5.0 HYDROGEOLOGICAL MODELLING

The process for assessing potential impacts of the Project on groundwater is to carry out hydrogeological modelling to simulate and predict changes in groundwater quality and levels. Hydrogeological modelling is done using computer software (Numerical Groundwater Modelling). The first part of the process is to develop a Conceptual Groundwater Model (CGM). A CGM is a qualitative representation of the controlling factors influencing groundwater occurrence, distribution and flow. The controlling factors can be summarised as follows:

- Classification of the strata into either an aquifer, aquitard or aquiclude, their relative positions and how they interact;
- Local and regional geology;
- Groundwater flow regime; and
- Impacts resulting from the existing and proposed activities influencing the geological and hydrogeological regimes.

A numerical groundwater model was developed to assess the potential changes to groundwater heads due to the proposed Project both during mining and after mine closure.

5.1 Conceptual Groundwater Model

The purpose of the CGM is to provide a visualisation and understanding of the controlling processes that are most important to how the hydrogeological system works. A strong conceptual understanding of the groundwater flow regime can be interrogated and used to verify the conclusions and recommendation of this GWIA. A conceptual model of the existing groundwater conditions can also be used to form a set of baseline conditions against which future impacts can be assessed.

A Conceptual Groundwater Model (CGM) was developed for the wider Study Area using the data outlined in Section 3.0. The CGM is based on the understanding of the Site Characterisation (Section 4.0), including previous groundwater testing and analysis, which is summarised in Sections 4.5 and 4.6 (Geological and Hydrogeological Setting). Section 5.1 below discusses the interpretation behind the CGM, which is presented in Figure 22 (note: the CGM is not presented to scale).

5.1.1 Hydrostratigraphy

The strata in the Study Area are considered to be poor groundwater resources. The surficial silts and clays limit the potential for recharge by rainfall infiltration (MER, 2006). The deeper strata of the LFB are characteristically tight rocks with a low fracture density, where fractures are predominantly clay-filled (Golder, 2010a). These characteristics of the LFB result in poor aquifer storage and transmissivity.

A summary of the hydrostratigraphy relevant to the Project is presented in 20. (Refer to Section 4.6.4, Table 10 and Table 11 for detailed discussion on hydraulic parameters of the strata).

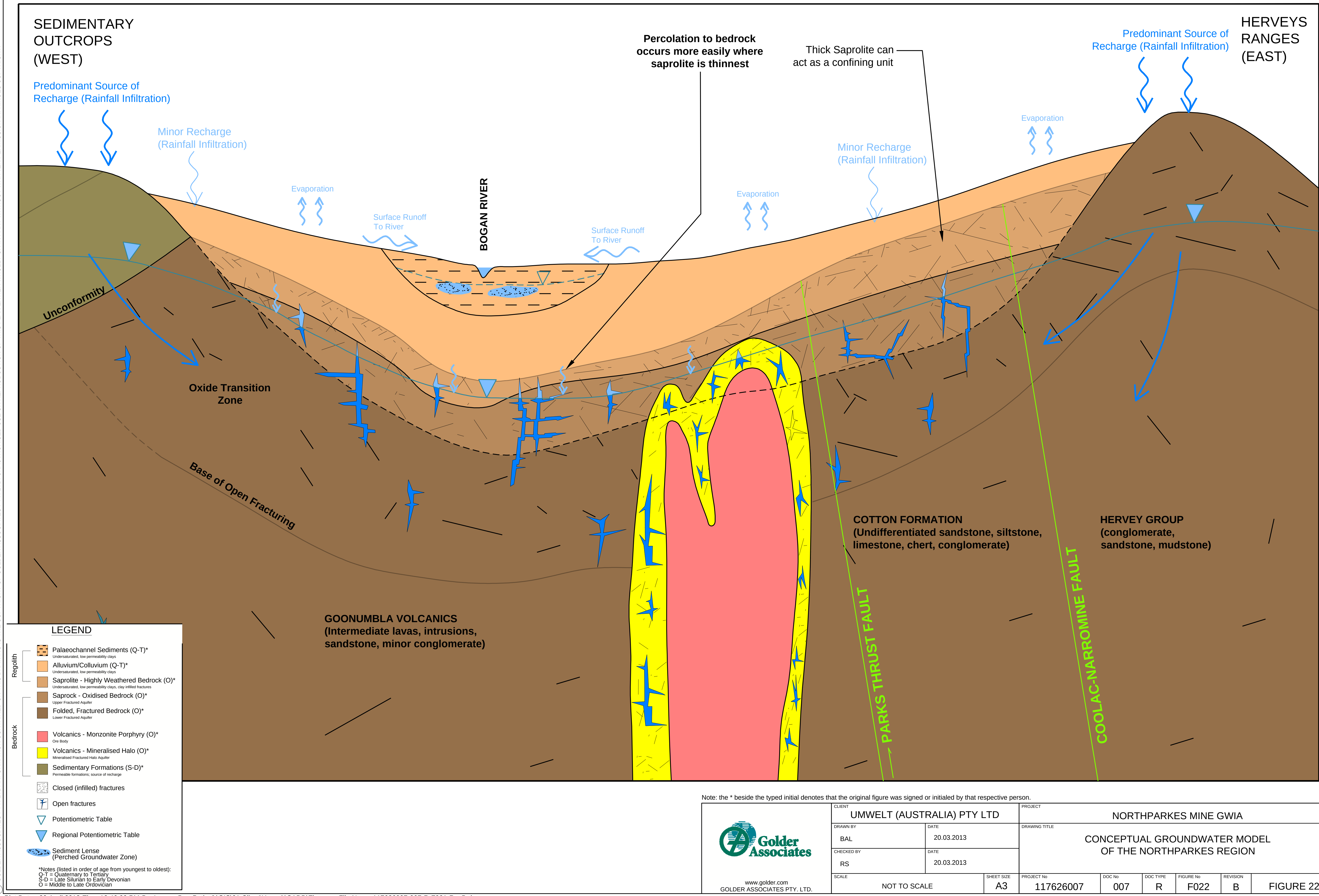
Table 20: Summary of the Hydrostratigraphy at the Project Area

Strata	Zone	Hydrostratigraphy	Groundwater Flow Characteristics	Unit Depth Range (mbgl)	Hydraulic Conductivity Range (m/s)(1)
Regolith	Transported Regolith	Undersaturated; Perched groundwater zones	Low permeability silts and clays; Low flow, intergranular controlled	0 – 6	$3x10^{-10}$ – $6x10^{-6}$
	Regolith and Saprolite (Alluvium/colluvium and highly weathered bedrock)	Undersaturated	Low permeability clays; Low flow, partly intergranular- and partly fracture-controlled	2 – 36	$3x10^{-12}$ – $8x10^{-10}$
Bedrock	Saprock (Oxidised bedrock)	Upper Fractured Aquifer	Moderately fractured bedrock; Low flow, fracture controlled	23 – 150	$8x10^{-10}$ – $7x10^{-6}$
	Fresh rock (OTZ to fresh bedrock)	Lower Fractured Aquifer	Occasionally fractured bedrock, Low flow, fracture controlled; Decreasing permeability with depth	0 – 592	$1x10^{-13}$ – $7x10^{-6}$
	Monzonite Intrusions	Ore Body Aquifers	Moderately Fractured, monzonite intrusions; Major open fractures, steeply dipping; Closed fractures (infilled with carbonates, sulfates, sulfides);	18 – 592	$6.3x10^{-10}$ – $2.1x10^{-7}$
	Mineralised Zone	Mineralised Fractured Halo Aquifer	Moderately fractured, altered bedrock; Dominantly vertical fractures in vicinity of ore bodies; Decreasing permeability with depth	50 – 125	$2.3x10^{-7}$ (2)
				>125	$1x10^{-7}$ – $5 x10^{-8}$

Notes:

(1) Refer to Section 4.6.4 for detailed hydraulic parameter data

(2) Mean value; range unavailable.



Note: the * beside the typed initial denotes that the original figure was signed or initialed by that respective person.

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	DRAWN BY: BAL	DATE: 20.03.2013	DRAWING TITLE: CONCEPTUAL GROUNDWATER MODEL OF THE NORTHPARKES REGION	
	CHECKED BY: RS	DATE: 20.03.2013		
	SCALE: NOT TO SCALE	SHEET SIZE: A3	PROJECT No: 117626007	DOC No: 007 / DOC TYPE: R / FIGURE No: F022 / REVISION: B / FIGURE 22

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5.1.1.1 Bedrock Aquifers

Previous studies (MER, 2006; Raymond, 2002; PB, 2011) have identified four principal bedrock aquifer systems, in general agreement, within the Study Area:

- *Lower Fractured Aquifer,* or fresh bedrock strata: the andesitic volcaniclastic sequence comprising the regional bedrock, and includes the “Oxide Transition Zone”, or OTZ;
- *Upper Fractured Aquifer,* or saprock: the upper oxidised zone of the hard (unweathered) bedrock strata, intersected in the Project Area between 20 and 50 mbgl;
- *Ore Body Aquifers*: the monzonite porphyry intrusions currently mined by NPM;
- *Mineralised Fractured Halo Aquifers*: the zones of contact alteration in the bedrock, which occur around the ore bodies.

The bedrock is considered to form discrete aquifers predominantly controlled by fracturing. The permeability of these aquifers is strongly influenced by stress conditions (overburden pressure, crustal horizontal stress field and stress field around mining voids). Groundwater migration within the bedrock strata are entirely joint or fracture controlled, and occurs within faults, shear zones and the intrusive contact zones (referred to in this report as “mineralised zones”; NPM, 2010).

The occurrence of fracturing within the bedrock is highest in the oxidised saprock zone and decreases with depth through to the fresh bedrock (including the zone of transition to fresh bedrock, the (OTZ; PB, 2011). Raymond (2002) infers the base of the OTZ forms the base of predominantly open, interconnected fracturing in the bedrock. Within the fresh bedrock, the density of fractures is lower, and fractures are generally disconnected, closed or in-filled.

Each zone is discussed in the following sections. Refer to Figure 3 for Project Area and mine plan layout for references to mine pit locations.

Fresh Bedrock (Lower Fractured Aquifer)

The deeper bedrock materials comprise mostly very low permeable mafic volcanic rocks and volcaniclastics, including andesite lavas and pyroclastics, breccia, diorite and the monzonite intrusions that host the ore bodies. Some fault structures can result in significant secondary porosity, but the fractures will only permit groundwater movement if they are sufficiently interconnected. Based on the interpreted screened strata and groundwater level data in Section 4.0, the groundwater level in the bedrock (including the transition from regolith to bedrock) ranges from approximately 220 to 261 m AHD, in boreholes MB11 and MB17 (respectively). Depending on location and ground elevation, this ranged from 9 to 58 mbgl in boreholes W1 and P149 (respectively).

The groundwater quality of the deeper bedrock ranges from fresh to saline. The fresh groundwater occurs in small pockets or compartments, generally confined to shallow depths near to recharge outcrops (Raymond, 2002). Groundwater in the deeper bedrock occurs within compartments (hydraulically separate fracture zones) and becomes predominantly stagnant and saline with depth (Raymond, 2002).

Saprock (Upper Fractured Aquifer)

Saprock is composed of oxidised bedrock and overlies the fresh bedrock, forming the upper profile of the bedrock aquifer. Saprock is a fractured, indurated and less weathered form of the overlying saprolitic clays and sediments (refer to regolith in Section 5.1.1.3). The occurrence of fracturing in the lower bedrock aquifer is highest in the saprock. The saprock represents a layer of enhanced permeability within the profile; it follows the undulating weathering front. The hydrogeological data from Raymond (2002) is consistent with a model where the bulk of groundwater occurs within the fractures of this stratum. The regional water table occurs predominantly within the saprock and prevails at about 40 mbgl (Raymond, 2002; MER, 2006).

Saprock has an average thickness of 21.7 m at the Project Area (calculated from exploration drilling data), and varies between 7 and 45 m thick (PB, 2011). As discussed under the local geology (4.5) saprock has been intersected at the site between 20 to 50 m depth. The potentiometric surface mapped by PB (2003) represents saprock zone and was inferred to generally coincide with the base of the saprolite. Aquifer tests in previous studies indicate that hydraulic conductivity is $8x10^{-10}$ to $7x10^{-6}$ in the saprock (Table 20).

The NOW database does not contain detailed geological logs or list the stratigraphy for bores in the Study Area. However, the depths and descriptions of the water bearing zones (refer to Metadata Table, APPENDIX A) indicate saprock likely forms the principal aquifer exploited for water, which is in agreement with PB (2011). Yields from this groundwater zone are low; NOW bore data indicates a yield range of 0.1 to 1.5 L/s (APPENDIX A). Water quality ranges from brackish to saline, however, this resource is utilised because it is the most extensive and accessible groundwater source in the Study Area.

Mineralised Zone (Mineralised Halo Fractured Aquifer)

This hydrostratigraphic unit was characterised by PB (2003) as a localised vertical halo around each ore body in the Project Area. The mineralised zones form aquifers that are separate from each other, but display similar characteristics. The aquifers are vertical and permeability is predominantly controlled by vertical to sub-vertical fractures. Permeability decreases from about 125 m depth (PB, 2003).

Mining of the ore deposits has disturbed these strata by enhancing the fracture regime within the halo, and increasing its permeability. PB (2003) concluded that fracturing due to disturbance from mining did not extend beyond the mineralised zone into the host rock aquifer. However, the enhanced permeability within the mineralised zone allows significantly more rainfall infiltration into the surface profile of the halo (PB, 2011).

Hydraulic tests during previous studies indicate the mean hydraulic conductivity is $2.7x10^{-10}$ m/s between 50 to 125 m depth. The range of hydraulic conductivity below 125 m is $1x10^{-7}$ to $5\ x10^{-8}$ to $5.6x10^{-6}$ (Table 20). Water quality data results have not been assigned to this stratum in previous studies.

5.1.1.2 Monzonite Intrusions (Ore Body Aquifers)

The hydrogeology of each of the exiting ore bodies has been investigated in varying detail in previous studies (Golder 1987, MER 1999, PB 2003 and 2011, Raymond 2002, SRK 2000) as well as various ongoing NPM investigations and monitoring). Groundwater seepage has been manageable at all ore bodies as a result of the low permeabilities of host rocks (MER, 2006). A brief summary of the characteristics of each ore body was given in Table 11.

The Ore Bodies are near-vertical monzonite intrusions within the Bedrock. This stratum is moderately fractured, with fracture orientation and density varying between individual ore bodies. Major open structures are steeply dipping and primarily strike NE-SW (E22) and NW-SE (E27) with secondary sets striking in the perpendicular direction. There are also shallow-dip structures striking between 90º and 120º (Raymond, 2002)

The hydraulic conductivity values for available Ore Bodies ranges from $6.3x10^{-10}$ to $4.8x10^{-6}$ m/s (Section 4.6.4). Reported observed seepages occurred between 205 and 224 mAHD, ranging from 0.07 to 0.5 ML/day.

Mining operations have not yet started at the GPR314 Ore Body. A review of the fracture density data in the area by SRK (2000) suggests a broadly similar trend to the frequency and size of fractures as seen in the north of the mine area. SRK (2000) geophysical mapping also corroborates this and suggests the inflows to the mine will be a similar order of magnitude as that seen in the other underground operations.

5.1.1.3 Regolith (Undersaturated Zone)

The regolith system is a relatively shallow groundwater system, typically less than 40 m in thickness. The regolith represents surficial soils and transported sediments, shallow alluvial and colluvial deposits, and the underlying saprolite (highly weathered bedrock), which forms the base of the profile. This shallow groundwater system generally comprises low permeability silts and clays, which is largely unsaturated (MER, 2006). PB (2011) considered the regolith as the least permeable strata, which exhibits decreasing permeability with depth (refer to Section 4.6).

Transported Regolith

This unit has not been described in detail, which is not an aquifer, but has been tested for infiltration rates by PB (2003). Infiltration results were estimated at 7.1 and 41.1 mm/day, but were slightly overestimated as they were not corrected for evaporation.

Hydraulic tests in previous studies indicate that hydraulic conductivity is 2.7×10^{-10} to 5.6×10^{-6} in the surface soils (Table 20).

Regolith / Saprolite

Palaeochannels are present in the regolith within the Bogan River catchment. Palaeochannel features occur beneath the Bogan River where the depth to bedrock is greatest and the regolith is thickest ("deeper regolith"). The deeper regolith is indicated to occur west of the Project Area and in areas north-east of the TSF (MER, 2006).

Pockets of groundwater have been found beneath some drainage channels of the palaeochannel sediments. These minor water bearing zones are perched above the regional water table, sustained by slow and often highly variable rainfall recharge from the surface (Raymond, 2002; MER, 2006). This alluvial system is low yielding and is generally not considered a productive resource in the Study Area.

Below this occurs saprolite with a relict texture grading downwards into the oxidised saprock zone (PB, 2003). Groundwater migration within the saprolite zone is believed to be partly intergranular and partly fracture controlled. However, the clayey nature of the materials inhibits flows of high magnitude (MER, 2006). The deep saprolite is usually in hydraulic continuity with the fractured rock system, which draws on storage in the overlying regolith (Raymond, 2002).

Based on the MER (2006) interpretation of screened strata and water levels, the regolith-saprock water levels range from approximately 233 to 273 m AHD in boreholes MB2 and MB6 (respectively). Depending on location and ground elevation, this ranged from 7 to 53 mbgl in boreholes Long Paddock and MB6 (respectively). Monitoring bore MB7, interpreted to be in the regolith, was dry at 24 m depth.

Conceptualisation in the previous studies (PB, 2011, Raymond, 2002, MER, 2006) indicates that groundwater zones encountered in the regolith groundwater are shallower than the deeper regional water table (as illustrated in the CGM, Figure 22); the regional water table lies well below the base of the palaeochannel (Raymond, 2002). The groundwater zones encountered in the regolith sediments are considered to be hydraulically separate from the deeper groundwater resource due to the low permeability sediments of the regolith and saprolite, which form a barrier to recharge and flow. It is inferred from previous studies however, that the regional water table is encountered in some instances, notably in deep fractured saprolite within bedrock depressions (refer to Figure 22; PB, 2011; Raymond, 2002).

5.1.2 Groundwater Recharge, Distribution and Movement

The regional hydrogeological setting is described in Section 4.6.3. The local hydrogeological regime of the Upper Bogan Valley is strongly influenced by the semi-arid conditions, with long recharge and discharge pathways (Raymond, 2002). The groundwater recharge and distribution mechanisms of the pathways are discussed in the following sections.

5.1.2.1 Aquifer Recharge

Recharge occurs on drainage divides and groundwater is discharged in the valley bottoms. In the Study Area, direct recharge from vertical percolation of rainfall infiltration occurs through the vadose zone. However, the rate of recharge is probably low because of the high evapotranspiration and soil moisture requirements (Raymond, 2002). A thick regolith profile can also act as a confining layer, impeding water percolation through the vadose zone.

Recharge to groundwater in the Study Area from two sources:

- Major recharge source: rainfall infiltration over drainage divides (basement rock outcrops at high altitude); and

- Minor recharge source: rainfall infiltration over the surface of the Upper Bogan Valley (regolith sediments).

The predominant source of recharge to the Upper and Lower Fractured Bedrock Aquifers is from direct rainfall recharge. Recharge can occur over more permeable units, such as the Devonian sediments that outcrop approximately 10km west of the site (Figure 8; Figure 22). By contrast, however, crystalline lithologies of the fractured rock aquifers in the Study Area have poor outcrop, and very low primary permeability and will receive a much reduced recharge rate. The bedrock outcrops 25 km east of the Project Area, in the Hervey Ranges, which rise to an altitude of about 800 m (Figure 22).

Recharge to the fractured, crystalline bedrock occurs where the bedrock sub-crops (i.e. where regolith cover is thinnest) or outcrops to the west, east and south of the Study Area (as shown on Figure 8). Groundwater levels indicate that some recharge occurs by rainfall infiltration within the Project Area where bedrock comes close to the surface just south of Pits E22 and E27. Raymond (2002) reports that problems with estimating recharge in arid areas include: spatial and temporal variability of recharge, including the climate and land use changes; the determination of representative water balance parameters; and accurately assessing the regional hydrogeological consequences of localized and indirect recharge. A recharge estimate to the bedrock has been provided by the Geoscience Australia MapConnect to be up to 0.1 mm/year (or <1% of the annual rainfall) within the Study Area.

Minor recharge to the sediments in the regolith occurs by rainfall infiltration through surface sediments. Due to the low permeability nature of the regolith cover, rainfall recharge areas are most likely to occur where the transported sediments or regolith materials offer a relatively thin cover over sub-cropping bedrock (MER, 2006). Here the groundwater may migrate more easily into the underlying weathered-fractured bedrock along the weathering interface. However, increasingly impermeable materials at depth may slow this process (MER, 2006). Rainfall infiltration into the regolith is probably negligible, but might be significant in times of flood, if there are parts of the area prone to flooding (PB, 2003).

Like the regolith zone, groundwater within the deeper hard rocks has been sustained through the downwards percolation of infiltrated rainfall. MER (2006) reports that rising water levels, probably attributed to recharge in the deeper zone, can be observed in certain piezometers. Examination of the rainfall record suggests an overall lag in response to rainfall recharge of as much as 2 years (MER, 2006).

Effects of Tailings Dam Emplacement

Potential impacts of the tailings dam emplacement are unknown. Mounds of higher groundwater levels would be expected to be associated with the elevated TSFs. Based on the elevated water levels from recent data it is likely that mounding occurs. This may be due to enhanced recharge at the tailings for one or more reasons, such as:

- Thinning or removal of the regolith near the tailings dams;
- Pore squeezing due to the weight of tailings on the ground surface; and
- Actual leakage from the tailings dams.

GHD (2009) reported that travel rates for tailings seepage would be exceptionally slow (e.g. 1 km per 1,000 years). It is likely that the clays present would adsorb or modify any mobile metals within the seepage. The impacts of such seepage would therefore be negligible (GHD, 2009).

5.1.2.2 Aquifer Discharge

Regional groundwater flow is in a northerly, down-valley direction towards the Wombin State Forest, as discussed in Section 4.7. The main groundwater sinks in the valley are located further downstream from the NPM site, and are likely to include baseflow from creeks and leakage into the alluvial sediments of the Bogan River Valley. However, the Upper Bogan Valley presents a very long valley profile and no groundwater discharge has been identified for some 20 km north of the site (i.e., down-gradient, near Peak Hill; Raymond, 2002). However, some minor losses by evapotranspiration may occur within the tree-lined lower reaches of Cookopie and Tenandra Creeks, and in the heavily forested area of Wombin State Forest (PB, 2003).

5.1.2.3 Structural Controls of Groundwater Flow in Bedrock

The flow direction of the regional groundwater is north to northwesterly direction. Groundwater follows long pathways along north-south trending structural subdivisions of the LFB. Fracturing in the bedrock in the Project Area appears to be near vertical and striking east to west (for example, near E27); whereas fracturing is less frequent near E22, where northerly trending open structures are evident (MER, 2006).

The lithological, structural and weathering features of the rocks indicate a high propensity for groundwater compartmentalisation across the valley. They are likely to have very low intergranular permeability, and will convey groundwater mainly in secondary permeability features such as fractures, major fault structures, and along stratigraphic unconformities (Raymond, 2002). This was demonstrated in the observation in MER (2006) that seepage from fractures in the pits was governed by the connectivity of these features. Poorly connected fractures and fractures in-filled by clay materials may drain slowly leaving elevated pore pressures short distances into the pit wall. In contrast, highly connected open fractures, particularly within the mineralised halo aquifers, tend to drain rapidly and tend to depressurize parts of the pit wall.

There is negligible groundwater storage and flow in the rock mass of the bedrock strata. Groundwater flow is therefore a result of the low recharge (and therefore low driving head) and controlled by prevailing pore pressures within the complex network of joints and fractures. AGC (1984) noted that "aquifers associated with the ore bodies" were unlikely to show regional continuity.

MER (2006) assumes that accumulated groundwater at depth may act as a relatively localized groundwater store that provides even slower and deeper percolation into the underlying less fractured bedrocks. If the deeper rocks are relatively impermeable (as is generally the case) then only a small component of deep percolation occurs.

5.1.3 Summary of the Conceptual Groundwater Model

The geological rock units encountered in the Project Area and across the wider Study Area have been grouped into two general rock types (refer to CGM, Figure 22). These are the:

- Transported and weathered sediments comprising the *Regolith*.

  The regolith is comprised of low permeability clays and soils. The base of the regolith is considered to be formed by a saprolite layer (heavily weathered bedrock). The regolith is predominantly undersaturated, except for pockets of groundwater that form perched groundwater zones within the Bogan River Palaeochannel sediments.

  Groundwater movement within the regolith is predominantly intergranular-controlled, except in the saprolite where groundwater movement is also partly fracture-controlled; however large flow volumes are inhibited by clayey sediments. Overall, the regolith is regarded as a low yielding, slightly brackish to saline unit and not considered as a groundwater resource in the Study Area.

- Volcanic, volcaniclastic and sedimentary strata comprising the fresh *Bedrock*.

  The bedrock is comprised of hard fractured rock. The upper bedrock is comprised of saprock (oxidised rock), becoming less oxidised with depth (OTZ through to fresh bedrock). Groundwater movement in the saprock and deeper bedrock is predominantly fracture-controlled within discrete compartments (i.e. they do not form extensive aquifer systems). As open fracturing decreases with depth, so too does the permeability of the aquifers. The density of open fractures is greatest in the saprock, and with depth become closed or in-filled with mineral precipitates or clay.

  Saprock is low yielding and of low water quality, but is accessed by regional groundwater users and is considered in this study to be the *Upper Fractured Aquifer.* Underlying the saprock is the OTZ and fresh bedrock, which are characteristically tight rocks with a low fracture density. Open fracturing decreases with depth to the base of the OTZ, and yields are lower than for saprock. In the current study, the OTZ and bedrock are collectively considered to be the *Lower Fractured Aquifer.*

  The Bedrock to Saprock units comprise the host rocks for the near-vertical monzonite intrusions that are mined by NPM. These units have a distinct fracturing system of lower permeability than the bedrock, referred to as *Ore Body Aquifers.*

  Localised fractured aquifers occur around the ore bodies in alteration contact zones around the monzonite intrusions. These *Mineralised Fractured Halo Aquifers* cut across the bedrock strata and exhibit decreased fracturing with depth into the fresh bedrock. These units are discrete, local aquifers and do not show regional continuity.

  The characteristics of the LFB result in poor aquifer storage and transmissivity. Water quality is fresh to saline, but is predominantly brackish to saline. Where fresh groundwater occurs, it is usually in shallow pockets or compartments near to recharge outcrops, and salinity generally increases with depth.

5.2 Numerical Groundwater Model

A numerical groundwater model was developed to assess potential changes to groundwater heads due to the proposed Project both during mining and after mine closure.

This assessment utilised previously accepted groundwater modelling undertaken at NPM by Mackie Environmental research (MER), as follows:

- Northparkes Mine Groundwater Management Studies E27 and E22 Pits (1999); and
- Northparkes Mine E48 Project; Groundwater Studies (2006).

Consideration was also given to the reported site characteristics and calibrated models presented by:

- Parsons Brinckerhoff: Northparkes Mine In-Pit Tailings Disposal Hydrogeology Investigation and Groundwater Impact Assessment (2003); and
- Coffey: Northparkes Project Groundwater Studies for Mine Dewatering (1993).

The MER 2006 modelling files used in the existing approvals for block cave mining at E48 were provided by MER to Golder in 2011. The MER 2006 groundwater model was reviewed and updated where additional information was available and to include relevant aspects of the Project.

The CGM (Section 5.1) was used to review the existing models and allow Golder to make robust updates of the model, where necessary.

5.2.1 Model Setup

A brief discussion of the development of the model is presented in the following sections. A full description of the modelling process and input parameters are given in APPENDIX C.

5.2.2 Model Software

Groundwater Vistas V6.15 B7 was used to develop the groundwater model of the Project Area. Groundwater Vistas is a Graphical User Interface for the USGS MODFLOW groundwater modelling code. MODFLOW was used in conjunction with the MODFLOW-SURFACT V4 software, which is an industry standard and widely accepted numerical code for the temporal simulation of saturated and unsaturated groundwater flow in three-dimensions.

5.2.3 Model Domain

The extent of the model domain was based on the MER 2006 groundwater model. The area covered by the model was sufficiently large to ensure potential impacts on groundwater heads from mining would be captured in the model.

The Project model was designed to begin at approximately ground level and extend to a depth of approximately 1,200 m below ground level (-925 mAHD). Layer elevations were derived from the MER 2006.

The vertical model layering can be summarised as follows:

- Regolith at the surface with an approximate average thickness of 50 m;
- Saprock underlying the Regolith with an approximately average thickness of 77 m;
- Oxidised Transition Zone with an approximately average thickness of 77 m;
- Bedrock (occasionally fractured) with a thickness of 525 m;
- Bedrock (less fractured) with a thickness of 755 m to the base of the model.

In addition to the vertical model layers, discrete zones with representative hydraulic parameters were assigned to the following known structures within the model domain:

- Caved zones (above the block cave mine areas);
- Open pits;
- Ore bodies (existing approved and proposed ore bodies as part of the Project) and associated mineralised halos (fractured aquifer);
- An enhanced hydraulic conductivity feature trending north-northwest E22;
- An enhanced hydraulic conductivity feature trending east to west through E26; and

- A low hydraulic conductivity fault trending east to west located to the south of E26.

These different zones can be seen in Figure 23.

5.2.4 Model Parameters

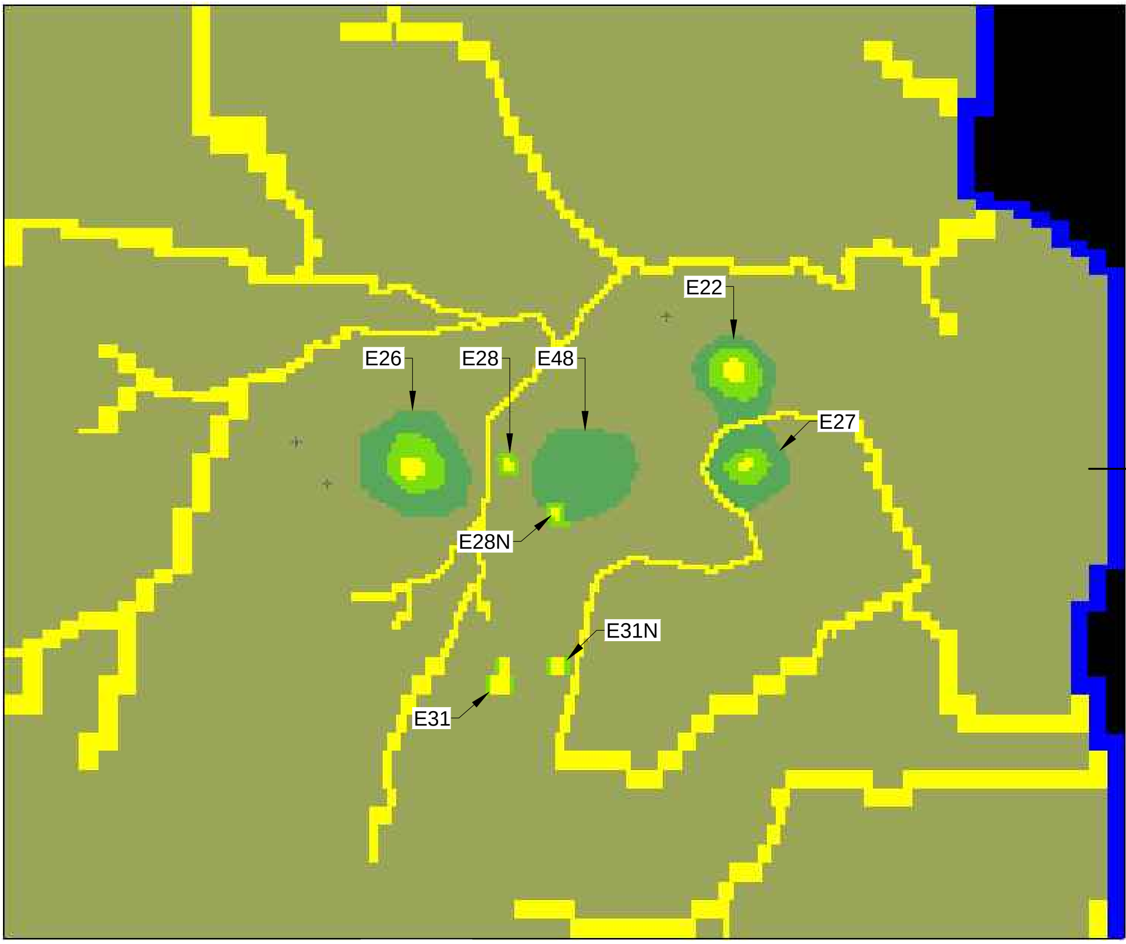
Properties for the materials listed above that are represented within the model were defined based on calibrated model values from MER (2006) and corroborated with other previous modelling and site investigation data at NPM.

These properties input to the model define the behaviour of the material with respect to groundwater flow and how it stores and releases groundwater. Hydraulic parameters relevant to MODFLOW include:

- Horizontal and vertical hydraulic conductivity;
- Specific yield and specific storage; and
- Drain cell conductance.

Values for these model properties were tested during model calibration, as discussed in Section 5.2.8.

South
North



PLAN VIEW
SCALE N.T.S.

SECTION A - CROSS SECTION- COLUMN 59
SCALE N.T.S.

Model Layer	Stratigraphic Unit (Hydraulic Conductivity Unit)
L1	Regolith
L2	Bedrock (saprock)
L3	Bedrock Oxidised Transition Zone
L4	Top of Bedrock (occasionally fractured)
L5 - L10	Bedrock (occasionally fractured)
L11 - L17	Bedrock (less fractured)

	Drain Cell
	Caved Zone
	Open Pit
	Mineralised Zone
	Constant Head Boundary
	No Flow Zone

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CLIENT: UMWELT (AUSTRALIA) PTY LTD		PROJECT: NORTHPARKES MINE		
DRAWN BY: HC	DATE: 21.03.2013	DRAWING TITLE: HYDRAULIC CONDUCTIVITY ZONES WITHIN THE MODEL		
CHECKED BY: HW	DATE: 30.04.2013			
SCALE: N.T.S.	SHEET SIZE: A4	PROJECT No: 117626007	DOC No: 007	DOC TYPE: R
FIGURE No: F0023	REVISION: 0	FIGURE 23		

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Plot Date: 30 April 2013 Time:4:32:13 PM By: Campbell, Helen Path: J:\hyd\2011\117626007_Umwelt_NorthParkesMine\Technical Doc\CADD\FIGURES - File Name:117626007-007-R-F0023-REV0.dwg

Model boundaries to the east, west and south were defined as no flow boundaries and located at sufficient distance from the Project Area as to limit the effect of the choice of boundary type on the result to an accepted level. No water is permitted to move into or out of the model across a no flow boundary. These are known as far-field boundaries and, due to their distance from the area of mining these do not require to be in conformance with the geometry of hydrogeologically controlled conditions. The eastern and western sides were aligned approximately north-south to be in approximate alignment with groundwater flow direction.

The northern model boundary was assigned a constant head boundary (CHB) condition coincident with the observed 228 mAHD regional piezometric contour (MER, 2006). A CHB permits water to move freely in or out of the model at a set elevation. This allows a known fixed groundwater level to be replicated in the model. At NPM, this was obtained from groundwater level monitoring in the vicinity of the Project Area (MER 2006, PB, 2001).

5.2.5 Aerial Recharge

Aerial recharge in the NPM model will be a function of direct infiltration from precipitation, leakage from the Tailing Storage Facilities (TSF) and seepage from waste rock and other management facilities.

These factors were incorporated into representative recharge rates for each of the following zones:

- Background Recharge (covering the full model domain in a uniform and constant manner at 0.4 mm/year);
- TSF 1 (11.0 mm/year);
- TSF2 (7.3 mm/year);
- Estcourt TSF (11.0 mm/year); and
- Rosedale TSF (11.0 mm/year).

These rates were obtained from previous modelling (MER, 2006) and applied in the model in accordance with the mine schedule.

The Background Recharge rate is noted as being low. This is based on previous studies at the site which suggested:

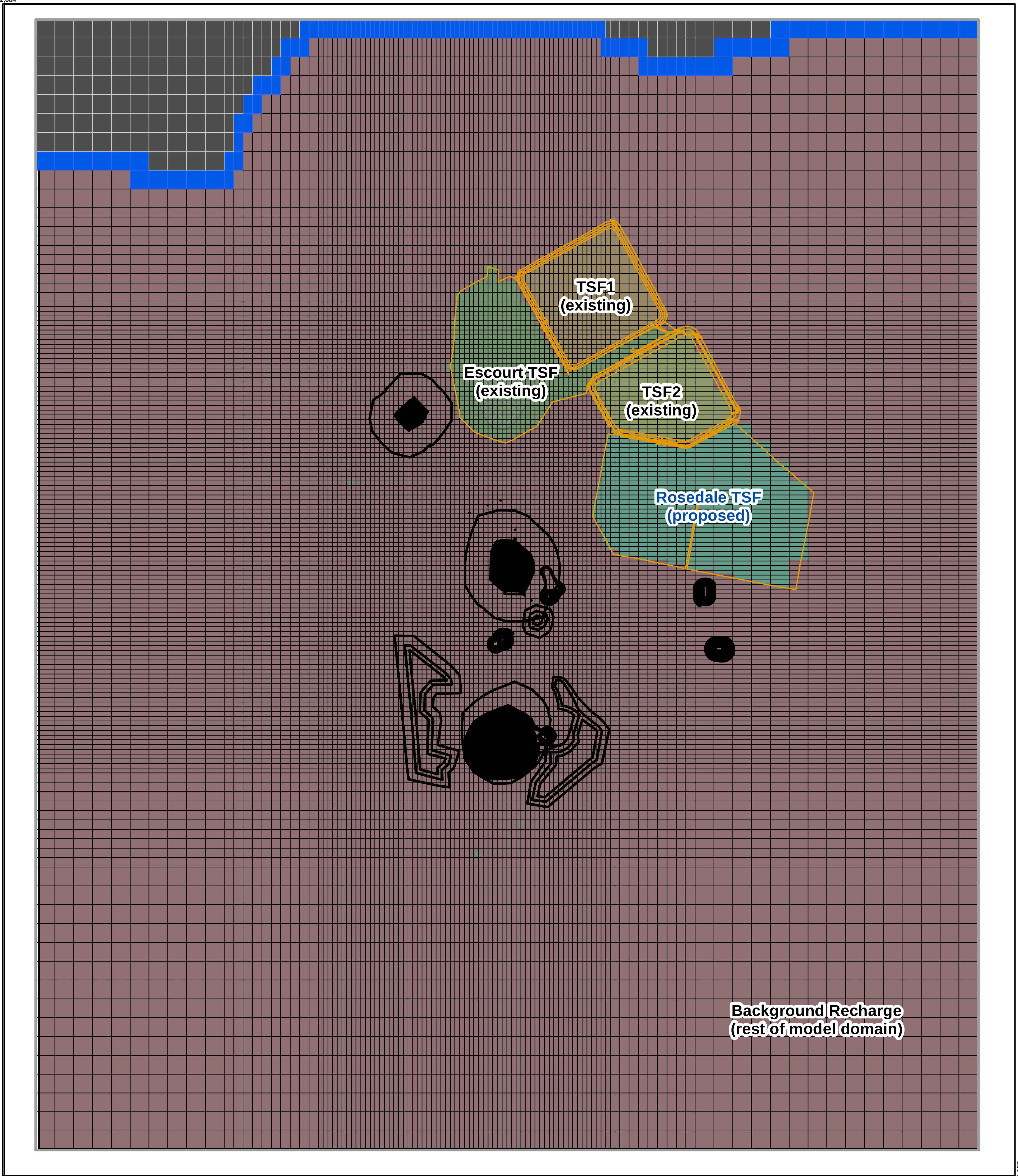
- The uniform groundwater levels over the site, combined with high salinity indicate the very little groundwater flow is occurring. Conditions are essentially static with negligible recharge or discharge through surface confining clays (Coffey, 1993);
- A very low distributed rainfall recharge rate averaging about 0.35 mm/year across most of the model domain is all that is required to establish a gradient similar to the observed regional gradient. This very low rate of recharge is directly attributed to the relatively impermeable shallow strata and the prevailing low rock mass permeabilities at depth, (MER, 2006);
- Comparison of piezometer water levels with rainfall data suggests that most piezometers do not show a discernible response to rainfall (PB, 2003). PB goes on to say there is minimal rainfall recharge through the regolith, reflected in the calibrated model using as little as 0.14% of the annual average rainfall as recharge (PB, 2003);

The low value used for recharge is considered conservative for impact purposes as a low recharge should extend the zone of influence of drawdown in response to mine dewatering. It should be noted however, that this may correspond to an underestimation of the modelled dewatering rates.

At the start of the modelling period, all zones were assigned with the Background Recharge value. Conditions were altered according to the historical or proposed progress of mining and development of the TSF.

Cessation of altered recharge for all TSF was assumed to be 2032, assuming three years of leakage from the TSF after cessation of mining. It was assumed that after three years, no further leakage would occur from the TSF. After this point, the recharge rate was set to that of the background recharge rate.

Initial groundwater heads were taken from steady state calibration (Figure 25) based on pre-mining groundwater levels (PB 2001).



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Recharge Zones in the Model Domain

LEGEND

- Mine Operations (Existing and Proposed)
- Tailings Storage Facilities (existing and proposed)
- Groundwater Model Extent
- No Flow Cell
- Constant Head Boundary
- Groundwater Model Cell Discretisation

0 0.5 1 2 3 4 Kilometers

SCALE (at A4) 1:40,000
Coordinate System: GDA 1994 MGA Zone 55

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FIGURE 24

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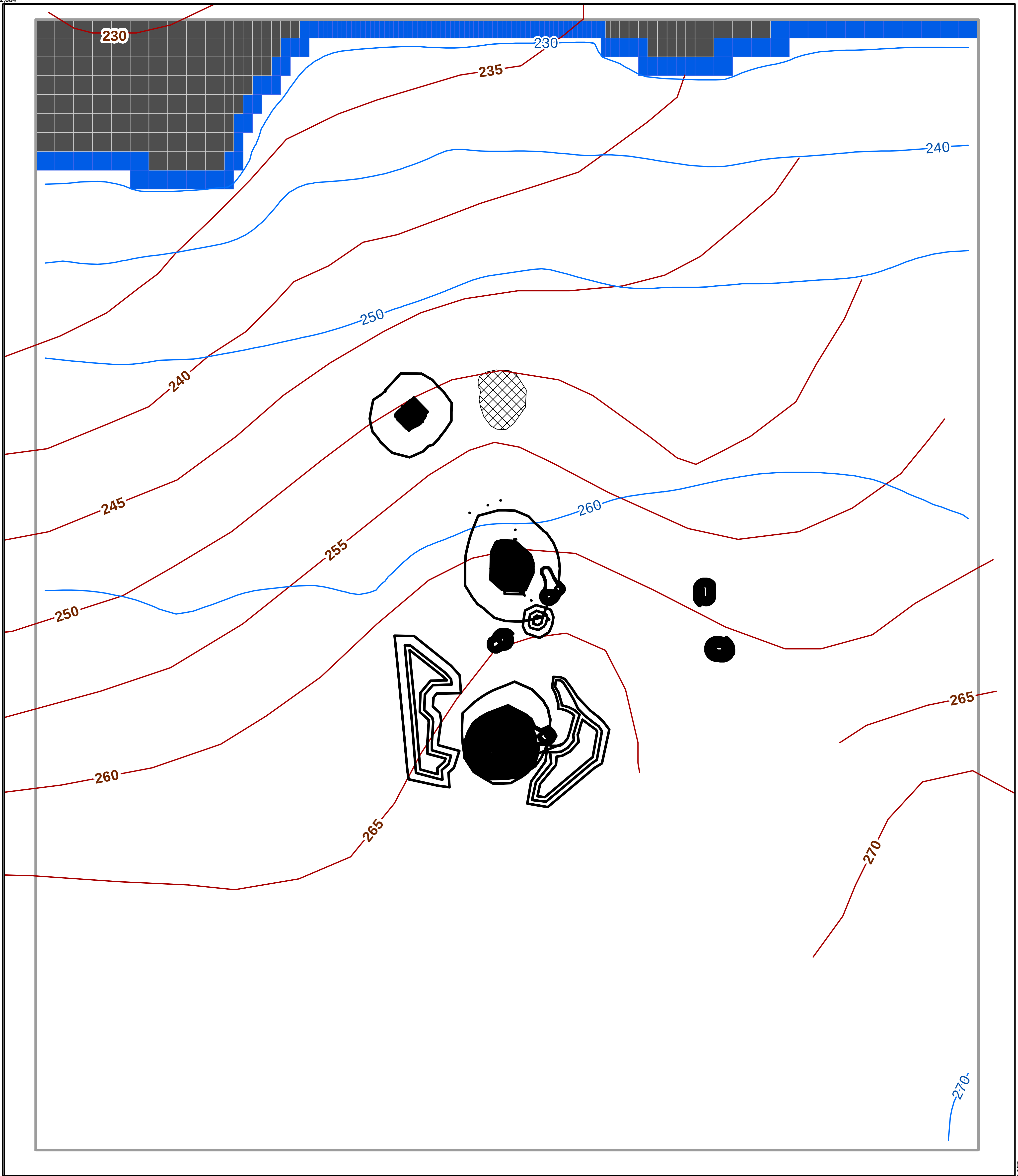

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Initial Groundwater Head against Observed Groundwater Levels (PB, 2001)

LEGEND

- Mine Operations (Existing and Proposed)
- Initial Modelled Groudnwater Head (Pre-mining)
- Inferred Groundwater Level (Pre-mining)
- Groundwater Model Extent
- No Flow Cell
- Constant Head Boundary

0 0.5 1 2 3 4 Kilometers

NOTES

SCALE (at A4) 1:40,000
Coordinate System: GDA 1994 MGA Zone 55

PROJECT: 117626007
DATE: 30/04/2013
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CHECKED: LJ

FIGURE 25

N

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5.2.6 Bogan River Modelling

The Bogan River and associated tributaries were considered not to be in hydraulic continuity with the groundwater. They are ephemeral (PB, 2003) and inferred to receive no baseflow contribution from groundwater. This is replicated in the model as the water table does not intersect the upper surface of the model at any point.

MER (2006) concluded that:

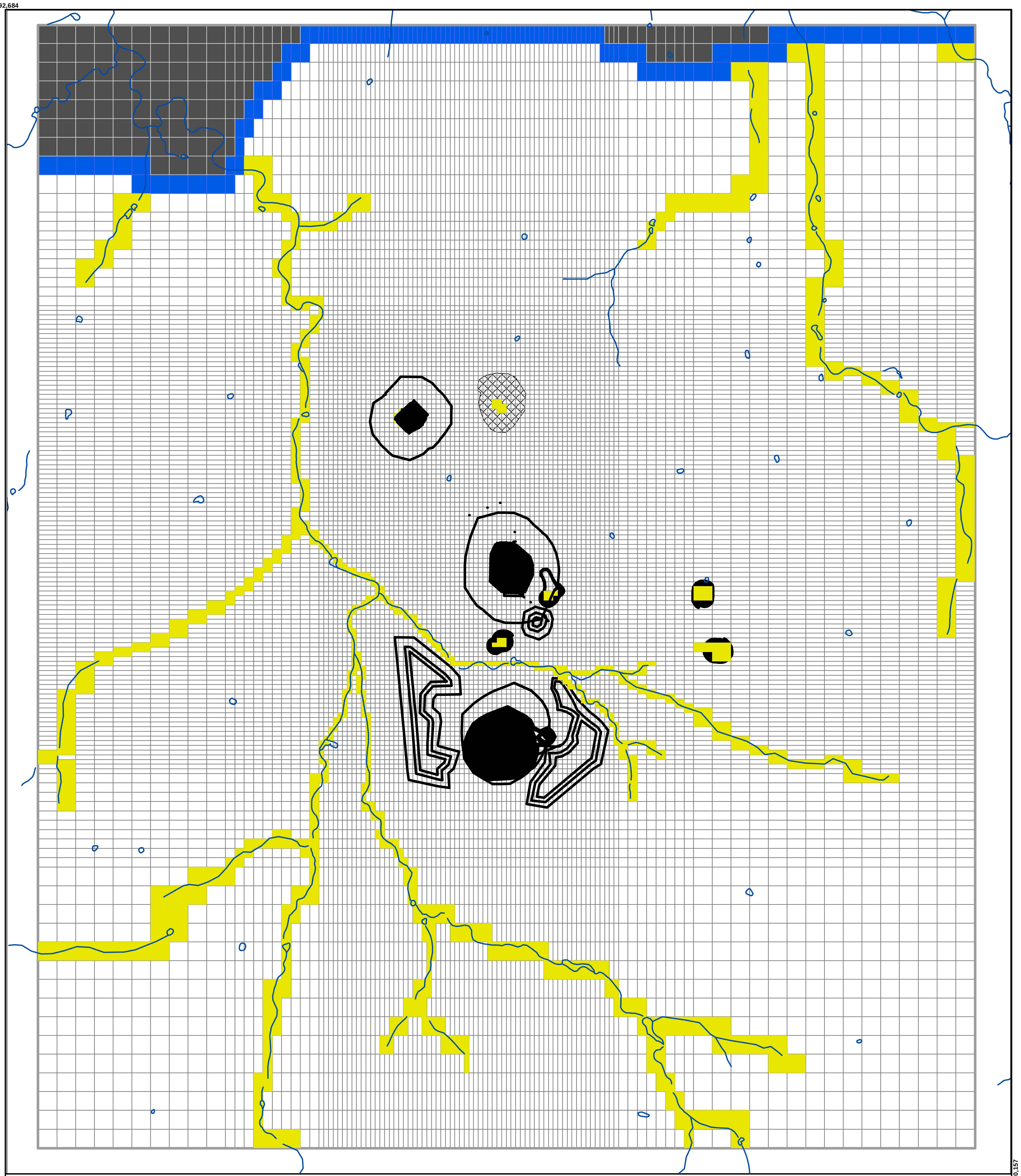
- *"Impact of sub-surface depressurisation on surface drainages including the Bogan River is predicted to be negligible. Based on the interpolated regional groundwater table, an unsaturated zone prevails between local drainages and deeper groundwater within the regolith. This zone is of the order of 30m. With the exception of bank storage, this scenario represents an influent river. Any increase in the depth to groundwater as a result of mining operations would not affect the leakage rate from the river channel and tributaries in a measurable way".*

Although the ephemeral Bogan River may contribute groundwater recharge during periods of flow, it has not been included in this model. This is because groundwater levels are below the base of the creek (MER, 2006) therefore it is assumed that groundwater depressurisation will not impact the surface water flow regime.

Furthermore, the ephemeral nature of the river means recharge will only be brief and not significantly contribute to the groundwater flow regime.

5.2.7 Surface Water Drain

A drainage pattern was incorporated into the model using drain cells located in the top layer, approximately 5 to 10 m below the upper surface of the model. The distribution of the drain cells are shown in Figure 26. These drain cells were likely to only be active if the TSF were to result in a significant rise in the water table due to the depth of the water table in the model.



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Groundwater Model with Drain Locations and Drain Cells (Layer 1)

LEGEND

- Mine Plan (existing and proposed)
- Drainage
- draincells
- Groundwater Model Extent
- No Flow Cell
- Constant Head Boundary
- Groundwater Model Cell Discretisation

NOTES

SCALE (at A4) 1:40,000
Coordinate System: GDA 1994 MGA Zone 55

PROJECT: 117626007
DATE: 30/04/2013
DRAWN: HW
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FIGURE 26

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Modelling Mine Progression

A detailed mine progression plan was not available at the time of modelling. Depths and anticipated annual extraction tonnage was available and these were used in this assessment.

Dewatering of the mine was simulated using drain cells. These allow the free removal of water from the model at a specified elevation to recreate instantaneous removal of water from the model. They do not permit water to enter the model.

Drain cells were sufficient to replicate the dewatering from the open pits as well as the block cave mines. These were applied in the model in a staged manner, to replicate the mine schedule.

The depth and periods of operation used in the Project model are summarised in Table 21.

Table 21: Assumed Simplified Mine Progression

Operation	Mining Period (Year) (Approximate)		Drain Cell Elevation (mAHD)	Model Layer/s
	Initiation	Cessation		
Open Pit Operations				
E22	1994	2032	140	1 to 3
E26	1995	2032	50	1 to 4
E27	1994	2005	80	1 to 3
E28	2018	2032	220	1 to 2
E28N	2018	2032	230	1
E31	2018	2019	210	1 to 2
E31N	2014	2017	220	1 to 2
Block Cave Mine				
E22 lift 1	2022	2032	-340	9
E26 Lift 1	1996	2032	-220	7
E26 Lift 2/2N	2022	2032	-560	12
E48 Lift 1	2006	2032	-300	9

Notes:

1. Historical mine progression taken from MER 2006.

It was assumed that all operations remained dewatered until cessation of mining in 2032.

5.2.8 Model Calibration

Model calibration is defined in the Australian Groundwater Modelling Guidelines (Barnett, et. al. 2012) as a process following model design and construction by which parameters are adjusted until model prediction fit historical measurements or observations, so the model can be accepted as a good representation of the physical system of interest.

The initial hydraulic parameters from the MER (2006) model were based on calibration against measured pit seepage rates at E22, E26 and E27. This range in hydraulic conductivity was consistent with previous modelling of the open cut pits (MER, 1999 and PB, 2001).

With the addition of more recent groundwater level observation data and total dewatering rates (assumed to be the total groundwater inflows to the underground mine), steady state and transient calibration of the MER 2006 and PB 2001 model parameters was undertaken.

Inflows to unmined operations were assumed to be of a similar order of magnitude to existing operations.

Transient Calibration

Transient calibration (i.e. calibration modelling over a historical period of time for which site observations were available) was conducted from initiation of mining at NPM (1 January 1994).

Initial groundwater heads, representing pre-mining conditions were taken from a calibrated steady state model. At this time an undisturbed water table has been assumed with a generally northward flow direction (PB, 2001).

Calibration by altering the hydraulic conductivity, specific storage and drain cell set up (both surface water drains and mine drain cells) was undertaken against the following observation data:

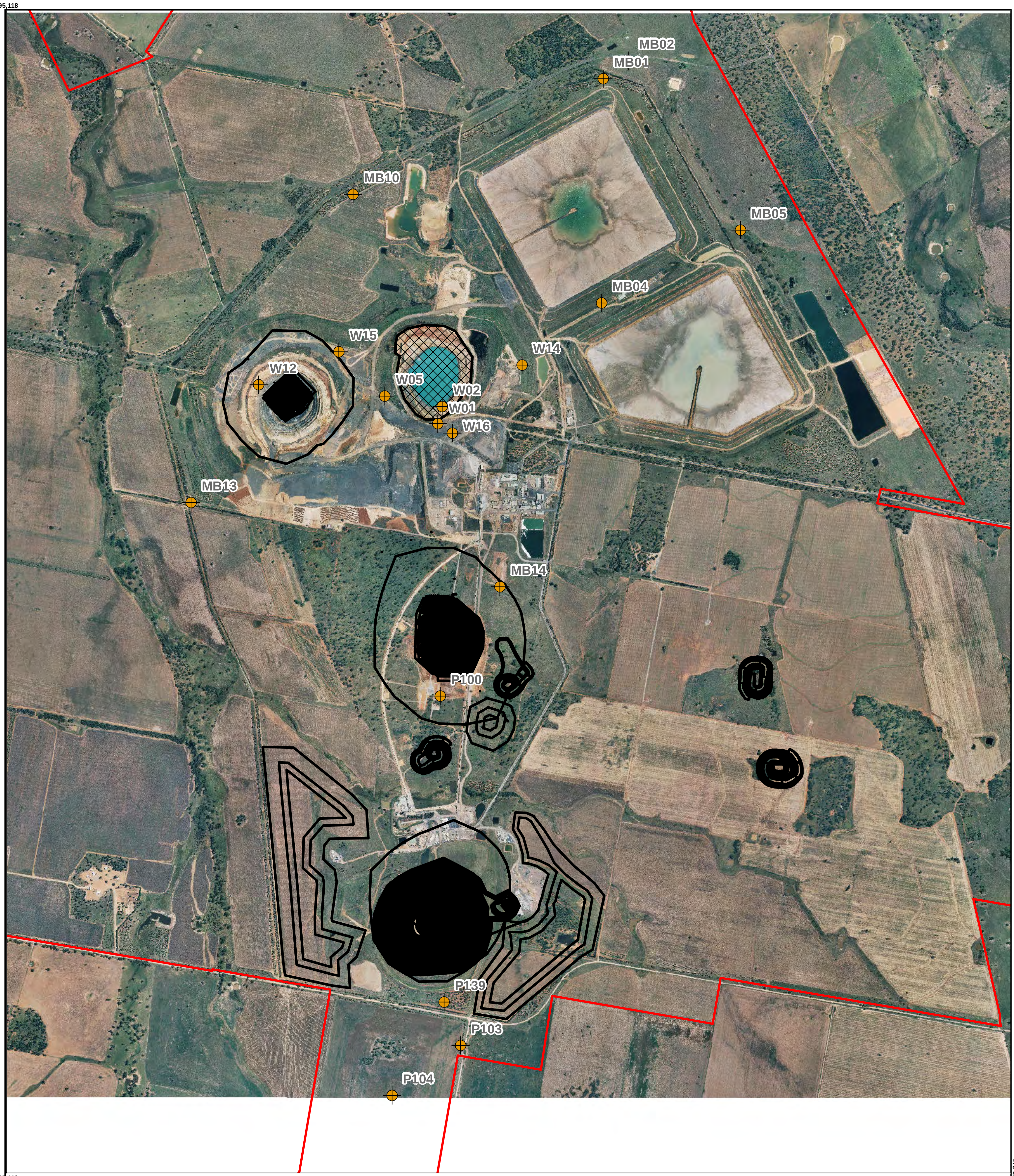
- Observed seepage rate into mine from 01/10/2002 to 31/07/2011; and
- Observed groundwater levels at selected observation bores (APPENDIX C). Not all observation bores at the site were used. Bores were selected based on the completeness of their records (both temporally and in terms of bore details) and to avoid repetition of adjacent bores with similar records.

No statistical analysis on the calibration was undertaken. This was due to the uncertainty in the observed dewatering rates from the mine and their highly fluctuating nature as well as the anticipated error in replicating the significant drawdowns within the model taking into account the temporal and spatial discretisation of the model.

Generally the modelled groundwater levels were in reasonable agreement with the observed groundwater levels for the majority of observation bores. The groundwater levels computed with the calibrated model tended to be higher than the observed groundwater levels.

Modelled drawdown was also generally greater than observed. This is likely due to the methodology employed in the model for capturing the actual dewatering at the mine. Drain cell conditions become instantaneously active at a given stress period, whereas in reality, the progression of the mine would be expected to dewater in a staged manner. Given the intended purpose of the investigation and the temporal resolution of the model, this was considered an acceptable level of calibration.

The groundwater level rise in the vicinity of the TSF was relatively well captured in the model, as demonstrated in MB1, MB2, MB4, MB5, MB10, MB13 and MB14 in (APPENDIX C). The trend in the modelled groundwater levels reflecting the observed trend in groundwater levels in the vicinity of the TSF suggests the values for recharge assigned to the TSF are acceptably representative of the processes occurring in this area.



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Mine Plan (Existing and Proposed) with Groundwater Observation Bore Locations

NOTES

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LEGEND

- Observation Wells utilised in MODFLOW
- Mine Plan (existing and proposed)
- Project Area

0 0.5 1 2 Kilometers

SCALE (at A4) 1:25,000
Coordinate System: GDA 1994 MGA Zone 55

PROJECT: 117626007
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FIGURE 27

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The observed total dewatering from all mine operations was considered more reliable for calibration modelling.

The calibration of hydraulic parameters to the observed underground to mill flow data, which is considered to have an error margin of ± 20%, is shown in Figure 28.

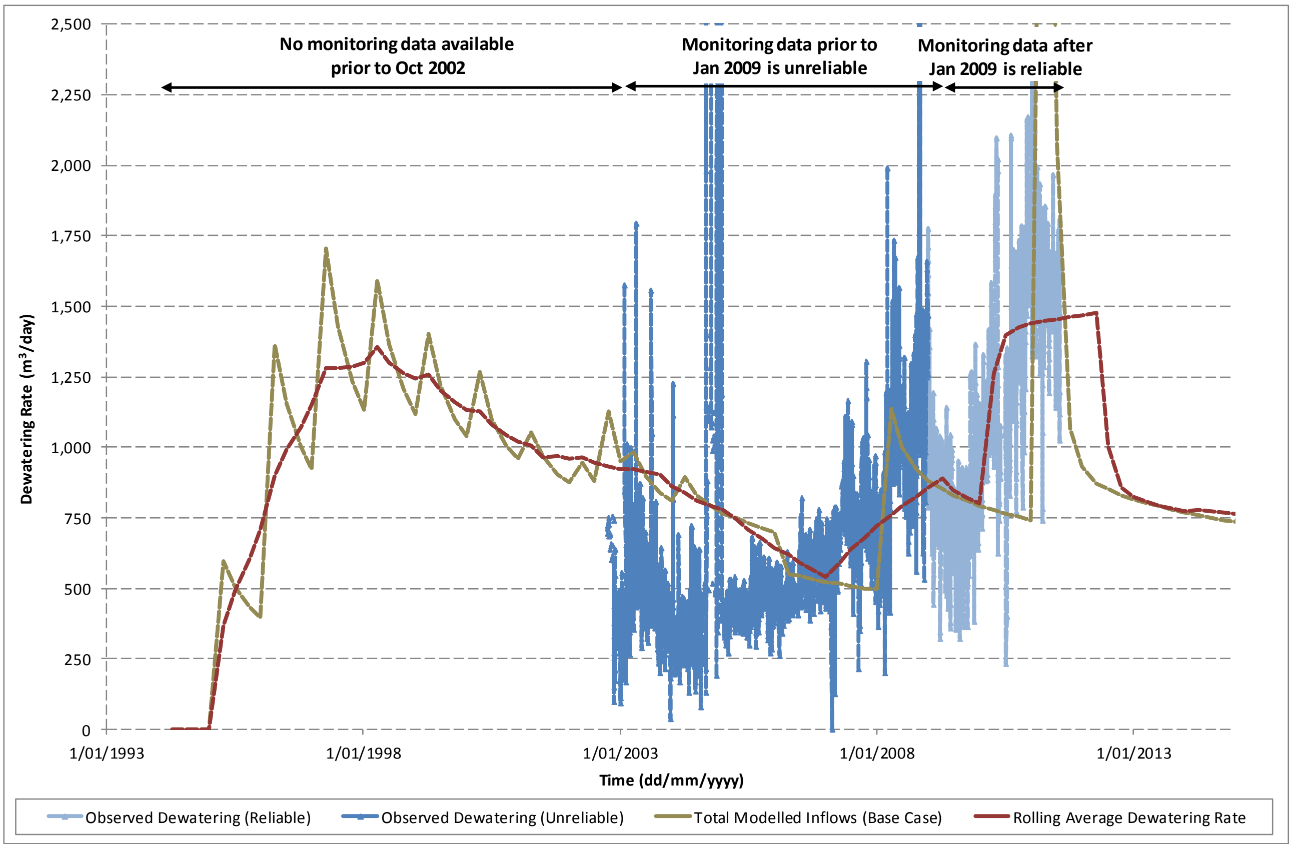


Figure 28: Observed verses Total Modelled Seepage Rate into all Mine Operations (± 20%)

Figure 28 shows the total modelled dewatering from all operations were in broad agreement with the observed dewatering. There is likely to be discrepancy between the observed groundwater seepage inflows and the modelled values as part of the historical mine progression was assumed, as shown in Table 21

The high peak in modelled dewatering in 2012 is due to the initiation of mining at E26 Lift 1. These peak inflows are not considered representative of actual observed dewatering rates due to the way in which the model replicated instantaneous dewatering in the deepest part of E26 Lift 1. In reality this would be progressively dewatered as the access to this part of the mine was established.

A rolling average has been presented in Figure 28 to remove this effect and this is considered more representative of actual inflows.

Calibrated hydraulic parameters for this Base Case model are summarised in Table 22.

Table 22: Calibrated Hydraulic Parameters for the Project Model

Strata / feature	Model Layer/s	Horizontal Hydraulic Conductivity: Kxy (m/d)	Vertical Hydraulic Conductivity: Kz (m/d)	Specific Storage (Ss)	Specific Yield (Sy)
Regolith	1	$9.0x10^{-3}$	$9.0x10^{-4}$	$5.0x10^{-4}$	0.15
Caved Zone	1	$6.0x10^{-3}$	$6.0x10^{-3}$	$9.0x10^{-4}$	0.0015*
Open Pit Zone	1 to 4	0.1	0.1	$5.0x10^{-4}$	0.15
Bedrock: Saprock/OTZ and the top of the moderately fractured bedrock	2 to 4	$1.0x10^{-3}$	$1.0x10^{-3}$	$7.5x10^{-4}$	0.015
Enhanced k features in vicinity of E22 and E26	2 to 4	$6.0x10^{-3}$	$6.0x10^{-3}$	(as bedrock layers: 2 to 4)	
Low k fault to south of E26	2 to 4	$1.0x10^{-6}$	$1.0x10^{-6}$		
Mineralized zone	2 to 12	$9.0x10^{-4}$	$9.0x10^{-4}$	(As bedrock of corresponding layers)	
Bedrock: moderately fractured	5 to 10	$9.0x10^{-5}$	$9.0x10^{-5}$	$7.5x10^{-4}$	0.015
Bedrock: occasionally fractured	11 to 17	$7.0x10^{-6}$	$7.0x10^{-6}$	$8.0x10^{-4}$	0.0015

Notes:

* As the hydraulic parameters of the caved zone are not well defined, conservative values were selected.

The calibrated model for the Project is within the expected range of hydraulic parameters and broadly consistent with previous groundwater models at the site.

5.2.9 Predictive Modelling

The calibrated model described above was used as the Base Case scenario for predictive modelling. Predictive modelling was undertaken for a single scenario.

As no alternative mine plan or schedule have been proposed, no predictive model scenarios were undertaken considering possible changes. Alternative model runs were concentrated on investigating the model behaviour through sensitivity analysis.

Predicted dewatering rates for the mine for the Base Case scenario is plotted in Figure 29.

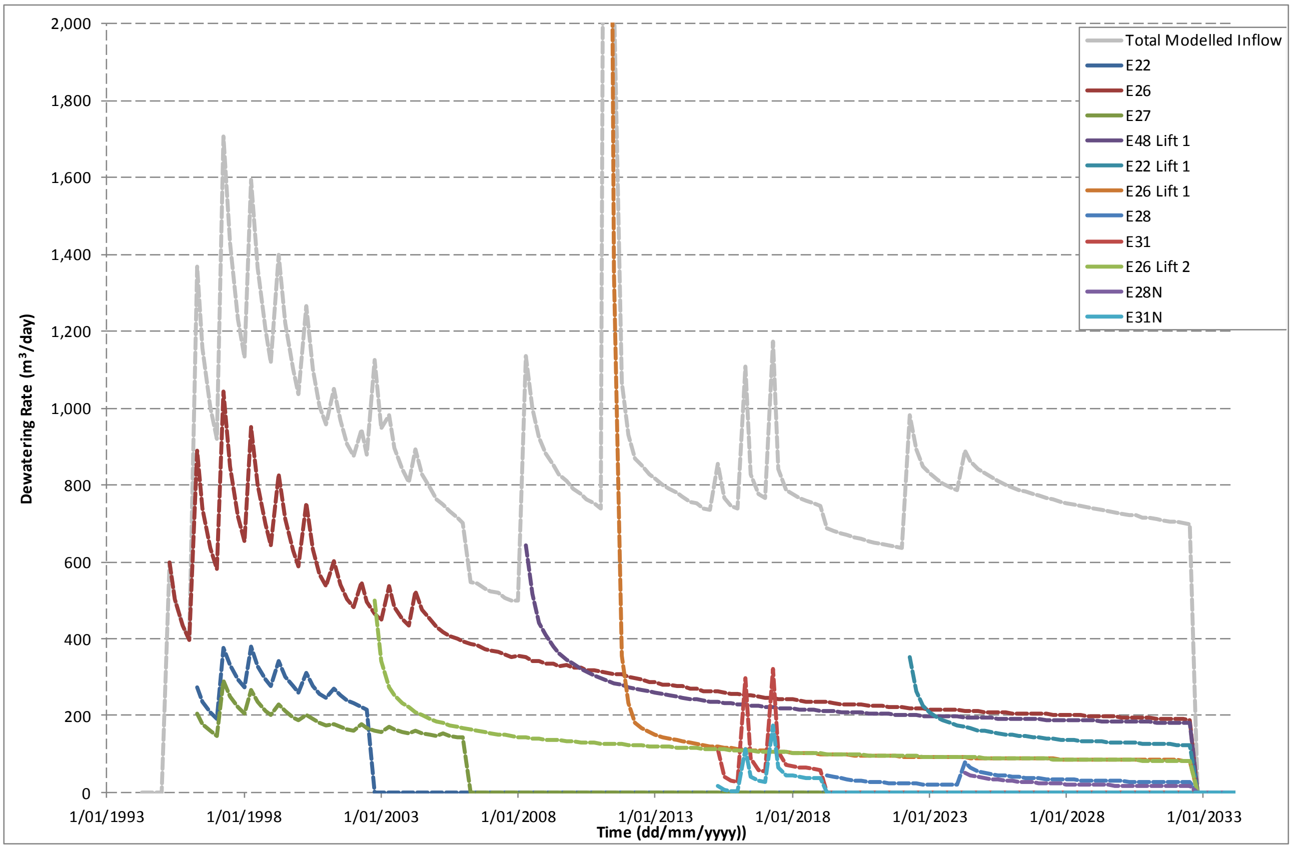
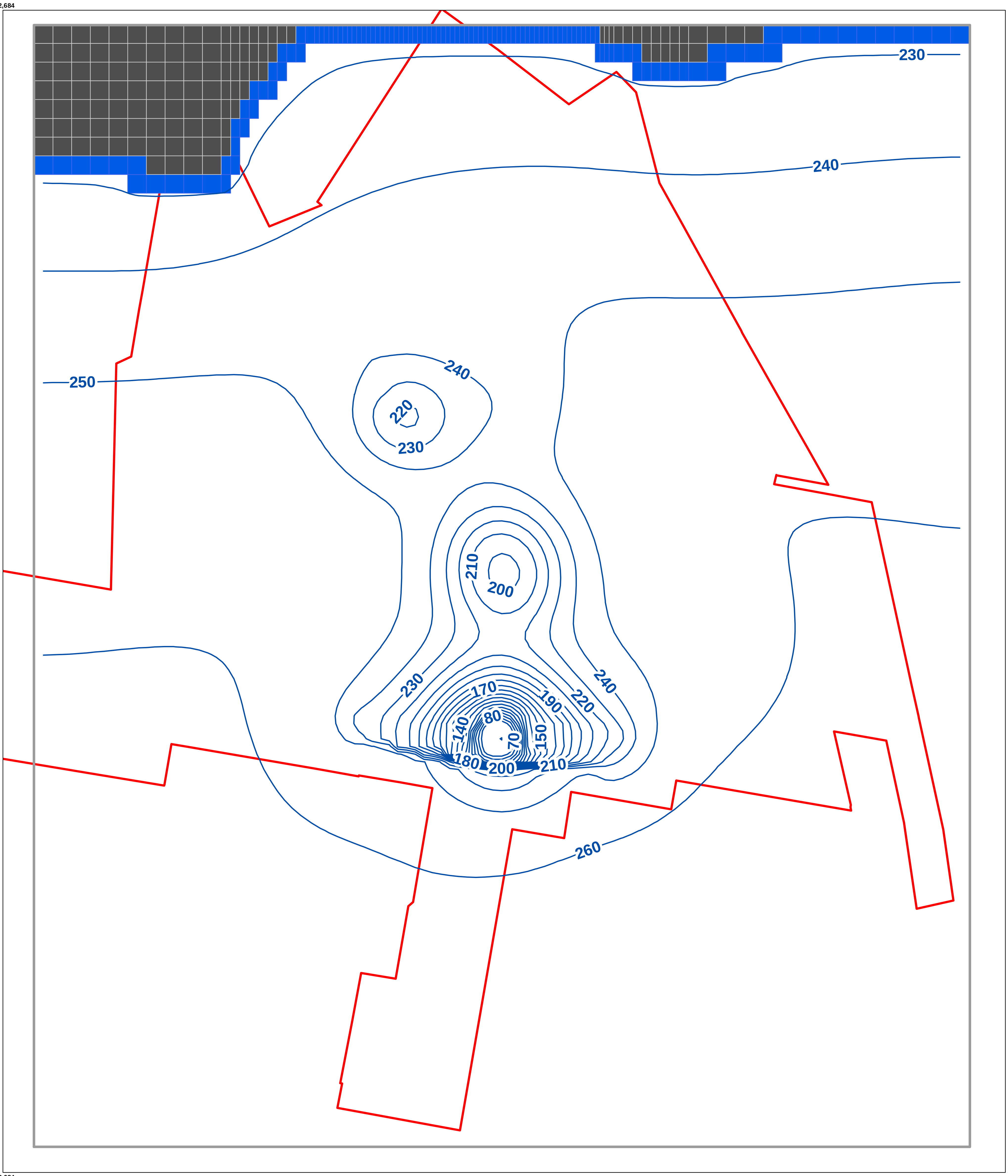


Figure 29: Modelled Total Inflows to the Mine

It should be noted that the modelled dewatering rate at in 2012 was considered unrealistically high. At this time in the model, dewatering begins at depth in E26 Lift 1. This value has been ignored for analysis. The quoted maximum inflows are likely to be more representative in modelled inflows in the subsequent stress period (of 2.1 ML/day).

The model predicted groundwater contours at the top of occasionally fractured bedrock at cessation of mining is shown in Figure 30 with 10 m drawdown contours plotted. Drawdown was calculated as the change in groundwater level from the initial groundwater level (Figure 25).



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Modelled Groundwater Contours at top of Bedrock (Layer 4) at Cessation of Mining

NOTES

LEGEND

- Grondwater Level (mAHD)
- Groundwater Model Extent
- No Flow Cell
- Constant Head Boundary
- Project Area

0 0.5 1 2 3 4 Kilometers

SCALE (at A4) 1:40,000

Coordinate System: GDA 1994 MGA Zone 55

PROJECT: 117626007
DATE: 30/04/2013
DRAWN: HW
CHECKED: LJ

FIGURE 30

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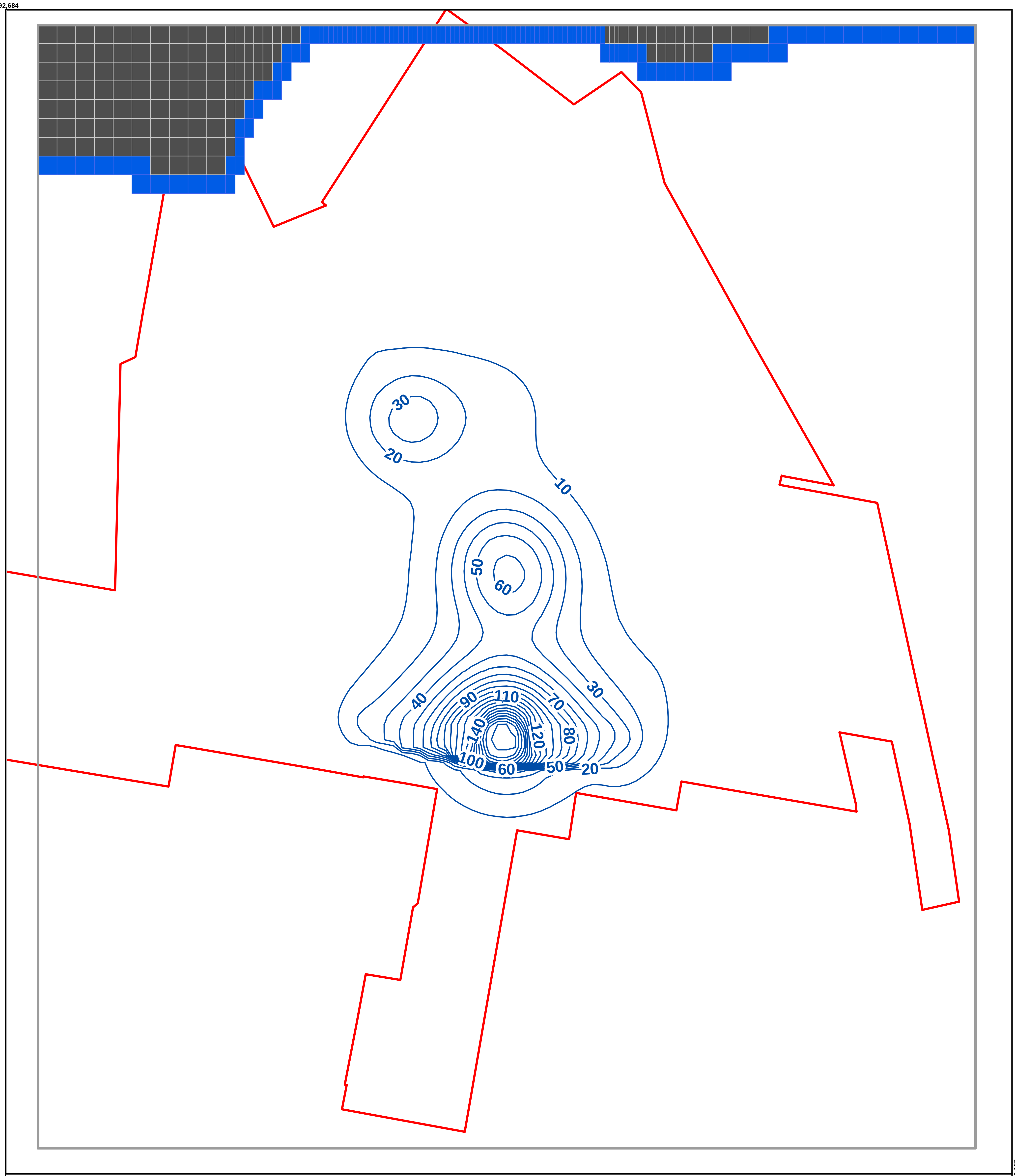

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Groundwater Drawdown at top of Bedrock (Layer 4) at Cessation of Mining

NOTES

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LEGEND

- Groundwater Drawdown (m)
- Groundwater Model Extent
- No Flow Cell
- Constant Head Boundary
- Project Area

0 0.5 1 2 3 4 Kilometers

SCALE (at A4) 1:40,000

Coordinate System: GDA 1994 MGA Zone 55

PROJECT:	117626007
DATE:	30/04/2013
DRAWN:	HW
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FIGURE 31

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A water balance for a numerical model provides an indication of the difference between water inflows to the model against water outflows from the model and any changes in the amount of water in storage within the model domain.

The Australian Groundwater Modelling Guidelines (Barnett, et. al. 2012) suggests 3 classes of model with a decreasing confidence from class 3 to class 1.

The model has an overall percentage error in the water balance of 0.6%. This is just above the 0.5% required to be a class 3 (the highest confidence class) model.

5.2.10 Mine Closure Modelling

Groundwater recovery within mine voids is initiated after cessation of mining (i.e. once dewatering has ceased and groundwater levels begin to recover). Recovery here was defined as approximate steady state conditions (i.e. where groundwater levels do not change significantly over time) and occurs at approximately 80% of the pre-mining groundwater levels.

Predicted recovery of groundwater levels to within 80% of their pre-mining levels occurred 77 years after cessation of mining. The maximum groundwater depression at this time was:

- Approximate groundwater depression of 42 m at E26;
- Approximate groundwater depression of 10 m at E22; and
- Approximate groundwater depression of 10 m at E48.

The shallower open pits were predicted to achieve complete recovery at this time.

It should be noted however that the potential effect of evaporation losses from flooded pits on groundwater levels has not been assessed in this model. It is likely that some permanent depression in groundwater levels would be likely. As no mine closure plan was available at the time of modelling, this could not be incorporated in to the model.

5.3 Conclusions from Predictive Model

In summary, modelling groundwater conditions at NPM suggests the following:

Regulatory Considerations:

- The extent of modelled drawdown of groundwater in the bedrock at cessation of the proposed mining is approximately 4.5 km from the pits;
- Due to the perched nature of the surface water, dewatering from the mine is not expected to impact surface water flow in the Bogan River or its tributaries;
- This is likely to be an over-estimation as computed drawdown is greater than historically observed drawdown. This is likely to be a result of the model discretisation and steepness of the actual drawdown cones surrounding each pit;
- Additional targeted groundwater level monitoring may be beneficial towards the north of the pits, to monitor the bedrock depressurisation;
- Additional targeted groundwater level monitoring may be beneficial towards the west of the pits, to reinforce confidence in the shallow groundwater and surface water conceptual model and to confirm there is no potential interaction between these systems;
- There is no impact from the locations of the TSF on the predicted zone of influence of dewatering the mine. This is as would be expected, due to the low permeability layers near the surface and the steepness of the drawdown predicted around each operation;

- There is a steady increase expected in groundwater seepage into the mine as the mine progresses. The maximum modelled inflow is 0.8 ML/day, at the end of 2010. Predictive modelling suggests a slightly lower peak inflow of 0.7 ML/day at the end of 2021;
- Modelled inflows to the individual operations are relatively stable. There are no significant predicted spikes in groundwater seepage other than at the start of each operation, and this is likely to be due to the instantaneous activation of the drain cell to replicate mine dewatering (modelling artefact);
- E26 and E48 are the most significant contributors to groundwater seepage;
- Discrepancies between the observed seepage and modelled seepage are likely to arise from details in the mine progression. It is considered however that the mine progression does not significantly impact the overall seepage rates into the mine;
- Groundwater levels are anticipated to recover to a post-mining groundwater level of 42 m (at E26) below pre-mining groundwater level after mine closure. The other block cave zones are predicted to be depressed by approximately 10 m; and
- The depression of groundwater in the vicinity of the open pits is not known. This is because the mine closure plan is not explicitly modelled to include additional evaporative losses in the location of the pits.

5.3.1 Sensitivity Analysis

Sensitivity analysis is a process to vary selected model parameters of the Base Case scenario. It provides information on the impact that selected parameters have on model predictions and is undertaken to provide an understanding of the uncertainty in the model parameters.

Sensitivity analysis was undertaken on seven aspects of the Base Case scenario model (i.e. all hydraulic and input parameters unchanged, unless otherwise stated). These were referred to as the Sensitivity Analysis (SA) models: SA1 to SA7 summarised as follows:

- **SA01 – TSF drains**: with the addition of seepage drains around all TSF. This was to investigate if drains or active dewatering from boreholes would be generally suitable to control rising groundwater levels downstream of the TSF;
- **SA02 - CSIRO climate scenario**: following recommendations from CSIRO (Barron et.al., 2010) in their change scenario analysis for all groundwater models, investigate potential climate change scenarios by decreasing recharge by 20%;
- **SA03 - Enhanced TSF recharge**: investigate the potential for increased leakage from the TSF by increasing the recharge beneath the footprint of al TSF by a single order of magnitude;
- **SA04 - Enhanced vertical hydraulic conductivity**: investigate the effect of the selected vertical hydraulic conductivity in the vicinity of the mine operations by increasing the vertical hydraulic conductivity (kz) in the following modelled strata (refer Table 22):
    - Regolith (model layer 1);
    - Caved zones (model layer 1);
    - Mineralised zone (model layers 2 to 12); and
    - Open pit areas (model layers 1 to 4).
- **SA05 - Enhanced vertical and horizontal hydraulic conductivity**: to investigate the effect of vertical and horizontal conductivity in the same strata as listed in SA04 in the above bullet point;
- **SA06 - Enhanced background recharge:** to investigate impact of the selected recharge value, this parameter was increased by 20% from the Base Case model;

- **SA07 - Enhanced recharge in the mine operations and caved zones**: to investigate of increasing the recharge rate in the caved zones only. Recharge rates were obtained from the MER model (2006).

Modelled total inflows to the mine for each scenario are given in Figure 32.

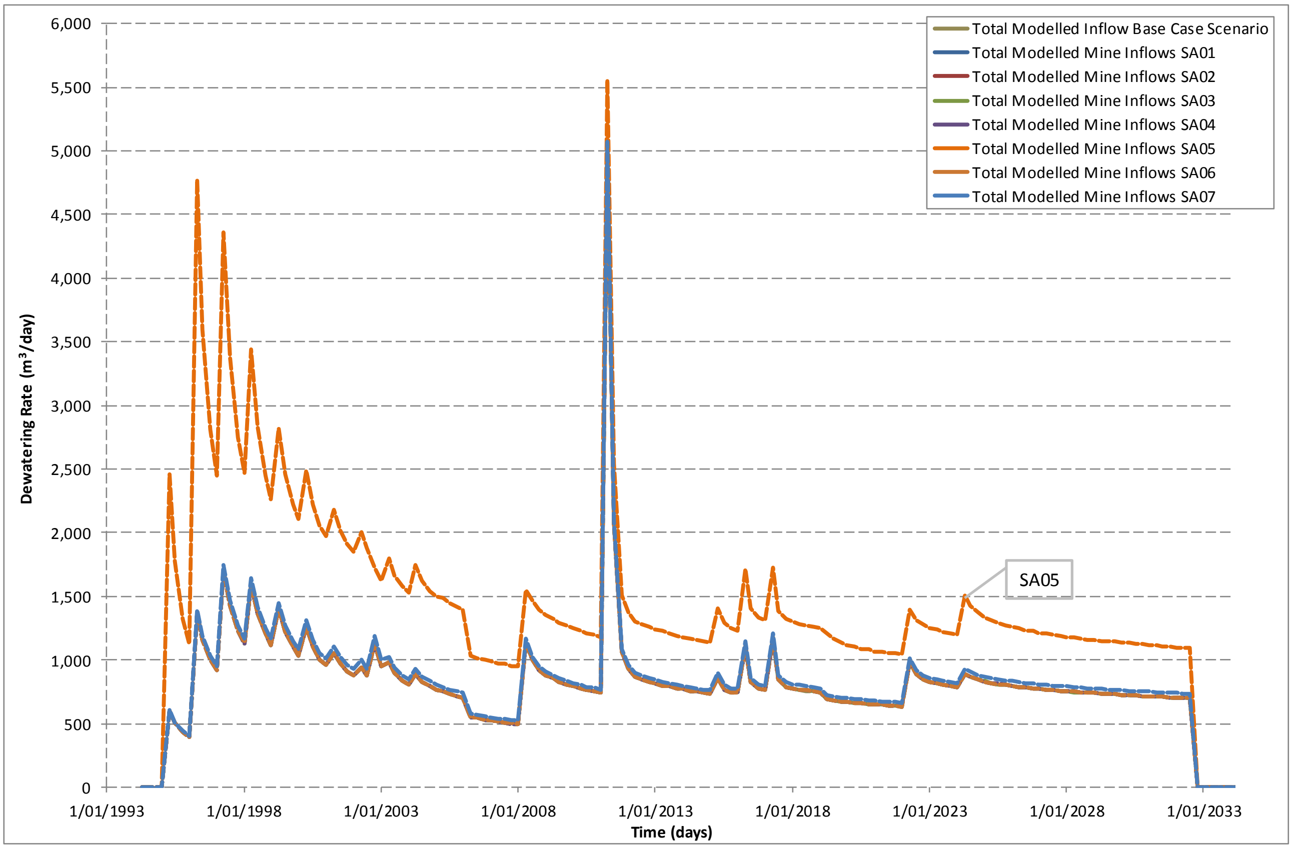


Figure 32: Modelled Groundwater Inflow to the Mine for all Sensitivity Analysis Model Runs

Figure 32 shows that there is no significant alteration to the predicted seepage rates into the mine or zone during sensitivity analysis. Sensitivity Analysis results can be summarised as follows:

- The two TSF sensitivity models: **SA01** (Additional drains around the TSF) and **SA03** (enhanced leakage from the TSF) would not be anticipated to alter the inflows to the mine as the drawdown from the mine does not significantly extend beneath the TSF. Furthermore, any increase pressure head beneath the TSF did not extend to the top of the occasionally fractured bedrock (Layer 4 in the model) due to the low permeability nature of the regolith;

- There is no significant alteration to groundwater levels during or after mining down hydraulic gradient of the Project Area in any of the scenarios;

- The two climate sensitivity models: **SA02** (CSIRO climate change scenario) and **SA06** (20% increased Background Recharge) were not likely to have a significant impact on the inflows. This was anticipated, due to the low recharge rates applied in the Base Case scenario as well as the low permeability strata at the surface that is known to impede recharge (MER, 2006).

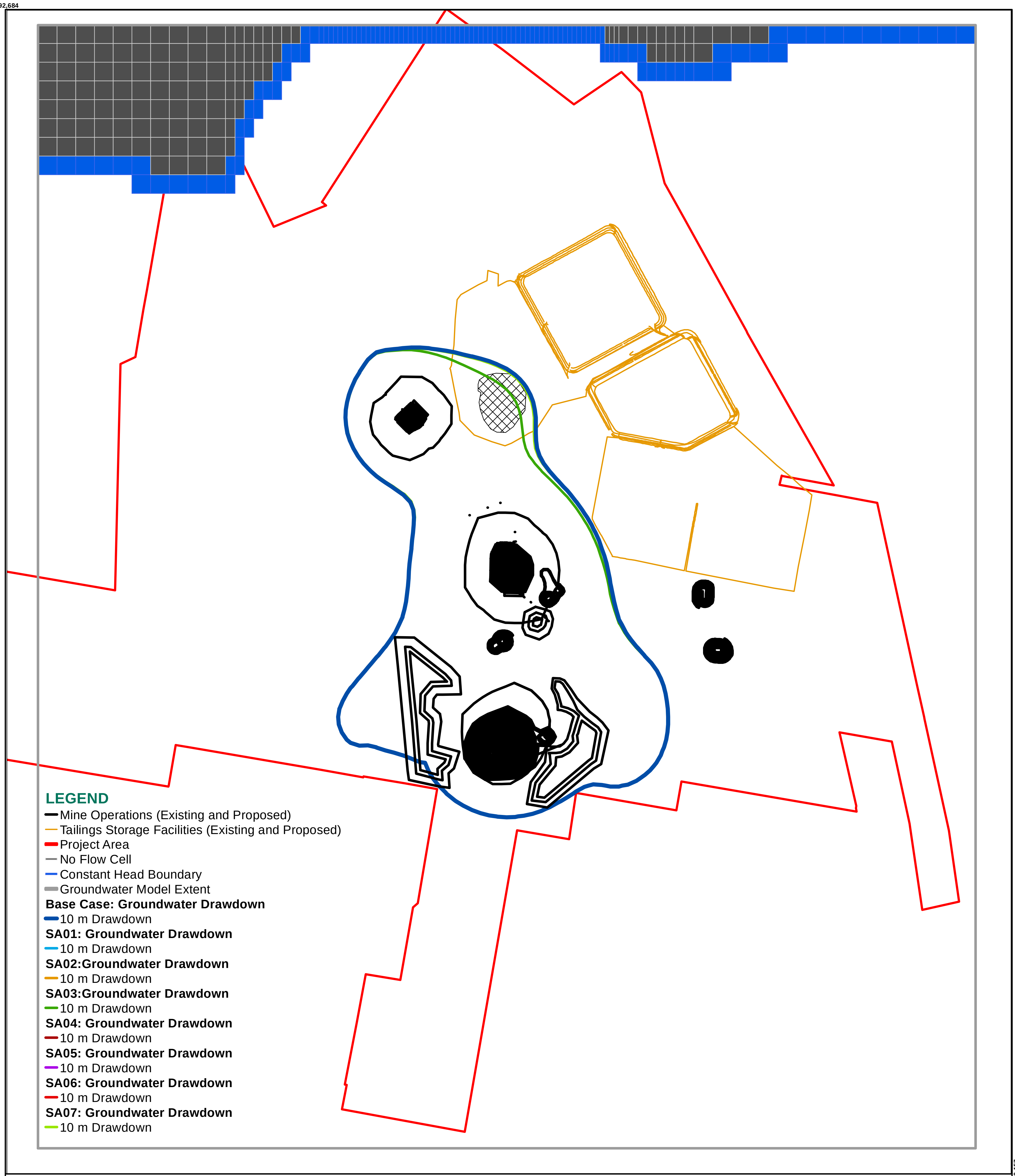
- **SA04** (increase in vertical hydraulic conductivity) did not significantly alter the model results, likely to be due to the dewatering effect observed in the model directly above the drain cells. Once dewatering was complete, those cells with enhanced vertical hydraulic conductivity remained dry. As recharge was not sufficiently high to permit significant additional recharge, despite the higher vertical hydraulic conductivity, no significant difference was observed in the modelling results;

- **SA05** (Enhanced vertical and horizontal hydraulic conductivity) scenario gave modelled inflows of up to approximately 40 % higher than the Base Case scenario. This is likely to be due to the higher horizontal permeability permitting significantly more flow to the drain cells from surrounding strata even after the cells directly above the drain cells become dewatered; and
- **SA07** (increased recharge in the caved zones) also did not deviate from the Base Case model result, likely to be due to a similar reason that the climate scenarios (SA02 and SA06) did not impact the results, i.e. the low permeability Regolith in the model as well as relatively low recharge rates throughout the model would likely result in limited variance in the model results when changing these parameters. The reasons for a limited impact are also similar to those discussed in SA04.

The extent of hardrock depressurisation for the sensitivity analyses (taken to be the top of the occasionally fractured bedrock; i.e. Layer 4 in the model) at the cessation of mining is shown in Figure 33 below.

Figure 32 and Figure 33 show that there is no discrepancy between the drawdown contours for all Sensitivity Analysis scenarios against the Base Case scenario.

Sensitivity Analysis results demonstrated that the low recharge rates are a controlling factor in the occurrence and flow of groundwater. Furthermore, the likely low permeability range of the strata throughout the model would be anticipated to limit the range of possible results from modelling, as demonstrated in the limited range of results produced in Sensitivity Analysis.



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Groundwater Drawdown at top of Bedrock (Layer 4) at Cessation of Mining for all Scenarios

NOTES

0 0.5 1 2 3 4 Kilometers

SCALE (at A4) 1:40,000
Coordinate System: GDA 1994 MGA Zone 55

PROJECT: 117626007
DATE: 30/04/2013
DRAWN: HW
CHECKED: LJ

FIGURE 33

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5.3.2 Model Assumptions

There are a number of assumptions made when undertaking the numerical modelling for the Project. Model assumptions should be considered when interpreting the modelling results. These assumptions are in in addition to those given in MER (2006) and include the following:

- MER (2006) E48 Project mine model was assumed to be reliable, in terms of all model input parameters, hydraulic parameters and mine progression. Additional monitoring data and dewatering observation data used in calibration did not significantly impact the calibration results of the MER 2006 model;
- Open pit mine progression was based on linear relationship between initial and final depths, progressing at stepped six monthly rate (the temporal resolution of the model) a rate that directly reflected the predicted extraction tonnage provided by NPM;
- Block cave mine progression was assumed initiate from the first extraction period from each operation and instantaneously result in caving above the base of the caved zone. This was represented by altering the hydraulic parameters of the model layers directly above the drain cells;
- Each operation continues to be dewatered until cessation of all mining. This is considered a worst case scenario in terms of inflows to the mine and extent of depressurisation as both results will be higher due to the potentially extended period of dewatering;
- No attempt has been made to replicate the temporal changes in hydraulic properties of the rock due to mining. This affects the likely infiltration rate, when subsidence reaches the near surface as well as in the rock mass;
- Increase in recharge will likely reduce the drawdown effect of the mine and therefore, the assumption causes drawdown due to the mining to be overestimated and inflow of groundwater to the mine to be underestimated;
- An equivalent porous medium (EPM) model was used to replicate the complex nature of fracture flow. This is considered an acceptable methodology for replicating the bulk properties of a fractured rock mass;
- Recharge was assumed to be constant. No attempt was made to create a transient data set reflecting time varying climatic conditions. As an observed response to recharge events are not readily reflected in groundwater levels (MER, 2006), this was considered an acceptable assumption; and
- The proposed TSF located to the east of E27 (referred to as future TSF Cell 1 and Cell 2) were assumed to begin operation as given in the MER 2006 model. The additional TSF modelling scenario included proposed TSF to the west and southeast of the pits. It was assumed that these TSF would be operational to the same time and have the same leakage rate as Cell 1 and Cell 2.

6.0 DISCUSSION ON GROUNDWATER IMPACT ASSESSMENT – MINING PHASE

The groundwater impact assessment in this report focuses on the impact and risks arising from the continuation and expansion of the existing mine (please refer to the Project description in Section 1 of this report). The current NPM mine operations already have existing environmental approvals.

The Limestone State Forest is currently managed by NPM in consultation of Forests NSW, in accordance with land swap and management agreements developed as part of the E48 Project.

The ecological values and comprehensive ecological assessment are discussed in separate technical reports prepared for NPM (Umwelt 2013, Northparkes Mines Step Change Project Flora and Fauna Assessment).

6.1 Impact assessment methodology

The potential groundwater impacts and risks as a result of the Project are assessed using a risk based framework. The risk-based approach allows the potential groundwater related risks associated with proposed mining activities to be considered and classified with respect to multiple evaluation criteria, such that the primary risk-driving activities are identified, prioritised and mitigated accordingly. The risk assessment process is summarised in Appendix D of this report.

The magnitude of an impact on groundwater resources was estimated considering the severity of the impact, the extent and duration of the impact. The categories of the sensitivity of the environmental values of groundwater resources were classified based on the groundwater quality and quantity, the size of aquifer, and the groundwater vulnerability. The significance of the groundwater impacts was assessed based on the magnitude of the impact and the sensitivity of resource/receptor. Impact Significance Assessment Results of the groundwater impact assessment were then used in the risk assessment. Descriptions for rating the sensitivity of the receptors and magnitude of impact on groundwater resources are presented in Appendix D.

6.2 Groundwater Vulnerability

The Study Area is located within zones of “Low to moderate” and “Moderate” groundwater vulnerability rating based on the NSW Groundwater Vulnerability Map (Department of Land and Water Conservation, Lachlan and Macintyre catchments, 2001). The vulnerability mapping considered major geologic and hydrogeologic factors that affect and control groundwater movement and vulnerability including depth to water table, recharge, aquifer media, soil media, topography (slope), vadose zone media and hydraulic conductivity of aquifer.

As discussed in Section 4, there are no GDEs (springs, karsts, wetlands) or national parks located within the Study Area. The river system within the Project Area is of the “influent” type. As the aquifers around the Project Area are very low yielding and of low quality, there is currently little development of groundwater sources in the vicinity of the Project Area and the potential for future development of these groundwater sources is minimal. The majority of groundwater varies from brackish to saline and has been classified as unsuitable for potable or agricultural use (either domestic, irrigation or for livestock watering) without treatment due to the elevated concentrations of sodium and chloride. Some natural exceedences of the ANZECC guidelines for stock water for aluminium, calcium, cobalt, fluoride and lead have been recorded (NPM, 2006). Yields from this groundwater zone are low; NOW bore data indicates a yield range of 0.1 L/s to 1.5 L/s. The groundwater in the region is generally not within the category “high productive” water source based on “NSW Aquifer Interference Policy” criteria. The criteria for “high productive” groundwater as defined in “NSW Aquifer Interference Policy” are total dissolved solids of less than 1,500 mg/L and water source that contains water supply works that can yield water at a rate greater than 5 L/sec. The groundwater in the Project Area is not considered to be “high productive” water source.

The alluvial aquifer system within and in the vicinity of the Study Area is low yielding and not generally used for productive land use such as the borefields in the Lachlan Valley.

6.3 Groundwater impact assessment – Mining phase

The key impacts of the Project on the groundwater regime during mining are summarised as follows.

6.3.1 Impact on Groundwater Levels and Flow

The impact of the proposed Project on groundwater levels is expected to be localised, and limited mainly to the vicinity of the mine operations.

A numerical groundwater model was developed to assess potential changes to groundwater heads due to the proposed Project both during mining and after mine closure. The assessment indicated that drawdown will occur where the rate of groundwater dewatering from the mine workings exceeds the recharge rate. Groundwater seepage into the underground or open cut mining areas could potentially induce groundwater flow from neighbouring strata (either from the host rock, or overlying regolith). This will lead to drawdown of the potentiometric surface within the immediate vicinity of the Project compared to pre-mining levels.

Pressure reductions from open cut mining are predicted to have a localised impact surrounding the mining operations. Depressurisation impacts are not predicted to have a large area of influence, due to the low hydraulic conductivity of the water-bearing formations (transported regolith, saprolite, saprock, fresh bedrocks), thus limiting the areal extent of impact. This prediction is supported by historical depressurisation from historical mining from the E22 and E27 pits (MER, 2006).

Based on the assessments described above, it is anticipated that the radius of groundwater depressurisation in the bedrock formation would extend up to approximately 4.5km from the pits at cessation of the proposed mining.

The study indicated that the Project will generate low volumes of seepage from the bedrock. The maximum seepage rate was estimated to be 0.8ML/year based on the modelling results.

Pre-mining water levels in 1983 were used to create a groundwater level contour map representing the saprock zone (PB, 2011). The contours show the regional groundwater flow is in a northerly, down-valley direction towards Wombin State Forest (Figure 14; PB, 2011). The predictive modelling results do not indicate a significant change in groundwater regional flow direction as a result of the Project activities.

6.3.2 Potential impact on surface water systems

There is no measureable groundwater impact on the surface water system within and in the vicinity of the Project Area as a result of the dewatering activities.

The surface water conceptualisation (refer to Section 4) was assessed as part of this GWIA. A tributary of the Bogan River, the Goonumbla Creek, runs east to west across the Project Area (Figure 1). The Bogan River channel runs north-south on the western side of the Project Area, coming to within 1 km of Pit E22 at its closest point. Surface drainage is northwards towards the Macquarie River and through the Wombin State Forest, located 7 km northwest of the mine.

The direction of groundwater flow through the Project Area is northwest, towards the Bogan River tributary. The depth to groundwater level is generally observed as being 40 mbgl in the Project Area, and ranging from 24 mbgl to 56 mbgl between the Project Area and the Bogan River tributary. Flow in the Bogan River only occurs after sustained periods of intense rainfall and the creeks are all ephemeral (Raymond, 2002; MER, 2006). Available information suggests the water table lies well below the base of the surface water features and does not intersect the surface drainage lines (Raymond, 2002). This suggests the groundwater does not provide baseflow to the surface water within the Project Area. Furthermore, low permeability clay soils and regolith units in the valley impede rainfall infiltration and can cause localised perched water table conditions, indicated by areas of surface ponding after rainstorms (Raymond, 2002).

6.3.3 Impact on Groundwater Quality

To assess the potential for the acid rock drainage (ARD) from the Project activities on groundwater quality, a reference was made to the ARD prediction and control and ARD Risk Review reports prepared by Rio Tinto

(Rio Tinto, 2011). The assessment provided a review of NPM operations with respect to acid rock drainage and concluded that:

The assessment of Acid Rock Drainage and Control is covered under a separate scope of work and is included in Rio Tinto (2011). Based on the conclusion reached by Rio Tinto (2011), it is considered that there is no significant risk in relation to acidic drainage and the ARD is unlikely to have adversely impact regional groundwater quality. The mobility of metals in the groundwater system within the Study Area is limited due to the low hydraulic conductivity and the presence of clays, which has a high capacity for adsorption and/or exchange of metals in groundwater. Hydrogeochemical modelling indicated that metal species are distributed mostly as insoluble metal carbonates, sulphates, sulphides, oxides and hydroxides. Considering the conclusion reached by previous investigations (Rio Tinto, 2011; Mackie Environmental Research, 2006), it is envisaged that leachate generated from TSF3 will unlikely adversely impact the regional groundwater quality.

The key risk is related to the oxidising of the caved waste rocks that subsidised. The rubble in the crater created by block cave mining and the rocks at the surface of other mine workings including drifts contains sulphur minerals that will be exposed to oxygen and water. The waste rocks that are from the weathered units contain low intact sulphide minerals than the waste from the underground development drives. The mine dewatering can created a zone of groundwater drawdown and exposure of mineralisation in the halo aquifer to oxygen. The oxidation products will enter the groundwater system when the groundwater flows into these areas and solubilise the oxidation products. This impact may cause elevated TDS, sulphate and metal/metalloid concentrations at neutral pH in groundwater, which can enter the groundwater system.

There is the potential for spills and contamination by metals and hydrocarbons from mine workshop, waste disposal and fuel storage areas; however adequate bunding and immediate clean-up of spills which is standard practice and/or a legislated requirement at mine sites, should prevent contamination of shallow strata and subsequent leakage to the groundwater system.

6.3.4 Impacts on Existing Registered Bores

Based on the extent of the predicted drawdown associated with the Project, no private groundwater users have been identified as being affected or potentially by the Project.

Aquifers within and in the vicinity of the Project Area are not well utilised, being that they are low yielding and the water is of low quality. The NOW database does not contain detailed geological logs or list the stratigraphy for bores in the Study Area. However, the depths and descriptions of the water bearing zones indicate saprock likely forms the principal aquifer exploited for water. Yields from this groundwater zone are low; NOW bore data indicates a yield range of 0.1 L/s to 1.5 L/s. Water quality ranges from brackish to saline; however, this resource is utilised because it is the most extensive and accessible groundwater source in the Study Area.

No private bores within the Mine Area are within the category “currently in use”. Private Bore GW002860 lies within the footprint of the tailings area and was constructed in 1930. It is understood this bore no longer exists. There are no private bores located within the zone of one-metre drawdown based on model result of 2013.

There are a small number of private bores identified within the immediate vicinity of the Project Area (refer to Figure 34). These bores primarily exploited the saprock oxidised zone aquifer of the host rock (beneath the aquifer). The majority of groundwater vary from brackish to saline and have been classified as unsuitable for potable use (either domestic, irrigation or for livestock watering) due to the elevated concentrations of sodium and chloride. Based on the available registered groundwater database, there are five private bores, one decommissioned private bore, and 13 NPM bores located within 5 km radius of the Mine Area.

There are 4 private bores (GW001668, GW002488, GW002526 and GW800009 and GW002860) located down gradient of the mine. Bore GW800009 (or MB3) is currently served as a monitoring bore. Bores GW002526, GW002488 and GW001668 were identified as “not in use” or “decommissioned” during the bore survey for NPM (PB, 2003).

Figure 34 shows the locations of bores registered with NOW within 5km and 8km radius of the Mine Area and the modelled one-meter drawdown contour. Information on these bores is summarised in Table 23 and presented in detail in Table A2 (Appendix A: Metadata).

Table 23: Registered bores within 5km radius of the Mine Area

GW WORKS NO.	MINE ID	COMPLETION DATE	OWNER	Drilled depth	PURPOSE
GW002860*	**-**	**1/02/1930**	**Private**	**47.50**	**Decommissioned**
GW018091	**-**	**1/02/1959**	**Private**	**48.80**	**Stock**
GW021708	**-**	**1/03/1964**	**Private**	**36.60**	**Stock**
GW034607	**-**	**1/01/1940**	**Private**	**70.10**	**Stock**
GW044455	**-**	**1/04/1975**	**Private**	**49.10**	**Stock**
GW070442	-	17/01/1993	Mines	215.60	Test Bore
GW800007	MB1	17/04/1994	Mines	36.50	Monitoring
GW800009	**MB3**	**17/04/1994**	**Private**	**60.00**	**Monitoring**
GW800011	MB2	16/04/1994	Mines	66.00	Monitoring
GW801222	P104	5/08/1994	Mines	250.00	Monitoring
GW801223	MB4	15/04/1997	Mines	60.00	Monitoring
GW801224	MB5	16/04/1997	Mines	60.00	Monitoring
GW801225	MB6	17/04/1997	Mines	43.00	Monitoring
GW801226	MB7	18/04/1997	Mines	24.00	Monitoring
GW801378	-	9/08/1994	Mines	250.00	Monitoring
GW803934	MB19	25/11/2009	Mines	102.00	Monitoring
GW803935	MB20	27/07/2008	Mines	54.00	Monitoring
GW803936	MB17	24/07/2008	Mines	66.00	Monitoring
GW803937	MB18	25/07/2008	Mines	90.00	Monitoring

6.3.5 Impact on Groundwater Dependent Ecosystems

There are no identified “high priority” Groundwater Dependent Ecosystems (GDEs) within or surrounding the Project Area. The closest identified “high priority” GDE is located approximately 50 kilometres to south east of the Project Area (refer to Section 4 of this report).

There are no known springs within the Study Area that are fed by groundwater around which groundwater dependent ecosystems have developed. The nearest high priority GDEs spring, identified in the local WSP (Section 4), is located outside of the Study Area and at a distance approximately 50 km southeast of Project Area (Lamberts Springs, Figure 21). Likelihood of impact to these receptors is minimal (rare) due to the limited radius of influence of the drawdown effects around the ore bodies mined and proposed for mining. Based on the numerical model results, it is anticipated that the drawdown is approximately 4.5km from the pits; therefore, the Project is unlikely to impact the identified Lamberts Springs. There are no known wetlands, karst GDEs within the Study Area.

Due to the distance between the Project and the high priority GDE springs, and the low volumes of groundwater extracted by the Project, impacts on these GDEs are unlikely. The magnitude of impact on GDE springs is considered to be ‘low’. The sensitivity of GDEs is considered to be ‘moderate’ and the significance of this impact is considered to be ‘low’.

A very small area of River Red Gum Woodland (approximately 2.1 hectares) occurs in the Project Area, and a number of other areas along Bogan River outside of the Project area. The ecological values and comprehensive ecological assessment are discussed in separate technical reports prepared for NPM (Umwelt 2013, Northparkes Mines Step Change Project Flora and Fauna Assessment). Please refer to the ecological assessment report for the discussion in relation to potential impact on the River Red Gum woodland. This woodland is likely to be supported by localised perched water near the surface. The likelihood of this receptor being impacted because of the loss of quantity of deeper groundwater due to mining operations is very low as the root zones of the woodland would be significantly shallower than the expected level in the deeper groundwater system.

The potential for leakage from the TFS ponds migrating northward and impacting upon the Wombin State Forest and the Bogan River tributary were investigated by PB for NPM (PB, 2003). They reported groundwater (particle) travel times of more than 1,000 years for distances of 1 km within a clay rich environment (i.e., the Regolith), which also has a high capacity for adsorption and/or exchange of potential metals in groundwater. This further supports the likelihood of rare to unlikely impacts to the identified receptors.

6.4 Groundwater impact assessment – Post Mining

The key impacts of the Project on the groundwater regime post mining are summarised as follows.

6.4.1 Potential subsidence of original surface and groundwater related impact due to underground block cave mine operations

Surface subsidence is a planned long-term outcome of NPM operations. The groundwater impact in relation to the surface subsidence would be localised to the mine operation areas. It is envisaged that the anticipated zone of subsidence will be confined to the locations of underground workings and within the Project Area boundaries. Given the low hydraulic conductivity and low flow rates within the aquifers, it is not anticipated that subsidence will detrimentally impact the regional groundwater flow regime.

6.4.2 Post Mining Recovery of groundwater levels

The range of post-mining water level fluctuation in the equilibrated subsidence zones is expected be greater than in the surrounding natural formation; however, this would not affect the principal behaviour of the groundwater system.

During the post-mining stage, mine dewatering will be decommissioned and the underground workings will slowly flood with groundwater and eventually an equilibrium water level will be reached over time. Equilibrium would occur when evaporative losses in the subsided crater area balance the long-term rainfall and groundwater seepage. It is likely that, despite the groundwater sink caused by additional evaporative losses (MER, 2006) no long term impact on post mining groundwater levels would be observed at any significant distance from the pits.

6.4.3 Potential impact on groundwater quality due to block caves at closure

The assessment of Acid Rock Drainage and Control is covered under a separate scope of work and is included in Rio Tinto (2011). The block caves at closures will be filled with a large mass of weakly mineralised waste rock rubble. The rubble in the crater created by block cave mining and the rocks at the surface of other mine workings including drifts contains sulphur minerals that will be exposed to oxygen and water. The waste rocks that are from the weathered units contain low intact sulphide minerals than the waste from the underground development drives. The mine dewatering can created a zone of groundwater drawdown and exposure of mineralisation in the halo aquifer to oxygen. The oxidation products will enter the groundwater system when the groundwater flows into these areas and solubilise the oxidation products. This impact may cause elevated TDS, sulphate and metal/metalloid concentrations at neutral pH in groundwater, which can enter the groundwater system.

Waste rocks will be characterised and appropriate management action would be undertaken if there is indication of potential impacts. Trigger values for surface and groundwater quality will be updated as part of the adaptive monitoring and management approach.

6.5 Results of Risk Analysis

The groundwater impact assessment described above indicates that the proposed Project does not pose a high risk to the groundwater regime for the following reasons:

- Depressurisation impacts are not predicted to have a large area of influence, due to the low hydraulic conductivity of the strata, thus limiting the areal extent of potential impact.
- As the aquifers around the Project Area are very low yielding and of low quality, there is currently very little groundwater source development in the vicinity of the Project Area. The potential for future development of these groundwater sources is minimal, therefore, the identified risks to the groundwater source are considered to be low. Based on the available information, there are no private bores within the Project Area. There are no private bores located within the modelled zone of drawdown (one-meter drawdown).
- There are no wetlands, karsts, high priority GDEs springs within the Project Area. The high priority GDEs, as identified in the local WSPs (Section 2), are located at distances greater than 50 km southeast of the Project Area and outside the predicted zone of drawdown. The mining operation will therefore be not expected to impact on high priority GDE springs.
- The anticipated zones of subsidence will be confined to the locations of underground pits and are likely to be contained within the NPM boundaries.

To address the potential groundwater impacts as a result of the Project activities, NPM will adopt a combination of preventative actions and management options to reduce the likelihood of adverse impacts occurring and to mitigate those risks. Management and mitigation measures are summarised in Table 24 and Section 9.0. Details of the groundwater impact assessment approach are included in Appendix D.

Due to this low risk, limited monitoring of groundwater levels and quality has been undertaken to date at NPM. Groundwater is currently monitored by NPM as is outlined in the Section 7.0. However, a monitoring program is required to confirm the conclusion reached that the risk to the groundwater regime is low. A monitoring program is therefore discussed in Section 7 as a result of this assessment.

A residual risk is the risk that remains after efforts have been made to manage and mitigate it as low as reasonably practicable. After a risk assessment, a residual risk is estimated based on the assumption that the management plan and mitigation measures are effective.

The findings of the risk assessment indicate that the risks associated with groundwater in the Study Area can be mitigated as described in the risk register (Appendix D). No residual risks are considered as ‘high’ in the risk analysis after efficient implementation of management and mitigation measures are implemented (Table 24).

Table 24: Results of Groundwater Impact Assessment and Risk Analysis

Risk Issue	Cause	Impact	Risk Rating prior to Management and Mitigation measures	Site Specific Control Measures/Mitigation	Site Specific Risk Rating inclusive of Mitigation and Controls
Leakage of introduced fluids during drilling or contaminated fluid. Leakage/spills of chemicals, hydrocarbons fuels, oils and petroleum products.	Poor design, Construction technique, Poor closure technique; Potential for spills and contamination by metals and hydrocarbons from mine workshop, waste disposal and fuel storage areas	Contamination, Non-compliance	Moderate	Apply the minimum construction requirements for water bores in Australia (National Uniform Drillers Licensing Committee, NUDLC rev.3, 2012); check quality of data regularly, establish a complete operational protocol and data handling system; Fuel and chemical storages to be constructed and adequately bunded to the relevant Australian Standard. Immediate clean-up of spills which is standard practice and/or legislated requirements at mine sites to prevent contamination of shallow strata and subsequent leakage to the groundwater system. Spill cleanup kits in accordance with Australian Standards (AS1940 and AS3780) will be kept on site.	Low
Change in land use (TSF3, new waste rock stockpiles)	Change of land use (TSF3, new waste rock dumps & stockpiles) and leakage beneath the dams/ponds	Additional recharge and change of groundwater flow	Moderate	Ensure appropriate planning and site design and install appropriate monitoring systems and develop contingency plan	Low

Risk Issue	Cause	Impact	Risk Rating prior to Management and Mitigation measures	Site Specific Control Measures/Mitigation	Site Specific Risk Rating inclusive of Mitigation and Controls
Subsidence of original surface due to block caving methods	An expected result of block cave mining techniques and operations	Change the characteristic of the aquifer and groundwater system	Low	The surface subsidence is an expected result of mining techniques and Project operations. Zones of subsidence are envisaged to be localised, contained within the Project Area boundaries. Given the low conductivity, the low flow rates within the aquifers and the localised zone affected by subsidence it is not anticipated that subsidence will detrimentally impact the regional groundwater flow regime.	Low
Subsidence of original surface due to block caving methods	Proximity of subsidence zone could potentially cause subsidence beneath dam or water storage facilities and seepage	Change in recharge; Create seepage of water beneath structures and change natural groundwater quality/conditions	High	Zone of subsidence will be localised, contained within the Project Area boundaries. There will be careful planning and site design in relation to the proximity of the subsidence zones to current and proposed tailings storage areas and water storage facilities to ensure that the subsidence zone does not encroach on these areas which could cause permanent changes in rock hydraulic characteristics and consequentially elevated seepage of water beneath. Appropriate monitoring systems will be in place to monitor the groundwater levels in the vicinity of the subsidence zones and waste facilities using shallow piezometers.	Low

Risk Issue	Cause	Impact	Risk Rating prior to Management and Mitigation measures	Site Specific Control Measures/Mitigation	Site Specific Risk Rating inclusive of Mitigation and Controls
Change in groundwater quality	Leakage of tailings water beneath TSF3, mobilising a high salinity/poor quality groundwater plume within the natural groundwater flow system	Degradation of groundwater quality	High	In order to reduce the potential for uncontrolled seepage of contaminated water accurate design and sizing of the correct water and waste containment facilities are required. TSF3 will be correctly sized, to prevent overflow and adhere to regulations which require the consideration of the flood events, and constructed to limit or prevent underground leakage. Adequate monitoring around and beneath tailings dam TSF3 will be carried out. All existing boreholes located within the footprints of TSF3 will be backfilled using cement – bentonite slurry so as to prevent leakage. Groundwater monitoring system using a series of shallow piezometers will be carried out to monitor the potential seepage from TSF3s. Tailings and waste rocks are to be characterised and appropriate management action would be undertaken if there is indication of potential impacts.	Low
Change in groundwater quality	Change the characteristic of the groundwater through subsidence. Oxidize the caved waste overburden/waste rocks that subsides and alter quality of groundwater and mine seepage water.	Alter quality of groundwater and mine seepage water.	High	Monitor quality of seepage water within the mine and treat as necessary; Tailings and waste rocks are to be characterised and appropriate management action would be undertaken if there is indication of potential impacts. Trigger values for surface and groundwater quality will be updated as part of the adaptive monitoring approach. Backfilling of the subsidence zones may be considered. The seepage water quality within the mine will be monitored and treated as necessary.	Moderate

Risk Issue	Cause	Impact	Risk Rating prior to Management and Mitigation measures	Site Specific Control Measures/Mitigation	Site Specific Risk Rating inclusive of Mitigation and Controls
Excessive groundwater drawdown	Dewatering of the mine lowers the regional water table of the saprock oxidised zone aquifer, and to a lesser extent, the regolith and host rock.	Change of regional groundwater flow direction	Low	Maintain monitoring and management of groundwater inflow into the underground mine operations and dewatering volumes at open pits to meet the requirements of 'NSW Aquifer Interference Policy' (2012).	Low
Excessive groundwater drawdown	Dewatering of the mine lowers the regional water table of the saprock oxidised zone aquifer, and to a lesser extent, the regolith and host rock.	Change of groundwater levels in the vicinity of the mine operations.	Moderate	The volume of water taken as a result of mining activities was modelled in this study prior to project approval and will be measured and reported. Maintain monitoring and management of groundwater inflow into the underground mine operations and dewatering volumes at open pits to meet the requirements of 'NSW Aquifer Interference Policy' (2012).	Moderate
Excessive groundwater drawdown	Dewatering of the mine lowers the regional water table of the saprock oxidised zone aquifer, and to a lesser extent, the regolith and host rock.	Degradation of the resource (limit supply) to other groundwater users / abstractors; Loss of groundwater yields at existing bores	Low	Groundwater within the Project Area is currently a poor yielding resource. There are no private groundwater users within the Project Area and the modelled zone of impact. Maintain monitoring and management program. Investigate cause.	Low
Excessive groundwater drawdown	Dewatering of the mine lowers the regional water table of the saprock oxidised zone aquifer, and to a lesser extent, the regolith and host rock.	Impact to nearby streams and/or river tributaries or disconnection of ephemeral streams	Low	Due to depth of encountered groundwater, these systems are not likely groundwater dependent.	Low

Risk Issue	Cause	Impact	Risk Rating prior to Management and Mitigation measures	Site Specific Control Measures/Mitigation	Site Specific Risk Rating inclusive of Mitigation and Controls
Excessive groundwater drawdown	Dewatering of the mine lowers the regional water table of the saprock oxidised zone aquifer, and to a lesser extent, the regolith and host rock.	Reduce availability of groundwater for high priority GDEs (springs, wetlands)	Low	The nearest high priority GDEs spring is located outside of the Study Area and at a distance greater than 50 km southeast of the Project Area (Lamberts Springs); Maintain effective monitoring and management programs.	Low
Excessive groundwater drawdown	Dewatering of the mine lowers the regional water table of the saprock oxidised zone aquifer, and to a lesser extent, the regolith and host rock.	Reduce availability of groundwater for River Red Gum Woodland and State Forest	Low	The predictive modelling suggests that Wombin State Forest is outside the zone of drawdown. Management strategy will be to monitor the changes in groundwater level and water quality using the water bore monitoring network. Trigger levels, regarding declines in groundwater levels and the degradation of groundwater quality will be established to manage the potential impacts. Where monitoring results indicate levels in excess of the trigger values, an investigation appropriate for the situation will be conducted to assess the need to implement additional monitoring and management/mitigation measures.	Low
Excessive groundwater drawdown	Over abstraction of water obtained from an appropriately authorised and reliable supply for the purposes of operation of the Project.	None-conformance of the operating rules of the relevant Water Sharing Plan (WSP)	Low	The volume of water taken as a result of mining activities was modelled in this study prior to project approval and will be measured and reported. Maintain monitoring and management of groundwater inflow into the underground mine operations and dewatering volumes at open pits to meet the requirements of 'NSW Aquifer Interference Policy' (2012).	Low

Risk Issue	Cause	Impact	Risk Rating prior to Management and Mitigation measures	Site Specific Control Measures/Mitigation	Site Specific Risk Rating inclusive of Mitigation and Controls
Post mining groundwater levels	Recovery of groundwater levels is inconsistent with post mine recovery plan and insufficient for planned recovery	Change in equilibrium water table levels and quality. Unavailable resource / reduced use of the water source.	Moderate	Revisit proposed rehabilitation management and monitoring plans and alter as necessary. Use of resource is already minimal	Low
Post mining groundwater quality	Recovery of groundwater is inconsistent with post mine recovery plan and insufficient for planned recovery. Oxidize the caved waste overburden and alter quality of groundwater and seepage water.	Change of water quality. Unavailable resource / reduced use of the water source.	High	Revisit proposed rehabilitation management and monitoring plans and alter as necessary. Use of resource is already minimal; Monitor water quality and treat as necessary	Moderate
Mine activities alter long-term recharge characteristics	Backfilling of the prescribed subsidence zones	Additional recharge to material near surface, pooling groundwater within the subsidence zones.	Low	Revisit proposed rehabilitation management and monitoring plans. Use of resource is already - overall impacts are considered low	Low

7.0 GROUNDWATER MONITORING

This section includes the monitoring objectives, groundwater monitoring strategy and the proposed groundwater monitoring program. A groundwater monitoring plan is required by NOW and will be prepared in conjunction with a surface water monitoring plan by NPM. NPM commit to the continuation of the existing approved groundwater monitoring program as part of the overall mine environmental monitoring (refer to Section 7.3.1).

7.1 Monitoring Objectives

A groundwater monitoring program is necessary to refine understanding of the hydrogeological regime and provide monitoring data to verify groundwater model results. The monitoring program will facilitate compliance with the conditions that are likely to be provided with the Project's approval. Regular monitoring of the network should continue to enable an understanding of seasonal water table fluctuations and include groundwater depth and groundwater quality measurements.
Objectives of the groundwater monitoring program are to:

- Establish a baseline against which future impacts and changes in groundwater can be assessed
- Monitor changes in groundwater and assess the extent to which these are caused by the Project
- Confirm the conclusion reached that the risk to the groundwater regime is low
- Help in setting trigger levels that prompt mitigation measures to be implemented when groundwater impacts exceed expected or target levels
- Provide data to verify the groundwater model and groundwater impact predictions made during the GWIA
- Meet legislative and regulatory requirements.

7.2 Groundwater Monitoring Strategy

The monitoring strategy describes the "why" behind the groundwater monitoring program and the strategy developed to define the groundwater monitoring program.

A number of priorities should be assigned when developing a groundwater monitoring program (Table 25). These priorities assist in the development of implementation of the program, along with sampling schedules and activities. Prioritisation ranking is relevant where all monitoring activities are undertaken as part of a regulatory requirement. The proposed priority ranking is considered to be proactive and to address not only the regulatory requirements but also potential community concern and stakeholder's requirements, and the need to establish a minimum of environmental baseline data.

Table 25: Monitoring Priorities

Rank	Driver/Category	Target for Monitoring
1	Environmental Incident/ Community Complaint Response	Respond to an environmental incident (i.e., hydrocarbon spill), or response to a legitimate community complaint
2	Compliance	Compliance with legislative conditions / monitoring requirements
3	Operational Monitoring	Monitoring of infrastructure facilities which are non-compliance or licence related
4	Stakeholder Engagement and Relationship	Monitoring of environmental values which are non-compliance or licence related in relation to improving stakeholder relations
5	Environmental Improvement and Performance	Monitoring of parameters and conditions which are non-compliance or licence related to improve environmental performance or lead to further environmental understanding

7.2.1 Groundwater Monitoring Suites

A standard groundwater monitoring suite is proposed to streamline groundwater monitoring and assist with consistency of the monitoring activities and collected dataset.

A field suite, comprising of a set of basic physical measurements taken with a calibrated multi-parameter water quality meter should be collected with observations made during routine monitoring. The field suite is used in most location and does not involve laboratory analysis. It is undertaken either on its own or in conjunction with the analytical suite.

- Flow rate (where applicable);
- Water level/pressure (where applicable);
- Temperature;
- pH;
- Electrical Conductivity; and
- Dissolved Oxygen.

A groundwater baseline suite should include the field suite parameters and a range of basic water chemistry analysis. This monitoring will enable the definition of the basic characteristics of groundwater.

Water samples should be collected from the monitoring bores on a twelve monthly basis (or as otherwise agreed with NOW) and the samples analysed for:

- Physico-chemical parameters;
- Major cations and anions;
- Nutrients - ammonia, nitrate, nitrite; and
- Dissolved metals (a metal scan).

It is recommended the water quality monitoring regime continue for the life of the Project. It is also recommended that groundwater water quality trigger values be derived for each monitoring bore. Details of the monitoring program will be included in Groundwater Monitoring Plan prepared by NPM.

7.2.2 Reporting

Monitoring data should be reviewed annually and reported internally as part of the environmental monitoring report and as required by regulatory requirements. In view of monitoring results, the monitoring strategy and monitoring programs may be updated.

A groundwater monitoring plan (GWMP) is required by NOW and will need to be prepared in conjunction with a surface water monitoring plan (SWMP). This will be prepared for the Project in accordance with relevant Project approval requirements.

7.3 Groundwater Monitoring Program

7.3.1 Existing groundwater monitoring network

The current NPM groundwater monitoring program will be maintained as part of the overall mine environmental monitoring. Groundwater at the mine is currently monitored by NPM personnel and/or the appointed sub-contractors. There are currently 48 groundwater monitoring locations in the vicinity of the Project Area. NPM hold relevant licences for groundwater interception associated with existing mining areas.

Table 12 in Section 4.7 of this report provides details of the existing monitoring bore network including bore IDs, bore depths and target monitoring strata. Locations of the existing groundwater monitoring bores are shown in Figure 9.

Monitoring includes:

- water level measurements or formation pressures in local and regional piezometers;
- water quality sampling (EC, pH and ionic speciation); and
- monitoring of inflows to the pits for water management purposes.

7.3.2 Proposed groundwater monitoring program

Additional monitoring is recommended to address the 'NSW Aquifer Interference Policy' (2012) and 'NSW Groundwater Quality Protection Policy' (1998) and is outlined below. The feasibility of the monitoring program should be addressed during development of the consolidated water monitoring and management plan to be prepared for the Project. A bore licence must be obtained from NOW prior to installation of any new monitoring bores. All monitoring bores will be constructed according to the Australian guidelines by an appropriately qualified water bore driller.

- The predictive modelling suggests that the Wombin State Forest to the north of the Study Area is outside the zone of drawdown (refer to Figure 34). Extended monitoring would be triggered if monitoring in the existing monitoring network suggested a variation from the modelling results. Additional groundwater monitoring points may be considered towards the north of the pits, to monitor the bedrock depressurisation and changes of groundwater quality between the mine and the Wombin State Forest to the north of the Study Area.
- A bore inventory will be carried out to confirm the "not-in-use" and "decommissioned" status of groundwater bores (GW001668, GW002488 and GW002860) that are located down-gradient of the Mine Area (refer to Table 26). Based on results of the bore assessment, appropriate monitoring will be determined. This is part of the control measures for the potential impact (potential loss of groundwater yields) to existing registered groundwater users as described in Section 6 of this report.

Table 26: Registered Bores near the Project Area

Bore ID	Distance and Direction from mine pits (km)	Year Drilled	Depth (m)	Status	Purpose
GW001668	7 km West	1925	124.4	Not in use	Unknown
GW002488	5.5 km North	1928	76.2	Not in use	Unknown
GW002526	4 km North	1928	108.5	Not in use	Unknown

- Additional monitoring bores will be installed around the proposed waste facilities (TSF3, new waste rock stockpiles) to monitor the potential impact to groundwater. Groundwater level and quality monitoring is required adjacent to the water storage facilities to ensure the effectiveness of designs, maintenance, and management. Monitoring recommendations include:
  - Existing boreholes should be used, up and down gradient of the storage facilities where possible, or else new monitoring boreholes must be constructed.
  - Regularly monitoring of groundwater levels.
  - Groundwater quality monitoring comprises major anions and cations, and selected dissolved metals indicators
  - Open boreholes located within the TSF3 footprints and not used for monitoring will be backfilled using cement – bentonite slurry to prevent seepage.

- The existing groundwater monitoring program, both in monitoring bores and from groundwater inflows to the mine, should be maintained as part of the overall mine environmental monitoring. This would assist in the further assessment of groundwater flow, occurrence and water quality.
- The monitoring points would include monitoring of daily and/or cumulative flows for pit waters and water directed to/from the underground operations; regular measurement of water quality (EC and pH) of pumped waters; and annual reporting as part of licensing conditions.
- Measurements of daily dewatering volumes from each individual open cut pit and underground mine sumps should be recorded with calibrated flow meters. This would provide an insight into the variability of inflows over time to each pits, which can be related to the recorded geological conditions encountered at each pit as well as provide additional data for a refined groundwater model.

8.0 CONCLUSIONS

Water requirements to service the expanded operations are estimated to be up to 7,000 ML/year (GHD, 2009). This water requirement will be satisfied by current sources, which includes groundwater from the PSC borefield in the Lachlan Valley and onsite water that has also been collected from the Project Area's surface water catchment (i.e. rainfall). It is projected that the Project's water requirements will not require an increased water take.

At the Project Area, deepening and extension of the mine will result in larger dewatering volumes and expected drawdown depths.

Numerical groundwater models have been prepared to undertake quantitative impact assessment of proposed mining-related activities. These are discussed individually.

8.1 Project Area Model

The previous model of dewatering at NPM was updated to account for the proposed mine plan and was calibrated against observed underground water inflows.

Prediction simulations were prepared based on an assumed mine plan to assess potential changes to groundwater heads due to the proposed Project. Modelling indicates the predicted impact due to extension of the mine is contained to within close proximity to expected subsidence craters. The extent of modelled drawdown of groundwater in the bedrock at cessation of the proposed mining is approximately 4.5 km from the pits. There is a steady increase expected in groundwater seepage into the mine as the mine progresses. Predictive modelling suggests a maximum modelled inflow is 0.8 ML/day. E28 and E46 are the most significant contributors to modelled groundwater seepage.

Qualitative assessment of the impact of groundwater decline on groundwater quality indicates minimal potential for adverse impact.

8.2 Impact and risk assessment

The impact of the proposed Project on groundwater levels is expected to be localised, and limited mainly to the vicinity of the mine operations. The predictive modelling results do not indicate a significant change in groundwater regional flow direction as a result of the Project activities.

There is no measureable groundwater impact on the surface water system within and in the vicinity of the Project Area as a result of the dewatering activities. Groundwater does not provide baseflow to the surface water within the Project Area and it is considered that the river system is of the "influent" type.

Based on the extent of the predicted drawdown associated with the Project, no private groundwater users have been identified as being affected or potentially by the Project. There are no private bores located within the zone of one-metre drawdown based on model result of 2013. No private bores within the Mine Area are within the category "currently in use". As the aquifers around the Project Area are very low yielding and of low quality, there is currently little development of groundwater sources in the vicinity of the Project Area and the potential for future development of these groundwater sources is minimal. The alluvial aquifer system within and in the vicinity of the Study Area is low yielding and not generally used for productive land use.

There are no identified "high priority" GDEs (springs, karsts, wetlands) or national parks located within or surrounding the Project Area. The nearest high priority GDEs spring, identified in the WSP for the NSW MDB Fractured Rock Groundwater Sources, is located outside of the Study Area and at a distance greater than 50 km southeast of the Project Area and is located well beyond the modelled zone of influence of the mine dewatering.

The assessment of Acid Rock Drainage and Control is covered under a separate scope of work and is included in Rio Tinto (2011). Based on the conclusion reached by Rio Tinto (2011), it is considered that there is no significant risk in relation to acidic drainage and it is envisaged that leachate generated from the waste facilities will unlikely adversely impact the regional groundwater quality. The key risk is related to the oxidising of the caved waste rocks that subsidised. The oxidation products will enter the groundwater system when the groundwater flows into these areas and solubilise the oxidation products. This impact may cause elevated TDS, sulphate and metal/metalloid concentrations at neutral pH in groundwater, which can enter the groundwater system.

There is the potential for spills and contamination by metals and hydrocarbons from mine workshop, waste disposal and fuel storage areas; however adequate bunding and immediate clean-up of spills which is standard practice and/or a legislated requirement at mine sites, should prevent contamination of shallow strata and subsequent leakage to the groundwater system.

The groundwater impact in relation to the surface subsidence would be localised to the mine operation areas. It is envisaged that the anticipated zone of subsidence will be confined to the locations of underground workings and within the Project Area boundaries.

The findings of the risk assessment indicate that the risks associated with groundwater in the Study Area can be mitigated. No residual risks are considered as 'high' in the risk analysis after efficient implementation of management and mitigation measures.

9.0 RECOMMENDATIONS ON MANAGEMENT MEASURES

Based on the results of this study, the following management measures are recommended:

- The existing groundwater monitoring program will be maintained. Proposed groundwater monitoring as a result of this study is included in Section 7.3.2 of this report.
- The extent of dewatering, impacts on current users and future resources will be assessed through the life of the project. If monitoring data does not confirm the predictive modelling results and the assessment that the risks to the groundwater regime are low, verification of the groundwater model may be carried out. Recharge rates and mechanisms will be taken into account in assessing whether dewatering is impacting on the groundwater resources or whether it is in response to varying climate conditions.
- Monitor dewatering volumes to verify that volumes are within licenced allocations.
- The monitoring and exploration wells are designed, constructed and decommissioned to limit the risk of interaction between aquifers/saturated zones according to the Australian guidelines/standards.
- There will be careful planning and site design in relation to the proximity of the subsidence zones to current and proposed tailings storage areas and water storage facilities to ensure that the subsidence zone does not encroach on tailings and water storage facilities. Subsidence could cause permanent changes in rock hydraulic characteristics and consequentially elevated seepage of water beneath. Appropriate monitoring systems will be in place to monitor the groundwater levels in the vicinity of the storage facilities using shallow piezometers.
- To reduce the potential for uncontrolled seepage of contaminated water accurate design and sizing of the water and waste containment facilities are required. The dams will be sized to prevent overflow and adhere to regulations which require the consideration of flood events, and constructed to limit or prevent underground leakage. Adequate monitoring around and beneath the tailings dam will be carried out. All existing boreholes located within the footprints of water and waste containment facilities must be backfilled using a cement – bentonite slurry so as to prevent leakage. A groundwater monitoring system using a series of shallow piezometers will be implemented to monitor the potential seepage from the waste facilities.
- Fuel and chemical storages to be constructed and adequately bunded to the relevant Australian Standard. Accurate records of oil volumes, purchased, used, disposed, and recycled are to be maintained. Stormwater runoff collection points from workshop and re-fuelling areas are to incorporate oil-water separators. Spill containment procedures are to be implemented to prevent migration and exposure of chemicals. The quality of runoff within the mine is to be monitored and runoff treated as necessary to meet relevant standards.

- Ensure correct protocols regarding cleaning up of spills or leaks. Spill cleanup kits are to be in accordance with Australian Standards (AS1940 and AS3780) and need to be kept on site. Any significant leaks or spills of hazardous materials must be cleaned up according to appropriate emergency clean-up operations. Immediate clean-up of spills, which is standard practice and/or a legislated requirement at mine sites, should prevent contamination of shallow strata and subsequent leakage to the groundwater system.

- Trigger levels, regarding declines in groundwater levels and the degradation of groundwater quality, will be established to manage the potential impacts as part of updated groundwater management plan. Where monitoring results indicate levels in excess of the trigger values, an investigation appropriate for the situation will be conducted to assess the need to implement management/mitigation/remedial measures.

- The proposed rehabilitation management and monitoring plans will be reviewed and altered as necessary. Backfilling of the subsidence zones may be considered. The seepage water quality within the mine will be monitored and treated as necessary.

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11.0 ACRONYMS AND GLOSSARY OF TERMS

Item	Definition
ADWG	Australian drinking water guidelines
AHD	Australian Height Datum
ANZECC	The Australian and New Zealand Environment Conservation Council
ARMCANZ	The Agriculture and Resource Management Council of Australia and New Zealand
Au	Gold
BDL	Baseline Diversion Limit
bgl	Below Ground Level
Cu	Copper
DECCW	Department of Environment, Climate Change and Water
DGRs	Director-General's requirements
DLWC	Department of Land and Water Conservation
DWR	Department of Water Resources
DWE	Department of Water and Energy
EA	Environmental Assessment
EC	Electrical conductivity
EMP	Environmental Management Plan
EPBC	*Environment Protection Biodiversity Conservation*
EPA Act	*Environmental Planning and Assessment Act*
EPP	Environmental Protection (Water) Policy
GAB	Great Artesian Basin
GDE	Groundwater Dependent Ecosystem.
GMA	Groundwater Management Areas
GMU	Groundwater Management Units
GWIA	Groundwater Assessment
HDD	Horizontal directional drilling
Km	Kilometre
LFB	Lachlan Fold Belt
L/s	Litre per second
LSI	Langelier Saturation Index
MDB	Murray Darling Basin
MDBA	Murray-Darling Basin Authority
m AHD	Metre in Australian Height Datum
ML	Mega litre

MNES	Matters of National Environmental Significance
MTpa	Mega tonnes per annum
NES	National Environmental Significance
NOW	New South Wales Office of Water
NSW	New South Wales
NPM	Northparkes Mines
OTZ	Oxide transition Zone
QA/QC	Quality Assurance/Quality Control
PSC	Parkes Shire Council
SAR	Sodium Adsorption Ratio
SDL	Sustainable diversion limit
SEWPAC	Sustainability, Environment, Water, Population and Communities
Ss	Specific storage
Sy	Specific yield
SWL	Standing water level (static water level)
S	Storage coefficient (Storativity)
TDS	Total dissolved solids
T	Transmissivity
TSF	Tailings storage facilities
VWP	Vibrating Wire Piezometer
WAL	Water Access Licence
WMA	*Water Management Act*
WSP	Water Sharing Plans
WRPA	Water resource plan area

GLOSSARY

Item	Definition
Abstraction	The removal of water from a resource e.g. the pumping of groundwater from an aquifer. Interchangeable with extraction.
Adsorption	The attraction and adhesion of ions from an aqueous solution to the surface of solids.
Allocation (water)	Volume of water entitlement to the holder of a Water licence.
Alluvial	Of, or pertaining to, material transported by water.
Alluvium	Sediments deposited by or in conjunction with running water in rivers, streams, or sheetwash and in alluvial fans.
Anabranch (surface	Section of a river or stream that diverts from the main channel or stem of the watercourse and rejoins the main stem downstream. Local anabranches can

water)	be the result of small islands in the watercourse. In larger anabranches, the flow can diverge for a distance of several kilometres before rejoining the main channel.
Analytical model	A mathematical model that provides an exact or approximate solution of a differential equation (and the associated initial and boundary conditions) for subsurface water movement or transport.
Anisotropy	The conditions under which one or more of the hydraulic properties of an aquifer vary with direction. (See also isotropy).
Anticline	A fold that is convex upward or had such an attitude at some stage of development. In simple anticlines the beds are oppositely inclined, whereas in more complex types the limbs may dip in the same direction. Some anticlines are of such complicated form that no simple definition can be given. Anticlines may also be defined as folds with older rocks toward the centre of curvature, providing the structural history has not been unusually complex.
Aquatic	Associated with and dependant on water e.g. aquatic vegetation.
Aquatic Ecosystems	The abiotic (physical and chemical) and biotic components, habitats and ecological processes contained within rivers and their riparian zones and reservoirs, lakes, wetlands and their fringing vegetation.
Aquiclude	A geologic formation which may contain water (sometimes in appreciable quantities), but is incapable of transmitting significant quantities under ordinary field conditions.
Aquifer	A geological formation comprising layers of rock, unconsolidated deposits or *regolith* that is capable of receiving, storing and transmitting significant quantities of water. The term is usually applied to saturated materials that currently contain water.
Aquifer system	Intercalated permeable and poorly permeable materials that comprise two or more permeable units separated by aquitards which impede vertical groundwater movement but do not affect the regional hydraulic continuity of the system.
Aquitard	A semi-pervious geologic formation which can store water but transmits water at a low rate compared to the aquifer.
Artesian aquifer	A confined aquifer in which the piezometric head sits above the ground surface so that the pressure causes water to flow freely from bores drilled into the aquifer.
Artesian bore	A 'flowing' bore, where the piezometric head level is at an elevation higher than ground level, such that water freely flows out of the bore without mechanical assistance.
Attenuation	The breakdown or dilution of contaminated water as it passes through the ground.
Available drawdown	The height of water above the depth at which the pump is set in a borehole at the time of water level measurement.
Average annual recharge	Is the volume of water added to the groundwater source naturally, usually by infiltration from rainfall and river flows, and assessed on a long-term average basis. This recognises that the amount of recharge to a groundwater source can vary from year to year depending on climatic conditions.

Baseflow	Part of the discharge which enters a stream channel mainly from groundwater (but also from lakes and glaciers) during long periods when no precipitation (or snowmelt) occurs.
Basement	A general term for the solid rock that lies underneath the soil and other unconsolidated material. Also known as bedrock. When exposed at the surface it is referred to as outcrop.
Basin	A depression of large size in which sediments have accumulated.
Bedrock	A general term for the solid rock that lies underneath the soil and other unconsolidated material. Also referred to basement. When exposed at the surface it is referred to as rock outcrop.
Bore	An 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. In this report, the term ‘well’ refers to infrastructure used to extract oil or gas and produced water from the subsurface. A ‘bore’ refers to the structure that is used to extract groundwater for domestic, stock, irrigation, industrial or commercial purposes.
Borehole	See definition for Bore.
Brackish	Water that contains between 3,000 and 10,000 mg/l of total dissolved solids.
Brine	Water that contains more than 35,000 mg/l of dissolved solids, saturated or nearly saturated with a salt – concentrate produced as a by-product of RO process. Also known as RO concentrate.
Brine Containment Ponds	Brine containment pond located downstream of the ROP
Catchment	(a) Area of land that collects rainfall and contributes to surface water (streams, rivers, wetlands) or to groundwater. (b) The total area of land potentially contributing to water flowing through a particular point.
Cone of depression	The piezometric groundwater surface which defines the area of influence of a borehole. The shape of a cone with large diameter at top.
Confined aquifer	An aquifer overlain by a confining layer of significantly lower hydraulic conductivity in which groundwater is under greater pressure than that of the atmosphere; the aquifer is bounded above and below by an aquiclude.
Contamination	The introduction of any substance into the environment by human activities.
Department of Land and Water Conservation (DLWC)	See NSW Office of Water
Department of Water Resources (DWR)	See NSW Office of Water
Department of Water and Energy (DWE)	See NSW Office of Water
Discharge	Water that moves from a *groundwater* body to the ground surface (or into a surface water body such as a lake or the ocean). Discharge typically leaves *aquifers* directly through *seepage* (*active discharge*) or indirectly *through capillary rise* (*passive discharge*). The term is also used to describe the

	process of water movement from a body of *groundwater*.
Discharge area	Where significant amounts of groundwater come to the surface, either as liquid water or as vapour by evaporation.
Dissolved solids	Minerals and organic matter dissolved in water.
Drawdown	The lowering of a watertable resulting from the removal of water from an aquifer or reduction in hydraulic pressure.
Electrical Conductivity	An *electrical conductivity*, a measure of the ability of a medium to conduct electricity. EC is used often as a surrogate measure of salinity levels in water or soil as the conductivity of a solution generally increases in proportion with its salt content. Three types of electrical conductivity measurements are made on soils: ECa measurements are taken in the field using an electromagnetic induction meter. EC15 measurements on a solution obtained by mixing one part soil with five parts distilled water.
Ecosystem	An organic community of plants, animals and bacteria and the physical and chemical environment they inhabit.
Effective porosity	The porosity contributing to the flow of water or the interconnected porosity.
Elevation	A general term for a topographic feature of any size that rises above the adjacent land or the surrounding ocean bottom; a place or station that is elevated. The vertical distance from a datum (usually mean sea level) to a point or object on the Earth's surface; especially the height of a ground point above the level of the sea. The term is used synonymously with altitude in referring to distance above sea level, but in modern surveying practice the term elevation is preferred to indicate heights on the Earth's surface, whereas altitude is used to indicate the heights of points in space above the Earth's surface.
Embargo	
Entitlement (water)	Right of access to a share of water from a specified water source.
Epeirogenic	The slow movements of the Earth's crust leading to the formation of features.
Equipotential	A line connecting points of equal hydraulic potential or hydraulic head.
Evaporation	The conversion of a liquid into a vapour. In the hydrological cycle, evaporation involves heat from the sun transforming water (held in surface storages in soil) from a liquid into a gaseous state. This allows the water to move from water bodies or the soil and enter the atmosphere as water vapour.
Extraction limit	Is the average yearly volume that can be extracted from a water source by all access licences.
Fault	(a) A fracture in the Earth’s crust along which the rocks on one side are displaced relative to those on the other. (b) a fracture which has experienced translation or movement of the fracture walls parallel to the plane of the fracture

Fault line	A fracture or fracture zone of the Earth's crust with displacement along one side in respect to the other.
Flow rate	The amount of surface water or *groundwater* flowing past a given point or line over a defined period of time. Measured as volume, depth or area of water per unit time.
Flow system	Local a flow system transporting groundwater in which discharge and recharge occur within a few kilometres of each other. Flows may be permanent or temporary and the water is typically transported down a hill-slope through an unconfined aquifer that is relatively thin (<20 m) and close to the surface.
Formation	(a) A unit in stratigraphy defining a succession of rocks of the same type. (b) A body of rock strata that consists of a certain lithology or combination of lithologies.
Fracture	A sub-planar discontinuity in a rock or soil formed by mechanical stresses.
Fractured rock aquifers	Rocks that are capable of receiving, storing and transmitting significant quantities of water due to the presence of numerous cracks, fissures or fractures in what would otherwise be an *impermeable* material.
Fresh water	Water with a salinity < 1000 mg/l; drinkable or potable water is implied.
Geological time scale	The subdivision of millions of years of geologic time into Eras, Periods and Epochs, allowing the interpretation of stratigraphic relationships between rocks.
Geology	The science relating to the history and development of the Earth's crust.
Gravel	In general, gravel refers to sedimentary grains having a particle size of between 2 and 4 mm. The term is applied to grains that are larger than coarse sand but finer than pebbles.
Groundwater	Water stored below the ground surface that saturates (in available openings) the soil or rock and is at greater than atmospheric pressure and will therefore flow freely into a bore or well. This term is most commonly applied to permanent bodies of water found under the ground.
Groundwater Dependent Ecosystems	Terrestrial or aquatic ecosystems whose ecological function and biodiversity are partially or entirely dependent on groundwater.
Groundwater flow	The movement of water through openings in sediment and rock that occurs in the zone of saturation. Lateral groundwater flow - movement of *groundwater* in a non-vertical direction. *Lateral groundwater flows* are usually, although not always, more or less parallel to the ground surface.
Groundwater Management Areas (GMA)	The primary administrative boundaries defining the regions over which the Great Artesian Basin groundwater resources are regulated.
Groundwater Management Units (GMU)	The administrative subdivision of the aquifer formations that are regulated within each Groundwater Management Area.
Groundwater model	A simplified conceptual or mathematical image of a groundwater system, describing the features essential to the purpose for which the model was

	developed and including various assumptions pertinent to the system. Mathematical groundwater models can include numerical and analytical models.
Groundwater resource	All groundwater available for beneficial use, including both human and natural uses.
Head (hydraulic head, static head)	The energy contained within a column of water resulting from elevation or pressure. The static head is the height at which the surface of a column of water could be supported against the action of atmospheric pressure.
'High security' Water	Regulated river (high security) have priority over the below access licences. High security entitlements cannot carryover water from one year to the next, but must be allocated water to a level specified in the respective WSP prior to general security water being made available in each year
Hydraulic conductivity (K)	A coefficient of proportionality describing the rate at which a fluid can move through the interconnected pore spaces in a porous medium, expressed as the rate of horizontal groundwater flow through a unit area (1 x 1) of an aquifer under a unit hydraulic gradient (δh / δl = 1). The density and viscosity of the fluid must be considered in determining conductivity. Values commonly range between $3x10^{-6}$ m/s and $4x10^{-4}$ m/s (or 0.02 and 40 m/day, respectively) for unconsolidated sand aquifers, less than $6x10^{-6}$ m/s (0.5 m/day) for sandstone, and below $1x10^{-9}$ m/s (0.0001 m/day) for clays or shale (see Hydraulic Gradient).
Hydraulic gradient	(a) The slope of the water table or potentiometric surface. The hydraulic gradient is determined from the decline in groundwater level (δh) at two measuring points divided by the distance between them (δl). (b) The change in hydraulic head with direction.
Hydraulic head (h)	The elevation in a well in reference to a specific datum; the mechanical energy per unit weight of water [L].
Hydrogeology	The study of *groundwater* movement through soil, sediment or rock under natural or induced conditions.
Hydrology	The study of water and water movement in relation to the land. Deals with the properties, laws, geographical distribution and movement of water on the land or under the Earth's surface.
Infiltration	The process whereby water enters the soil through its surface. The downward movement of water into the soil profile.
Interstices	Openings or void space in a rock capable of holding water.
Isotropic	The condition of having properties that are uniform in all directions, opposite of anisotropic.
Joints	Fractures along which there has been little or no displacement parallel to the fracture surface.
Labile	Constantly undergoing or likely to undergo change; unstable.
Leakage	A flux of fluid from or into an aquifer or reservoir. This commonly refers to cross-formational flow.
Licence	An authority to explore for or produce water, oil or gas in a particular area issued to an individual, entity or company by the governing state.

Lithology	The physical and mineralogical characteristics of a rock. The characteristics, including grain size, of the strata of the subsurface media.
Langelier Saturation Index	Langelier Saturation Index is a calculated number used to predict the calcium carbonate stability of water. It indicates whether the water will precipitate, dissolve, or be in equilibrium with calcium carbonate.
Maximum Drawdown Level	Maximum allowable drawdown defined for each aquifer in order to protect MNES (under the EPBC Act). If reached, it corresponds to an impact to MNES and triggers a serie of make good actions. A threshold level has also been defined to provide an early impact warning prior to potentially reaching the Maximum Drawdown level
Mesozoic	An era of geologic time between approximately 230 and 65 million years ago and including the Triassic, Jurassic and Cretaceous Periods (see Era).
Metamorphic rock	Rock of any origin altered in mineralogical composition, chemical composition or structure by heat, pressure, or movement at depth in the Earth's crust. Examples of metamorphic rocks include schist, gneiss and quartzite. Most have parallel bands of minerals evident.
Mining (minerals)	Economic extraction of useful materials, ores, minerals or coal
Mining (groundwater)	In hydrogeology, this implies extraction of water from a groundwater system which is not currently receiving recharge.
Nested monitoring wells	A groundwater installation comprising a single large diameter hole containing multiple piezometer casings screened at varying depths to intersect different aquifers or aquifer levels. The construction of nested wells requires the accurate placement of individual filter packs and bentonite seals to isolate each of the aquifers intersected.
NSW Office of Water	In July 2009 the NSW government issued Administrative Orders abolishing the Department of Water and Energy (DWE) and establishing two new agencies to manage the functions of the former Department. The water responsibilities formerly in DWE are now managed by the NSW Office of Water (www.water.nsw.gov.au/), in the Department of Environment, Climate Change and Water (DECCW). NSW government websites related to water can be found at the new website: www.water.nsw.gov.au.
NSW Water Legislation	The two key pieces of legislation for the management of water in NSW are the *Water Management Act 2000* and the *Water Act 1912*. See http://www.water.nsw.gov.au/Water-Management/Law-and-Policy/Law-and-Policy/default.aspx.
Outcrop	(a) The part of a rock formation that appears at the surface of the ground. (b) A term used in connection with a vein or lode as an essential part of the definition of apex. It does not necessarily imply the visible presentation of the mineral on the surface of the earth, but includes those deposits that are so near to the surface as to be found easily by digging. (c) The part of a geologic formation or structure that appears at the surface of the earth; also, bedrock that is covered only by surficial deposits such as alluvium. (d) To appear exposed and visible at the earth's surface; to crop out.
Overburden	Designates material of any nature, consolidated or unconsolidated, that overlies a deposit of useful materials, ores, or coal--esp. those deposits that are mined from the surface by open cuts.

Oxide Transition Zone	The zone between the fresh bedrock and the saprock (the upper oxidised bedrock unit). This zone is slightly more oxidised than the fresh bedrock, but less oxidised than the saprock.
Palaeochannel	A river channel or drainage line incised into an ancient land surface that has been subsequently in-filled by the deposition of younger sediments.
Palaeozoic	an era of geologic time extending between around 600 and 230 million years ago and including the Cambrian, Ordovician, Silurian, Devonian, Carboniferous and Permian Periods (see Era).
Perched aquifer (perched water table)	An aquifer in which infiltrating water remains separated from an underlying main body of groundwater, with an unsaturated zone existing between the two. Usually perching occurs due to the presence of an intermediate impermeable or low permeability layer. Where the perched aquifer is unconfined, a perched water table exists. See aquifer.
Perennial River	A river which may be dry for part of the year, due to seasonal variations in weather.
Period	A geologic timeframe smaller than Eras and subdivided into Epochs.
Permeability	A measure of the capacity of rock or stratum to allow water or other fluids such as oil or gas to pass through it (i.e. the relative ease with which a porous medium can transmit a fluid). Typically measured in darcies or millidarcies.
Permeable	Materials that liquids flow though with relative ease.
Permian	A geological time period approximately 298 to 251 million years ago.
pH	A measure of the acidity or alkalinity of water. It is related to the free hydrogen ion concentration in solution pH = 7 is neutral; pH < 7 acidic; pH > 7 alkaline. (activity). Used as an indicator of acidity (pH < 7) or alkalinity (pH > 7).
Phase	Sequenced operational areas to divide the progression of an activity, including wellfield/borefield development, mining development or similar construction activity.
Piezometer	A pressure measuring device (a tube or pipe, or other device), open to the atmosphere at the top and to water at the bottom, and sealed along its length, used to measure the hydraulic head in a geologic unit. This device typically is an instrument that measures fluid pressure at a given point rather than integrating pressures over a well. (b) A borehole cased and completed with a seal(s) adjacent to the slotted section to observe the *groundwater* pressure over the slotted interval rather than the elevation of the *watertable*.
Piezometric head	The elevation to which water will rise in a *piezometer* connected to a point in an *aquifer*. Differences in piezometric head determine the hydraulic *gradient* and therefore the direction of *groundwater* flow.
Piezometric surface	A surface of equal hydraulic heads or potentials, typically depicted by a map of *equipotentials* such as a map of water-table elevations. See potentiometric surface.

Piper diagram	A graphical means of displaying the ratios of the principal ionic constituents in water. (modified from Davis and DeWiest, 1966, and Freeze and Cherry, 1979). SMOW is standard mean ocean water.
Pleistocene	An epoch of geologic time between approximately 2 million and 10,000 years ago (see Epoch).
Pore water pressure	Pressure exerted by fluid in the void space of soil or rock. It is usually expressed with respect to atmospheric pressure so that positive pressures indicate that the porous medium is saturated and negative pressures indicate that it is unsaturated.
Porosity (s or n)	The volume of the voids divided by the total volume of porous medium (the percentage of a rock or soil that is represented by open voids or spaces): *Effective porosity* - the interconnected porosity which contributes to groundwater flow. Often used synonymously with specific yield although the two terms are not synonymous. *fracture porosity* - the porosity of the fractures; *intergranular porosity* - the porosity between the grains of a sediment or sedimentary rock; *primary porosity* - intergranular porosity formed during the deposition of the sediment or from vesicles in igneous rocks; *secondary porosity* - porosity formed after the rock is lithified by either dissolution or fracturing.
Porous	Having porosity.
Potable	Drinkable. Potable waters can be consumed safely.
Potable water	Water that is safe and palatable for human use.
Potentiometric surface	A surface of equal hydraulic heads or potentials, typically depicted by a map of equipotentials such as a map of water-table elevations.
Precipitation	(a) Water condensing from the atmosphere and falling under gravity in drops or particles (e.g., snow, hail, sleet) to the land surface. (b) Formation of a solid from dissolved or suspended matter. (c) The transfer of water from the atmosphere to the land surface, predominantly as rainfall, but also includes dews, frosts, mists, snow, sleet, hail and fog.
Preferential flow	The preferential movement of groundwater through more permeable zones in the subsurface.
Preferential flow (sediment or rock)	Rapid groundwater flow that occurs through any structure significantly more permeable than the bulk sediment or rock.
Preferential flow (soil)	Rapid soil water flow that occurs through *macropores* or any other structure significantly more permeable than the bulk soil.
Preferred pathway	A channel (fracture in rock) or pore (in a soil layer or weathered rock) that has higher *permeability* through which water flows preferentially. Old tree root channels are preferred pathways in many clayey *subsoil*s in the South-West Agricultural Region.

Production bore (or well)	A bore from which abstraction of groundwater may take place, either through pumping or artesian flow. See also Production Well.
Pump-out Test (Pumping Test, Test Pumping)	A test conducted in a production bore or other installation using a pump to abstract groundwater. May be used to estimate the hydraulic characteristics of the aquifer or bore. Commonly involves the use of a production bore in association with observation bores.
Radius of influence	Radial distance to points where hydraulic head is noticeably affected by a pumping well.
Recharge	The water that moves into a groundwater body and therefore replenishes or increases sub-surface storage. Recharge typically enters an aquifer by rainfall infiltrating the soil surface and then percolating through the zone of aeration (unsaturated soil). Recharge can also come via irrigation, the leakage of surface water storage or leakage from other aquifers. Recharge rate is expressed in units of depth per unit time (e.g. mm/year). The process by which water enters the groundwater system or, more precisely, enters the phreatic zone.
Recharge area	An area of land from which a significant amount of *groundwater* recharge occurs. In the agricultural areas most of the cleared land that is not discharging *groundwater* contributes some *recharge*.
Recovery	The rate at which the water level in a pumped bore rises once abstraction has ceased.
Refusal, drilling	The depth or point at which borehole drilling cannot continue due to the competency (or mechanical strength) of the rock.
Regolith	Regolith is a general term for the layer of unconsolidated, weathered materials that rests on unaltered bedrock. In this study, the regolith comprises alluvium, colluvium and the underlying saprolite layer.
Regulated river (high security)	Regulated river (high security) have priority over the below access licences. High security entitlements cannot carryover water from one year to the next, but must be allocated water to a level specified in the respective WSP prior to general security water being made available in each year
Regulated river (general security)	Regulated rivers (general security) have next priority after 'high security' entitlements in access licences and form the bulk of water supplied to irrigators in NSW.
Rehabilitation	To restore to former condition or status.
Risk assessment	The overall process of using available information to predict how often hazards or specified events may occur (likelihood) and the magnitude of their consequences (adapted from AS/NZS 43601999).
Risk management	The systematic evaluation of the water supply system, the identification of hazards and hazardous events, the assessment of risks, and the development and implementation of preventive strategies to manage the risks.

River	A physical channel in which runoff will flow; generally larger than a stream, but often used interchangeably.
Runoff	(a) That portion of the rainfall that is not absorbed by the deep strata, is used by vegetation or lost by evaporation, or that may find its way into streams as surface flow. (b) Water flowing downslope over the ground surface, also known as overland flow. *Precipitation* that does not *infiltrate* into the soil and is not stored in depressions becomes run-off.
Sustainable yield	The volume of water that can be annually withdrawn from an aquifer (or groundwater basin or system) without 1) exceeding average annual recharge; 2) violating water rights; 3) creating uneconomic conditions for water use; or 4) creating undesirable side effects, such as subsidence or saline water intrusion.
Saline (water)	A term used to describe water that has high *salinity* levels (in excess of 5,000 mg/L) which limit its suitability for many uses.
Saline water	Water that is generally considered unsuitable for human consumption or for irrigation because of its high content of dissolved solids.
Salinity	An accumulation of soluble salts in the soil *root zone*, at levels where plant growth or land use is adversely affected. Also used to indicate the amounts of various types of salt present in soil or water. (see Total Dissolved Solids).
Sand	Sedimentary mineral grains deposited by wind or water action having a particle size of between 1/16 and 2 mm diameter. The grains are made up of predominantly quartz and can include other minerals such as feldspars, mica, glauconite and iron oxides.
Sandstone	A sedimentary rock composed predominantly of consolidated sand-sized grains (typically between 1/16 and 2 mm), usually quartz, with some cement.
Sanitation	The treatment and disposal of waste from the human body and grey water generated through household activity.
Sodium Adsorption Ratio	Sodium Adsorption Ratio the ratio of sodium to calcium and magnesium. For most irrigation schemes a SAR of between 10 and 20 is required to avoid the sodicity of the water degrading the physical structure of the soils
Saprock	The upper, oxidised layer of the regional bedrock. Saprock is distinguished from saprolite by its greater rock strength, determined when drilling refusal is reached. In this study, the saprock includes the Oxide Transition Zone.
Saprolite	Bedrock that has been chemically “rotted” *in situ.* The term is often applied to the lower portion of a weathering profile (i.e. regolith).
Saturated zone	The part of a body of soil or rock in which the voids and spaces are filled with water.
Screen, slotted section	A section of casing, usually steel or PVC, with apertures or slots cut into the tubing to allow groundwater to flow through. Screen usually refers to machined sections with openings that can be sized appropriate to the aquifer matrix and filter pack grading.
Sediment	a) Solid material, both mineral and organic, that is in suspension, is being transported, or has been moved from its site of origin by air, water, gravity, or ice and has come to rest on the Earth's surface either above or below sea

	level.
	b) Solid material, whether mineral or organic, which has been moved from its position of origin and redeposited.
Sedimentary rock	Any rock that has formed from the consolidation of sediment.
Seep	Point at where seepage occurs.
Seepage	
Shale	A fine-grained *sedimentary rock* comprised of clays and other finely sized mineral particles.
Share component	Of the water access licence is the volume share of water made available in a water source. It is similar to the entitlement volume on previous water licences under the *Water Act 1912*. The amount of water a licence holder is allocated in any year as a result of an available water determination is based on their share component.
Silt	Silts are sedimentary grains having a particle size of between 0.002 to 0.05 mm diameter. It is almost always deposited by water action and usually comprises finely divided particles of quartz, carbonate dust, carbon and iron pyrite minerals. Silt transmits and absorbs water but does not become sticky and is therefore considered to be non-plastic.
Siltstone	A *sedimentary rock* comprised of *silt*-size particles cemented together. They are the result of grains of silt particles having been deposited layer upon layer, compacted by the weight of overlying material and cemented together over millions of years to form a hard rock.
Sorption	The general process by which solutes, ions, and colloids become attached (sorbed) to solid matter in a porous medium. Sorption includes absorption and adsorption.
Specific storage (Ss)	The amount of water absorbed, released or expelled from storage in a unit volume (i.e. 1 x 1 x 1) of aquifer under a unit change in hydraulic head (i.e. $\delta h = \pm 1$).
Specific yield (Sy)	The quantity of groundwater that will drain under gravity from a unit volume (i.e. 1 x 1 x 1) of an unconfined aquifer. A unit decline in hydraulic head under unconfined conditions results in both a reduction in pressure and in the saturated thickness of the aquifer. Because of this, the storativity of an unconfined aquifer is related to the specific yield (Sy), the thickness of the saturated zone (h) and the specific storage (Ss) according to the equation $S = Sy + h\ Ss$. The product of specific storage and saturated thickness (i.e. h Ss) is generally considerably less than the value of the specific yield. Hence, for almost all unconfined aquifers, the storativity is considered to be equivalent to the specific yield (see Storage Coefficient, Specific Storage).
Standing water level (static water level, SWL)	The depth to groundwater measured at any given time when pumping or recovery is not occurring.
Storage coefficient (Storativity; S)	The volume of groundwater that is expelled from or absorbed into storage under a unit change (i.e. $\delta h = \pm 1$) in hydraulic head over a unit area (i.e. 1 x 1) of the aquifer. The storativity of a confined aquifer is related to the specific storage (Ss) and saturated thickness (b), by the equation $S = b\ Ss$ (see Specific Storage).

Storativity	The volume of water that a saturated confined aquifer releases from storage per unit surface area of the aquifer per unit decline in the water table. Quantifies the aquifers ability to release water.
Stratigraphy	The study of stratified rocks, especially their age, correlation and character.
Streamflow	See ‘surface flow’
Stygofauna	Fauna that lives within the groundwater system
Subcrop	That part of a geologic formation that is buried below the subsurface; that is, not exposed at land surface.
Subsidence	(a) The vertical movement of the surface, although small-scale horizontal movements may be present. This sinking or settlement of the land surface can be caused by a number of processes, including production of fluids, solution, compaction, or cooling of magmatic bodies. (b) Lowering of the ground surface resulting from removal of hydrostatic pore space pressure (through buoyancy) or collapse of underground mine voids.
Surface flow	A term used to describe the movement of water across the ground surface as *run-off* or stream flow (a river, creek or stream would e regarded as ‘surface flow’ or ‘streamflow’). See ‘streamflow’.
Sustainable yield	Is the volume that can be extracted by all water users in a groundwater source without causing unacceptable impacts (i.e. without detrimentally affecting existing supplies or flows to dependent environments). The average annual recharge minus the portion reserved for the environment determines the sustainable yield.
Tertiary	A period of geologic time between approximately 65 and 2 million years ago (see Period).
Threshold Level	Defined value (measurable criteria such as water level, water quality) that if reached for an environmental or operation monitoring aspect provides an early warning to a potentially upcoming impact
Total dissolved solids (TDS)	An expression of the total soluble mineral content of water determined by either measuring the residue on evaporation or the sum of analysed chemical constituents. Usually quoted in milligrams per litre (mg/L) or the equivalent parts per million (ppm), TDS may also be approximated from electrical conductivity (EC) measurements using the conversion EC (µS/cm) x 0.68 = TDS (mg/L) (see Electrical Conductivity and salinity).
Transmissivity (T)	The rate of horizontal groundwater flow through the full saturated thickness (b) of an aquifer across a unit width (i.e. an area of b x 1) (ie. through a 1 metre wide slice across the entire depth of an *aquifer*) under a unit hydraulic gradient (δh / δl = 1). Transmissivity may be quoted as m^3/day/m [L^3/T/L], but is more commonly expressed as m^2/day [L^2/T]. It provides a better comparison of the possible yield of an *aquifer* than saturated *hydraulic conductivity* because it takes into account the saturated thickness of an *aquifer*. Transmissivity is related to the hydraulic conductivity of the aquifer by the equation T=Kb.
Tremie pipe	A narrow diameter pipe, which keeps the sealing materials from becoming bridged inside the well casing and prevents dissolution of liquid grout.
Triassic	A period of geologic time extending from 230 to 180 million years ago (see Period).

Trigger Level	Value of an operational or environmental measurable criteria (such as water level or water quality values) that if reached corresponds to the petroleum field activities having an impact on the environment.
Unconfined aquifer (water table aquifer)	An aquifer in which the surface of the saturated zone is at atmospheric pressure. See *aquifer*.
Water Access Licences (Under Water Management Act 2000 NSW).	There are a range of categories for water access licences (under WMA 2000). In this report the three categories being discussed are regulated river (high security), regulated river (general security) and supplementary water. Town water needs, domestic and stock have the highest priority of the licence categories. The following broadly describes the next three categories: *Regulated river (high security)* – have priority over general security access licences. High security entitlements cannot carryover water from one year to the next, but must be allocated water to a level specified in the respective WSP prior to general security water being made available in each year. *Regulated river (general security)* – have next priority in access licences and form the bulk of water supplied to irrigators in NSW S*upplementary water* – have lowest priority of access of the three listed categories. In reporting the availability of supplementary water, consideration has been given to whether the total volume of the supplementary / high flow event should be used, or the simulated diversions of such water. The estimated volume of water diverted includes the ability of licensed infrastructure to actually capture such flows, whereas the volume of the total flow event may well represent flood waters that are too large or too quick to be accessed by existing infrastructure. The volume of water diverted also reflects the impact of share limits and other environmental restrictions to access during specific events. Accordingly, this report uses simulated diversion of supplementary flows as the primary measure of availability.
Unsaturated zone	The part of a body of soil or rock separating the land surface and the water table.
Vibrating Wire Piezometer (VWP)	The sensor of the VWP consists of a pressure transducer with an internal thin resonating wire connected to a sensitive perpendicular diaphragm. Water pressure exerted against the diaphragm wall causes it to deflect and alter the tension of the wire and this in turn causes the wire to resonate at different frequencies. An electromagnetic field induced from coils adjacent to the vibrating wire causes it to be plucked and resonate at a frequency signal which is sent through the signal cable to a readout unit or logger at the ground surface.
Water balance	The relationship between input, storage and output within a hydrological system. If the amount of water entering the system is the same as the amount leaving, then storage remains constant and the system can be considered to be in equilibrium. Where input exceeds output, the water balance becomes altered and the amount of water stored in the system increases. Conversely, the balance can be altered as storage decreases in response to output exceeding input.

Watertable	(a) The upper surface of a body of *groundwater* occurring in an *unconfined aquifer*. At the watertable, pore water pressure equals the atmospheric pressure. (b) The surface of a body of groundwater within an unconfined aquifer at which the pressure is atmospheric.
Well	A shallow work that is larger in diameter than a bore, but usually no greater than 1.5 m wide. Commonly, wells are less than 20 m deep and may be partially lined with concrete cylinders.
Well yield	The discharge of well at (nearly) steady flow $[L^3t^{-1}]$.
Wetland	Those areas that are inundated or saturated by surface or groundwater at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Lands transitional between terrestrial and aquatic systems where the water table is usually at or near the surface or the land is covered by shallow water. For purposes of this classification, wetlands must have one or more of the following three attributes 1. At least periodically, the land supports predominantly hydrophytes; 2. The substrate is predominantly undrained hydric soils; and 3. The substrate is non-soil and is saturated with water or covered by shallow water at some time during the growing season of each year.
Yield	The quantity of water removed from a water resource e.g. yield of a borehole.

Report Signature Page

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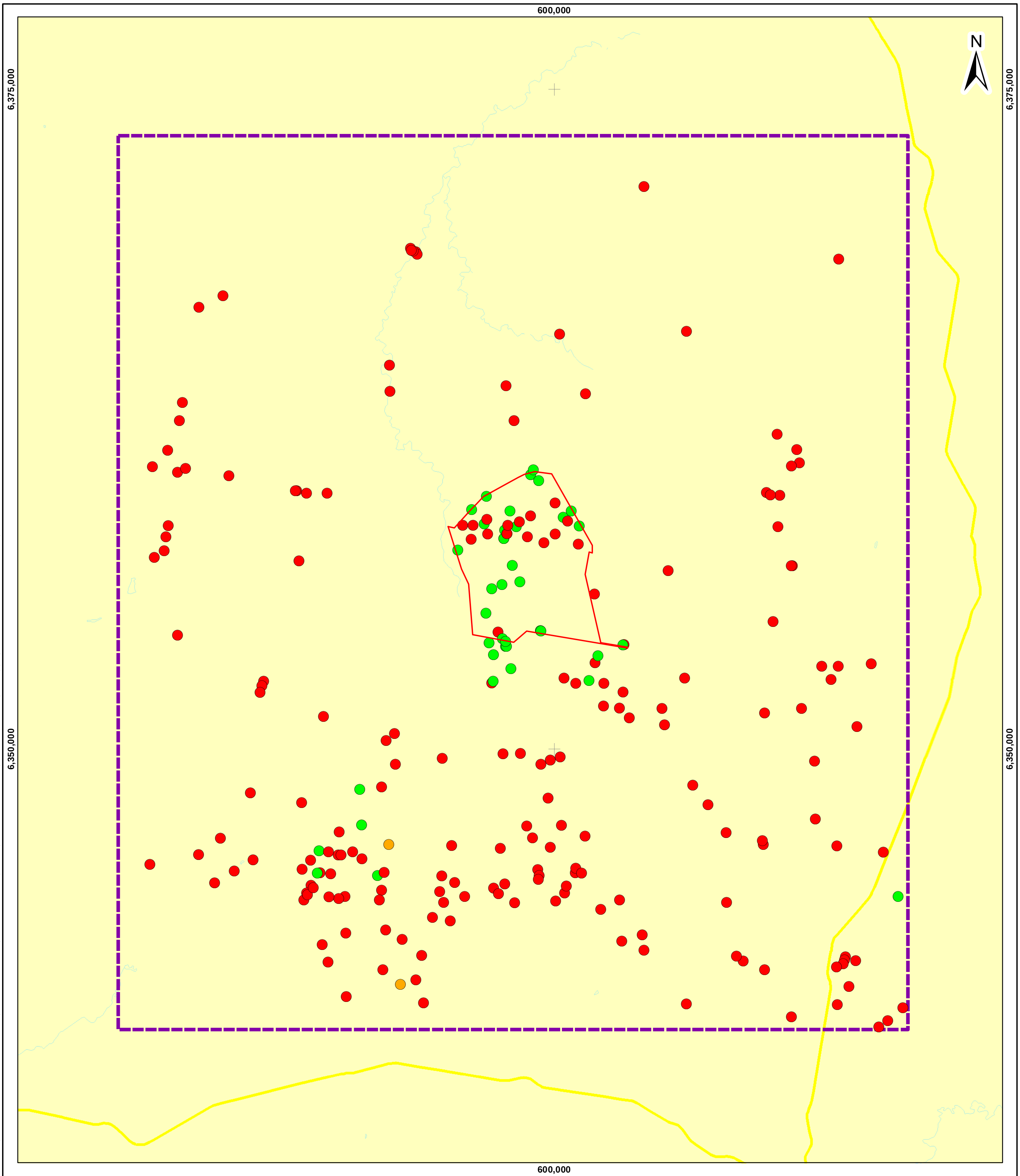
APPENDIX A

Metadata (Please refer to CD for Tables A1 and A2)



NORTHPARKES MINE GWA

UMWELT (AUSTRALIA) PTY. LTD.

METADATA MAP
BORE CHEMISTRY

LEGEND

- Project Area
- Study Area
- River
- Major Roads

Metadata

Bore Chemistry Rank

- 1
- 2
- 3

0 1 2 4 6 Kilometers

SCALE (at A4) 1:200,000

Coordinate System: GDA 1994 MGA Zone 55

PROJECT:	**117626007**
DATE:	**30/04/2013**
DRAWN:	**FA**
CHECKED:	**RS**

APPENDIX A1

Golder Associates

NOTES

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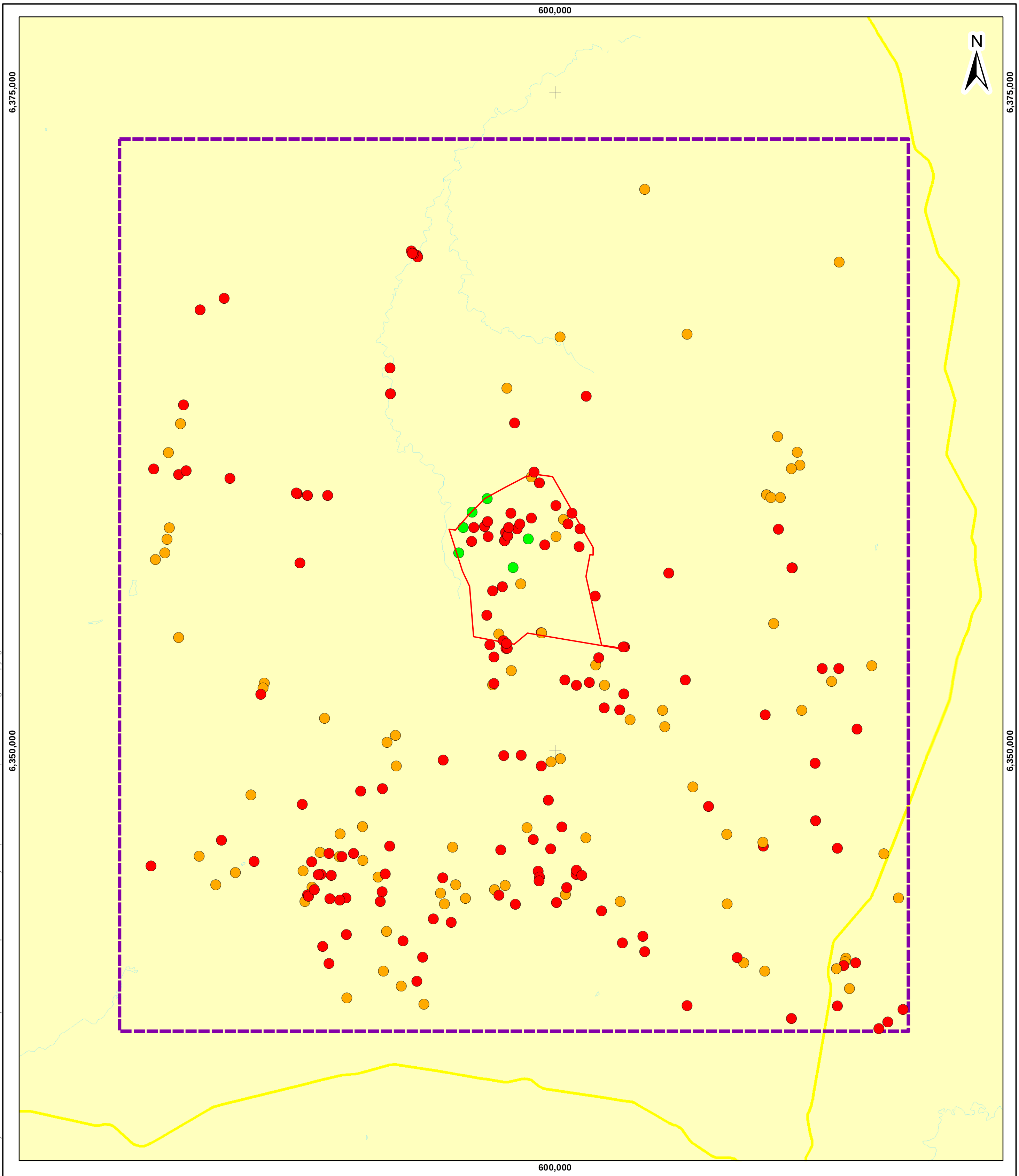

NORTHPARKES MINE GWA

UMWELT (AUSTRALIA) PTY. LTD.

METADATA MAP
BORE CONSTRUCTION

LEGEND

- Project Area
- Study Area
- River
- Major Roads

Metadata

Construction Rank

- 1
- 2
- 3

NOTES

0 1 2 4 6 Kilometers

SCALE (at A4) 1:200,000

Coordinate System: GDA 1994 MGA Zone 55

PROJECT:	117626007
DATE:	30/04/2013
DRAWN:	FA
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APPENDIX A2

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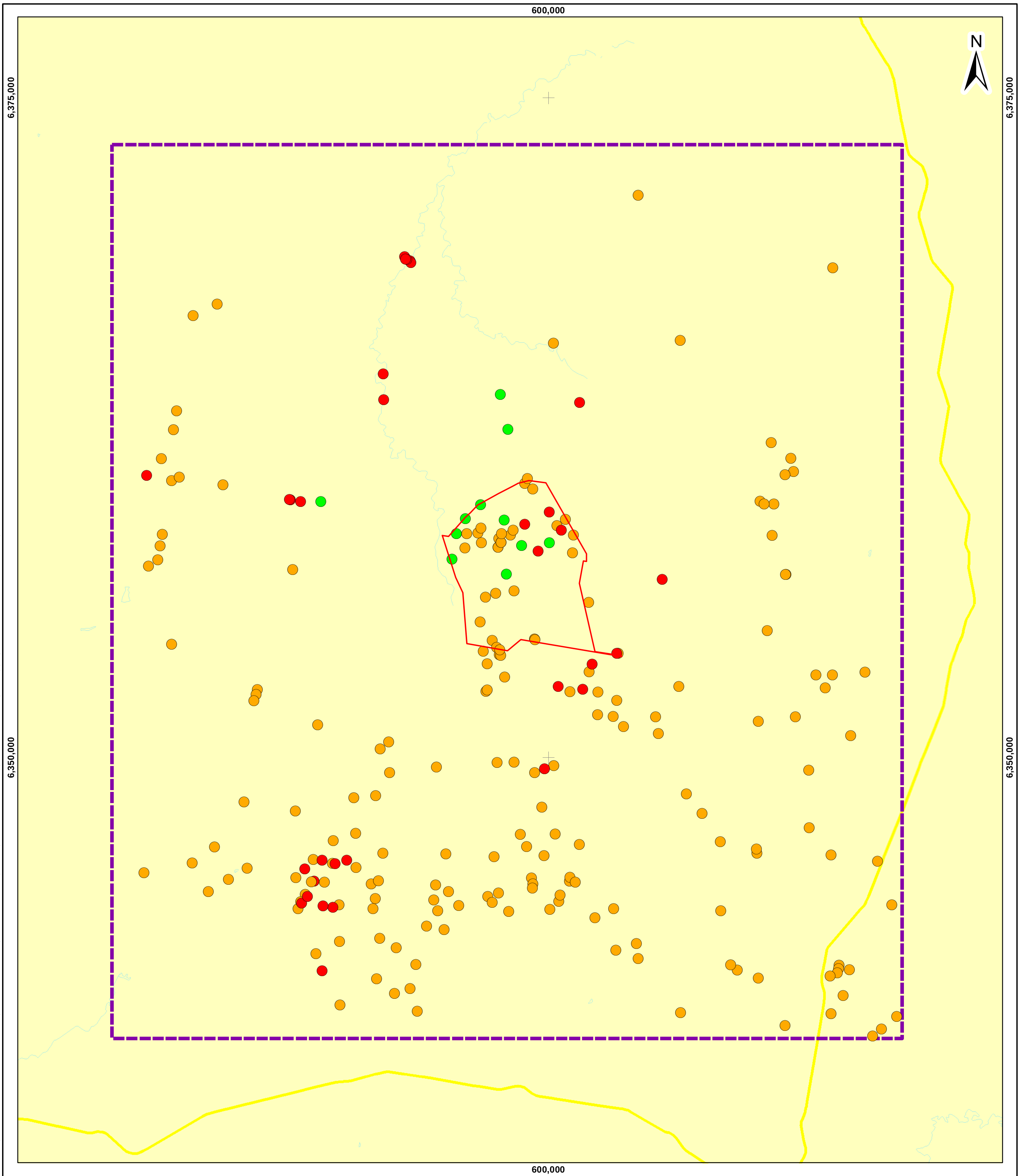

NORTHPARKES MINE GWA

UMWELT (AUSTRALIA) PTY. LTD.

METADATA MAP
BORE DEPTH

LEGEND

Project Area
Study Area
Major Roads
River

Metadata

Bore Depth Rank

1
2
3

0 1 2 4 6 Kilometers

SCALE (at A4) 1:200,000

Coordinate System: GDA 1994 MGA Zone 55

PROJECT: 117626007
DATE: 30/04/2013
DRAWN: FA
CHECKED: RS

APPENDIX A3

Golder Associates

NOTES

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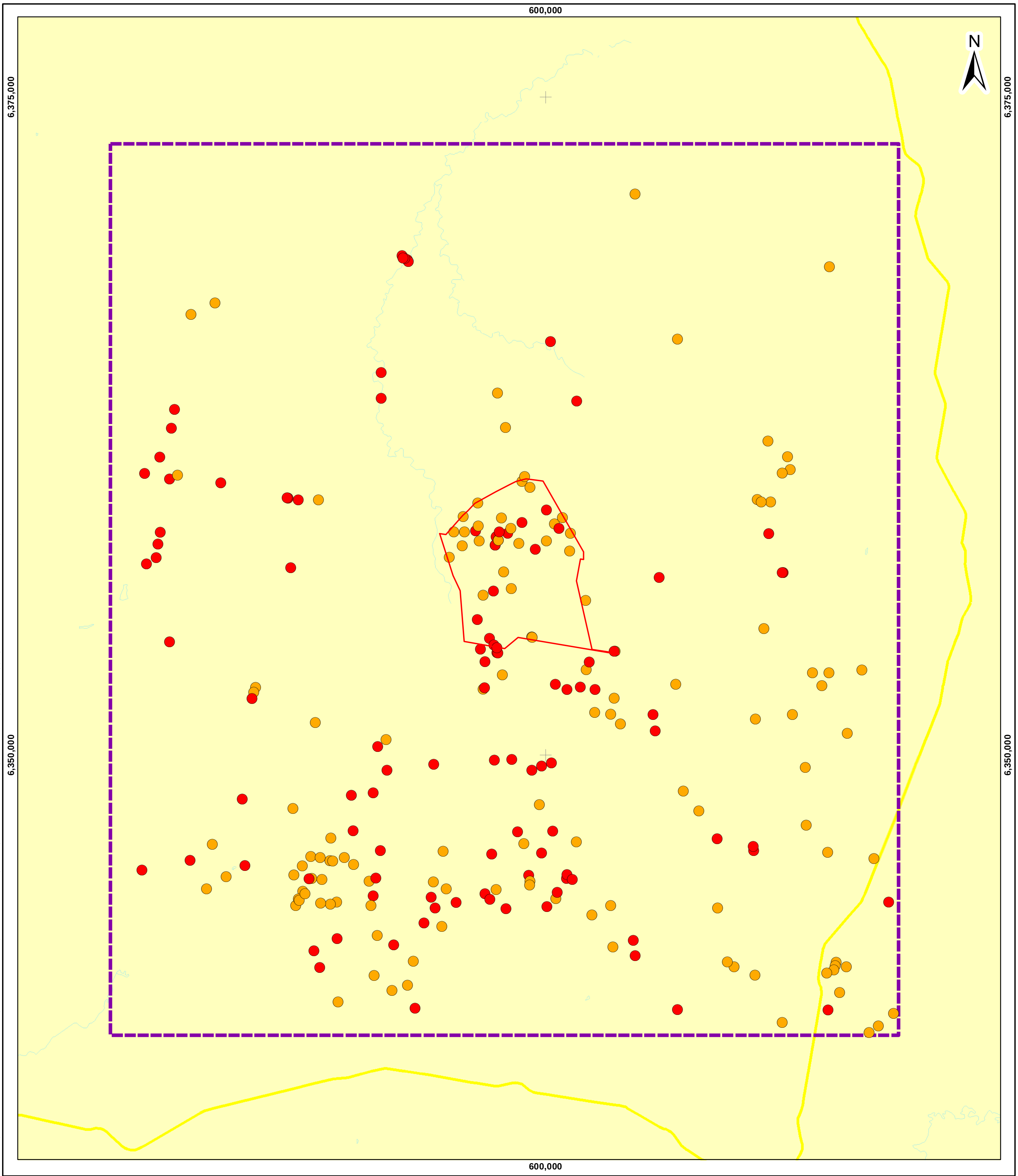


NORTHPARKES MINE GWA

UMWELT (AUSTRALIA) PTY. LTD.

METADATA MAP
BORE STRATIGRAPHY

LEGEND

- Project Area
- Study Area
- River
- Major Roads

Metadata

Stratigraphy Rank

- 1
- 2
- 3

0 1 2 4 6 Kilometers

SCALE (at A4) 1:200,000

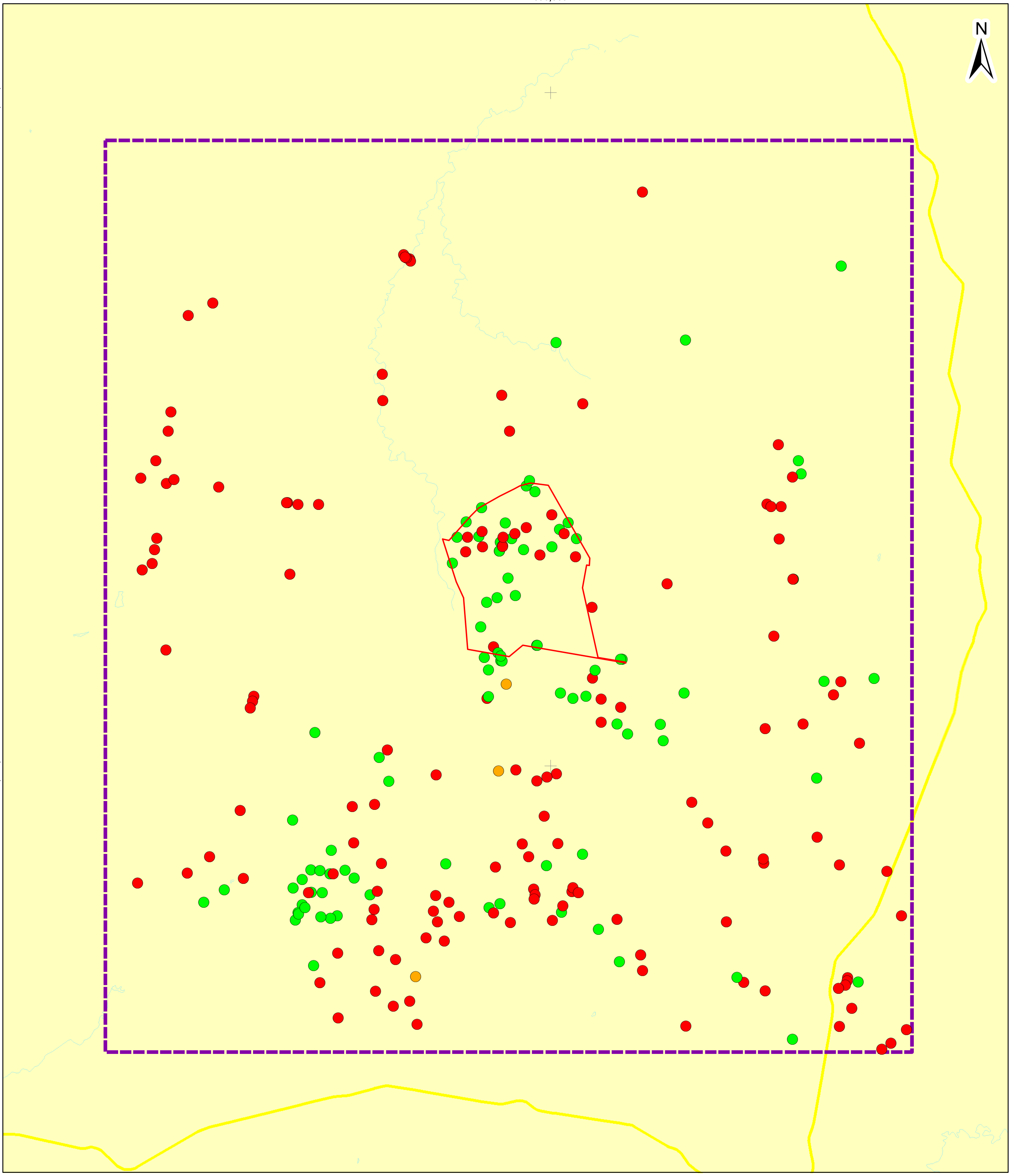
Coordinate System: GDA 1994 MGA Zone 55

PROJECT:	117626007
DATE:	30/04/2013
DRAWN:	FA
CHECKED:	RS

APPENDIX A4

Golder Associates

NOTES



NORTHPARKES MINE GWA

UMWELT (AUSTRALIA) PTY. LTD.

METADATA MAP
WATER LEVEL

LEGEND

Project Area
Study Area
Major Roads
River

Metadata

Water Level Rank

1
2
3

0 1 2 4 6 Kilometers

SCALE (at A4) 1:200,000

Coordinate System: GDA 1994 MGA Zone 55

PROJECT: 117626007
DATE: 30/04/2013
DRAWN: FA
CHECKED: RS

APPENDIX A5

Golder Associates

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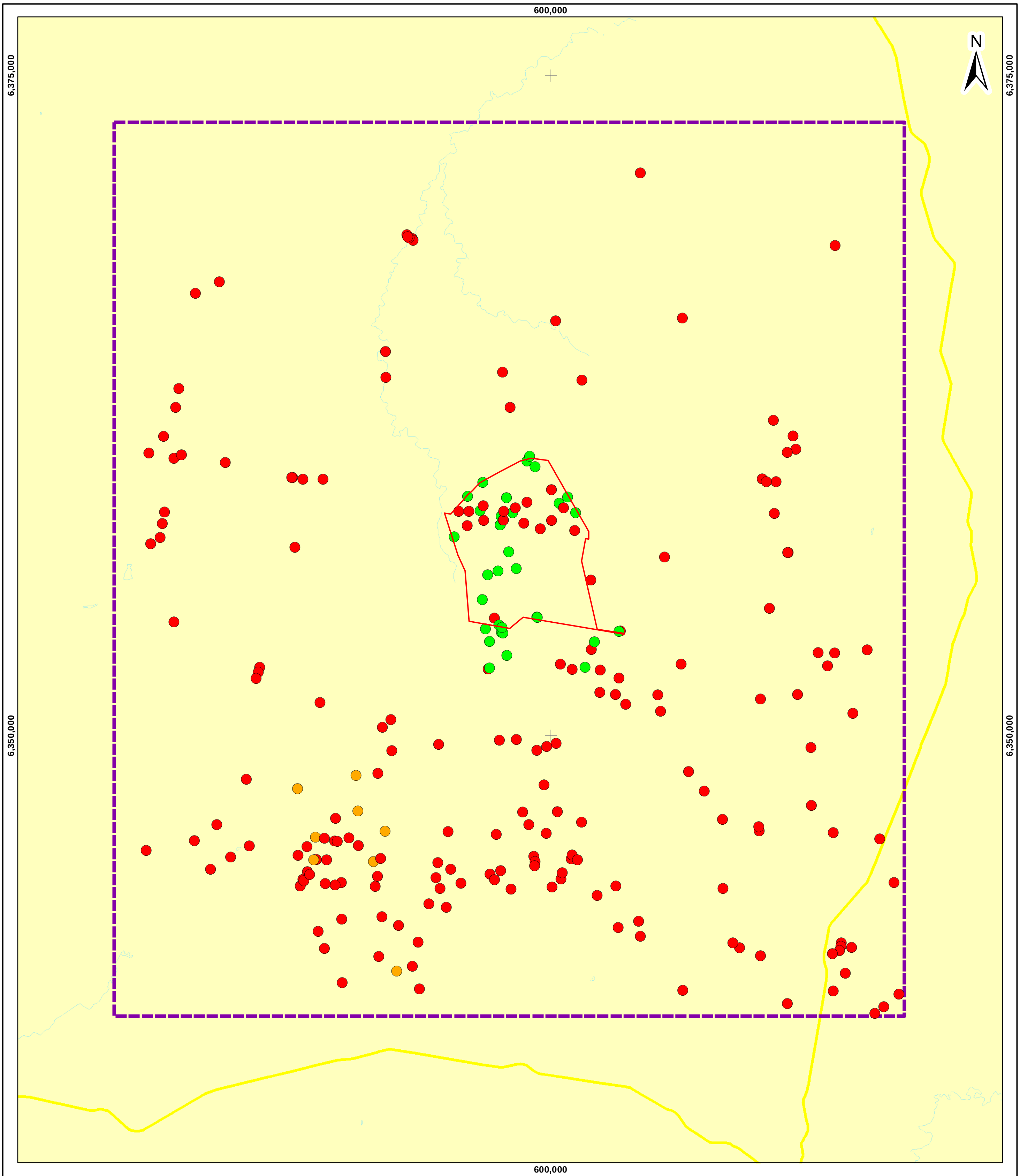

NORTHPARKES MINE GWA

UMWELT (AUSTRALIA) PTY. LTD.

METADATA MAP
WATER QUALITY

LEGEND

Project Area

Metadata

Water Quality Rank

- 1
- 2
- 3

Study Area

River

Major Roads

NOTES

0 1 2 4 6 Kilometers

SCALE (at A4) 1:200,000

Coordinate System: GDA 1994 MGA Zone 55

PROJECT:	117626007
DATE:	30/04/2013
DRAWN:	FA
CHECKED:	RS

APPENDIX A6

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APPENDIX B

Legislative Framework

APPENDIX B - LEGISLATIVE FRAMEWORK

1.0 INTRODUCTION

NPM currently seeks Project Approval from the Minister for Planning under Part 3A of the EP&A Act for the development of further mining operations including open cut mining, and depth extensions to existing ore bodies and development of a new ore body. This section of the GWIA identifies and summarises key legislation applicable to groundwater issues related to the Project.

The relevant legislation assessed for this report includes:

- Commonwealth Water Legislation
  - *Water Act 2007* and the *Murray Darling Basin Plan*
  - *Environment Protection and Biodiversity Conservation Act 1999*
- Water Legislation in NSW
  - *Environmental Planning and Assessment Act 1979*
  - *Water Management Act 200*0
  - *Water Act 1912*
  - *Environmental Planning and Assessment Act 1979* (EP&A Act)
- NSW State Groundwater Related Policies
  - 'NSW Groundwater Policy Framework Document – General'
  - 'NSW Groundwater Quality Protection Policy', 1998
  - 'NSW Groundwater Dependant Ecosystem Policy', 2002
  - 'Aquifer Interference Policy', 2012
- Water Licensing Requirements
- Guidelines for Fresh and Marine Water Quality (ANZECC)

2.0 COMMONWEALTH WATER LEGISLATION

In addition to the NSW State legislation, the Project may trigger concurrent Commonwealth assessment requirements as identified within this section of the GWIA. The Study Area is located within the Murray Darling Basin.

2.1 Water Act 2007 and the Murray Darling Basin Plan

The Commonwealth *Water Act 2007* (Water Act 2007) regulates the management of water resources in the Murray Darling Basin (MDB). It was enacted to enable the Commonwealth to coordinate the management of water resources in the MDB (through the Murray-Darling Basin Authority (MDBA) as the national regulatory authority, through the implemention of the Murray-Darling Basin Plan (Basin Plan). The Basin Plan came into legal effect on 24 November 2012 (MDBA, 2012).

The Basin Plan includes enforceable limits on the quantities of surface water and groundwater that can be taken from the Murray-Darling Basin water resources. The Basin Plan establishes limits on the quantities of surface water and groundwater which can be accessed from basin water resources in each water 'sustainable diversion limit' (SDLs) resource unit. The SDL is the maximum amount of water that can be taken for consumptive use. It takes effect in 2019.

Water sharing plans (WSPs) created by the NSW Government, and the Basin Plan developed by the MDBA for the Commonwealth Government, are required under separate legislation. WSPs implemented under the *Water Management Act 2000* (WMA 2000) are required to be in accordance with SDLs as identified within the Basin Plan (pursuant to the Water Act 2007), for maintenance of the environmental values of surface and groundwater sources. This may have the effect of restricting the granting of approvals under state laws (including the WMA 2000), which apply to the extraction of water, or interference with aquifers, within the area covered by the Basin Plan. The WMA 2000 is a NSW based legislation that is interacting with Commonwealth *Water Act 2007*.

Consequently while the Water Act 2007 does not alter the need for a Water Access License (WAL) and/or aquifer interference approval under the WMA 2000, water allocations and potential groundwater management strategies under the WMA 2000 need to be consistent with the SDLs for surface and groundwater established under the Basin Plan. WSPs amended or replaced after the Basin Plan took effect on 24 November 2012, will need to be accredited by the MDBA.

Under the Basin Plan (2012), there are two water resource plan areas (WRPA) within the Study Area (Lachlan and South Western Fractured Rock WRPA (GW11) and Lachlan Alluvium WRPA (GW10). A summary of the related GMA and WRPA within the Study Area is summarised in Table B1. The allocation for the SDL area that is potentially relevant to the WRPAs is also presented in Table B1.

- GW10: There is a small area of the Lachlan Alluvium WRPA within the Study Area, 15 km south of the mine site. To date, the zone of influence from NPM activities is restricted within the vicinity of the mine site itself, due to the hydraulic properties of the host rock. It is not the intention of the Project to source water from the Lachlan Alluvium and this WRPA (GW10) is not considered to be relevant to the Project.
- GW 11: There are five groundwater SDL resource units (GS10, GS19, GS20, GS39 and GS51) within the Lachlan and South Western Fractured Rock WRPA (GW11). While these groundwater sources are subject to SDLs under the Basin Plan only the groundwater SDL resource unit Lachlan Fold Belt (GS20) is considered relevant to the Project (refer to Figure 4). The Water Act 2007 therefore covers the fractured rocks of the Lachlan Fold Belt.

Table B1: Summary of GMA and WRPA relevant to the Project

GMA	**WRPA in the MDB Plan and related groundwater SDL resource units**	**WSP**	**BDL[1] for the SDL[2] resource unit**	**Long-term average SDL for a SDL-resource**	**Water Allocation Status**
Lachlan Fold Belt (GMA 811)	Lachlan and South Western Fractured Rock WRPA (GW11) SDL - Lachlan Fold Belt (GS20)	*Water Sharing Plan for the NSW Murray Darling Basin Fractured Rock Groundwater Sources* Potentially impacted water management zones - 'Other'	142.4 GL/year	259.0 GL/year	-

[1] Baseline Diversion Limit (BDL) = the baseline limit of take from an SDL resource unit
[2] Sustainable Diversion Limit (SDL) = maximum long-term annual average quantities of water that can on a sustainable basis from Basin water resources as a whole
WSP: Water Sharing Plan
GMA: Groundwater management area
WRPA: Water resource plan area

MDB: Murray Darling Basin

2.2 Environment Protection and Biodiversity Conservation Act 1999

Projects that have a significant impact on matters of National Environmental Significance (NES), which would require concurrent approval under the Commonwealth *Environment Protection Biodiversity Conservation Act 1999* (EPBC Act).

- The EPBC Act provides that a person proposing to take an action, which may impact matters of NES must refer the proposal to the Minister for Sustainability, Environment, Water, Population and Communities (SEWPAC).
- Recent reforms to the EPBC Act have resulted in matters of NES being expanded to include consideration of the impact of large mining proposals upon water resources. This includes the Minister for SEWPAC taking advice from an Independent Expert Scientific Committee in relation to the protection of water resources.

At the time of preparing this report, we assume that the Project has not been declared a controlled action and a referral is under consideration.

Please refer to Section Environmental Value) and Section Risk Assessment) for discussion about environmental values and the risk assessment.

3.0 WATER LEGISLATION IN NSW

The NSW State legislations that are related to the Project including:

- *Environmental Planning and Assessment Act 1979;*
- *Water Management Act 2000*; and,
- *Water Act 1912* (Water Act).

3.1 Environmental Planning and Assessment Act 1979

The *Environmental Planning and Assessment Act 1979* (EP&A Act) regulates all development in NSW including the Project, which is to be assessed as a State Significant Development in accordance with Part 4 of the EP&A Act. It is understood that the Project is being assessed as a transitional Part 3A of the EP&A Act.

NPM are in the process of obtaining advice on the approval pathway for the Project and this will involve advice from NSW Department of Planning and Infrastructure (DP&I) as to whether or not revised NSW Director-General's Requirements (DGRs) will be issued for the project. The previous DGRs (2011) for the NPM "Step-Change-Project" will however not specifically apply although the guidance material and relevant legislation will be applicable. The DGRs (2011) specifically require the assessment of a number of groundwater related issues including:

- *A detailed local and regional groundwater model, including a modelled zone of influence both during mine operations and post mine life until equilibrium is achieved;*
- *An assessment of the potential to intercept groundwater and predicted dewatering volumes;*
- *An assessment of potential loss of groundwater water flows to the environment and other land users; and*
- *An assessment of groundwater potential water quality impacts on the environment and other water users.*

In addition to the DGRs, the NOW has provided the following comments to be addressed in the EA:

- Adequate and secure water supply for the proposal. Confirmation that water supplies for construction and operation are sourced from an appropriately authorised and reliable supply. It is recognised a significant increase in water demand is proposed as part of this proposal.
- Identification of site water demands, water sources (surface and groundwater), water disposal methods and water storage structures in the form of a water balance. The water balance is to outline the proposed water management on the site and to also include details of any water reticulation infrastructure that supplies water to and within the site.
- An impact assessment on adjacent licensed water users (surface and groundwater), the riparian environment and groundwater-dependent ecosystems. This is to meet the requirements of the NSW State Groundwater Policy Framework document in addition to the objects and principles of the Water Management Act 2000.
- An assessment of the potential to intercept groundwater and predicted dewatering volumes, water quality and disposal/retention methods. This is to also include the modelled zone of influence for a number of stages both during mine operations and post mine life until equilibrium is achieved.
- A water balance is to be prepared for any voids created by mining which hold water during and post mine life and is to include all inputs and outputs for a number of stages both during mine operations and post mine life until equilibrium is achieved.
- An impact assessment of the potential occurrence and management of acid generating material.
- Preparation of a surface water management plan and groundwater management plan to integrate the proposed water balance and management for the site and to identify adequate mitigating and monitoring requirements.
- Existing and proposed water licensing requirements in accordance with the Water Act 1912 and Water Management Act 2000 (whichever is relevant) and the NSW Inland Groundwater Water Shortage Zones Order No. 2, 2008 (22 December 2008). This is to demonstrate that existing licences (include licence numbers) and licensed uses are appropriate, and to identify where additional licences are proposed.
- An impact assessment of the construction, operation and final landform of any proposed on-site waste rock emplacements, tailings storage facilities and other potentially contaminating facilities to meet the requirements of the NSW State Groundwater Policy framework document and the objects and principles of the Water Management Act 2000.
- Proposals to carry out works within 40m of a watercourse are in accordance with NOW's Guidelines for Controlled Activities (August 2010). Watercourse diversions require additional assessment regarding stability and rehabilitation to achieve ecosystem functioning requirements, in addition to addressing impacts to the existing watercourse.

3.2 Water Management Act 2000

Water Management Act 2000 provisions for developing water sharing plans and licensing water extractions operate independently of the Basin Plan. The objectives of the *Water Management Act 2000* (WMA 2000) are to provide for the sustainable and integrated management of water and to guide water management activities in NSW. The WMA 2000 provides for four types of approvals:

- Water use approval: authorising the use of water at a specified location for a particular purpose for up to 10 years;
- Water management work approval;

- Controlled activity approval; and
- Aquifer interference activity approval – authorises the holder to conduct activities that affect an aquifer such as approval for activities that intersect groundwater, other than a water supply bore, for up to 10 years.

The approvals for the water use, water management work and controlled activity are assumed to be applied for the Project under Part 3A of the *Environmental Planning and Assessment Act 1979* (EP&A Act).

Aquifer interference licensing corresponds to the volume of water extracted from a water source as part of an aquifer interference activity. This includes induced leakage from an aquifer source to another as a result of groundwater extraction or any taking of water directly related to the activity being undertaken. The activity being undertaken requires aquifer interference approval.

An aquifer interference approval confers a right on its holder to carry out one or more specified aquifer interference activities at a specified location, or in a specified area, in the course of carrying out specified activities. In the absence of an approval, carrying out activities that "interfere" with an aquifer is an offence under the WMA 2000. It is also an offence to harm an aquifer including an act or omission that adversely affects the capacity of an aquifer to hold or carry water. The WMA 2000 requires that aquifer interference activities avoid or minimise their impact on the water source and land degradation, and where possible, the land must be rehabilitated.

3.2.1 Water Sharing Plans

Water Sharing Plans (WSPs) are statutory instruments created under the WMA 2000 to set out the rules for the sharing of water in a particular water source between water users and the environment and rules for the trading of water in a particular water source. WSPs also set the allocations for Water Access Licence (WAL) holders to draw water from particular sources within a WSP area, such as rivers, lakes and groundwater sources. In addition, WSPs set the water trading rules and procedures within the regulated water source, and the mechanisms for the controlled release of unassigned water (if any).

WSPs for groundwater include rules that:

- Reserve the storage component of the aquifer;
- Protect a proportion of the natural recharge – that is, the volume of water added to a groundwater system naturally, usually by infiltration from rainfall and river flows;
- Refine recharge estimates and, if necessary, reduce entitlements in those systems that are over-allocated; and
- Set distance limits between any new bores and surrounding water users and groundwater dependent ecosystems.

For a WSP the entitlement is not associated to the land and can be used in any part of the GMA (subject to a hydrogeological impact assessment with respect to neighbouring users or environmental requirements). Entitlements cannot be traded or sold *between* separate and different GMAs. Water supply for resource mines is also covered under the applicable WSPs. If a water resource is fully allocated, water for mining use is not subject to exemptions for the allocation caps (i.e., mines do not have access to extra water). In this situation, further water allocation is only available through the water market. Where the water resource is not fully allocated, it may be possible to apply for additional license entitlements through the NOW.

There is a small area of alluvial units within the Study Area, 15 km south of the mine site. To date, the zone of influence from NPM activities is restricted within the vicinity of the mine site itself, due to the hydraulic properties of the host rock. It is not the intention of the Project to source water from the Lachlan Unregulated and Alluvial groundwater resources and the WSP for this groundwater resource is not considered to be relevant to the Project.

The WSP that is relevant to the Project is the *Water Sharing Plan for the NSW Murray Darling Basin Fractured Rock Groundwater Sources*, commenced 16 January 2012. The Study Area encompasses one of the ten groundwater sources identified within NSW MDB fractured rock plan area - the Lachlan Fold Belt MDB. The Lachlan Fold Belt MDB groundwater sources include groundwater contained in:

- all rocks within the outcropped and buried areas
- all alluvial sediments within the outcropped areas

New water access licences may be considered in this area if it is a local water utility, major water utility, domestic and stock and town water supply, and salinity and water table management. Granting of water access licences may also be considered as part of a controlled allocation order made in relation to any unassigned water in this water source.

It is not the intention of the Project to source water from the groundwater resources in the MDB fractured rock plan area, however; the regolith and oxidized zone of the host rock are very tight and low yielding and very low quantities of mine inflow is expected around the mine site (Section 5). The estimated dewatering volume based on the numerical groundwater modelling is in the range of 730 ML/year (~2 ML/day) (refer to Section 5) and the modelling results suggest that there is no increase in existing groundwater requirements as a result of the Project.

3.2.2 Water Access Licences

The WMA 2000 establishes categories of water access licences (WALs). The category most relevant to the Project’s activities is an aquifer WAL.

Each WAL category can be further broken into two components. A “share component” providing entitlement to a specified share of available water within a water management area and an “extraction component” gives entitlement to take water at a specific time and rate, under specific circumstances and location. WALs do not include the works or activity approval aspects. For example a water supply works approval and/or water use approval may be required in addition to a WAL unless approved in accordance with an activity under the EP&A Act. Water works are subject to approval (or registration) before their installation.

Each year, "available water determinations" are made specifying the percentage of the "share component" that may be consumed for each licence category. These determinations will vary depending on environmental conditions such as recharge rates and changes in demands on water resources regulated by the WSP. The licensing regime under the WMA 2000 differs from the Water Act as licences are not tied to the land and water entitlements are therefore tradeable within a defined groundwater source. This means NPM may be able to (or be required to, if there is no unassigned water available) purchase water allocations from other WAL holders if insufficient water is initially allocated to NPM under its WAL(s) obtained for the Project. However, there is no obligation for those holding water allocations to sell and this will require ongoing management by NPM as part of the Project.

NPM already hold a number of WALs under the WMA 2000 (up to approximately 10.5 GL from Lachlan Alluvial sources).

The annual water demand of mine site operations for a 8.5 MTpa production rate is up to 7,000 ML/year (GHD, 2009). NPM has previously imported up to 3,670 ML/year (2003) for mining operations (NPM, 2008). Sources of water include groundwater (current license/allocation totals 2,650 ML/year) from the PSC borefield in the Lachlan Valley and onsite water that has also been harvested from the site’s surface catchment (i.e. rainfall). It is projected that the Project’s water requirements will not require an increased water take and the Project will not alter NPMs existing WALs nor impact upon further WSPs than what is existing.

3.3 Water Act 1912

The *Water Act 1912* (Water Act) has a limited role in regulation of surface water and groundwater in NSW as it is currently being phased out and replaced by the WMA 2000. The Water Act applies only to water sources (rivers, lakes and groundwater aquifers) in NSW where a WSP (implemented in accordance with the WMA 2000) has not commenced. Under the Water Act, a permit and/or licence must be obtained to extract surface water (Part 2 of the Act) or groundwater (Part 5 of the Act).

Where the WMA 2000 does not apply, the Water Act governs the issue of new water licences and the trade of water licences and allocations. When a WSP commences, existing Water Act licences are converted to WMA 2000 water access licences, and water supply works and use approvals.

Water supply for the Study Area is covered under the relevant WSP (*Water Sharing Plan for the NSW Murray Darling Basin (MDB) Fractured Rock Groundwater Sources, January 2012*); therefore, the Water Act 1912 does not apply to the Project.

4.0 ADDITIONAL NSW STATE GROUNDWATER RELATED POLICIES

In addition to the principal NSW State legislation of the WMA 2000 and Water Act, the GWIA has been prepared with due consideration of relevant state policies and guidelines addressed in accordance with the principal legislation including:

- NSW Groundwater Policy Framework Document – General
- NSW Groundwater Quality Protection Policy, 1998;
- NSW Groundwater Dependant Ecosystem Policy, 2002;
- Aquifer Interference (AI) Policy, 2012.

4.1 NSW Groundwater Policy

The NSW State 'Groundwater Policy' provides a direction on the ecologically sustainable management of NSW groundwater resources, including consideration of the beneficial use of aquifers for both now and in the future. (Beneficial use is defined within the *Guidelines for Groundwater Protection in Australia* (ARMCANZ and ANZECC 1995) as the environment values of the groundwater "*…which are conducive to public benefit, welfare, safety or health and which require protection from the effects of pollution, waste discharge and deposits*".

In accordance with the NOW comments, an impact assessment of the Project activities upon adjacent licensed groundwater users, the riparian environment and groundwater-dependent ecosystems has been undertaken to meet the requirements of the NSW State Groundwater Policy in addition to the objects and principles of the Water Management Act 2000.

4.2 NSW Groundwater Quality Protection Policy

The NSW 'Groundwater Quality Protection Policy' (1998) is designed to protect groundwater resources against pollution. This policy states that the objectives of the policy will be achieved by applying the management principles listed below.

- All groundwater systems should be managed such that their most sensitive identified beneficial use (or environmental value) is maintained;
- Town water supplies should be afforded special protection against contamination;
- Groundwater pollution should be prevented so that future remediation is not required;
- For new developments, the scale and scope of work required to demonstrate adequate groundwater protection shall be commensurate with the risk the development poses to a groundwater system and the value of the groundwater resource;

- A groundwater pumper shall bear the responsibility for environmental damage or degradation caused by using groundwaters that are incompatible with soil, vegetation and receiving waters;
- Groundwater dependent ecosystems will be afforded protection;
- Groundwater quality protection should be integrated with the management of groundwater quality;
- The cumulative impacts of developments on groundwater quality should be recognised by all those who manage, use, or impact on the resource; and
- Where possible and practical, environmentally degraded areas should be rehabilitated and their ecosystem support functions restored.

There is no town water supply within and in the vicinity of the Study Area. As the aquifers around the mine site are very low yielding and have low water quality, there is currently very little development in the vicinity of the mine site and the potential for future development of these groundwater sources is minimal. The majority of groundwater vary from brackish to saline and have been classified as unsuitable for potable use (either domestic, irrigation or for livestock watering) due to the elevated concentrations of sodium and chloride. The alluvial aquifer system within and in the vicinity of the Study Area is low yielding and not generally used for productive land use such as the borefields in the Lachlan Valley. As discussed in Section 4 of this report, there are no GDEs (springs, karsts, wetlands) or national parks located within the Study Area. There were no findings of significant risk based on the acid rock drainage risk review at the Study Area (RioTinto, 2011).

The potential impact on groundwater quality in the Study Area in relation to the tailings storage facilities, waste rock dumps, ore stockpiles, chemical storages, sulphur minerals in the rubble-filled block caves at closure will be addressed using effective management measures and adaptive monitoring approach.

4.3 NSW Groundwater Dependent Ecosystems Policy

The NSW ‘Groundwater Dependent Ecosystems Policy’ (2002) provides guidance and how to protect and manage GDEs. It ensures that the most vulnerable and valuable ecosystems are protected. Under this policy, GDEs are to be identified, maintained and protected and pollution to GDEs is to be prevented; also degraded areas should be rehabilitated.

The ‘Groundwater Dependant Ecosystem Policy’ (2002) also lists types of ecosystem in NSW, as follows:

- Terrestrial vegetation;
- Baseflow in streams (e.g. spring flow);
- Aquifer and cave ecosystems; and
- Wetlands.

As will be noted in Section 4, GDEs identified in the WSP Murray Darling Basin Fractured Rock Aquifers are outside the Study Area and more than 50 km away from the mine site. Further details are presented in Section 4.

4.4 Aquifer Interference Policy

The ‘Aquifer Interference (AI) Policy’ (2012), which is a new regulation in NSW and a key component of the NSW Government’s Strategic Regional Land Use Policy, was released on September 11, 2012. The AI Policy applies to all aquifer interference activities including mining, extractive, coal seam gas, dewatering, water injection into aquifers and activities with the potential to impact groundwater quality or result in structural damage to an aquifer.

One of the key objectives of the AI Policy is to assess the potential impacts of projects relative to minimal impact considerations for the affected water sources. These considerations include:

- Threshold values with respect to changes to water tables (in unconfined aquifers), changes to water pressure (in confined aquifers) and changes to water quality arising from proposed aquifer interference activities;
- Two standards of minimal impact considerations have been developed for highly productive or less productive groundwater sources:
- Highly productive groundwater sources are defined as having total dissolved solids values less than 1,500 mg/L and are capable of yielding groundwater at a rate greater than 5 L/s. Within this category, minimal harm considerations have been developed for alluvial, coastal sand, porous and fractured rock water sources.
- Less productive groundwater sources are those that do not meet the above criteria, with separate considerations developed for alluvial and porous/fractured rock water sources.
- Minimal harm considerations which afford protection to specific environmental values of groundwater under the AI Policy, including groundwater sources, connected surface water sources, GDEs, groundwater dependent culturally significant sites and water users. The values are protected through the application of the previously mentioned threshold values, and vertical and horizontal buffers for certain activities (e.g. underground mining).

Additional considerations are also addressed in the AI Policy, including the potential for acid generation, rising water tables, enhanced aquifer connectivity through bore construction, subsidence or hydraulic fracturing, and disposal methods for extracted water. The AI Policy requires new mining and petroleum exploration activities that take more than 3 ML/year from groundwater sources to hold a water access licence.

For the Project, mine dewatering occurs within the WSP MDB Fractured Rock Aquifers and there is no highly productive aquifer overlying the target formation; therefore, there is limited potential to impact adjacent groundwater sources. The majority of groundwater vary from brackish to saline and have been classified as unsuitable for potable use (either domestic, irrigation or for livestock watering) due to the elevated concentrations of sodium and chloride. Predicted dewatering volume at the Study Area is in the range of 730 ML/year (~2 ML/day) based on the numerical groundwater model results as presented in Section 5. NPM already hold a number of WALs under the WMA 2000 (up to approximately 10.5 GL) for mine water supply and it is envisaged that no further WALs are required for the Project.

5.0 WATER LICENSING REQUIREMENTS

There are water licensing requirements in accordance with the *Water Act 1912* and *Water Management Act 2000* and the NSW Inland Groundwater Water Shortage Zones Order No. 2, 2008 (22 December 2008). The requirement is to demonstrate that existing licences (include licence numbers) and licensed uses are appropriate, and to identify where additional licences are proposed.

The existing water licenses are as follows:

- Water Licence 70SA009535 (granted 6 May 1998) for 496ML, administered by the Department of Natural Resources (DNR).
- Water Licence 70AL600028 for 2 976ML, administered by DNR.
- Bore licences for dewatering, administered by DNR
  - E22 Pit - 80BL241019
  - E26 Pit – 80BL241042

- E27 Pit – 80BL241023
- E48 Pit – 80BL241020

- Extraction Bore Water Licences, administered by DNR
  - GW 700801 70BL226550 (“Avondale”)
  - GW 700802 70BL226867 (“Avondale”)

It is envisaged that the Project’s water requirements will not require an increased groundwater demand. The dewatering volume from mining activities is estimated in Section 5 based on the numerical model results.

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APPENDIX C

Project Area Model

1.0 BACKGROUND TO NUMERICAL GROUNDWATER MODELLING

Northparkes Mine (NPM) located in the Project Area (Figure C1) is approximately 27 km north of Parkes, New South Wales. Copper and gold mining operations began in the Project Area in 1993 as an open cut operation, later utilising block cave mining methods in 2006, (Figure C1 shows the existing and proposed mine operations relevant to the Groundwater Impact Assessment [GWIA] undertaken by Golder Associates Pty Ltd [Golder]).

Historical development of the mine operations and tailings storage facilities (TSF) in the Project Area under existing approvals is summarised as follows:

- Ore processing plant at a rate of up to 8.5 megatonnes per annum (Mtpa);
- Open cut mining at E22 and E27 commenced in late 1993 and early 1994 respectively;
- TSF 1 commissioned May 1994;
- TSF 2 commissioned February 1997;
- Block cave mining at E26 commenced in June 1996;
- Block cave mining at E48 commenced in August 2004; and
- Escourt TSF constructed in 2012.

Further details of the existing and proposed mine schedule are given in Section 1.1 below.

Under the Environmental Planning and Assessment Act 1979, Rio Tinto is required to prepare an Environmental Assessment (EA) for the approval of the proposed Extension Project. The EA will address the potential impacts and issues of the proposed NPM Extension Project.

NPM is located within the Lachlan Fold Belt, which comprises generally low permeability strata that produce low to very low yielding bores. This is reflected in the relatively low observed combined volume of groundwater pumped for dewatering of the open cast pits and block cave mine operations at the site.

Copper and gold mining operations at NPM has the potential to impact on local and regional groundwater resources and the environmental values supported by these groundwater resources. As part of the EA process, a GWIA has been undertaken.

The purpose of this GWIA is to establish a reasonable understanding of the groundwater system upon which to evaluate potential impacts from NPM operations on groundwater resources within the Project Area and Study Area. Its purpose is also to identify the regional environmental values and the measures necessary to manage impacts based on a groundwater monitoring strategy. Environmental impacts of potential concern include:

- The long term impact to the groundwater resources from Project Area operations; and
- Impacts to other groundwater users.

Impacts to the identified groundwater dependant ecosystems are specifically required to be addressed.

The objectives of the numerical groundwater model were to support the GWIA process and provide predictive modelling results to evaluate the potential change in groundwater levels due to NPM activities.

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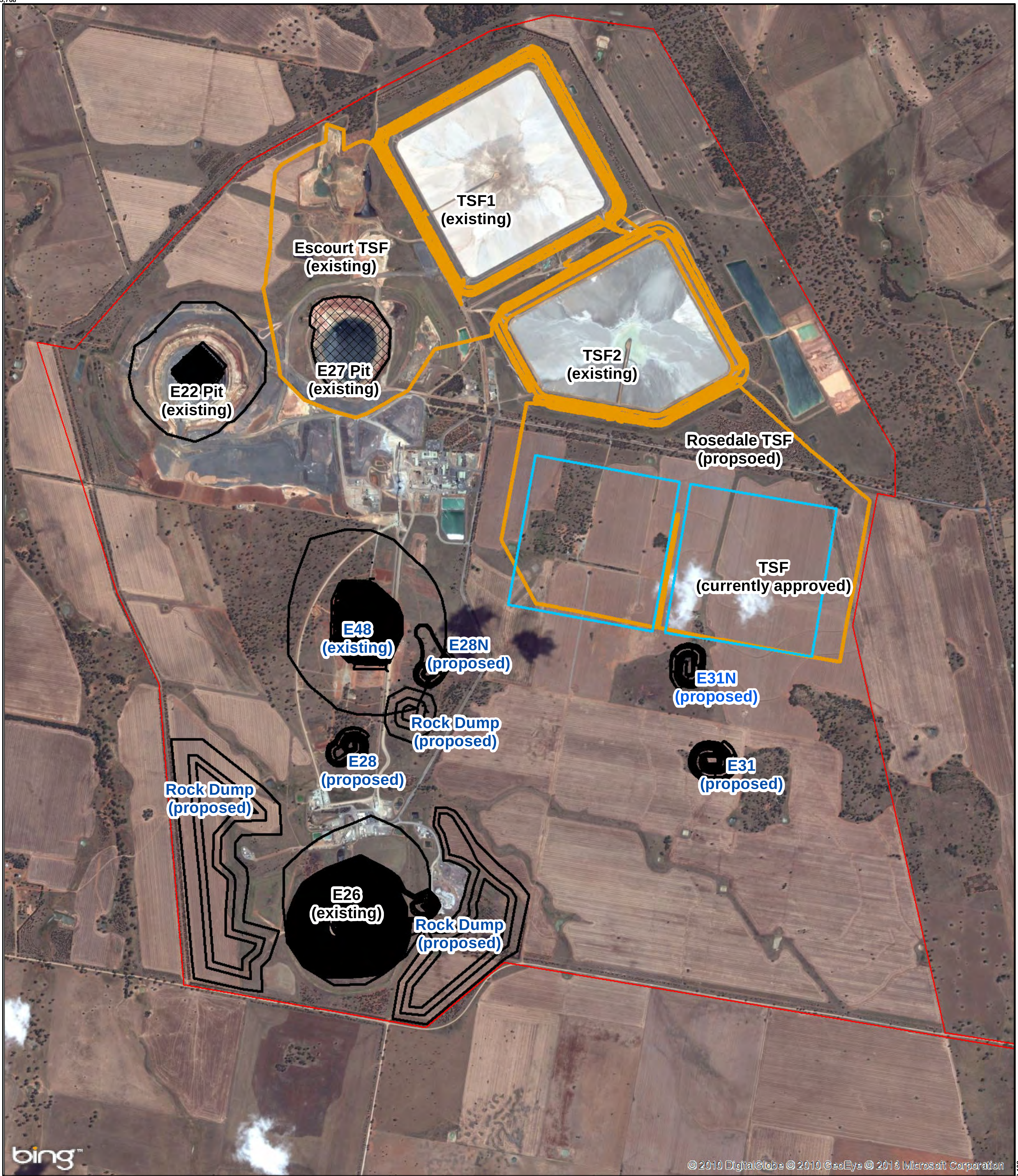

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6,353,108

NORTHPARKES MINE
Groundwater Modelling

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Existing and Proposed Mine Operations at Northparkes Mine

LEGEND

- Pit Layout
- Project Area
- Tailings Storage Facilities (Existing and Proposed)
- Mine Operations (Existing and Proposed)
- TSF Currently Approved Permits

0 0.5 1 2 Kilometers

SCALE (at A4) 1:24,000

Coordinate System: GDA 1994 MGA Zone 55

PROJECT: 117626007
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FIGURE C1

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1.1 Northparkes Extension Project Summary

The NPM Extension Project includes the continuation of some of the mining under existing approvals and includes further development of other known ore bodies, as summarised in Table C1 and shown in Figure C1. All components of the Extension Project are located within land which is subject to both the existing Project Approval (PA06_0026) Area and established mining leases (ML 1247, ML1367 and ML1641).

Table C1: Selected Components of the NPM Extension Project to the Groundwater Impact Assessment

Component	Existing and Approved Operations	Proposed Step Change Project Operations
Mining Areas	■ Block cave mining of E26 and E48 ore bodies; and ■ Open cut mining of E22 (ceased in 2010).	■ Continued block caving of the E26 and E48 ore bodies (as per current approval); ■ Development of block cave mining in the E22 resource (previously subject to open cut mining); ■ Development of open cut mining area in existing mine subsidence zone for E26; ■ Development of four small open cuts (E28, E28N, E31 and E31N); ■ All proposed open cut mining areas are located within the existing PA 06_0026 Project Area and existing Mining leases.
Mine Life	■ Until 2025.	■ Extension of mining by 7 years until 2032.
Infrastructure	**Operation of:** ■ Tailings storage facilities	**Construction and operation of:** ■ TSF to be augmented to connect existing and approved TSF through the development of Rosedale TSF to the south of TSF 2; ■ Establishment of new waste stockpiles to store waste material generated during open cut mining campaigns, including a vehicle washdown area; and ■ Continued operation of existing processing plant, site offices, underground access, water supply infrastructure and logistics connections.
Ore Processing	■ Up to 8.5 Mtpa.	■ Continuation of processing up to 8.5 Mtpa of ore through the existing processing plant sourced from underground and open cut mining areas.

Approximate timeframes for the implementation of existing and proposal Extension Project mining areas and infrastructure is given in the chart in Table C2.

Rehabilitation at NPM is managed under the Landscape Management Plan (LMP) that incorporates mine closure, final void management and rehabilitation activities for the operations (GHD, 2009). A detailed Mine Closure plan will be prepared in consultation with relevant stakeholders at least three years before the end of mine life.

As no detailed mine closure plan is available at time of modelling, the closure of the mine will be modelled by switching the drain cells off and allowing recovery in the model until approximately steady state conditions are observed (i.e. no significant change in groundwater heads over time).

Table C2: Approximate Timeframe for Existing and Proposed Extension Project Mining Areas and Infrastructure

	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
Open Pit Operations																																			
E22	X	X	X	X	X																														
E26		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X								
E27	X	X	X	X	X	X	X	X	X	X	X	X																							
E28 and E28 N																									X	X									
E31 and E31N																					X	X	X	X											
Block Cave Mine																																			
E22																													X	X	X	X	X	X	
E26 Lift 1			X	X	X	X	X	X	X	X																			X	X	X	X	X	X	X
E26 Lift 2																														X	X	X	X	X	X
E26 Lift 2/2N								X	X	X	X	X	X	X	X	X	X	X	X																
E48													X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X						
Tailings Storage Facilities																																			
TSF 1	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
TSF 2				X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Escourt TSF																				X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Rosedale TSF																					X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

Key: Operational time period of the mine* / TSF (shaded) | Nonoperational time period (unshaded)

Note: * for the purposes of the GWIA, operational is considered to be dewatered and not necessarily operational ore extraction.

2.0 NORTHPARKES PROJECT AREA – NUMERICAL GROUNDWATER MODEL

A numerical groundwater model was developed to assess potential changes to groundwater heads due to the proposed NPM Extension Project.

The aim of this assessment was to build on the previously accepted groundwater modelling projects undertaken by Mackie Environmental research (MER):

- Northparkes Mine Groundwater Management Studies E27 and E22 Pits (1999); and
- Northparkes Mine E48 Project; Groundwater Studies (2006).

Consideration was also given to the reported site characteristics and calibrated models presented by:

- Parsons Brinckerhoff: Northparkes Mine In-Pit Tailings Disposal Hydrogeology Investigation and Groundwater Impact Assessment (2003); and
- Coffey: Northparkes Project Groundwater Studies for Mine Dewatering (1993).

The MER 2006 modelling files used in the existing approvals for block cave mining at E48 were provided by MER to Golder in 2011. The MER 2006 groundwater model was reviewed and updated where additional information was available and to include relevant aspects of the Extension Project.

A conceptual groundwater model (CGM) was created as part of this GWIA. This was used to review the existing models (e.g. MER 2006 numerical groundwater model) and permit Golder to make robust updates of the model. The CGM was created utilising previous EA information and included consideration of:

- The updated NPM Extension Project mine schedule including open cut and block cave mine progression and development of the new tailings storage facilities (TSF);
- Updated environmental monitoring data (e.g. groundwater level monitoring and rain fall);
- Published Geological Maps; and
- Further geological investigations in the Project Area.

Details of the CGM were discussed in Main Text of this GWIA report (Golder, 20113).

2.1 Model Setup

The development of the model is presented in the following sections. This includes the model set up and data used for the model, provides assumptions made during model development and discusses groundwater model calibration, modelled prediction results as well as the results of sensitivity analysis.

2.1.1 Model Software

Groundwater Vistas V6.15 B7 was used to develop the groundwater model in the Project Area. Groundwater Vistas is a Graphical User Interface for the USGS MODFLOW groundwater modelling code. MODFLOW was used in conjunction with the MODFLOW-SURFACT V4 software, which is an industry standard and widely accepted numerical code for the temporal simulation of saturated and unsaturated groundwater flow in three-dimensions.

Of particular benefit in this application, the MODFLOW-SURFACT software solves the fully saturated/unsaturated groundwater flow equations to rigorously model desaturation and re-saturation of strata that is expected to occur when modelling closure scenarios of the Project.

Model Domain

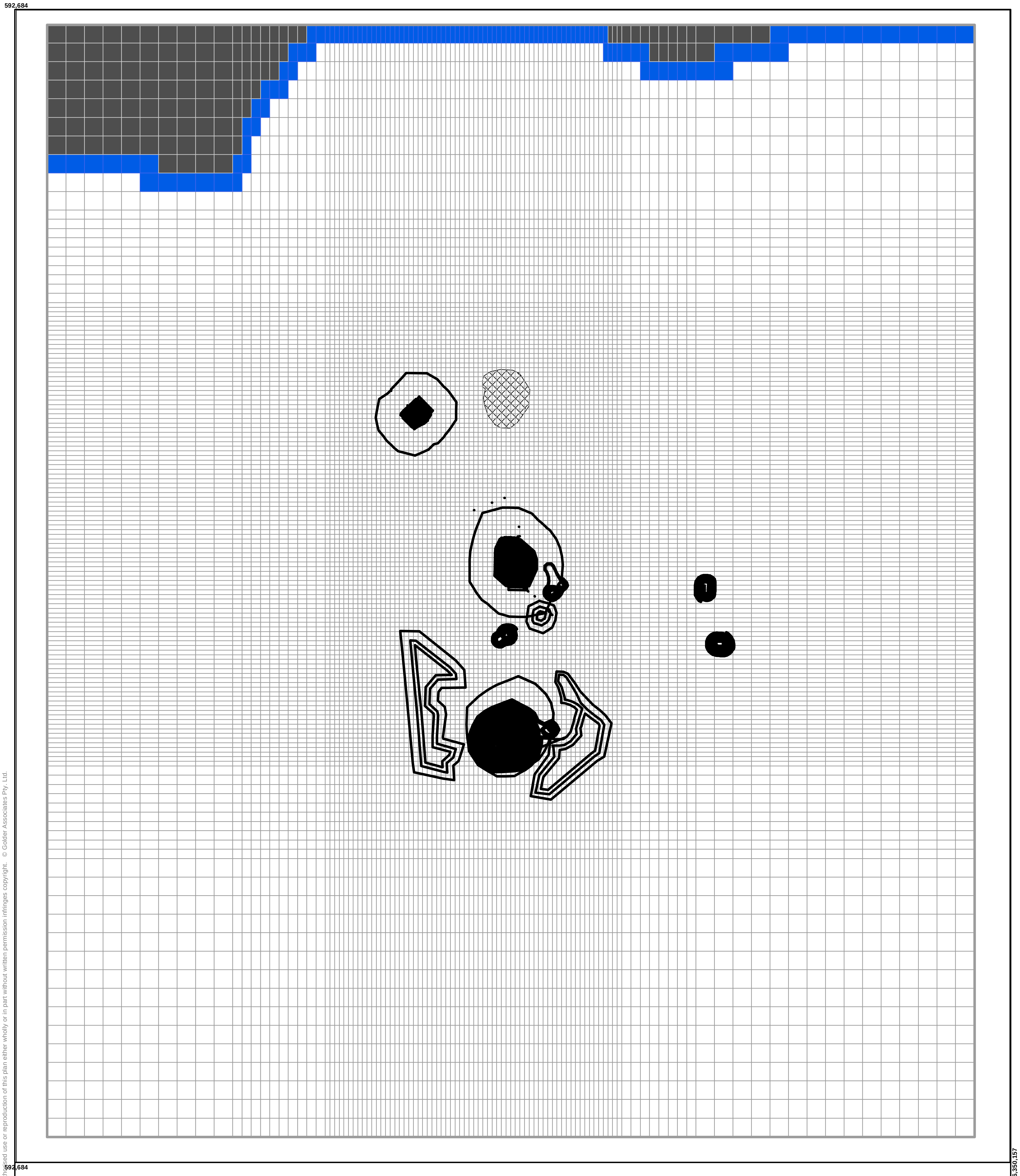
The model grid and input data was converted, where necessary, to the MGA94 coordinate system, Zone 55. Updated relevant geometric data are presented in Table C3.

Table C3: Northparkes Project Area Model – Model Extent and Grid Discretisation

Parameter	Values
Model Origin (southwest corner)	593019.0, 6350435.9
Angle of Rotation	Grid orientated North-South
Number of Columns	107
Column Width	From 200 m to 50 m
Number of Rows	145
Row Height	From 200 m to 50 m
Number of Layers	17
Total Cells	263,755
Number of Active Cells	261,698

Grid Discretisation

The model grid spacing was based on the MER 2006 model, with greatest refinement (50 m by 50 m cells) in the vicinity of the existing and proposed operations. Figure C2 presents the adopted model domain and grid discretisation in plan view for the EP model.



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Groundwater Modelling

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MODFLOW Model Domain and Grid Discretisation

LEGEND

- Mine Operations (Existing and Proposed)
- Groundwater Model Extent
- No Flow Cell
- Constant Head Boundary
- Groundwater Model Cell Discretisation
- Pit E27Pit (Approximated for Modelling)

0 0.5 1 2 3 4 Kilometers

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SCALE (at A4) 1:40,000

Coordinate System: GDA 1994 MGA Zone 55

PROJECT:	117626007
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FIGURE C2

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Golder reviewed the MER 2006 model and concluded the following:

- MER 2006 was considered to be fit for purpose for the Extension Project GWIA in that it sufficiently captured the groundwater behaviour in the Project Area;
- To expedite the modelling process and for consistency with the previous E48 GWIA, the groundwater model was based on the model domain created by MER (2006);
- Horizontally extents of the model domain were considered sufficient for the Project;

Some alterations were necessary and updates made in response to more up to date site observations and environmental monitoring. Changes to the model can be summarised as follows:

- The model domain was extended vertically with the addition of five layers at the base of the model. This was necessary to accommodate the deeper proposed mining for the Extension Project over that which was required in the E48 GWIA;
- The model grid discretisation was based on the grid discretisation used in MER (2006) although grid refinement was extended to the east of the operations to encompass E31 and E31N pit developments, which were not considered in the MER 2006 model; and
- The upper surface of the model has been interpolated to be a few metres above the top of the regional regolith (MER, 2006) as determined by rotary air blast (RAB) drilling refusal depth.

These changes are discussed further in the following sections under their relevant headings.

2.1.2 Model Geometry

Model Layers

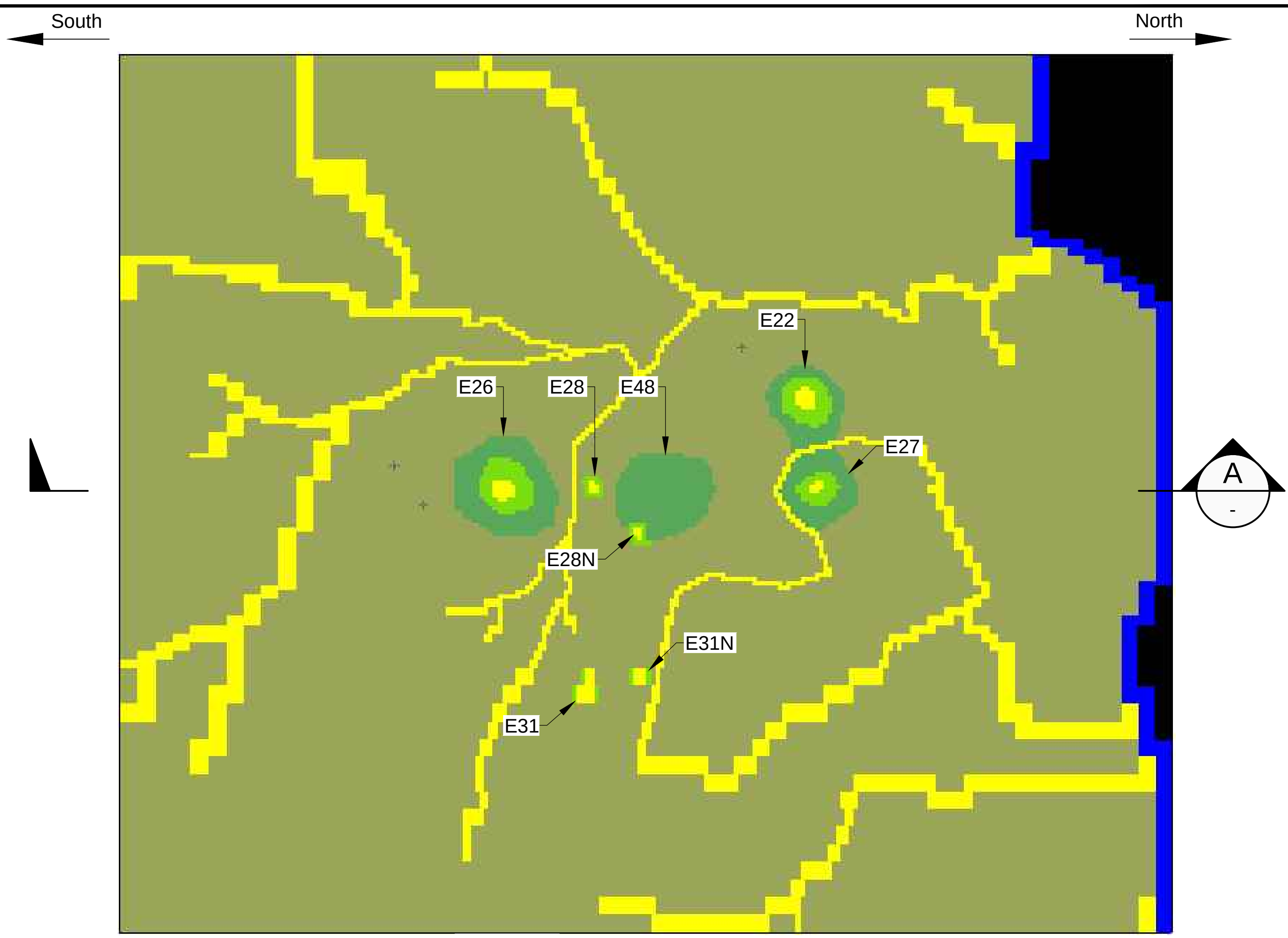
The Extension Project model consists of a total of 17 layers from the ground surface to a depth of approximately 1,200 m below ground level (-925 mAHD [metres Australian Height Datum]), of which the upper 12 layers were based on the MER 2006 model. The model layering, indicating stratigraphical grouping, model layer elevation and mine operation depths are summarised in Table C4.

The additional model layers were added to the base of the model with equal thickness of 65 m (layers 13 to 15) and 205 m (layers 16 and 17) to accommodate the additional depth of the mining proposed in the Extension Project and to allow for the base of the model domain to be sufficiently below the base of the modelled mine to reduce the impact of this boundary to an acceptable level.

Figure C3 presents a north-south cross-section through the proposed EP groundwater model through the E26, E28, E48 and E27 mined areas.

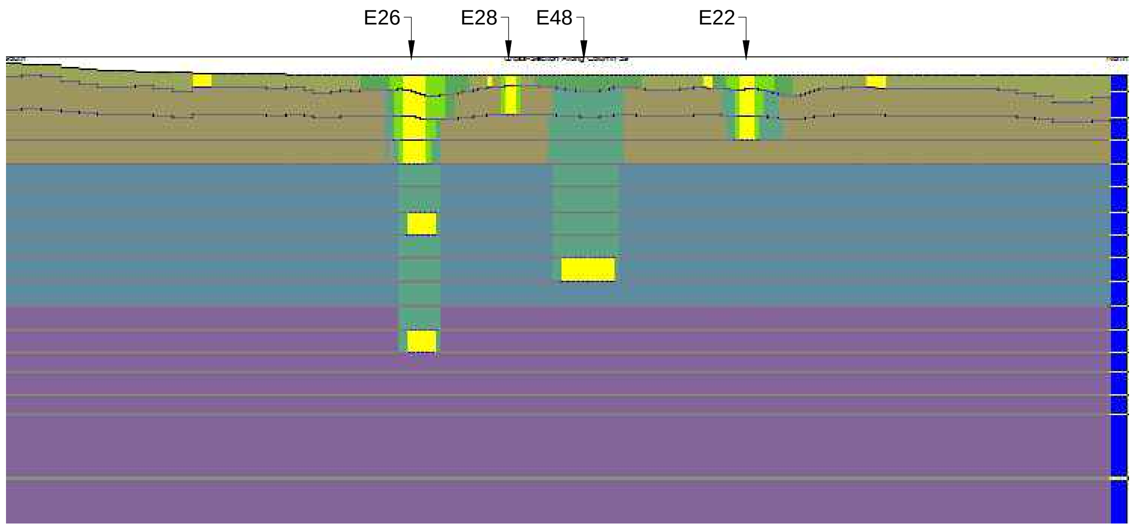
Table C4: Extension Project Groundwater Model Layers

Model Layer	Stratigraphical Unit	Mean Top Elevation (mAHD)	Layer Thickness (m)	Mean Top Elevation Mining Datum (m DATUM)	Underground Mine Depth (mAHD)				Open Pit Mining Depth (mAHD)						
					E22 Lift 1	E26 Lift 1	E26 Lift 2/2N	E48 Lift 1	E22	E26	E27	E28	E28N	E31	E31N
L 1	Regolith	282	53 (variable)	10282 (average)									230		
L 2	Saprock	229	77 (variable)	10229 (average)								220		210	224
L 3	Oxidised Transition Zone	152	77 (variable)	10152 (average)		90			140		78				
L 4	Bedrock (moderately fractured)	75	75 (planar)	10075 (horizontal)	43					48					
L 5	Bedrock (moderately fractured)	0	75 (planar)	10000 (horizontal)											
L 6	Bedrock (moderately fractured)	-75	75 (planar)	9925 (horizontal)											
L 7	Bedrock (moderately fractured)	-150	75 (planar)	9850 (horizontal)		-220		-157							
L 8	Bedrock (moderately fractured)	-225	75 (planar)	9775 (horizontal)			-230								
L 9	Bedrock (moderately fractured)	-300	75 (planar)	9700 (horizontal)	-340			-300							
L 10	Bedrock (moderately fractured)	-375	75 (planar)	9625 (horizontal)											
L 11	Bedrock (occasionally fractured)	-450	75 (planar)	9550 (horizontal)											
L 12	Bedrock (occasionally fractured)	-525	75 (planar)	9475 (horizontal)			-560								
L 13	Bedrock (occasionally fractured)	-600	65 (planar)	9400 (horizontal)											
L 14	Bedrock (occasionally fractured)	-665	65 (planar)	9335 (horizontal)											
L 15	Bedrock (occasionally fractured)	-730	65 (planar)	9270 (horizontal)											
L 16	Bedrock (occasionally fractured)	-795	205 (planar)	9205 (horizontal)											
L 17	Bedrock (occasionally fractured)	-1000	205 (planar)	9000 (horizontal)											
	Base of model:	**-1205**	**-**	**8795 (horizontal)**											



PLAN VIEW

SCALE N.T.S.



SECTION (A / -) CROSS SECTION- COLUMN 59

SCALE N.T.S.

Model Layer		Stratigraphical Unit
	L1	Regolith
	L2	Bedrock (saprock)
	L3	Bedrock Oxidised Transition Zone
	L4	Top of Bedrock (occasionally fractured)
	L5 - L10	Bedrock (occasionally fractured)
	L11 - L17	Bedrock (less fractured)

	Drain Cell
	Caved Zone
	Open Pit
	Mineralised Zone
	Constant Head Boundary
	No Flow Zone

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CLIENT: UMWELT (AUSTRALIA) PTY LTD			PROJECT: NORTHPARKES MINE					
DRAWN BY: HC	DATE: 21.03.2013		DRAWING TITLE: NUMERICAL MODEL CROSS SECTION					
CHECKED BY: HW	DATE: 25.03.2013							
SCALE: N.T.S.		SHEET SIZE: A4	PROJECT No: 117626007	DOC No: 007	DOC TYPE: R	FIGURE No: F002	REVISION: B	FIGURE C3

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Plot Date: 25 March 2013 Time:4:40:19 PM By: Campbell, Helen Path: J:\hyd\2011\117626007_Umwelt_NorthParkesMine\Technical Doc\CADD\FIGURES - File Name:117626007-007-R-F002-REVB.dwg

Layer Elevations

Layer elevations were derived from the MER 2006 model. The upper surface of Layers 1 to 3 were defined from rotary air blast (RAB) drilling refusal depths reported in MER, 2006. The remaining underlying layers are horizontal and planar.

The base of Layer 1 represents the base of transported regolith, Layer 2 represents regolith and Layer 3 the weathered rock referred to as the oxidised zone. These were determined in MER 2006 by subsurface mapping of the transported regolith, weathered rock and an assumed thickness of the slightly weathered rock.

Active Area

The model active area is essentially a block model. No attempt has been made to reconstruct structural features or groundwater divides to delineate the model. Boundaries to the east, west and south are far-field boundaries located at sufficient distance from the Project Area to not influence the result.

Inactive cells were attributed to the north of the assumed constant head boundary in the northern end of the model (Figure C2). This is discussed further in Section 2.1.4.

2.1.3 Model Boundaries

Model boundaries to the east, west and south were defined as no flow boundaries and located at sufficient distance from the Project Area as to limit the effect of the choice of boundary type on the result to an accepted level. These are known as far-field boundaries and do not require to be in conformance with the geometry of hydrogeologically controlled boundary conditions due to their distance from the Project Area. The eastern and western sides were aligned approximately north-south to be in approximate alignment with groundwater flow direction.

The northern model boundary was assigned a constant head boundary condition coincident with the observed 228 mAHD regional piezometric contour (MER, 2006). This was obtained from groundwater level monitoring in the vicinity of the Project Area (MER 2006, PB, 2001).

Basement Inflow

It is assumed that there was no vertical basement flux into or out the sub-domain model.

Aerial Recharge

Aerial recharge in the NPM model will be a function of the following factors:

- Direct infiltration from precipitation;
- Leakage from the TSF.

In reality, recharge will also be a function of:

- Infiltration from overland flow:
  - The long term average runoff coefficient used by DLWC for the Goonumbla area (for dam size legislative purposes) is approximately 11% of the mean annual rainfall at the Goonumbla Bureau of Meteorology (BoM) stations (DLWC, 1999);
  - After sustained precipitation, enhanced infiltration may occur within subsidence zones as a result of connective fracturing caused by mining (MER, 2006). Connective fracturing or slight movements along existing fractures and joints potentially changes the connectivity of secondary pore space. This may increase rock permeability due to new or existing fractures forming. Where this occurs between the draw bell and the surface, enhanced recharge may occur. However there is uncertainty in the actual and potential future degree of fracturing, its interconnectivity and the behaviour of the low permeability regolith, therefore this effect was difficult to quantify;

- Evaporation; and
- Seepage from waste rock and other management facilities.

No evapotranspiration term or additional seepage was incorporated into the model. Recharge in the model was simplified to incorporate these factors, giving a low recharge rate (Table C5).

No attempt was made to reassess or calibrate the transient recharge or enhanced infiltration in the caved zones or open pits. A value for enhanced infiltration in the caved zone was allowed for by altering hydraulic conductivity in the anticipated caved zones. Furthermore, sensitivity analysis was conducted on the recharge rates to check the validity of the assumptions against selected recharge values (Section □ of this Appendix).

Increased hydraulic conductivity values in the caved zones were obtained after consideration of the calibrated PB (2003) groundwater model and from site investigation data. The area of the predicted caved zones above the block cave mines were taken from the Extension Project mine site plan (NPM, 2011).

TSF were also included in the model in a staged manner, according to the anticipated development of these facilities. For the base-case model scenario, the timing and locations of these TSF were assumed to be the same to the MER 2006 model. Recharge rates from leakage varied in each TSF as detailed in Table C5 with the locations shown in Figure C4.

Table C5: Recharge Rates into the Model

Recharge Zone	Recharge Rate (m/d)	[mm/year]	Duration of Recharge
Background Recharge	1.0×10^{-6}	[0.4]	Full Model Duration
TSF1	3.0×10^{-5}	[11.0]	Jan 1994 to end of mining plus three years (2031)
TSF2	2.0×10^{-5}	[7.3]	June 1994 to end of mining plus three years (2031)
Escourt TSF	3.0×10^{-5}	[11.0]	Jan 1997 to end of mining plus three years (2031)
Rosedale TSF	3.0×10^{-5}	[11.0]	Jan 2013 to end of mining plus three years (2031)

The Background Recharge rate is noted as being low. This is based on previous studies at the site which suggested:

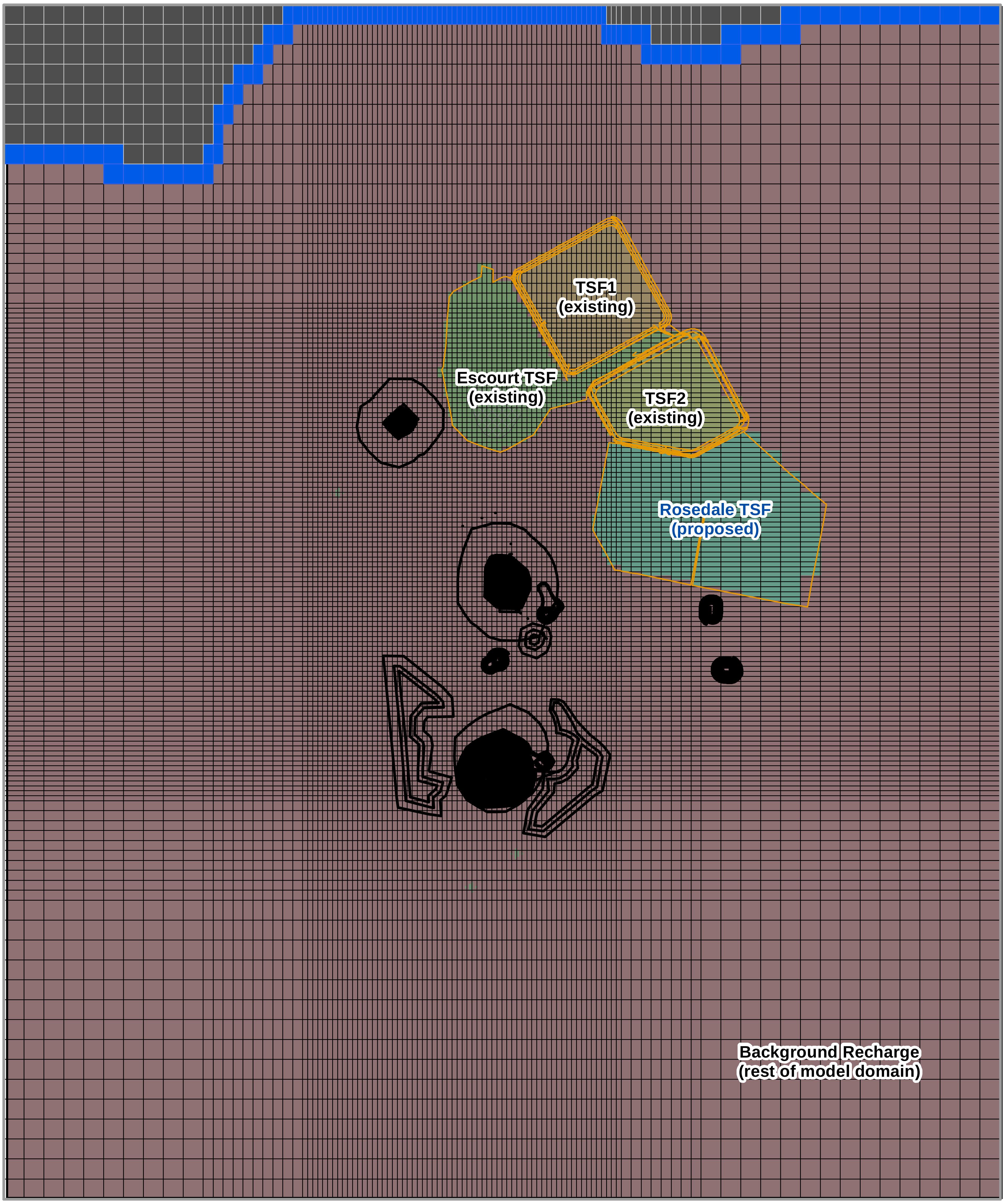
- The uniform groundwater levels over the site, combined with high salinity indicate the very little groundwater flow is occurring. Conditions are essentially static with negligible recharge or discharge through surface confining clays (Coffey, 1993);
- A very low distributed rainfall recharge rate averaging about 0.35 mm/year across most of the model domain is all that is required to establish a gradient similar to the observed regional gradient. This very low rate of recharge is directly attributed to the relatively impermeable shallow strata and the prevailing low rock mass permeabilities at depth, (MER, 2006);
- Comparison of piezometer water levels with rainfall data suggests that most piezometers do not show a discernible response to rainfall. PB goes on to say there is minimal rainfall recharge through the regolith, reflected in the calibrated model using as little as 0.14% of the annual average rainfall as recharge (PB, 2003);

The low value used for recharge is considered conservative for impact purposes as a low recharge should extend the zone of influence of drawdown in response to mine dewatering. It should be noted however, that this may correspond to an underestimation of the modelled dewatering rates.

At the start of the modelling period, all zones were assigned with the Background Recharge value. Conditions were altered according to the historical or proposed progress of mining and development of the TSF.

Cessation of altered recharge for all TSF was assumed to be 2032, assuming three years of leakage from the TSF after cessation of mining. It was assumed that after three years, no further leakage would occur from the TSF. After this point, the recharge rate was set to that of the background recharge rate.

Initial groundwater heads were taken from steady state calibration (Figure C5) based on pre-mining groundwater levels (PB, 2001).



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Recharge Zones in the Model Domain

LEGEND

- Mine Operations (Existing and Proposed)
- Tailings Storage Facilities (existing and proposed)
- Groundwater Model Extent
- No Flow Cell
- Constant Head Boundary
- Groundwater Model Cell Discretisation

0 0.5 1 2 3 4 Kilometers

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SCALE (at A4) 1:40,000
Coordinate System: GDA 1994 MGA Zone 55

PROJECT: 117626007
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FIGURE C4

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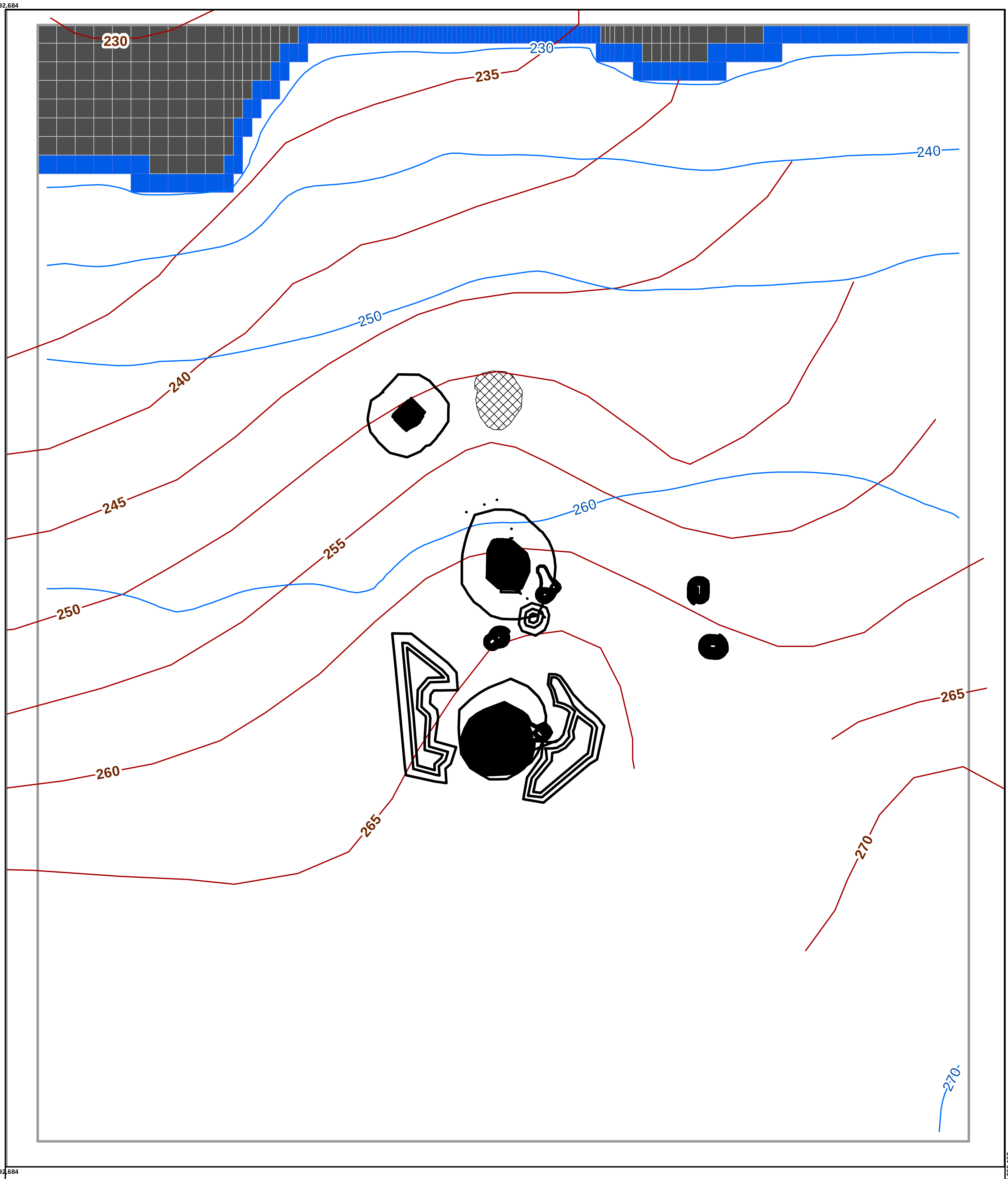

NORTHPARKES MINE
Groundwater Modelling

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Initial Groundwater Head against Observed Groundwater Levels (PB, 2001)

LEGEND

- Mine Operations (Existing and Proposed)
- Initial Modelled Groundwater Head (Pre-mining)
- Inferred Groundwater Level (Pre-mining)
- Groundwater Model Extent
- No Flow Cell
- Constant Head Boundary

NOTES

SCALE (at A4) 1:40,000
Coordinate System: GDA 1994 MGA Zone 55

PROJECT: 117626007
DATE: 30/04/2013
DRAWN: HW
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FIGURE C5

Bogan River

The Bogan River and associated tributaries were considered not to be in hydraulic continuity with the groundwater. They are ephemeral (PB, 2003) and inferred to receive no baseflow contribution from groundwater. This is replicated in the model as the water table does not intersect the upper surface of the model at any point.

MER (2006) concluded that:

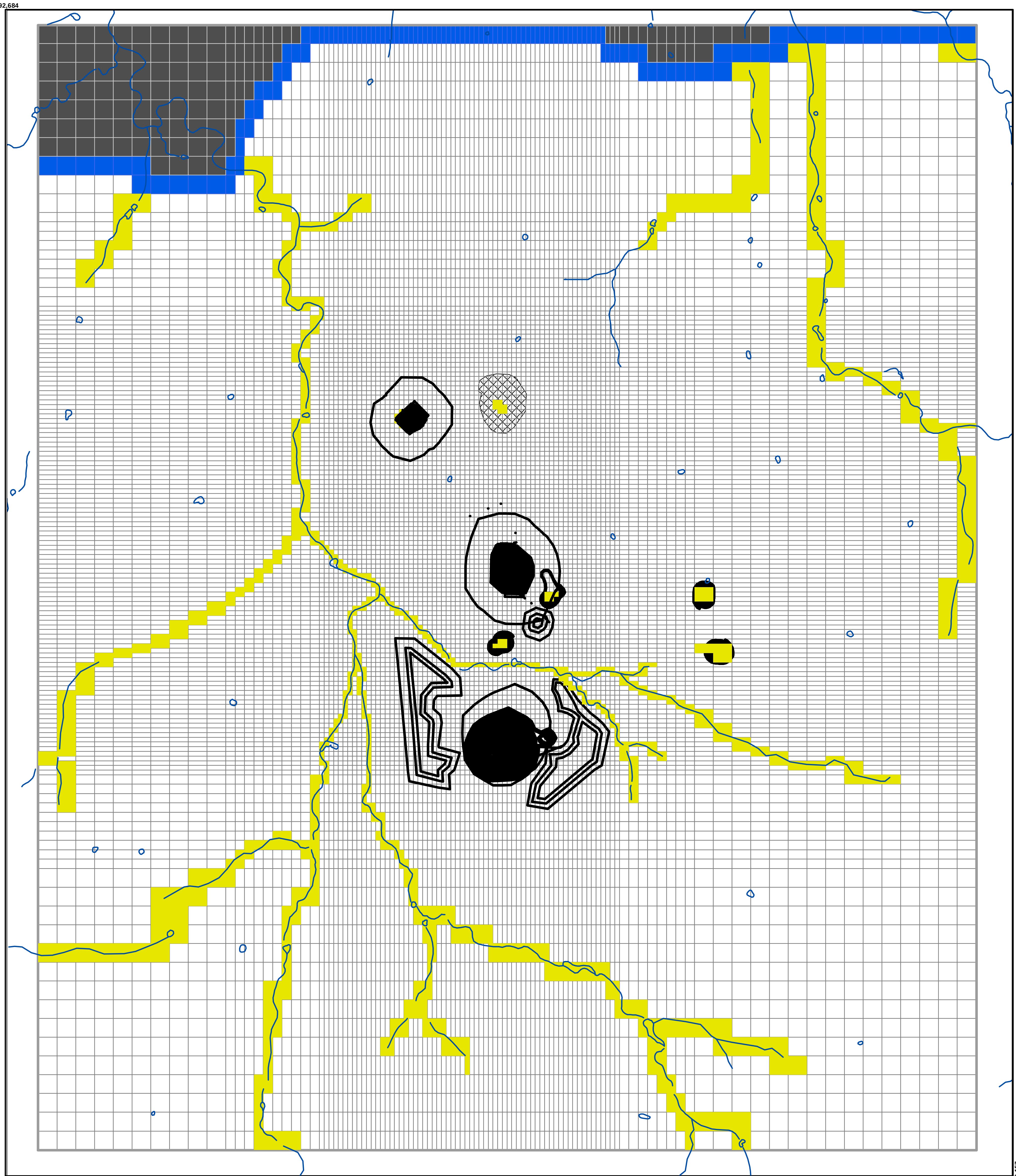
- *Impact of sub-surface depressurisation on surface drainages including the Bogan River is predicted to be negligible. Based on the interpolated regional groundwater table, an unsaturated zone prevails between local drainages and deeper groundwater within the regolith. This zone is of the order of 30m. With the exception of bank storage, this scenario represents an influent river. Any increase in the depth to groundwater as a result of mining operations would not affect the leakage rate from the river channel and tributaries in a measurable way.*

Although the ephemeral Bogan River may contribute groundwater recharge during periods of flow, it has not been included in this model. This is because groundwater levels are below the base of the creek (MER, 2006) therefore it is assumed that groundwater depressurisation will not impact the surface water flow regime.

Furthermore, the ephemeral nature of the river means recharge will only be brief and not significantly contribute to the groundwater flaw regime.

Surface Water Drain Cells

A drainage pattern (NPM, 2011) was incorporated into the model using drain cells located in the top layer, approximately 5 to 10 m below the upper surface of the model. The distribution of the drain cells are shown in Figure C6.



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Groundwater Model with Drain Locations and Drain Cells (Layer 1)

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LEGEND

- Mine Plan (existing and proposed)
- Drainage
- draincells
- Groundwater Model Extent
- No Flow Cell
- Constant Head Boundary
- Groundwater Model Cell Discretisation

0 0.5 1 2 3 4 Kilometers

SCALE (at A4) 1:40,000

Coordinate System: GDA 1994 MGA Zone 55

PROJECT: 117626007
DATE: 30/04/2013
DRAWN: HW
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FIGURE C6

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Mine Progression

A detailed mine progression plan was not available at the time of modelling (NPM, 2011). Depths and anticipated annual extraction tonnage was available and these were used in this assessment (NPM, 2011).

Mine progression was simulated using two different methodologies for the block cave and open pit mines, summarised as follows:

- Block cave mining: fixed head drain cell conditions were set at the draw level (i.e. deepest extent) of each lift in each of the block cave mine locations. These were set to become active and inactive according to the anticipated dewatering period (Table C6). Hydraulic parameters were altered to simulate the progression of caving directly above the drain cells;
- Open Pit mining: fixed head drain cell conditions were progressed in a linear fashion from surface level to anticipated depth of the mine, over the period of historical and proposed mining. This required the assumption that a unit relationship exist between extraction tonnage and depth. Due to the resolution of time steps in the model, this was deemed reasonable. Hydraulic parameters were altered to reflect the progression of the open pit.

Drain cells allow the flux of water out of the model to a specified head (drain cell level) with a specified resistance to flow (conductance).

Initial mine progression captured in the MER, 2006 model (i.e. mining before 2006) was replicated in the Extension Project model. Mine progression with respect to the depth of mining after this date was assumed from predicted extraction tonnage rates provided by Umwelt (NPM, 2011). This included both recorded and predicted mine progression in terms of extraction tonnage.

The depth and periods of operation used in the Extension Project model are summarised in Table C6.

Table C6: Assumed Simplified Mine Progression

Operation	Mining Period (Year)		Drain Cell Elevation (mAHD)	Model Layer/s
	Initiation	Cessation		
Open Pit Operations				
E22	1994	2032	140	1 to 3
E26	1995	2032	50	1 to 4
E27	1994	2005	80	1 to 3
E28	2018	2032	220	1 to 2
E28N	2018	2032	230	1
E31	2018	2019	210	1 to 2
E31N	2014	2017	220	1 to 2
Block Cave Mine				
E22 lift 1	2022	2032	-340	9
E26 Lift 1	1996	2032	-220	7
E26 Lift 2/2N	2022	2032	-560	12
E48 Lift 1	2006	2032	-300	9

Notes:
1. Conversion from AHD to mine datum is: AHD + 10,000 m = mine datum; and
2. Historical mine progression taken from MER 2006.

It was assumed that all operations remained dewatered until cessation of mining in 2032.

2.1.4 Model Parameters

Initial hydraulic parameters were assigned to each model layer based on calibrated values from the MER 2006 groundwater model as well as additional conceptualisation from the PB 2003 groundwater model (Section 5 of the Main Text). It should be noted that the MER model (2006) was calibrated to observed pit inflows only whilst the PB model (2003) was calibrated to steady state groundwater levels only.

Hydraulic parameters relevant to MODFLOW include:

- Horizontal and vertical hydraulic conductivity;
- Specific yield and specific storage; and
- Drain cell conductance.

Based on site investigation data and observed and inferred structural features, MER (2006) included a number of high and low hydraulic conductivity features, restricted to Layers 2 and 3 (bedrock [saprock] and bedrock [Oxidised Transition Zone OTZ] respectively). These features were retained in the Project model and can be summarised as follows:

- Low permeability fault zone to the south of E26 observed by Coffey (1993) during hydraulic testing and groundwater monitoring;
- An enhanced hydraulic conductivity zone running approximately east-west through E26 (MER, 2006); and
- An enhanced hydraulic conductivity feature trending north-northwest E22 (MER, 2006).

Both enhanced hydraulic conductivity features listed above are believed to be attributed to an increased density of the fracture network that is governed by joint and fracture connectivity, allowing increased hydraulic conductivity in these zones.

PB (2003) identified an oxidised zone (approximately coincident with Layer 1 [regolith] in the MER 2006 model) and a deeper host rock zones for their groundwater model. PB also identified an upper and deeper mineralised halo around each ore body based on field investigations (PB, 2003). This was broadly consistent with the MER 2006 model and was considered a suitable methodology for representing the bulk properties of the strata (Section 4 of the Main Text).

No attempt was made to simulate the complex nature of the fracture flow in the hardrock strata. Simulation by horizontal model layers is designed to represent an equivalent porous medium (EPM) with the introduction of numerous layers facilitating representation of a three dimensional flow and depressurisation regime (MER, 2006).

In summary, the hydraulic conductivity in the model was input into the model as follows:

- Layer 1: Regolith with enhanced hydraulic conductivity in the anticipated:
  - Caved zones; and
  - Open pits;
- Layers 2: Saprock with zones of altered hydraulic conductivity in the anticipated:
  - Caved Zones;
  - Open Pits;
  - Mineralised halos (fractured aquifer);
  - An enhanced hydraulic conductivity feature trending north-northwest E22;

- An enhanced hydraulic conductivity feature trending east to west through E26; and
- A low hydraulic conductivity fault trending east to west located to the south of E26;

- Layer 3: OTZ with zone of altered hydraulic conductivity as in model Layer 2;
- Layer 4: Top of the moderately fractured bedrock with zones of altered hydraulic conductivity as in model Layer 2;
- Layer 5 to 10: moderately fractured bedrock with enhanced hydraulic conductivity in the ore bodies and mineralised halos, due to mining;
- Layers 11 to 12: occasionally fractured bedrock with enhanced hydraulic conductivity in the ore bodies and mineralised halos. The hydraulic conductivity in the ore body and mineralised halos were not differentiated for the purposes of modelling. They were assumed to behave in the same manner once block cave mining was initiated;
- Layers 13 to 15: occasionally fractured bedrock.

Due to the likely vertical and horizontal nature of the in situ fracturing and faulting, the vertical to horizontal hydraulic conductivity was assigned the same value (i.e. it was assumed that there was isotropy in all zones).

The calibrated parameter datasets is presented in Section 2.2.

2.2 Model Calibration

The initial hydraulic parameters from the MER (2006) model were based on a coarse calibration against measured pit seepage rates at E22, E26 and E27. This range in hydraulic conductivity was consistent with previous modelling of the open cut pits (MER, 1999 and PB, 2001).

With the addition of more recent groundwater level observation data and total dewatering rates (assumed to be the total groundwater inflows to the underground mine), steady state and transient calibration of the MER 2006 and PB 2001 model parameters was undertaken.

Inflows to unmined operations were assumed to be of a similar order of magnitude to existing operations.

2.2.1 Transient Calibration

Model simulations were conducted from a commencement date of 01/01/1994 in order to represent progressive excavations at each of the open cut pits and subsequent development of E26 lifts 1 and 2. Initial groundwater heads, representing pre-mining conditions were taken from a calibrated steady state model. At this time an undisturbed water table has been assumed with a generally northward flow direction (PB, 2001).

Calibration by altering the hydraulic conductivity, specific storage and drain cell set up (both surface water drains and mine drain cells) was undertaken against the following observation data:

- Observed seepage rate into mine from 01/10/2002 to 31/07/2011; and
- Observed groundwater levels at selected observation bores (Figure C8). Not all observation bores at the site were used. Bores were selected based on the completeness of their records (both temporally and in terms of bore details) and to avoid repetition of adjacent bores with similar records.

No statistical analysis on the calibration was undertaken.

Target groundwater levels input into the model are shown against the calibrated modelled groundwater level for all observation bores in Figure C8. Note that the time on the x-axis is in days and the head on the y-axis is in mAHD.

Generally the modelled groundwater levels were in reasonable agreement with the observed groundwater levels for the majority of observation bores. The groundwater levels computed with the calibrated model tended to be higher than the observed groundwater levels.

Modelled drawdown was also generally greater than observed. This is likely due to the methodology employed in the model for capturing the actual dewatering at the mine. Drain cell conditions become instantaneously active at a given stress period, whereas in reality, the progression of the mine would be expected to dewater in a staged manner. Given the intended purpose of the investigation and the temporal resolution of the model, this was considered an acceptable level of calibration.

The groundwater level rise in the vicinity of the TSF was relatively well captured in the model, as demonstrated in MB1, MB2, MB4, MB5, MB10, MB13 and MB14 in Figure C8 (the first seven hydrographs presented in this figure). The trend in the modelled groundwater levels reflecting the observed trend in groundwater levels in the vicinity of the TSF suggests the values for recharge assigned to the TSF are acceptably representative of the processes occurring in this area.

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Mine Plan (Existing and Proposed) with Groundwater Observation Bore Locations

NOTES

LEGEND

- Observation Wells utilised in MODFLOW
- Mine Plan (existing and proposed)
- Project Area

0 0.5 1 2 Kilometers

SCALE (at A4) 1:25,000
Coordinate System: GDA 1994 MGA Zone 55

PROJECT: 117626007
DATE: 30/04/2013
DRAWN: HW
CHECKED: LJ

FIGURE C7

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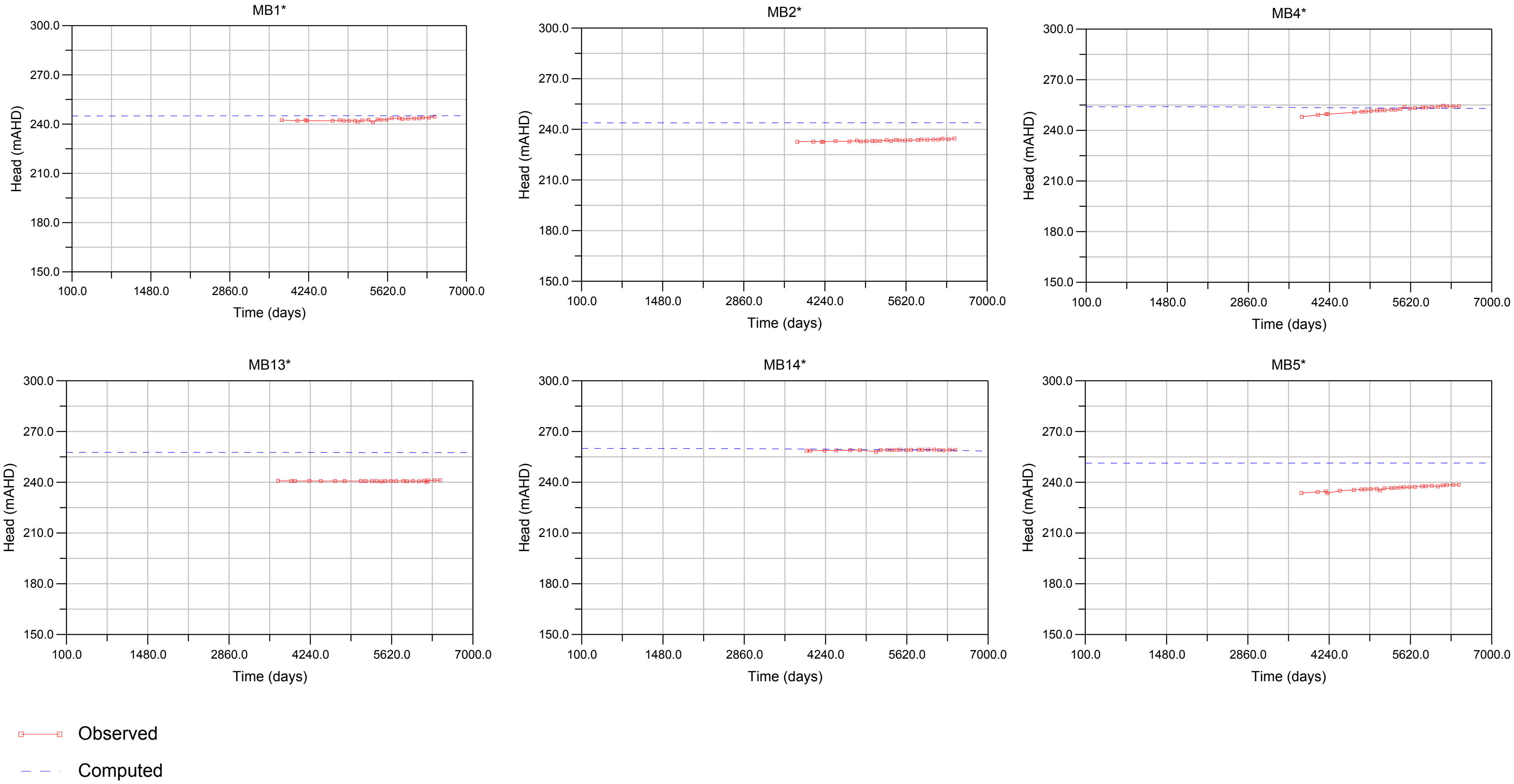
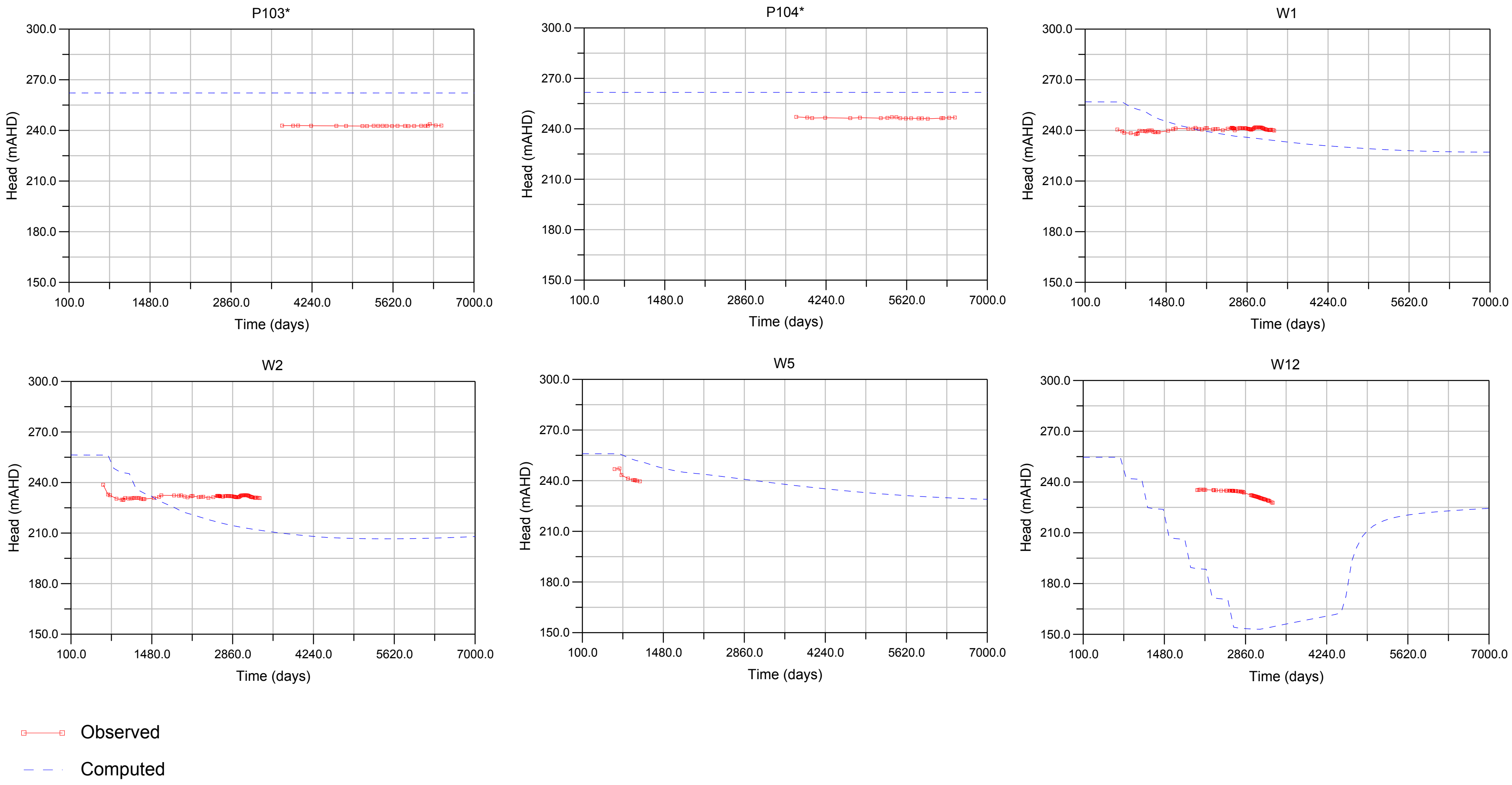
File Location: J:\hyd\2011\117626007_Umwelt_NorthParkesMine\Technical Doc\GIS\Project\Rev0\117626007_007_FC007_Rev0_MEP-03_MEP_obh.mxd



MB1*
MB2*
MB4*
MB13*
MB14*
MB5*
Head (mAHD)
300.0
270.0
240.0
210.0
180.0
150.0
100.0
1480.0
2860.0
4240.0
5620.0
7000.0
Time (days)
Observed
Computed



P103*
P104*
W1
W2
W5
W12
Head (mAHD)
Time (days)
300.0
270.0
240.0
210.0
180.0
150.0
100.0
1480.0
2860.0
4240.0
5620.0
7000.0
Observed
Computed

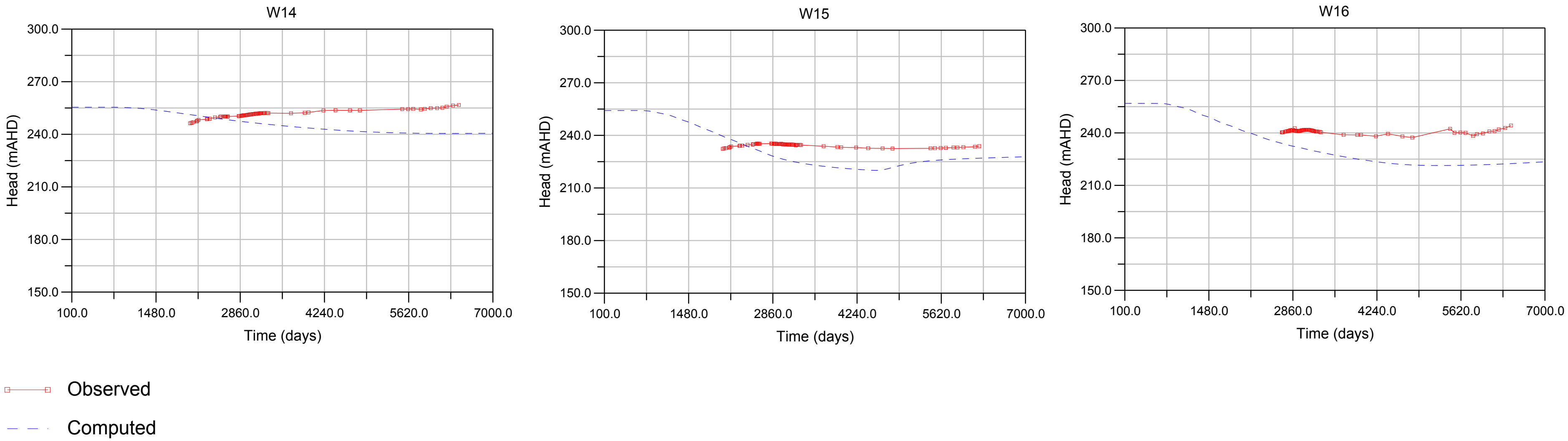


Figure C8: Selected Target and Modelled Groundwater Level Hydrographs

Underground to mill flow data (i.e. the observed total dewatering from all mine operations), was considered more reliable as the very low rock mass permeability and discretely fractured nature of the strata resulted in steep depressurisation gradients. This made calibration against historical groundwater levels problematic, especially given the coarseness of the model grid in the vicinity of the mine and the relatively short monitoring record available for each observation bore.

The calibration of hydraulic parameters to the observed underground to mill flow data, which is considered to have an error margin of ± 20%, is shown in Figure C9.

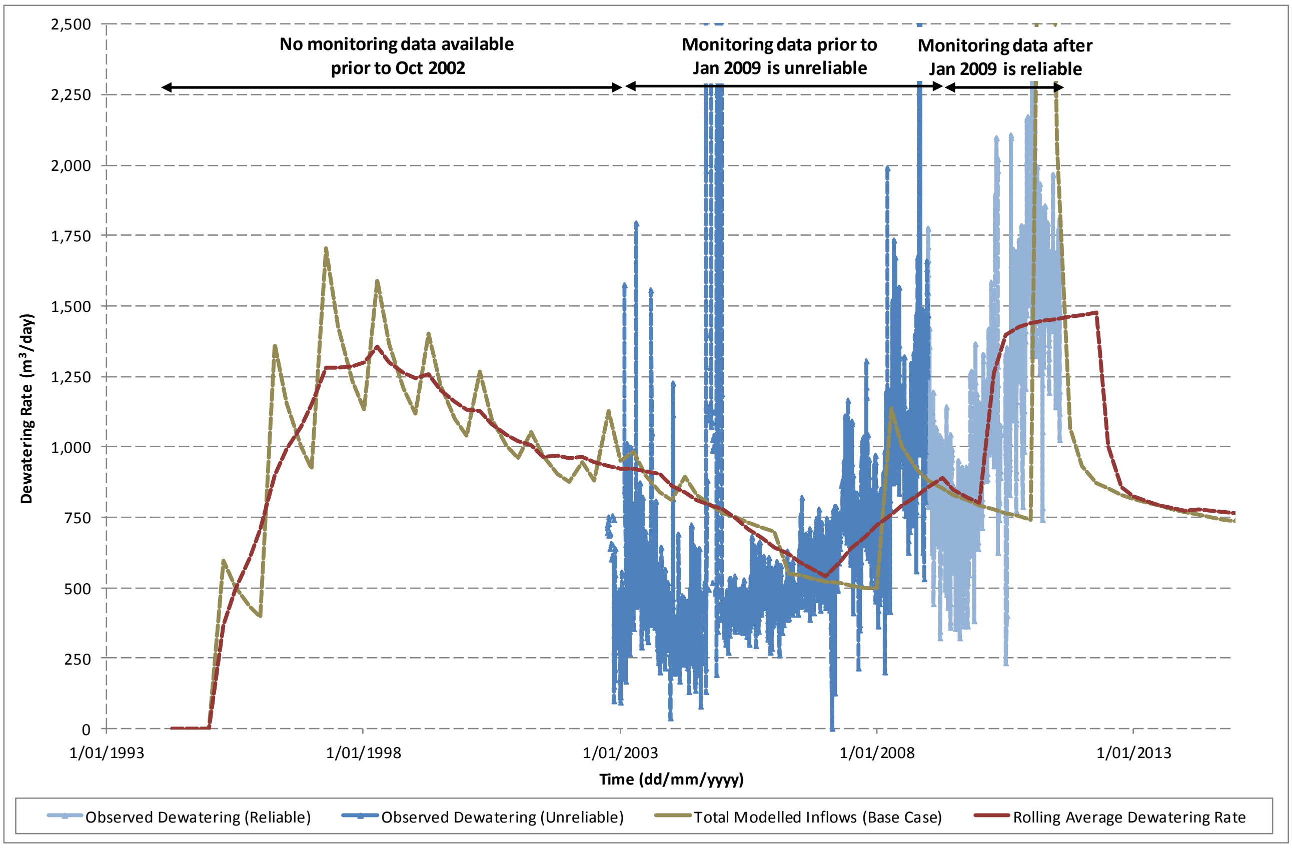


Figure C9: Observed verses Total Modelled Seepage Rate into all Mine Operations (± 20%)

Figure C9 shows the total modelled inflows to all operations were in broad agreement with the observed underground seepage. There is likely to be discrepancy between the observed groundwater seepage inflows and the modelled values as part of the historical mine progression was assumed, as shown in Table C6

The high peak in modelled dewatering in 2012 is due to the initiation of mining at E26 Lift 1. These peak inflows are not considered representative of actual observed dewatering rates due to the way in which the model replicated instantaneous dewatering in the deepest part of E26 Lift 1. In reality this would be progressively dewatered as the access to this part of the mine was established.

A rolling average has been presented in Figure C9 to remove this effect and this is considered more representative of actual inflows

Calibrated hydraulic parameters for this Base Case scenario model are summarised in Table C7.

Table C7: Calibrated Hydraulic Parameters for the Project Model

<table>
<tr><th>Strata / feature</th><th>Model Layer/s</th><th>Horizontal Hydraulic Conductivity: Kxy (m/d)</th><th>Vertical Hydraulic Conductivity: Kz (m/d)</th><th>Specific Storage (Ss)</th><th>Specific Yield (Sy)</th></tr>
<tr><td>Regolith</td><td>1</td><td>$9.0x10^{-3}$</td><td>$9.0x10^{-4}$</td><td>$5.0x10^{-4}$</td><td>0.15</td></tr>
<tr><td>Caved Zone</td><td>1</td><td>$6.0x10^{-3}$</td><td>$6.0x10^{-3}$</td><td>$9.0x10^{-4}$</td><td>0.0015</td></tr>
<tr><td>Open Pit Zone</td><td>1 to 4</td><td>0.1</td><td>0.1</td><td>$5.0x10^{-4}$</td><td>0.15</td></tr>
<tr><td>Bedrock: Saprock/OTZ and the top of the moderately fractured bedrock</td><td>2 to 4</td><td>$1.0x10^{-3}$</td><td>$1.0x10^{-3}$</td><td>$7.5x10^{-4}$</td><td>0.015</td></tr>
<tr><td>Enhanced k features in vicinity of E22 and E26</td><td>2 to 4</td><td>$6.0x10^{-3}$</td><td>$6.0x10^{-3}$</td><td colspan="2" rowspan="2">(as bedrock layers: 2 to 4)</td></tr>
<tr><td>Low k fault to south of E26</td><td>2 to 4</td><td>$1.0x10^{-6}$</td><td>$1.0x10^{-6}$</td></tr>
<tr><td>Mineralized zone</td><td>2 to 12</td><td>$9.0x10^{-4}$</td><td>$9.0x10^{-4}$</td><td colspan="2">(As bedrock of corresponding layers)</td></tr>
<tr><td>Bedrock: moderately fractured</td><td>5 to 10</td><td>$9.0x10^{-5}$</td><td>$9.0x10^{-5}$</td><td>$7.5x10^{-4}$</td><td>0.015</td></tr>
<tr><td>Bedrock: occasionally fractured</td><td>11 to 17</td><td>$7.0x10^{-6}$</td><td>$7.0x10^{-6}$</td><td>$8.0x10^{-4}$</td><td>0.0015</td></tr>
</table>

Notes:

* As the hydraulic parameters of the caved zone are not well defined, conservative values were selected.

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The calibrated model for the Extension Project is within the expected range of hydraulic parameters and broadly consistent with previous groundwater models at the site.

2.3 Predictive Modelling

The calibrated model described above was used as the base case scenario for predictive modelling. Predictive modelling was undertaken for a single scenario.

As no alternative mine plan or schedule have been proposed, no predictive model scenarios were undertaken considering possible changes. Alternative model runs were concentrated on investigating the model behaviour through sensitivity analysis.

Predicted inflows to the mine for the base case scenario is given in Table C8 and plotted in Figure C10.

Table C8: Predicted Total Inflows to the Mine (± 20%)

Model Time		Total Modeled Inflows	
Time (days)	Date (dd/mm/yy)	m^3/d	ML/d
100	11/04/1993	0	0.0
365	1/01/1993	0	0.0
465	11/04/1994	597	0.6
648	11/10/1994	502	0.5
731	1/01/1995	433	0.4
1014	10/10/1995	396	0.4
1096	1/01/1996	1367	1.4
1379	10/10/1996	1156	1.2
1462	1/01/1997	1003	1.0
1744	11/10/1997	921	0.9
1827	2/01/1998	1707	1.7
2110	11/10/1998	1429	1.4
2192	2/01/1999	1232	1.2
2475	11/10/1999	1131	1.1
2558	1/01/2000	1595	1.6
2841	11/10/2000	1366	1.4
2923	2/01/2001	1205	1.2
3206	11/10/2001	1119	1.1
3289	2/01/2002	1400	1.4
3571	12/10/2002	1222	1.2
3654	3/01/2003	1100	1.1
3937	11/10/2003	1036	1.0
4019	2/01/2004	1265	1.3
4302	12/10/2004	1101	1.1
4385	2/01/2005	1005	1.0
4668	12/10/2005	957	1.0
4750	3/01/2006	1050	1.1

Model Time		Total Modeled Inflows	
Time (days)	Date (dd/mm/yy)	m^3/d	ML/d
5033	12/10/2006	966	1.0
5116	3/01/2007	905	0.9
5398	12/10/2007	874	0.9
5481	3/01/2008	944	0.9
5764	12/10/2008	880	0.9
5846	3/01/2009	1125	1.1
6129	13/10/2009	948	0.9
6212	3/01/2010	983	1.0
6495	13/10/2010	897	0.9
6577	4/01/2011	840	0.8
6860	12/10/2011	809	0.8
6943	3/01/2012	893	0.9
7225	13/10/2012	829	0.8
7308	4/01/2013	793	0.8
7591	13/10/2013	764	0.8
7673	4/01/2014	749	0.7
7956	14/10/2014	731	0.7
8039	4/01/2015	713	0.7
8322	13/10/2015	701	0.7
8404	4/01/2016	547	0.5
8687	13/10/2016	544	0.5
8770	4/01/2017	529	0.5
9052	14/10/2017	522	0.5
9135	5/01/2018	518	0.5
9418	14/10/2018	507	0.5
9500	5/01/2019	500	0.5
9783	14/10/2019	499	0.5
9866	4/01/2020	1136	1.1
10149	14/10/2020	999	1.0
10231	5/01/2021	923	0.9
10514	14/10/2021	882	0.9
10597	5/01/2022	853	0.9
10879	15/10/2022	828	0.8
10962	6/01/2023	809	0.8
11245	14/10/2023	790	0.8
11327	5/01/2024	777	0.8
11610	15/10/2024	762	0.8

Model Time		Total Modeled Inflows	
Time (days)	Date (dd/mm/yy)	m^3/d	ML/d
11693	5/01/2025	752	0.8
11976	15/10/2025	739	0.7
12058	6/01/2026	5046*	5.0*
12341	15/10/2026	2073	2.1
12424	6/01/2027	1066	1.1
12706	15/10/2027	930	0.9
12789	6/01/2028	869	0.9
13072	15/10/2028	850	0.8
13154	6/01/2029	827	0.8
13437	16/10/2029	817	0.8
13520	6/01/2030	799	0.8
13803	16/10/2030	791	0.8
13885	7/01/2031	779	0.8
14068	7/07/2031	0	0
14168	15/10/2032	0	0

Notes:

* Modelled inflows at 06/01/2026 are considered unrealistically high. This stress period in the model represents the initiation of dewatering in E26 Lift 1. This value has been ignored for analysis. The quoted maximum inflows are likely to be more representative in modelled inflows in the subsequent stress period (of 2.1 ML/day).

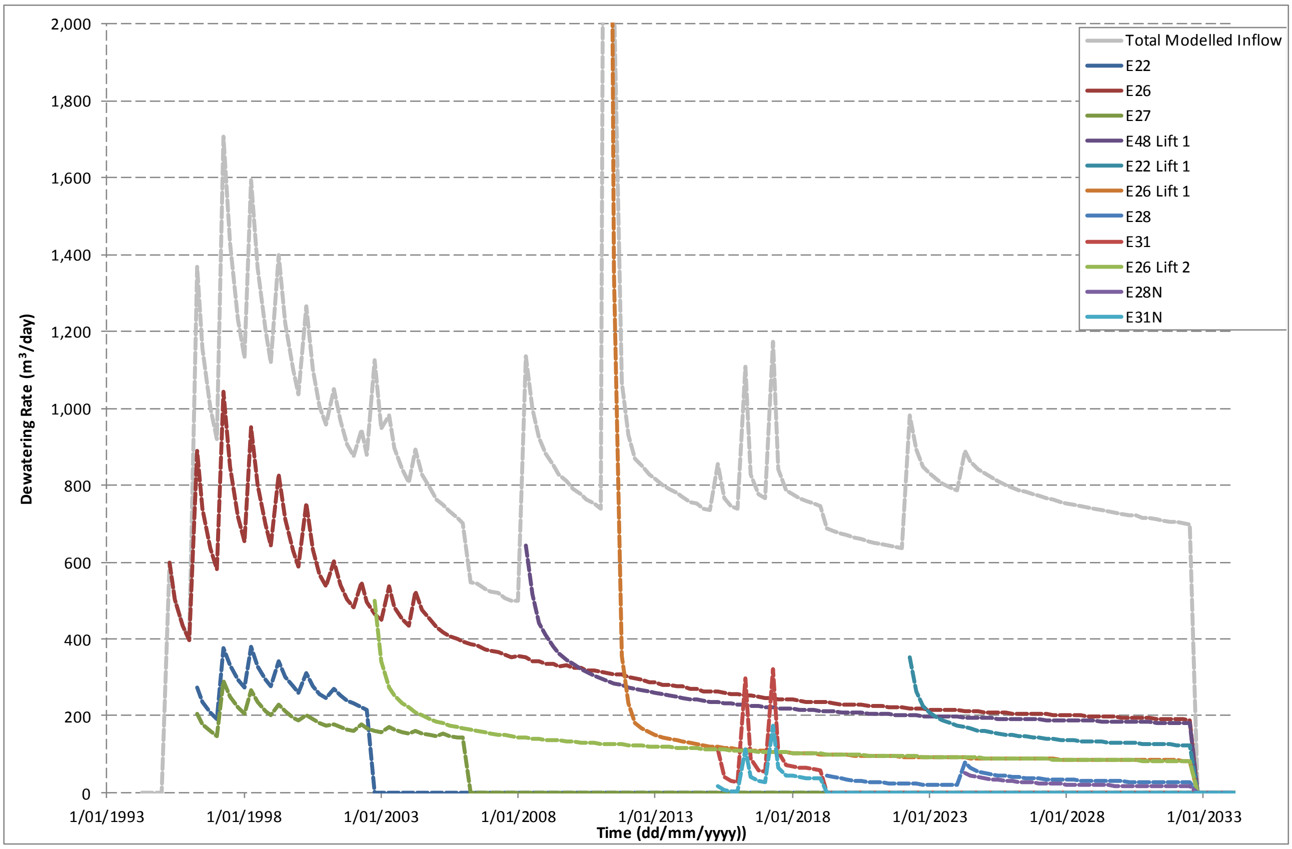
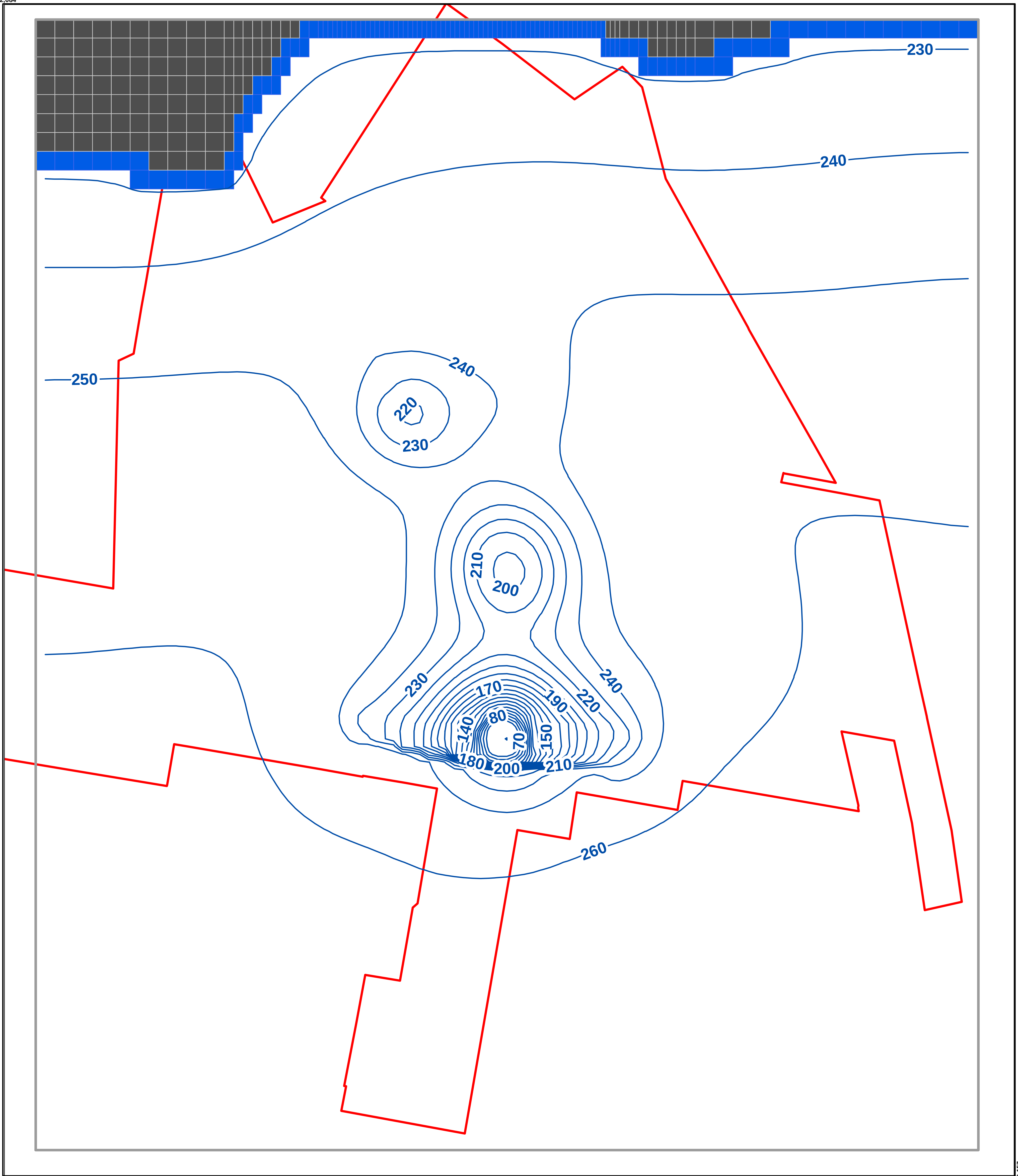


Figure C10: Modelled Total Inflow Rates to the Mine

The predicted groundwater contours (in Layer 4 of the model) at the cessation of mining is shown in Figure C11 and 10 m drawdown contours (calculated as drawdown from initial heads, representative of pre-mining groundwater levels) is shown in Figure C12.



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Modelled Groundwater Contours at top of Bedrock (Layer 4) at Cessation of Mining

NOTES

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LEGEND

- Grondwater Level (mAHD)
- Groundwater Model Extent
- No Flow Cell
- Constant Head Boundary
- Project Area

0 0.5 1 2 3 4 Kilometers

SCALE (at A4) 1:40,000
Coordinate System: GDA 1994 MGA Zone 55

PROJECT: 117626007
DATE: 30/04/2013
DRAWN: HW
CHECKED: LJ

FIGURE C11

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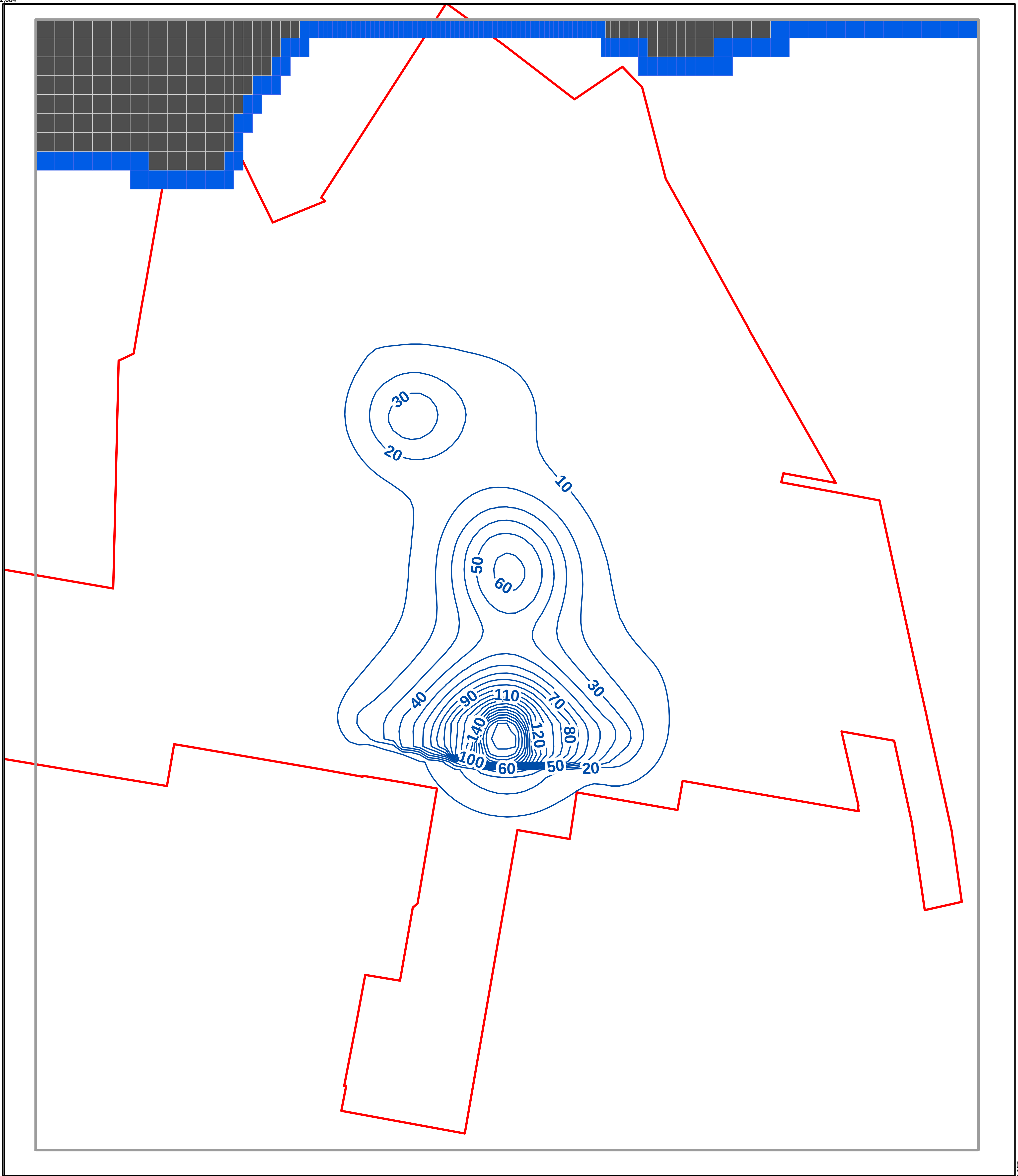

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Groundwater Drawdown at top of Bedrock (Layer 4) at Cessation of Mining

NOTES

LEGEND

- Groundwater Drawdown (m)
- Groundwater Model Extent
- No Flow Cell
- Constant Head Boundary
- Project Area

0 0.5 1 2 3 4 Kilometers

SCALE (at A4) 1:40,000
Coordinate System: GDA 1994 MGA Zone 55

PROJECT:	117626007
DATE:	30/04/2013
DRAWN:	HW
CHECKED:	LJ

FIGURE C12

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Golder Associates

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Table C9 gives the average water balance values for each component of the recharge and discharge on the model for the calibration period and predictive period. The water balance consists of inflow and outflow from the various model boundary conditions into or out of the model domain.

Table C9: Summary Water Balance for Base Case Scenario Model

Recharge / Discharge Component	Average Flux (m^3/d)	
	Calibration Period	Prediction Period
Storage inflow	404	311
Recharge inflow	175	171
Total inflow	579	482
Drain outflow	-450	-216
Constant Head outflow	-60	-66
Storage outflow	-70	-201
Total outflow	-580	-483
Percentage error	-0.92	-0.25

The model error summarised in Table C9 is considered reasonable, at -0.92 % for the calibration period and -0.25 % over the predictive modelling period. This gives an overall average percentage error of 0.59 % over the whole model domain and time.

The Australian Groundwater Modelling Guidelines (Barnett, et. al. 2012) suggests 3 classes of model with a decreasing confidence from class 3 to class 1. The NPM EP model has an overall percentage error in the water balance of 0.6%. This is just above the 0.5% required to be a class 3 (the highest confidence class) model.

2.3.1 Mine Closure Modelling

Groundwater recovery within mine voids is initiated after cessation of mining (i.e. once dewatering has ceased and groundwater levels begin to recover). Recovery here was defined as approximate steady state conditions (i.e. where groundwater levels do not change significantly over time) and occurs at approximately 80% of the pre-mining groundwater levels.

Predicted recovery of groundwater levels to within 80% of their pre-mining levels occurred 77 years after cessation of mining. The maximum groundwater depression at this time was:

- Approximate groundwater depression of 42 m at E26;
- Approximate groundwater depression of 10 m at E22; and
- Approximate groundwater depression of 10 m at E48.

The shallower open pits were predicted to achieve complete recovery at this time.

It should be noted however that the potential effect of evaporation losses from flooded pits on groundwater levels has not been assessed in this model. It is likely that some depression in groundwater levels would be likely. As not mine closure plan was available at the time of modelling, this could not be incorporated in to the model.

2.4 Conclusions from Project Area Model

In summary, modelling groundwater conditions at NPM suggests the following:

Regulatory Considerations:

- Due to the perched nature of the surface water, dewatering from the mine is not expected to impact surface water flow in the Bogan River or its tributaries;
- The extent of modelled drawdown of groundwater in the bedrock at cessation of the proposed mining is approximately 4.5 km from the pits;
- This is likely to be an over-estimation as computed drawdown is greater than historically observed drawdown. This is likely to be a result of the model discretisation and steepness of the actual drawdown cones surrounding each pit;
- Additional targeted groundwater level monitoring may be beneficial towards the north of the pits, to monitor the bedrock depressurisation;
- Additional targeted groundwater level monitoring may be beneficial towards the west of the pits, to reinforce confidence in the shallow groundwater and surface water conceptual model and to confirm there is no potential interaction between these systems;
- There is no impact from the locations of the tailings on the predicted zone of influence of dewatering the mine. This is as would be expected, due to the low permeability layers near the surface and the steepness of the drawdown predicted around each operation;
- There is a steady increase expected in groundwater seepage into the mine as the mine progresses. The maximum modelled inflow is 0.8 ML/day, at the end of 2010. Predictive modelling suggests a slightly lower peak inflow of 0.7 ML/day at the end of 2021;
- Modelled inflows to the individual operations are relatively stable. There are no significant predicted spikes in groundwater seepage other than at the start of each operation, and this is likely to be due to the instantaneous activation of the drain cell to replicate mine dewatering (modelling artefact);
- E28 and E46 are the most significant contributors to groundwater seepage; and
- Discrepancies between the observed seepage and modelled seepage are likely to arise from uncertainties in the mine progression. It is considered however that the mine progression does not significantly impact the overall seepage rates into the mine;
- Groundwater levels are anticipated to recover to a post-mining groundwater level of 42 m (at E26) below pre-mining groundwater level after mine closure. The other block cave zones are predicted to be depressed by approximately 10 m; and
- The depression of groundwater in the vicinity of the open pits is not known. This is because the mine closure plan is not explicitly modelled to include additional evaporative losses in the location of the pits.

2.5 Sensitivity Analysis

Sensitivity analysis was undertaken on the base case scenario model. Sensitivity analysis provides information on the effect of selected parameters in the model and is undertaken to provide an understanding of the uncertainty in the model parameters and how these impact the modelling results.

Sensitivity analysis was undertaken on seven aspects of the base case scenario model (i.e. all hydraulic and input parameters unchanged, unless otherwise stated). These were referred to as the Sensitivity Analysis (SA) models: SA1 to SA7 summarised as follows:

- **SA01 – TSF drains**: with the addition of seepage drains around all TSF. This was to investigate if drains or active dewatering from boreholes would be generally suitable to control rising groundwater levels downstream of the TSF;

- **SA02 - CSIRO climate scenario**: following recommendations from CSIRO (Barron et.al., 2010) in their change scenario analysis for all groundwater models, investigate potential climate change scenarios by decreasing recharge by 20%;
- **SA03 - Enhanced TSF recharge**: investigate the potential for increased leakage from the TSF by increasing the recharge beneath the footprint of al TSF by a single order of magnitude;
- **SA04 - Enhanced vertical hydraulic conductivity**: investigate the effect of the selected vertical hydraulic conductivity in the vicinity of the mine operations by increasing the vertical hydraulic conductivity (kz) in the following modelled strata (refer Table C7):
  - Regolith (model layer 1);
  - Caved zones (model layer 1);
  - Mineralised zone (model layers 2 to 12); and
  - Open pit areas (model layers 1 to 4).
- **SA05 - Enhanced vertical and horizontal hydraulic conductivity**: to investigate the effect of vertical and horizontal conductivity (kxyz) in the same strata as listed in SA04 in the above bullet point;
- **SA06 - Enhanced background recharge:** to investigate impact of the selected recharge value, this parameter was increased by 20% from the base case model;
- **SA07 - Enhanced recharge in the mine operations and caved zones**: to investigate of increasing the recharge rate in the caved zones only. Recharge rates were obtained from the MER model (2006).

Modelled total inflows to the mine for each scenario are given in Figure C13.

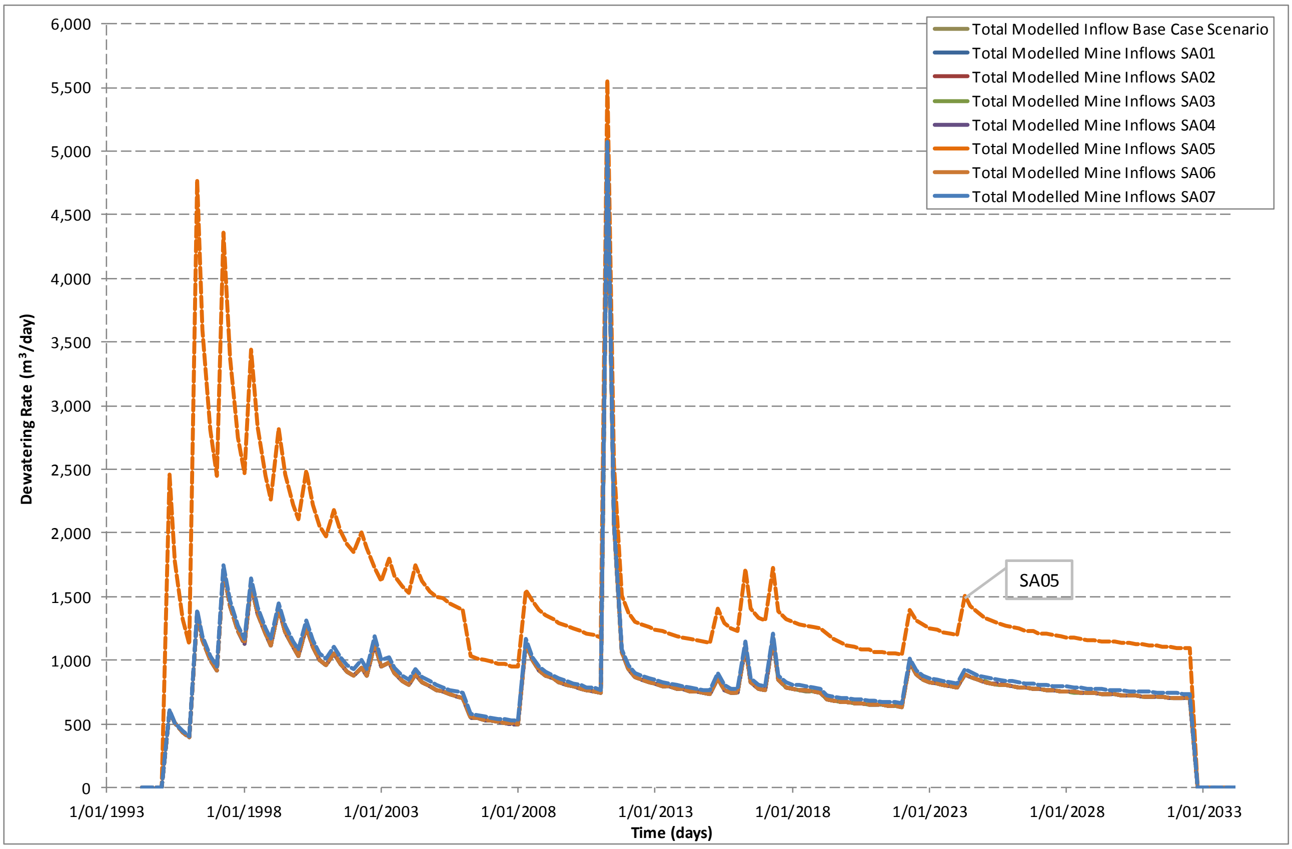


Figure C13: Modelled Groundwater Inflow to the Mine for all Sensitivity Analysis Model Runs

Figure C13 shows that there is no significant alteration to the predicted seepage rates into the mine or zone during sensitivity analysis. Sensitivity Analysis results can be summarised as follows:

- The two TSF sensitivity models: **SA01** (Additional drains around the TSF) and **SA03** (enhanced leakage from the TSF) would not be anticipated to alter the inflows to the mine as the drawdown from the mine does not significantly extend beneath the TSF. Furthermore, any increase pressure head beneath the TSF did not extend to the top of the occasionally fractured bedrock (Layer 4 in the model) due to the low permeability nature of the regolith;

- There is no significant alteration to groundwater levels during or after mining down hydraulic gradient of the Mine Site in any of the scenarios;

- The two climate sensitivity models: **SA02** (CSIRO climate change scenario) and **SA06** (20% increased Background Recharge) were not likely to have a significant impact on the inflows. This was anticipated, due to the low recharge rates applied in the base case scenario as well as the low permeability strata at the surface that is known to impede recharge (MER, 2006).

- **SA04** (increase in vertical hydraulic conductivity) did not significantly alter the model results, likely to be due to the dewatering effect observed in the model directly above the drain cells. Once dewatering was complete, those cells with enhanced vertical hydraulic conductivity remained dry. As recharge was not sufficiently high to permit significant additional recharge, despite the higher vertical hydraulic conductivity, no significant difference was observed in the modelling results;

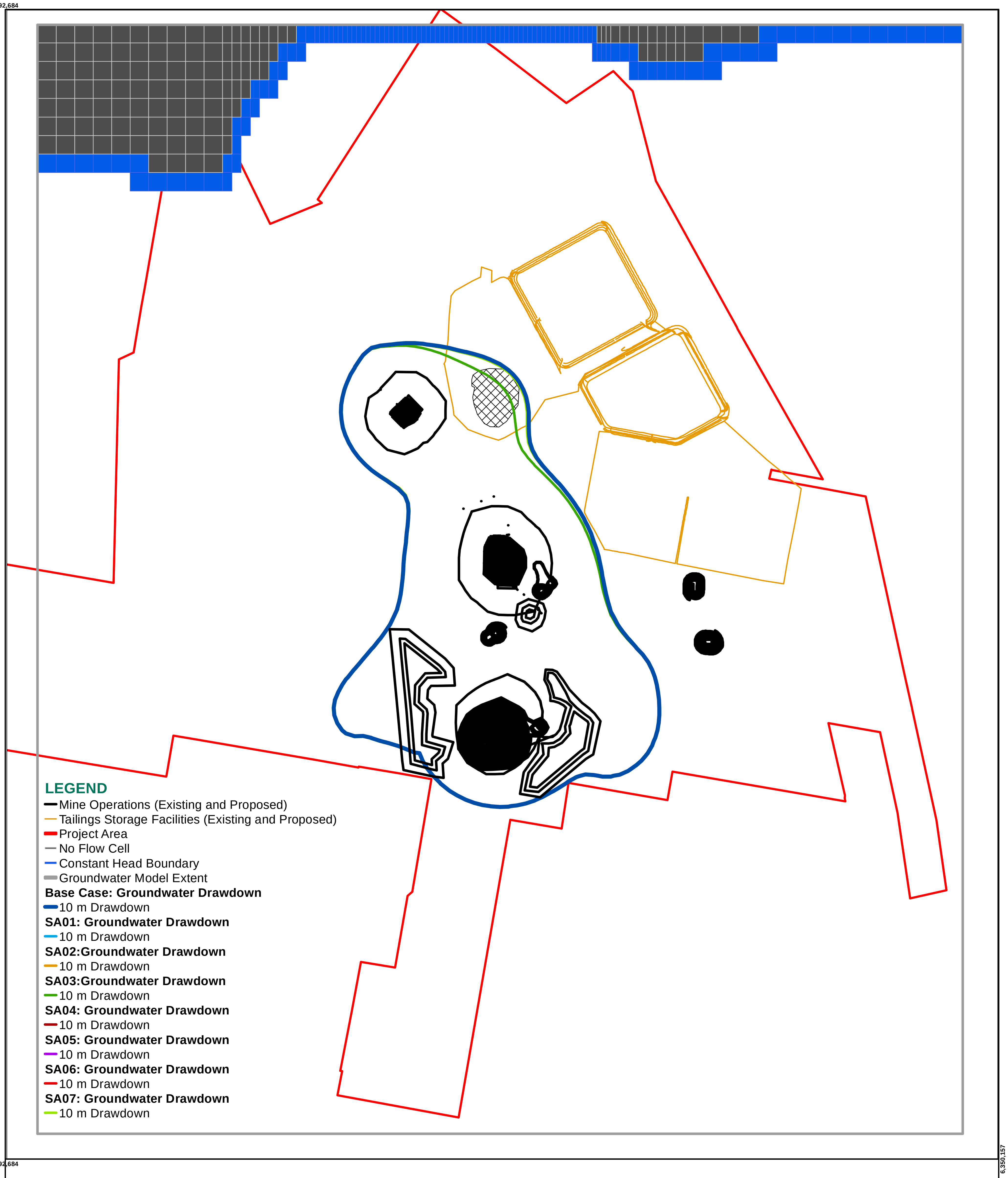
- **SA05** (Enhanced vertical and horizontal hydraulic conductivity) scenario gave modelled inflows of up to approximately 40 % higher than the base case scenario. This is likely to be due to the higher horizontal permeability permitting significantly more flow to the drain cells from surrounding strata even after the cells directly above the drain cells and become dewatered; and

- **SA07** (increased recharge in the caved zones) also did not deviate from the base case model result, likely to be due to a similar reason that the climate scenarios (SA02 and SA06) did not impact the results, i.e. the low permeability Regolith (Layer 1) in the model as well as relatively low recharge rates throughout the model would likely result in limited variance in the model results when changing these parameters. The reasons for a limited impact are also similar to those discussed in SA04.

The extent of hardrock depressurisation for the sensitivity analyses (taken to be the top of the occasionally fractured bedrock; i.e. Layer 4 in the model) at the cessation of mining is shown in Figure C14 below.

Figure C13 and Figure C14 show that there is no discrepancy between the drawdown contours for all Sensitivity Analysis scenarios against the base case scenario.

Sensitivity Analysis results demonstrated that the low recharge rates are a controlling factor in the occurrence and flow of groundwater. Furthermore, the likely low permeability range of the strata throughout the model would be anticipated to limit the range of possible results from modelling, as demonstrated in the limited range of results produced in Sensitivity Analysis.



NORTHPARKES MINE
Groundwater Modelling

UMWELT (AUSTRALIA) PTY. LTD.

Groundwater Drawdown at top of Bedrock (Layer 4) at Cessation of Mining for all Scenarios

NOTES

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SCALE (at A4) 1:40,000
Coordinate System: GDA 1994 MGA Zone 55

PROJECT: 117626007
DATE: 30/04/2013
DRAWN: HW
CHECKED: LJ

FIGURE C14

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Golder Associates

File Location: J:\hyd\2011\117626007_Umwelt_NorthParkesMine\Technical Doc\GIS\Project\Rev0\117626007_007_FC014_Rev0_MEP-03_GWconSA.mxd

2.6 Model Assumptions

There are a number of assumptions made when undertaking the numerical modelling for the Project. Model assumptions should be considered when interpreting the modelling results. These assumptions are in in addition to those given in MER (2006) and include the following:

- MER 2006 E48 Project mine model was assumed to be reliable, in terms of all model input parameters, hydraulic parameters and mine progression. Additional monitoring data and dewatering observation data used in calibration did not significantly impact the calibration results of the MER 2006 model;
- Open pit mine progression was based on linear relationship between initial and final depths, progressing at stepped six monthly rate (the temporal resolution of the model) a rate that directly reflected the predicted extraction tonnage provided by NPM (2012);
- Block cave mine progression was assumed initiate from the first extraction period from each operation and instantaneously result in caving above the base of the caved zone. This was represented by altering the hydraulic parameters of the model layers directly above the drain cells;
- Each operation continues to be dewatered until cessation of all mining. This is considered a worst case scenario in terms of inflows to the mine and extent of depressurisation as both results will be higher due to the potentially extended period of dewatering;
- No attempt has been made to replicate the temporal changes in hydraulic properties of the rock due to mining. This affects the likely infiltration rate, when subsidence reaches the near surface as well as in the rock mass;
- Increase in recharge will likely reduce the drawdown effect of the mine and therefore, the assumption causes drawdown due to the mining to be overestimated and inflow of groundwater to the mine to be underestimated;
- An equivalent porous medium (EPM) model was used to replicate the complex nature of fracture flow. This is considered an acceptable methodology for replicating the bulk properties of a fractured rock mass;
- Recharge was assumed to be constant. No attempt was made to create a transient data set reflecting time varying climatic conditions. As an observed response to recharge events are not readily reflected in groundwater levels (MER, 2006), this was considered an acceptable assumption; and
- The proposed tailings located to the east of E27 (referred to as future TSF Cell 1 and Cell 2) were assumed to begin operation as given in the MER 2006 model. The additional tailings modelling scenario included proposed tailings to the west and southeast of the pits. It was assumed that these tailings would be operational to the same time and have the same leakage rate as Cell 1 and Cell 2.

3.0 REFERENCES

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APPENDIX C
Northparkes Project Area - Groundwater Numerical Model

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APPENDIX D

Groundwater Impact Assessment and Risk Register

APPENDIX D

This appendix includes risk assessment objectives and process and the matrix of the impact significance that was applied to the risk assessment process.

1.1 Risk Assessment Objectives

In this section the potential impacts and risks to local and regional groundwater resources from the Project are assessed using a risk based framework. The risk-based approach allows the potential groundwater related risks associated with proposed mining activities to be considered and classified with respect to multiple evaluation criteria, such that the primary risk-driving activities are identified, prioritised and mitigated accordingly.

The process used to assess the risk of groundwater impacts is described. Potential groundwater impacts are discussed along with the results of the risk assessment. Measures to limit the risks, called risk mitigation measures, are discussed and the risk re-assessed to include the mitigation measures. There are two primary types of risk to be managed for this project:

- The impact of the activities on potential receptors; the potential receptors being:
  - Environmental values, as described in Section 4.0 of the main report;
  - Surrounding aquifers; and
  - The local community through town or individual domestic water supplies, recreational areas and activities, agricultural activities relying on groundwater and industrial groundwater users.
- The regulatory risks (adherence to applicable legislation)

1.2 Risk Assessment Process

A risk is defined by the Australia/New Zealand Standard for Risk Management (AS/NZSISO 31000:2009) as *the effect of uncertainty on objectives*. It is measured in terms of a combination of the consequences of an event, and the likelihood of an event occurring.

The potential impacts and risks to groundwater and environmental values associated with the Project activities were identified. The potential risks were assessed qualitatively and assigned a risk ranking according to the likelihood of the risk occurring, and the associated consequences, as discussed later in this section of the report.

Likelihood and consequence are defined as:

- The likelihood is the probability for an event to occur;
- The consequence is the effect that the event will have on different receptors or parameters. The consequence can be to human health and safety, to the natural environment and/or to the Project's reputation. Consequences can also be financial impacts.

The type of risk assessment carried out for this project is called a qualitative risk assessment because it uses qualitative descriptors to derive a risk rating. Some types of risk can also be assessed quantitatively, particularly financial risks. The matrix of descriptors used to assess the risk consequences is presented in Table D1. The table includes a description of the categories of consequences considered, and a description of the relative magnitude of the consequence for each category. The matrix used to evaluate the risk likelihood is presented in Table D2.

A risk category between one (low, tolerable) and four (critical, least tolerable), according to the matrix, is presented in Table D3. A risk issue assessed as Category 1 (low) is generally considered to be tolerable in its current state, without the need for mitigation actions to reduce the risk. Category 1 risks generally represent risk issues that are either very unlikely to occur, or that would result in a minor or negligible consequence if they do occur. Risk issues assessed as Category 2 to 4 (moderate to critical) may or may not be tolerable but generally require further evaluation of potential contingency actions or mitigation measures required. The risk matrix and risk rating definition are presented in Table D3.

Table D1: Risk Assessment Definitions - Consequences

Consequence Categories		Health and Safety	Natural Environment	Financial
Catastrophic	**5**	Fatality	Destruction of sensitive environmental features. Severe impact on ecosystem. Regulatory & high level Government intervention/action.	Financial loss in excess of $100 million
Major	**4**	Permanent disabling injury and/or long term off work	Long term impact of regional significance on sensitive environmental features. Regulatory intervention/action.	Financial loss from $50 to $100 million
Serious	**3**	Injury requiring medical treatment, time off work and rehabilitation	Short term impact on sensitive environmental features. Triggers regulatory investigation.	Financial loss from $5 to $50 million
Medium	**2**	Injury requiring medical treatment with no lost time	Impact on fauna, flora and/or habitat, but no negative effects on ecosystems. Requires immediate regulator notification.	Financial loss from $500,000 to $5 million
Minor	**1**	Minor injury - first aid treatment	Negligible impact on fauna, flora, habitat, aquatic ecosystems or water resources. Incident reporting according to routine protocols.	Financial loss from $0 to $500,000

Table D2: Risk Assessment Definitions - Likelihood

Likelihood Categories		Guidance	Supplementary Guidance
Almost Certain	**A**	Is expected to occur in most circumstances	Occurs daily/weekly
Likely	**B**	Could occur in most circumstances	Occurs monthly
Possible	**C**	Has occurred here or elsewhere	Occurs once a year
Unlikely	**D**	Hasn't occurred yet but could	Occurs once in 10 years
Rare	**E**	Very unlikely, may occur in exceptional circumstances	Occurs once in 100 years

Table D3: Risk Matrix and Risk Tolerance Definition

Likelihood	Consequence				
	1 - Minor	**2 - Medium**	**3 - Serious**	**4 - Major**	**5 - Catastrophic**
A - Almost Certain	Moderate	High	Critical	Critical	Critical
B - Likely	Moderate	High	High	Critical	Critical
C - Possible	Low	Moderate	High	Critical	Critical
D - Unlikely	Low	Low	Moderate	High	Critical
E - Rare	Low	Low	Moderate	High	High

Matrix of Significance of Groundwater Impact

This section presents the matrix of significance for groundwater impact assessment.

Impact Significance Assessment Descriptions of various categories for rating the sensitivity of groundwater resources and magnitude of impact on groundwater resources are presented in Table D4 and Table D5, respectively. The magnitude of an impact on groundwater resources was estimated considering the severity of the impact, extent and duration of the impact. The categories of the sensitivity of the environmental values of groundwater resources were classified based on the groundwater quality and quantity, the size of aquifer, and the groundwater vulnerability. The matrix of significance utilised for the groundwater impact assessment is shown in Table D6. The significance of the groundwater impacts was estimated based on the magnitude of the impact and the sensitivity of resource/receptor.

Table D4: Sensitivity of groundwater resources

Category	Description
High	• The groundwater has good water quality and quantity. • National designated groundwater-dependent ecosystems. • Groundwater vulnerability rating: "High" or "Moderate to High"
Moderate	• Local groundwater supply of moderate water quality and quantity. Water quality is not suitable for human consumption but may be used for other consumptive use. • National designated groundwater-dependent ecosystems. • Groundwater vulnerability rating: "Moderate" or "Low to Moderate"
Low	• Local groundwater supply of limited water quantity, poor water quality unsuitable for general consumptive uses. • Groundwater vulnerability rating: "Low to Moderate" or "Low"

Table D5: Magnitude of impact on groundwater resources

Category	Description
High	• Activity likely to have severe negative impact on groundwater resources and/or groundwater-dependent ecosystems. • Impact on district groundwater resources (groundwater quality, quantity, aquifer characteristics such as transmissivity, hydraulic conductivity, and storativity). • Recovery (if possible) is likely to take up to 25 years.
Moderate	• Impact on groundwater resources and/or groundwater-dependent ecosystems will be detectable but not severe. • Generally occurring within 10 km of impact site. • Recovery is likely to take up to 7 years.
Low	• Impact on groundwater resources and/or groundwater-dependent ecosystems may be detectable but is small and highly unlikely to have any significance. • Effects immediate surrounds of impact and extends for up to 2 km radius. • Recovery short term up to 3 years.

Table D6: Matrix of significance for groundwater impact assessment

	Sensitivity of Environmental Value		
Magnitude of Impact	**High**	**Moderate**	**Low**
High	**Major**	**High**	**Moderate**
Moderate	**High**	**Moderate**	**Low**
Low	**Moderate**	**Low**	**Negligible**

Risk Issue	Cause	Impact	Risk Rating prior to Management and Mitigation measures	Site Specific Control Measures/Mitigation	Site Specific Risk Rating inclusive of Mitigation and Controls
Leakage of introduced fluids during drilling or contaminated fluid. Leakage/spills of chemicals, hydrocarbons fuels, oils and petroleum products.	Poor design, Construction technique, Poor closure technique; Potential for spills and contamination by metals and hydrocarbons from mine workshop, waste disposal and fuel storage areas	Contamination, Non-compliance	Moderate	Apply the minimum construction requirements for water bores in Australia (National Uniform Drillers Licensing Committee, NUDLC rev.3, 2012); check quality of data regularly, establish a complete operational protocol and data handling system; Fuel and chemical storages to be constructed and adequately bunded to the relevant Australian Standard. Immediate clean-up of spills which is standard practice and/or a legislated requirements at mine sites to prevent contamination of shallow strata and subsequent leakage to the groundwater system. Spill cleanup kits in accordance with Australian Standards (AS1940 and AS3780) will be kept on site.	Low
Change in land use (TSF3, new waste rock stockpiles)	Change of land use (TSF3, new waste rock dumps & stockpiles) and leakage beneath the dams/ponds	Additional recharge and change of groundwater flow	Moderate	Ensure appropriate planning and site design and install appropriate monitoring systems and develop contingency plan	Low
Subsidence of original surface due to block caving methods	An expected result of block cave mining techniques and operations	Change the characteristic of the aquifer and groundwater system	Low	The surface subsidence is an expected result of mining techniques and Project operations. Zones of subsidence are envisaged to be localised, contained within the mine site boundaries. Given the low conductivity, the low flow rates within the aquifers and the localised zone affected by subsidence it is not anticipated that subsidence will detrimentally impact the regional groundwater flow regime.	Low
Subsidence of original surface due to block caving methods	Proximity of subsidence zone could potentially cause subsidence beneath dam or water storage facilities and seepage	Change in recharge; Create seepage of water beneath structures and change natural groundwater quality/conditions	High	Zone of subsidence will be localised, contained within the mine site boundaries. There will be careful planning and site design in relation to the proximity of the subsidence zones to current and proposed tailings storage areas and water storage facilities to ensure that the subsidence zone does not encroach on these areas which could cause permanent changes in rock hydraulic characteristics and consequentially elevated seepage of water beneath. Appropriate monitoring systems will be in place to monitor the groundwater levels in the vicinity of the subsidence zones and waste facilities using shallow piezometers.	Low
Change in groundwater quality	Leakage of tailings water beneath TSF3, mobilising a high salinity/poor quality groundwater plume within the natural groundwater flow system	Degradation of groundwater quality	High	In order to reduce the potential for uncontrolled seepage of contaminated water accurate design and sizing of the correct water and waste containment facilities are required. TSF3 will be correctly sized, to prevent overflow and adhere to regulations which require the consideration of the flood events, and constructed to limit or prevent underground leakage. Adequate monitoring around and beneath tailings dam TSF3 will be carried out. All existing boreholes located within the footprints of TSF3 will be backfilled using a cement – bentonite slurry so as to prevent leakage . Groundwater monitoring system using a series of shallow piezometers will be carried out to monitor the potential seepage from TSF3s. Tailings and waste rocks are to be characterised and appropriate management action would be undertaken if there is indication of potential impacts.	Low
Change in groundwater quality	Change the characteristic of the groundwater through subsidence. Oxidize the caved waste overburden/waste rocks that subsides and alter quality of groundwater and mine seepage water.	Alter quality of groundwater and mine seepage water.	High	Monitor quality of seepage water within the mine and treat as necessary; Tailings and waste rocks are to be characterised and appropriate management action would be undertaken if there is indication of potential impacts. Trigger values for surface and groundwater quality will be updated as part of the adaptive monitoring approach. Backfilling of the subsidence zones may be considered. The seepage water quality within the mine will be monitored and treated as necessary.	Moderate
Excessive groundwater drawdown	Dewatering of the mine lowers the regional water table of the saprock oxidised zone aquifer, and to a lesser extent, the regolith and host rock.	Change of regional groundwater flow direction	Low	Maintain monitoring and management of groundwater inflow into the underground mine operations and dewatering volumes at open pits to meet the requirements of 'NSW Aquifer Interference Policy' (2012).	Low
Excessive groundwater drawdown	Dewatering of the mine lowers the regional water table of the saprock oxidised zone aquifer, and to a lesser extent, the regolith and host rock.	Change of groundwater levels in the vicinity of the mine operations.	Moderate	The volume of water taken as a result of mining activities was modelled in this study prior to project approval and will be measured and reported. Maintain monitoring and management of groundwater inflow into the underground mine operations and dewatering volumes at open pits to meet the requirements of 'NSW Aquifer Interference Policy' (2012).	Moderate
Excessive groundwater drawdown	Dewatering of the mine lowers the regional water table of the saprock oxidised zone aquifer, and to a lesser extent, the regolith and host rock.	Degradation of the resource (limit supply) to other groundwater users / abstractors; Loss of groundwater yields at existing bores	Low	Groundwater within the Project Area is currently a poor yielding resource. There are no private groundwater users within the Project Area and the modelled zone of impact. Maintain monitoring and management program. Investigate cause.	Low
Excessive groundwater drawdown	Dewatering of the mine lowers the regional water table of the saprock oxidised zone aquifer, and to a lesser extent, the regolith and host rock.	Impact to nearby streams and/or river tributaries or disconnection of ephemeral streams	Low	Due to depth of encountered groundwater, these systems are not likely groundwater dependent.	Low
Excessive groundwater drawdown	Dewatering of the mine lowers the regional water table of the saprock oxidised zone aquifer, and to a lesser extent, the regolith and host rock.	Reduce availability of groundwater for high priority GDEs (springs, wetlands)	Low	The nearest high priority GDEs spring is located outside of the Study Area and at a distance greater than 50 km southeast of the mine site (Lamberts Springs); Maintain effective monitoring and management programs.	Low
Excessive groundwater drawdown	Dewatering of the mine lowers the regional water table of the saprock oxidised zone aquifer, and to a lesser extent, the regolith and host rock.	Reduce availability of groundwater for River Red Gum Woodland and State Forest	Low	The predictive modelling suggests that Wombin State Forest is outside the zone of drawdown. Management strategy will be to monitor the changes in groundwater level and water quality using the water bore monitoring network. Trigger levels, regarding declines in groundwater levels and the degradation of groundwater quality will be established to manage the potential impacts. Where monitoring results indicate levels in excess of the trigger values, an investigation appropriate for the situation will be conducted to assess the need to implement additional monitoring and management/mitigation measures.	Low
Excessive groundwater drawdown	Over abstraction of water obtained from an appropriately authorised and reliable supply for the purposes of operation of the Project.	None-conformance of the operating rules of the relevant Water Sharing Plan (WSP)	Low	The volume of water taken as a result of mining activities was modelled in this study prior to project approval and will be measured and reported. Maintain monitoring and management of groundwater inflow into the underground mine operations and dewatering volumes at open pits to meet the requirements of 'NSW Aquifer Interference Policy' (2012).	Low
Post mining groundwater levels	Recovery of groundwater levels is inconsistent with post mine recovery plan and insufficient for planned recovery	Change in equilibrium water table levels and quality. Unavailable resource / reduced use of the water	Moderate	Revisit proposed rehabilitation management and monitoring plans and alter as necessary. Use of resource is already minimal	Low
Post mining groundwater quality	Recovery of groundwater is inconsistent with post mine recovery plan and insufficient for planned recovery. Oxidize the caved waste overburden and alter quality of groundwater and seepage water.	Change of water quality. Unavailable resource / reduced use of the water source.	High	Revisit proposed rehabilitation management and monitoring plans and alter as necessary. Use of resource is already minimal; Monitor water quality and treat as necessary	Moderate
Mine activities alter long-term recharge characteristics	Backfilling of the prescribed subsidence zones	Additional recharge to material near surface, pooling groundwater within the subsidence zones.	Low	Revisit proposed rehabilitation management and monitoring plans. Use of resource is already - overall impacts are considered low	Low

APPENDIX E

Water Quality Data (Please Refer to CD for Table E1)

APPENDIX F

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LIMITATIONS

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