Yandicoogina Pocket and Billiard South

Supplementary Hydrogeological Information

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1. HYDROGEOLOGY SUMMARY

The hydrogeological investigations for the Yandicoogina Pocket and Billiard South proposal (**the Proposal**) focused addressing the work programs outlined in the requirements of the Environmental Scoping Document (EPA 2014) for the Proposal.

These programs included:

- Collation of historical data to construct baseline information on water quality and quantity.
- Construction of a conceptual hydrogeological model for the site that includes the entire site water balance and groundwater and surface water interactions.
- Drilling and long term pumping testing analysis on the installed bores to determine the hydraulic properties of the Tertiary Channel Iron Ore deposit (**CID**) aquifer and connectivity to the Weeli Wolli Creek floodplain alluvial aquifer.
- Construction of a numerical groundwater model to determine life of mine water balance and dewatering volumes.
- Investigation of the impact of surplus water discharge from the Hope Downs 1 (**HD1**) mine operation into Weeli Wolli Creek on the water balance, recharge and water quality in the CID aquifer and Fortescue Marsh.
- As Weeli Wolli Creek is a major tributary and may contribute significant volume of water to the Fortescue Marsh (~40 km down gradient of the Proposal area), extensive investigations were undertaken on the impact of current and proposed mine operations on the water quality and the potential for cumulative impacts on the Fortescue Marsh.

2. HYDROLOGICAL SETTING

2.1 RAINFALL AND CLIMATE

The Yandicoogina area is a semi-arid to arid environment characterised by hot summers and warm winters. The region experiences climate extremes, where severe droughts and major floods can follow in close succession.

Rainfall records for Weeli Wolli Creek are available from the Department of Water (**DoW**) gauging stations at Wonmunna (507012) from 1984, Tarina (505040) from 1985 and Waterloo Bore (505041) from 1985. A weather station was established in the current Yandicoogina mine site, recording daily rainfall since 1998. Daily gridded rainfall data from Bureau of Meteorology (**BoM**) are also available for the period 1906 – 2011 for the catchment. Based on detailed analysis of the observed rainfall records, the long term mean annual rainfall (1906 to 2011) estimated for the Proposal area is 309 mm. Rainfall is highly variable between years with the annual recorded rainfall for the region varying from 50 mm to 910 mm. It is also highly seasonal with rain falling mainly in the summer months from January to March, as a result of scattered thunderstorms producing heavy localised falls in short periods. Tropical lows originating off the Pilbara coast can also bring widespread rain to the area. Winters are typically dry and mild though winter rain events can occur in June and July as a result of tropical cloud bands that intermittently affect the area.

The mean annual Class A pan evaporation estimated for the region is approximately 3,280 mm. The mean annual evaporation rate (sheltered free water surface) recorded at the Yandicoogina mine site weather station, between April 2004 and March 2009, is 1,900 mm/year, which exceeds the mean annual rainfall keeping the landscape typically arid.

2.2 BACKGROUND AND GROUNDWATER OCCURRENCE

The Proposal consists of CID between 600 and 1,000 m wide, 7,100 m long and 100 m deep. The CID was deposited in the ancestral equivalents of Weeli Wolli Creek. This narrow, meandering palaeochannel is imbedded in the basement Weeli Wolli Formation.

Conceptually, three main hydro-stratigraphic units are recognised in the Proposal pit area. They comprise the relatively impermeable basement of the Weeli Wolli Formation, the overlying highly permeable fractured Palaeochannel Iron Ore deposit (CID), and the semi permeable floodplain alluvium of Weeli Wolli Creek. The CID ore body is divided into three main units based on mineralogy and chemistry: the upper ore zone (**GVU**); the lower ore zone (**GVL**); and material that forms the footwall waste zone of the orebody (**LGC**). The latter unit forms the major aquifer within the deposit due to the development of secondary fractures and cavities which are the target for dewatering bores (Figure 2-1). The high porosity and coarse pore spaces in the ore body allow it to drain freely.

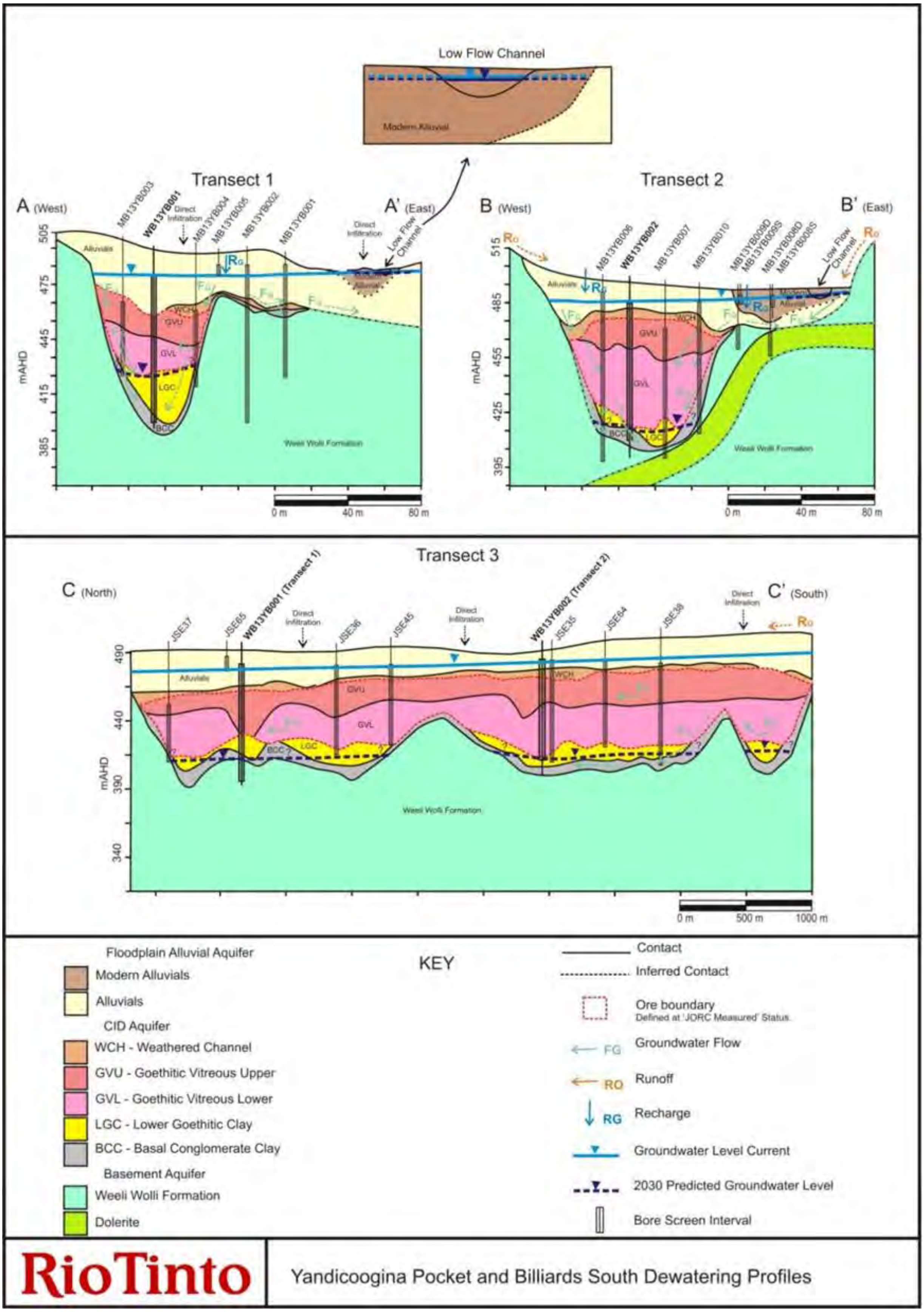

Figure 2-1: Cross-section showing hydro stratigraphic units for the Proposal

The location of Weeli Wolli Creek relative to the underlying and adjacent CID aquifer has a significant impact on the rate of surface water and groundwater exchange. The low flow channel of the creek is underlain by the CID at the southern section of the Pocket deposit and for the remainder of its 7,100 m length runs parallel to the Billiard South deposit (with up to 700 m offset) prior to the second crossing at the confluence of Weeli Wolli and Marillana Creeks (Figure 2-2).

The long process of erosion and weathering along Weeli Wolli Creek has had a significant effect on the hydraulic properties of the underlying basement and the ore body in terms of increased weathering and a subsequent increase in overall porosity. The impact of these processes on the hydraulic characteristics depends mainly on topography and local structural geology. Therefore, the degree of evolution and development of the fractured aquifer are not uniform throughout the CID. For example, areas that fall outside of the CID are characterised by fewer fractures and much lower porosity, and rarely contain groundwater (Reference 7). Hydraulic conductivity of the Weeli Wolli Formation is expected to be strongly influenced by the major structures. On a small scale, the Weeli Wolli Formation could appear to be impermeable and individual boreholes may yield little or no groundwater (Reference 10). However, on a larger scale, the major structures are expected to act as conduits for groundwater and may play a significant role in groundwater flow particularly at the section where Weeli Wolli Creek overlies the Billiard North deposit.

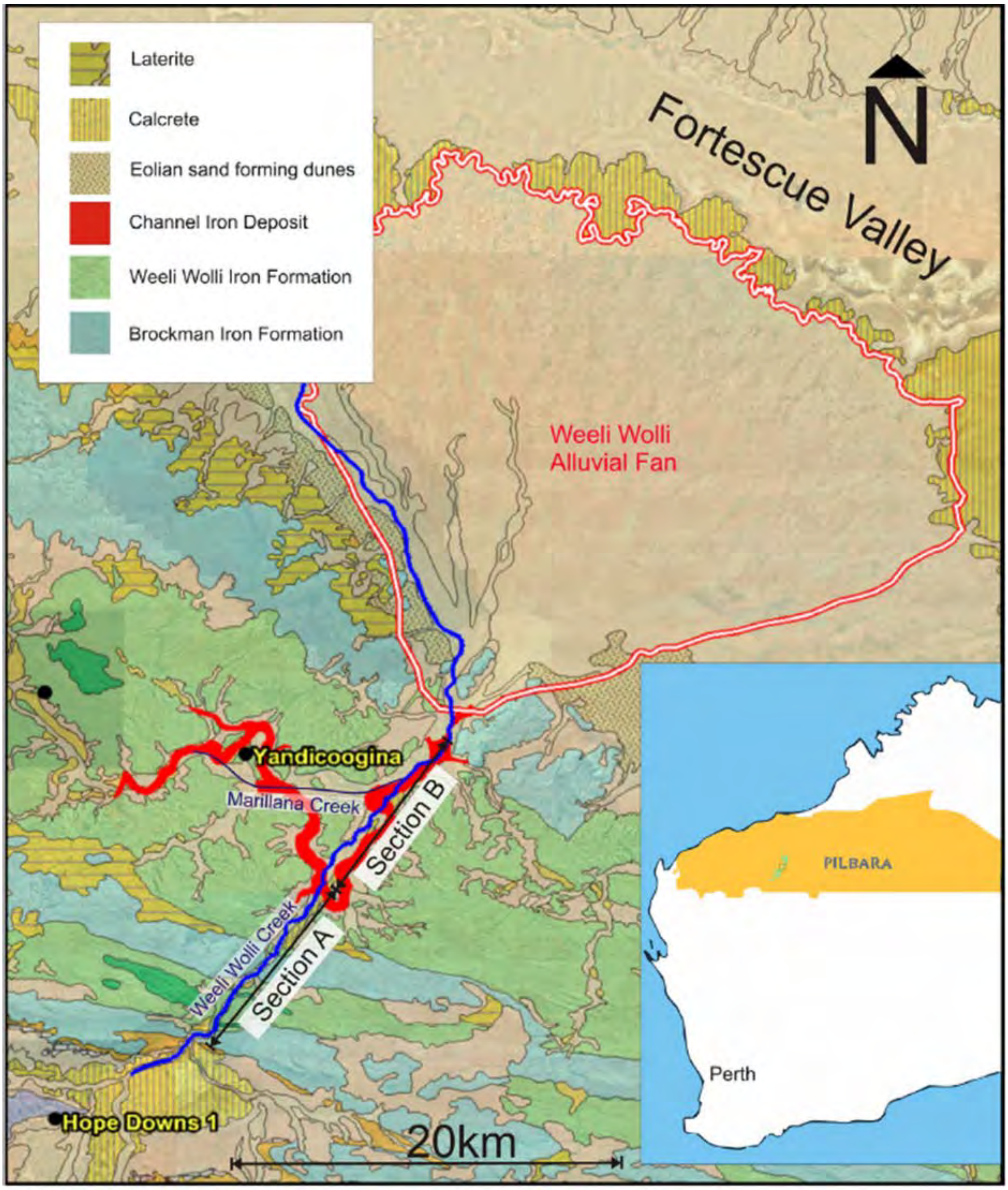

Figure 2-2: **Geological map showing the Weeli Wolli Creek System and the CID Aquifer relative to the Fortescue Marsh**

The CID is therefore postulated to be a heterogeneous aquifer exhibiting a variable permeability along its length, but overall increasing permeability with depth, related to secondary porosity developed in discrete zones formed by fractures, solution channels and cavity features. The development of solution features has largely superseded the primary porosity of the interstitial pore space. Permeability is generally lowest within the GVU zone and highest in sections of the GVL and LGC zone where large voids are often encountered. However the LGC is highly variable and may also exhibit very low permeability in clay zones (Reference 29).

The CID aquifer is invariably connected to the overlying/adjacent alluvial aquifer, along the creeks (Figure 2-2). The thickness of the floodplain alluvium estimated from the PFS drilling program (References 25) is between 6 and 24 m, with the greatest thickness occurring adjacent to the Weeli Wolli Creek. The thickness of alluvium increases downstream, reaching up to 80 m in thickness, 4 km down-gradient from Proposal area.

In general, the creek alluvium is comprised of inter-bedded layers of clays to sands and gravels to cobbles. The coarse alluvium of the low flow creek bed is highly conductive (K~ 1000 m/d), resulting in rapid recharge to the underlying alluvium during creek flows (Reference 8 & 6). These aquifers are only recharged during large flood events from Weeli Wolli Creek that occur following large or intense rainfall events > 20 mm (Reference 8). High water levels in the creek following rainfall events combined with flow outside the low flow channel results in direct infiltration to the floodplain alluvium and CID aquifer. This is evident from increased recharge during flood events (Reference 11) and enhanced recharge since 2007 due to permanent flow along the creek (Hope Downs 1 surplus mine water discharge). Recharge may also occur by groundwater inflow from the basement rocks where upward hydraulic gradients occur, however this has not been observed to date, likely owing to a focus on monitoring bore installation, primarily within the CID aquifer.

The regional hydraulic gradient and discharge of groundwater in the Proposal area is from a southwest to north-northeast direction towards Fortescue Marsh. Additional discharge from the CID occurs through evapotranspiration by phreatophytic vegetation in the creek alluvium.

3. FIELD INVESTIGATIONS

The 2015 hydrogeological drilling programme comprised the drilling of 21 investigation bores within the proposed Pocket and Billiard South pit and 57 piezometers (Figure 3-1) and included the installation of 10 monitoring bores in the Weeli Wolli Creek alluvium adjacent to riparian tree health monitoring sites. The drilling program was designed to investigate the interconnection between Weeli Wolli Creek, floodplain alluvium and the CID aquifer.

The previous 2013 drilling program comprised two transects and included an investigation bore (in the middle of the CID aquifer) and five (northern transect) and seven (southern transect) piezometers located between the bore and Weeli Wolli Creek. These transects were 2.2 km apart and aligned perpendicular to the CID strike.

The results of major dissolved ions analysis from monitoring and investigation bores sampled during well development show identical chemical composition of groundwater from alluvial and CID aquifers suggesting similar recharge processes and/or mixing between the two aquifers. However, the chloride (**Cl**) concentration results show an increasing trend in concentration from the investigation bore within the CID aquifer towards Weeli Wolli Creek. This is likely due to increased transpiration of recharge water by phreatophytic vegetation along Weeli Wolli Creek which results in an overall concentration increase without significant change in the chemical composition.

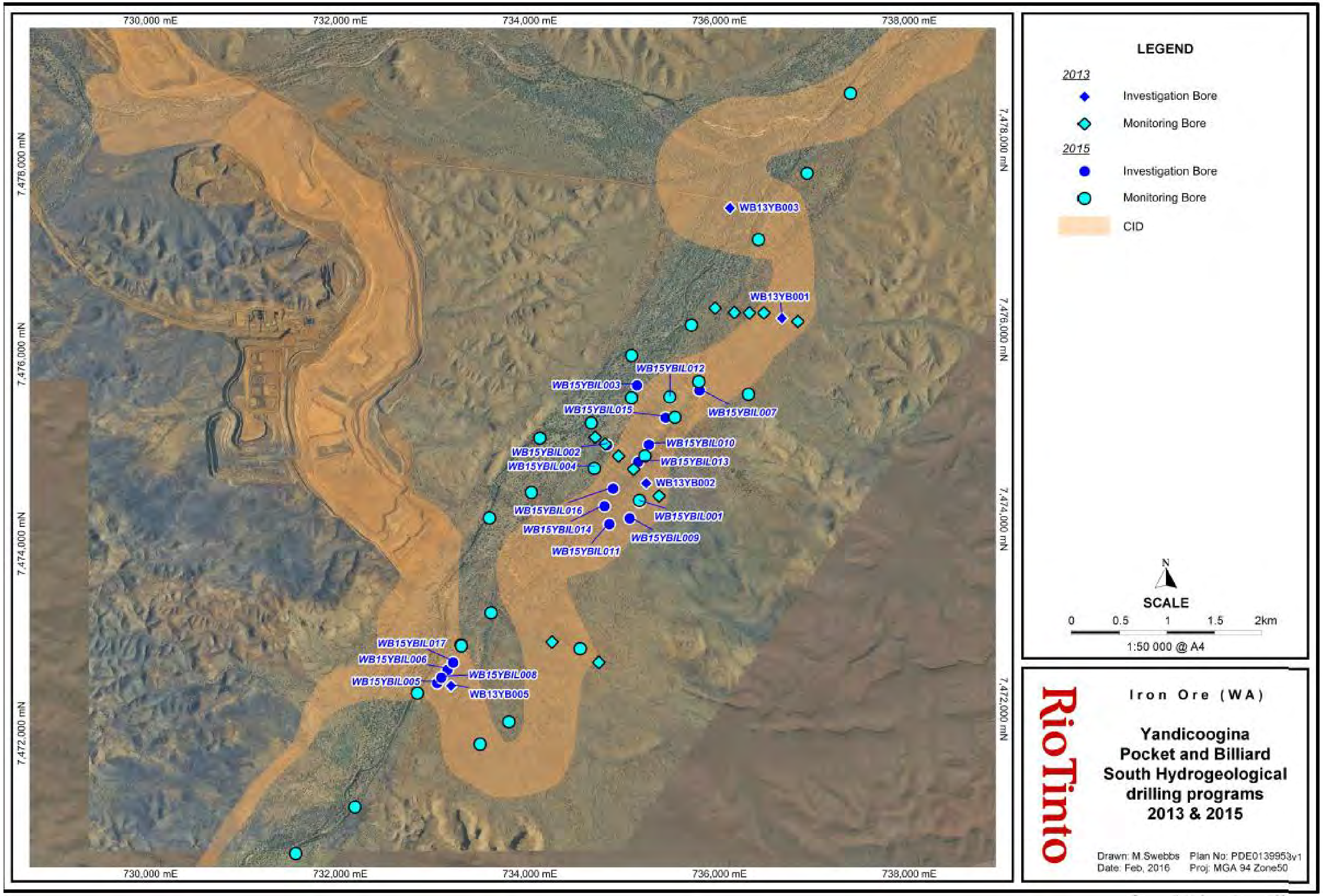

Figure 3-1: Yandicoogina Pocket and Billiard South Hydrogeological drilling programs 2013 & 2015

3.1 LONG-TERM TESTING PUMPING

A Long-Term Pumping Testing (**LTPT**) program was designed to subject the groundwater system to significant and prolonged stress, to simulate mine dewatering. The objectives of the LTPT program were to test: longitudinal heterogeneity; the influence of channel geometry on the propagation of drawdown; and to refine aquifer hydraulic parameters (i.e. hydraulic conductivity and porosity) as well as providing a better understanding of the connectivity between the alluvial and the CID aquifers.

The LTPT program was designed to pump two investigation bores on two transects installed during the prefeasibility study. Investigation bore WB13YB001 was pumped at 100 L/s for 28 days prior to commencing pumping from investigation bore WB13YB002 after which point they were pumped concurrently at rates of 100 L/s and 22 L/s, respectively, for 25 days (Reference 12). A network comprising 25 piezometers located over the entire length of the channel and alluvial aquifer adjacent to Weeli Wolli Creek were monitored for the duration of 53 days (Figure 3-2).

The result of the LTPT program suggests:

- The drawdown cone allowed calculation of a bulk specific yield of the Billiard south deposit as 17%. The average calculated hydraulic conductivity was ~60 m/d, higher than that calculated during the 12 day pumping test (35 m/d).

- The fivefold difference in constant pumping test rates highlights significant longitudinal hydraulic heterogeneity of the CID aquifer along the Billiard South deposit. This has implications for planning the relative locations of investigation bores to ensure abstraction from any bore is maximised and efficiently implemented.

- The hydrogeological logging of the two investigation bores shows a significant difference in the thickness of the LGC unit. WB13YB001 intersected 40 m of LGC whereas WB13YB002 intersected 10 m. Since this unit is characterised by a relatively high hydraulic conductivity it may influence the yields from each investigation bore. Therefore a more accurate spatial distribution of the thickness of LGC layer will be carried out during feasibility study to optimise the location of dewatering bore fields; and

- Pumping of WB13YB001 and WB13YB002 bores resulted in an elongated drawdown cone with the major axis propagating along the strike of the CID ore body both up gradient and down gradient of the channel due to the discharge boundary effects of the surrounding Weeli Wolli Formation that is characterised by a relatively low permeability. Unlike the JSW deposit, the rate of leakage from alluvial sediments along Weeli Wolli Creek floodplain is rather limited. The limited propagation of the drawdown cone into the alluvium aquifer, outside of the CID aquifer, suggests that mine dewatering may not have a significant impact on the water table under the low flow channel within the floodplain.

- Furthermore, the short term pumping testing (8 hours) of the 2015 drilling program that included 17 investigation bores suggests that the connection between the alluvial and CID aquifers is limited. Further field investigations are planned for the Feasibility study during 2016 to better understand the connectivity between the two relevant aquifers.

The extended duration test pumping contributed to an increased understanding in the overall behaviour of the system and greater confidence in the numbers obtained for the hydraulic parameters. Results from the LTPT suggest the Proposal can be dewatered more efficiently than previously anticipated albeit with a higher number of investigation bores, particularly at the southern section of the Proposal (Reference 25). The information derived from the programme will be used to update and validate parameters in the numerical groundwater model during the Feasibility Study. This will reduce the uncertainty associated with dewatering predictions.

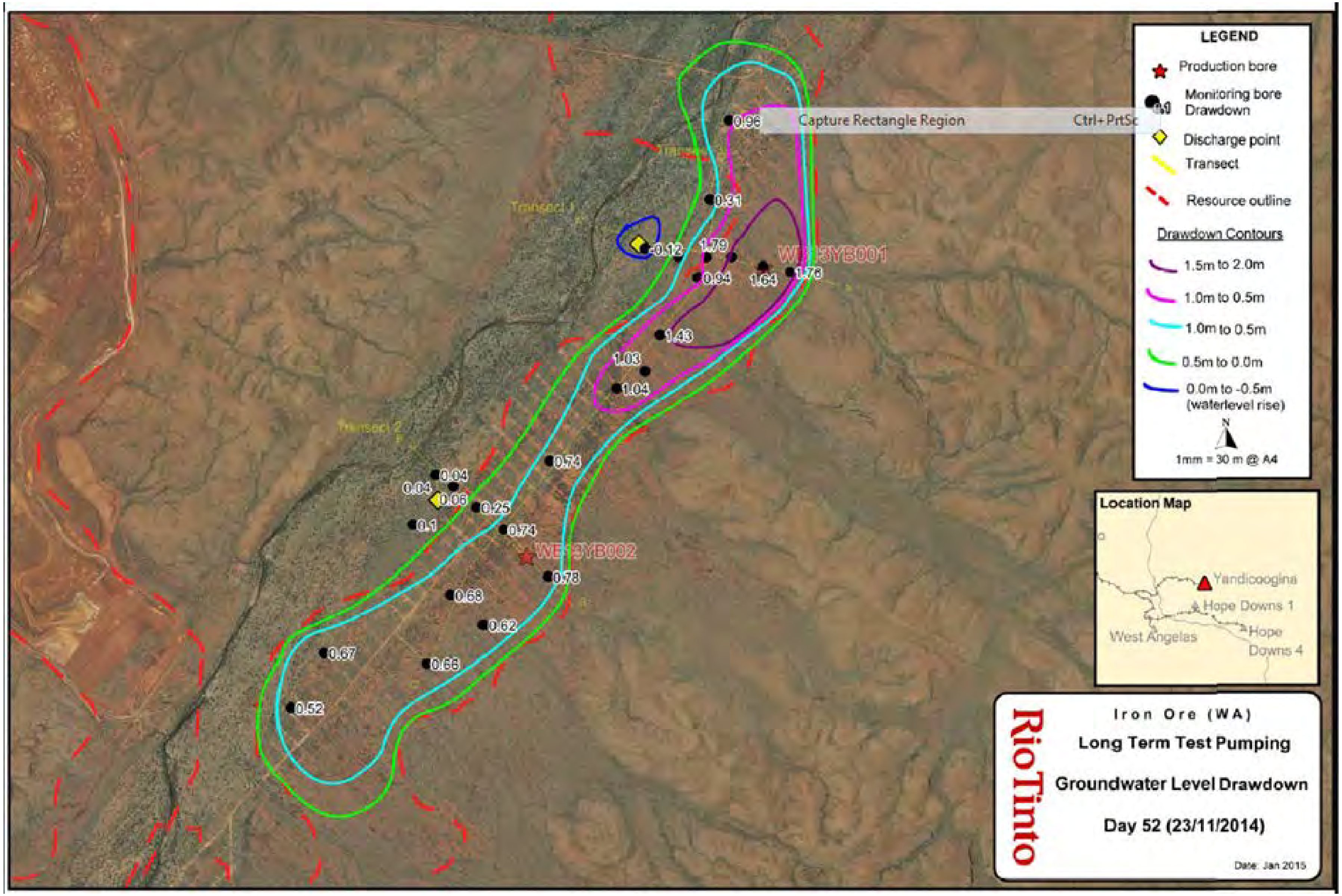

Figure 3-2: **Long term Test Pumping groundwater level Drawdown Day 52**

4. IMPACT OF DISCHARGE ON THE HYDROLOGIC REGIME

The continuous discharge of surplus mine water from HD1 into Weeli Wolli Creek may affect the hydrologic regime, by elevating groundwater levels (increased recharge) and altering the exchange rate between streams and underlying aquifers. However, it is unclear whether volumes of infiltrated water and recharge processes are within the range of natural variability. In order to determine the impact of discharge and leakage from Weeli Wolli Creek into the CID aquifer a detailed study was commenced in 2010.

Surface water samples were collected from twelve points (WW1–WW20) located at discreet intervals of 1 to 2.5 km downstream from the primary discharge location (HD1 discharge) along the creek, encompassing a total length of 24 km (Figure 4-1). In addition, groundwater samples were collected from monitoring bores along Weeli Wolli Creek at Billiard South deposit (Figure 4-1). The longitudinal extent of surface saturation along Weeli Wolli Creek has been recorded by ground-based field observations since February 2007 for a total of 83 observations, whilst discharge rates to the creek have been recorded monthly at discharge points DP1 and DP2 (Reference 6).

The major finding of the study suggests that the impact of recharge from continuous flow (due to discharge into the creek at HD1 mining operation since 2007) on the hydrologic regime of the creek has not extended beyond 27 km from the HD1 discharge point. It was concluded that although more than 220 GL of mine water discharge since 2007 has changed the nature of the connectedness of Weeli Wolli Creek to the underlying aquifer in the upper section, associated with the impermeable Weeli Wolli Formation, there has been negligible impact on the overall hydrologic regime of the broader catchment. Most of the recharge to the groundwater aquifer along Weeli Wolli Creek occurs where the creek flows adjacent to or across the CID aquifer.

The calculated rates of recharge as a result of continuous discharge from HD1 are also commensurate with those from large flooding events that occur in the region every few years (Reference 6). Changes in surface water connectivity and sustained periods of saturation may nevertheless have localised and probably relatively short-term impacts (until the next flood) on the ecology of streams. However, the importance of no or low (surface) flow periods in ephemeral streams to overall stream functioning (from an eco-hydrological perspective) is largely unknown as most studies of the eco-hydrological impacts of altered flows in the Pilbara have focused on reduced rather than increased flows associated with drawdown. By increasing the understanding of the overall hydrologic regime show that management of artificial discharge to ephemeral creeks in dryland environments, at least from the volume of discharge perspective, can be optimised if there is high storage capacity in the underlying aquifer.

The results of this study also suggest that the storage capacity of the CID and underlying aquifers are much larger at the mouth of Weeli Wolli Creek draining into Fortescue Valley. This study also shows that the total dissolved solutes (**TDS**) and chloride (**Cl**) concentrations remained relatively constant (Cl ~40 mg/L) since 1998. The only source of Cl in groundwater in the CID aquifer is recharge from rainfall and more importantly during flooding events (~40 mg/L Cl; Reference 8). As the concentration of Cl in surface water in Weeli Wolli Creek ranges from 70 mg/l to 130 mg/l and much higher than that in the CID under the Billiard North area, it is anticipated that groundwater in the CID would have similar Cl concentration to that of surface water due to recharge of 220 GL of surface water into the CID. However the nearly constant Cl concentration in the Billiard North CID aquifer, which is the conduit for groundwater flow, suggests the dominance of recharge from rainfall and flooding compared to influence from surplus mine water discharge at both Yandi and Hope Downs 1 mining operations.

Therefore, it has been hypothesised (Reference 6) that the aquifer storage capacity at the mouth of Weeli Wolli Creek (alluvial fan), 4 km down gradient from the Proposal area, is many times larger than 220 GL. The development of a new numerical model is proposed for the Feasibility Study that accounts for the change in hydraulics and better explains why discharge into Weeli Wolli Creek has little impact on the overall water balance of the CID aquifer at the outlet to the Fortescue Marsh.

This model will be based on the assumption that the storage capacity of the aquifer will increase dramatically (> ten-fold) at the mouth of Weeli Wolli Creek compared to the upper part of the CID at Billiards South. In this section the formation underlying the CID comprises fractured and mineralised Brockman Iron Formation (cross-section C–C', Figure 4-2) that is characterised by a higher transmissivity compared to the Weeli Wolli Formation and un-mineralised Brockman Iron Formation underlying the upper part of the catchment (cross-section B–B', Figure 4-2). As the volume of water recharging the aquifer is insignificant compared with the volume of groundwater storage, a change in Cl concentration is not observed.

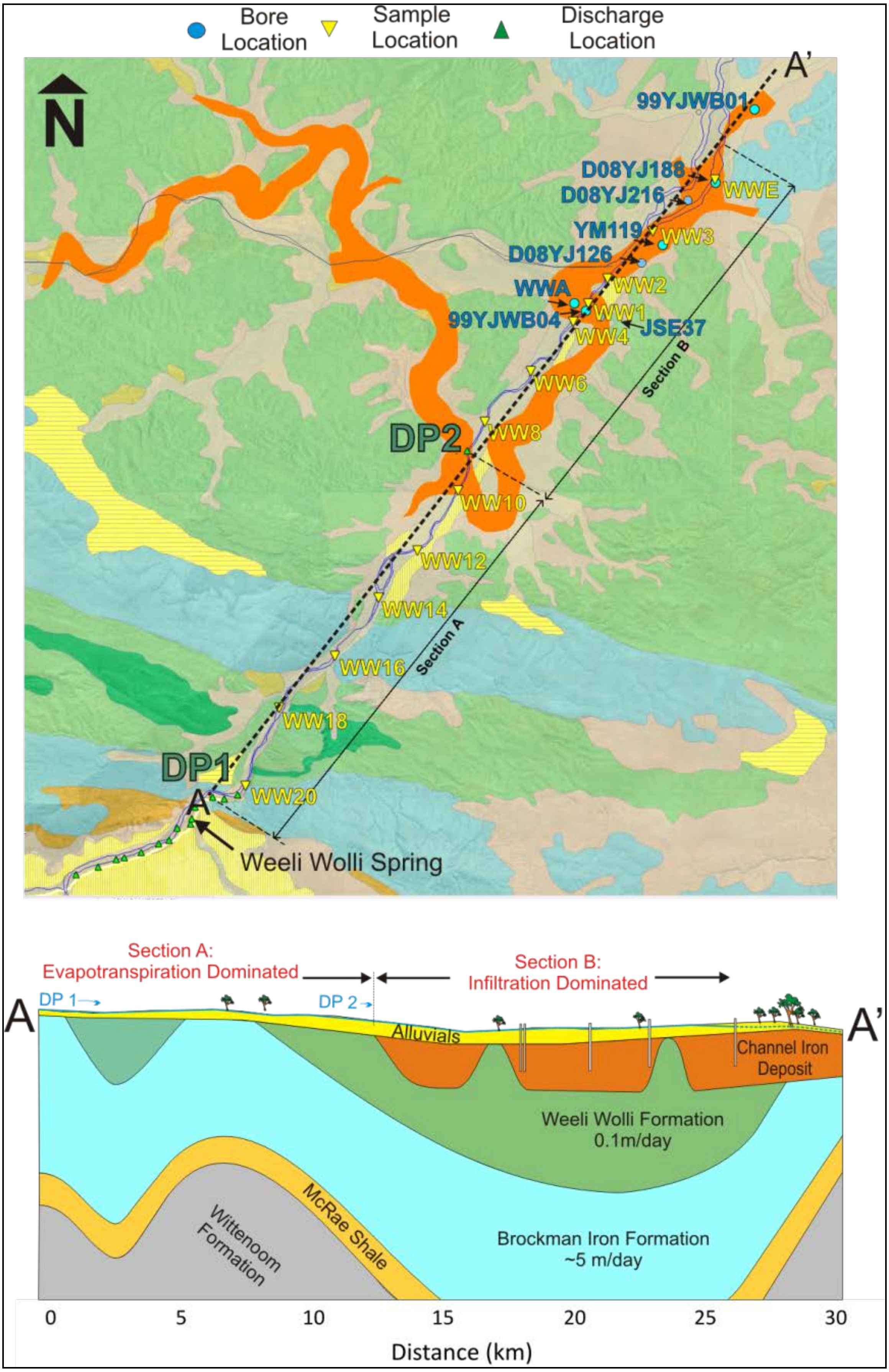

Figure 4-1: **The Weeli Wolli Creek study area sample points, nearby groundwater bores and discharge location**

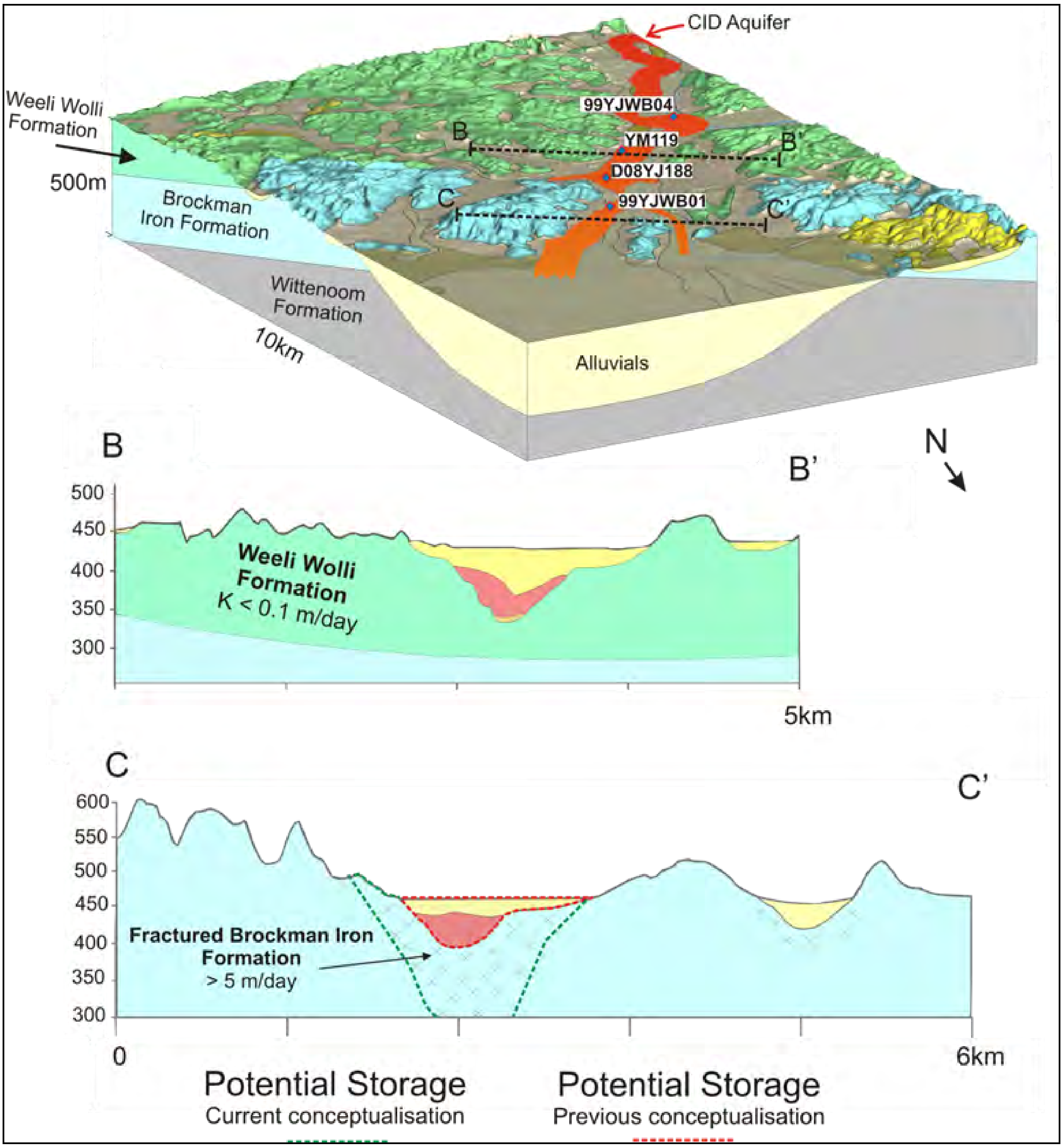

Figure 4-2: 3D geology of the mouth of Weeli Wolli Creek where it meets the Fortescue Valley

Figure 4-2 illustrates the variation in hydrogeology and the resultant increase in potential groundwater storage. The two transects highlight the difference between the previous conceptual models that were characterised by relatively much smaller groundwater storage compared to the new hypothesised model proposed by this study.

5. CUMULATIVE IMPACTS OF SURPLUS MINE WATER MANAGEMENT ON FORETESCUE MARSH

UUnderstanding the impact of water management along Weeli Wolli Creek, which is a major tributary of the Fortescue Marsh, is a requirement for predicting and managing the potential environmental impacts as a consequence of developing the Proposal. In order to address this, a major collaborative investigation was initiated by the Proponent and the University of Western Australia (**UWA**) in 2011 to understand the hydrological history as well as water quality and quantity of surface and groundwater of Fortescue Marsh.

Fortescue Marsh is the terminus for surface water and groundwater from the Marillana and Weeli Wolli Creek catchments; therefore change in the water budget in this catchment due to mine operations may have an impact on the Marsh water balance. The Marsh occupies a trough between the Chichester and Hamersley ranges and occurs at a mid-section of the Fortescue River (Figure 5-1). The Fortescue River is approximately 760 km long, rising 30 km south of the town of Newman. The Fortescue River drains a 30,000 km^2 catchment of the Hamersley Basin and contiguously flows only following large flood events.

Physiographically, the river is divided into two sections; the Upper Fortescue River (**UFR**) is separated from the Lower Fortescue River (**LFR**) by the Goodiadarrie Hills (Figure 5-1). The LFR drains in a westerly direction towards the coast, whereas east of the hills the Fortescue Marsh receives drainage from the UFR.

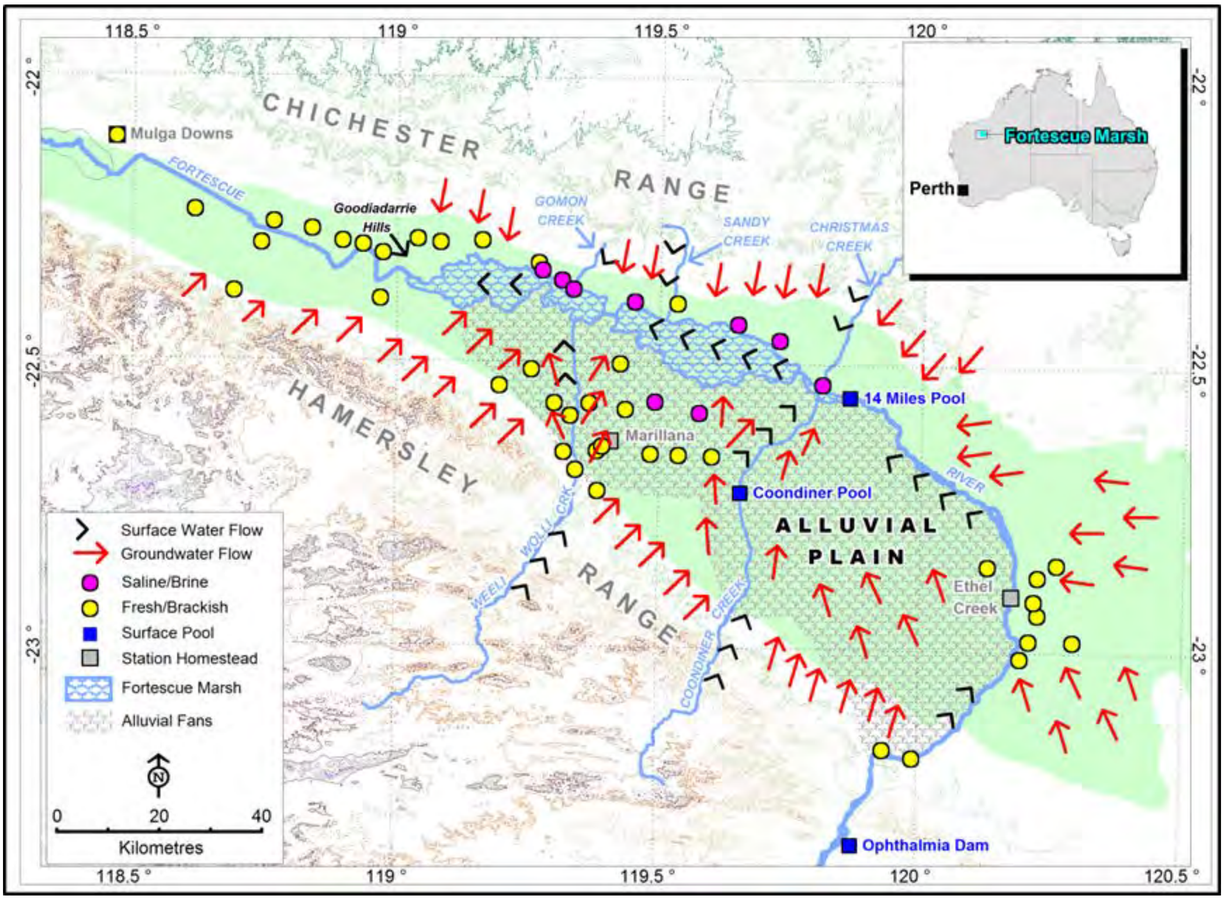

Figure 5-1: Major drainage pathways in the Proposal area

The hydraulic gradient, between Ophthalmia Dam and Goodiadarrie Hills ~100 m/180 km and 14 Miles Pool and Goodiadarrie Hills is close to zero (~1 m/90 km). The hydraulic conductivity is also low 0.1-1.0 m/year

The findings of this collaborative study reveal new insights into the functioning of this large inland wetland. The hydrology of the Fortescue Marsh is fundamentally driven by infrequent large rainfall events. Recharge occurs during these events from the alluvium to the underlying aquifers. The highly saline nature of groundwater coupled with a low hydraulic gradient suggests that horizontal groundwater flows are very slow (< 5.0 m/year). The chemical and isotopic signatures of groundwater under the marsh suggest the dominance of vertical flow processes (Reference 27).

The chemical characteristics of surface water and groundwater allowed decoupling of water and salt evolution in groundwater over time. With the exception of deep brine groundwater under the Fortescue Marsh, most of the groundwater reflects modern recharge. However, the salt inventory reflects accumulation of salt over millennia. The Cl mass balance calculations suggest between 40,000 and 700,000 years would be required to accumulate the observed salt load in the Fortescue Marsh (Reference 27 and 7).

A study to identify the chemical evolution of groundwater and surface water across the Hamersley Basin using strontium and oxygen isotopes as tracer shows that the geochemical composition of deep groundwater of the terminal Fortescue Marsh represents the ultimate geochemical signature, reflecting mixing between major ions sourced primarily from flood water with a minor amount of ions derived from weathering of the basin rock (Reference 7).

6. GROUNDWATER MODEL

6.1 GENERAL

As the Billiards South ore body is approximately 99% below water table, extensive dewatering is required to draw the water level below the pit floor; some 60 m to 80 m below natural surface. A numerical groundwater model was developed for the Proposal pre-feasibility study. It is a regional model designed to estimate the dewatering requirements for the whole of the Yandicoogina operations mine site, including the Oxbow, JSW JC and JSE pits together with the Pocket and Billiard South pits (Reference 34). The model was independently reviewed by Hydrogeologic Pty. Ltd. based on the 2012 Australian Groundwater Modelling Guidelines (Reference 35). The review finds that a Class 2 model confidence level classification has been achieved; therefore it is suitable for mining project impact prediction purposes.

6.2 RECIRCULATION

A number of water sources will contribute to significant recirculation of water when developing and dewatering the Proposal. To better understand the contribution of the various water sources and their impact on the dewatering requirements for the Proposal, the mine plan and associated dewatering model (Figure 6-1) was rerun to examine its sensitivity to the following sources:

- HD1 discharge down Weeli Wolli Creek (Figure 6-2); and
- Pumping at JSE pit (Figure 6-3).

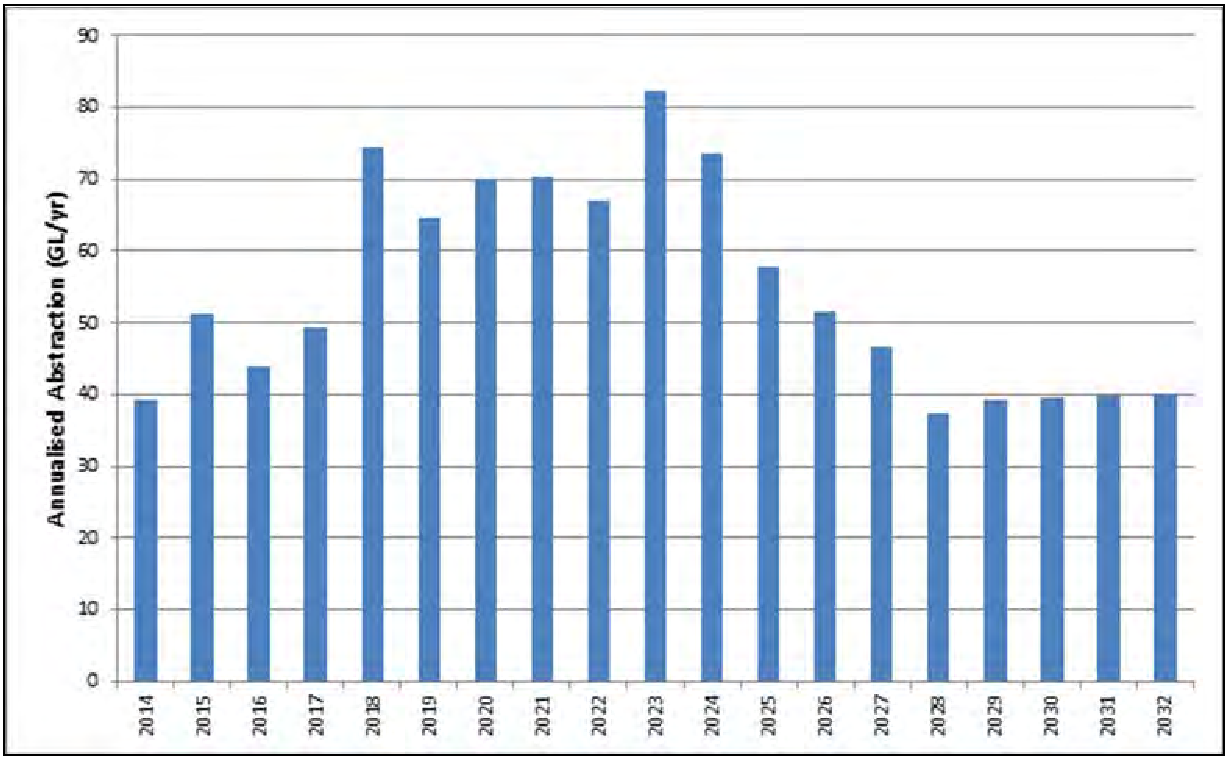

Figure 6-1: Total Yandicoogina Operations Dewatering requirements

The model was most sensitive to the HD1 discharge. The removal of the HD1 discharge from the model reduced the dewatering peak from 80GL/a to 69 GL/a (based on the A2 mine stage model), with only two annual peaks around 60GL/a or above (Figure 6-2).

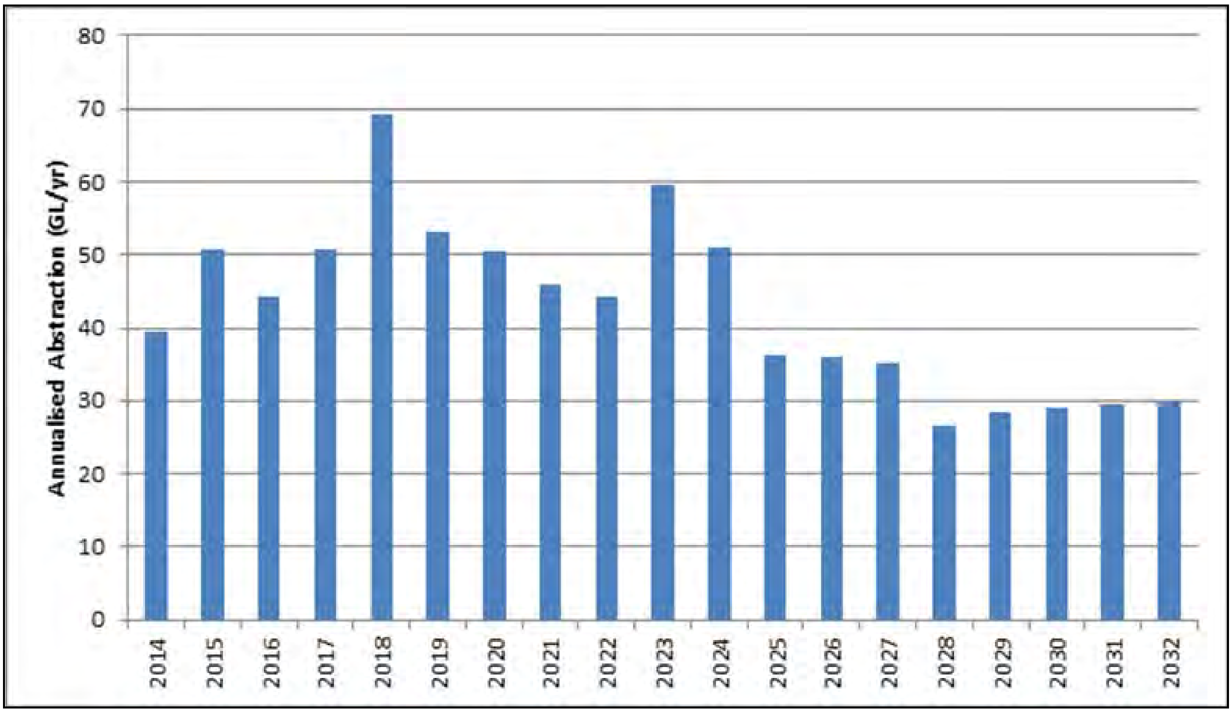

Figure 6-2: **Predicted dewatering requirements for the Proposal with no discharge from HD1 flowing in Weeli Wolli Creek**

Cessation of dewatering at JSE would result in a reduction in annual peak from 82 GL/a to 77GL/a (based on the A4 mine schedule) (Figure 6-3).

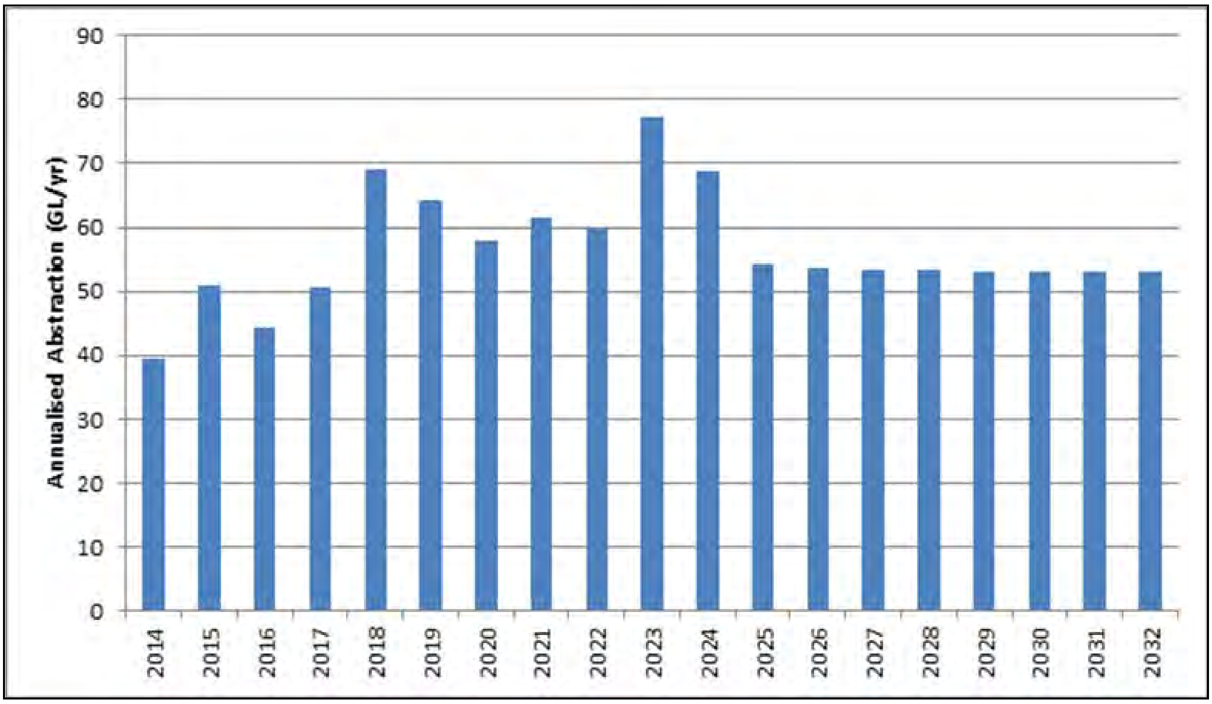

Figure 6-3: **Predicted dewatering requirements for the Proposal with no pumping occurring in JSE**

The A30B mine plan results in a peak water abstraction from the Proposal of ~ 50 GL/year in 2022 (Figure 6-4) and a peak total Yandicoogina Operations Abstraction of 75 GL/year in 2018 (Figure 6-5). The current hydrogeological investigation and lessons learnt from historical mining operation data for JC, JSE and JSW were used to select dewatering sites in Billiard South.

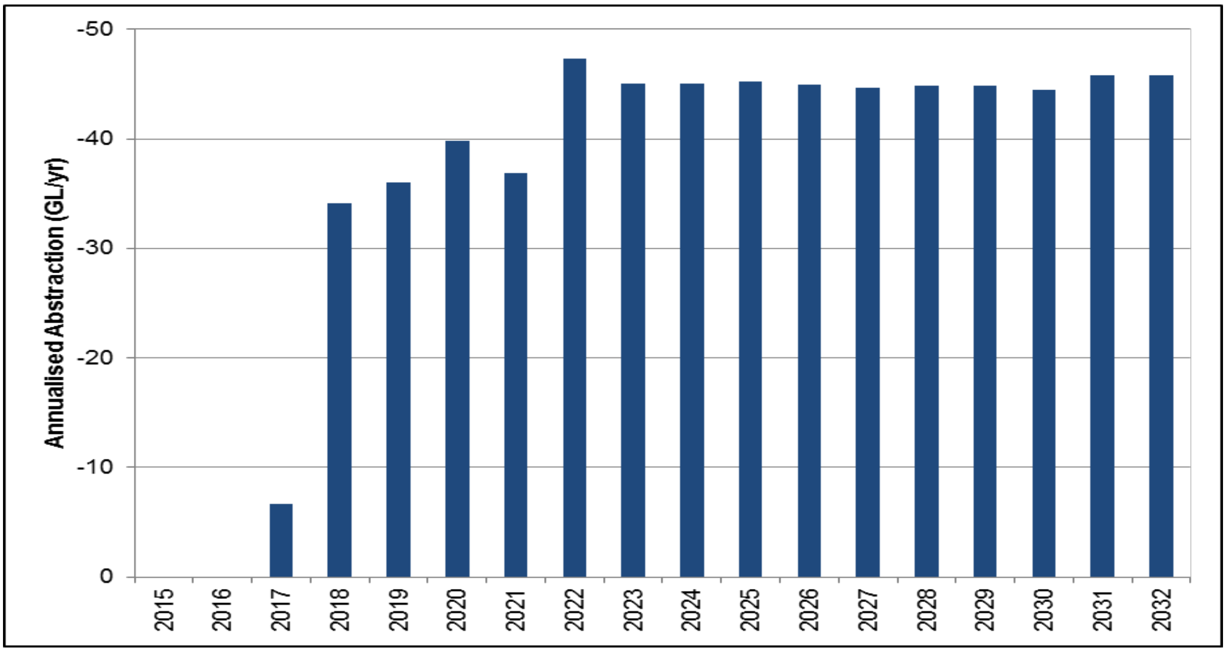

Figure 6-4: Predicted life of mine abstraction rates for the Proposal

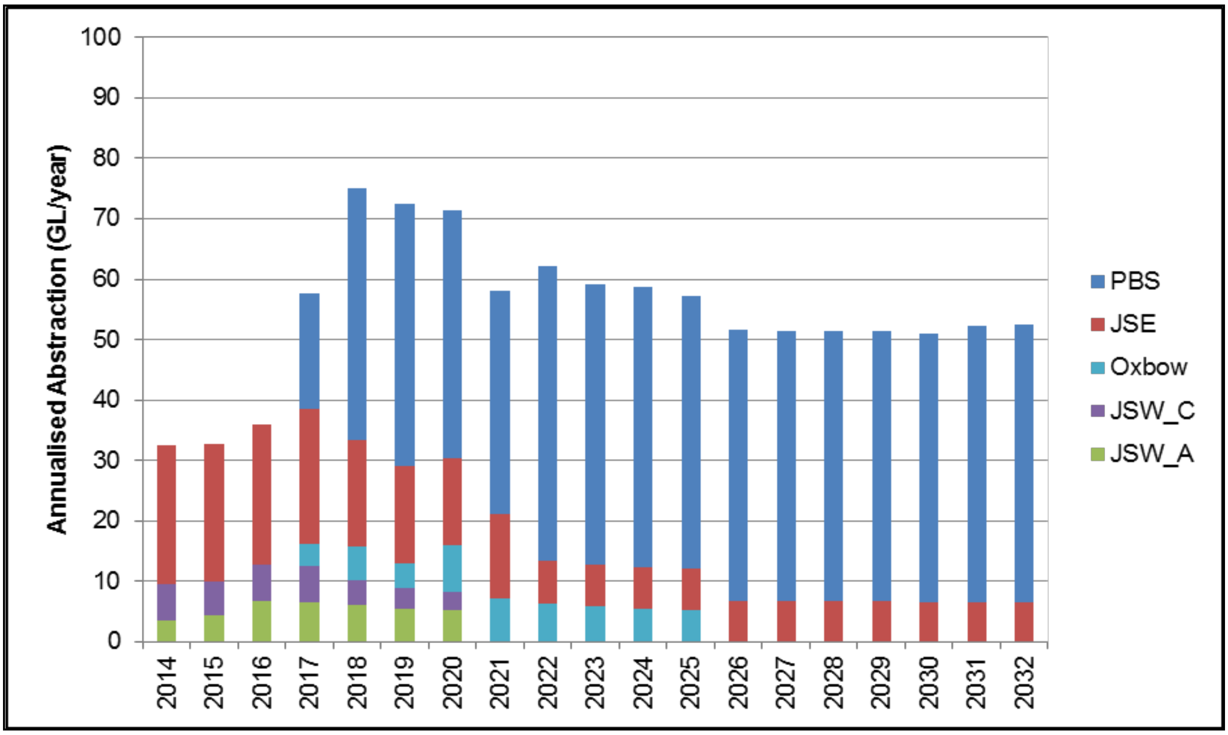

Figure 6-5: Predicted Total Yandicoogina Operations Dewatering requirements (by pit)

7. CONCEPTUALISATION OF FLOODPLAIN ECOLOGICAL REGIME

In the baseline settings, the riparian zones on Weeli Wolli Creek were interpreted to be predominantly dependent on surface water and pore water derived from direct rainfall, overland flow and episodic stream flow events (Reference 31). Depths to the water table from bores in the CID range from 12 to 20 m below ground level (**bgl**) likely provided low groundwater dependency.

Since about 1997, the disposal of surplus groundwater into Weeli Wolli Creek increased the water availability. The increase was reflected in the presence of perennial stream flow and mounding of the water table to comparatively shallow depths. The changed surface water and groundwater environments provided potential for increased groundwater use (medium dependency) within the riparian zone, commensurate with reduced surface water and pore water dependencies. Decay of water availability to the riparian zones would be inevitable once the disposal of surplus groundwater ceases or is substantially reduced.

The proposed mining at Billiard South would impose further changes to the water availability on Weeli Wolli Creek. Perennial stream flow in the low-flow channel and opportunities for flooding of adjacent riparian zones would be largely undisturbed. Dewatering of the proposed pit would, however, substantially lower the water table with an excessive rate of decline. Ultimately the water table would be lowered to below baseline elevations, with associated potential deficits in the available water and declines in potentials for groundwater dependency.

Contextually, the water availability risks to the riparian zone would predominantly have aspects that reflect the adaptability of riparian floristics:

- In drawing from alternative sources when groundwater availability is reduced by 23 to 27 percent from current scenarios.
- Reverting to baseline dependencies on surface water and pore water.
- To net reductions of about 10 per cent in total water availability.

Environmental water reliance of the riparian zone along Weeli Wooli Creek encompasses the following:

- Retention of perennial surface water flows, at least initially.
- Limiting changes to periods of high floodwater.
- Limiting changes to groundwater level.

Development of the Proposal will have limited impact on the initial two requirements; however groundwater level will be significantly lowered during mining. Under these conditions only the true groundwater dependent riparian floristics will experience water availability stress due to drought-like conditions. The percentage scale of the changes in the water availability has been used to define potential risks to the Riparian Zone and is further detailed in Reference 38.

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