3.1	3.27	3.19	
BH2	Rangal Coal Measures	70.0	0.10	169.8	169.9	17.72	17.75	17.60	17.60		17.50		17.50	17.20	17.40	17.40	17.30	17.30					17.3	17.21	17.04	
BH3	Rangal Coal Measures	43.0	0.59	176.5	177.1	38.93	38.94	39.00	39.00						39.07		39.06							39.10	39	
BH4	Burngrove Fm	33.0	0.47	170.2	170.7	6.60	6.66	6.70	7.15		7.40		7.50	7.20	7.65	7.65	7.76	7.70				7.7		7.73	7.23	
BH5	Burngrove Fm	62.0	0.63	176.6	177.2	30.16	29.87	29.00	28.60		28.80		28.70	29.40	29.73	29.50	29.44	27.20				27.2		28.49	28.05	
BH6	Rewan Fm	30.0	0.23	142.0	142.2	5.26	5.17	5.50	5.80						6.21		6.60	6.50			6.6		6.5	6.90	5.98	
BH8	Rewan Fm	15.0	0.46	142.9	143.4	5.99	3.95	7.30	4.60						4.59		5.00	5.00			5		5	5.66	3.83	
BH8A	Alluvium	7.1	0.16	142.9	143.1	5.61	3.56	3.90	4.10						5.13		5.50	5.70			5.5		5.7	5.01	4.03	
1307MB	Alluvium	7.0	0.83	143.16	144.0				dry						dry		dry	8.40	8.4				8.4			
1308MB	Alluvium/weathered rock (Tertiary Duaringa Fm)	14.0	0.82	143.30	144.1				8.05						8.40		8.80				8.8					
1309MB	Alluvium	18.0	0.75	124.43	125.2				16.80						16.65				16.2						16.45	17.18
1312MB	Alluvium	17.0	0.83	125.93	126.8				17.10						16.65				15.60					16.32	16.62	
1314MB	Weathered rock (Rangal Coal Measures)	5.0	0.77	146.48	147.3				dry						dry		5.23									
1315MB	Weathered rock (Rangal Coal Measures)	8.0	0.70	147.73	148.4				dry						7.46		9.02									
1316MB	Weathered rock (Rangal Coal Measures)	9.0	0.72	148.03	148.7				dry						dry		10.10									
1321MB	Weathered rock (Rangal Coal Measures)	25.0	0.80	172.42	173.2				dry						7.28		dry									
1322MB	Weathered rock (Burngrove Fm)	25.0	0.87	162.69	163.6				9.90						9.90					10.2				11.66	9.95	
1323MB	Weathered rock (Burngrove Fm)	25.0	0.80	164.44	165.2				13.45											13.15				13.15	13.05	12.49
1324MB	Weathered rock (Burngrove Fm)	25.0	0.86	158.60	159.5				dry						19.63		dry									
1301aMB	Weathered rock (Tertiary)	11.0	0.82	151.83	152.7				7.30	7.20		7.20			7.33					6.37				7.23	6.68	
1301bMB	Weathered rock (Rangal Coal Measures)	18.0	0.80	151.69	152.5				6.90	6.90		6.80			7.53					6.10				7.04	6.46	
1302MB	Weathered rock (Tertiary)	6.0	0.82	153.64	154.5				6.40	6.73		6.27			dry		6.31									
1303MB	Weathered rock (Tertiary)	6.0	0.77	156.90	157.7				7.00	dry		dry			dry		6.90									
1304aMB	Weathered rock (Tertiary)	9.0	0.98	153.35	154.3				7.70	7.50		7.46			7.41						7.15	7.14				
1304bMB	Weathered rock (Rangal Coal Measures)	17.0	0.88	153.33	154.2				7.70	7.30		7.60			8.24						7.60	7.44		7.74	6.82	
1305MB	Weathered rock (Tertiary)	6.6	0.78	156.30	157.1				dry	dry		dry			dry		dry									
1410MB	Alluvium	18.0	0.64	126.05	126.7																				17.4	17.47
1411MB	Alluvium	20.0		128.23																						
1417MB	Weathered rock (Burngrove Fm)	15.0	0.61	175.56	176.2																				9.45	9.28
1418MB	Weathered rock (Burngrove Fm)	21.0	0.50	175.56	176.1																				11.35	
1419MB	Weathered rock (Tertiary Duaringa Fm)	15.0	0.50	137.96	138.5																				13.3	
1420MB	Weathered rock (Tertiary Duaringa Fm)	15.0	0.50	138.43	138.9																				15.4	
1425MB#	Alluvium	21.0		125.12																						
1426MB	Alluvium	26.0	0.78	128.79	129.6																				24.78	23.95
1428MB	Alluvium	26.0	0.5	127.90	128.4																				26.8	
1430MB#	Alluvium	27.0		127.56																						
1432MB#	Alluvium	12.0		134.75																						
1529MB#	Rangal Coal Measures	39.0		123.81																						
1531MB	Alluvium	27.0	0.75	125.53	126.3																				21.66	21.66
1533MB	Alluvium	27.0	0.82	132.36	133.2																				27.18	27.18
1534MB	Rangal Coal Measures	33.0	0.8	132.52	133.3																				28.67	28.67
1535MB#	Rangal Coal Measures	45.5		180.241																						
1536MB	Rangal Coal Measures	41.5	0.66	148.504	149.2																				34.61	34.61
1537MB	Burngrove Fm (coal seam)	36.5	0.77	157.71	158.5																				21.44	16.78
1538MB#	Rangal Coal Measures	79.0		153.18																						
1539MB	Rangal Coal Measures	59.0	0.67	152.20	152.9																				30	

*Top of casing

No water level data currently available

PARSONS BRINCKERHOFF

Table C2: Groundwater levels (mAHD)

Site	Screened formation	Total depth (m)	Casing height (m)	Surface RL (m)	TOC* (mAHD)	1/8/1997	1/1/1998	1/6/1998	1/12/1998	1/6/1999	1/2/2000	1/6/2000	1/7/2001	1/1/2002	1/7/2002	1/1/2003	19/06/2006	3/04/2007	20/12/2007	1/3/2010	1/7/2010	1/9/2011	1/10/2011	1/11/2011	1/7/2012	1/8/2012	1/9/2012
BH1	Rangal Coal Measures	18.0	0.53	157.7	158.2		155.3	155.5	155.9	156.4	155.4	156.0	155.8	155.2	154.6	154.6	155.0	155.8	155.5	155.4	155.4	156.1	155.9	155.8	156.1	155.9	155.9
BH2	Rangal Coal Measures	70.0	0.10	169.8	169.9	139.5	139.1	138.3	140.0	140.2	142.1	142.1	143.0	143.9	144.2	145.1	148.5	149.2	149.5	150.4	150.6	151.7	151.7	151.7	152.5	152.1	152.1
BH3	Rangal Coal Measures	43.0	0.59	176.5	177.1		138.5	138.7	138.8	137.6	138.0	138.0	138.6	138.4	138.4	138.1	137.8			138.1	137.5	138.2	138.2	138.2	138.1	138.2	138.2
BH4	Burngrove Fm	33.0	0.47	170.2	170.7	160.7	160.7	161.1	162.2	161.4	160.4	160.3	161.0	160.2	159.9	160.3	160.5	161.3	160.8	161.7	162.6	163.8	163.4	163.6	164.3	164.3	163.7
BH5	Burngrove Fm	62.0	0.63	176.6	177.2	149.2	147.0	149.3	149.7	149.8	149.2	147.7	147.3	142.2	145.2	145.3	140.5	146.1	146.2	148.7	147.1	148.9	147.5	147.1	148.8	147.8	147.3
BH6	Rewan Fm	30.0	0.23	142.0	142.2																				136.9	136.7	136.6
BH8	Rewan Fm	15.0	0.46	142.9	143.4																			138.7	139.4	139.1	139.3
BH8A	Alluvium	7.1	0.16	142.9	143.1																			138.3	138.4	139.3	138.6
1307MB	Alluvium	7.0	0.83	143.16	144.0																						
1308MB	Alluvium/weathered rock (Tertiary Duaringa Fm)	14.0	0.82	143.30	144.1																						
1309MB	Alluvium	18.0	0.75	124.43	125.2																						
1312MB	Alluvium	17.0	0.83	125.93	126.8																						
1314MB	Weathered rock (Rangal Coal Measures)	5.0	0.77	146.48	147.3																						
1315MB	Weathered rock (Rangal Coal Measures)	8.0	0.70	147.73	148.4																						
1316MB	Weathered rock (Rangal Coal Measures)	9.0	0.72	148.03	148.7																						
1321MB	Weathered rock (Rangal Coal Measures)	25.0	0.80	172.42	173.2																						
1322MB	Weathered rock (Burngrove Fm)	25.0	0.87	162.69	163.6																						
1323MB	Weathered rock (Burngrove Fm)	25.0	0.80	164.44	165.2																						
1324MB	Weathered rock (Burngrove Fm)	25.0	0.86	158.60	159.5																						
1301aMB	Weathered rock (Tertiary)	11.0	0.82	151.83	152.7																						
1301bMB	Weathered rock (Rangal Coal Measures)	18.0	0.80	151.69	152.5																						
1302MB	Weathered rock (Tertiary)	6.0	0.82	153.64	154.5																						
1303MB	Weathered rock (Tertiary)	6.0	0.77	156.90	157.7																						
1304aMB	Weathered rock (Tertiary)	9.0	0.98	153.35	154.3																						
1304bMB	Weathered rock (Rangal Coal Measures)	17.0	0.88	153.33	154.2																						
1305MB	Weathered rock (Tertiary)	6.6	0.78	156.30	157.1																						
1410MB	Alluvium	18.0	0.64	126.05	126.7																						
1411MB	Alluvium	20.0		128.23																							
1417MB	Weathered rock (Burngrove Fm)	15.0	0.61	175.56	176.2																						
1418MB	Weathered rock (Burngrove Fm)	21.0	0.50	175.56	176.1																						
1419MB	Weathered rock (Tertiary Duaringa Fm)	15.0	0.50	137.96	138.5																						
1420MB	Weathered rock (Tertiary Duaringa Fm)	15.0	0.50	138.43	138.9												110.41										
1425MB#	Alluvium	21.0		125.12																							
1426MB	Alluvium	26.0	0.78	128.79	129.6																						
1428MB	Alluvium	26.0	0.5	127.90	128.4																						
1430MB#	Alluvium	27.0		127.56																							
1432MB#	Alluvium	12.0		134.75																							
1529MB#	Rangal Coal Measures	39.0		123.81																							
1531MB	Alluvium	27.0	0.75	125.53	126.3																						
1533MB	Alluvium	27.0	0.82	132.36	133.2																						
1534MB	Rangal Coal Measures	33.0	0.8	132.52	133.3																						
1535MB#	Rangal Coal Measures	45.5		180.24																							
1536MB	Rangal Coal Measures	41.5	0.66	148.50	149.2																						
1537MB	Burngrove Fm (coal seam)	36.5	0.77	157.71	158.5																						
1538MB#	Rangal Coal Measures	79.0		153.18																							
1539MB	Rangal Coal Measures	59.0	0.67	152.20	152.9																						

*Top of casing

No water level data currently available

PARSONS BRINCKERHOFF

Table C2: Groundwater levels (mAHD) Cont.

Site	Screened formation	Total depth (m)	Casing height (m)	Surface RL (m)	TOC* (mAHD)	1/10/2012	1/11/2012	1/6/2013	1/9/2013	1/10/2013	13/11/2013	23/11/2013	29/11/2013	1/12/2013	1/1/2014	1/2/2014	1/3/2014	1/4/2014	12/3/2014	17/3/2014	18/3/2014	8/4/2014	9/4/2014	8/10/2014	4/5/2015	6/8/2015
BH1	Rangal Coal Measures	18.0	0.53	157.7	158.2	155.8	155.8	155.8	155.6		155.3		155.3	155.3	155.3	155.3	155.2	155.1					155.1	155.0	155.0	158.2
BH2	Rangal Coal Measures	70.0	0.10	169.8	169.9	152.2	152.2	152.3	152.3		152.4		152.4	152.7	152.5	152.5	152.6	152.6					152.6	152.7	152.9	
BH3	Rangal Coal Measures	43.0	0.59	176.5	177.1	138.2	138.2	138.1	138.1						138.0		138.0							138.0	136.1	
BH4	Burngrove Fm	33.0	0.47	170.2	170.7	164.1	164.0	164.0	163.5		163.3		163.2	163.5	163.0	163.0	162.9	163.0				163.0		162.9	163.4	
BH5	Burngrove Fm	62.0	0.63	176.6	177.2	147.1	147.4	148.2	148.6		148.4		148.5	147.8	147.5	147.7	147.8	150.0				150.0		148.7	149.2	
BH6	Rewan Fm	30.0	0.23	142.0	142.2	137.0	137.1	136.7	136.4						136.0		135.6	135.7			135.6		135.7	135.3	136.3	
BH8	Rewan Fm	15.0	0.46	142.9	143.4	137.4	139.4	136.1	138.8						138.8		138.4	138.4			138.4		138.4	137.7	139.5	
BH8A	Alluvium	7.1	0.16	142.9	143.1	137.5	139.5	139.2	139.0						137.9		137.6	137.4			137.6		137.4	138.1	139.0	
1307MB	Alluvium	7.0	0.83	143.16	144.0													135.6	135.6				135.6			
1308MB	Alluvium/weathered rock (Tertiary Duaringa Fm)	14.0	0.82	143.30	144.1				136.07						135.72		135.32				138.6					
1309MB	Alluvium	18.0	0.75	124.43	125.2				108.4						108.5				108.98						108.48	107.87
1312MB	Alluvium	17.0	0.83	125.93	126.8				109.66						110.11				111.16					110.44	109.91	
1314MB	Weathered rock (Rangal Coal Measures)	5.0	0.77	146.48	147.3												142.02									
1315MB	Weathered rock (Rangal Coal Measures)	8.0	0.70	147.73	148.4										140.97		139.41									
1316MB	Weathered rock (Rangal Coal Measures)	9.0	0.72	148.03	148.7												138.65									
1321MB	Weathered rock (Rangal Coal Measures)	25.0	0.80	172.42	173.2										165.94											
1322MB	Weathered rock (Burngrove Fm)	25.0	0.87	162.69	163.6				153.658						153.66					153.36				151.90	153.24	
1323MB	Weathered rock (Burngrove Fm)	25.0	0.80	164.44	165.2				151.79											152.09				152.09	151.89	152.8
1324MB	Weathered rock (Burngrove Fm)	25.0	0.86	158.60	159.5										139.83											
1301aMB	Weathered rock (Tertiary)	11.0	0.82	151.83	152.7				145.35	145.45		145.45			145.32					146.28				145.42	145.65	
1301bMB	Weathered rock (Rangal Coal Measures)	18.0	0.80	151.69	152.5				145.59	145.59		145.69			144.96					146.39				145.45	145.73	
1302MB	Weathered rock (Tertiary)	6.0	0.82	153.64	154.5				148.06	147.73		148.19					148.15									
1303MB	Weathered rock (Tertiary)	6.0	0.77	156.90	157.7				150.67								150.77									
1304aMB	Weathered rock (Tertiary)	9.0	0.98	153.35	154.3				146.63	146.83		146.87			146.92						147.2	147.2				
1304bMB	Weathered rock (Rangal Coal Measures)	17.0	0.88	153.33	154.2				146.51	146.91		146.61			145.97						146.6	146.8		146.5	147.0	
1305MB	Weathered rock (Tertiary)	6.6	0.78	156.30	157.1																					
1410MB	Alluvium	18.0	0.64	126.05	126.7																				109.2	109.2
1411MB	Alluvium	20.0		128.23																						
1417MB	Weathered rock (Burngrove Fm)	15.0	0.61	175.56	176.2																				166.6	166.9
1418MB	Weathered rock (Burngrove Fm)	21.0	0.50	175.56	176.1																				164.7	
1419MB	Weathered rock (Tertiary Duaringa Fm)	15.0	0.50	137.96	138.5																				125.2	
1420MB	Weathered rock (Tertiary Duaringa Fm)	15.0	0.50	138.43	138.9																				123.5	
1425MB#	Alluvium	21.0		125.12																						
1426MB	Alluvium	26.0	0.78	128.79	129.6																				104.5	105.6
1428MB	Alluvium	26.0	0.5	127.90	128.4																				101.6	
1430MB#	Alluvium	27.0		127.56																						
1432MB#	Alluvium	12.0		134.75																						
1529MB#	Rangal Coal Measures	39.0		123.81																						
1531MB	Alluvium	27.0	0.75	125.53	126.3																				104.6	104.6
1533MB	Alluvium	27.0	0.82	132.36	133.2																				106.0	106.0
1534MB	Rangal Coal Measures	33.0	0.8	132.52	133.3																				104.6	104.6
1535MB#	Rangal Coal Measures	45.5		180.24																						
1536MB	Rangal Coal Measures	41.5	0.66	148.50	149.2																				114.6	114.6
1537MB	Burngrove Fm (coal seam)	36.5	0.77	157.71	158.5																				137.0	141.7
1538MB#	Rangal Coal Measures																									
1539MB	Rangal Coal Measures	59.0	0.67	152.20	152.9																				122.9	

*Top of casing

#No water level data currently available

PARSONS BRINCKERHOFF

Attachment D

Groundwater quality



PARSONS BRINCKERHOFF

BH1 - Rangal Coal Measures			23/08/1999	9/02/2000	26/06/2000	18/12/2000	3/07/2001	14/01/2002	2/07/2002	20/01/2003	13/01/2004	12/07/2004	25/07/2005	5/12/2005	3/04/2007	24/07/2007	20/12/2007	29/01/2009	11/03/2010	21/07/2010	20/09/2011	18/10/2011	25/07/2012	28/08/2012	28/11/2012	26/09/2012	18/10/2012	12/06/2013	2/09/2013	13/11/2013	29/11/2013	11/12/2013	15/01/2014	5/02/2014	3/03/2014	9/04/2014	15/05/2014	17/06/2014	8/10/2014
	Unit	LOR																																					
Physical parameters																																							
Electrical conductivity	µS/cm		11,000	12,900	12,500	11,300	13,200	12,800	12,000	12,000	13,000	14,000	13,000	11,000	13,000	14,000		14,000	14,000	15,000	15,000	14,000	14,000	13,000	14,000	15,000	15,000	15,000	15,000			15,000	15,000	15,000	15,000	14,000	14,000		14,000
pH	pH units																							7.20	7.00	7.70	7.00	6.80	6.40	7.10			7.30	7.70	7.30	7.30	7.40	7.40		7.50
Total dissolved solids	mg/L																												9,000	8,580			9,930	9,660	9,530	8,910	8,660	8,920		8,950
Total suspended solids	mg/L																																			18	40	59		39
Major/minor ions																																							
Bicarbonate alkalinity as CaCO3	mg/L														940	1,000			540	1,000	1,100	1,100						840								760	680		700
Carbonate alkalinity as CaCO3	mg/L	5																					<5	<5	<5	<5	<5	<5				<5	<5	<5	<5	<5	<5		<5
Hydroxide alkalinity as CaCO3	mg/L	5																																	<5	<5	<5		<5
Total alkalinity as CaCO3	mg/L																						820	860	910	1,000	970	840											
Total hardness as $CaCO_3$	mg/L																											2,500											
Bicarbonate alkalinity as HCO3	mg/L																																840	830	800	790	930	830		
Calcium as Ca - dissolved	mg/L		124	122	136		154	148	160	170	170	160	170	170	220	180							170	180	130	190	190						170	190	180	180	110		190
Calcium as Ca - total	mg/L																						180	180	140	180	180	180	150			170							
Chloride as Cl	mg/L		2,990	3,150	3,470	3,580	3,170	4,480	3,500	4,300		3,600	3,000	3,600	5,100	5,000							4,200	4,200	4,800	4,300	5,000	4,200	4,700			4,900	4,300	4,200	4,000	4,500	N.A.		4,300
Chlorine - free as Cl2	mg/L	0.1																														<0.1	<0.1						
Chlorine - total as Cl2	mg/L	0.1																											0										
Fluoride as F	mg/L	0.1																					0	0	<1	<1	0	<1	0			<0.1	1	<0.1					
Flourine	mg/L	1													0	0		< 1																					
Potassium as K - total	mg/L	0.1																					9	11	9	10	10	11	9			<0.1							
Potassium as K - dissolved	mg/L		6	10	10	10	14	16					10	8	15	14							9	14	8	10	10						9	11					
Sodium as Na - dissolved	mg/L		1,600	1,960	2,090	2,260	2,760	2,550	2,500	2,300		2,400	2,800	2,600	2,800	2,900							3,300	2,000	2,600	2,800	3,000						2,900	2,500	2,700	2,500	1,600		2,400
Sodium as Na - total	mg/L																						2,500	2,600	2,700	2,600	2,700	2,800	2,600			2,700							
Sulphate as SO_4	mg/L	1	1,390	904	1,220	1,040	1,350	1,250	1,200	1,300	1,200	1,200	800	1,300									860	890	570	710	670	840	910			940	950	1,000	1,100	1,000	N.A.		890
Nutrients																																							
Ammonia as N	mg/L	0.05																																	<0.05	<0.05	<0.05		<0.05
Phosphorus	mg/L	0.005																																	<0.005	<0.005	<0.005		<0.005
Phosphorus as PO_4	mg/L	0.01																																	<0.01	0	0		<0.01
Nitrate as N	mg/L	0.01																					0	0	0	0	0	<0.01	0			0	0	0	0	1	<0.05		0
Nitrite as N	mg/L	0.002																										0	<0.002			0	<0.002	0	<0.002	<0.005	<0.005		<0.005
Nitrite + Nitrate as N	mg/L	0.01																					0	0	0	0	0	0	0			0	0	0	0	1	0		0
Dissolved metals																																							
Aluminium	µg/L	2																																	<25	<2	<2		16
Arsenic	µg/L	1																																	<5	<1	<1		<1
Boron	µg/L	100																																	1,400	1,100	930		1,300
Cadmium	µg/L	0.1																																	<25	0	<0.1		<0.1
Chromium	µg/L	1																					38	20	17	25	11								<0.5	22	<1		<1
Cobalt	µg/L	1																					1	2	2	2	1								<5	<1	<1		<1
Copper	µg/L	1																					7	6	11	4	5								<5	2	<1		<1
Iron	µg/L	5																					760	820	1200	850	2200	60	710			<5	420	<50	<5	<50	<50		<50
Lead	µg/L	1																					<1	<1	<1	<1	<1								<5	<1	<1		<1
Manganese	µg/L	1																																	240	170	43		3
Magnesium	mg/L	1	326	357	470	363	381	411	400	400	420	420	540	420	510	490							440	480	360	480	490						400	430					
Mercury	mg/L	0.0005																																	<0.0005	<0.0005	<0.0005		<0.0001
Molybdenum	µg/L	1																					2	2	11	<1	2								<5	2	1		1
Nickel	µg/L	1																					13	10	12	8	8								<5	<1	1		<1
Selenium	µg/L	1																					21	33	54	43	9								<5	1	2		2
Silver	µg/L	1																					<1	2	<1	<1	3								<5	<1	<1		<1
Uranium	µg/L	1																					9	8	7	7	7								12	10	1		10
Vanadium	µg/L	1																					3	1	<1	<1	<1								<5	<1	<1		<1
Zinc	µg/L	5																					10	12	34	<2	5								<25	8	12		10
Total metals																																							
Aluminium	µg/L	10																																	390	80	60		490
Arsenic	µg/L	1																																	<5	<1	<1		<1
Boron	µg/L	50																																	1,600	980	940		1,300
Cadmium	µg/L	0.1																																	300	<0.1	<0.1		<0.1
Chromium	µg/L	1																					10	8	8	11	8								<0.5	24	2		3
Cobalt	µg/L	1																					7	2	12	10	9								<5	1	2		8
Copper	µg/L	1																					11	5	71	16	15								6	2	1		2
Iron	µg/L	50																					2,900	1,100	6,600	4,800	6,300	510	30,000			130	110	190	5	160	190		440
Lead	µg/L	1																					2	<1	5	2	8								<5	<1	<1		<1
Manganese	µg/L	1																																	1,300	390	360		2,200
Magnesium	mg/L	1																					450	360	370	480	450	490	440			460			<0.0005	<0.0005	<0.0005		<0.0001
Mercury	mg/L	0.0005																					<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005			<0.0005	<0.0005	<0.0005	<0.0005				
Molybdenum	µg/L	1																					2	2	12	<1	4								<5	2	<1		1
Nickel	µg/L	1																					16	12	26	15	14								<5	2	2		3
Selenium	µg/L	1																					8	51	85	63	15								<5	1	<1		2
Silver	µg/L	1																					<1	<1	<1	1	4								<5	<1	<1		1
Uranium	µg/L	1																					8	9	8	8	7								12	11	9		11
Vanadium	µg/L	1																					14	<1	6	11	<1								<5	<1	5		<1
Zinc	µg/L	5																					23	17	43	20	19								<25	8	12		16
BTEX																																							
Benzene	µg/L	0.5		<1	<1	<1	<1		<1	<0.1	<0.1	<1.0	<1	<1.0			<1	< 1																	<0.1	<0.1	<0.1	<0.1	
Toluene	µg/L	0.5		<2	<2	<2	<2		<1	<0.1	<0.1	<1.0	<1	<1.0			<1	< 1																					
Ethylbenzene	µg/L	2																																					
Xylene	µg/L	1													1		<1																						
Total Petroleum Hydrocarbons																																							
TRH C_6-C_9	µg/L	40															<10						<40	<40	<40	<40	<40	<40	<40	<40	<40	<40	<40	<40	<40	<40	<40	<40	<40
TPH C_6-C_{10}	µg/L	50	<50	<50	<50	<50	<50		<50	85	180		<50	<50			<50						94	<100	<50	<50	<100		<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50
TPH C_6-C_{36}	µg/L	400																																	<450	<450	<450	<450	<400
TPH C_{10}-C_{36}	µg/L	100	<100	<100	<100	<100	<100		<100	170	140		<100	<100			<100						100	<200	<100	<100	<200	<200	<200	<200	<200	<200	<200	<200	<200	<200	<200	<200	<200
TRH C_{10}-C_{40}	µg/L	400																																					<400
Total Recoverable Hydrocarbons - NEPM 2013 Fractions																																							
TRH C_6-C_{10}	µg/L	50																																					
TRH C_6-C_{10} minus BTEX (F1)	µg/L	50																																	<50	<50	<50	<50	<50	
TRH >C_{10}-C_{16} (F2)	µg/L	60																																		<60	<60	<60	<60	<60	<60
TRH >C_{16}-C_{34} (F3)	µg/L	500																																		<500	<500	<500	<500	<500	<500
TRH >C_{34}-C_{40} (F4)	µg/L	500																																		<500	<500	<500	<500	<500	<500
TRH C_{10}-C_{40}	µg/L	400																																					<400	<400	<400	<400	<400
TPH C_{10}-C_{40}	µg/L	50	<100	<50	<50	<50	<50		<50	<50	<50		<50	<50	50		<50						<50	<200	<50	<50	<200	<200	<200	<200	<200	<200	<200	<200	<200	<200	<200	<200	<200
TRH C_{10}-C_{40}	µg/L	200																																					<200	<200	<200	<200	<200

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BH2 • Range Coal Measures	Unit	LOR	23/06/1999	9/02/2000	26/06/2000	18/12/2000	3/07/2001	14/01/2002	2/07/2002	20/01/2003	13/01/2004	12/07/2004	30/06/2004	25/07/2005	5/12/2005	19/06/2006	3/04/2007	24/07/2007	20/12/2007	29/01/2009	11/03/2010	21/07/2010	20/09/2011	18/10/2011	27/11/2012	29/08/2012	28/09/2012	18/10/2012	12/06/2013	2/09/2013	13/11/2013	29/11/2013	11/12/2013	7/01/2014	5/02/2014	3/03/2014	9/04/2014	15/05/2014	17/06/2014	8/10/2014
Physical parameters																																								
Electrical conductivity	µS/cm		16,500	16,900	16,800	15,300	13,800	15,800	15,000	15,000	16,000	18,000		16,000	11,000	11,000	12,000	10,000			15,000	15,000	17,000	16,000	15,000	14,000	15,000	16,000	15,000	15,000	16,000				16,000	16,000	16,000	16,000	16,000	16,000		16,000
pH	pH units																								7.80	7.00	7.10	7.00	6.70	7.20				7.30	7.40	7.30	7.30	7.40	7.40		7.40
Total dissolved solids	mg/L																												9,300	9,030				9,330	9,340	9,920	9,210	8,790	9,020		9,110
Total suspended solids	mg/L																																			91	93	55			51
Major/minor ions																																								
Bicarbonate alkalinity as CaCO3	mg/L																800	970				990	1,000	1,100	1,100				940								970	940			980
Carbonate alkalinity as CaCO3	mg/L	5																							<5	<5	<5	<5	<5					<5	<5	<5	<5	<5	<5		<5
Hydroxide alkalinity as CaCO3	mg/L	5																																		<5	<5	<5			<5
Total alkalinity as CaCO3	mg/L																								900	940	980	1,000	940												
Total hardness as $CaCO_3$	mg/L																												980												
Bicarbonate alkalinity as HCO3	mg/L																																	980	1,000	990	1,000	1,200	1,100		
Calcium as Ca – dissolved	mg/L		139	144	139		140	128	150	160	170	160		160	170	5	160	150							110	150	130	140							130	120	130	52		130
Calcium as Ca – total	mg/L																								110	140	140	120	130	94				110							
Chloride as Cl	mg/L		5,380	4,860	5,470	5,550	4,760	5,960	5,200	6,100		5,700		5,700	3,600	115	4,200	4,600							4,800	4,400	4,800	4,500	4,800	5,200				5,700	5,000	4,900	4,800	5,300	N.A.		5,000
Chlorine – free as Cl_2	mg/L	0.1																																<0.1	0						
Chlorine – total as Cl_2	mg/L	0.1																												0						0					
Fluoride as F	mg/L	0.1																							<1	<0.1	<1	<1	<1	<0.1				<0.1	<0.1	<0.1					
Fluorine	mg/L	1														< 1.	0	0		< 1																					
Potassium as K – total	mg/L	0.1																							12	15	16	15	20	16				2							
Potassium as K – dissolved	mg/L		18	25	28	24	33	34						17	8	0	14	16							12	19	15	17							16	21					
Sodium as Na – dissolved	mg/L		3,160	2,980	3,280	3,410	4,280	3,440	3,600	3,200		3,600		3,800	2,600	122	2,900	3,500							3,000	2,200	3,300	3,800							3,600	3,200	3,400	3,200	1,400		3,200
Sodium as Na – total	mg/L																								3,200	3,000	3,400	3,300	3,500	3,400				3,300							
Sulphate as SO_4	mg/L	1	147	61	3	<1	<1	1	<1	<1	<1	<10		<5	1,300										12	<1	<1	2	<10	<1				<1	3	3	3	1	N.A.		<1
Nutrients																																									
Ammonia as N	mg/L	0.05																																		5	4	4		4
Phosphorus	mg/L	0.005																																		<0.006	0	0		0
Phosphorus as PO_4	mg/L	0.01																																		<0.01	0	0		0
Nitrate as N	mg/L	0.01																							<0.01	0	<0.01	0	<0.01	<0.01				0	<0.01	0	0	<0.025		<0.05
Nitrite as N	mg/L	0.002																											0	<0.002				<0.002	<0.002	0	<0.002	<0.005		<0.005
Nitrite + Nitrate as N	mg/L	0.01																							<0.01	0	<0.01	0	<0.01					0	<0.01	0	0	<0.005		<0.005
Dissolved metals																																								
Aluminium	µg/L	2																																		<25	4	20		<5
Arsenic	µg/L	1																																		<5	<1	<1		<1
Boron	µg/L	100																																		1,400	1,100	1,100		1,600
Cadmium	µg/L	0.1																																		<25	<0.1	<0.1		<0.1
Chromium	µg/L	1																							16	24	28	12								<0.5	<1	<1		<1
Cobalt	µg/L	1																							<1	<1	<1	<1								<5	<1	<1		<1
Copper	µg/L	1																							6	6	5	3								<5	3	<1		<1
Iron	µg/L	5																							1,500	1,200	1,500	2,200	460	690				<5	1,200	<50	<5	<50	<50		<50
Lead	µg/L	1																							<1	<1	<1	<1								<5	<1	<1		<1
Manganese	µg/L	1																																		27	22	17		17
Magnesium	mg/L	1	183	192	235	185	173	171	180	190	200	200		200	420	12	160	160							130	150	150	170							150	140					
Mercury	mg/L	0.0005																																		<0.0005	<0.0005	<0.0005		<0.0001
Molybdenum	µg/L	1																							4	2	<1	<1								<5	<1	<1		<1
Nickel	µg/L	1																							10	13	7	8								<5	3	1		1
Selenium	µg/L	1																							63	47	55	10								<5	<1	<1		<1
Silver	µg/L	1																							<1	2	<1	<1								<5	<1	<1		<1
Uranium	µg/L	1																							<1	<1	<1	<1								<5	<1	<1		<1
Vanadium	µg/L	1																							<1	<1	<1	<1								<5	<1	<1		<1
Zinc	µg/L	5																							8	13	<2	<2								<25	24	13		28
Total metals																																									
Aluminium	µg/L	10																																		1,000	450	38		390
Arsenic	µg/L	1																																		<5	<1	<1		<1
Boron	µg/L	50																																		1,500	1,100	1,100		1,600
Cadmium	µg/L	0.1																																		3,100	<0.1	<0.1		<0.1
Chromium	µg/L	1																							31	8	10	10								<0.5	33	<1		10
Cobalt	µg/L	1																							2	1	1	1								<5	<1	<1		<1
Copper	µg/L	1																							46	6	8	5								19	6	1		5
Iron	µg/L	50																							5,900	720	1,900	3,000	3,200	1,200				1,200	1,400	840	3,100	2,300	870		1,800
Lead	µg/L	1																							2	<1	<1	<1								<5	2	<1		1
Manganese	µg/L	1																																		100	39	19		28
Magnesium	mg/L	1																							130	110	160	150	160	140				160			<0.0005	<0.0005	<0.0005		<0.0001
Mercury	mg/L	0.0005																							<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005				<0.0005	<0.0005	<0.0005	<0.0005			
Molybdenum	µg/L	1																							7	4	<1	2								<5	2	<1		1
Nickel	µg/L	1																							47	19	12	12								13	9	2		6
Selenium	µg/L	1																							57	58	76	15								<5	<1	<1		<1
Silver	µg/L	1																							<1	<1	<1	<1								<5	<1	<1		1
Uranium	µg/L	1																							<1	<1	<1	<1								<5	<1	<1		<1
Vanadium	µg/L	1																							<1	<1	<1	<1								<5	1	<1		<1
Zinc	µg/L	5																							61	18	4	32								29	32	23		41
BTEX																																									
Benzene	µg/L	0.5		<1	<1	<1	<1	0	<1	<0.1	<0.1	<1.0		<1	<1.0	<1			<1	< 1											0	<0.5	<0.1				<0.1	<0.1	<0.1	<0.1	
Toluene	µg/L	0.5		<2	<2	<2	<2	0	<1	<0.1	<0.1	<1.0		2	<1.0	<1			<1	< 1																					
Ethylbenzene	µg/L	2																																							
Xylene	µg/L	1															1		<1																							
Total Petroleum Hydrocarbons																																									
TPH C_6–C_9	µg/L	40																	<10						<40	<40	<40	<40	<40	<40	<40	<40		<40	<40	<40	<40	<40	<40		<40
TPH C_{10}–C_{14}	µg/L	50	<50	<50	<50	<50	<50			<50	110	290		<50	<50				<50						<50	<100	<50	<100	<50					<50	<50	<50	<50	<50	<50		<50
TPH C_{15}–C_{28}	µg/L	400																																		<450	<450	<450		<400
TPH C_{29}–C_{36}	µg/L	100	<100	<100	<100	<100	<100			<100	310	550		<100	<100				<100						<100	<200	<100	<200	<200	<200	<200	<200		<200	<200	<200	<200	<200	<200		<200
TRH C_{10}–C_{40}	µg/L	400																																							
Total Recoverable Hydrocarbons - NEPM 2013 Fractions																																									
TRH C_6–C_{10}	µg/L	50																																		<50	<50	<50	<50	<50	<50		<50
TRH C_6–C_{10} minus BTEX (F1)	µg/L	50																																		<50	<50	<50	<50	<50			
TRH >C_{10}–C_{16} (F2)	µg/L	60																																		<60	<60	<60	<60	<60	<60		<60
TRH >C_{16}–C_{34} (F3)	µg/L	500																																		<500	<500	<500	<500	<500	<500		<500
TRH >C_{34}–C_{40} (F4)	µg/L	500																																		<500	<500	<500	<500	<500	<500		<500
TRH C_{15}–C_{40}	µg/L	400																																							
TRH C_{10}–C_{36}	µg/L	50	<100	<50	<50	<50	<50			<50	<50	<50		<50	<50		50		<50						<50	<200	<50	<200	<200	<200	<200	<200		<200	<200	<200	<200	<200	<200		<200
TRH C_{10}–C_{40}	µg/L	200																																		<200	<200	<200	<200	<200	<200		<200

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BH3 - Rangal Coal Measures			3/07/2001	2/07/2002	12/07/2004	5/12/2005	19/06/2006	6/12/2007	29/01/2009	20/09/2011	18/10/2011	25/07/2012	27/11/2012	28/08/2012	26/09/2012	18/10/2012	12/06/2013	2/09/2013	15/01/2014	8/10/2014
	Unit	LOR																		
Physical parameters																				
Electrical conductivity	µS/cm		7,900		11,000	8,900	8,800		10,000	7,200	6,700	7,300	6,200	6,400	6,800	6,800	6,800	7,300	7,300	7,800
pH	pH units											7.00	7.80	6.90	6.90	6.90	6.70	7.10	7.60	7.40
Total dissolved solids	mg/L																4,100	4,410	4,560	4,850
Total suspended solids	mg/L																			1,000
Major/minor ions																				
Bicarbonate alkalinity as CaCO3	mg/L									1,600	1,600						1,300			1,300
Carbonate alkalinity as CaCO3	mg/L	5										<5	<5	<5	<5	<5	<5		<5	<5
Hydroxide alkalinity as CaCO3	mg/L	5																		<5
Total alkalinity as CaCO3	mg/L											1,300	1,300	1,300	1,700	1,400	1,300			
Total hardness as $CaCO_3$	mg/L																670			
Bicarbonate alkalinity as HCO3	mg/L																		1,500	
Calcium as Ca - dissolved	mg/L		74	72	83	81	5					68	59	68	70	69			75	65
Calcium as Ca - total	mg/L											77	54	66	66	66	71	59		
Chloride as Cl	mg/L		1,820	2,000	2,300	1,900	48					1,500	1,300	1,300	1,200	1,500	1,200	1,500	1,500	1,600
Chlorine - free as Cl_2	mg/L	0.1																	0	
Chlorine - total as Cl_2	mg/L	0.1																0		
Fluoride as F	mg/L	0.1										0	<1	0	0	0	0	0	0	
Flourine	mg/L	1					< 1.		< 1											
Potassium as K - total	mg/L	0.1										8	6	8	7	9	12	7		
Potassium as K - dissolved	mg/L		12			8	0					8	6	9	7	7			10	
Sodium as Na - dissolved	mg/L		2,050		2,100	2,100	78					1,500	1,400	900	1,400	1,600			1,800	1,500
Sodium as Na - total	mg/L											1,600	1,400	1,100	1,400	1,500	1,500	1,500		
Sulphate as SO_4	mg/L	1	804		840	750						550	490	510	480	570	480	570	510	560
Nutrients																				
Ammonia as N	mg/L	0.05																		0
Phosphorus	mg/L	0.005																		<0.005
Phosphorus as PO_4	mg/L	0.01																		0
Nitrate as N	mg/L	0.01										0	0	0	<0.01	<0.01	0	<0.01	0	<0.05
Nitrite as N	mg/L	0.002															0	<0.002	0	<0.005
Nitrite + Nitrate as N	mg/L	0.01										0	0	0	<0.01	<0.01	0		0	<0.005
Dissolved metals																				
Aluminium	µg/L	2																		<5
Arsenic	µg/L	1																		4
Boron	µg/L	100																		1,200
Cadmium	µg/L	0.1																		<0.1
Chromium	µg/L	1										37	19	28	31	14				<1
Cobalt	µg/L	1										10	11	11	9	8				4
Copper	µg/L	1										4	3	3	6	1				3
Iron	µg/L	5										270	440	300	330	470	32	590	4,200	<50
Lead	µg/L	1										<1	<1	<1	<1	<1				<1
Manganese	µg/L	1																		580
Magnesium	mg/L	1	145		190	190	16					140	110	100	130	130			140	
Mercury	mg/L	0.0005																		<0.0001
Molybdenum	µg/L	1										8	11	9	4	7				9
Nickel	µg/L	1										13	12	13	10	8				14
Selenium	µg/L	1										20	18	13	14	5				<1
Silver	µg/L	1										<1	<1	<1	<1	<1				<1
Uranium	µg/L	1										7	8	8	7	7				7
Vanadium	µg/L	1										9	3	6	6	3				<1
Zinc	µg/L	5										13	10	15	<2	3				26
Total metals																				
Aluminium	µg/L	10																		2,500
Arsenic	µg/L	1																		11
Boron	µg/L	50																		1,300
Cadmium	µg/L	0.1																		<0.1
Chromium	µg/L	1										29	9	6	11	5				23
Cobalt	µg/L	1										32	13	12	14	10				12
Copper	µg/L	1										34	21	4	11	6				9
Iron	µg/L	50										21,000	5,300	410	5,700	4,500	6,600	11,000	3,200	4,200
Lead	µg/L	1										14	3	<1	3	1				4
Manganese	µg/L	1																		870
Magnesium	mg/L	1										150	110	73	130	130	120	120		<0.0001
Mercury	mg/L	0.0005										<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	
Molybdenum	µg/L	1										10	10	9	4	8				10
Nickel	µg/L	1										50	33	14	21	13				27
Selenium	µg/L	1										15	31	28	34	10				<1
Silver	µg/L	1										<1	<1	<1	<1	<1				<1
Uranium	µg/L	1										9	9	8	8	7				8
Vanadium	µg/L	1										56	10	<1	10	4				6
Zinc	µg/L	5										100	43	19	20	14				57
BTEX																				
Benzene	µg/L	0.5	<1	<1	<1.0	<1.0	<1	<1	< 1									<0.1		
Toluene	µg/L	0.5	<2		<1.0	<1.0	<1	<1	< 1											
Ethylbenzene	µg/L	2																		
Xylene	µg/L	1						<1												
Total Petroleum Hydrocarbons																				
TPH C_6-C_9	µg/L	40						<10				<40	<40	<40	<40	<40	<40	<40	<40	<40
TPH C_{10}-C_{14}	µg/L	50	<50			<50		<50				51	<50	<100	<50	<100		<50	<50	220
TPH C_{10}-C_{36}	µg/L	400																		800
TPH C_{15}-C_{28}	µg/L	100	<100			<100		<100				<100	<100	<200	<100	<200	<200	<200	<200	510
TRH C_{28}-C_{40}	µg/L	400																		<400
Total Recoverable Hydrocarbons - NEPM 2013 Fractions																				
TRH C_6-C_{10}	µg/L	50																	<50	<50
TRH C_6-C_{10} minus BTEX (F1)	µg/L	50																<50	<50	
TRH >C_{10}-C_{16} (F2)	µg/L	60																	<60	320
TRH >C_{16}-C_{34} (F3)	µg/L	500																	<500	770
TRH >C_{34}-C_{40} (F4)	µg/L	500																	<500	<500
TRH C_{10}-C_{40}	µg/L	400																		<400
TPH C_{26}-C_{36}	µg/L	50	<50			<50		<50				<50	<50	<200	<50	<200	<200	<200	<200	<200
TRH C_{31}-C_{40}	µg/L	200																		<200

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BH4 • Burngrove Formation			23/06/1999	9/02/2000	26/06/2000	18/12/2000	3/07/2001	14/01/2002	2/07/2002	2/01/2003	13/01/2004	12/07/2004	25/07/2005	5/12/2005	19/06/2006	3/04/2007	24/07/2007	20/12/2007	29/01/2009	11/03/2010	21/07/2010	21/09/2011	20/10/2011	25/07/2012	28/08/2012	26/09/2012	18/10/2012	27/11/2012	12/06/2013	2/09/2013	13/11/2013	29/11/2013	11/12/2013	7/01/2014	11/02/2014	3/03/2014	8/04/2014	15/05/2014	17/06/2014	8/10/2014
	Unit	LOR																																					
Physical parameters																																							
Electrical conductivity	µS/cm		7,660	7,940	7,560	6,930	6,810	7,170	7,200	7,000	8,100	8,400	8,400	7,300	6,800	6,600	6,500		7,300	7,000	6,700	3,900	3,400	3,500	3,300	3,400	3,300	3,000	6,400	3,400				3,800	3,400	3,300	3,300	3,300	3,300		3,300
pH	pH units															6.90	6.80	6.80	6.80	7.40	7.10	6.70										6.80	6.80	6.80	6.80	6.80	6.80		6.80
Total dissolved solids	mg/L																											3,900	2,080				2,180	2,200	2,030	1,940	2,050	2,060		1,990
Total suspended solids	mg/L																																			27	20	18			13
Major/minor ions																																								
Bicarbonate alkalinity as CaCO3	mg/L															690	710			690	660	630	700					330								310	300			320
Carbonate alkalinity as CaCO3	mg/L	5																						<5	<5	<5	<5	<5	<5				<5	<5	<5	<5	<5	<5			<5
Hydroxide alkalinity as CaCO3	mg/L	5																																		<5	<5	<5			<5
Total alkalinity as CaCO3	mg/L																							470	480	550	480	370	330												
Total hardness as $CaCO_3$	mg/L																												410												
Bicarbonate alkalinity as HCO3	mg/L																																320	310	320	320	380	370			
Calcium as Ca – dissolved	mg/L		131	132	125		129	129	140	140	140	140	150	140	6	270	270							87	73	90	88	80						110	83	84	79	52			83
Calcium as Ca – total	mg/L																							93	72	89	80	80	83	70			88								
Chloride as Cl	mg/L		2,150	1,840	2,130	2,160	2,060	2,300	2,100	2,200		2,200	2,000	1,900	45	1,800	2,100							500	620	600	640	540	540	570			590	520	520	580	590	N.A.		560
Chlorine – free as Cl_2	mg/L	0.1																															<0.1	<0.1	0					
Chlorine – total as Cl_2	mg/L	0.1																												0										
Fluoride as F	mg/L	0.1																						1	1	1	1	1	0	0			0	0	<0.1					
Fluorine	mg/L	1													<1	0	0		< 1																					
Potassium as K – total	mg/L	0.1														3	1	2	2	2	3	3										13								
Potassium as K – dissolved	mg/L		9	13	12	12	16	18					10	10	0	5	6							3	1	2	2	2						4	3					
Sodium as Na – dissolved	mg/L		1,230	1,150	1,310	1,320	1,400	1,380	1,300	1,300		1,300	1,400	1,400	48	1,800	1,600							580	280	640	630	570						650	570	600	530	240			580
Sodium as Na – total	mg/L																							590	370	600	570	570	570	570			640								
Sulphate as SO_4	mg/L	1	347	28	28	31	28	29	28	23	<1	<10	18	<10										360	420	390	440	400	380	490			570	490	530	620	410	N.A.		440
Nutrients																																								
Ammonia as N	mg/L	0.05																																		<0.05	0	<0.05			<0.05
Phosphorus	mg/L	0.005																																		0	0	0			0
Phosphorus as PO_4	mg/L	0.01																																		0	0	0			0
Nitrate as N	mg/L	0.01																						0	0	<0.01	0	0	0	0			0	<0.01	<0.01	0	1	0			<0.01
Nitrite as N	mg/L	0.002																											0	<0.002			0	<0.002	<0.002	<0.002	<0.005	<0.005			<0.005
Nitrite + Nitrate as N	mg/L	0.01																						0	0	<0.01	0	0	0	0			0	0	<0.01	0	1	0			<0.005
Dissolved metals																																								
Aluminium	µg/L	2																																		<2	3	10			<5
Arsenic	µg/L	1																																		<1	<1	1			<1
Boron	µg/L	100																																		940	710	630			850
Cadmium	µg/L	0.1																																		<5	<0.1	<0.1			<0.1
Chromium	µg/L	1																						17	13	13	8	8								<0.1	25	<1			<1
Cobalt	µg/L	1																						<1	<1	<1	<1	<1								3	1	<1			1
Copper	µg/L	1																						5	4	2	2	4								<1	4	1			5
Iron	µg/L	5																						280	310	400	590	500	68	590			<5	<50	<5	5	<50	<50			<50
Lead	µg/L	1																						<1	<1	<1	<1	<1								<1	<1	<1			<1
Manganese	µg/L	1																																		<1	<1	<1			<1
Magnesium	mg/L	1	137	132	137	134	119	130	130	130	140	140	130	130	10	200	190							52	24	55	53	47						60		380	270	270			230
Mercury	mg/L	0.0005																																		<0.0005	<0.0005	<0.0005			<0.0001
Molybdenum	µg/L	1																						<1	1	<1	<1	2								<1	<1	<1			<1
Nickel	µg/L	1																						7	5	5	4	5								4	2	3			2
Selenium	µg/L	1																						10	13	21	<5	22								<2	<1	<1			<1
Silver	µg/L	1																						<1	<1	<1	<1	<1								<1	<1	<1			<1
Uranium	µg/L	1																						<1	1	<1	<1	<1								<1	<1	<1			<1
Vanadium	µg/L	1																						4	3	2	2	2								<1	<1	<1			<1
Zinc	µg/L	5																						8	14	<2	<2	5								30	10	18			20
Total metals																																								
Aluminium	µg/L	10																																		750	110	20			100
Arsenic	µg/L	1																																		1	<1	1			1
Boron	µg/L	50																																		1,200	620	640			880
Cadmium	µg/L	0.1																																		740	<0.1	<0.1			<0.1
Chromium	µg/L	1																						14	4	3	2	8								<0.1	21	<1			1
Cobalt	µg/L	1																						1	<1	<1	<1	2								4	2	1			1
Copper	µg/L	1																						7	4	4	2	15								9	4	2			6
Iron	µg/L	50																						1,200	350	560	720	1,300	1,200	530			490	220	570	8	240	200			250
Lead	µg/L	1																						2	<1	<1	<1	1								2	<1	<1			<1
Manganese	µg/L	1																																		4,900	270	250			340
Magnesium	mg/L	1																						54	32	57	47	48	50	52			56			<0.0005	<0.0005	<0.0005			<0.0001
Mercury	mg/L	0.0005																						<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005			<0.0005	<0.0005	0	<0.0005					
Molybdenum	µg/L	1																						2	1	<1	<1	3								1	<1	<1			<1
Nickel	µg/L	1																						12	6	6	5	20								7	6	4			3
Selenium	µg/L	1																						<5	28	37	6	21								<2	<1	<1			<1
Silver	µg/L	1																						<1	<1	<1	<1	<1								<1	<1	<1			<1
Uranium	µg/L	1																						<1	1	<1	<1	<1								<1	<1	<1			<1
Vanadium	µg/L	1																						2	<1	<1	<1	2								2	<1	1			<1
Zinc	µg/L	5																						26	18	<2	3	23								45	8	8			11
BTEX																																								
Benzene	µg/L	0.5		<1	<1	<1	<1	0	<1	<0.1	<0.1	<1.0	<1	<1.0	<1	0		<1	< 1																	<0.1	<0.1	<0.1	<0.1		
Toluene	µg/L	0.5		<2	<2	<2	<2	0	<1	<0.1	<0.1	<1.0	<1	<1.0	<1	0		<1	< 1																					
Ethylbenzene	µg/L	2																																						
Xylene	µg/L	1														1		<1																						
Total Petroleum Hydrocarbons																																								
TPH C_6–C_9	µg/L	40																< 10						<40	<40	<40	<40	<40	<40	<40	<40	<40	<40	<40	<40	<40	<40	<40	<40	<40
TPH C_{10}–C_{14}	µg/L	50	<50	<50	<50	<50	<50		<50	77	750		<50	<50				<50						73	<100	<50	<100	<50	<50	<50	<50	<50	<50	<50	110	<50	<50	<50	<50	<50
TPH C_{15}–C_{28}	µg/L	400																																		<450	<450	<450	<450	<400	
TPH C_{29}–C_{36}	µg/L	100	<100	<100	<100	<100	<100		<100	480	510		<100	<100				<100						<100	<200	<100	<200	<100	<200	<200	<200	<200	<200	<200	<200	<200	<200	<200	<200	<200
TRH C_{10}–C_{40}	µg/L	400																																						<400
Total Recoverable Hydrocarbons • NEPM 2013 Fractions																																								
TRH C_6–C_{10}	µg/L	50																																		<50	<50	<50	<50	<50	
TRH C_6–C_{10} minus BTEX (F1)	µg/L	50																																		<50	<50	<50	<50	<50	<50
TRH >C_{10}–C_{16} (F2)	µg/L	60																																		<60	<60	<60	<60	<60	<60
TRH >C_{16}–C_{34} (F3)	µg/L	500																																		<500	<500	<500	<500	<500	<500
TRH >C_{34}–C_{40} (F4)	µg/L	500																																		<500	<500	<500	<500	<500	<500
TRH C_{10}–C_{36}	µg/L	400																																						<400
TRH C_{10}–C_{40}	µg/L	50	<100	<50	<50	<50	<50		<50	<50	<50		<50	<50				<50						<50	<200	<50	<200	<50	<200	<200	<200	<200	<200	<200	<200	<200	<200	<200	<200	<200
TRH C_{10}–C_{36}	µg/L	200																																		<200	<200	<200	<200	<200	<200

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BH5 - Burngrove Formation			23/06/1999	9/02/2000	18/12/2000	3/07/2001	14/01/2002	12/07/2004	25/07/2005	5/12/2005	19/06/2006	3/04/2007	24/07/2007	20/12/2007	29/01/2009	20/09/2011	18/10/2011	25/07/2012	28/08/2012	26/09/2012	18/10/2012	27/11/2012	12/06/2013	12/06/2013	2/09/2013	13/11/2013	11/12/2013	29/11/2013	8/01/2014	5/02/2014	3/03/2014	8/04/2014	15/05/2014	11/06/2014	8/10/2014
	Unit	LOR																																
Physical parameters																																		
Electrical conductivity	µS/cm		17,400	17,600	15,300	14,600	15,900	18,000	14,000	14,000	14,000	16,000	15,000		19,000	20,000	19,000	20,000	18,000	19,000	19,000	17,000	18,000	18,000	20,000		19,000		19,000	19,000	20,000	19,000	19,000		19,000
pH	pH units																	7.20	7.10	7.10	7.00	7.70	7.30	6.50	7.20		7.40		7.40	7.30	7.40	7.30	7.40		7.40
Total dissolved solids	mg/L																						11,000	11,000	12,000		11,700		11,900	12,300	10,900	10,700	10,700		11,600
Total suspended solids	mg/L																														79	110	91		130
Major/minor ions																																		
Bicarbonate alkalinity as CaCO3	mg/L											890	850			1,100	1,100														930	900		940
Carbonate alkalinity as CaCO3	mg/L	5																<5	<5	<5	<5	<5	<5	<5			<5		<5	<5	<5	<5	<5		<5
Hydroxide alkalinity as CaCO3	mg/L	5																													<5	<5	<5		<5
Total alkalinity as CaCO3	mg/L																	900	920	900	960	1,100	920	920											
Total hardness as $CaCO_3$	mg/L																						1,300	1,300											
Bicarbonate alkalinity as HCO3	mg/L																						920				940		960	970	990	1,100	1,100		
Calcium as Ca - dissolved	mg/L		170	169		159	138	170	170	180	9	300	240					220	250	280	230	230							210	210	200	220	73		210
Calcium as Ca - total	mg/L																	220	280	240	220	230	200	200	170		200								
Chloride as Cl	mg/L		5,970	5,160	5,560	5,440	6,150	5,700	4,500	5,300	59	6,200	6,100					6,700	5,900	5,800	5,900	6,800	5,000	5,000	6,700		7,100		5,900	6,200	6,700	6,400	N.A.		6,600
Chlorine - free as Cl_2	mg/L	0,1																									<0,1		<0,1						
Chlorine - total as Cl_2	mg/L	0,1																							0					0					
Fluoride as F	mg/L	0,1																0	<0,1	<1	<1	<1	<1	<1	<0,1		<0,1		<0,1	<0,1					
Flourine	mg/L	1									< 1,	0	0		< 1																				
Potassium as K - total	mg/L	0,1																19	20	19	18	19	22	22	20		5								
Potassium as K - dissolved	mg/L		16	24	21	30	32		12	16	0	17	18					18	19	21	19	18							17	27					
Sodium as Na - dissolved	mg/L		3,380	3,220	3,460	4,540	3,760	3,500	3,000	3,900	157	3,300	4,300					3,700	3,000	4,100	4,200	3,800							4,000	3,800	4,000	3,600	1,400		4,000
Sodium as Na - total	mg/L																	3,800	3,300	4,000	4,000	3,800	4,000	4,000	4,100		3,800								
Sulphate as SO_4	mg/L	1	<1	1	<1	6	2	<10,	26	<50,								<1	<1	<1	1	2	<10	<10	3		<1		<1	<20	<1	3	N.A.		3
Nutrients																																			
Ammonia as N	mg/L	0,05																													4	4	4		3
Phosphorus	mg/L	0,005																													<0,006	0	0		0
Phosphorus as PO_4	mg/L	0,01																													<0,01	0	0		0
Nitrate as N	mg/L	0,01																0	<0,01	<0,01	0	<0,01	0	0	0		0		<0,01	0	0	1	<0,05		<0,05
Nitrite as N	mg/L	0,002																					0	0	<0,002		0		<0,002	<0,002	<0,002	<0,005	<0,005		<0,005
Nitrite + Nitrate as N	mg/L	0,01																0	0	0	0	<0,01	0	0	0		0		<0,01	0	0	1	<0,005		<0,005
Dissolved metals																																			
Aluminium	µg/L	2																													<25	5	5		<5
Arsenic	µg/L	1																													<5	2	4		2
Boron	µg/L	100																													1,000	840	750		1,400
Cadmium	µg/L	0,1																													<25	<0,1	<0,1		<0,1
Chromium	µg/L	1																29	24	28	12	17									<0,5	<1	<1		<1
Cobalt	µg/L	1																2	1	1	1	1									<5	<1	<1		<1
Copper	µg/L	1																13	12	9	4	7									<5	2	<1		<1
Iron	µg/L	5																16,000	14,000	18,000	20,000	20,000	13,000	13,000	6,900		<5		16,000	<50	<5	<50	<50		71
Lead	µg/L	1																<1	<1	<1	<1	<1									<5	<1	<1		<1
Manganese	µg/L	1																													900	710	810		730
Magnesium	mg/L	1	174	164	146	149	142	160	140	170	13	240	190					230	170	240	220	210							190	190					
Mercury	mg/L	0,0005																													<0,0005	<0,0005	<0,0005		<0,0001
Molybdenum	µg/L	1																3	3	<1	3	4									<5	5	5		3
Nickel	µg/L	1																13	13	15	13	11									<5	6	6		3
Selenium	µg/L	1																67	45	69	12	67									<5	<1	<1		<1
Silver	µg/L	1																<1	<1	<1	<1	<1									<5	<1	<1		<1
Uranium	µg/L	1																<1	<1	<1	<1	<1									<5	<1	<1		<1
Vanadium	µg/L	1																5	<1	<1	<1	<1									<5	<1	1		1
Zinc	µg/L	5																11	9	5	2	6									<25	14	6		9
Total metals																																			
Aluminium	µg/L	10																													450	220	35		520
Arsenic	µg/L	1																													84	29	27		58
Boron	µg/L	50																													1,200	900	750		1,500
Cadmium	µg/L	0,1																													47,000	<0,1	<0,1		<0,1
Chromium	µg/L	1																32	7	9	29	21									<0,5	45	3		15
Cobalt	µg/L	1																2	1	1	2	2									<5	<1	<1		<1
Copper	µg/L	1																17	9	10	10	24									16	5	3		6
Iron	µg/L	50																19,000	5,600	17,000	25,000	21,000	28,000	28,000	23,000		4,000		14,000	19,000	9	16,000	13,000		23,000
Lead	µg/L	1																1	<1	<1	1	1									<5	<1	<1		1
Manganese	µg/L	1																													1,100	750	770		800
Magnesium	mg/L	1																220	190	210	210	220	200	200	190		210				<0,0005	<0,0005	<0,0005		<0,0001
Mercury	mg/L	0,0005																<0,0005	<0,0005	<0,0005	<0,0005	<0,0005	<0,0005	<0,0005	<0,0005		<0,0005		<0,0005	<0,0005	<0,0005				
Molybdenum	µg/L	1																6	4	2	8	7									6	5	5		5
Nickel	µg/L	1																26	15	15	29	33									11	12	8		11
Selenium	µg/L	1																76	66	65	19	53									<5	<1	<1		<1
Silver	µg/L	1																<1	<1	<1	<1	<1									<5	<1	<1		<1
Uranium	µg/L	1																<1	<1	<1	<1	<1									<5	<1	<1		<1
Vanadium	µg/L	1																<1	<1	<1	<1	<1									<5	<1	2		1
Zinc	µg/L	5																32	16	4	17	39									40	23	11		36
BTEX																																			
Benzene	µg/L	0,5		<1	<1	<1		<1,0	<1	<1,0	<1			<1	< 1								<0,5		<0,1	<0,5		<0,1			<0,1	<0,1	<0,1	<0,1	
Toluene	µg/L	0,5		<2	<2	<2		<1,0	<1	<1,0	<1			<1	< 1																					
Ethylbenzene	µg/L	2																																	
Xylene	µg/L	1												<1																					
Total Petroleum Hydrocarbons																																			
TPH C_6–C_9	µg/L	40												<10				<40	<40	<40	<40	<40	<40	<40	<40	<40	<40	<40	<40	<40	<40	<40	<40	<40	<800
TPH C_{10}–C_{14}	µg/L	50	<50	<50	<50	<50	<50			<50	<50			<50				53	<100	<50	<100	<50	<50		<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50
TPH C_{15}–C_{28}	µg/L	400																													<450	<450	<450	<450	<400
TPH C_{29}–C_{36}	µg/L	100	<100	<100	<100	<100	<100			<100	<100			<100				<100	<200	<100	<200	<100	<200	<200	<200	<200	<200	<200	<200	<200	<200	<200	<200	<200	<200
TRH C_{10}–C_{40}	µg/L	400																																	<400
Total Recoverable Hydrocarbons - NEPM 2013 Fractions																																			
TRH C_6–C_{10}	µg/L	50																					<50			<50	<50	<50	<50	<50	<50	<50	<50	<50	<1000
TRH C_6–C_{10} minus BTEX (F1)	µg/L	50																					<50		<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	
TRH >C_{10}–C_{16} (F2)	µg/L	60																					<60			<60	<60	<60	<60	<60	<60	<60	<60	<60	<60
TRH >C_{16}–C_{34} (F3)	µg/L	500																					<500			<500	<500	<500	<500	<500	<500	<500	<500	<500	<500
TRH >C_{34}–C_{40} (F4)	µg/L	500																					<500			<500	<500	<500	<500	<500	<500	<500	<500	<500	<500
TRH C_{10}–C_{36}	µg/L	400																													<400	<400	<400	<400	<400
TPH C_{10}–C_{36}	µg/L	50	<100	<50	<50	<50			<50	<50				<50				<50	<200	<50	<200	<50	<200	<200	<200	<200	<200	<200	<200	<200	<200	<200	<200	<200	<200
TRH C_{10}–C_{50}	µg/L	200																													<200	<200	<200	<200	<200

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BH6 - Rewan Fm			25/07/2012	28/08/2012	27/09/2012	18/10/2012	28/11/2012	13/06/2013	2/09/2013	15/01/2014	9/04/2014	8/10/2014
	Unit	LOR										
Physical parameters												
Electrical conductivity	µS/cm		15,000	13,000	14,000	13,000	12,000	13,000	13,000	13,000	13,000	13,000
pH	pH units		7.30	7.10	7.10	7.10	7.80	6.90	7.30	7.80	7.70	7.50
Total dissolved solids	mg/L							7,700	7,480	7,700	7,500	7,710
Total suspended solids	mg/L										49	44
Major/minor ions												
Bicarbonate alkalinity as CaCO3	mg/L							740			750	770
Carbonate alkalinity as CaCO3	mg/L	5	<5	<5	<5	<5	<5	<5		<5	<5	<5
Hydroxide alkalinity as CaCO3	mg/L	5									<5	<5
Total alkalinity as CaCO3	mg/L		800	770	810	830	950	740				
Total hardness as $CaCO_3$	mg/L							910				
Bicarbonate alkalinity as HCO3	mg/L									810	910	
Calcium as Ca - dissolved	mg/L		110	130	110	110	110			96	100	100
Calcium as Ca - total	mg/L		120	130	120	140	110	100	77			
Chloride as Cl	mg/L		4,300	4,200	4,300	3,800	4,100	3,500	3,800	3,500	3,700	3,600
Chlorine - free as Cl_2	mg/L	0.1								<0.1		
Chlorine - total as Cl_2	mg/L	0.1							0			
Fluoride as F	mg/L	0.1	<0.1	0	<1	0	<1	<0.1	0	1		
Flourine	mg/L	1										
Potassium as K - total	mg/L	0.1	10	12	10	12	10	11	10			
Potassium as K - dissolved	mg/L		10	12	10	10	10			10		
Sodium as Na - dissolved	mg/L		2,900	2,200	2,800	2,900	2,900			2,800	2,600	2,600
Sodium as Na - total	mg/L		2,400	2,400	2,800	3,600	3,000	2,700	2,700			
Sulphate as SO_4	mg/L	1	470	450	480	510	540	570	710	820	870	900
Nutrients												
Ammonia as N	mg/L	0.05									1	1
Phosphorus	mg/L	0.005									0	0
Phosphorus as PO_4	mg/L	0.01									0	0
Nitrate as N	mg/L	0.01	0	0	0	0	0	0	0	0	0	<0.05
Nitrite as N	mg/L	0.002						0	0	0	<0.005	0
Nitrite + Nitrate as N	mg/L	0.01	0	0	0	0	0	0	0	1	0	0
Dissolved metals												
Aluminium	µg/L	2									<2	8
Arsenic	µg/L	1									<1	<1
Boron	µg/L	100									800	1,100
Cadmium	µg/L	0.1									<0.1	<0.1
Chromium	µg/L	1	28	21	25	11	15				<1	<1
Cobalt	µg/L	1	<1	<1	<1	<1	<1				<1	<1
Copper	µg/L	1	10	6	6	3	7				1	1
Iron	µg/L	5	530	470	640	950	760	220	590	1,700	<50	<50
Lead	µg/L	1	<1	<1	<1	<1	<1				<1	<1
Manganese	µg/L	1									100	89
Magnesium	mg/L	1	190	150	180	180	180			160		
Mercury	mg/L	0.0005									<0.0005	<0.0001
Molybdenum	µg/L	1	2	3	<1	3	4				5	4
Nickel	µg/L	1	9	10	10	6	8				2	1
Selenium	µg/L	1	62	36	54	12	55				<1	<1
Silver	µg/L	1	<1	<1	<1	<1	<1				<1	<1
Uranium	µg/L	1	<1	<1	<1	<1	<1				<1	<1
Vanadium	µg/L	1	4	2	<1	<1	<1				<1	<1
Zinc	µg/L	5	8	8	<2	<2	5				12	21
Total metals												
Aluminium	µg/L	10									150	760
Arsenic	µg/L	1									<1	<1
Boron	µg/L	50									840	1,100
Cadmium	µg/L	0.1									<0.1	<0.1
Chromium	µg/L	1	19	8	6	15	30				3	10
Cobalt	µg/L	1	1	<1	<1	1	2				<1	<1
Copper	µg/L	1	9	6	9	6	35				3	5
Iron	µg/L	50	1,900	650	870	2,800	3,300	400	1,100	580	950	2,200
Lead	µg/L	1	1	<1	<1	<1	2				<1	2
Manganese	µg/L	1									120	140
Magnesium	mg/L	1	190	160	190	220	180	160	150		<0.0005	<0.0001
Mercury	mg/L	0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005		
Molybdenum	µg/L	1	4	4	<1	4	7				5	5
Nickel	µg/L	1	17	13	13	13	34				3	6
Selenium	µg/L	1	18	59	57	17	46				<1	<1
Silver	µg/L	1	<1	<1	<1	<1	<1				<1	<1
Uranium	µg/L	1	<1	<1	<1	<1	<1				<1	<1
Vanadium	µg/L	1	7	<1	<1	<1	2				<1	<1
Zinc	µg/L	5	19	15	4	5	47				19	36
BTEX												
Benzene	µg/L	0.5							N.A.		<0.1	
Toluene	µg/L	0.5										
Ethylbenzene	µg/L	2										
Xylene	µg/L	1										
Total Petroleum Hydrocarbons												
TPH C_6-C_9	µg/L	40	<40	<40	<40	<40	<40	<40		<40	<40	<40
TPH C_{10}-C_{14}	µg/L	50	93	<100	<50	<100	<50			<50	<50	<50
TPH C_{10}-C_{36}	µg/L	400									<450	<400
TPH C_{15}-C_{28}	µg/L	100	<100	<200	<100	<200	<100	<200		<200	<200	<200
TRH C_{29}-C_{40}	µg/L	400										<400
Total Recoverable Hydrocarbons - NEPM 2013 Fractions												
TRH C_6-C_{10}	µg/L	50								<50	<50	<50
TRH C_6-C_{10} minus BTEX (F1)	µg/L	50								<50	<50	
TRH >C_{10}-C_{16} (F2)	µg/L	60								<60	<60	<60
TRH >C_{16}-C_{34} (F3)	µg/L	500								<500	<500	<500
TRH >C_{34}-C_{40} (F4)	µg/L	500								<500	<500	<500
TRH C_{10}-C_{40}	µg/L	400									<400	<400
TPH C_{29}-C_{36}	µg/L	50	<50	<200	<50	<200	<50	<200		<200	<200	<200
TRH C_{37}-C_{40}	µg/L	200									<200	<200

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BH8 - Rewan Fm			28/08/2012	27/09/2012	18/10/2012	28/11/2012	13/06/2013	4/09/2013	15/01/2014	9/04/2014	8/10/2014
	Unit	LOR									
Physical parameters											
Electrical conductivity	µS/cm		29,000	31,000	31,000	26,000	23,000	25,000	22,000	20,000	20,000
pH	pH units		7.10	7.00	7.00	7.70	6.80	7.20	7.80	7.40	7.60
Total dissolved solids	mg/L						14,000	15,700	14,400	11,500	12,200
Total suspended solids	mg/L									1,100	38
Major/minor ions											
Bicarbonate alkalinity as CaCO3	mg/L						470			430	530
Carbonate alkalinity as CaCO3	mg/L	5	<5	<5	<5	<5	<5		<5	<5	<5
Hydroxide alkalinity as CaCO3	mg/L	5								<5	<5
Total alkalinity as CaCO3	mg/L		430	490	460	510	470				
Total hardness as $CaCO_3$	mg/L						2,400				
Bicarbonate alkalinity as HCO3	mg/L								440	530	
Calcium as Ca - dissolved	mg/L		420	420	410	340			240	220	190
Calcium as Ca - total	mg/L		450	430	380	360	250	210			
Chloride as Cl	mg/L		12,000	11,000	12,000	11,000	7,900	8,200	7,200	7,100	5,900
Chlorine - free as Cl_2	mg/L	0.1							0		
Chlorine - total as Cl_2	mg/L	0.1						0			
Fluoride as F	mg/L	0.1	<0.1	<1	<1	<1	<1	<0.1	1		
Flourine	mg/L	1									
Potassium as K - total	mg/L	0.1	16	14	13	12	13	13			
Potassium as K - dissolved	mg/L		15	14	13	12			14		
Sodium as Na - dissolved	mg/L		4,900	6,500	5,800	5,400			4,400	3,900	4,000
Sodium as Na - total	mg/L		5,300	6,400	6,000	5,600	5,000	5,000			
Sulphate as SO_4	mg/L	1	640	620	710	740	890	930	770	800	1,100
Nutrients											
Ammonia as N	mg/L	0.05								<0.05	<0.05
Phosphorus	mg/L	0.005								0	0
Phosphorus as PO_4	mg/L	0.01								0	0
Nitrate as N	mg/L	0.01	2	2	3	2	1	1	1	1	1
Nitrite as N	mg/L	0.002					0	<0.002	<0.002	<0.005	<0.005
Nitrite + Nitrate as N	mg/L	0.01	2	2	3	2	1	1	1	1	1
Dissolved metals											
Aluminium	µg/L	2								<2	54
Arsenic	µg/L	1								<1	<1
Boron	µg/L	100								1,700	1,600
Cadmium	µg/L	0.1								<0.1	<0.1
Chromium	µg/L	1	15	17	9	13				<1	<1
Cobalt	µg/L	1	2	2	2	2				<1	<1
Copper	µg/L	1	10	12	10	16				2	<1
Iron	µg/L	5	2,200	2,800	3,500	2,900	<50	1,000	3,900	<50	<50
Lead	µg/L	1	<1	<1	<1	<1				<1	<1
Manganese	µg/L	1								2	10
Magnesium	mg/L	1	580	700	710	590			320		
Mercury	mg/L	0.0005								<0.0005	<0.0001
Molybdenum	µg/L	1	1	<1	<1	1				1	<1
Nickel	µg/L	1	30	20	24	24				2	<1
Selenium	µg/L	1	47	93	33	160				3	6
Silver	µg/L	1	3	2	2	2				<1	<1
Uranium	µg/L	1	2	2	2	2				2	2
Vanadium	µg/L	1	<1	<1	<1	<1				<1	1
Zinc	µg/L	5	13	<2	<2	12				<5	15
Total metals											
Aluminium	µg/L	10								7,400	170
Arsenic	µg/L	1								4	<1
Boron	µg/L	50								1,800	1,600
Cadmium	µg/L	0.1								<1	<0.1
Chromium	µg/L	1	8	5	9	10				14	3
Cobalt	µg/L	1	2	2	2	2				32	<1
Copper	µg/L	1	8	17	15	39				30	2
Iron	µg/L	50	2,000	2,600	3,900	3,700	360	10,000	2,900	14,000	220
Lead	µg/L	1	<1	<1	<1	<1				7	<1
Manganese	µg/L	1								1,400	25
Magnesium	mg/L	1	610	720	650	610	430	440		<0.0005	<0.0001
Mercury	mg/L	0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005		
Molybdenum	µg/L	1	1	<1	<1	2				1	<1
Nickel	µg/L	1	31	26	27	37				27	2
Selenium	µg/L	1	130	110	33	91				4	6
Silver	µg/L	1	2	2	2	2				<2	<1
Uranium	µg/L	1	2	2	2	2				2	2
Vanadium	µg/L	1	<1	<1	9	<1				25	<1
Zinc	µg/L	5	17	7	11	49				53	14
BTEX											
Benzene	µg/L	0.5						<0.1		<0.1	
Toluene	µg/L	0.5									
Ethylbenzene	µg/L	2									
Xylene	µg/L	1									
Total Petroleum Hydrocarbons											
TPH C_6-C_9	µg/L	40	<40	<40	<40	<40	<40	<40	<40	<40	<40
TPH C_{10}-C_{14}	µg/L	50	<100	<50	<100	<50		<50	<50	<50	<50
TPH C_{10}-C_{36}	µg/L	400								<450	<400
TPH C_{15}-C_{28}	µg/L	100	<200	<100	<200	<100	<200	<200	<200	<200	<200
TRH C_{29}-C_{40}	µg/L	400									<400
Total Recoverable Hydrocarbons - NEPM 2013 Fractions											
TRH C_6-C_{10}	µg/L	50							<50	<50	<50
TRH C_6-C_{10} minus BTEX (F1)	µg/L	50						<50	<50	<50	
TRH >C_{10}-C_{16} (F2)	µg/L	60							<60	<60	<60
TRH >C_{16}-C_{34} (F3)	µg/L	500							<500	<500	<500
TRH >C_{34}-C_{40} (F4)	µg/L	500							<500	<500	<500
TRH C_{10}-C_{40}	µg/L	400								<400	<400
TPH C_{29}-C_{36}	µg/L	50	<200	<50	<200	<50	<200	<200	<200	<200	<200
TRH C_{37}-C_{40}	µg/L	200								<200	<200

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BH8A - Blackwater Creek Alluvium			28/08/2012	27/09/2012	18/10/2012	28/11/2012	13/06/2013	4/09/2013	15/01/2014	9/04/2014	8/10/2014
	Unit	LOR									
Physical parameters											
Electrical conductivity	µS/cm		42,000	42,000	42,000	34,000	30,000	27,000	19,000	20,000	17,000
pH	pH units		6.90	6.80	6.80	7.60	6.60	7.20	7.90	7.50	7.60
Total dissolved solids	mg/L						18,000	17,300	12,700	11,600	10,700
Total suspended solids	mg/L									1,200	2,200
Major/minor ions											
Bicarbonate alkalinity as CaCO3	mg/L						350			430	470
Carbonate alkalinity as CaCO3	mg/L	5	<5	<5	<5	<5	<5		<5	<5	<5
Hydroxide alkalinity as CaCO3	mg/L	5								<5	<5
Total alkalinity as CaCO3	mg/L		340	420	350	320	350				
Total hardness as $CaCO_3$	mg/L						3,800				
Bicarbonate alkalinity as HCO3	mg/L								560	520	
Calcium as Ca - dissolved	mg/L		810	810	720	600			170	210	150
Calcium as Ca - total	mg/L		910	790	690	610	450	280			
Chloride as Cl	mg/L		19,000	16,000	18,000	14,000	10,000	9,000	6,100	7,100	5,300
Chlorine - free as Cl_2	mg/L	0.1							<0.1		
Chlorine - total as Cl_2	mg/L	0.1						0			
Fluoride as F	mg/L	0.1	0	<1	<1	<2	<1	<0.1	0		
Flourine	mg/L	1									
Potassium as K - total	mg/L	0.1	19	20	17	16	20	14			
Potassium as K - dissolved	mg/L		22	21	18	16			10		
Sodium as Na - dissolved	mg/L		6,600	8,700	7,800	6,800			4,100	3,800	3,500
Sodium as Na - total	mg/L		6,600	8,500	7,700	6,800	6,400	5,400			
Sulphate as SO_4	mg/L	1	680	720	690	630	700	770	1,100	590	910
Nutrients											
Ammonia as N	mg/L	0.05								<0.05	<0.05
Phosphorus	mg/L	0.005								<0.005	<0.005
Phosphorus as PO_4	mg/L	0.01								0	<0.01
Nitrate as N	mg/L	0.01	3	3	3	3	2	1	1	1	0
Nitrite as N	mg/L	0.002					0	<0.002	<0.002	<0.005	<0.005
Nitrite + Nitrate as N	mg/L	0.01	3	3	3	3	2	1	1	1	0
Dissolved metals											
Aluminium	µg/L	2								<2	<5
Arsenic	µg/L	1								<1	<1
Boron	µg/L	100								2,000	2,000
Cadmium	µg/L	0.1								<0.1	<0.1
Chromium	µg/L	1	12	16	6	10				<1	<1
Cobalt	µg/L	1	6	6	3	4				<1	<1
Copper	µg/L	1	17	21	14	26				3	<1
Iron	µg/L	5	3,600	5,200	7,100	4,600	<50	1,200	580	<50	<50
Lead	µg/L	1	<1	<1	<1	<1				<1	<1
Manganese	µg/L	1								1	<1
Magnesium	mg/L	1	1,100	1,100	1,100	850			290		
Mercury	mg/L	0.0005								<0.0005	<0.0001
Molybdenum	µg/L	1	1	<1	<1	2				<1	<1
Nickel	µg/L	1	59	46	46	44				2	1
Selenium	µg/L	1	50	110	30	210				3	2
Silver	µg/L	1	3	3	2	2				<1	<1
Uranium	µg/L	1	2	2	1	2				2	1
Vanadium	µg/L	1	<1	<1	12	<1				<1	1
Zinc	µg/L	5	28	8	5	21				6	<5
Total metals											
Aluminium	µg/L	10								14,000	32,000
Arsenic	µg/L	1								7	20
Boron	µg/L	50								17,000	2,100
Cadmium	µg/L	0.1								0	0
Chromium	µg/L	1	44	12	21	6				21	45
Cobalt	µg/L	1	39	10	17	7				49	120
Copper	µg/L	1	54	37	31	50				56	120
Iron	µg/L	50	21,000	8,000	18,000	7,500	36000	22,000	180	24,000	64,000
Lead	µg/L	1	8	1	4	1				13	32
Manganese	µg/L	1								24,000	6,700
Magnesium	mg/L	1	920	1,100	960	850	640	440		<0.0005	0
Mercury	mg/L	0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005		
Molybdenum	µg/L	1	2	<1	1	2				1	<1
Nickel	µg/L	1	88	54	60	51				40	94
Selenium	µg/L	1	190	140	35	110				4	4
Silver	µg/L	1	4	3	3	2				<1	<1
Uranium	µg/L	1	2	2	2	2				2	2
Vanadium	µg/L	1	51	<1	35	<1				38	87
Zinc	µg/L	5	88	46	52	67				95	180
BTEX											
Benzene	µg/L	0.5						<0.1		<0.1	
Toluene	µg/L	0.5									
Ethylbenzene	µg/L	2									
Xylene	µg/L	1									
Total Petroleum Hydrocarbons											
TPH C_6-C_9	µg/L	40	<40	<40	<40	<40	<40	<40	<40	<40	<400
TPH C_{10}-C_{14}	µg/L	50	<100	<50	<100	<50		<50	<50	<50	<50
TPH C_{10}-C_{36}	µg/L	400								<450	<400
TPH C_{15}-C_{28}	µg/L	100	<200	<100	<200	<100	<200	<200	<200	<200	<200
TRH C_{29}-C_{40}	µg/L	400									<400
Total Recoverable Hydrocarbons - NEPM 2013 Fractions											
TRH C_6-C_{10}	µg/L	50							<50	<50	<500
TRH C_6-C_{10} minus BTEX (F1)	µg/L	50						<50	<50	<50	
TRH >C_{10}-C_{16} (F2)	µg/L	60							<60	<60	<60
TRH >C_{16}-C_{34} (F3)	µg/L	500							<500	<500	<500
TRH >C_{34}-C_{40} (F4)	µg/L	500							<500	<500	<500
TRH C_{10}-C_{40}	µg/L	400								<400	<400
TPH C_{29}-C_{36}	µg/L	50	<200	300	<200	<50	<200	<200	<200	<200	<200
TRH C_{37}-C_{40}	µg/L	200								<200	<200

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1301aMB - Duaringa Formation			4/09/2013	18/09/2013	23/11/2013	17/10/2013	14/01/2014	17/03/2014	8/10/2014
	Unit	LOR							
Physical parameters									
Electrical conductivity	µS/cm		10,000	10,000	14,000	11,000	11,000	12,000	15,000
pH	pH units		7.30	7.30	7.60	7.50	7.30	7.30	7.50
Total dissolved solids	mg/L		6,500	5,780	9,120	7,280	5,820	7,190	9,360
Total suspended solids	mg/L							200	5,300
Major/minor ions									
Bicarbonate alkalinity as CaCO3	mg/L							380	450
Carbonate alkalinity as CaCO3	mg/L	5		<5	<5	<5	<5	<5	<5
Hydroxide alkalinity as CaCO3	mg/L	5						<5	<5
Total alkalinity as CaCO3	mg/L				990				
Total hardness as $CaCO_3$	mg/L								
Bicarbonate alkalinity as HCO3	mg/L				990	390	380	460	
Calcium as Ca - dissolved	mg/L			140	200	170	170	230	240
Calcium as Ca - total	mg/L		130						
Chloride as Cl	mg/L		2,700	2,800	3,200	4,000	2,800	3,200	4,300
Chlorine - free as Cl_2	mg/L	0					0		
Chlorine - total as Cl_2	mg/L	0		0		0			
Fluoride as F	mg/L	0	0	<1	0	0	<1		
Flourine	mg/L	1							
Potassium as K - total	mg/L	0	10						
Potassium as K - dissolved	mg/L				19	14	12		
Sodium as Na - dissolved	mg/L			1,900	1,900	2,300	1,900	2,000	2,700
Sodium as Na - total	mg/L		1,800						
Sulphate as SO_4	mg/L	1	1,100	1,100	870	1,200	1,100	1,100	1,300
Nutrients									
Ammonia as N	mg/L	0						<0.05	<0.05
Phosphorus	mg/L	0						0	0
Phosphorus as PO_4	mg/L	0						0	0
Nitrate as N	mg/L	0	<0.01	0	0	<0.01	0	1	<0.05
Nitrite as N	mg/L	0	0	0	0	<0.002	<0.002	<0.005	<0.005
Nitrite + Nitrate as N	mg/L	0		0	0	<0.01	0	1	0
Dissolved metals									
Aluminium	µg/L	2						<5	9
Arsenic	µg/L	1						<1	<1
Boron	µg/L	100						360	640
Cadmium	µg/L	0						<0.1	0
Chromium	µg/L	1						12	<1
Cobalt	µg/L	1						<1	<1
Copper	µg/L	1						<1	<1
Iron	µg/L	5	920	600	<50	<500	16,000	<5	<50
Lead	µg/L	1						<1	<1
Manganese	µg/L	1						54	<1
Magnesium	mg/L	1		200	270	280	170		
Mercury	mg/L	0						<0.0005	<0.0001
Molybdenum	µg/L	1						<1	4
Nickel	µg/L	1						2	<1
Selenium	µg/L	1						<1	<1
Silver	µg/L	1						<1	<1
Uranium	µg/L	1						4	9
Vanadium	µg/L	1						<1	3
Zinc	µg/L	5						28	<5
Total metals									
Aluminium	µg/L	10						2,500	50,000
Arsenic	µg/L	1						1	15
Boron	µg/L	50						360	660
Cadmium	µg/L	0						<0.1	1
Chromium	µg/L	1						48	68
Cobalt	µg/L	1						5	100
Copper	µg/L	1						7	67
Iron	µg/L	50	19,000	12,000	840	<500	<50	4,600	95,000
Lead	µg/L	1						4	82
Manganese	µg/L	1						150	1,200
Magnesium	mg/L	1	180					<0.0005	0
Mercury	mg/L	0	<0.0005	<0.0005		<0.0005	<0.0005	<0.0005	
Molybdenum	µg/L	1						<1	3
Nickel	µg/L	1						8	86
Selenium	µg/L	1						<1	4
Silver	µg/L	1						<1	2
Uranium	µg/L	1						4	12
Vanadium	µg/L	1						9	180
Zinc	µg/L	5						69	160
BTEX									
Benzene	µg/L	1	N.A.	<0.1	<0.1	<0.1		<0.1	
Toluene	µg/L	1						<0.5	
Ethylbenzene	µg/L	2							
Xylene	µg/L	1						<1	
Total Petroleum Hydrocarbons									
TPH C_6-C_9	µg/L	40		<40	<40	<40	<40	<40	<400
TPH C_{10}-C_{14}	µg/L	50		<50	<50	<50	<50	<50	<50
TPH C_{10}-C_{36}	µg/L	400						<450	<400
TPH C_{15}-C_{28}	µg/L	100		<200	<200	<200	<200	<200	<200
TRH C_{29}-C_{40}	µg/L	400							<400
Total Recoverable Hydrocarbons - NEPM 2013 Fractions									
TRH C_6-C_{10}	µg/L	50			<50	<50	<50	<50	<500
TRH C_6-C_{10} minus BTEX (F1)	µg/L	50		<50	<50	<50	<50	<50	
TRH >C_{10}-C_{16} (F2)	µg/L	60		<60	<60	<60	<60	<60	<60
TRH >C_{16}-C_{34} (F3)	µg/L	500		<500	<500	<500	<500	<500	<500
TRH >C_{34}-C_{40} (F4)	µg/L	500		<500	<500	<500	<500	<500	<500
TRH C_{10}-C_{40}	µg/L	400						<400	<400
TPH C_{29}-C_{36}	µg/L	50		<200	<200	<200	<200	<200	<200
TRH C_{37}-C_{40}	µg/L	200						<200	<200

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1301bMB - Rangal Coal Measures			4/09/2013	18/09/2013	17/10/2013	23/11/2013	14/01/2014	17/03/2014	8/10/2014
	Unit	LOR							
Physical parameters									
Electrical conductivity	µS/cm		14,000	14,000	13,000	11,000	15,000	15,000	15,000
pH	pH units		7.10	7.00	7.70	7.50	7.20	7.40	7.40
Total dissolved solids	mg/L		8,160	8,920	8,860	6,940	8,150	9,260	9,590
Total suspended solids	mg/L							28	40
Major/minor ions									
Bicarbonate alkalinity as CaCO3	mg/L							970	900
Carbonate alkalinity as CaCO3	mg/L	5		<5	<5	<5	<5	<5	<5
Hydroxide alkalinity as CaCO3	mg/L	5						<5	<5
Total alkalinity as CaCO3	mg/L					380		970	
Total hardness as $CaCO_3$	mg/L								
Bicarbonate alkalinity as HCO3	mg/L				950	380	990	1,200	
Calcium as Ca - dissolved	mg/L			240	210	150	220	230	240
Calcium as Ca - total	mg/L		240						
Chloride as Cl	mg/L		4,800	3,800	3,800	2,600	4,500	4,600	4,700
Chlorine - free as Cl_2	mg/L	0.1					0		
Chlorine - total as Cl_2	mg/L	0.1	0	0	0				
Fluoride as F	mg/L	0.1	<0.1	<1	<0.1	0	<1		
Flourine	mg/L	1							
Potassium as K - total	mg/L	0.1	9						
Potassium as K - dissolved	mg/L				16	13	10		
Sodium as Na - dissolved	mg/L			2,800	2,500	1,600	1,400	2,700	2,600
Sodium as Na - total	mg/L		2,800						
Sulphate as SO_4	mg/L	1	540	720	1,000	1,100	670	590	580
Nutrients									
Ammonia as N	mg/L	0.05						0	0
Phosphorus	mg/L	0.005						<0.006	<0.005
Phosphorus as PO_4	mg/L	0.01						<0.01	<0.01
Nitrate as N	mg/L	0.01	<0.01	<0.01	0	0	0	1	<0.05
Nitrite as N	mg/L	0.002	<0.002	<0.002	0	0	<0.002	0	<0.005
Nitrite + Nitrate as N	mg/L	0.01		0	0	0	0	1	<0.005
Dissolved metals									
Aluminium	µg/L	2						<5	5
Arsenic	µg/L	1						<1	<1
Boron	µg/L	100						590	780
Cadmium	µg/L	0.1						<0.1	<0.1
Chromium	µg/L	1						<1	<1
Cobalt	µg/L	1						<1	<1
Copper	µg/L	1						<1	<1
Iron	µg/L	5	1,800	2,000	<500	<50	590	<5	<50
Lead	µg/L	1						<1	<1
Manganese	µg/L	1						850	750
Magnesium	mg/L	1		310	270	210	280		
Mercury	mg/L	0.0005						<0.0005	<0.0001
Molybdenum	µg/L	1						<1	1
Nickel	µg/L	1						2	2
Selenium	µg/L	1						<1	<1
Silver	µg/L	1						<1	<1
Uranium	µg/L	1						2	1
Vanadium	µg/L	1						<1	<1
Zinc	µg/L	5						11	20
Total metals									
Aluminium	µg/L	10						29	730
Arsenic	µg/L	1						<1	<1
Boron	µg/L	50						590	850
Cadmium	µg/L	0.1						<0.1	<0.1
Chromium	µg/L	1						1	9
Cobalt	µg/L	1						<1	<1
Copper	µg/L	1						1	5
Iron	µg/L	50	23,000	12,000	<500	9,900	<50	320	2,900
Lead	µg/L	1						<1	1
Manganese	µg/L	1						890	730
Magnesium	mg/L	1	310					<0.0005	<0.0001
Mercury	mg/L	0.0005	<0.0005	<0.0005	<0.0005	0	<0.0005	<0.0005	
Molybdenum	µg/L	1						1	2
Nickel	µg/L	1						3	6
Selenium	µg/L	1						<1	<1
Silver	µg/L	1						<1	<1
Uranium	µg/L	1						2	1
Vanadium	µg/L	1						<1	<1
Zinc	µg/L	5						26	35
BTEX									
Benzene	µg/L	0.5	N.A.	<0.1	<0.1	<0.1		<0.1	
Toluene	µg/L	0.5						<0.5	
Ethylbenzene	µg/L	2							
Xylene	µg/L	1						<1	
Total Petroleum Hydrocarbons									
TPH C_6-C_9	µg/L	40		<40	<40	<40	<40	<40	<40
TPH C_{10}-C_{14}	µg/L	50		<50	<50	<50	<50	<50	<50
TPH C_{10}-C_{36}	µg/L	400						<450	<400
TPH C_{15}-C_{28}	µg/L	100		<200	<200	<200	<200	<200	<200
TRH C_{29}-C_{40}	µg/L	400							<400
Total Recoverable Hydrocarbons - NEPM 2013 Fractions									
TRH C_6-C_{10}	µg/L	50			<50	<50	<50	<50	<50
TRH C_6-C_{10} minus BTEX (F1)	µg/L	50		<50	<50	<50	<50	<50	
TRH >C_{10}-C_{16} (F2)	µg/L	60		<60	<60	<60	<60	<60	<60
TRH >C_{16}-C_{34} (F3)	µg/L	500		<500	<500	<500	<500	<500	<500
TRH >C_{34}-C_{40} (F4)	µg/L	500		<500	<500	<500	<500	<500	<500
TRH C_{10}-C_{40}	µg/L	400						<400	<400
TPH C_{29}-C_{36}	µg/L	50		<200	<200	<200	<200	<200	<200
TRH C_{37}-C_{40}	µg/L	200						<200	<200

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1304aMB - Duaringa Formation			4/09/2013	18/09/2013	17/10/2013	23/11/2013	14/01/2014	8/04/2014
	Unit	LOR						
Physical parameters								
Electrical conductivity	µS/cm		10,000	10,000	11,000	11,000	11,000	28,000
pH	pH units		7.50	7.40	7.60	7.50	7.50	7.10
Total dissolved solids	mg/L		6,340	6,330	7,010	6,870	6,100	16,700
Total suspended solids	mg/L							82
Major/minor ions								
Bicarbonate alkalinity as CaCO3	mg/L							700
Carbonate alkalinity as CaCO3	mg/L	5		<5	<5	<5	<5	<5
Hydroxide alkalinity as CaCO3	mg/L	5						<5
Total alkalinity as CaCO3	mg/L					380		
Total hardness as $CaCO_3$	mg/L							
Bicarbonate alkalinity as HCO3	mg/L				350	380	420	860
Calcium as Ca - dissolved	mg/L			150	150	190	170	550
Calcium as Ca - total	mg/L		140					
Chloride as Cl	mg/L		2,800	2,800	2,700	2,600	2,800	10,000
Chlorine - free as Cl_2	mg/L	0.1					0	
Chlorine - total as Cl_2	mg/L	0.1	0	0				
Fluoride as F	mg/L	0.1	0	<1	0	1	<1	
Flourine	mg/L	1						
Potassium as K - total	mg/L	0.1	6					
Potassium as K - dissolved	mg/L				11	34	6	
Sodium as Na - dissolved	mg/L			1,900	2,100	1,800	2,000	4,400
Sodium as Na - total	mg/L		1,800					
Sulphate as SO_4	mg/L	1	1,100	1,100	1,100	1,000	1,100	850
Nutrients								
Ammonia as N	mg/L	0.05						0
Phosphorus	mg/L	0.005						<0.005
Phosphorus as PO_4	mg/L	0.01						<0.01
Nitrate as N	mg/L	0.01	<0.01	<0.01	<0.01	0	0	1
Nitrite as N	mg/L	0.002	<0.002	<0.002	0	0	<0.002	<0.005
Nitrite + Nitrate as N	mg/L	0.01			0	0	0	1
Dissolved metals								
Aluminium	µg/L	2						4
Arsenic	µg/L	1						<1
Boron	µg/L	100						870
Cadmium	µg/L	0.1						<0.1
Chromium	µg/L	1						<1
Cobalt	µg/L	1						<1
Copper	µg/L	1						<1
Iron	µg/L	5	1,300	930	<500	<50	1,400	<50
Lead	µg/L	1						<1
Manganese	µg/L	1						1,200
Magnesium	mg/L	1		200	200	320	190	
Mercury	mg/L	0.0005						<0.0005
Molybdenum	µg/L	1						2
Nickel	µg/L	1						3
Selenium	µg/L	1						<1
Silver	µg/L	1						<1
Uranium	µg/L	1						5
Vanadium	µg/L	1						<1
Zinc	µg/L	5						24
Total metals								
Aluminium	µg/L	10						180
Arsenic	µg/L	1						<1
Boron	µg/L	50						820
Cadmium	µg/L	0.1						<0.1
Chromium	µg/L	1						64
Cobalt	µg/L	1						<1
Copper	µg/L	1						3
Iron	µg/L	50	5,700	3,900	2,000	1,400	29,000	5,300
Lead	µg/L	1						<1
Manganese	µg/L	1						1,200
Magnesium	mg/L	1	190					<0.0005
Mercury	mg/L	0.0005	<0.0005	<0.0005	<0.0005	0	<0.0005	
Molybdenum	µg/L	1						2
Nickel	µg/L	1						7
Selenium	µg/L	1						<1
Silver	µg/L	1						<1
Uranium	µg/L	1						5
Vanadium	µg/L	1						<1
Zinc	µg/L	5						47
BTEX								
Benzene	µg/L	0.5	N.A.	<0.1	<0.1	<0.1		<0.1
Toluene	µg/L	0.5						
Ethylbenzene	µg/L	2						
Xylene	µg/L	1						
Total Petroleum Hydrocarbons								
TPH C_6-C_9	µg/L	40		<40	<40	<40	<40	<40
TPH C_{10}-C_{14}	µg/L	50		<50	<50	<50	<50	<50
TPH C_{10}-C_{36}	µg/L	400						<450
TPH C_{15}-C_{28}	µg/L	100		<200	<200	<200	<200	<200
TRH C_{29}-C_{40}	µg/L	400						
Total Recoverable Hydrocarbons - NEPM 2013 Fractions								
TRH C_6-C_{10}	µg/L	50			<50	<50	<50	<50
TRH C_6-C_{10} minus BTEX (F1)	µg/L	50		<50	<50	<50	<50	<50
TRH >C_{10}-C_{16} (F2)	µg/L	60		<60	<60	<60	<60	<60
TRH >C_{16}-C_{34} (F3)	µg/L	500		<500	<500	<500	<500	<500
TRH >C_{34}-C_{40} (F4)	µg/L	500		<500	<500	<500	<500	<500
TRH C_{10}-C_{40}	µg/L	400						<400
TPH C_{29}-C_{36}	µg/L	50		<200	<200	<200	<200	<200
TRH C_{37}-C_{40}	µg/L	200						<200

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1304bMB - Rangal Coal Measures			4/09/2013	18/09/2013	17/10/2013	23/11/2013	14/01/2014	8/04/2014	8/10/2014
	Unit	LOR							
Physical parameters									
Electrical conductivity	µS/cm		24,000	25,000	12,000	22,000	27,000	28,000	28,000
pH	pH units		7.20	7.10	11.50	7.50	7.10	7.10	7.30
Total dissolved solids	mg/L		15,000	16,300	7,500	14,400	18,100	17,000	19,300
Total suspended solids	mg/L							87	90
Major/minor ions									
Bicarbonate alkalinity as CaCO3	mg/L							710	700
Carbonate alkalinity as CaCO3	mg/L	5		<5		<5	<5	<5	<5
Hydroxide alkalinity as CaCO3	mg/L	5						<5	<5
Total alkalinity as CaCO3	mg/L					380			
Total hardness as $CaCO_3$	mg/L								
Bicarbonate alkalinity as HCO3	mg/L				<5	380	740	860	
Calcium as Ca - dissolved	mg/L			400	340	250	430	500	530
Calcium as Ca - total	mg/L		420						
Chloride as Cl	mg/L		7,400	9,100	3,500	5,500	9,700	10,000	10,000
Chlorine - free as Cl_2	mg/L	0.1					0		
Chlorine - total as Cl_2	mg/L	0.1	0	0	0				
Fluoride as F	mg/L	0.1	<0.1	<1	0	0	<1		
Flourine	mg/L	1							
Potassium as K - total	mg/L	0.1	13						
Potassium as K - dissolved	mg/L					47	14		
Sodium as Na - dissolved	mg/L			4,300	2,300	2,900	2,400	4,400	4,900
Sodium as Na - total	mg/L		4,100						
Sulphate as SO_4	mg/L	1	1,100	990	1,100	940	780	850	820
Nutrients									
Ammonia as N	mg/L	0.05						0	0
Phosphorus	mg/L	0.005						<0.005	<0.005
Phosphorus as PO_4	mg/L	0.01						<0.01	<0.01
Nitrate as N	mg/L	0.01	<0.01	<0.01	0	1	0	0	<0.1
Nitrite as N	mg/L	0.002	<0.002	<0.002	0	0	<0.002	<0.005	<0.005
Nitrite + Nitrate as N	mg/L	0.01			0	1	0	0	<0.005
Dissolved metals									
Aluminium	µg/L	2						2	8
Arsenic	µg/L	1						<1	<1
Boron	µg/L	100						850	1,100
Cadmium	µg/L	0.1						<0.1	<0.1
Chromium	µg/L	1						<1	<1
Cobalt	µg/L	1						<1	<1
Copper	µg/L	1						<1	2
Iron	µg/L	5	2,800	3,100	<500	140	3,900	<50	<50
Lead	µg/L	1						<1	<1
Manganese	µg/L	1						1,200	1,100
Magnesium	mg/L	1		870	2	660	810		
Mercury	mg/L	0.0005						<0.0005	<0.0001
Molybdenum	µg/L	1						2	1
Nickel	µg/L	1						4	2
Selenium	µg/L	1						<1	<1
Silver	µg/L	1						<1	<1
Uranium	µg/L	1						5	4
Vanadium	µg/L	1						<1	<1
Zinc	µg/L	5						42	34
Total metals									
Aluminium	µg/L	10						130	990
Arsenic	µg/L	1						<1	<1
Boron	µg/L	50						730	1,100
Cadmium	µg/L	0.1						<0.1	<0.1
Chromium	µg/L	1						5	6
Cobalt	µg/L	1						<1	<1
Copper	µg/L	1						4	6
Iron	µg/L	50	11,000	9,800	<500	920	1,600	5,400	6,700
Lead	µg/L	1						<1	<1
Manganese	µg/L	1						1,100	1,100
Magnesium	mg/L	1	800					<0.0005	<0.0001
Mercury	mg/L	0.0005	<0.0005	<0.0005	<0.0005		<0.0005		
Molybdenum	µg/L	1						2	2
Nickel	µg/L	1						7	6
Selenium	µg/L	1						<1	<1
Silver	µg/L	1						<1	<1
Uranium	µg/L	1						5	4
Vanadium	µg/L	1						<1	<1
Zinc	µg/L	5						62	51
BTEX									
Benzene	µg/L	0.5	N.A.	<0.1	<0.1	<0.1		<0.1	
Toluene	µg/L	0.5							
Ethylbenzene	µg/L	2							
Xylene	µg/L	1							
Total Petroleum Hydrocarbons									
TPH C_6-C_9	µg/L	40		<40		<40	<40	<40	<40
TPH C_{10}-C_{14}	µg/L	50		<50	<50	<50	<50	<50	<50
TPH C_{10}-C_{36}	µg/L	400						<450	<400
TPH C_{15}-C_{28}	µg/L	100		<200	<200	<200	<200	<200	<200
TRH C_{29}-C_{40}	µg/L	400							<400
Total Recoverable Hydrocarbons - NEPM 2013 Fractions									
TRH C_6-C_{10}	µg/L	50				<50	<50	<50	<50
TRH C_6-C_{10} minus BTEX (F1)	µg/L	50		<50		<50	<50	<50	
TRH >C_{10}-C_{16} (F2)	µg/L	60		<60	74	<60	<60	<60	<60
TRH >C_{16}-C_{34} (F3)	µg/L	500		<500		<500	<500	<500	<500
TRH >C_{34}-C_{40} (F4)	µg/L	500		<500		<500	<500	<500	<500
TRH C_{10}-C_{40}	µg/L	400						<400	<400
TPH C_{29}-C_{36}	µg/L	50		<200	<200	<200	<200	<200	<200
TRH C_{37}-C_{40}	µg/L	200						<200	<200

PARSONS BRINCKERHOFF

1308MB - Duaringa Formation			3/09/2013	15/01/2014
	Unit	**LOR**		
Physical parameters				
Electrical conductivity	µS/cm		12,000	12,000
pH	pH units		7.70	8.00
Total dissolved solids	mg/L		7,670	7,850
Total suspended solids	mg/L			
Major/minor ions				
Bicarbonate alkalinity as CaCO3	mg/L			
Carbonate alkalinity as CaCO3	mg/L	5		<5
Hydroxide alkalinity as CaCO3	mg/L	5		
Total alkalinity as CaCO3	mg/L			
Total hardness as $CaCO_3$	mg/L			
Bicarbonate alkalinity as HCO3	mg/L			530
Calcium as Ca - dissolved	mg/L			82
Calcium as Ca - total	mg/L		67	
Chloride as Cl	mg/L		3,200	3,400
Chlorine - free as Cl_2	mg/L	0.1		0
Chlorine - total as Cl_2	mg/L	0.1	0	
Fluoride as F	mg/L	0.1	2	2
Flourine	mg/L	1		
Potassium as K - total	mg/L	0.1	1	
Potassium as K - dissolved	mg/L			2
Sodium as Na - dissolved	mg/L			2,900
Sodium as Na - total	mg/L		2,400	
Sulphate as SO_4	mg/L	1	930	930
Nutrients				
Ammonia as N	mg/L	0.05		
Phosphorus	mg/L	0.005		
Phosphorus as PO_4	mg/L	0.01		
Nitrate as N	mg/L	0.01	0	0
Nitrite as N	mg/L	0.002	0	<0.002
Nitrite + Nitrate as N	mg/L	0.01	0	0
Dissolved metals				
Aluminium	µg/L	2		
Arsenic	µg/L	1		
Boron	µg/L	100		
Cadmium	µg/L	0.1		
Chromium	µg/L	1		
Cobalt	µg/L	1		
Copper	µg/L	1		
Iron	µg/L	5	640	3,300
Lead	µg/L	1		
Manganese	µg/L	1		
Magnesium	mg/L	1		190
Mercury	mg/L	0.0005		
Molybdenum	µg/L	1		
Nickel	µg/L	1		
Selenium	µg/L	1		
Silver	µg/L	1		
Uranium	µg/L	1		
Vanadium	µg/L	1		
Zinc	µg/L	5		
Total metals				
Aluminium	µg/L	10		
Arsenic	µg/L	1		
Boron	µg/L	50		
Cadmium	µg/L	0.1		
Chromium	µg/L	1		
Cobalt	µg/L	1		
Copper	µg/L	1		
Iron	µg/L	50	28,000	3,600
Lead	µg/L	1		
Manganese	µg/L	1		
Magnesium	mg/L	1	180	
Mercury	mg/L	0.0005	<0.0005	<0.0005
Molybdenum	µg/L	1		
Nickel	µg/L	1		
Selenium	µg/L	1		
Silver	µg/L	1		
Uranium	µg/L	1		
Vanadium	µg/L	1		
Zinc	µg/L	5		
BTEX				
Benzene	µg/L	0.5		
Toluene	µg/L	0.5		
Ethylbenzene	µg/L	2		
Xylene	µg/L	1		
Total Petroleum Hydrocarbons				
TPH C_6-C_9	µg/L	40		<40
TPH C_{10}-C_{14}	µg/L	50		<50
TPH C_{10}-C_{36}	µg/L	400		
TPH C_{15}-C_{28}	µg/L	100		<200
TRH C_{29}-C_{40}	µg/L	400		
Total Recoverable Hydrocarbons - NEPM 2013 Fractions				
TRH C_6-C_{10}	µg/L	50		<50
TRH C_6-C_{10} minus BTEX (F1)	µg/L	50		<50
TRH >C_{10}-C_{16} (F2)	µg/L	60		<60
TRH >C_{16}-C_{34} (F3)	µg/L	500		<500
TRH >C_{34}-C_{40} (F4)	µg/L	500		<500
TRH C_{10}-C_{40}	µg/L	400		
TPH C_{29}-C_{36}	µg/L	50		<200
TRH C_{37}-C_{40}	µg/L	200		

PARSONS BRINCKERHOFF

1309MB - Mackenzie River Alluvium			3/09/2013	15/01/2014	12/03/2014
	Unit	LOR			
Physical parameters					
Electrical conductivity	µS/cm		2,700	3,100	3,100
pH	pH units		7.20	7.80	7.50
Total dissolved solids	mg/L		1,680	2,040	1,910
Total suspended solids	mg/L				190
Major/minor ions					
Bicarbonate alkalinity as CaCO3	mg/L				600
Carbonate alkalinity as CaCO3	mg/L	5		<5	<5
Hydroxide alkalinity as CaCO3	mg/L	5			<5
Total alkalinity as CaCO3	mg/L				
Total hardness as $CaCO_3$	mg/L				
Bicarbonate alkalinity as HCO3	mg/L			640	730
Calcium as Ca - dissolved	mg/L			150	150
Calcium as Ca - total	mg/L		110		
Chloride as Cl	mg/L		350	470	440
Chlorine - free as Cl_2	mg/L	0.1		0.2	
Chlorine - total as Cl_2	mg/L	0.1	0.1		
Fluoride as F	mg/L	0.1	0.2	0.2	
Flourine	mg/L	1			
Potassium as K - total	mg/L	0.1	3.7		
Potassium as K - dissolved	mg/L			3.3	
Sodium as Na - dissolved	mg/L			430	430
Sodium as Na - total	mg/L		360		
Sulphate as SO_4	mg/L	1	77	390	350
Nutrients					
Ammonia as N	mg/L	0.05			<0.05
Phosphorus	mg/L	0.005			0.086
Phosphorus as PO_4	mg/L	0.01			0.26
Nitrate as N	mg/L	0.01	<0.01	0.11	0.073
Nitrite as N	mg/L	0.002	0.015	0.005	0.019
Nitrite + Nitrate as N	mg/L	0.01	0.01	0.11	0.092
Dissolved metals					
Aluminium	µg/L	2			<5
Arsenic	µg/L	1			<1
Boron	µg/L	100			120
Cadmium	µg/L	0.1			<0.1
Chromium	µg/L	1			<1
Cobalt	µg/L	1			3
Copper	µg/L	1			<1
Iron	µg/L	5	1,700	12,000	<5
Lead	µg/L	1			<1
Manganese	µg/L	1			31
Magnesium	mg/L	1		79	
Mercury	mg/L	0.0005			<0.0005
Molybdenum	µg/L	1			3
Nickel	µg/L	1			3
Selenium	µg/L	1			<1
Silver	µg/L	1			<1
Uranium	µg/L	1			13
Vanadium	µg/L	1			<1
Zinc	µg/L	5			10
Total metals					
Aluminium	µg/L	10			2400
Arsenic	µg/L	1			2
Boron	µg/L	50			110
Cadmium	µg/L	0.1			<0.1
Chromium	µg/L	1			5
Cobalt	µg/L	1			7
Copper	µg/L	1			7
Iron	µg/L	50	5,500	9,600	5,200
Lead	µg/L	1			3
Manganese	µg/L	1			62
Magnesium	mg/L	1	54		<0.0005
Mercury	mg/L	0.0005	<0.0005	<0.0005	<0.0005
Molybdenum	µg/L	1			3
Nickel	µg/L	1			13
Selenium	µg/L	1			1
Silver	µg/L	1			<1
Uranium	µg/L	1			14
Vanadium	µg/L	1			10
Zinc	µg/L	5			22
BTEX					
Benzene	µg/L	0.5	<2		<0.5
Toluene	µg/L	0.5			
Ethylbenzene	µg/L	2			
Xylene	µg/L	1			
Total Petroleum Hydrocarbons					
TPH C_6-C_9	µg/L	40	<800	<40	<40
TPH C_{10}-C_{14}	µg/L	50	<50	<50	<50
TPH C_{10}-C_{36}	µg/L	400			<450
TPH C_{15}-C_{28}	µg/L	100	<200	<200	<200
TRH C_{29}-C_{40}	µg/L	400			
Total Recoverable Hydrocarbons - NEPM 2013 Fractions					
TRH C_6-C_{10}	µg/L	50		<50	<50
TRH C_6-C_{10} minus BTEX (F1)	µg/L	50	<1000	<50	<50
TRH >C_{10}-C_{16} (F2)	µg/L	60		<60	<60
TRH >C_{16}-C_{34} (F3)	µg/L	500		<500	<500
TRH >C_{34}-C_{40} (F4)	µg/L	500		<500	<500
TRH C_{10}-C_{40}	µg/L	400			<400
TPH C_{29}-C_{36}	µg/L	50	<200	<200	<200
TRH C_{37}-C_{40}	µg/L	200			<200

PARSONS BRINCKERHOFF

1312MB - Mackenzie River Alluvium			3/09/2013	15/01/2014	13/03/2014	8/10/2014
	Unit	**LOR**				
Physical parameters						
Electrical conductivity	µS/cm		2,700	2,600	3,800	3,500
pH	pH units		7.10	7.80	7.60	7.40
Total dissolved solids	mg/L		1,710	1,700	2,500	2,500
Total suspended solids	mg/L				390	2,200
Major/minor ions						
Bicarbonate alkalinity as CaCO3	mg/L				710	600
Carbonate alkalinity as CaCO3	mg/L	5		<5	<5	<5
Hydroxide alkalinity as CaCO3	mg/L	5			<5	<5
Total alkalinity as CaCO3	mg/L					
Total hardness as $CaCO_3$	mg/L					
Bicarbonate alkalinity as HCO3	mg/L			570	870	
Calcium as Ca - dissolved	mg/L			170	160	160
Calcium as Ca - total	mg/L		110			
Chloride as Cl	mg/L		300	370	590	770
Chlorine - free as Cl_2	mg/L	0.1		<0.1		
Chlorine - total as Cl_2	mg/L	0.1	0.2			
Fluoride as F	mg/L	0.1	0.8	0.2		
Flourine	mg/L	1				
Potassium as K - total	mg/L	0.1	1.8			
Potassium as K - dissolved	mg/L			3.9		
Sodium as Na - dissolved	mg/L			320	560	670
Sodium as Na - total	mg/L		390			
Sulphate as SO_4	mg/L	1	330	360	420	460
Nutrients						
Ammonia as N	mg/L	0.05			<0.05	<0.05
Phosphorus	mg/L	0.005			0.19	0.28
Phosphorus as PO_4	mg/L	0.01			0.59	0.85
Nitrate as N	mg/L	0.01	0.24	0.14	0.24	0.19
Nitrite as N	mg/L	0.002	0.003	0.033	0.095	<0.005
Nitrite + Nitrate as N	mg/L	0.01	0.24	0.27	0.33	0.19
Dissolved metals						
Aluminium	µg/L	2			<5	8
Arsenic	µg/L	1			1	1
Boron	µg/L	100			160	210
Cadmium	µg/L	0.1			<0.1	<0.1
Chromium	µg/L	1			<1	<1
Cobalt	µg/L	1			3	2
Copper	µg/L	1			<1	<1
Iron	µg/L	5	3,800	4,600	<5	<50
Lead	µg/L	1			<1	<1
Manganese	µg/L	1			160	43
Magnesium	mg/L	1		80		
Mercury	mg/L	0.0005			<0.0005	<0.0001
Molybdenum	µg/L	1			3	1
Nickel	µg/L	1			5	4
Selenium	µg/L	1			3	2
Silver	µg/L	1			<1	<1
Uranium	µg/L	1			37	20
Vanadium	µg/L	1			7	10
Zinc	µg/L	5			9	<5
Total metals						
Aluminium	µg/L	10			4000	38000
Arsenic	µg/L	1			3	10
Boron	µg/L	50			160	240
Cadmium	µg/L	0.1			<0.1	0.1
Chromium	µg/L	1			11	84
Cobalt	µg/L	1			11	52
Copper	µg/L	1			9	57
Iron	µg/L	50	8,500	2,300	7,000	64,000
Lead	µg/L	1			5	39
Manganese	µg/L	1			230	270
Magnesium	mg/L	1	70		<0.0005	0.0001
Mercury	mg/L	0.0005	<0.0005	<0.0005	<0.0005	
Molybdenum	µg/L	1			3	1
Nickel	µg/L	1			26	120
Selenium	µg/L	1			3	6
Silver	µg/L	1			<1	<1
Uranium	µg/L	1			38	26
Vanadium	µg/L	1			22	120
Zinc	µg/L	5			34	150
BTEX						
Benzene	µg/L	0.5	<0.1		<0.5	
Toluene	µg/L	0.5			<0.5	
Ethylbenzene	µg/L	2				
Xylene	µg/L	1			<1	
Total Petroleum Hydrocarbons						
TPH C_6-C_9	µg/L	40	<40	<40	<40	<400
TPH C_{10}-C_{14}	µg/L	50	<50	<50	<50	<50
TPH C_{10}-C_{36}	µg/L	400			<450	<400
TPH C_{15}-C_{28}	µg/L	100	<200	<200	<200	<200
TRH C_{29}-C_{40}	µg/L	400				<400
Total Recoverable Hydrocarbons - NEPM 2013 Fractions						
TRH C_6-C_{10}	µg/L	50		<50	<50	<500
TRH C_6-C_{10} minus BTEX (F1)	µg/L	50	<50	<50	<50	
TRH >C_{10}-C_{16} (F2)	µg/L	60		<60	<60	<60
TRH >C_{16}-C_{34} (F3)	µg/L	500		<500	<500	<500
TRH >C_{34}-C_{40} (F4)	µg/L	500		<500	<500	<500
TRH C_{10}-C_{40}	µg/L	400			<400	<400
TPH C_{29}-C_{36}	µg/L	50	<200	<200	<200	<200
TRH C_{37}-C_{40}	µg/L	200			<200	<200

PARSONS BRINCKERHOFF

1322MB - Burngrove Formation			2/09/2013	7/01/2014	17/03/2014	8/10/2014
	Unit	LOR				
Physical parameters						
Electrical conductivity	µS/cm		14,000	14,000	14,000	14,000
pH	pH units		7.10	7.40	7.40	7.20
Total dissolved solids	mg/L		7,830	8,340	7,990	8,330
Total suspended solids	mg/L				330	7,600
Major/minor ions						
Bicarbonate alkalinity as CaCO3	mg/L				1,600	1,500
Carbonate alkalinity as CaCO3	mg/L	5		<5	<5	<5
Hydroxide alkalinity as CaCO3	mg/L	5			<5	<5
Total alkalinity as CaCO3	mg/L				1,600	
Total hardness as $CaCO_3$	mg/L					
Bicarbonate alkalinity as HCO3	mg/L			1,600	2,000	
Calcium as Ca - dissolved	mg/L			120	110	100
Calcium as Ca - total	mg/L		80			
Chloride as Cl	mg/L		3,700	3,800	3,200	3,700
Chlorine - free as Cl_2	mg/L	0.1		<0.1		
Chlorine - total as Cl_2	mg/L	0.1	0			
Fluoride as F	mg/L	0.1	<0.1	<0.1		
Flourine	mg/L	1				
Potassium as K - total	mg/L	0.1	14			
Potassium as K - dissolved	mg/L			12		
Sodium as Na - dissolved	mg/L			2,900	2,800	3,000
Sodium as Na - total	mg/L		2,900			
Sulphate as SO_4	mg/L	1	710	650	550	670
Nutrients						
Ammonia as N	mg/L	0.05			1	1
Phosphorus	mg/L	0.005			0	<0.005
Phosphorus as PO_4	mg/L	0.01			0	0
Nitrate as N	mg/L	0.01	<0.01	0	0	<0.05
Nitrite as N	mg/L	0.002	<0.002	0	0	0
Nitrite + Nitrate as N	mg/L	0.01		0	0	0
Dissolved metals						
Aluminium	µg/L	2			<5	9
Arsenic	µg/L	1			2	1
Boron	µg/L	100			770	980
Cadmium	µg/L	0.1			<0.1	0
Chromium	µg/L	1			<1	<1
Cobalt	µg/L	1			<1	<1
Copper	µg/L	1			<1	2
Iron	µg/L	5	850	710	<5	<50
Lead	µg/L	1			<1	<1
Manganese	µg/L	1			60	27
Magnesium	mg/L	1		220		
Mercury	mg/L	0.0005			<0.0005	<0.0001
Molybdenum	µg/L	1			<1	<1
Nickel	µg/L	1			2	3
Selenium	µg/L	1			<1	<1
Silver	µg/L	1			<1	<1
Uranium	µg/L	1			<1	<1
Vanadium	µg/L	1			<1	2
Zinc	µg/L	5			35	8
Total metals						
Aluminium	µg/L	10			2,500	40,000
Arsenic	µg/L	1			4	19
Boron	µg/L	50			800	1,100
Cadmium	µg/L	0.1			<0.1	1
Chromium	µg/L	1			5	37
Cobalt	µg/L	1			3	35
Copper	µg/L	1			12	160
Iron	µg/L	50	44,000	1,600	5,000	79,000
Lead	µg/L	1			3	48
Manganese	µg/L	1			130	1,000
Magnesium	mg/L	1	190		<0.0005	0
Mercury	mg/L	0.0005	<0.0005	<0.0005	<0.0005	
Molybdenum	µg/L	1			1	1
Nickel	µg/L	1			7	83
Selenium	µg/L	1			<1	4
Silver	µg/L	1			<1	<1
Uranium	µg/L	1			<1	1
Vanadium	µg/L	1			5	85
Zinc	µg/L	5			140	290
BTEX						
Benzene	µg/L	0.5	<0.1		<0.1	
Toluene	µg/L	0.5			<0.5	
Ethylbenzene	µg/L	2				
Xylene	µg/L	1			<1	
Total Petroleum Hydrocarbons						
TPH C_6-C_9	µg/L	40	<40	<40	<40	<400
TPH C_{10}-C_{14}	µg/L	50	<50	<50	<50	<50
TPH C_{10}-C_{36}	µg/L	400			<450	<400
TPH C_{15}-C_{28}	µg/L	100	<200	<200	<200	<200
TRH C_{29}-C_{40}	µg/L	400				<400
Total Recoverable Hydrocarbons - NEPM 2013 Fractions						
TRH C_6-C_{10}	µg/L	50		<50	<50	<500
TRH C_6-C_{10} minus BTEX (F1)	µg/L	50	<50	<50	<50	
TRH >C_{10}-C_{16} (F2)	µg/L	60		<60	<60	<60
TRH >C_{16}-C_{34} (F3)	µg/L	500		<500	<500	<500
TRH >C_{34}-C_{40} (F4)	µg/L	500		<500	<500	<500
TRH C_{10}-C_{40}	µg/L	400			<400	<400
TPH C_{29}-C_{36}	µg/L	50	<200	<200	<200	<200
TRH C_{37}-C_{40}	µg/L	200			<200	<200

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1323MB - Burngrove Formation			2/09/2013	7/01/2014	17/03/2014	8/10/2014	5/08/2015
	Unit	LOR					
Physical parameters							
Electrical conductivity	µS/cm		11,000	8,100	11,000	13,000	14,090
pH	pH units		7.00	7.50	7.20	7.30	6.46
Total dissolved solids	mg/L		6,870	5,240	6,860	8,470	8,390
Total suspended solids	mg/L				77	97	
Major/minor ions							
Bicarbonate alkalinity as CaCO3	mg/L				620	670	666
Carbonate alkalinity as CaCO3	mg/L	5		<5	<5	<5	<1
Hydroxide alkalinity as CaCO3	mg/L	5			<5	<5	
Total alkalinity as CaCO3	mg/L				620		
Total hardness as $CaCO_3$	mg/L						
Bicarbonate alkalinity as HCO3	mg/L			440	750		
Calcium as Ca - dissolved	mg/L			210	260	290	404
Calcium as Ca - total	mg/L		240				
Chloride as Cl	mg/L		3,600	2,300	2,900	4,100	4,660
Chlorine - free as Cl_2	mg/L	0.1		<0.1			
Chlorine - total as Cl_2	mg/L	0.1	0.1				
Fluoride as F	mg/L	0.1	<0.1	<0.1			0.3
Flourine	mg/L	1					
Potassium as K - total	mg/L	0.1	100				
Potassium as K - dissolved	mg/L			170			10
Sodium as Na - dissolved	mg/L			1,000	1,400	1,800	1,620
Sodium as Na - total	mg/L		1,400				
Sulphate as SO_4	mg/L	1	380	610	290	290	
Nutrients							
Ammonia as N	mg/L	0.05			0.23	0.22	
Phosphorus	mg/L	0.005			<0.006	<0.005	<0.01
Phosphorus as PO_4	mg/L	0.01			<0.01	<0.01	
Nitrate as N	mg/L	0.01	<0.01	<0.01	0.14	0.069	2.04
Nitrite as N	mg/L	0.002	<0.002	<0.002	0.015	<0.005	<0.01
Nitrite + Nitrate as N	mg/L	0.01		0.01	0.15	0.072	2.04
Dissolved metals							
Aluminium	µg/L	2			<5	11	<10
Arsenic	µg/L	1			1	<1	<1
Boron	µg/L	100			350	580	
Cadmium	µg/L	0.1			<0.1	<0.1	
Chromium	µg/L	1			<1	<1	
Cobalt	µg/L	1			<1	<1	
Copper	µg/L	1			<1	<1	
Iron	µg/L	5	5,100	1,000	40	<50	80
Lead	µg/L	1			<1	<1	
Manganese	µg/L	1			960	230	
Magnesium	mg/L	1		290			531
Mercury	mg/L	0.0005			<0.0005	<0.0001	<0.0001
Molybdenum	µg/L	1			4	3	
Nickel	µg/L	1			6	2	
Selenium	µg/L	1			<1	2	
Silver	µg/L	1			<1	<1	
Uranium	µg/L	1			2	2	
Vanadium	µg/L	1			<1	<1	
Zinc	µg/L	5			39	18	
Total metals							
Aluminium	µg/L	10			540	1100	
Arsenic	µg/L	1			2	2	19
Boron	µg/L	50			330	600	
Cadmium	µg/L	0.1			<0.1	<0.1	
Chromium	µg/L	1			8	5	
Cobalt	µg/L	1			1	<1	
Copper	µg/L	1			4	4	
Iron	µg/L	50	66,000	3,400	1,300	1,400	25,900
Lead	µg/L	1			<1	<1	
Manganese	µg/L	1			1,000	250	
Magnesium	mg/L	1	410		<0.0005	<0.0001	558
Mercury	mg/L	0.0005	<0.0005	<0.0005			<0.0001
Molybdenum	µg/L	1			5	3	
Nickel	µg/L	1			10	5	
Selenium	µg/L	1			<1	2	
Silver	µg/L	1			<1	<1	
Uranium	µg/L	1			2	2	
Vanadium	µg/L	1			<1	<1	
Zinc	µg/L	5			60	27	
BTEX							
Benzene	µg/L	0.5	<0.1		<0.1		
Toluene	µg/L	0.5			<0.5		
Ethylbenzene	µg/L	2					
Xylene	µg/L	1			<1		
Total Petroleum Hydrocarbons							
TPH C_6-C_9	µg/L	40	<40	<40	<40	<40	<20
TPH C_{10}-C_{14}	µg/L	50	<50	<50	<50	<50	
TPH C_{10}-C_{36}	µg/L	400			<450	<400	<50
TPH C_{15}-C_{28}	µg/L	100	<200	<200	<200	<200	<100
TRH C_{29}-C_{40}	µg/L	400				<400	
Total Recoverable Hydrocarbons - NEPM 2013 Fractions							
TRH C_6-C_{10}	µg/L	50		<50	<50	<50	<20
TRH C_6-C_{10} minus BTEX (F1)	µg/L	50	<50	<50	<50		<20
TRH >C_{10}-C_{16} (F2)	µg/L	60		<60	<60	<60	<100
TRH >C_{16}-C_{34} (F3)	µg/L	500		<500	<500	<500	<100
TRH >C_{34}-C_{40} (F4)	µg/L	500		<500	<500	<500	<100
TRH C_{10}-C_{40}	µg/L	400			<400	<400	
TPH C_{29}-C_{36}	µg/L	50	<200	<200	<200	<200	<50
TRH C_{37}-C_{40}	µg/L	200			<200	<200	

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1417MB - Burngrove Formation			5/08/2015
	Unit	**LOR**	
Physical parameters			
Electrical conductivity	µS/cm		2,820
pH	pH units		7.09
Total dissolved solids	mg/L		1,570
Total suspended solids	mg/L		
Major/minor ions			
Bicarbonate alkalinity as CaCO3	mg/L		974
Carbonate alkalinity as CaCO3	mg/L	5	<1
Hydroxide alkalinity as CaCO3	mg/L	5	
Total alkalinity as CaCO3	mg/L		
Total hardness as $CaCO_3$	mg/L		
Bicarbonate alkalinity as HCO3	mg/L		
Calcium as Ca - dissolved	mg/L		53
Calcium as Ca - total	mg/L		
Chloride as Cl	mg/L		256
Chlorine - free as Cl_2	mg/L	0.1	
Chlorine - total as Cl_2	mg/L	0.1	
Fluoride as F	mg/L	0.1	2.4
Flourine	mg/L	1	
Potassium as K - total	mg/L	0.1	
Potassium as K - dissolved	mg/L		1
Sodium as Na - dissolved	mg/L		491
Sodium as Na - total	mg/L		
Sulphate as SO_4	mg/L	1	
Nutrients			
Ammonia as N	mg/L	0.05	
Phosphorus	mg/L	0.005	<0.01
Phosphorus as PO_4	mg/L	0.01	
Nitrate as N	mg/L	0.01	<0.01
Nitrite as N	mg/L	0.002	<0.01
Nitrite + Nitrate as N	mg/L	0.01	<0.01
Dissolved metals			
Aluminium	µg/L	2	<10
Arsenic	µg/L	1	<1
Boron	µg/L	100	
Cadmium	µg/L	0.1	
Chromium	µg/L	1	
Cobalt	µg/L	1	
Copper	µg/L	1	
Iron	µg/L	5	<50
Lead	µg/L	1	
Manganese	µg/L	1	
Magnesium	mg/L	1	20
Mercury	mg/L	0.0005	<0.0005
Molybdenum	µg/L	1	
Nickel	µg/L	1	
Selenium	µg/L	1	
Silver	µg/L	1	
Uranium	µg/L	1	
Vanadium	µg/L	1	
Zinc	µg/L	5	
Total metals			
Aluminium	µg/L	10	
Arsenic	µg/L	1	7
Boron	µg/L	50	
Cadmium	µg/L	0.1	
Chromium	µg/L	1	
Cobalt	µg/L	1	
Copper	µg/L	1	
Iron	µg/L	50	20500
Lead	µg/L	1	
Manganese	µg/L	1	
Magnesium	mg/L	1	25
Mercury	mg/L	0.0005	<0.0001
Molybdenum	µg/L	1	
Nickel	µg/L	1	
Selenium	µg/L	1	
Silver	µg/L	1	
Uranium	µg/L	1	
Vanadium	µg/L	1	
Zinc	µg/L	5	
BTEX			
Benzene	µg/L	0.5	
Toluene	µg/L	0.5	
Ethylbenzene	µg/L	2	
Xylene	µg/L	1	
Total Petroleum Hydrocarbons			
TPH C_6-C_9	µg/L	40	<20
TPH C_{10}-C_{14}	µg/L	50	
TPH C_{10}-C_{36}	µg/L	400	110
TPH C_{15}-C_{28}	µg/L	100	110
TRH C_{29}-C_{40}	µg/L	400	
Total Recoverable Hydrocarbons - NEPM 2013 Fractions			
TRH C_6-C_{10}	µg/L	50	<20
TRH C_6-C_{10} minus BTEX (F1)	µg/L	50	<20
TRH >C_{10}-C_{16} (F2)	µg/L	60	<100
TRH >C_{16}-C_{34} (F3)	µg/L	500	130
TRH >C_{34}-C_{40} (F4)	µg/L	500	<100
TRH C_{10}-C_{40}	µg/L	400	
TPH C_{29}-C_{36}	µg/L	50	<50
TRH C_{37}-C_{40}	µg/L	200	

PARSONS BRINCKERHOFF

1531MB - Mackenzie River Alluvium			6/08/2015
	Unit	**LOR**	
Physical parameters			
Electrical conductivity	µS/cm		1,109
pH	pH units		6.79
Total dissolved solids	mg/L		881
Total suspended solids	mg/L		
Major/minor ions			
Bicarbonate alkalinity as CaCO3	mg/L		273
Carbonate alkalinity as CaCO3	mg/L	5	<1
Hydroxide alkalinity as CaCO3	mg/L	5	
Total alkalinity as CaCO3	mg/L		
Total hardness as $CaCO_3$	mg/L		
Bicarbonate alkalinity as HCO3	mg/L		
Calcium as Ca - dissolved	mg/L		51
Calcium as Ca - total	mg/L		
Chloride as Cl	mg/L		61
Chlorine - free as Cl_2	mg/L	0.1	
Chlorine - total as Cl_2	mg/L	0.1	
Fluoride as F	mg/L	0.1	0
Flourine	mg/L	1	
Potassium as K - total	mg/L	0.1	
Potassium as K - dissolved	mg/L		4
Sodium as Na - dissolved	mg/L		124
Sodium as Na - total	mg/L		
Sulphate as SO_4	mg/L	1	
Nutrients			
Ammonia as N	mg/L	0.05	
Phosphorus	mg/L	0.005	0
Phosphorus as PO_4	mg/L	0.01	
Nitrate as N	mg/L	0.01	<0.01
Nitrite as N	mg/L	0.002	<0.01
Nitrite + Nitrate as N	mg/L	0.01	<0.01
Dissolved metals			
Aluminium	µg/L	2	20
Arsenic	µg/L	1	16
Boron	µg/L	100	
Cadmium	µg/L	0.1	
Chromium	µg/L	1	
Cobalt	µg/L	1	
Copper	µg/L	1	
Iron	µg/L	5	11,600
Lead	µg/L	1	
Manganese	µg/L	1	
Magnesium	mg/L	1	23
Mercury	mg/L	0.0005	<0.0001
Molybdenum	µg/L	1	
Nickel	µg/L	1	
Selenium	µg/L	1	
Silver	µg/L	1	
Uranium	µg/L	1	
Vanadium	µg/L	1	
Zinc	µg/L	5	
Total metals			
Aluminium	µg/L	10	
Arsenic	µg/L	1	20
Boron	µg/L	50	
Cadmium	µg/L	0.1	
Chromium	µg/L	1	
Cobalt	µg/L	1	
Copper	µg/L	1	
Iron	µg/L	50	16,800
Lead	µg/L	1	
Manganese	µg/L	1	
Magnesium	mg/L	1	28
Mercury	mg/L	0.0005	<0.0001
Molybdenum	µg/L	1	
Nickel	µg/L	1	
Selenium	µg/L	1	
Silver	µg/L	1	
Uranium	µg/L	1	
Vanadium	µg/L	1	
Zinc	µg/L	5	
BTEX			
Benzene	µg/L	0.5	
Toluene	µg/L	0.5	
Ethylbenzene	µg/L	2	
Xylene	µg/L	1	
Total Petroleum Hydrocarbons			
TPH C_6-C_9	µg/L	40	<20
TPH C_{10}-C_{14}	µg/L	50	
TPH C_{10}-C_{36}	µg/L	400	1,400
TPH C_{15}-C_{28}	µg/L	100	370
TRH C_{29}-C_{40}	µg/L	400	
Total Recoverable Hydrocarbons - NEPM 2013 Fractions			
TRH C_6-C_{10}	µg/L	50	<20
TRH C_6-C_{10} minus BTEX (F1)	µg/L	50	<20
TRH >C_{10}-C_{16} (F2)	µg/L	60	1,160
TRH >C_{16}-C_{34} (F3)	µg/L	500	240
TRH >C_{34}-C_{40} (F4)	µg/L	500	<100
TRH C_{10}-C_{40}	µg/L	400	
TPH C_{29}-C_{36}	µg/L	50	<50
TRH C_{37}-C_{40}	µg/L	200	

PARSONS BRINCKERHOFF

1534MB - Rangal Coal Measures			6/08/2015
	Unit	**LOR**	
Physical parameters			
Electrical conductivity	µS/cm		2,160
pH	pH units		6.71
Total dissolved solids	mg/L		1,250
Total suspended solids	mg/L		
Major/minor ions			
Bicarbonate alkalinity as CaCO3	mg/L		392
Carbonate alkalinity as CaCO3	mg/L	5	<1
Hydroxide alkalinity as CaCO3	mg/L	5	
Total alkalinity as CaCO3	mg/L		
Total hardness as $CaCO_3$	mg/L		
Bicarbonate alkalinity as HCO3	mg/L		
Calcium as Ca - dissolved	mg/L		51
Calcium as Ca - total	mg/L		
Chloride as Cl	mg/L		299
Chlorine - free as Cl_2	mg/L	0.1	
Chlorine - total as Cl_2	mg/L	0.1	
Fluoride as F	mg/L	0.1	1
Flourine	mg/L	1	
Potassium as K - total	mg/L	0.1	
Potassium as K - dissolved	mg/L		159
Sodium as Na - dissolved	mg/L		180
Sodium as Na - total	mg/L		
Sulphate as SO_4	mg/L	1	
Nutrients			
Ammonia as N	mg/L	0.05	
Phosphorus	mg/L	0.005	<0.01
Phosphorus as PO_4	mg/L	0.01	
Nitrate as N	mg/L	0.01	<0.01
Nitrite as N	mg/L	0.002	<0.01
Nitrite + Nitrate as N	mg/L	0.01	<0.01
Dissolved metals			
Aluminium	µg/L	2	<10
Arsenic	µg/L	1	9
Boron	µg/L	100	
Cadmium	µg/L	0.1	
Chromium	µg/L	1	
Cobalt	µg/L	1	
Copper	µg/L	1	
Iron	µg/L	5	7,180
Lead	µg/L	1	
Manganese	µg/L	1	
Magnesium	mg/L	1	34
Mercury	mg/L	0.0005	<0.0001
Molybdenum	µg/L	1	
Nickel	µg/L	1	
Selenium	µg/L	1	
Silver	µg/L	1	
Uranium	µg/L	1	
Vanadium	µg/L	1	
Zinc	µg/L	5	
Total metals			
Aluminium	µg/L	10	
Arsenic	µg/L	1	12
Boron	µg/L	50	
Cadmium	µg/L	0.1	
Chromium	µg/L	1	
Cobalt	µg/L	1	
Copper	µg/L	1	
Iron	µg/L	50	8,380
Lead	µg/L	1	
Manganese	µg/L	1	
Magnesium	mg/L	1	36
Mercury	mg/L	0.0005	<0.0001
Molybdenum	µg/L	1	
Nickel	µg/L	1	
Selenium	µg/L	1	
Silver	µg/L	1	
Uranium	µg/L	1	
Vanadium	µg/L	1	
Zinc	µg/L	5	
BTEX			
Benzene	µg/L	0.5	
Toluene	µg/L	0.5	
Ethylbenzene	µg/L	2	
Xylene	µg/L	1	
Total Petroleum Hydrocarbons			
TPH C_6-C_9	µg/L	40	<180
TPH C_{10}-C_{14}	µg/L	50	
TPH C_{10}-C_{36}	µg/L	400	830
TPH C_{15}-C_{28}	µg/L	100	310
TRH C_{29}-C_{40}	µg/L	400	
Total Recoverable Hydrocarbons - NEPM 2013 Fractions			
TRH C_6-C_{10}	µg/L	50	<30
TRH C_6-C_{10} minus BTEX (F1)	µg/L	50	<20
TRH >C_{10}-C_{16} (F2)	µg/L	60	590
TRH >C_{16}-C_{34} (F3)	µg/L	500	240
TRH >C_{34}-C_{40} (F4)	µg/L	500	<100
TRH C_{10}-C_{40}	µg/L	400	
TPH C_{29}-C_{36}	µg/L	50	<50
TRH C_{37}-C_{40}	µg/L	200	

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1539MB - Rangal Coal Measures			7/08/2015
	Unit	**LOR**	
Physical parameters			
Electrical conductivity	µS/cm		476
pH	pH units		8.32
Total dissolved solids	mg/L		281
Total suspended solids	mg/L		
Major/minor ions			
Bicarbonate alkalinity as CaCO3	mg/L		120
Carbonate alkalinity as CaCO3	mg/L	5	<1
Hydroxide alkalinity as CaCO3	mg/L	5	
Total alkalinity as CaCO3	mg/L		
Total hardness as $CaCO_3$	mg/L		
Bicarbonate alkalinity as HCO3	mg/L		
Calcium as Ca - dissolved	mg/L		20
Calcium as Ca - total	mg/L		
Chloride as Cl	mg/L		74
Chlorine - free as Cl_2	mg/L	0.1	
Chlorine - total as Cl_2	mg/L	0.1	
Fluoride as F	mg/L	0.1	0.2
Flourine	mg/L	1	
Potassium as K - total	mg/L	0.1	
Potassium as K - dissolved	mg/L		4
Sodium as Na - dissolved	mg/L		47
Sodium as Na - total	mg/L		
Sulphate as SO_4	mg/L	1	
Nutrients			
Ammonia as N	mg/L	0.05	
Phosphorus	mg/L	0.005	0.02
Phosphorus as PO_4	mg/L	0.01	
Nitrate as N	mg/L	0.01	0.03
Nitrite as N	mg/L	0.002	<0.01
Nitrite + Nitrate as N	mg/L	0.01	0.03
Dissolved metals			
Aluminium	µg/L	2	80
Arsenic	µg/L	1	<1
Boron	µg/L	100	
Cadmium	µg/L	0.1	
Chromium	µg/L	1	
Cobalt	µg/L	1	
Copper	µg/L	1	
Iron	µg/L	5	<50
Lead	µg/L	1	
Manganese	µg/L	1	
Magnesium	mg/L	1	9
Mercury	mg/L	0.0005	<0.0001
Molybdenum	µg/L	1	
Nickel	µg/L	1	
Selenium	µg/L	1	
Silver	µg/L	1	
Uranium	µg/L	1	
Vanadium	µg/L	1	
Zinc	µg/L	5	
Total metals			
Aluminium	µg/L	10	
Arsenic	µg/L	1	3
Boron	µg/L	50	
Cadmium	µg/L	0.1	
Chromium	µg/L	1	
Cobalt	µg/L	1	
Copper	µg/L	1	
Iron	µg/L	50	4,410
Lead	µg/L	1	
Manganese	µg/L	1	
Magnesium	mg/L	1	9
Mercury	mg/L	0.0005	<0.0001
Molybdenum	µg/L	1	
Nickel	µg/L	1	
Selenium	µg/L	1	
Silver	µg/L	1	
Uranium	µg/L	1	
Vanadium	µg/L	1	
Zinc	µg/L	5	
BTEX			
Benzene	µg/L	0.5	
Toluene	µg/L	0.5	
Ethylbenzene	µg/L	2	
Xylene	µg/L	1	
Total Petroleum Hydrocarbons			
TPH C_6-C_9	µg/L	40	<190
TPH C_{10}-C_{14}	µg/L	50	
TPH C_{10}-C_{36}	µg/L	400	<50
TPH C_{15}-C_{28}	µg/L	100	<100
TRH C_{29}-C_{40}	µg/L	400	
Total Recoverable Hydrocarbons - NEPM 2013 Fractions			
TRH C_6-C_{10}	µg/L	50	<30
TRH C_6-C_{10} minus BTEX (F1)	µg/L	50	<20
TRH >C_{10}-C_{16} (F2)	µg/L	60	<100
TRH >C_{16}-C_{34} (F3)	µg/L	500	<100
TRH >C_{34}-C_{40} (F4)	µg/L	500	<100
TRH C_{10}-C_{40}	µg/L	400	
TPH C_{29}-C_{36}	µg/L	50	<50
TRH C_{37}-C_{40}	µg/L	200	

Attachment E

Groundwater model review by independent peer reviewer



Heritage Computing Pty Ltd ● ABN 75 392 967 126 ● T/A HydroSimulations

PO Box 241, Gerringong NSW 2534. Phone: (+61 2) 4234 3802 stuart.brown@hydrosimulations.com

DATE: 10 June 2016

TO: Louisa Rochford
Principal Hydrogeologist
WSP | Parsons Brinckerhoff
680 George St, Sydney, NSW2000

FROM: Dr Stuart Brown

RE: Curragh Extension Project Groundwater Model: Final Review

OUR REF: HC2016/26

1 Introduction

HydroSimulations (HS) was engaged by WSP | Parsons Brinckerhoff to provide peer review of groundwater impact modelling undertaken as part of a groundwater impact assessment of the Curragh Extension Project. The groundwater assessment was carried out by WSP | Parsons Brinckerhoff for Wesfarmers Resources Pty Ltd.

The Curragh Mine Project (Curragh Mine) is an open cut coal mine located approximately 6 kilometres (km) north of the township of Blackwater in Central Queensland. The mine is operated by Wesfarmers Curragh Pty Ltd (WCPL) under Environmental Authority (EA) EPML00643713. The Curragh Extension Project (the Project) will involve extension of open cut coal mining operations at Curragh Mine in four adjacent Mining Lease (ML) areas within Mineral Development Licence (MDL) 162 tenement. The purpose of the Curragh Extension Project is to extend the estimated life of the Curragh Mine from 2030 to approximately 2038.

A local groundwater model was developed by WSP|PB for proposed Pit X associated with the Curragh Extension Project in October 2015. Feedback from the Independent Expert Scientific Committee (IESC) on 4 November 2015 recommended that a more extensive groundwater model be developed that is capable of assessing the cumulative impacts from all existing and proposed pits as well as neighboring mines.

1.1 Scope of this review

This review was conducted with reference to the concepts and standards outlined in the Australian Groundwater Modelling Guidelines (AGMG; Barnett *et al.*, 2012). A progress review was carried out by me in the early stages of model development (HS, 2016), and I was kept informed of progress throughout. The progress review found that the proposed approach was generally appropriate. A draft report dated 23 May2016 was updated by PB|WSP following my initial peer review on 3 June 2016.This review is of the numerical modelling as completed and presented in the WSP|PB draft final report dated 9 June 2016. No model runs were carried out as part of this review.

2 Summary of assessment

A summary of this assessment against the standard AGMG compliance checklist is shown in Table 1. Assessment against the recommendations in the IESC advice is summarised in Table 2. In general, I find the modelling report to be very well written and presented document with comprehensive discussion on conceptualisation and groundwater impact to GDEs. I find the model and report to be appropriate in relation to the stated objectives.

Table 1. Assessment of the Curragh groundwater model against the AGMG checklist

Item	Model aspect	Comments	Compliant
1	Are the model objectives and model confidence level classifications clearly stated?	Objective clearly stated (Section 7.1); Assessed Class 2 (Section 7.2)	Yes
2	Are the objectives satisfied?	Yes	Yes
3	Is the conceptual model consistent with objectives and confidence level classification?	Conceptual model has appropriate detail and well-presented	Yes
4	Is the conceptual model based on all available data, presented clearly and reviewed by an appropriate reviewer?	Very good conceptualisation; well constrained geology	Yes
5	Does the model design conform to best practice?	Appropriate for mine impact assessment	Yes
6	Is the model calibration satisfactory?	Yes, SRMS statistic is reasonable and inflows consistent with measured.	Yes
7	Are the calibrated parameter values and estimated fluxes plausible?	Yes, parameter values match well with literature values, and observed inflows	Yes
8	Do the model predictions conform to best practice?	Appropriate for Class 2 model; **It is noted further analysis of the final void will be reported separately.	Yes**
9	Is the uncertainty associated with the predictions reported?	Yes, in Section 7.6.	Yes
10	Is the model fit for purpose?	The model provides a reasonable and conservative prediction of groundwater impacts.	**Yes**

Table 2. Summary of proponent commitments from the IESC advice dated 4 November 2015

Item	IESC Recommendation / comment	Report section	Addressed ?
5a	Consider cumulative impacts from all pits in the proposed expansion; existing operations and other nearby mines.	Section 7.4.1.1	Yes
5b	Include a formal calibration, sensitivity analysis and uncertainty analysis	Included in Sections 7.4.2, 7.4.4 and 7.6.	Yes
5c	Include hydrogeological detail within the Rangal Coal measures, including the known influence of weathering.	Described in Section 2.4.2.3; Section 4.1;	Yes
5d	[Assess] the potential effects of paleochannels, faults and other structural features	Described in Section 2.4.3; Section 4.1;	Yes
17a	Collect and use groundwater monitoring bore data for calibration	Sections 3.1.1 and 7.4.3.1.	Yes
17b	Incorporate results of GDE field verification studies	Section 5.2.3.	Yes
17c	Simulate the effects of backfilling mine pits on recharge and groundwater flow	Section 7.4.1.2	Yes
20	Requirement for a peer review.	This review	Yes

3 Commentary

3.1 Model planning and objectives

The modeling objectives are clearly presented in Section 7.1 of the report. They are consistent with the requirements of a groundwater impact assessment and incorporate the recommendations from the IESC advice dated 4 November 2015.

In my opinion, the modelling and reporting satisfy the objectives as stated. The model characteristics are consistent with a **Class 2 model** as listed in the Australian Groundwater Modelling Guidelines.

3.2 Conceptualisation

Hydrogeological conceptualisation provides the basis for most decisions relating to model design. Of greatest importance is providing an understanding of:

- The geometry and structure of groundwater systems
- Relevant hydrological processes and stresses
- Realistic and representative ranges in aquifer property values
- The behaviour of the natural system as indicated from monitoring data.
- The interactions between surface water and groundwater

The IESC advice notice (November 2015) refers to a number of important aspects to be conceptualised and included in the numerical model (as listed in Table 2).

The model report provides a reasonably detailed description of the regional and site geology and hydrogeology. In particular, groundwater-surface water interaction and GDEs are discussed in some detail. This discussion provides a sound basis for the modelling decisions in relation to those model boundaries and receptors.

3.3 Model design and construction

The model was run using MODFLOW-USG (Panday et al., 2013). This is an appropriate choice for impact modelling. MODFLOW-USG is well suited to modelling groundwater impacts due to mining because it allows the simulation of progressive back-filling of pits with waste-rock with significantly different hydraulic characteristics and recharge.

3.3.1 Model domain and neighbouring mines

The model domain is appropriate in its extent as it incorporates the neighbouring mines for cumulative drawdown analysis. This is also indicated by model predictions of water table drawdown related to the project which are not obviously influenced by the model boundaries (Report Figure 7.10 and 7.16).

The approach of representing the neighbouring mines as drain cells in the level of the target coal seam (and overlying layers) for the duration of those mining operations is appropriate. The neighbouring mines have been represented in sufficient detail for the cumulative assessment.

General head boundaries (GHB) are a good choice for the model boundaries where the topography is relatively flat and the model margins need to cut arbitrarily across minor catchments.

3.3.2 Model discretisation

A cell dimension of 100m x 100m (10^4 m^2) are appropriate for a large scale mining operation such as this. This allows adequate representation of the mine pits while keeping the model to a manageable size (< 10^6 cells). Ten layers were used to represent hydrogeological units. Five layers were used to represent the Rangal Coal Measures, providing sufficient vertical discretisation.

Annual stress periods are appropriate for the proposed mining period. Given the lack of detailed information for early years of mine operation, slightly longer (three year) periods for past mining provide a reasonable approximation of the dynamic starting conditions (as of 2015).

3.3.3 Boundary conditions

The model area includes rivers that contain permanent water (e.g. the Mackenzie River), as well as ephemeral systems. The Mackenzie River was simulated using the MODFLOW River package, with the elevations set from LiDAR information and the conductance calculated on the assumption of a clay substrate material. This assumption seems appropriate based on the information presented. Ephemeral streams were modelled using the MODFLOW Drain package.

Drain boundaries are commonly used for ephemeral streams because they simulate discharge when the water table is above the creek bed, but do not provide water to the underlying material when the groundwater level falls below the creek bed. This is appropriate in most cases, but may under-represent the role of these features as sources of recharge during high rainfall.

Rainfall recharge and evaporation were applied to the top active layer is appropriate for this model. Recharge and evaporation (particularly the latter) are often altered within reasonable bounds during calibration.

3.3.4 Hydraulic properties

A comprehensive summary of hydraulic properties for relevant hydrogeological units is presented in Table 4.2 of the report. The table provides an excellent guide for the ranges in those properties at are adopted in the predictive model. Table 7.5 of the report shows that the adopted parameters are reasonable compared with measured and calibrated values from numerous other studies.

3.3.5 Palaeochannels and faults

The hydraulic behavior of faults can be highly variable and difficult to uniquely charaterise. The most practical approach is to address the possible role of the faults during the sensitivity analysis by specifying them in successive runs as somewhat more transmissive and somewhat less transmissive than the host rock. The model report notes that there are numerous local-scale faults (Illustrated in Figure 2.8 of the report) which would be impractical to include in a regional scale model. At the scale of the model, it is most practical to represent such faulting using the *representative elementary volume* approach. This approach has been adopted in the Curragh numerical model, and I consider it to be appropriate.

Palaeochannels deposits are described in Section 2.4.2.1 of the report, and are parameterized as part of the alluvial deposits.

3.4 Calibration and sensitivity

The model parameters were calibrated by matching modelled groundwater levels to monitored groundwater levels at groundwater monitoring bores. The calibration performance is discussed in Section 7.4.3.1 of the report. The scaled RMS using weighted data is 5.8% and, using unweighted data is 13%.

The model water balance presented in Table 7.6 of the report, with a reported balance error of 0.00.

The model performance was also assessed by checking the modelled mine inflows for the calibration period, against the measured groundwater inflows at each pit (bearing in mind the large uncertainties in measurements of pit inflow). Table 7.7 of the report shows that the predicted mine inflows are relatively close to the observed inflows, except for Pit U which is underestimated by the model. The close match between the modelled and observed pit inflows provides confidence in the model forecasts.

3.5 Predictions

Model predictions are presented at Section 7.5 of the report. Groundwater predictions for the **Curragh Extension Project** (CEP) were calculated from the difference in results between a *base case model run* (all mines without the CEP) and a *cumulative model run* (the base case plus the CEP). The model predictions are:

- Estimates of mine inflow (Section 7.5.3 of the report)
- Estimates of future groundwater drawdown (Sections 7.5.4 and 8.2.1 of the report)

- Estimates of loss from streams (Section 8.2.2 of the report)
- Change in saturation of alluvium (impact to GDEs; Section 8.2.4 of the report)

The results are presented in a clear manner and on high quality maps and graphs. I note that, given the ephemeral nature of many of the streams and the poor connectivity between the Mackenzie River and the underlying alluvium, the predicted minor losses seem plausible.

Although final voids were included in the model there is no detailed discussion related to the ongoing impact. However, I understand that further work is planned to complete more detailed modelling of these voids as required by Environmental Authority (EPML00643713) conditions G13 and G14

3.6 Uncertainty

An uncertainty analysis is presented in Section 7.6 of the report. The analysis was carried out by first identifying the most sensitive parameters (in terms of calibration statistics). A series of model runs was then performed with those sensitive parameters varied within reasonable uncertainty limits, and key prediction indicators tabulated. This is a fairly straightforward (and common) alternative to more complex PEST-based methods (e.g. Doherty et al. 2010).

I hope you find these comments useful. Please call me if you need any clarification or have any other questions.

Yours sincerely,



Dr Stuart Brown

4 References

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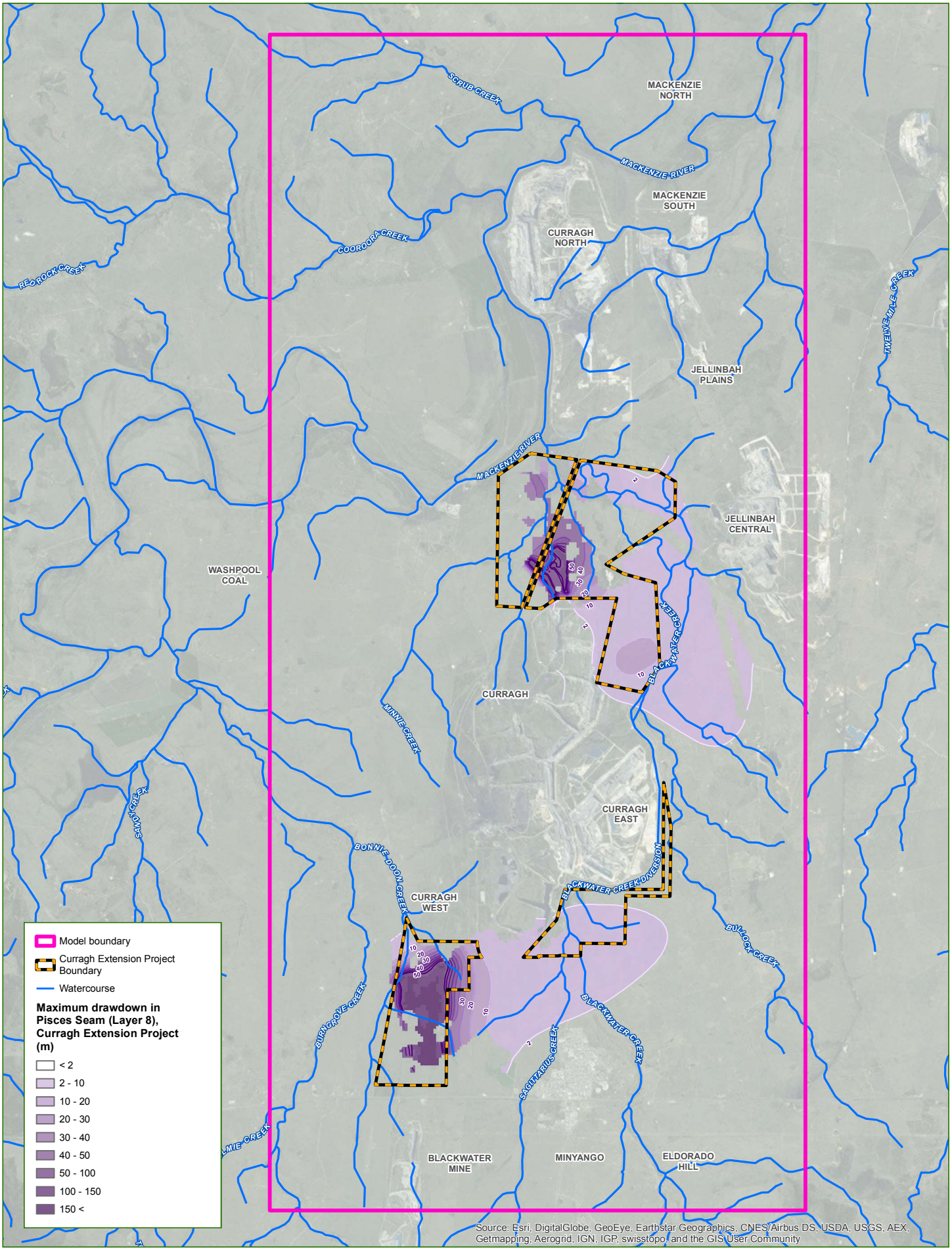
Mackie, C. D. (2009). Hydrogeological characterisation of coal measures and overview of impacts of coal mining on groundwater systems in the Upper Hunter Valley of NSW. PhD Thesis, University of Technology, Sydney.

Panday, S., C. D. Langevin, R. G. Niswonger, M. Ibaraki and J. D. Hughes (2013). MODFLOW–USG Version 1: An unstructured grid version of MODFLOW for simulating groundwater flow and tightly coupled processes using a control volume finite-difference formulation, U.S. Geological Survey

Attachment F

Maximum drawdown in the alluvium, Pisces Seam (Layer 8) and Burngrove Formation (Layer 9) - Base case





Wesfarmers
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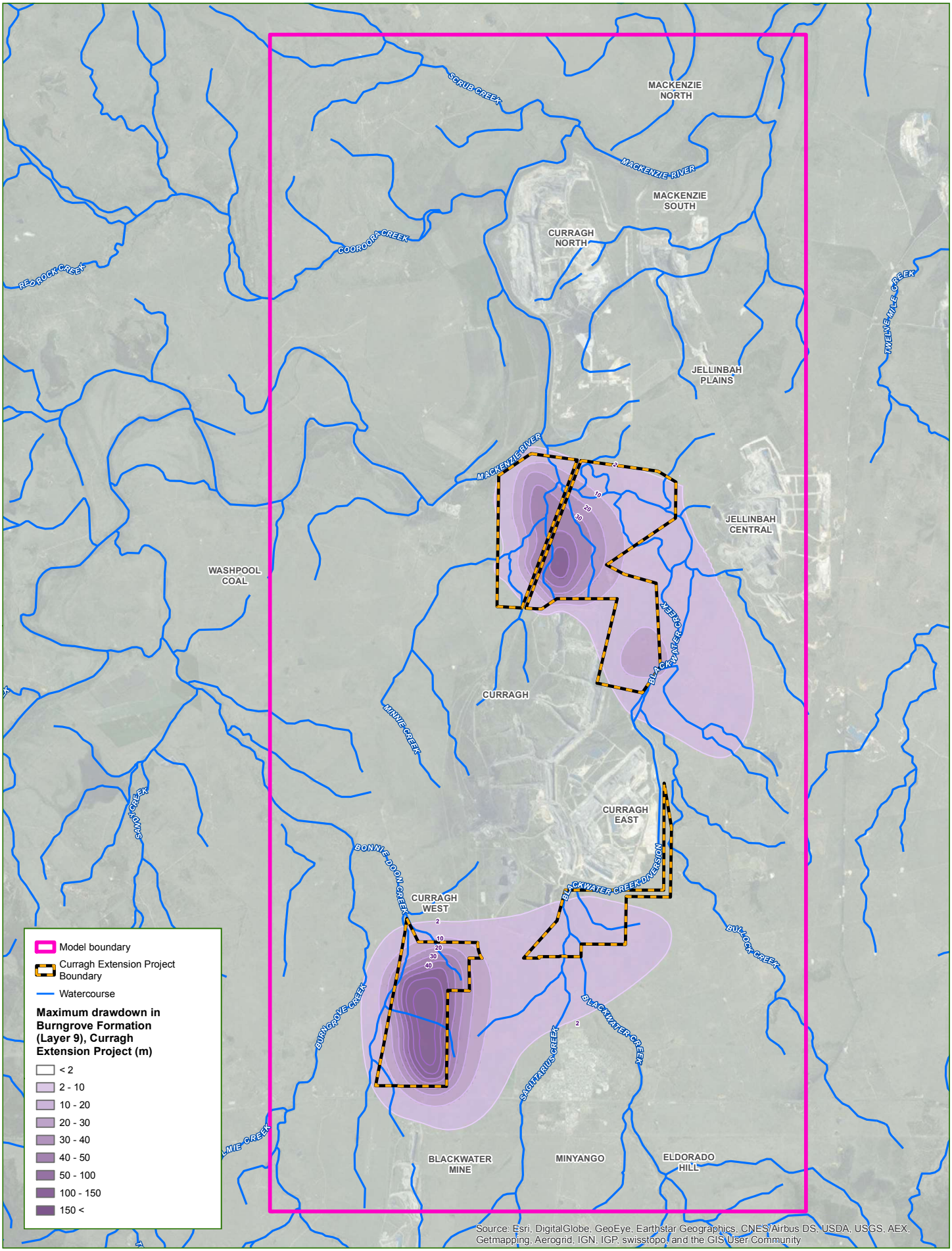
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Data Source:
All data from WSP/PB (2016)

Groundwater impact assessment
Curragh Extension Project
Attachment F.1
Maximum drawdown in Pisces Seam (Layer 8), Curragh Extension Project

MXD Number: 2172652H_GIS_SW_F018_A4
Date: 20/05/2016
Author: VD
Approved by: LR
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Projection: Transverse Mercator
Coordinate System: GDA 1994 MGA Zone 55

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Groundwater impact assessment
Curragh Extension Project
Attachment F.2
Maximum drawdown in Burngrove Formation (Layer 9), Curragh Extension Project

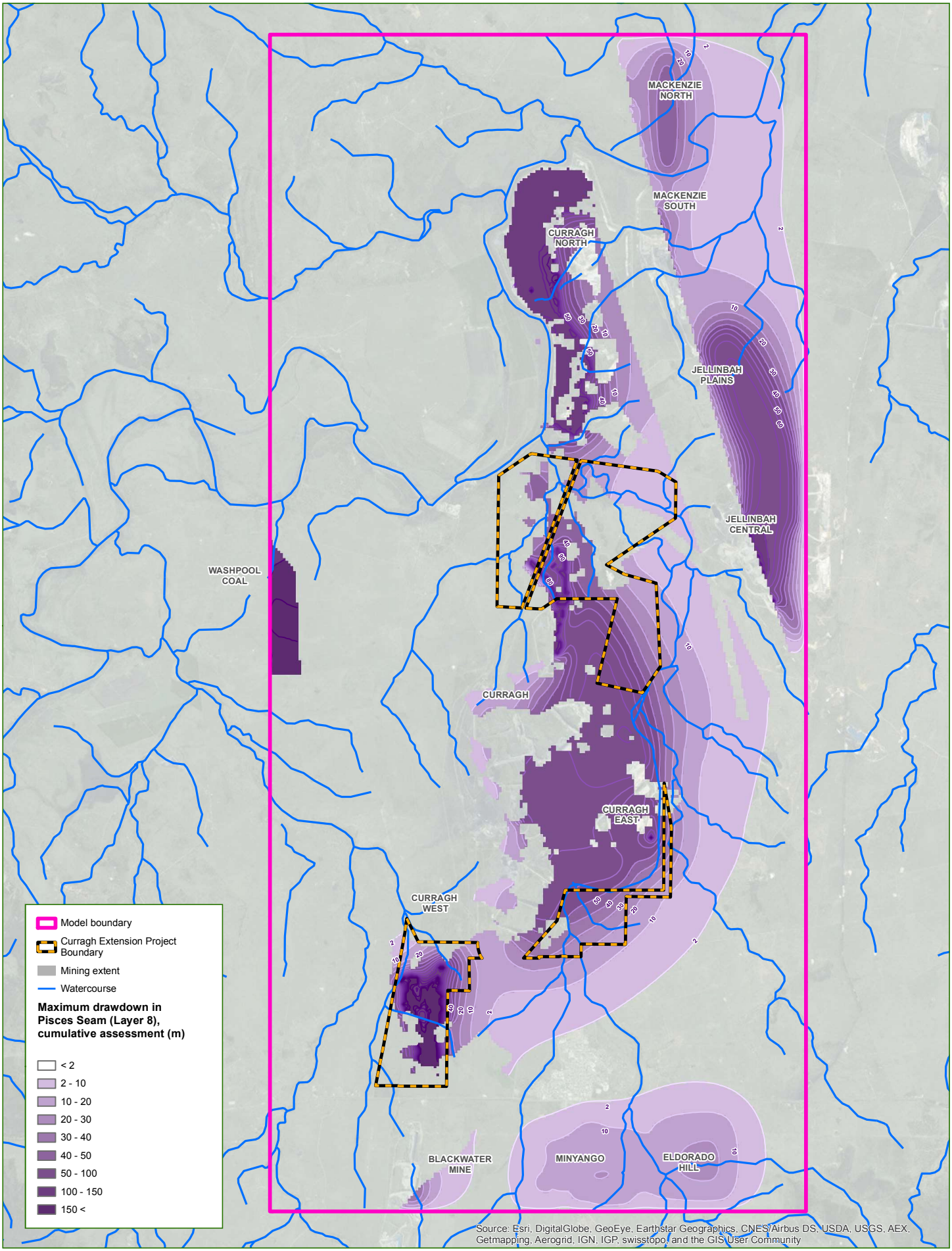
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Date: 20/05/2016
Author: VD
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Attachment G

Maximum drawdown in the alluvium, Pisces Seam (Layer 8) and Burngrove Formation (Layer 9) - Cumulative run





Wesfarmers
PARSONS BRINCKERHOFF

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Scale 1:135,000

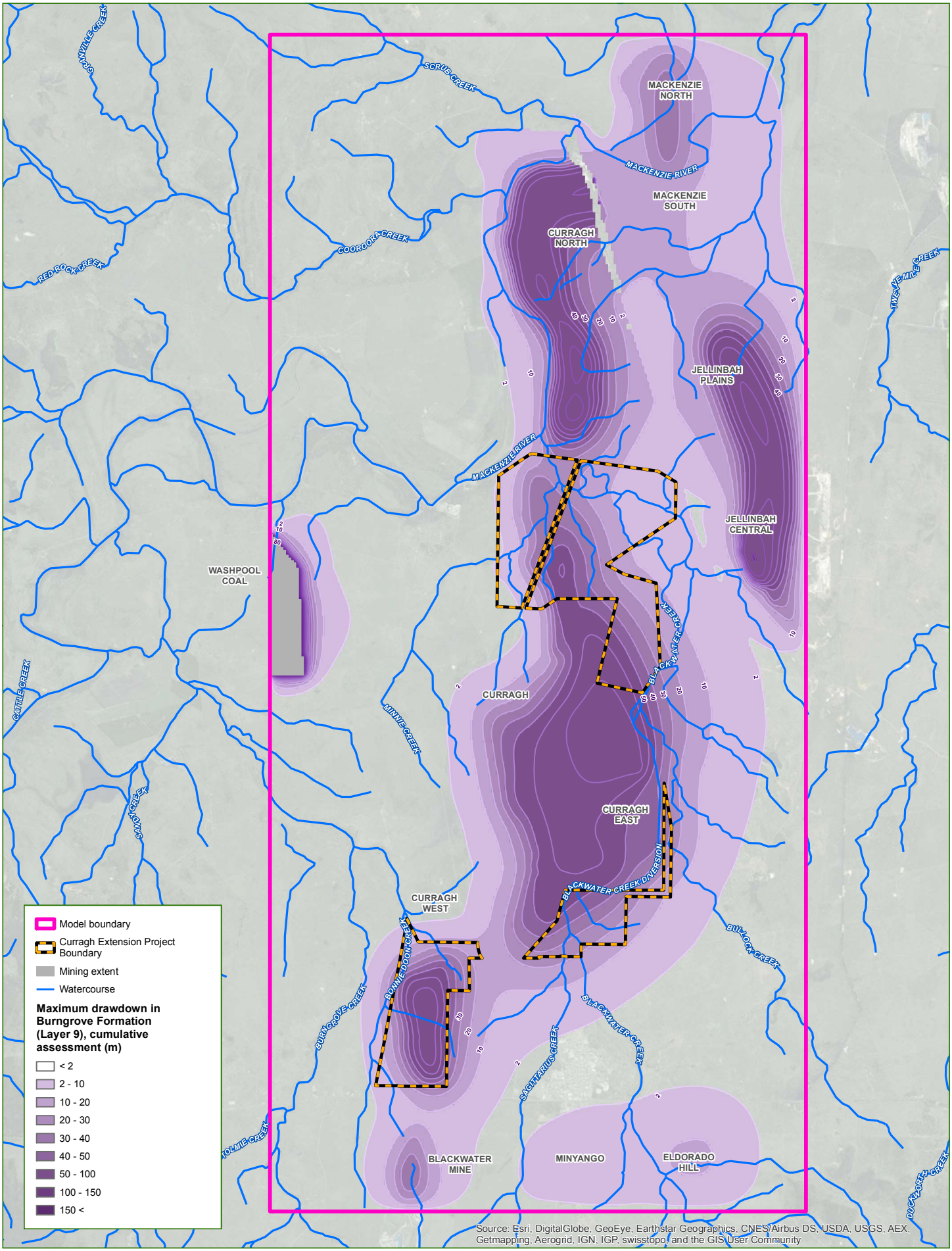
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Groundwater impact assessment
Curragh Extension Project
Attachment G.1
Maximum drawdown in Pisces Seam (Layer 8), cumulative assessment

MXD Number: 2172652H_GIS_SW_F014_A5
Date: 20/05/2016
Author: VD
Approved by: LR
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Groundwater impact assessment
Curragh Extension Project
Attachment G.2
Maximum drawdown in Burngrove Formation (Layer 9), cumulative assessment

MXD Number: 2172652H_GIS_SW_F015_A4
Date: 20/05/2016
Author: VD
Approved by: LR
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