Critical importance of conceptual model development when assessing mine impacts on groundwater dependent ecosystems: case study of an Australian mine development

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Abstract

Changes to groundwater conditions were assessed in the context of proposed open cut mining potentially impacting local groundwater dependent ecosystems (GDEs). Assessment of baseline groundwater conditions and reviews of published information on local GDEs and ecological studies were used to assess the nature of groundwater dependence of local GDEs. A revised conceptual model of GDEs found that key flora/fauna communities were more likely to be influenced by rainfall infiltration to the unsaturated zone in basement rocks (unaffected by mining) and recharge – discharge processes of nearby palaeochannel aquifers than those groundwater systems directly influenced by mining.

Keywords: hydrogeology, mine dewatering, impacts, groundwater dependent ecosystems

Introduction

SIMEC Mining is currently considering developing a new, hematite iron ore (open cut) mine at Iron Sultan, located at Camel Hills ("Site"), approximately 45 km west of the town of Whyalla in South Australia, Australia (Figure 1). A hydrogeological assessment was undertaken to evaluate potential changes to groundwater conditions as a result of the proposed mine.

The scope of the assessment comprised drilling investigations, well installations, field permeability testing, water quality sampling and analyses and assessment of other available data.

Site Setting

The Site is located in the Gawler Ranges district and to the west of the Iron Baron Mining Area (IBMA) (Figure 1) and within an arid to semi-arid climate, with potential evaporation substantially higher than rainfall (average rainfall and "Class A" pan evaporation are around 270 and 2,550/annum, respectively). The Site is located on the western flank of the regionally extensive, north-south trending Middleback Ranges (approximate elevation of 350 m Australian Height Datum, mAHD). A series of inter-connected salt lakes and playas, lie to the west of the Site (approximate elevation of 180-200 mAHD). The District is

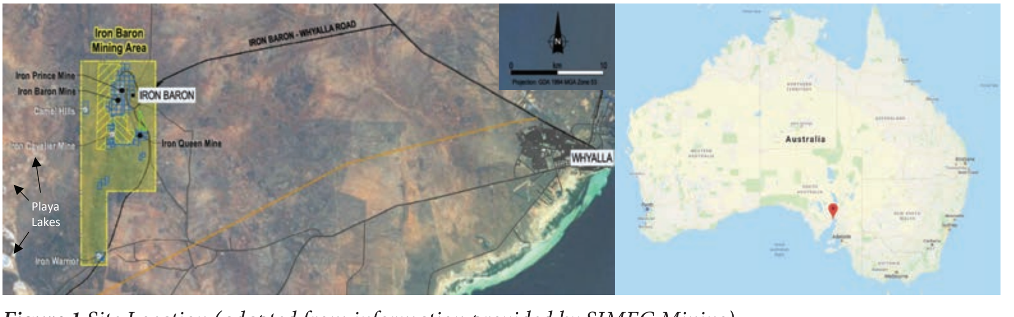

Figure 1 *Site Location (adapted from information provided by SIMEC Mining)*

characterised by three major physiographic units, "Sand Dunes & Flats", "Plains" and "Hills & Rises" (DEWNR, 2013). A number of GDEs have also been mapped at a regional level. Surface water runoff is to the west, with flows in creeks between the salt lakes / playas typically ephemeral.

Regional Geology and Hydrogeology

The Site is situated in the Gawler Craton, a stable crystalline basement province containing Archaean to Mesoproterozoic rocks with thin overlying sediments of Neoproterozoic to Quaternary age overlying the basement rock (Rudd, 1094; Drexel et al., 1993). The key units in the region belong to the Middleback Subgroup and comprise a basal dolomite unit overlain by two iron formations that are separated by a schist unit of clastic origin. The depositional environment is interpreted to have been a shallow sea with a north-south trending shoreline with periods of shoreline progradation and marine transgression (Roache, 1996). The Kimban Orogeny has resulted in formation of broad, open folds and major north to northeast-trending mylonitic shear zones. The Kalinjala Mylonite Zone is a major north-south linear zone of intense ductile deformation extending the length of the eastern Eyre Peninsula (Roache, 1996). This depositional and orogenic environment has resulted in the formation of the steeply dipping, north-south trending Middleback Ranges.

The regional hydrogeology is characterised by unconfined/confined, fractured rock hydrogeological units of the Middleback Ranges underlying unconfined aquifers in surficial Tertiary and Quaternary sediments located in lower areas of the landscape. The fractured rock units are saline to brackish with low yields. Groundwater of potable quality is mostly found in Quaternary limestone and Tertiary sand aquifers along the south and west coasts (Berens et al., 2011).

Although groundwater recharge rates to the fractured rock units are not well understood, recharge is thought to mostly occur where basement rocks outcrop or sub-crop at or near the Ranges (Berens et al., 2011). Recharge to fractured rock groundwater systems in this setting is considered to be irregular and localised (Berens et al., 2011).

Initial Conceptual Model

Prior to the undertaking of field (hydrogeology) investigations, an initial hydrogeological (conceptual) model was developed to describe groundwater conditions, with a focus on likely groundwater recharge – discharge processes.

Groundwater recharge occurs along the ranges, with groundwater flows from these areas to the west. Hydraulic gradients are a subdued reflection of the topographic gradients. Groundwater discharges to the salt lakes / playas and supports their presence. Vegetation in the salt lakes / playa areas rely on groundwater sourced from groundwater recharging in the ranges.

Hydrogeology Investigations

The key stratigraphic units of interest are the Katunga Dolomite, Lower Middleback Formation and Cook Gap Schist of the Middleback Subgroup, which together with steeply dipping banded iron formations (BIFs), comprise the north-south trending main ridge of the Middleback Ranges (Parker and Flint, 2012). Granitic basement and dolerite is commonly encountered on both sides of Camel Hills, with dolerite and amphibolite intrusions found as cross-cutting structures. Schist / quartzite units are observed along the eastern side of the hills (Parker and Flint, 2012). The results of site mapping indicate that a north-south striking limonite-goethite orebody exists and is bound by the BIFs (east), granitoid rocks (west) and fault structures to the north and south (Figure 3). Quaternary-age scree deposits overlie the bedrock to the west of the Site. Fractured rock aquifers are present at depth, with the groundwater system low yielding and saline-hypersaline quality. Recharge occurs along the ranges to the east of the deposit, with groundwater discharging to the west towards the salt lakes / playas (Figure 1).

Baseline hydrogeological investigations were undertaken to characterise site groundwater conditions and define, by way of reviews of published information on local GDEs and ecological studies, the nature of groundwater dependence of GDEs at and downstream of the deposit. Hydraulic conductivities of the orebody rocks (CHMW02 & 05) were measured to range between 2.7 to 3.5 × 10-3 m/s, whereas the east and west wall rocks (CHMW01, 3 & 4) have measured hydraulic conductivities that range from 2.1 × 10-7 to 8.9 × 10-6 m/s. Groundwater within the orebody rocks typically have lower Chloride concentrations (78 to 96 mg/L, CHMW02 & 05) than that found in groundwater in wall rocks (275 to 750 mg/L, CHMW01 & 3), suggesting higher rate of groundwater movement along the north-south orebody.

The orebody rocks are interpreted to form a "strip aquifer"; mining below the water table is likely to cause preferential flows and drawdowns beyond the pit to be greater along strike of the orebody. Groundwater levels across the site, measured at the time of site investigations range between 150.0 and 150.5 mAHD and indicate a westerly hydraulic gradient reflecting topographic gradients (Figure 2).

Revised Conceptual Model

The initial conceptual model has been revised in light of further analysis of site hydrogeological and other data. Key focus of this revision was the interpretation of likely interactions between groundwater conditions and GDEs. Regional scale mapping of GDEs (NWC, 2012) was utilised, with two key GDE types identified locally: 1. GDEs that rely on subsurface presence of groundwater (vegetation), 2. GDEs that rely on surface expression of groundwater (rivers, wetlands, springs) (Figure 3). This revision of the conceptual model proposes a subdivision of upland, mid-catchment and lowland groundwater sub-catchments, corresponding with the three major physiographic units, Sand Dunes & Flats, Plains and Hills & Rises (Figure 4).

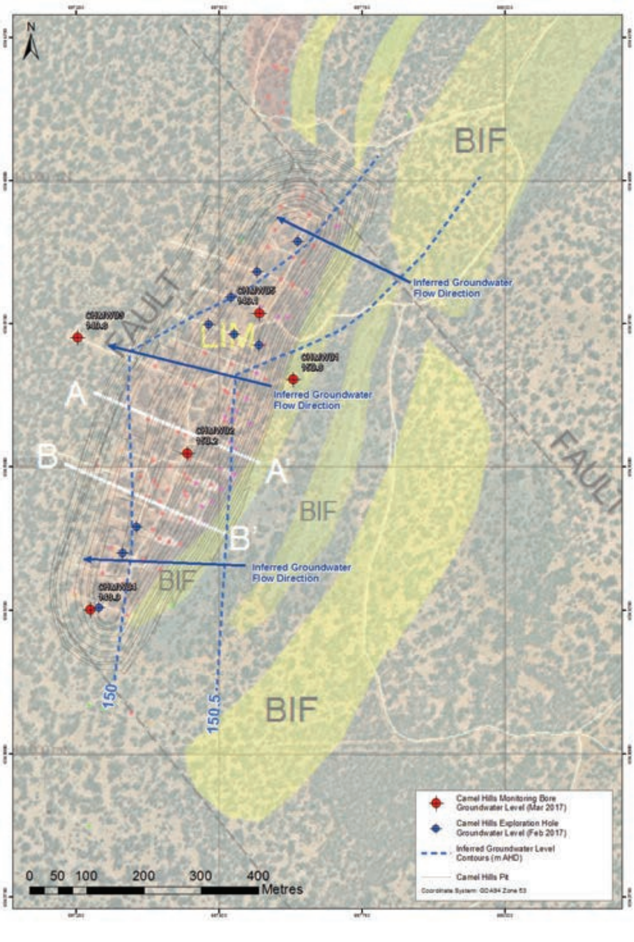

Figure 2 *Site Geology, Groundwater Levels and Flow Directions*

Upland Area

Groundwater recharge rates are highest in the Upland Area (“Hills & Rises”), primarily due to the presence of outcropping bedrock units (i.e. fractured BIFs, Quartzites). The results of site investigations indicate that local hydrogeological units are strongly anisotropic, with east-west hydraulic conductivities orders-of-magnitude lower than north-south hydraulic conductivities. This is due to the depositional and orogenic environment resulting in north-south striking rocks. Estimates of net groundwater recharge have been made using the CSIRO groundwater recharge-discharge calculation method (Leaney et al., 2011) and available groundwater quality data. Specific inputs included annual rainfall, annual rainfall chloride flux, groundwater chloride concentration, soil clay content, soil type, and vegetation type. Net groundwater recharge rates are estimated to range from 0.3 to 6.1 mm/year (or about 0.1 to 2.3 % of average annual rainfall).

Key terrestrial vegetation species in this area include Hummock grassland (Triodia *irritans*), Gilja (*Eucalyptus brachycalyx*) Red Mallee (*Eucalyptus oleosa*) (EBS 2015) (Brandle, 2010). These are deep rooted plant species, particularly the Triodia species which is very deep-rooted. Given that historic depths to groundwater (at IBMA) are reported to range from 40.46 to 122.22 m below ground level (Jacobs, 2017), it is expected that these species tap small pockets within faulted / fractured rocks that are highly weathered and contain infiltrated waters. These pockets are seasonally replenished by direct infiltration of rainfall. It is interpreted that for this reason mapping data show vegetation density in this area to be low and GDEs mapping data (Figure 4) suggest that there is a “*low potential for groundwater interaction*”.

Mid-Catchment Area

Groundwater recharge rates are likely to be substantially lower than in the Upland Area (“Plains”) due to the presence of above-water table Quaternary scree deposits, which mostly lie above the water table and minimise downward percolation of infiltrated waters. Estimated baseflow rates to the Lowland Area to the west, based on measured hydraulic conductivities and gradients are very low, estimated to be just 90 m^3/day/1 km section. This calculation assumes a notional 20 m aquifer thickness contributes to groundwater discharges to stream / drainage lines between salt lakes and playas to the west in the Lowland Area. The mapped data indicate a “*high potential for groundwater interaction*” with

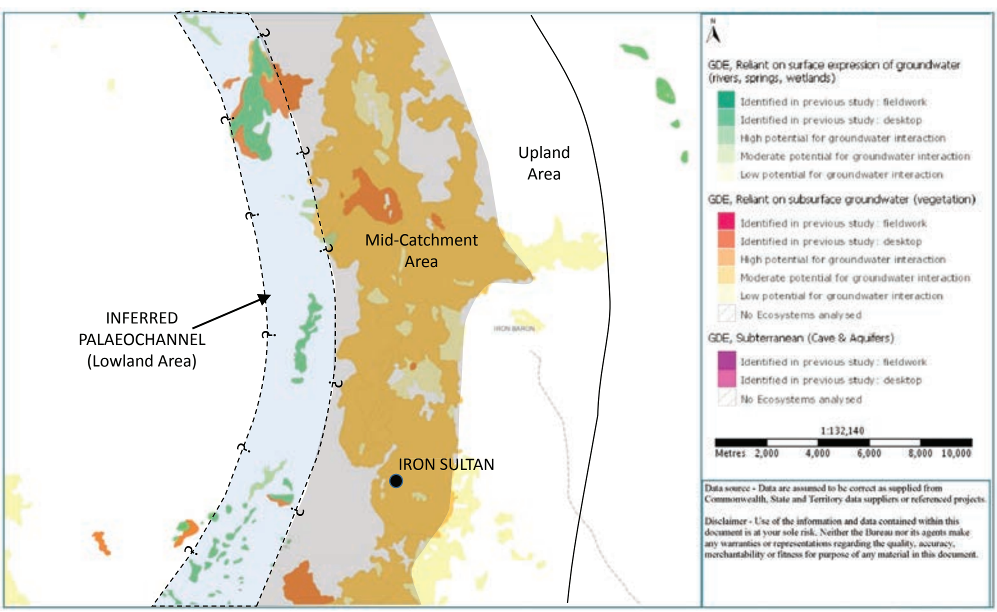

***Figure 3** Mapped GDEs (adapted from NWC, 2012)*

vegetation density higher than in the Upland Area and more dependent on groundwater. It is interpreted here that the presence of scree deposits and greater degree and depth of weathering provide a larger and more uniform storage of rainfall infiltration, above the water table, supporting this higher vegetation density.

Lowland Area

The Lowland Area ("Sand Dunes & Flats") is characterised by saltmarsh, sand dunes and plains. Small watercourses, such as Salt Creek located to the south of the study area, drain surface runoff between (and to) the salt lakes / playas. While there are no known streamflow gauging data for any of these local watercourses, anecdotal evidence indicates that these watercourses are ephemeral and only flow periodically during the months of February to March, when high intensity storms (e.g. related to ex-tropical cyclones in the summer months) are at their greatest (Mining Plus, 2015); Jacobs, 2017).

It is interpreted that a palaeovalley exists along an indicative alignment as illustrated in Figure 3, based on the locations of mapped GDEs as well as regional palaeovalley mapping undertaken by Bell et al. (2012). It is expected it has a much higher storage capacity and hydraulic conductivity than adjacent and more extensive weathered and fractured basement aquifers. The cross-sectional area and properties of the aquifers in the palaeovalley aquifers are unknown but expected to be similar to the Gawler-Eucla palaeovalley "demonstration site" (Magee, 2009).

Conceptually, it is considered that given the likely low permeabilities of basement rock, and ephemeral nature of flows to high intensity rainfall events along and to the palaeovalley, that groundwater is not a significant contributor to surface water flows. However, groundwater heads at the palaeovalley are probably strongly controlled by heads in the adjacent basement rock. Groundwater discharge rates to the salt lakes / playas, and related drainage likes, are likely at around the same rates of evaporation, resulting in surface precipitation of salt at the surface.

Key vegetation in the saltmarsh and drainage areas includes (*Eucalyptus Oleosa ssp oleosa*) (*Eucalyptus gracilis*) (*Lomandra effusa*) (*Geijera linearifolia*) (*Triodia scariosa ssp scariosa*) (Bebbington 2011) Sandhill Wattle (*Acacia ligulata*), Lignum (*Muehlenbeckia cunninghamii*) and Samphire (*Tecticornia indica*), while in the sand dune and plain areas there are Black Oak (*Casuarina Pauper*), Cypress Pine (*Callitris glaucophylla*), Mallee pine (*Callitris preissii*) and Boonaree (*Heterodendrum oleaefolium*) (Brandle, 2010). The underlined species are deep rooted (BGSA, 2018) and do not source saline groundwater. It is inferred that these plant species draw groundwater from shallow aquifers within palaeochannel sediments and sediments in other drainage lines. These aquifers are periodically recharged during periods of high stream flow (seepage losses) and infiltration of runoff from adjacent areas (Figure 4).

Conclusions

The results of the study have led to modification of the conceptual model in that the vegetation communities are more likely to rely on direct rainfall infiltration to the unsaturated zone and/or shallow ephemeral aquifers within drainage / palaeovalley-related sediments rather than discharge of deeper, regional groundwater. Specifically, the study has found that local areas along the creek line where deeper-rooted vegetation are noted are more likely to be tapping into small zones where local recharge of groundwater occurs and collects in fresh water "pockets", above the regional, saline water table. Salt lake and salt marsh surface features present in the salt lake / playas reflect zones of groundwater discharge and salt accumulation, primarily in areas where shallow clays are present in the near-surface. The study highlights the critical importance of understanding GDEs, the nature of their occurrence and their connections with local and regional groundwater systems.

Acknowledgements

The author thanks SIMEC Mining (Jennifer Gerard and Chris Smyth) for supporting the preparation of this paper and presentation of company information and Jennifer Lallier, Aidan Moyse and Wade Dodson for their technical assistance.

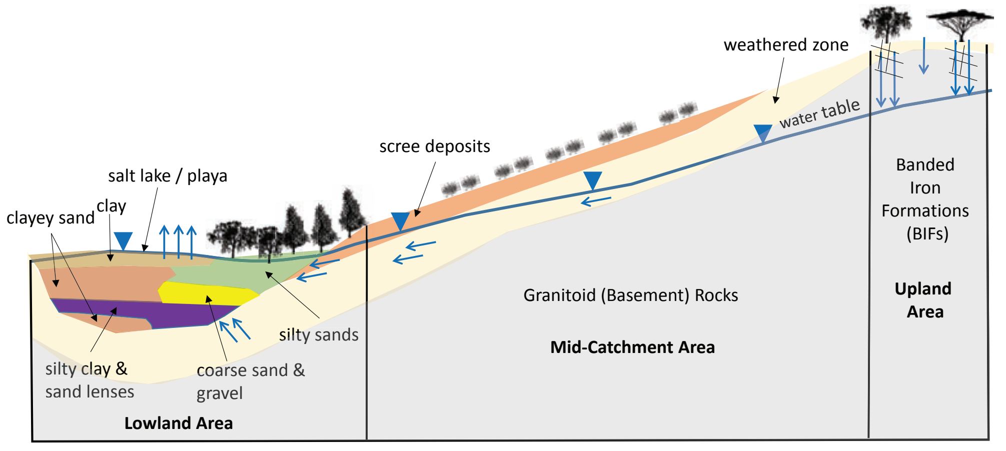

Figure 4 *Revised Conceptual Model*

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