

Yandicoogina Water Balance; Pre and Post Mining Hydraulics and Hydrochemistry

Author/s: Glenn Kirkpatrick, Shawan Dogramaci

Reviewed By: Wade Dodson

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EXECUTIVE SUMMARY

The groundwater elevations for the period 1974 - 2009 and hydrochemical composition of the groundwater from the CID and alluvium aquifers, and surface water of the Marillana and Weeli Wolli Creeks were analysed. The results suggest that the response of the groundwater in the CID aquifer in terms of water level rise to natural processes such as recharge from intense rainfall events over short periods of time has been much higher than the response to human induced disturbance due to mining. The estimated recharge volume calculated from water table rise after rainfall events can be as high as 30 GL per event over a 25 km length of Marillana Creek which is comparable to annual dewatering discharge volume from RTIO and BHPB Yandicoogina mining operations.

The groundwater level response to changes in the water budget due to natural and human induced processes is immediate, highlighting the connection between various aquifers and creek systems. The water level drawdown and change extends 12 km downstream from the mining area of Junction Central and beyond this point the water table elevation has remained stable since observations started in 1999. This suggests the induced change due to the Yandicoogina mining operation extends 12 km from the centre of mining at Junction Central.

The Cl concentration record and results from recent groundwater and surface water sampling programs of CID aquifer and Marillana and Weeli Wolli Creeks show that 20% of the discharge water to the creeks had been lost by evaporation and evapotranspiration. The remaining 80% of the discharge has leaked into the underlying alluvium and CID aquifers. As a result the salinity of the CID has increased by 20% due to evapoconcentration of surface water and the subsequent leakage and mixing with the CID aquifer.

The 20% increase in Cl concentration however is limited to the 12 km down gradient from Junction Central, beyond which no increase in Cl concentration is observed. The Cl concentration of CID groundwater beyond this point is ~65% less (45 mg/l) than that measured up gradient at JSE (150 mg/l) and JC (120 mg/l) suggesting a strong influence of mixing with much fresher surface water (i.e. recharge from intense rainfall events that is characterised by very low Cl concentration). This suggests the groundwater system of the CID adjacent to the Weeli Wolli Creek is dominated by surface water recharge from intense rainfall events rather than groundwater through flow.

Despite the conclusive evidence that the mine operation has only limited impact on the downstream environment in terms of water quality and quantity, the strategy to discharge water in the creek up gradient of open pit mining areas has significant practical impact. The up to 80% leakage of the surface water to the underlying aquifers and subsequently to mining pits means constant recycling of water, wasting energy and resources. The recommendation from this study is that it is imperative to relocate all Rio Tinto and BHP Billiton discharge outlets along the Marillana Creek down gradient of open pit mining areas. This will significantly reduce the dewatering volume required to achieve dry mining conditions and enable mine plan targets to be met in a timely fashion.

1. INTRODUCTION

There have been various hydrogeological investigations throughout the Yandicoogina lease since 1978. These studies emphasize that conceptually the Channel Iron Deposit (CID) is incised into the basement Weeli Wolli Formation and overlain by a thin veneer of alluvials. Higher permeability is related to secondary porosity in the CID and alluvium underlying Marillana and Weeli Wolli Creek beds. The surrounding basement is considered impermeable except in localised areas resulting from fractures. Recharge occurs in the creek systems from high intensity rainfall events where creeks cross the palaeochannel.

The discharge of surplus mine water from dewatering of BHP Billiton's (BHPB) Yandi, Rio Tinto Iron Ore's (RTIO) Yandicoogina and Rio Tinto's JV Hope Downs 1 mine operation, into Marillana and Weeli Wolli Creeks have increased over two folds since their inceptions. The permanent flow from continuous discharge to these creeks resulted in an increased potential for down gradient leakage into the underlying aquifers. This is particularly true where the creeks cross or flow adjacent to the CID. The increased gradient between creek water levels and underlying groundwater in mine voids also caused a significant increase in leakage into the CID aquifer. The quantification of the leakage rate between the creek and surrounding aquifers is therefore essential in updating the groundwater balance, taking into account the updated hydrogeological setting and the groundwater-surface water interaction that has been impacted by mining operations.

In addition to the conventional groundwater level data and hydraulic parameter estimation from pumping test programs, hydrochemical data was used in this report to identify the long term impact of mining operations on groundwater quality in the CID aquifer. Hydrochemical composition of groundwater from different aquifers can provide additional information on the evapoconcentration of water prior and/or during recharge, groundwater/surface water as well as aquifer material and groundwater interactions. This information ultimately can be used to refine the conceptual hydrogeological model. The combination of conventional hydrogeological and hydrochemical models is an effective tool for the construction of reliable numerical groundwater models that can be used for mine water management planning.

In addition to general geochemical processes, groundwater surface water mixing specifically at the Yandicoogina mine site has an important role in modifying groundwater chemistry. This is particularly true for the period starting in 1991 where BHP Billiton's Yandi mine dewatering commenced and the surplus water discharged into Marillana Creek flows adjacent to the CID aquifer of the RTIO Yandicoogina mine operation.

The major ion analysis of groundwater from CID, alluvium and bedrock aquifers has been carried out intermittently since the commencement of BHP Billiton's Yandi mining operation in 1991. More frequent sampling and analysis were carried out after the start of Rio Tinto mining operations in 1998. The RTIO EnviroSys data base contains hydrochemical records from 759 bores located at RTIO Yandicoogina mine operation. Most of the major ion concentration record is captured since 2000.

Furthermore, understanding the pre and post mining water balance of the main aquifers, associated groundwater levels estimations and change in chemical composition of groundwater since mining commenced are essential data sets in putting forward a closure plan for RTIO Yandicoogina mining operation. This is important because it will provide critical information for understanding the time required for the water quality and quantity to recover after mining operations cease.

The objectives of this study are therefore to;

- Define the pre mining and current groundwater conditions and hence impacts from mining operations on the flow system
- Determine the importance of creek seepage into the CID aquifer and mine pits
- Present a conceptual hydrogeological model for optimising Yandicoogina wide dewatering planning
- Present data that can be used in closure planning in terms of water quality and quantity.

2. LOCATION AND SETTING

The RTIO Yandicoogina mine site is located approximately 85km northwest of Newman and 145km east of Tom Price in the Central Pilbara. The 54km Yandicoogina access road is 135km northwest of Newman on the Great Northern Highway. Of the existing open pit mines, Junction Central (JC) commenced in 1998 and Junction South East (JSE) commenced in 2006. These sites are located upstream of the intersection of Marillana Creek and Weeli Wolli Creek within the Weeli Wolli regional catchment. The life of mine plan for the RTIO operation includes mining of additional deposits both up gradient and down gradient of existing open pits. In addition to the existing pits; this study covers three proposed new pits namely; Oxbow, Junction South West (JSW), and Billiard. The focus of the study is the whole of lease, from the up gradient western Oxbow through to the down gradient north-eastern Billiard deposits (Fig. 1).

The operations mine a CID, which forms a major aquifer in the area with approximately 80% of the ore body situated below the natural water table. The deposits are positioned adjacent to current creek systems, with sections underlain by the creek bed itself. The creeks are prone to periodic, short term flooding each wet season from November to April.

The Marillana Creek catchment originates 20km to the east of the Great Northern Highway, and runs predominately east-west draining into the Weeli Wolli Creek system downstream of RTIO's Yandicoogina mine operations. The Marillana Creek system has a total catchment area of 2,230km². The headwaters rise from the high relief areas of Hamersley Range where the surface water drains in an east and north easterly direction into the Munjina Claypan. The Claypan, an internally draining basin, has a total area of approximately 274km². It is subject to periodic inundation following rainfall events and has the potential to retain surface water flows for lower flood events, ≤ 1 in 10 year annual recurrence interval (ARI). Surface water flows that exceed the internal holding capacity of the basin will spill south east and return into Marillana Creek proper. The Lower Marillana Creek drains in an easterly direction through the existing BHPB Yandi and RTIO Yandicoogina operations. It continues its path downstream onto wide, flat plains before discharging into Weeli Wolli Creek. Major tributaries of the Marillana Creek catchment include Lamb Creek, Phil's Creek and Yandicoogina Creek. As for most parts of the Pilbara, the normal condition for these watercourses is dry. Runoff is ephemeral, occurring only after significant and intense rainfall events.

The Yandicoogina CID is located within the Marillana Creek regional catchment and occurs within a broad structural basin of the Yandicoogina Syncline, formed by synclinal folding of the Lower Proterozoic Brockman Iron Formation, which is conformably overlain by the Weeli Wolli Formation. The total length of the CID is over 80km, but within the RTIO lease it is 42km long, approximately 500m wide and average thickness of 60m. The CID is located in the central part of a broad, east-trending drainage basin with the Hamersley Range to the north and an unnamed range to the south (PPK, 1998). The CID, where it outcrops as a result of recent dissection from modern day drainages, forms a series of characteristic

'mesas' which are generally orientated with the present day drainage, with surface gradients of 1.5m/km along the axis of the basin (PPK, 1998).

Marillana Creek contains one flow gauging station, Flat Rocks (WRC number 708001), located approximately 27 km west of the current Yandicoogina mining operations. Daily flow data for the gauging station were available for the period August 1967 to May 2008, with occasional missing data. Weeli Wolli Creek has the Tarina flow gauging station (WRC number 708014) upstream of RTIO's Yandicoogina operations and the confluence with Marillana Creek. This site is actively monitored by DoW and data is available from 1985 to the present.

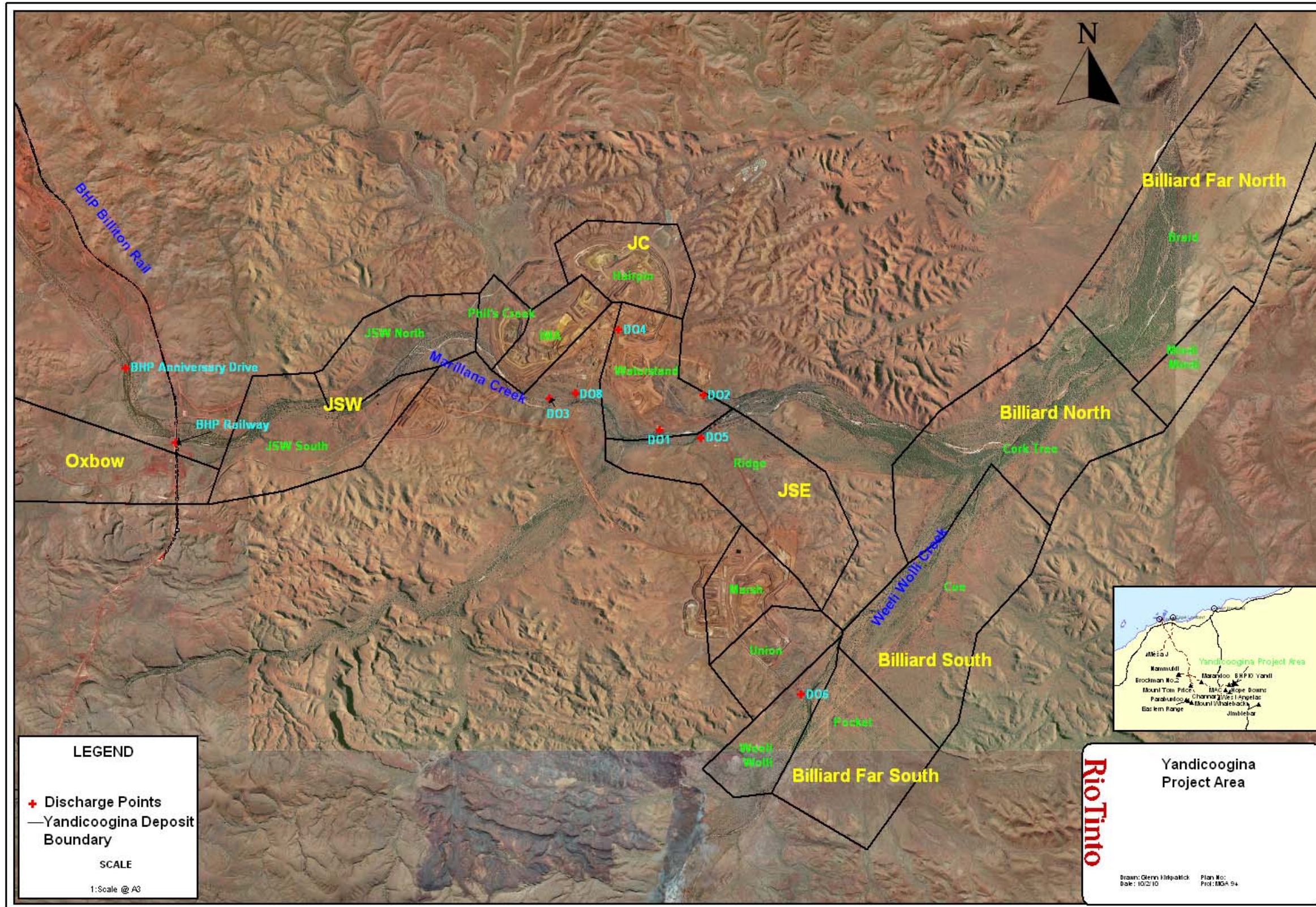


Figure 1. Location of Yandicoogina mine and project areas.

3. CLIMATE

The climate of the Yandicoogina area is classified as semi arid with hot, wet summers from October to April and mild winters from May to September. Rainfall occurs from the two climatic systems with the larger quantity precipitating in the summer months from tropical systems, and moderate falls from low pressure systems in winter.

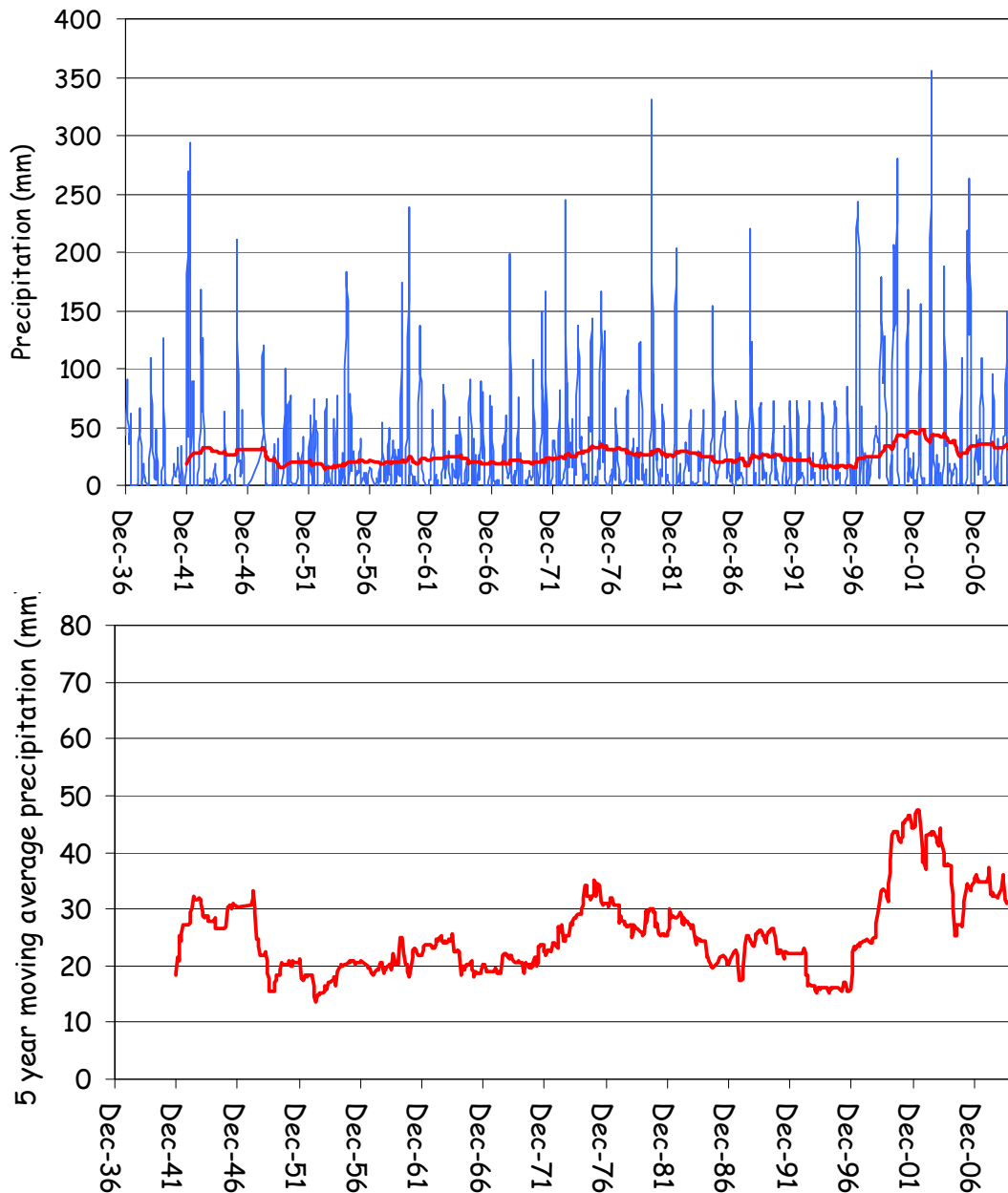


Figure 2. Monthly precipitation record for Marillana weather station 1936 to 2009. The five year moving average highlights the higher than average rainfall since 1996.

Climatic data was obtained from five weather stations that surround the Yandicoogina mine operation. These include Flat Rocks Weather Station located 40 km east, Marillana Station 20 km south, Wittenoom Station 69 km northeast, Newman Station 60 km southeast, and Yandicoogina Weather Station at the mine site. The data from the stations were combined to complete the rainfall record since 1936.

Rainfall data taken from the Marillana Weather Station which had the longest record was used in this report (Fig. 2). The record indicates that most precipitation falls in the wet season from either intense cyclonic or thunderstorm activities during the summer months. Approximately 85% of the annual rainfall occurs in summer months. The largest single rainfall event recorded, in December 2002, resulted from a cyclone with approximately 400mm.

The long term record shows a relatively higher rate of rainfall compared to mean rainfall in the last decade particularly since 1999. The rainfall record for 1995 and 2006 period includes five large scale cyclones. The five year moving average clearly shows an increasing trend since 1996 reaching a maximum in 2001. Accumulative moving average suggests rainfall excess particularly after 1999 which coincide with the commencement of Rio Tinto operations and the discharge of mining surplus water into Marillana Creek.

The cumulative differences between annual and long-term mean rainfalls (Fig. 3) for Marillana weather station illustrate how these annual departures from the mean can have cumulative effects on groundwater levels over time.

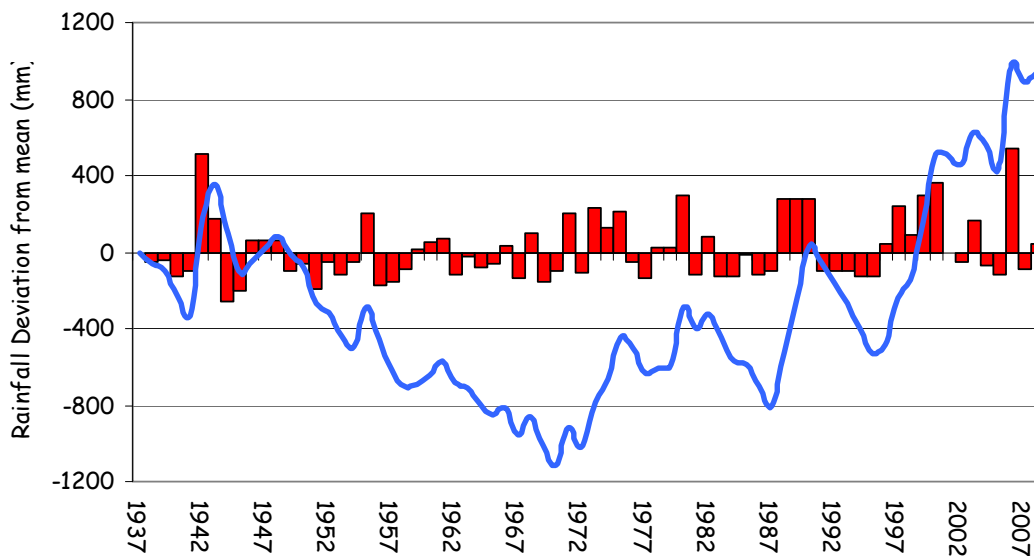


Figure 3. Deviation of annual rainfall from the long term mean (red columns) and accumulative rainfall excess and deficit (blue line) for 1937 - 2009 record at Marillana weather station.

For example, after a series of years with lower than mean rainfall groundwater levels may be lower. Figure 3 illustrates how the difference between annual rainfall and the mean rainfall, when accumulated from one year to the next, can produce trends of 'excess' or 'deficit' rainfall. 'Deficit' rainfall early in the period 1937 to about 1942, and 1950–1968 produced a cumulative 'deficit' of rainfall (bars shown below the zero line) whereas higher-than-average annual rainfall after 1942 and 1997 produced an excess (bars shown above the zero line).

Because the main source of recharge to groundwater is rainfall, daily, monthly, seasonal, yearly, and long-term fluctuations of the watertable are closely related to variations in rainfall

and the excesses or deficits illustrated in Figure 3. When rainfall is higher than the long-term mean, recharge is greater than discharge, groundwater levels rise, hydraulic gradients steepen, and subsequently discharge increases. When rainfall is in deficit relative to the long-term, and there is less recharge, water levels drop, hydraulic gradients flatten, and discharge decreases. The rise and fall of the watertable maintains the natural balance between recharge and discharge.

The results of the analysis suggest that the increasing trend of excess rainfall occurs in ~1996 and this coincides with the start of mining operations at RTIO's Yandicoogina. The fluctuation in the water table and estimation of leakage and determining pre-mining water levels as well as the impact of dewatering of mine pits on the surrounding water levels should take into account the long term variation in rainfall deficit and excess relative to long term mean.

4. PREVIOUS INVESTIGATIONS

4.1 Mineral resource drilling

The earliest groundwater level measurements were carried out in 1974 when mineral resource drilling commenced on ten transects along the CID from Oxbow down gradient to the JSE deposit. Thereafter studies have been ongoing to define the resource to present day, with groundwater level measurements collected at the end of each drilling program from open holes. The open drill hole water levels are captured in the RTIO Acquire Drill hole data base. Although the measurements are from open holes, the recorded levels are generally in agreement with subsequent monitoring bores installed for the explicit purpose of gauging groundwater levels.

The initial drilling program in 1974 comprised of a grid spacing of 2000 x 100m. The drilling was conducted over the full length of the CID from Oxbow to southern JSE. Groundwater level measurements were collected in late August/September 1974 at the completion of this program.

The initial mining area in Junction Central consisted of four localised drilling programs on a 50 x 100m grid to define the resource. Programs were conducted in 1995, 1999, 2001/02, and 2003, providing groundwater levels for these periods at Junction Central.

To expand beyond 48Mt/a, intensive 50 x 100m grid drilling programs throughout the JSE deposit were conducted in 2000, 2003, 2004 and 2005. In conjunction with the open mineral resource drill holes; dewatering investigations were undertaken, giving similar water level readings to adjacent open drill holes.

To establish the extent of the CID ore body up gradient a 100 x 200m drilling program throughout the whole Oxbow deposit was conducted in 2003. Groundwater level measurements for Oxbow were recorded on three occasions 1974, 1993 and in 2008. The latter following a hydrogeological drilling program.

Water level measurements in Junction South West were obtained from three infill drilling programs in 2002, 2004 and 2006. The 50 x 100m grid drilling program consisted of drilling both north and south of Marillana Creek.

At Billiards, four groundwater monitoring bores were established in 1999. These were evenly spaced along the extent of Billiards deposit with ongoing groundwater level measurements recorded to the present. Infill drilling programs on a 100 x 200m grid spacing throughout the Billiard deposit started in 2004 and have been ongoing from 2006 to 2009. In addition to the

transient monitoring, groundwater levels were recorded from mineral holes in 1977, 1999, 2004 and 2006 to 2008 campaigns.

The above mineral hole drilling campaigns and subsequent groundwater level measurements represent a valuable source of information for re-constructing the pre-mining groundwater levels across the RTIO held lease areas.

4.2 Hydrogeological investigations

Extensive hydrogeological investigations have been ongoing at Yandicoogina since late 1970. Monitoring data on regional, CID and Marillana alluvium water levels have been recorded prior to the commencement of mine operations at the Junction Central (JC) since 1998 and the Junction Southeast (JSE) since 2006. In addition, monthly groundwater abstraction and surplus discharge rates have been monitored as part of compliance for the recorded period.

The earliest hydrogeological investigation in the area concentrated on the feasibility of dewatering the CID to achieve dry mining conditions at Junction Central (Rock Water, 1979). This was followed by stage two and three of the investigation that included long term test pumping and the prediction of the dewatering volumes required at JC (Australian Groundwater Consultants, 1980; Australian Groundwater Consultants, 1981). The results of these investigations showed that the Marillana Creek is hydraulically connected to the underlying aquifers and the recharge from the creek accounts for ~25% of the water budget of the CID aquifer (Australian Groundwater Consultants, 1981).

These studies were followed by investigation of mining activities along Marillana Creek on the water balance of the CID aquifer which concluded that there is very little through flow in the CID within the Junction Central area (Peck, A.J., 1995). A water balance and the calibration of a numerical model that included the Junction Central pit and interaction between surface water and groundwater highlighted additional work required to adequately represent Marillana Creek in the numerical model (Peck, A. J. 1997).

Following these works and due to the development of a new interface for numerical modelling code MODFLOW (MacDonald et al., 1988) a new model was commissioned for Junction Central to predict long term dewatering volumes (Australian Groundwater Consultants, 1997). The model predicted that a total volume of $6.9 \times 10^6 \text{m}^3$ of groundwater will need to be removed to reduce the water level to RL 465m AHD within the initial mine footprint of JC. Dewatering to RL 465m AHD should be achieved after 125 days pumping at a cumulative rate of 38,000kL/d from ten bores (Flour Daniel Pty Ltd, 1998).

The Marillana Creek seepage into the CID aquifer and mine closure plan for the Junction Central were combined in the following studies that was carried out by Peck (Peck, A. J., and Associates Pty Ltd, 1998a, b). The dewatering of JC was the focus of two additional studies that included test pumping and aquifer hydraulic parameter estimation in Hairpin and Phil's Creek bore fields east and south of JC deposit (Liquid Earth, 2002a, b, Liquid Earth, 2003). The results of these investigation highlighted that the installed bore fields were unable to completely dewater the mine area to a depth of 60m below ground level. The inability to dewater to plan was a result of under designing the dewatering capacity required. The dewatering design was under estimated by the numerical modelling. In short, using an algorithm to represent dewatering bores as constant volume sinks resulted in drying of model cells which cut off further groundwater inflow in the model, hence the underestimation of the dewatering volumes.

The prefeasibility study into the expansion of the mining operation from 36 to 48Mt/a was commissioned in 2003 and predictions into the dewatering requirements to achieve dry mining conditions at Junction South East (JSE) were investigated by Liquid Earth (2005).

Following this study, a new groundwater model was prepared for the JSE area (MWH, 2005) and included Junction Central pit. A review of historical groundwater model since 2003 and up to 2007 using data and new information obtained from drilling programs and dewatering has concluded that there was a good calibration until February 2007 (coincident with discharge from Hope Downs 1 reaching Weeli Wolli Creek adjacent to JSE). After this point there was a deviation of the observed from modelled predicted levels, with the model over-predicted the success of dewatering (MWH, 2007).

A detailed analysis of previous works and historical data, and an extensive hydrogeological investigation focusing on trial dewatering and aquifer testing was completed by Kirkpatrick and Dogramaci (2009).

5. GEOLOGY

The Yandicoogina area consists of Proterozoic basement rocks of the Hamersley Group. The majority of the outcrop being the Weeli Wolli Formation, comprising jaspilite and shale. The Weeli Wolli Formation is overlain by relatively thin Tertiary and Quaternary sediments. The basement rocks comprise Banded Iron Formation (BIF), chert, shale and volcanic rocks. The thin alluvium and colluvium cover consists of valley fill and recent alluvium deposits, which includes the CID, and are restricted to areas close to present drainages.

The Proterozoic basement rocks have been faulted and folded into a gently synclinal structure called the Yandicoogina Syncline which controls the geomorphology and ultimately the location of the CID and present drainage system. Fractured basement rocks and their weathered profile underlie and enclose the CID and are hydraulically connected to the CID aquifer.

The CID is a Tertiary age, iron rich sedimentary deposit which in filled the ancient river channels. The CID is a continuous, mineralised, pisolitic iron ore that occurs adjacent to the present day Marillana, Yandicoogina and Weeli Wolli Creek systems. The CID consists of pisolitic clasts of goethite-hematite, clay and fossil wood fragments with an approximately average thickness of 60m. The CID clasts (peloids) are typically irregular or sub-angular to sub-rounded in shape. These iron rich peloids are interpreted to represent the end product of detrital weathering via sheet wash processes deposited in low lying areas (Ramanidou, et al, 2003).

A detailed 1:10,000 investigation into the geology of the Yandicoogina area was undertaken by Youngman, 1997, where the lithologies have been divided into four main groups:

- Basement rocks of Archaean and Proterozoic age consisting of Banded Iron Formation (BIF), shale, dolerite and dolomite (Wittenoom Formation found further upstream of the study area). Several dolerite dykes cut through these BIF sequences throughout the area.
- Altered basement rocks of the Proterozoic consisting of lateritic profiles and basement rocks of various weathered states. This Basal Clay Conglomerate (BCC) consists of clasts of BIF, chert and shale in a yellow-white clay matrix.
- Early Tertiary Channel Iron Deposits comprise chemically enriched weathered BIF and fluvial deposits. The CID consists of iron oxide spheroids that have formed in-situ by chemical precipitation of hydrated iron oxides around hematite nuclei. The outer coating of the nuclei is composed of goethite and the matrix is a mixture of goethite,

limonite and ferruginised wood fragments. The CID is divided into two parts; a clayey basal zone and an upper economic pisolite zone. The basal zone or Limonitic Goethite Channel (LGC) overlies the Basal Conglomerate and consists of limonite, clay and goethite often with the CID texture altered. The Pisolitic zone consists of two parts the bottom high grade ore (GVL), and the lower grade ore (GVU).

- Tertiary and Quaternary overburden material is a mixture of very coarse, unconsolidated lateritic pisolite, poorly sorted angular to rounded BIF, chert, CID and dolomite gravels in a sandy clay matrix. Aggregates range from sand to boulder in size. Overlying the main ore deposit is a Weathered Channel Horizon (WCH) consisting of pisolitic material with low iron content and contains various amounts of clay.

The surrounding floodplain containing the CID comprises mainly gravelly clays that have filled the valleys via sheet wash and colluvial processes. Buried river channels may occur within the flood plain but the extent and locations are poorly documented. The flood plain in turn is incised by modern drainages. The modern drainage of the Yandicoogina, Marillana, Weeli Wolli Creeks and other tributaries contain unconsolidated conglomerates (river gravels) up to 5m thick. The river gravels contain boulder to gravel size clasts comprising mainly BIF, shale, siltstone, chert, dolerite and minor calcrete and duricrust.

6. HYDROGEOLOGY

6.1 Groundwater occurrence

This study recognises three main aquifers in the Yandicoogina region. They comprise the fractured basement aquifer, the overlying unconfined fractured CID aquifer and the localised surficial unconfined alluvial aquifer. These aquifers are recharged by direct infiltration of rainfall and through creek beds. The CID is recharged primarily by the leakage through the alluvium in areas where the creeks overly the CID. Exceptionally high water levels in the creek from rainfall and discharge of surplus mine water flood areas beyond the alluvium resulting in direct infiltration to the CID. Groundwater can discharge from the aquifers to the Marillana Creek after a flood event and via evapotranspiration.

The CID aquifer is a relatively narrow meandering palaeochannel imbedded in the basement comprising mainly Weeli Wolli Formation. The heterogeneous aquifer exhibits a variable but overall increasing permeability with depth, related to secondary porosity developed in discrete zones formed by fractures, solution channels and cavity features (MWH, 2006). The development of solution features has largely superseded the primary porosity of the interstitial pore space.

The alluvial flood plain deposits that overlie the CID and basement aquifers and the river gravel in the beds of Marillana and Weeli Wolli Creek systems consist of mixtures of poorly sorted gravels, sand, silt and clay. The alluvium deposit underlying the creek beds filled with river gravels is primarily recharged by surface flow, usually following/during a rainfall event. Discharge of surplus water from mine dewatering operations to Marillana and Weeli Wolli Creeks has resulted in greater recharge and increased storage within the creek alluvium. Transmissivity is variable within the alluvial aquifer. Groundwater moves freely within the coarser less clayey sediments but flow may slow within the underlying clayey sections of the alluvium. The coarse river gravels of the upper alluvium of the creek bed are highly permeable and where thick over a larger area have the ability to transmit and store large volumes of groundwater.

The basement aquifer is a fractured rock aquifer which consists of inter-bedded banded iron formation, banded chert, shale and dolerite. It underlies and surrounds the CID and alluvial aquifers. The aquifer permeability is variable and largely dependent on the development of structural features and weathering. Monitoring bores screened against unconsolidated or in-situ weathered basement lithologies demonstrate hydraulic connection with the CID following dewatering abstraction. Groundwater in the basement rocks occurs in secondary porosity associated with the weathered zone and within fractures in the bedrock, with lower hydraulic conductivities than the CID and flood plain alluvium. However, local and regional fracture systems within the basement rocks are capable of providing significant water yields.

The hydraulic connection between the alluvium and the CID is consistent through the area. Due to the permanent presence of surface water as a result of dewatering discharge from mining operations, the alluvial and CID aquifers are being constantly recharged. The natural depth to groundwater varies from 3 to 20 m below surface with the groundwater flow direction to the east and southeast in the west and to the northeast in the east.

The long term monitoring of dewatering volumes and groundwater levels in the CID aquifer suggests that previous models underestimated the dewatering volumes required to meet mine schedules. Incorrect conceptualisation of water input from surrounding bedrock, and the overlying alluvium aquifers are the likely causes for this underestimation encountered in the model predictions. In depth analysis of the previous works and historical data and an extensive hydrogeological investigation focusing on trial dewatering and aquifer testing of the aquifer demonstrated a good hydraulic connection between the CID and alluvium/in-situ weathered bedrock aquifers (Kirkpatrick and Dogramaci 2009). Based on the information obtained from this investigation, the conceptual model for the groundwater flow system underlying the flood plains of Marillana Creek was updated. The new conceptual model comprises a CID that is surrounded by relatively transmissive alluvium/in-situ weathered bedrock that is in direct hydraulic connection with the CID. The river gravel underlying Marillana Creek and overlying the alluvium/in-situ weathered bedrock contributes a significant volume of water to the CID aquifer.

6.2 Pre-mining groundwater levels

In order to calculate the regional pre-mining water balance and map the associated groundwater level distribution, the historical water level data was collated along the Yandicoogina palaeochannel from Oxbow deposit to Billiard north (Fig. 4). In 1999, four additional shallow exploration holes were drilled along the full extent of the resource adjacent to Weeli Wolli Creek, these water levels were used in conjunction with 1974 levels to contour the conceptual pre mining groundwater level in the CID across the greater Yandicoogina length (Fig. 26).

Based on this data, a conceptual pre-mining CID groundwater level contour map was created along the channel and the gradient was calculated based on the groundwater level elevations from measured resource drill holes detailed previously. The contour map indicates a water level gradient of 0.002 (two meter decrease every kilometre along 42km strike of the palaeochannel). This resembles the natural surface elevation gradient with a drop of 98m along 40 km distance starting from west of Oxbow to Billiard north.

The water levels in shallow monitoring bores drilled to the depth of approximately 50m below ground level along the Weeli Wolli Creek (YW-P20, YW-P23, YW-P6 and YW-P4) range from 460 to 467mRL. Monitoring bore YM119 has the longest continuous record at Billiard from May 1991 to 2009. The water level in 1991 was 465mRL to present day levels at 476mRL.

6.3 Groundwater chemistry

Total dissolved ions (TDS) in groundwater from the CID and alluvium range from 100mg/l to 1290mg/l. The alluvium groundwater contains higher TDS compared to the CID aquifer. The groundwater from both aquifers are dominated by bicarbonate (HCO_3) anions. Sodium (Na) constitutes a higher portion of the major cations followed by Calcium (Ca) and Magnesium (Mg).

Chloride (Cl) concentration ranges from 15mg/L for the relatively fresh groundwater in the CID to a maximum of 280mg/l in the alluvium. The average Cl concentration in the CID is 30% lower than that in the alluvium at ~120mg/L. The relatively higher concentration of Cl in the shallow alluvium aquifer is due to direct evaporation from groundwater and evapotranspiration by native vegetation along Marillana Creek.

6.4 Mine dewatering and water management

The dewatering strategy of the CID is based on the interference of drawdown impacts from a series of “cluster” borefields located up gradient and down gradient of the active mining area. In-pit dewatering from multiple sumps are also utilised to remove the groundwater drainage from the lower sections of the CID aquifer. The sumps are used to remove groundwater seepage in advance of mining deeper benches.

The original JC dewatering borefield drilled in 1997/98 consisted of the Sacrificial and Permanent borefields. Eleven dewatering bores were installed; six bores (SP01-06) were installed in the active mining pit area (Sacrificial Borefield) and five dewatering bores (PP01-05) in the Permanent Borefield. Water levels in the vicinity of the Sacrificial Borefield located in the initial mining area were lowered **65.5m** (458.5mRL) six months after abstraction commenced. This level has been sustained with continuous pumping. Water level in the Permanent Borefield located down gradient of the initial mining area was lowered by **55m** (462mRL) within the first six months then continued to gradually decrease. The original Sacrificial Borefield was mined out and relocated further down gradient of the active mining area in early 2000. Water level remained constant, around 455mRL.

As the JC mine void expanded two new permanent bore fields were commissioned in late 2002 (Phil’s Creek and Hairpin Borefields). Phil’s Creek Borefield (PC001-008) was installed to replace the Sacrificial Borefield and Hairpin Borefield (HP001-007) was to replace the Permanent Borefield (an unfortunate name as it was mined out). Eight production bores were constructed, of which only five were commissioned in Phil’s Creek. Seven production bores were constructed in Hairpin of which only four were commissioned.

The Waterstand Borefield was constructed in late 2004 to facilitate further expansion of the JC mine void. Water level around the Waterstand borefield is 455mRL, comprising **59m** of drawdown, and has remained consistent to 2009. Monitoring bore YM117, seven hundred meters down gradient near Marillana Creek has water level of 500mRL, and monitoring bore YM119 seven hundred meters up gradient has a water level of 485mRL (Figures 8 & 10). These water level elevations have remained consistent since the commencement of the Waterstand Borefield.

Marillana Creek Borefield, located adjacent to Marillana Creek was commissioned in 2007 to phase out the Waterstand Borefield as mining progressed. The water level within the borefield was lowered ~17m (494mRL) decreasing a further 30m by January 2010. Monitoring point YM119 (500m up gradient) shows reasonably consistent water levels at 475mRL.

Expansion of RTIO Yandicoogina operations continued and in 2005 the mining and dewatering of the JSE deposit commenced. Dewatering borefields were constructed in

Junction South East in 2004 and 2005 and commissioned in 2006. Thirteen production bores were constructed in three separate borefields known as Central, Sacrificial and Southern JSE. At the same time five re-injection bores were constructed in Billiards (RB001-005).

The groundwater level in the Central JSE Borefield was 497mRL at the commencement of dewatering in June 2006 decreasing to 468mRL in 2008. The groundwater level at the commissioning of the Sacrificial JSE Borefield was 494mRL and this was lowered to 480mRL in 2010. The groundwater level at the commissioning of the Southern Borefield in June 2008 was 494mRL decreasing to 480mRL in February 2010. The progression of mining in JSE towards the north required the construction of the Northern Borefield (NB001-004) in 2007 which was commissioned in 2008. The groundwater level in the borefield in June 2008 was 459mRL decreasing to 439mRL by February 2010.

The Re-injection Borefield (RB001-007) in Billiards was commissioned to re-inject surplus water from JSE dewatering. Water levels increased between August 2006 (490mRL) and August 2007 (498mRL). Groundwater levels have remained largely consistent since, however the total injection volume has been decreasing from a peak of 15ML/day at commissioning to ~7ML/day presently, this despite the drilling and construction of new injection bores to compliment the system in 2008.

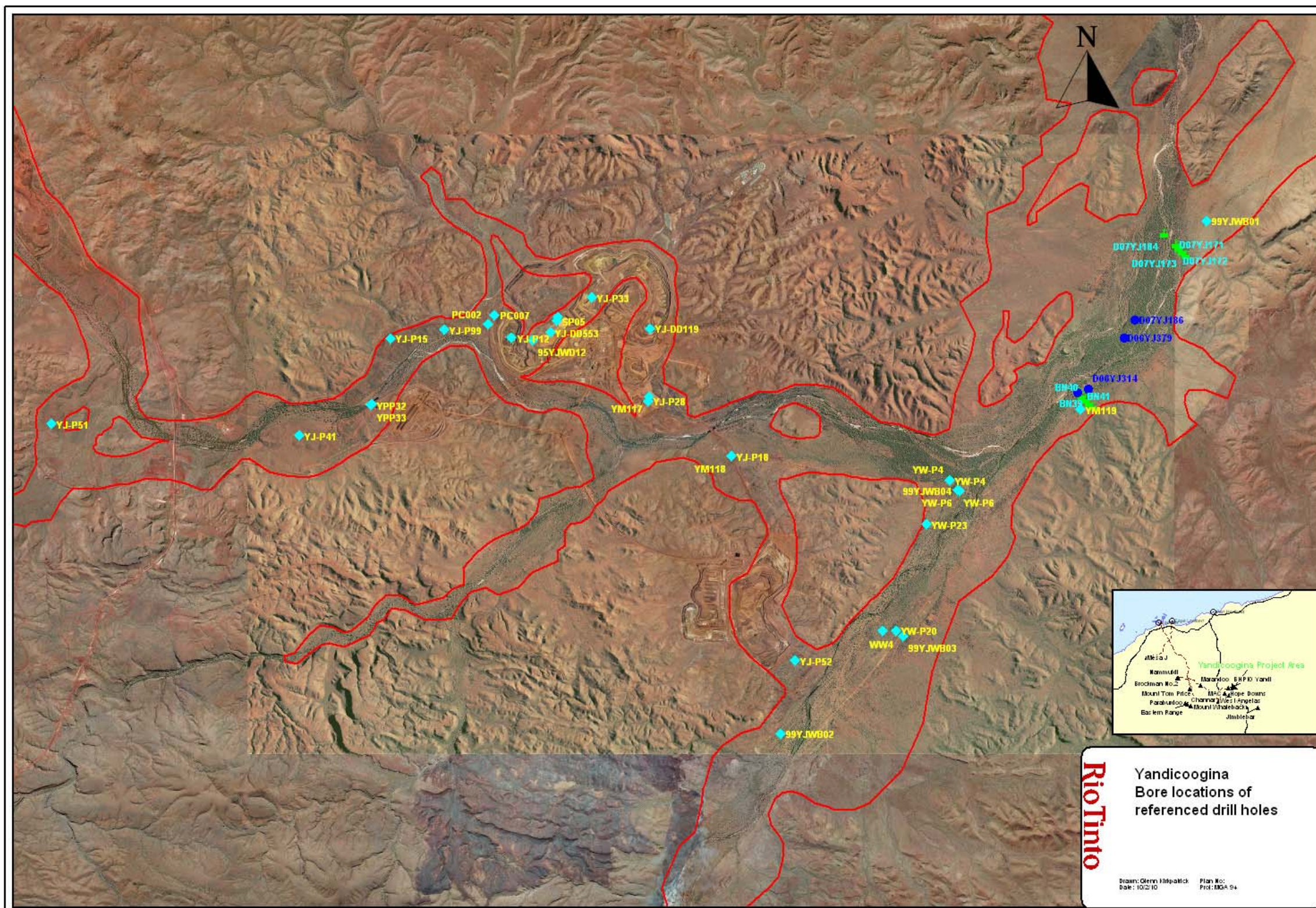


Figure 4. Location of Referred drill holes

7. IMPACTS OF MINING

The processes associated with mining that had significant impact on groundwater levels of commenced in May 1992 when BHPB started dewatering and discharging surplus water to Marillana Creek upstream of RTIO Yandicoogina. Dewatering of RTIO's Junction Central commenced in March 1998. Likewise RTIO began discharging surplus dewatering water to Marillana Creek shortly after commencing dewatering. Hope Downs 1 mining operation began discharging surplus water to Weeli Wolli Creek a further ~10km upstream of RTIO Yandicoogina Billiards deposit in January 2007.

In 2009 the total dewatering required for dry mining conditions in RTIO's Yandicoogina JC and JSE pits comprised approximately 25GL. This includes all borefield and sump pumping across the combined operations. Dewatering water is used on site in preference to establishing further water supply sources, however dewatering needs far out strip water demand.

Re injection of part of the surplus water from JSE dewatering into the CID aquifer down gradient in Billiard deposit is part of the water management strategy. The infrastructure in terms of dewatering and injection bores was completed in 2006. Although originally designed to inject up to 15ML/day (~5.5GL) the CID has largely been filled and <7ML/day was injected in 2009 for a total of 2.5GL.

The management strategy for the remainder of the surplus water is to pipe to the nearest drainage line for controlled discharge to ephemeral creeks. This is also the strategy employed at adjacent iron ore mines, such that, in 2009, a total of ~50GL of surplus water was discharged into Marillana and Weeli Wolli Creeks. This consists of RTIO discharge of 14GL into Marillana Creek from Yandicoogina operations, ~30GL into Weeli Wolli Creek from Hope Downs 1 mining operations with an additional ~5GL from BHPB mining operations into Marillana Creek (Fig. 5).

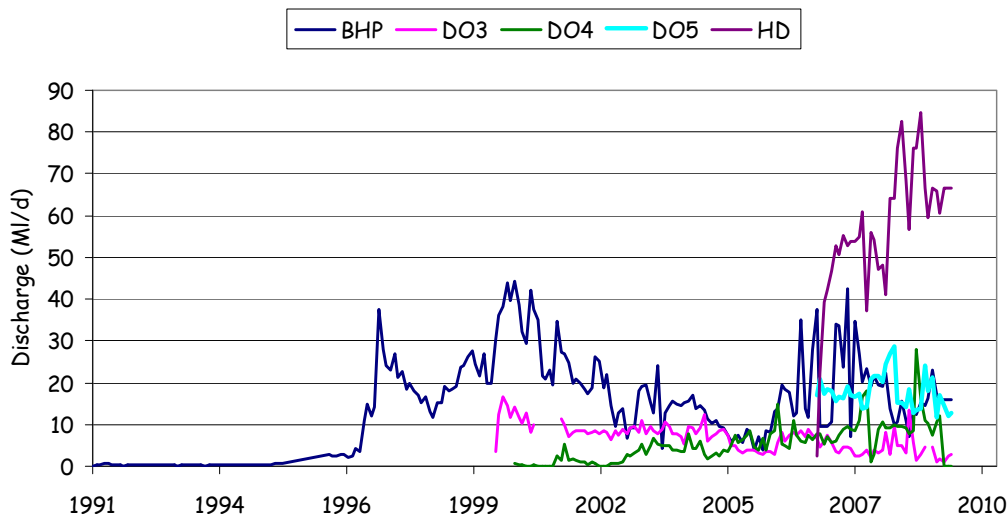


Figure 5. Daily discharge volumes from BHPB and RTIO operations.

7.1 Groundwater level impacts

7.1.1 Oxbow

Groundwater levels (AHD) are 518mRL at the western end of the Oxbow deposit (YJ-P51) to 516mRL in the eastern end (YJ-P41) near the BHP Billiton rail line (Fig. 6). The calculated pre mining gradient for the Oxbow deposit is approximately 0.001. A large tributary of Marillana Creek crosses through the centre of the Oxbow pit which could influence water levels after large scale rainfall events.

The discharge from BHPB dewatering two kilometres up gradient from the Oxbow deposit started in 1992. The discharge of surplus water into Marillana Creek from 1992 to 2007 ranges from 6.6 to 40ML/d, with an average of approximately 16ML/d. In 2007, the original discharge outlet was relocated 1.2km down gradient of the Oxbow deposit where Marillana Creek crosses the palaeochannel east of the BHPB railway line (Fig. 1).

The measured water level elevation in 1994 was approximately 12m higher (530mRL) than that measured in originally following 1974 campaign. The increased groundwater level was a result of recharge to the CID from the discharge into Marillana Creek up gradient of the deposit by BHPB.

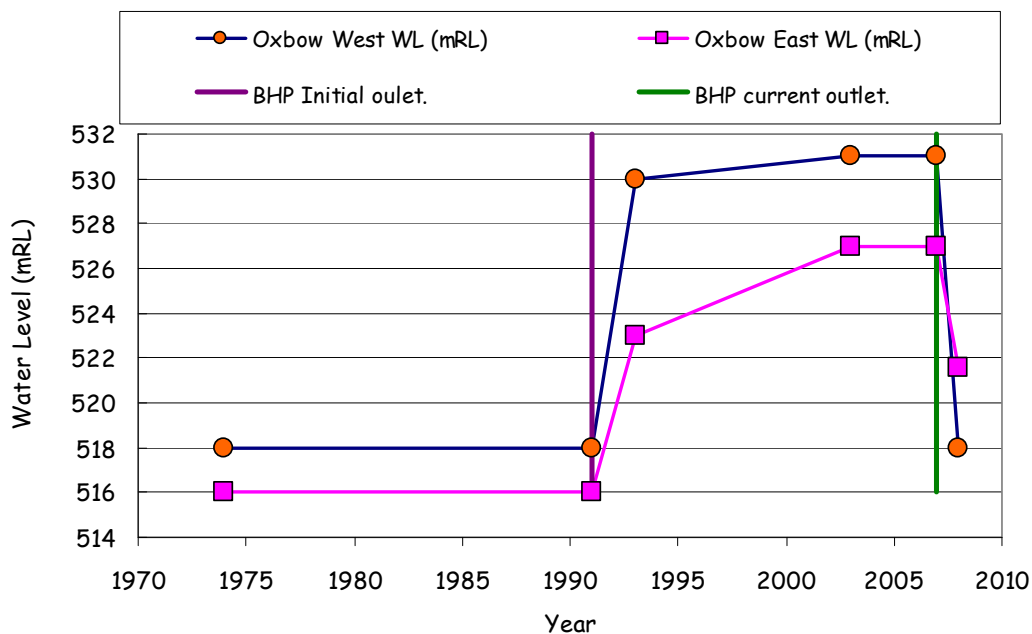


Figure 6. Oxbow water level change over time with significant events displayed.

The 2003 groundwater levels (531mRL in the west to 527mRL in the east) were similar to levels measured in 1994. The hydraulic gradient had increased from 0.001 measured in 1974 to 0.0015m suggesting considerable recharge to the CID in the west from the BHPB discharge outlet. The increased gradient reflects the transmissive nature of the CID, the recharge from Marillana Creek surplus water, and subsequently the higher rate of throughflow in the CID.

In 2008 a hydrogeological drilling program was completed over the Oxbow region. The measured water levels in 2008 following the relocation of the BHPB discharge outlet demonstrate that the gradient of 1.5m per kilometre has reversed due to a combination of the relocation of BHPB discharge outlet down gradient of the deposit and the impact of BHPB dewatering a pit 5km up gradient of the Oxbow deposit. Groundwater levels at the western edge of the Oxbow deposit have returned to the pre BHPB discharge levels of 1974 at 518mRL.

The chronology of the Oxbow deposit water levels (Fig. 6) demonstrates the reversal in groundwater gradient after 2007 following the relocation of the BHPB discharge point (green line). The reversal of the gradient after relocation of the discharge outlet clearly highlights the interconnection between Marillana Creek and CID aquifer.

6.1.2 Junction Southwest

Several studies were completed over the greater JSW deposit, which is subdivided into four smaller deposits, JSW A, B, C and D. One transect was drilled in the 1974 program through the western side of JSW deposit with a standing water level of 513mRL. The water level at the eastern side of JSW was measured in a single drill hole YJ-P15 and was 511mRL. The groundwater level gradient calculated from the limited data points was approximately 0.0007, which is half the hydraulic gradient calculated in Oxbow deposit.

In 1993 the measured groundwater level is approximately 4m higher (517mRL) than that measured in 1974 at the western edge of JSW deposit. The increase in water level is a result of recharge to the CID from surface water from the permanently flowing Marillana Creek, due to BHP Billiton discharge.

Despite the 4m rise in water level at the western end of JSW deposit, the water level measured in the eastern side of JSW in 1993 (YJ-P15), had not changed relative to the water level measured in 1974 (Fig. 26). The similarity in water level elevation suggests that the excess recharge and water table rise at the western margin has not dissipated further than 9km down gradient from the BHPB discharge point.

Measured groundwater levels in 2002 in the west were 519mRL indicating a further 2m rise since 1993. The throughflow of the saturated CID extended towards RTIO's Junction Central (JC) deposit, as indicated by a one meter rise in water level in eastern side of JSW since 1993.

The calculated groundwater gradient for 2002 had increased substantially to 3.5m per kilometre throughout the JSW deposit partly due to the continuous recharge up gradient, with most of the impact resulting from RTIO dewatering at JC at the eastern end of JSW. The comparison of groundwater gradient between 1993 and 2002 at JSW reveals two distinct slopes; the gradient from JSW-A deposit through to western edge of JSW-C deposit has increased by only 1.5m per kilometre since 1993, due to recharge to the CID from Marillana Creek. The groundwater gradient from JSW-C deposit through to JC on the other hand has increased by 5m per kilometre due to the dewatering of the adjacent JC deposit since 1998.

By 2004 groundwater levels throughout the JSW-A deposit decreased by approximately one meter, to 519mRL. The decrease in the water level coincides with the decrease in the discharge volume from BHPB outlet from 0.83GL in 1999 to 0.38GL in 2004 (Fig. 5).

The water level at the eastern edge of JSW-D deposit near JC deposit was lowered a further 10m (492mRL) due to RTIO in-pit dewatering at JC. The groundwater gradient from JSW-A deposit to Marillana Creek was similar to 1993. The groundwater gradient over the whole JSW deposit had increased to 5.5m per kilometres resulting mainly from increased dewatering at JC deposit.

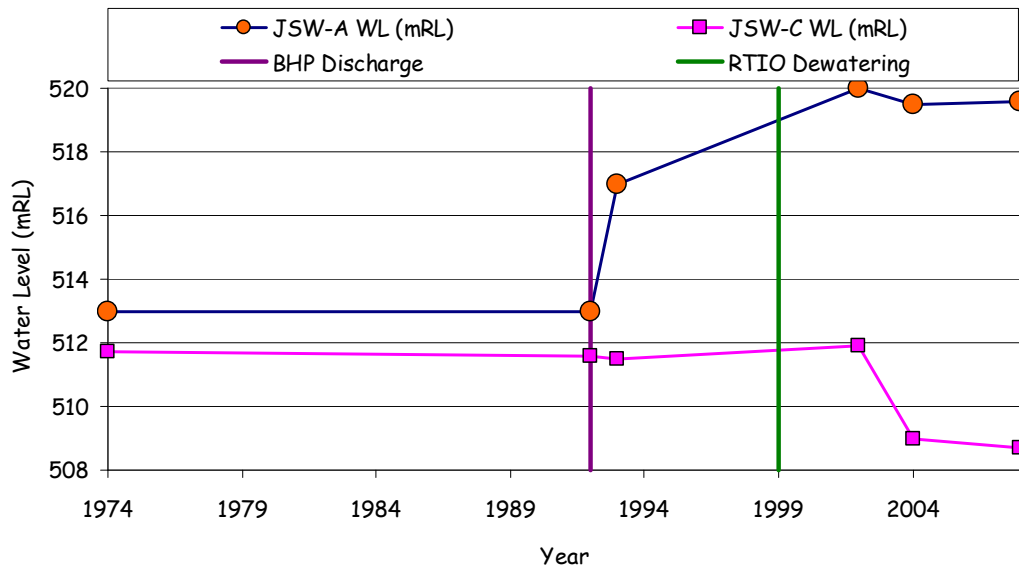


Figure 5. Junction South West water level change over time for the different deposits with significant events displayed.

The groundwater levels measured in late 2008 show the CID west of JSW-A deposit (~520mRL), are similar to 2002 and 2004 levels, due to the saturation of the CID/alluvial aquifer from continuous surface water flow down Marillana Creek adjacent to the deposit. A further 10m decline in levels (482mRL) at the eastern margin of JSW-D is due to continuing dewatering at JC. The groundwater gradient for deposit JSW-A is comparable with groundwater gradients from 2004. Deposit JSW-C and JSW-D show a 14m per kilometre gradient due to the continuous dewatering of JC deposit with the advancement of mining.

Figure seven illustrates the chronology of JSW, where water levels in the west increased substantially due to the commencement of BHPB discharging surplus water into Marillana Creek (blue line). The influence from RTIO dewatering in JC is clearly illustrated by significant declining water level in the eastern section of JSW (pink line).

6.1.3 Junction Central (JC)

In 1974 the groundwater level in the western side of JC deposit was 506mRL (bore hole YJ-P12) and 488mRL (bore hole YJ-P28) in the east. The calculated gradient of 0.0025 is similar to greater Yandicoogina deposit groundwater gradient of 0.002. By 1995 the water levels had risen 2m in the west (95YJWD12) and 6m (YJ-P33) towards the centre of the deposit, due to increased recharge to the CID from Marillana Creek.

The commencement of dewatering in RTIO initial mining area in July 1998 lowered water levels by up to 19m in the west of JC deposit compared to water levels in 1974. The drawdown in water levels in 2005 in the bores adjacent to the original bore field was 35m (drill hole YJ-DD553) compared to the measured levels in 1974.

Observation bore YJ-DD119, located in the eastern part of JC has been monitored since dewatering started in 1998 (Fig. 8). The hydrograph shows one initial measurement taken in September 1994 and then a 7m rise in water level to 1998. The water level drawdown of up to 25m, owing to dewatering, is clearly shown after 1998 onwards. The seven meter rise in water levels in November 1999 to April 2000 is the result of greater than average rainfall (1060mm). Thereafter the commissioning of two additional dewatering bores (SP05 and SP06) resulted in continued water level decline. The chronology of the events that has occurred and impacted the water level at JC is presented in Figure 9.

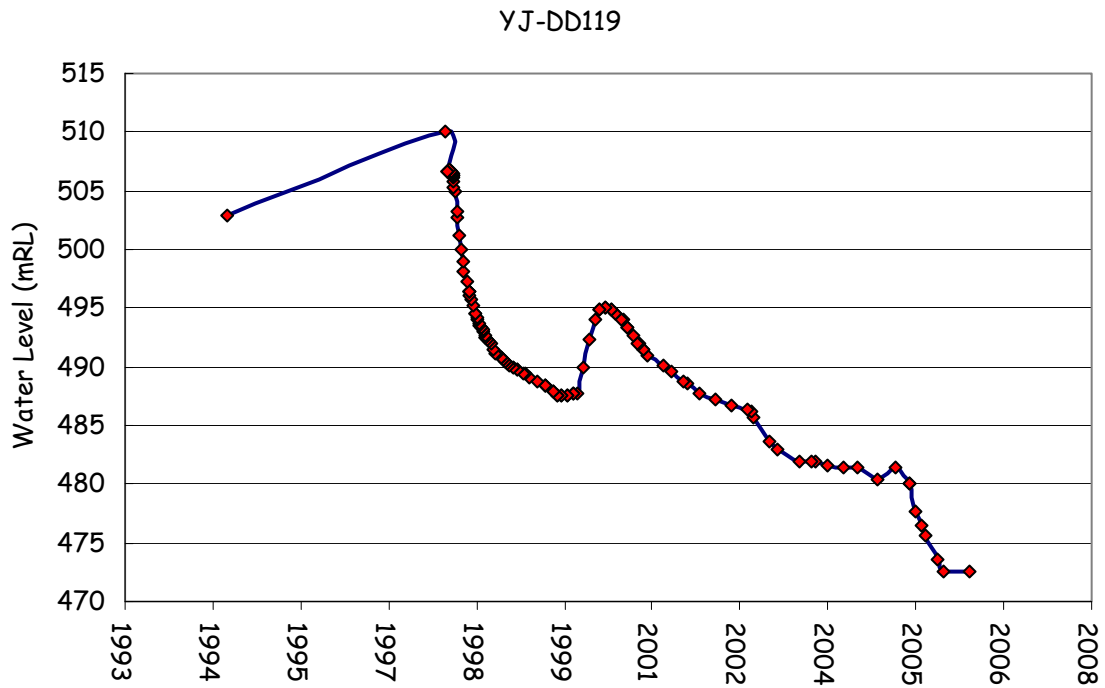


Figure 6. Long term monitoring bore YJ-DD119 in Junction Central

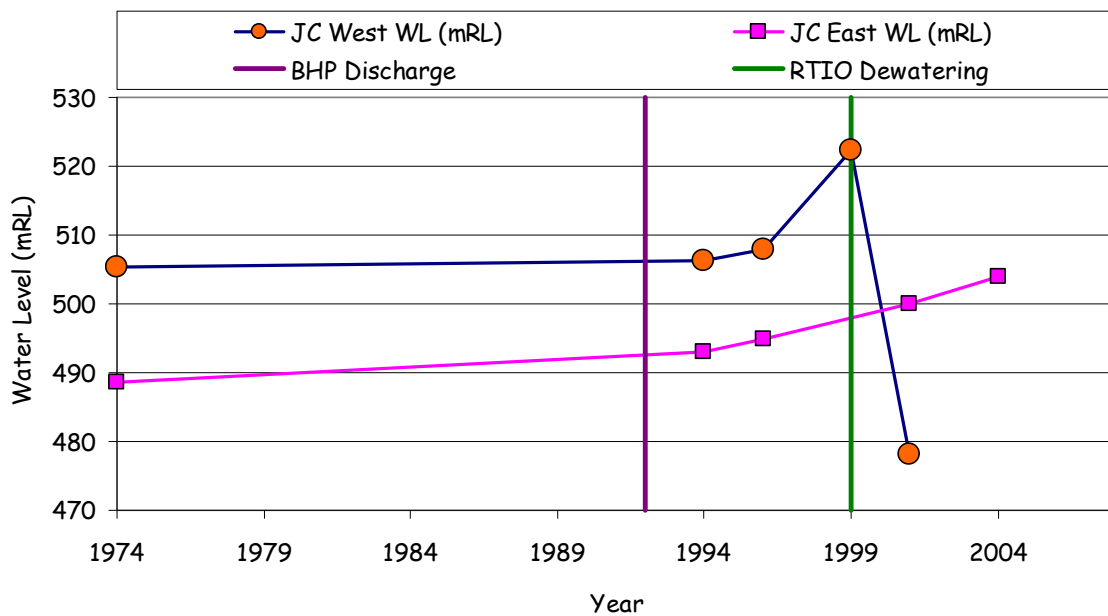


Figure 7. The chronology of events and water level response in CID aquifer at JC.

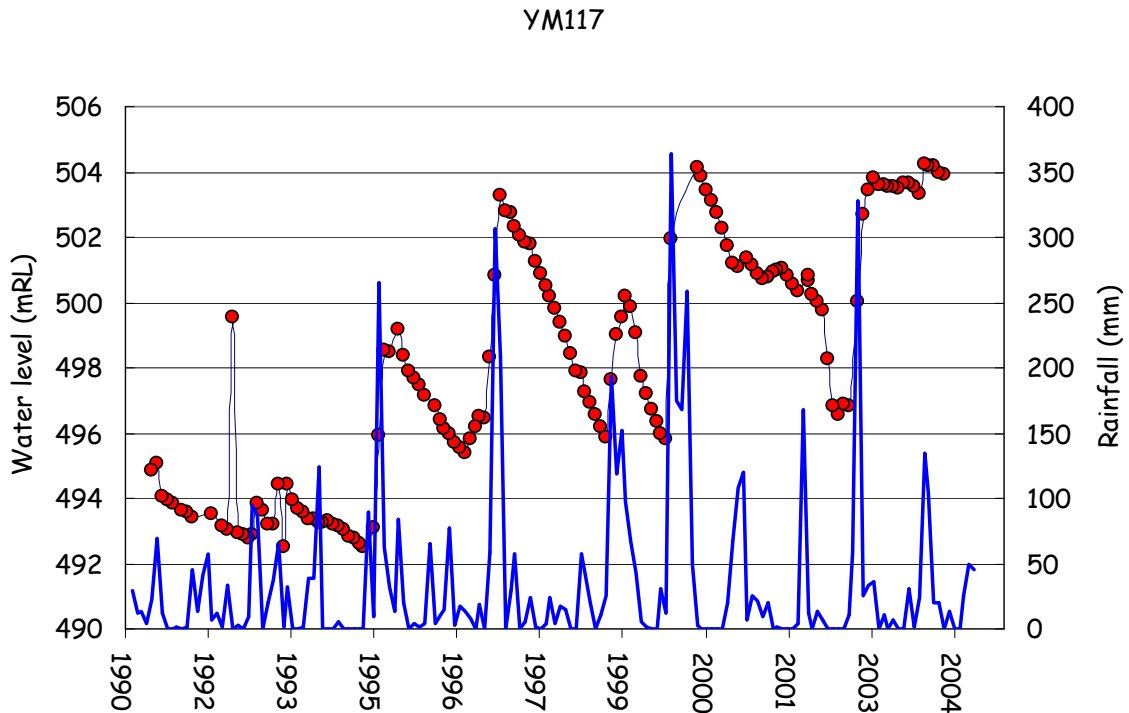


Figure 8. Water level records from 1991 to 2004 in monitoring bore YM117 at Junction Central deposit.

A large scale drilling program covering Hairpin, the eastern section of the JC deposit and some additional holes in the Phil's Creek deposit was completed in 2001. The groundwater levels show continued drawdown due to dewatering throughout the area (Fig. 9). Dewatering since 1998 has resulted in a localised reversal of groundwater gradients in the east towards the pumping wells. Water level measured in monitoring bore YM117 adjacent to Marillana Creek has increased due to continued recharge to the CID from Marillana Creek and increasing rainfall (Fig. 10). The hydrograph shows the immediate response of the groundwater level in the CID aquifer to high rainfall events. The rapid increase in water level by up to 8m suggests a high degree of connectivity to the underlying aquifers.

The immediate 8m rise in water table (recharge) translates to a seepage of up to 1.6m assuming a porosity of 0.2. The time required for the water table to dissipate and return to pre recharge levels is ~18 months. The graph shows that an above average rainfall event resulting in an 8m water level rise over four weeks would negate the impact of six months continuous dewatering.

The annual abstraction volume from dewatering JC deposit ranges from 5 to 9GL/a. since 1998 (Fig. 11, Graph A). The increase and decrease in abstraction volumes in JC deposit illustrated in Graph A, is driven by a combination of BHP Billiton's discharge increases and decreases, coupled with RTIO's own advances in mining depth.

When comparing the rainfall for Yandicoogina and BHP Billiton discharge (Fig. 11, Graph B) there is an apparent trend of increasing discharge after a significant rainfall event. The lag time for the increase in discharge is approximately six months after the rainfall event indicating rainfall has a dominant impact on the groundwater system throughout Yandicoogina.

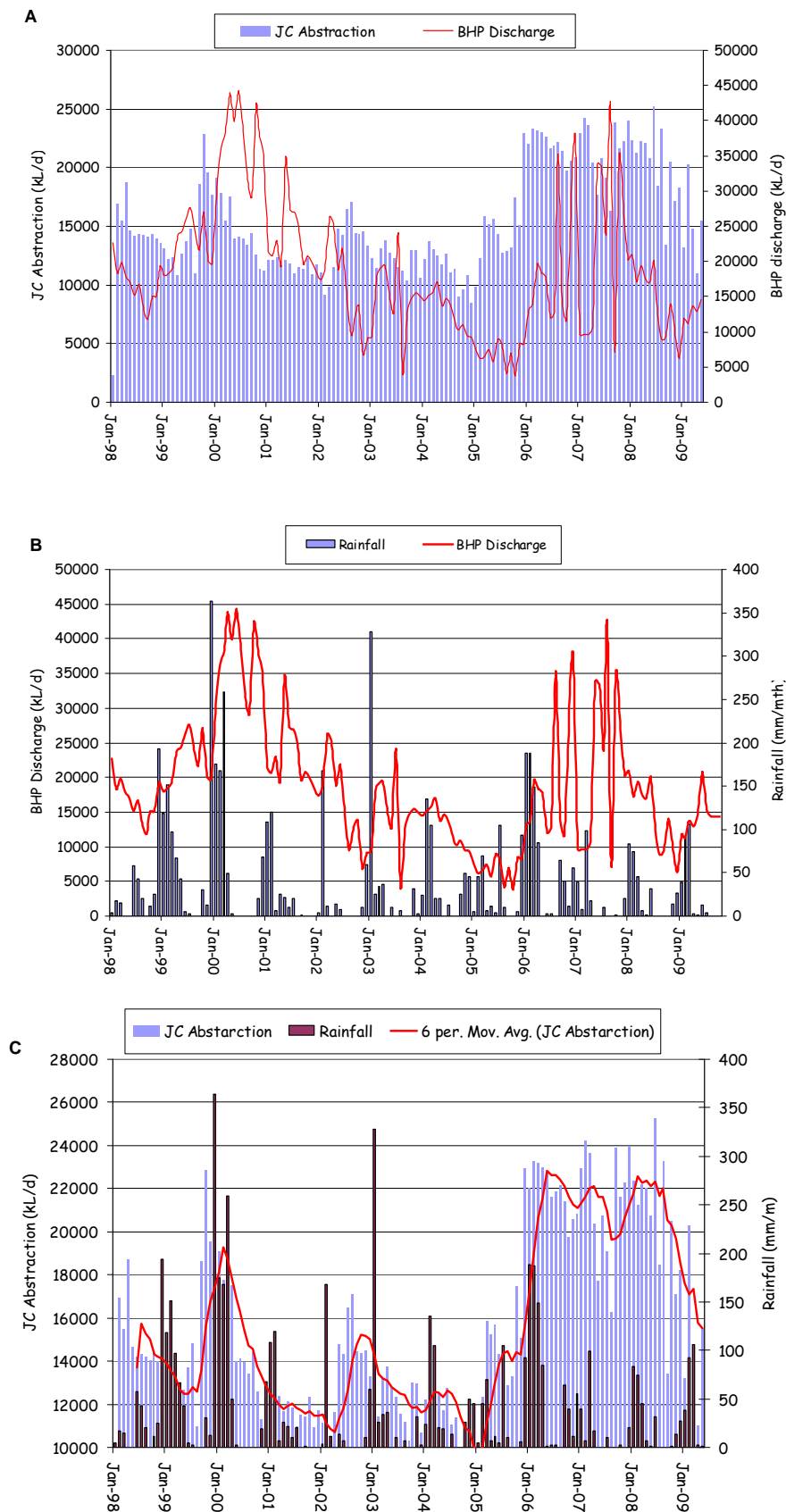


Figure 9. The above graphs (A-C) illustrate the relationship between rainfall, discharge and abstraction.

The higher than average rainfall since 1996 has resulted in greater than average recharge. Therefore, JC dewatering shows a direct relationship between rainfall and abstraction from Yandicoogina mining deposits. The consecutive years of higher than average rainfall has exacerbated dewatering since below watertable mining commenced. The lower mining proceeds in the pits, the higher the hydraulic gradient created (as the creek is constantly saturated from surplus discharge) resulting in ever increasing recharge into the aquifer underlying the mine voids.

7.1.4 Junction Southeast (JSE)

Groundwater level measured in JSE show a comparatively consistent groundwater gradient of approximately 0.0018 in 1974. Standing water level measured in the north near Marillana Creek was 485mRL in bore hole YJ-P18, and 476mRL measured in bore hole YJ-P52 to the south near Weeli Wolli Creek.

By 2000, the groundwater level had increased by up to 23m in JSE due to recharge from Marillana Creek. The dewatering of JC has an immediate impact on the rate of water table rise north of the deposit. Close examination of the water level along JSE shows that the rate of rise in the bores closer to the JC bore field is less compared to the bores further down gradient.

Water level and groundwater gradient measured in 2004 were consistent with water levels measured in 2000. A decline of one meter in water levels in the bores closest to JC is due to the impact of continued expansion of the cone of depression as a result of dewatering the JC pits.

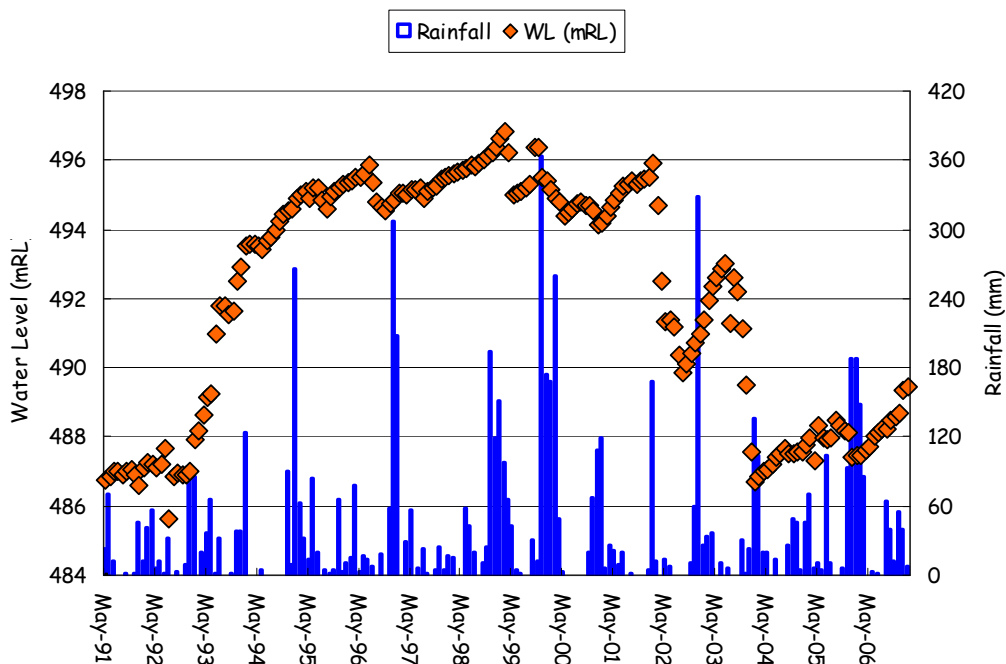


Figure 10. YM118 hydrograph for northern JSE deposit.

The water level in bore YM118, located on the north-western end of JSE deposit near Marillana Creek has been monitored since the May 1991 (Fig. 12). Prior to BHPB discharging water in 1992, the level in this bore was 487mRL. The water level begins to rise steadily and reaches 496mRL, approximately 10m higher than initial levels, by May 1995. The level stabilises after 1995 until Junction central dewatering started in 1998. The water level drawdown reached pre 1991 levels after six years of continuous dewatering. The

hydrograph also shows the rapid response of water level in the CID aquifer to recharge from intense rainfall events and discharge due to dewatering.

The hydrograph data from monitoring bore 99YJWB02 located in the southern section of Billiard deposit across Weeli Wolli Creek shows instant water level response to large rainfall events and JSE dewatering (Fig. 13). The graph shows an 8m decline resulting from dewatering of the JSE deposit that commenced in September 2006. However, in mid 2007 groundwater levels had risen by approximately 2m due to recharge from Weeli Wolli Creek to the CID aquifer as a result of Hope Downs 1 dewatering discharge of surplus water into the creek approximately 10km upstream.

The abstraction volume for JSE was compared with the discharge volumes from the two up gradient mining areas (RTIO Yandi and Hope Downs 1), with a combined discharge volume of 50GL in 2009 (Fig. 14). The discharge volume is two folds greater than abstraction for JSE. Therefore recharge throughout JSE will increase and result in the requirement for greater dewatering at JSE to met mine plan targets. The subsequent increase in pumping in June 2008 from ~30 to 40ML/day (Fig 14) from the Southern Borefield reversed the increasing water level trend; but has not been able to lower groundwater levels below 488m RL throughout 2009 (Fig 13.).

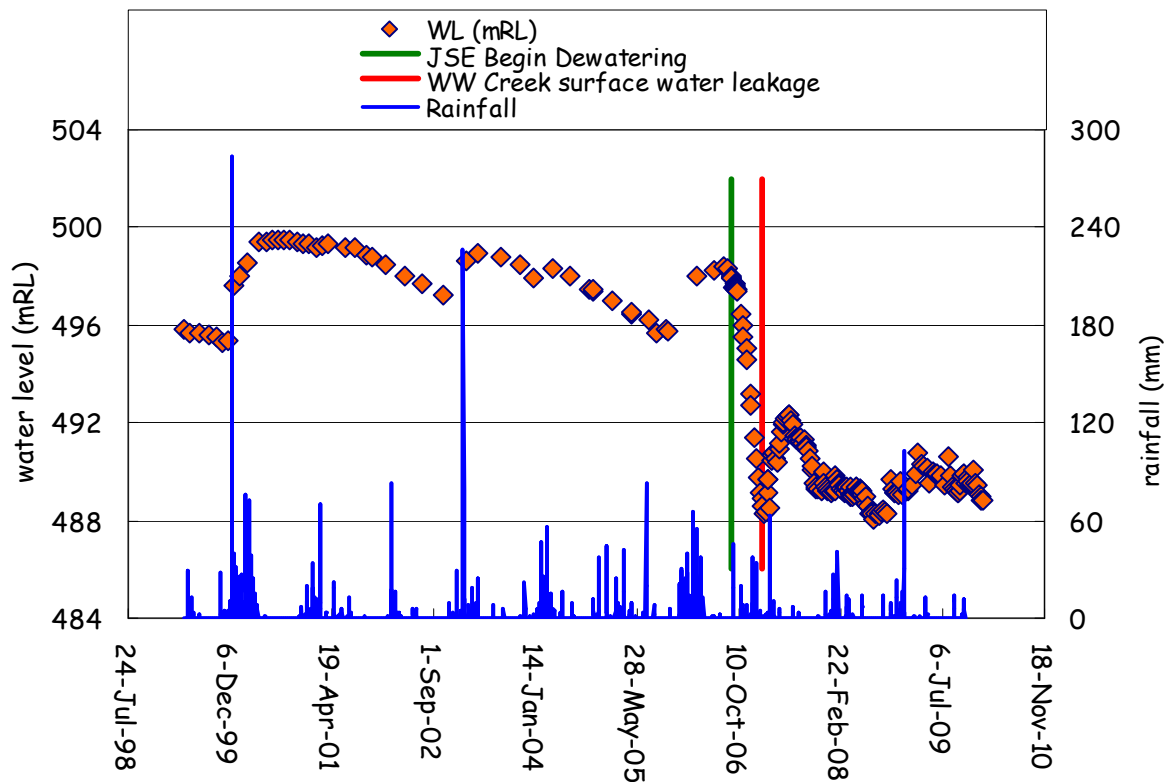


Figure 11. Water levels in monitoring bore 99YJWB02 located at the southern part of JSE deposit.

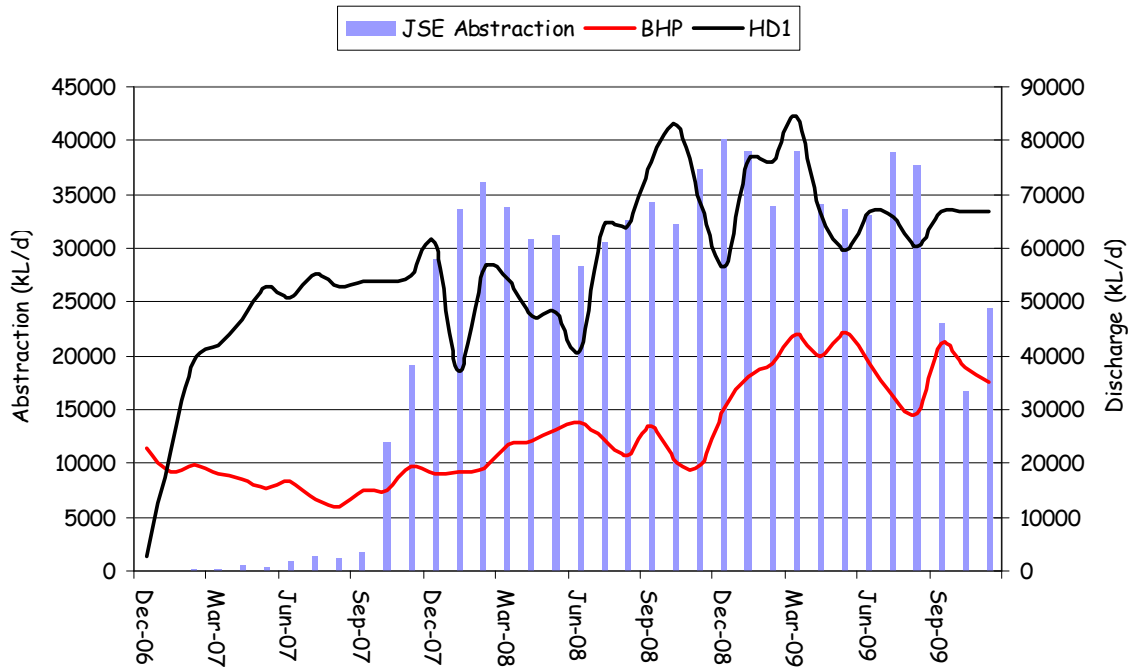


Figure 12 JSE abstraction vs. discharge indicating the discharge volume is close to two folds that of abstraction.

7.1.5 Billiards

The flow direction in the CID adjacent to Weeli Wolli Creek prior to 1999 is to the northeast over the 18km ore body, with a groundwater level gradient of 0.002. The pre-mining records suggest that the gradient in the CID aquifer adjacent to Weeli Wolli Creek was similar to that in the up gradient portion of the CID aquifer adjacent to Marillana Creek.

Water level response is instantaneous in relation to large rainfall events, shown by sharp rises in water level then decay over time. The rapid response of the groundwater level is due to the proximity of the monitoring bore to Weeli Wolli Creek and the rapid recession curve highlights the rate of discharge via evapotranspiration. Given the rate of decline taken from the gradients in Figures 13 and 15 is 70mm/d and assuming a porosity of 0.2; the discharge calculated is roughly ~14mm/d. This is consistent with the chloride mass balance calculation that suggests a loss of ~10mm/day due to evapoconcentration. The discharge from the CID in the dry season can only occur due to transpiration of the deep rooted vegetation along the creek. Given the above assumptions, the accumulated volume of water loss along a 100m length of the creek would amount to 560m³/d (100m length X 400m width X 0.014m discharge).

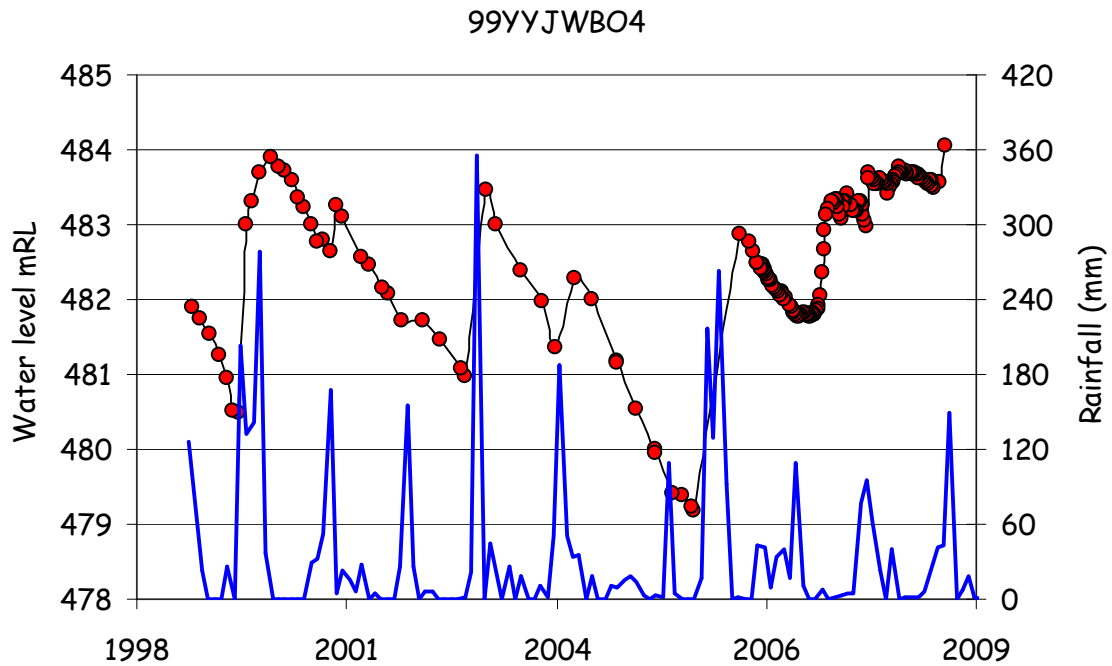


Figure 13. Water level in the CID aquifer up gradient from the confluence of Marillana and Weeli Wolli Creek. Note the rise of 2m after Hope Downs 1 discharge to Weeli Wolli Creek commenced in 2007.

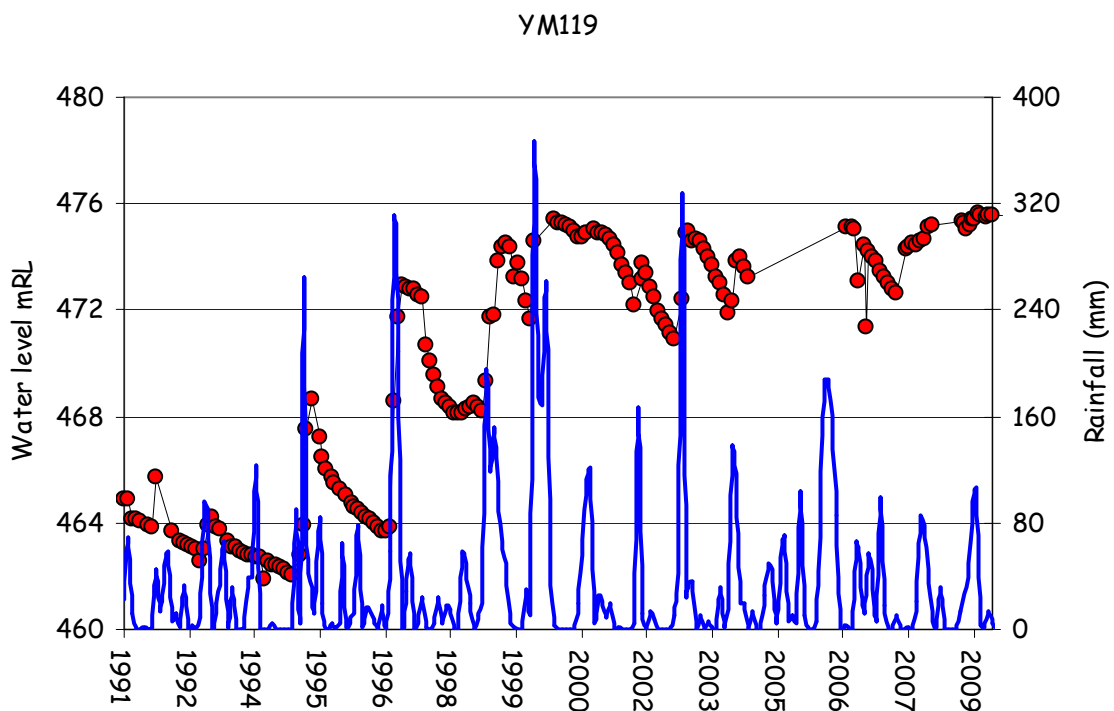


Figure 14. Water level in the CID aquifer adjacent to Weeli Wolli Creek 2.3km down gradient from the confluence with Marillana Creek. The rainfall record is shown to highlight the rapid recharge of the CID after intense rainfall events. The data also shows a greater response to a rainfall events pre HD1 discharge,

Ongoing investigations into the rate of tree water use in the Pilbara region suggests that on average, mature trees can use up to 120L/d (P. Grierson, pers. com.). The estimated number of trees that can utilise 560m³/d can be calculated by dividing the total water loss by tree water use rate (4600 trees). This number of trees is consistent with the number of trees along a 100m length of Marillana and Weeli Wolli Creeks estimated from aerial photographs. Water level elevations in the southern portion of Billiard, upstream of the confluence of Marillana and Weeli Wolli Creeks, were rising between 2004 and 2007 due to injection into the CID aquifer prior to Hope Downs 1 discharge.

A comparison of water level records between 1991 and 1995 show minimal change in water level despite the permanent flow in the Marillana Creek since late 1991 (bore YM119). However, a clear increasing trend in the water level by 2m/a is observed between 1995 and 2000. Since 2000 only a small change of a few metres in the water level is observed after rainfall events (Fig. 16). The upward trend in water level in YM119 between 1995 and 2000 may be the result of a combination of rainfall events (excess rainfall compared to long term mean) coupled with increased recharge from the creek due to permanent flow. A change of one metre in level is observed in this bore since 2007, when the discharge into the Weeli Wolli Creek from Hope Downs 1 commenced.

The importance of relative recharge from intense rainfall events compared to permanent recharge due to saturated surface water flow is shown in Figure 16. Results from data loggers show expected water level rise based on the change in discharge volume. The deep CID bore D06YJ379 (Fig 17), located downstream of the confluence almost mimics the discharge data from 2008 taken from the Gabion station at Hope Downs 1. The total discharge increased in July 2008 from approximately 1 to 2.5GL/month, resulting in a moderate increase in CID groundwater levels. A subsequent decrease in October 2008 by 1GL/a in discharge results in an instant decrease in CID groundwater levels. However the response of water level to intense rainfall events is higher than the response to the increased discharge.

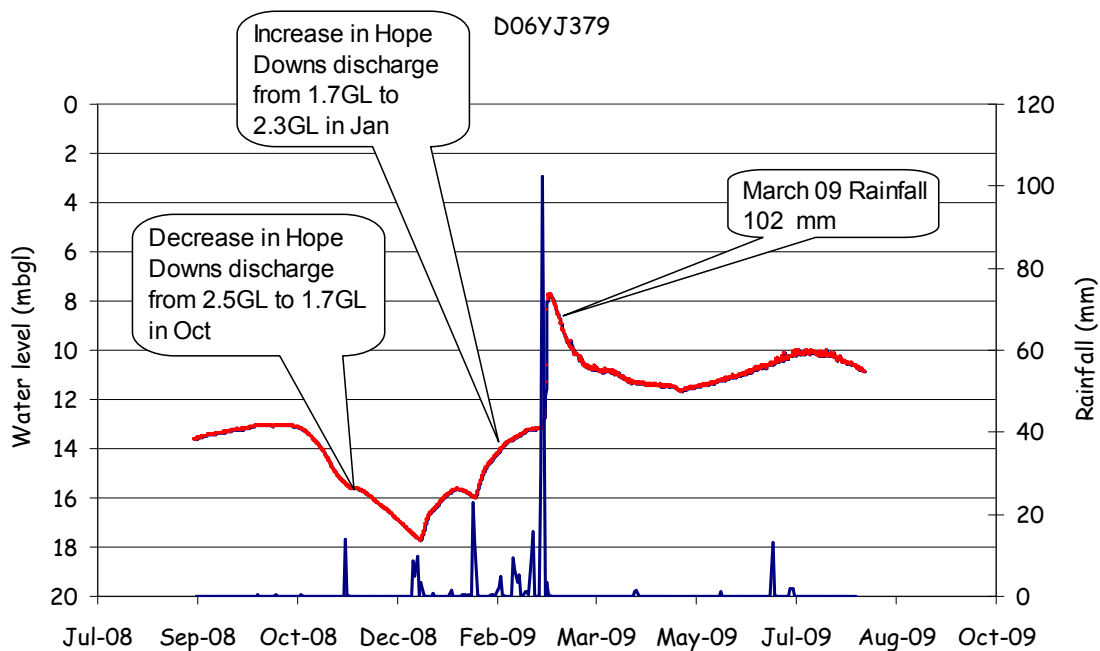


Figure 15. Water level response to changes in discharge volume to Weeli Wolli Creek.

The impact of surface water flow from mine discharge extends up to 12km from Yandicoogina mining area, beyond this point there is no evidence that the discharge of surplus water or dewatering has impacted on groundwater levels. This is illustrated in Figure 18 where groundwater levels show the no change since 1998. Ongoing monitoring in this area is required over time to monitor the extent and changes in surface flow with associated groundwater level responses (and any increase in discharge from any of the three mines has the potential to extend the length of impact).

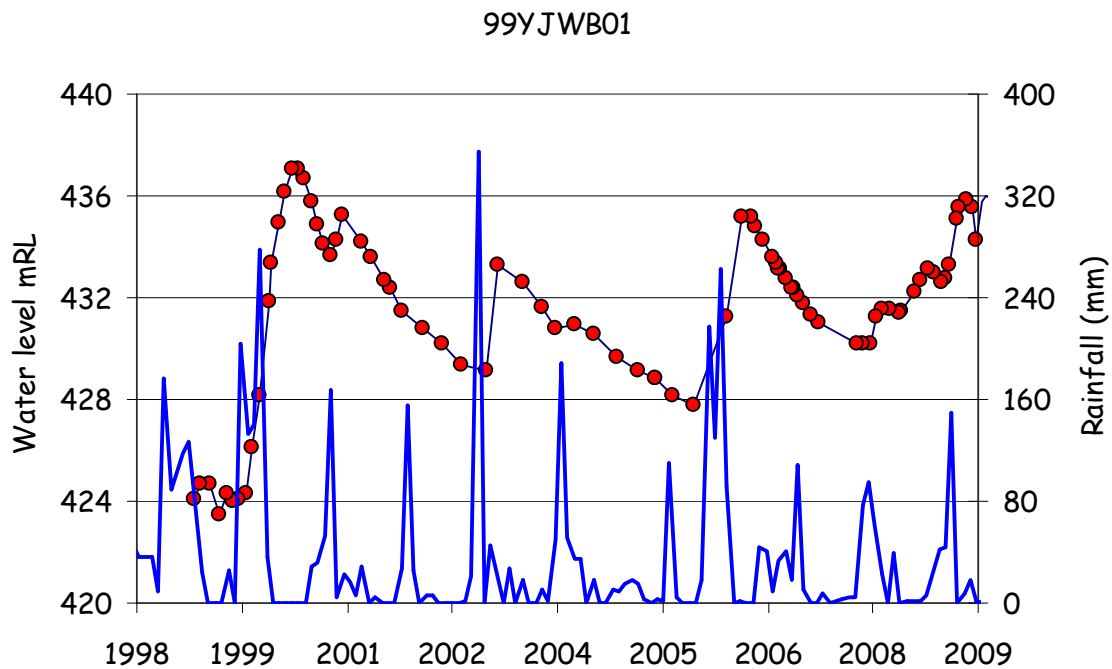


Figure 16. Water level in the CID aquifer adjacent to Weeli Wolli Creek 6.5km down gradient from the confluence with Marillana Creek. The rainfall record is shown to highlight the rapid recharge of the CID after intense rainfall events.

7.2 Impacts to groundwater chemistry

The Cl concentration in water can be used as a proxy to determine the degree of evaporation on groundwater chemistry. If evaporation is the dominant process the major ion data would fall on the evaporation line shown as a solid line in Figure 19. The plots show that except for HCO_3 ions, there are general increasing trends for the remaining major ion concentrations with the increase in Cl concentration. However, most of the major ion data fall to the left of the evaporation line suggesting that the increase in major ion concentration is not only due to evaporation but is also due to the dissolution of minerals. The latter occurs during recharge and ground water throughflow in the aquifer.

The shift (slope of the trend) from the evaporation line suggests addition of ions to the groundwater due to mineral dissolution. The larger the shift from the evaporation line indicating a higher rate of mineral dissolution.

A comprehensive geochemical model for the evolution of rainfall to groundwater and throughflow in the Hope Downs 1 area 50km east of Yandicoogina is presented by Dogramaci and Dodson (2009). Geochemical modelling of the evolution of rainfall to groundwater in the Hamersley Basin suggests that evapotranspiration of infiltrated rainfall in the unsaturated zone followed by carbonate minerals dissolution and clay minerals hydrolysis can accurately predict the measured major ion compositions in groundwater of the basin.

Additional processes that impact groundwater chemistry at Yandicoogina comprise the leakage of surface water from Marillana Creek to the underlying CID and alluvium. The interconnection between Marillana Creek surface water and leakage to the underlying aquifers is discussed in the previous sections. The result of water level analysis indicate an increased rate of leakage from the creek to the CID aquifer when the relative head difference between surface water and groundwater is changed due to mining activities such as dewatering of the aquifers and increase discharge saturating the creek beds.

The long term Cl concentration trends from selected CID and alluvium bores are shown in Figure 19 and 20. The graphs are tabulated according to the location of the sampled bores along the CID groundwater flow line from west to east. The order of the bores is from up gradient of Junction South West (JSW) towards Junction Central (JC), Junction South East (JSE), Billiard South and Billiard North.

Chloride concentration in groundwater from two CID bores (YPP32 and YPP33) at the western end of the JSW palaeochannel show an increasing trend from ~70mg/L prior to the RTIO Yandicoogina mine operation in 1998 to 90mg/L in 2005. Unlike the adjacent CID aquifer, the Cl concentration in two 5m shallow bores from the alluvium aquifer (Marillana 3 and Marillana 4) in JSW show a decreasing trend from ~200mg/L prior to 1998 to ~150mg/L in 1999.

The decrease in the Cl concentration of the alluvium aquifer is due to the mixing (recharge) of surface water in Marillana Creek, derived from dewatering the CID, with groundwater from the alluvium aquifer. The Cl concentration stabilises at ~150mg/L after 1999 suggesting equilibrium between the rate of leakage and the rate of evapotranspiration from the alluvium aquifer.

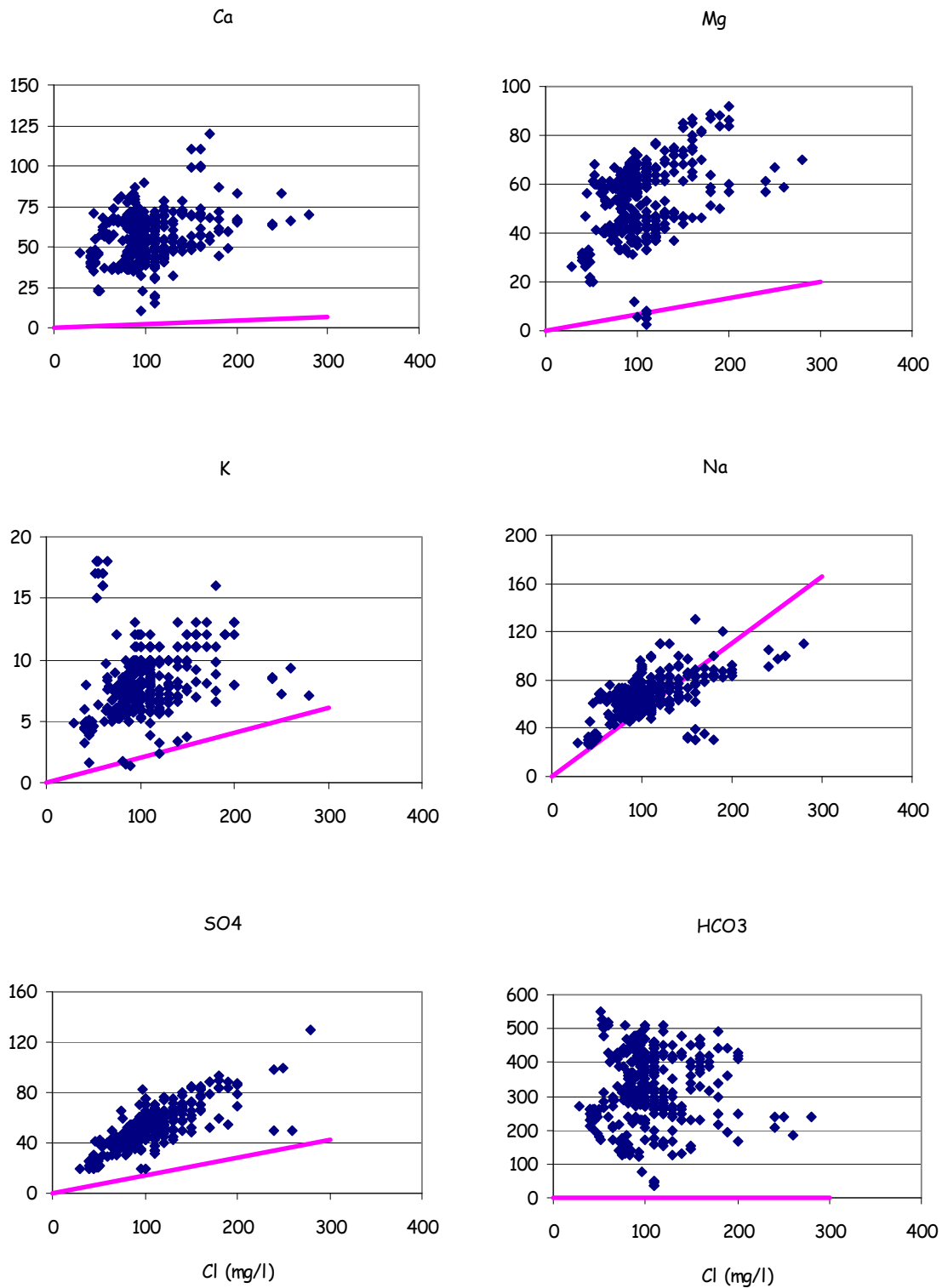


Figure 17. Major ion concentrations in groundwater of the CID and alluvium. Most of the data fall to the left of the evaporation line (solid line) indicating mineral dissolution.

The increasing trend in Cl concentration in the CID aquifer is also due to mixing; but with the more saline alluvium groundwater that is characterised by a Cl concentration of ~150mg/L. The estimate of the percentage of mixing between the two end members namely, alluvium and CID aquifers, can be carried out using a Cl mass balance equation as follows;

$$Cl_p \times 1 = \{Cl_{All} \cdot X + Cl_{CID} (1-X)\}$$

Where Cl_p and Cl_{CID} represent pre and post mixing concentration of Cl in the CID aquifer respectively; and Cl_{All} represents Cl concentration in the alluvium aquifer. Assuming complete mixing between the two aquifers, the results of the calculation suggests that 25% of the water in the CID aquifer is derived from leakage from the alluvium aquifer.

The drawdown in watertable in Junction Central due to dewatering activity since 1998 resulted in the expansion of the cone of depression up gradient towards JSW deposit. This has resulted in a higher head difference between the water level in the alluvium and the adjacent CID aquifer and consequently, a higher rate of leakage. The increased leakage rate results in an increase in salinity in the CID aquifer. The slope of the increasing trend suggests an increase in Cl concentration by 0.005mg/L/day over the last 10 years.

The Cl concentration from CID bore (YJ-P99) adjacent to Phil's Creek, 2km down gradient from the previous two bores shows a similar increasing trend from 80 to 120mg/L over the last 10 years. The increasing trend in Cl concentration corresponds to the concomitant drawdown in the watertable due to the dewatering operation in the adjacent JC deposit. The watertable rebound of ~10m and salinity decrease by 60mg/L is due to recharge from a 132mm rainfall event in February 2005 (Fig.20). The significant watertable rise and decrease in Cl concentration by one fold in response to a rainfall event is further evidence for the high rate of leakage and connectivity between surface water from Marillana Creek and the underlying aquifers.

Further down gradient at the eastern edge of, but still within the JC deposit, bores PC002, and PC007, the groundwater exhibits a similar pattern of decreasing salinity prior to 1998 and increasing trends after 1999. The rate of increase in Cl concentration is similar and consistent with the increase in the up gradient bores of ~20 to 30mg/L over the previous 10 years.

The Cl concentration in the CID aquifer down gradient of Junction Central (JC) has only been measured since 2006. The Cl concentrations in these bores are slightly higher than the up gradient bores and range from ~100 to 140mg/L. The slight increase in Cl concentration along the CID flow path is consistent with continuous mixing of the more saline alluvium and CID groundwaters. The Cl concentration of the alluvium bore in this part of the CID aquifer is ~140mg/L which is similar to the Cl concentration in the alluvium aquifer up gradient of JSE deposit.

The Cl concentration in the CID and alluvium aquifers down gradient from JSE in the Weeli Wolli Creek (Fig. 21) are similar to that measured at the up gradient bores. The average Cl concentration in the alluvium aquifer is ~200mg/L and in the CID aquifer is ~ 150mg/L (bores WW4 and JSE16).

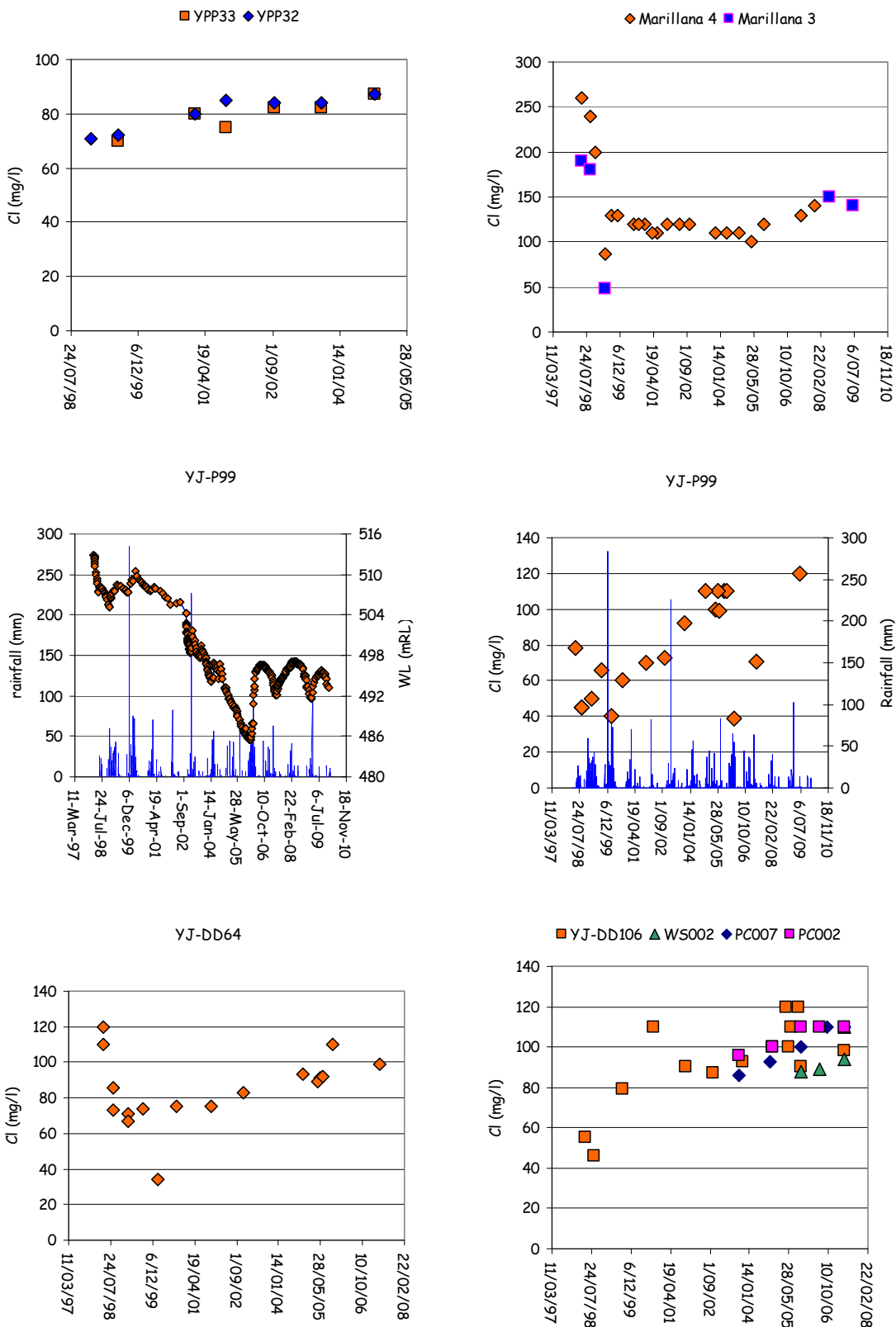


Figure 18. Chloride concentration in mg/L since 1997 from CID and alluvium bores at Junction South West (JSW) and Junction Central (JC).

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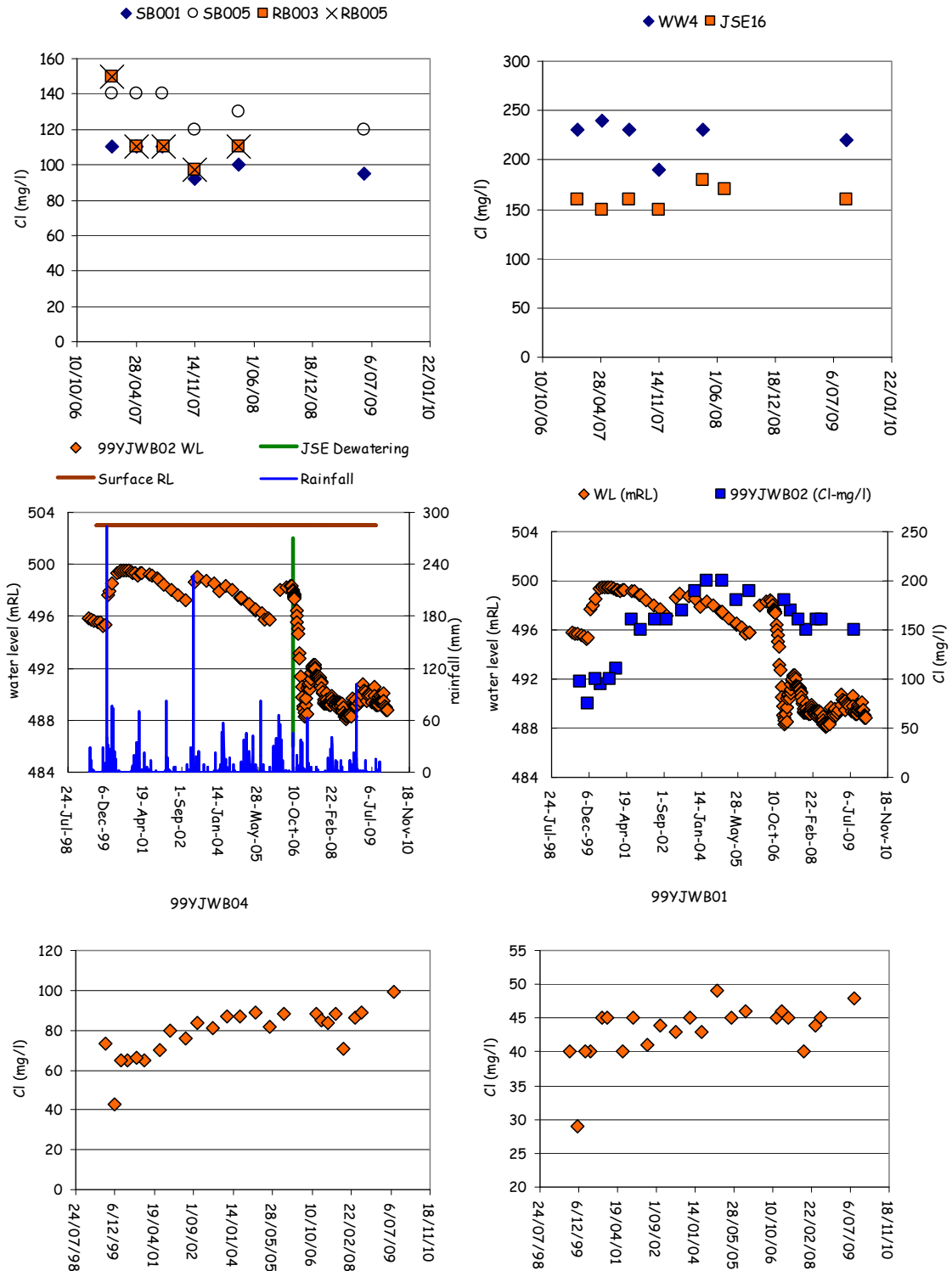


Figure 19. Chloride concentration in mg/L since 1997 from bore holes installed into the CID aquifer at Junction South East (JSE), Billiard South and Billiard North.

The dewatering of the CID aquifer at JSE and the reinjection of surplus water (Cl concentration of ~150mg/L) 800m down gradient 99YJWB02 bore commenced in September 2006. The continuous dewatering and reinjection coincides with the decrease in Cl concentration as is shown in Figure 21. The Cl concentration in the CID aquifer down gradient from the confluence with Marillana Creek (Fig. 21) show an increasing trend from 1999 to 2006 which is consistent with observations along the CID aquifer (bore 99YJWB04). The trend stabilises after 2006 at 85mg/L. The Cl concentration is lower in bore 99YJWB01 located 6km down gradient from the confluence and no change in Cl concentration can be observed since the monitoring started in 1999. The Cl concentration in the CID groundwater ranges from 40 to 50mg/L suggesting no influence of mining activity on water quality of the CID beyond 6km of the confluence.

7.3 Impacts to surface water chemistry in Marillana Creek

At present there are no reliable estimates of hydrologic fluxes between groundwater and surface water along RTIO's Yandicoogina operations. This gap in the hydrological cycle not only leaves the water budget of the CID aquifer uncertain, it also hampers mining operations in terms of uncertainty in the dewatering volumes required for dry mining conditions.

Identifying the chemical composition of the end members (i.e. groundwater, rainfall, and surface water) and comparing their chloride concentration will provide information on the impact of each of these processes on surface water chemistry. By measuring the Cl concentration along the axis's of the creek with that of groundwater from underlying alluvium and CID aquifers we may be able to quantify surface water leakage along the axes of the creek.

The Marillana Creek investigation program comprised two rounds of field sampling activities to investigate the nature and extent of leakage into the underlying aquifers, to assess potential risk to mining operations in terms of increased water volumes being discharged to the creeks from dewatering bore fields and pit sumps, and to develop a conceptual model for surface water groundwater interaction. The two rounds of sampling took place on the 27th April, and 28th August 2008 respectively.

The section of the Marillana Creek that falls within the RTIO tenements was divided into 10 segments of approximately 1000m length. Three additional sites 1000m apart were also selected down gradient of the confluence along Weeli Wollie Creek for similar measurements (Fig. 22). The flow rate, temperature, EC, and pH measurements were carried out at the headwaters of each segment. A 500mL sample of surface water from the headwaters of each segment was taken and sent to SGS laboratory for Cl analysis.

The flow rates were measured using Turbo-Prop propeller with electromagnetic pickup (accuracy of ± 0.1 m/s). The Eh was measured using a Pt electrode (YSI 3540 ORP) with Ag/AgCl reference calibrated with Zobell solution. The pH was measured using a glass/AgCl combination pH electrode (YSI 3530) calibrated with standard pH 4 and 7 buffer solution to an accuracy of ± 0.05 pH units. The temperature was measured using TPS field Lab -90 FL series using a silicon transistor built into the tip of the conductivity sensor with accuracy of $\pm 0.2^\circ\text{C}$.

Water and Cl mass balances were carried out for every segment to estimate the rate of seepage from the Marillana Creek to the underlying aquifers. The flow volume was calculated by estimating the cross sectional area of the creek and multiplying by the flow velocity at the start of each segment. Assuming no change in storage (steady state condition) the difference in calculated water balance in headwaters of each segment will represent the loss or gain of water from or to the underlying aquifers. The location of the measurement sites, flow velocity, calculated flow volume and the Cl concentration are shown in Table 1.

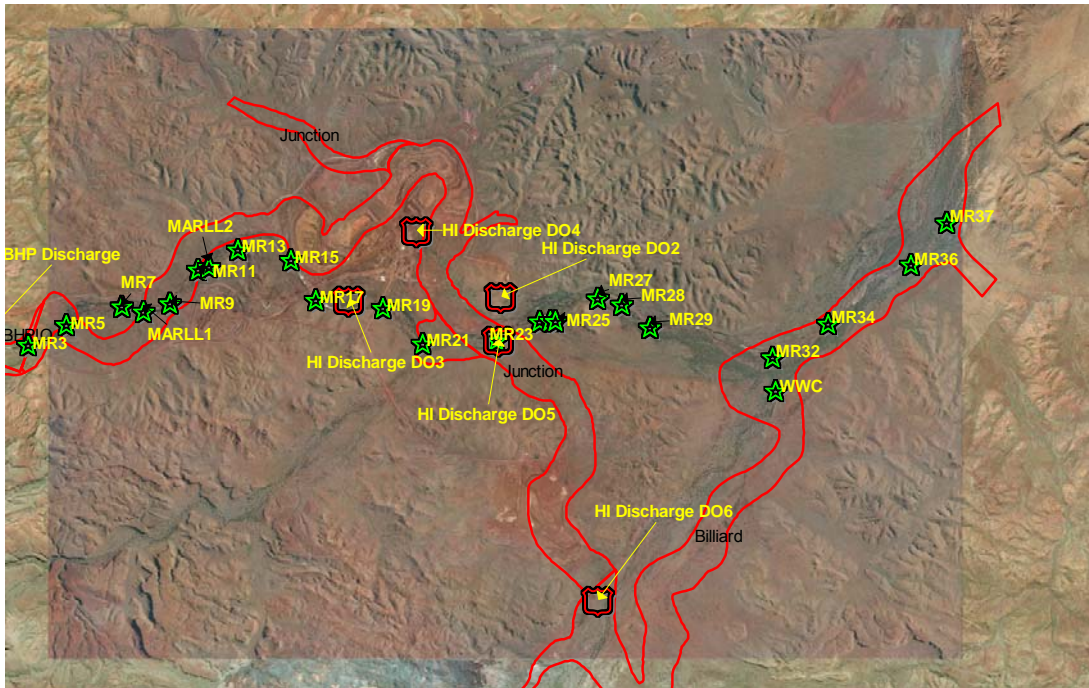


Figure 20. The CID boundary superimposed on an aerial photograph of RTIO Yandicoogina mine operation. MR denotes surface water measurement sites along the axis of Marillana Creek. BHPB and RTIO surface discharge points are also shown denoted by DO.

The Cl concentration of the two sampling programs along the axis of Marillana Creek show similar trends despite the four month interval between the first and second sampling programs. However there is a significant difference between the two sampling programs downstream of the confluence. The concentration of Cl beyond the confluence of Marillana and Weeli Wollie Creeks is much higher in April compared to the August sampling program (Figure 23). The dilution of Cl concentration due to the doubling of discharge of relatively fresh water from Hope downs mining operation (~50mg/L) to the Weeli Wollie Creek in June 2008 is the explanation for relatively low concentration of Cl beyond the confluence of Marillana and Weeli Wollie Creeks. This increased recharge to the CID aquifer was observed from water level data in the bores down gradient from the confluence with Weeli Wollie Creek.

The Cl concentration at MR3 which is 800m down gradient of the BHPB discharge point is ~125mg/L and increases to ~150mg/L at MR17 approximately 6km down gradient. The Cl concentration then decreases to ~105mg/L due to discharge of relatively fresher water (DO3) from RTIO mining operation into the creek (Fig. 22). For the next 4km the Cl concentration increases before reaching MR23 where a second outlet (DO5) discharges into the creek. At this location, the addition of relatively fresher discharge water also results in a decrease in Cl concentration.

Table 1. The site identification numbers, sampling locations, stream characteristics and Cl concentrations at each sampling site along Marillana Creek. The V, W, D, A and Q denotes velocity, width, maximum depth of the flowing stream, area and discharge in April 2008, respectively.

Sample ID		E (m)	N (m)	Cl (mg/l)		Stream Characteristics				
				April	August	V (m ³ /s)	W (m)	D (m)	A (m ²)	Q (m ³ /d)
MR3	Flowing	721519	7478378	121	128	0.5	3.2	0.40	0.40	29307
MR5	Flowing	722276	7478770	125	127	0.4	6.4	0.19	0.15	15759
MR7	Flowing	723382	7479136	128	128	0.3	3.3	0.26	0.27	9822
MR9	Flowing	724326	7479205	135	134	0.3	6	0.08	0.08	6013
MR13	Flowing	725682	7480253	142	135	0.2	14	0.09	0.05	6048
MR15	Flowing	726733	7480047	145	148	0.1	6	0.08	0.07	2540
MR19	No Flow	728561	7479131	137	130					
MR21	Flowing	729337	7478441	150	140	0.3	4.8	0.09	0.05	2696
MR23	Flowing	730806	7478508	105	100	0.3	2.8	0.18	0.1	3629
MR25	Flowing	731965	7478905	115	106	0.4	1.6	0.1	0.05	1382
MR27	No flow	732813	7479346	119	110					
MR29	No Flow	733845	7478792	119	111					
WWC				108	87					
MR34	Flowing	737377	7478876	136	104	0.5	6	0.08	0.04	5184
MR36	No Flow	739010	7480016	135	105	0.1	5	0.06		
MR37	Dry	739728	7480840							

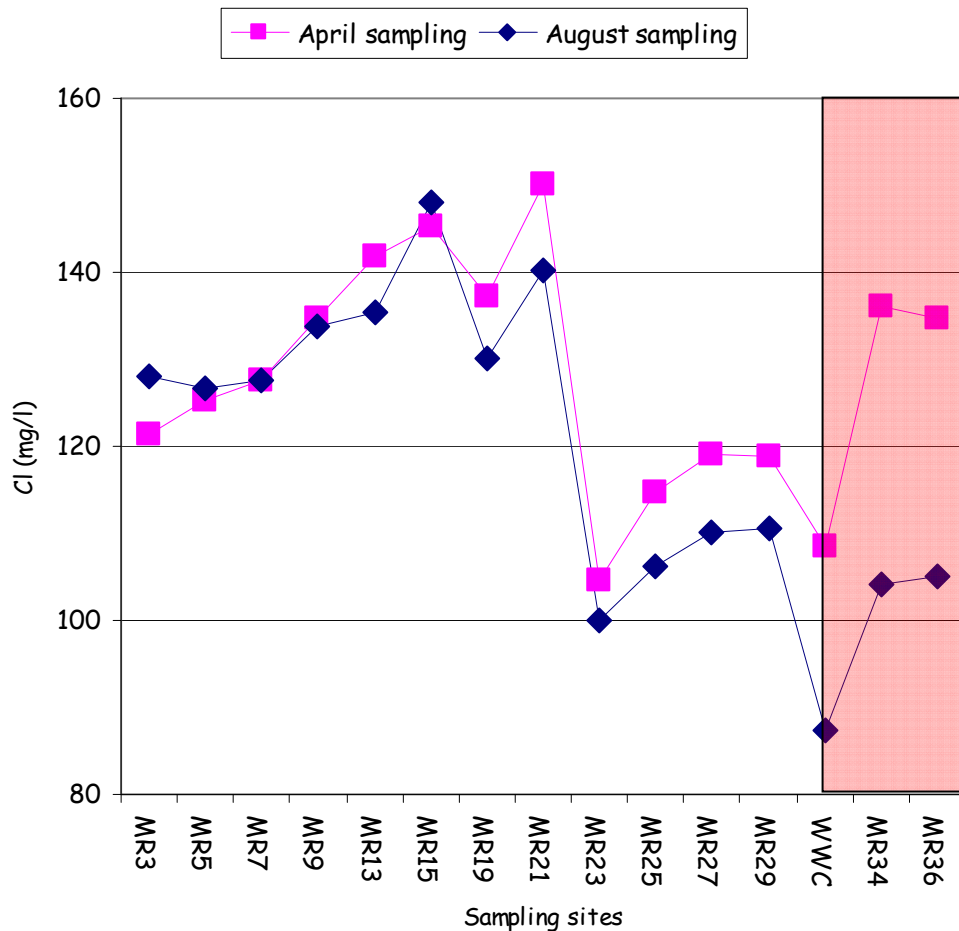


Figure 21. The chloride concentration of surface water along approximately 17km of Marillana Creek showing similar trend for sampling programs in April and August 2008.

A further increase in Cl concentration from 100 to ~120mg/L occurs before Marillana Creek surface water mixes with the fresher surface water of Weeli Wolli creek derived from Hope Downs 1 discharge. At this point the Cl concentration trend for both sampling points departs. The down ward trend in Cl concentration along the Weeli Wolli Creek in August is due to the increase in the discharge volume from Hope Downs 1 operation into Weeli Wolli Creek from 13,000ML in April to 19000ML in August (Fig. 6).

7.3.1 Surface flow volumes in Marillana Creek

The flow volume at the first observation site 800m down gradient from BHPB discharge point (MR3) was ~29ML/d and 8ML/d in April and August 2008, respectively. The higher volume measured in April is due to the higher rate of discharge from the BHPB discharge point. The measured BHPB discharge in April was ~500,000ML compared to 265,000ML in August.

The flow rate in April decreases from 29 ML/d at MR3 site to ~6ML/d ~2km down gradient at MR9 site. There is an apparent increase of flow between MR9 and MR11 to ~8ML/day then flow recedes to zero at MR17, approximately 9km from MR3 (Fig. 24).

The inflow into discontinuous pools between MR17 and MR19 ranged from 2 to ~5ML/d suggesting high rates of through flow under the Marillana Creek gravel. The inflow rate into

the pools also confirms the estimates of high hydraulic conductivity of the material filling the creek bed.

Downstream of MR19 site, the creek flow is due to RTIO Yandicoogina mining operation discharge into the Marillana Creek through the outlet DO3 (Fig. 22). In April the discharge volume was 290,000ML. The continuous flow diminishes beyond MR25 site into a series of pools along a 4km section up to MR29. The creek flow and water pools disappear beyond MR29 site and there is no evidence of surface flow at the last segment from the confluence with Weeli Wolli Creek.

The measured flow at the Weeli Wolli Creek is due to discharge into the Weeli Wolli Creek at Hopes Downs 1 gabion outfall approximately 20km up stream of the confluence. The flow volume at the confluence is 7ML/d, decreasing to ~1ML/d, 3.5km down stream at MR 36 before disappearing entirely at site MR37. Beyond this point there is no evidence of surface flow or base flow.

The discharge rates from DO3 and DO5 in August were three folds higher than that in April at ~300,000ML/d each. The general decrease in Cl concentrations along the creek also suggests the addition of higher percentage of fresher groundwater to the creek. The disappearance, pooling and emergence of water through the river bed material are due to changes in local topography and water transfer between aquifer and material underlying the creek bed.

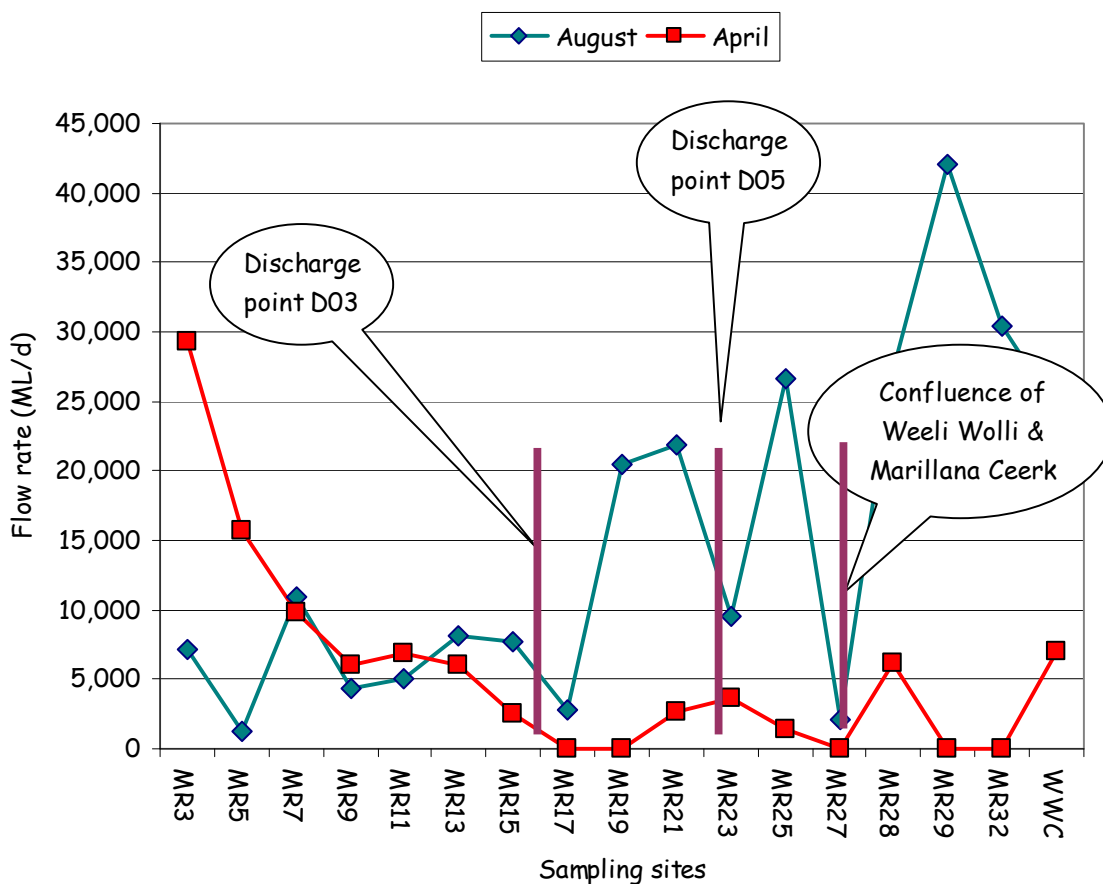


Figure 22. The surface water flow rate along Marillana Creek from BHPB discharge point to 26km down gradient.

7.3.2 Steady state water balance

The Cl concentration in the alluvium aquifer underlying the creek bed in Marillana 1 and 2 bores that represent the throughflow salinity are ~138mg/L and 147mg/L respectively. The difference in surface water and through flow salinity represents evapotranspiration loss by phreatophytic vegetation along the Marillana Creek. The rate of evaporation and evapotranspiration depends on the climatic condition, the cross sectional area of the open channel and the phreatophytic vegetation width and type at each site.

Assuming steady state conditions (i.e. no change in storage under the creek bed), the leakage flux from the creek bed can be estimated using a water and chloride mass balance.

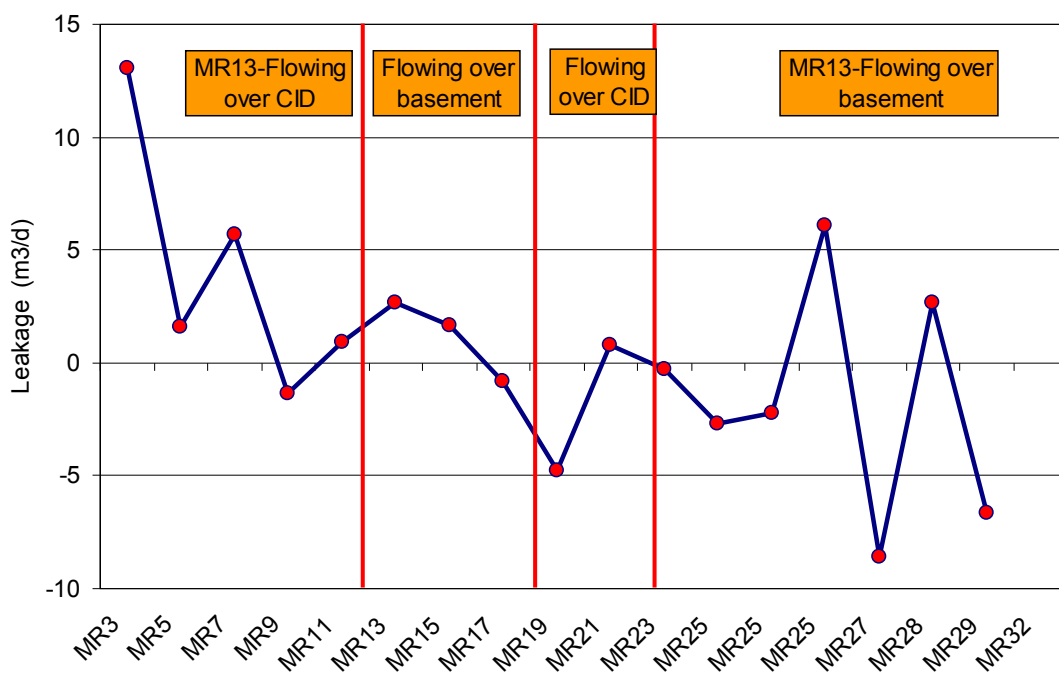


Figure 23. Water budget showing losses of surface flow through leakage

Throughflow volume for each segment was calculated using a thickness of the alluvium of 2m (Kirkpatrick and Dogramaci, 2009) and width of the Creek (estimated from aerial photographs). Evaporation losses were calculated by comparing Cl concentrations of the up stream with down stream sites for each segment. Evapotranspiration losses were calculated by comparing Cl concentration in the through flow (Marillana 1 and 2 bores) and surface flow.

For example, the measured Cl concentration in April increased from 120mg/L at MR3 to 140mg/L at MR13 suggesting moderate evaporation of surface water. Based on Cl mass balance calculations, the estimated water loss between MR3 and MR14 due to evapoconcentration is ~2ML/d.

The results of the calculations are shown in Figure 25. The downward trend represents leakage loss from the creek to underlying groundwater and the upward trend represents water gain from the underlying alluvium due to the change in capacity to conduct the volume flowing from the up stream site. The inflow to the pools along the creek occur due to the change in hydraulic properties of the alluvium, reduction in cross sectional area or bed rock

highs resulting in change in the creek gradient. Although the graph shows that most of the surface flow losses occur between MR3 and MR11, the loss from saturated alluvium underlying the creek bed occurs up to MR 29 approximately 15km from the BHPB discharge point.

The observed salinity and flow data coupled with mass balance calculations suggests that the loss of surface water discharge to the underlying aquifers along the 15km segment of Marillana Creek represents between 60 to 80 % of the total discharge. The general decreasing trend in Cl suggests that most of the discharge water leaks into the underlying aquifers along the 15km segment of Marillana Creek.

8. CONCLUSIONS

Dewatering of the CID aquifer has resulted in changes to groundwater level gradients and consequently the flow regime in the CID and surrounding alluvium/in-situ weathered aquifers along Marillana Creek adjacent to the open pit mine voids. The impacts however, are localised to 12km down gradient of RTIO's Junction Central operations.

The direct response to rainfall shown in most of the monitoring bores within the CID along Marillana Creek emphasises the permeable nature of the palaeochannel and the good hydraulic connection between the creek and underlying aquifers. The relative importance of recharge following intense rainfall events in comparison to the average dewatering volume from borefields at JC and JSE pits can be demonstrated through analysis of water level changes, surface discharges and Cl concentrations.

For example, the recharge estimated from the rainfall event in March 2005 that resulted in an 8m rise in water level in bore 99YJWB01 (Fig.20) is much greater than changes brought as a result of surface water discharge. Assuming an average width of the CID and alluvium aquifers of one kilometre, the volume of recharge along a kilometre length of CID aquifer was approximately 1.6GL. A typical borefield that comprises 5 production bores with a capacity of approximately 50 L/s each could pump 20,000m³/day (~ 0.6G/month). In order to remove the amount of recharge from this rainfall event the borefield would have to pump continuously for ~3months to abstract the recharge water. Such rainfall events and subsequent recharge equates to 25% of the borefield annual abstraction rate.

Long term observations indicate water levels can rise by up to 10m in the CID aquifer after intense rainfall events. This translates to ~16GL of water along the 20km section of Marillana Creek. This is greater than the amount of surplus water discharged to Marillana Creek over 12 months from combined operations (BHPB & RTIO). This has implications for dewatering volumes and predictions. Theoretically this volume of recharge should be included in the prediction of the maximum volume required to dewater to achieve dry mining conditions. However, examining previous numerical models and investigations shows that this is not the case and the amount of recharge from rainfall events have not been adequately captured in the groundwater models due to erroneous conceptualisation. In addition, permanent discharge along the creek creates saturated conditions prior to rainfall events that makes recharge more rapid compared to natural dry creek bed conditions.

The chloride concentrations along Marillana Creek from various aquifers and surface water provides powerful evidence to substantiate the model for the localised impact of the discharged surplus water into the creeks. The estimated 20% loss of water in the Marillana Creek due to evaporation and evapotranspiration should result in increased Cl concentration in groundwater via through flow down gradient of the mining operation. However this change has not materialised and no change has been observed beyond 12km from JC mining area. Moreover, the approximately 65% decrease of Cl concentration from 150mg/l at the mining site to 50mg/l in monitoring bore (99YJWB01) corroborates the dominance of recharge along

creek drainages as a result of rainfall events. Any increase in salinity at the mine site is masked by dilution through mixing of fresh rainfall with Cl concentrations of <1mg/l with groundwater from CID aquifer.

Contouring pre mining and post mining water level and calculating the groundwater gradient throughout RTIO's Yandicoogina lease, results in a groundwater gradient of 2m per kilometre (Fig 26 & 27). The 2008 water level contours shows the complexity around the dewatering borefields, however the water level at the western edge of Oxbow (520m AHD) is equivalent to water levels recorded in 1974. This is also true at the northern end of the Billiard deposit where the water level (440m AHD) is similar to the measured water level in 1999. This corroborates the model presented and discussed in this report, that dewatering and discharge into Marillana Creek has significant local impact on the groundwater system in terms of reversal of flow gradient but no impact on the larger catchment scale. The overall volume of dewatering from Yandicoogina has not increased but decreased due to evaporation. The local scale increase in the dewatering of individual pits is only due to constant recycling of groundwater.

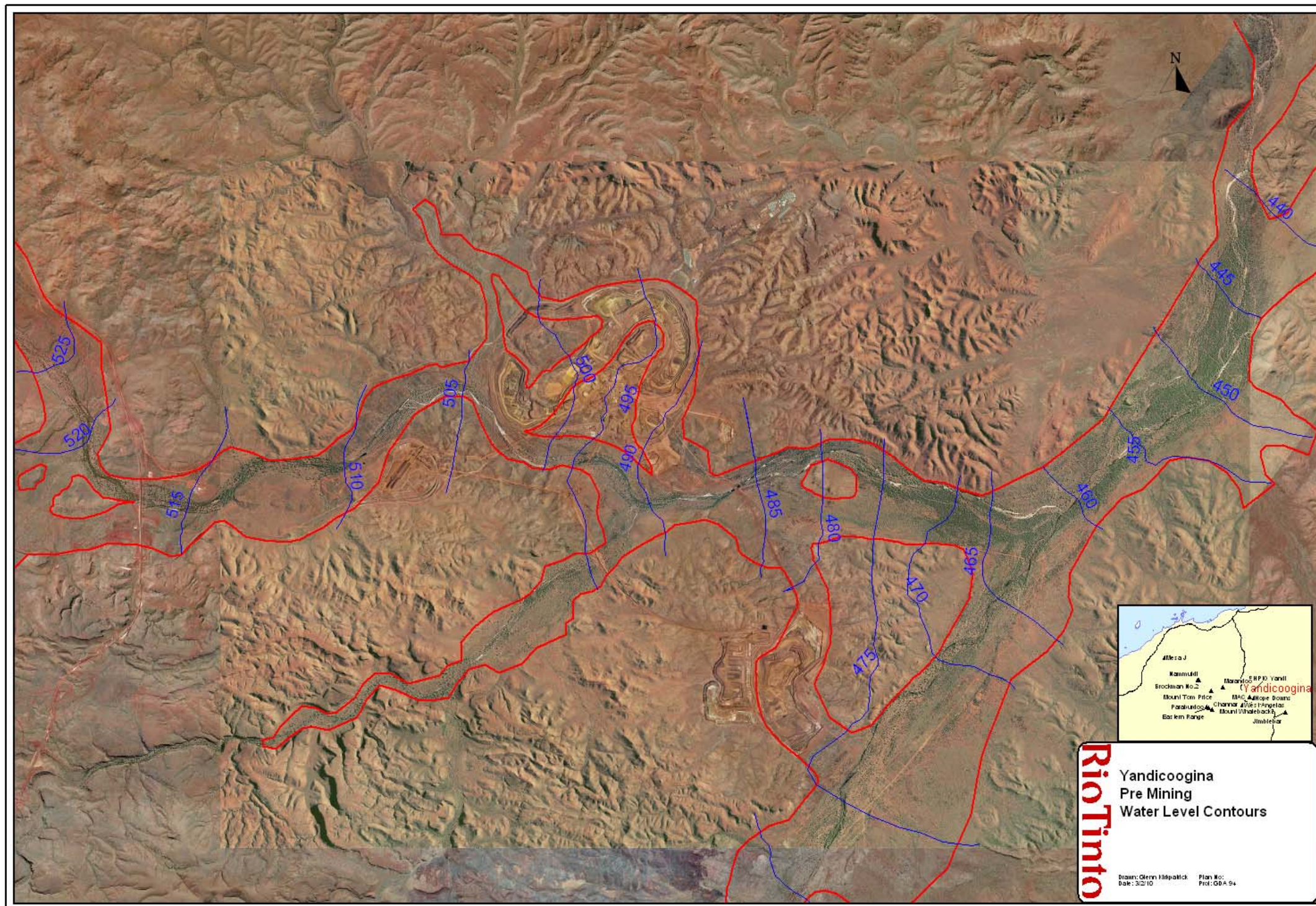


Figure 24. Yandicoogina pre mining water level contour map

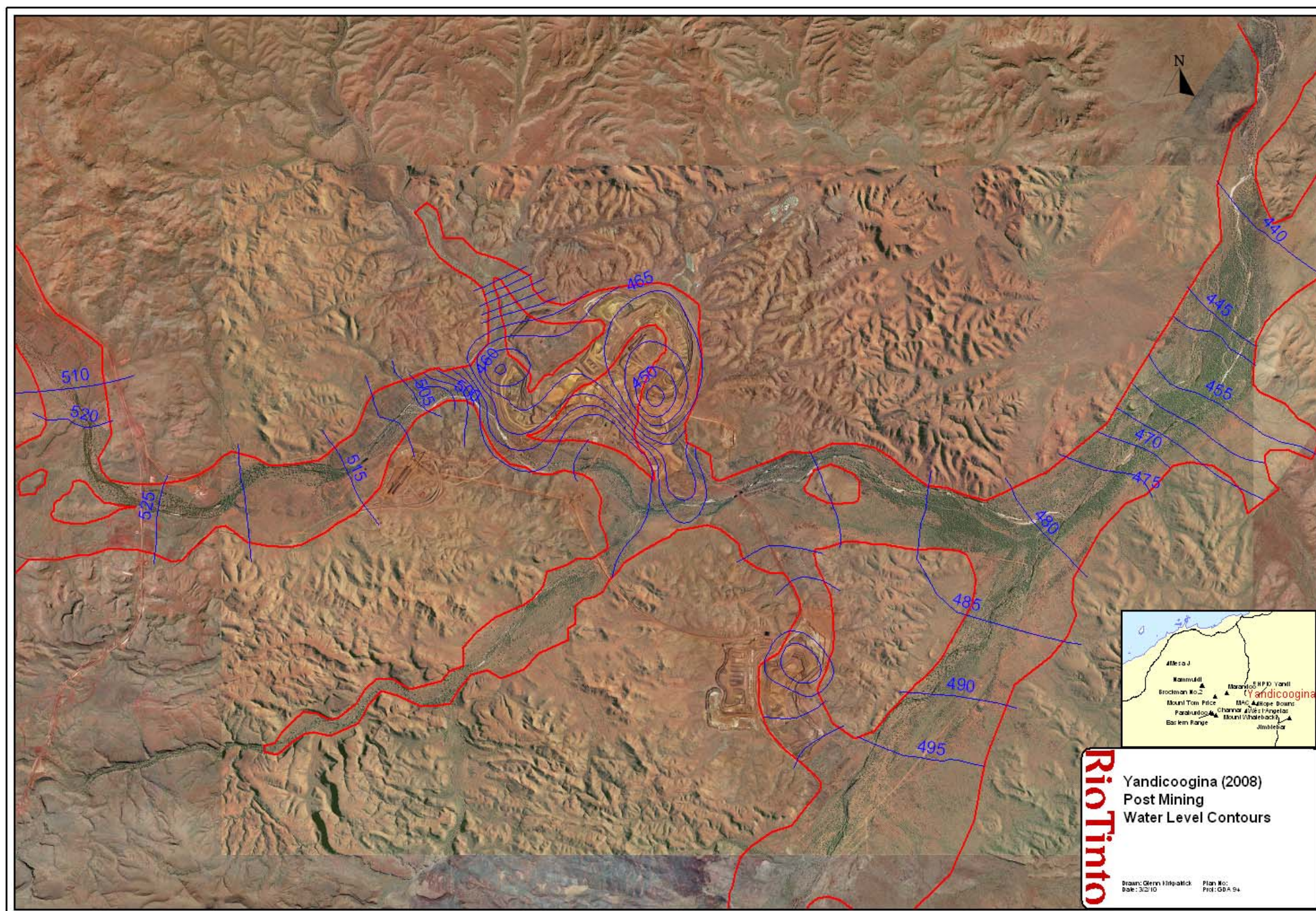


Figure 25. Yandicoogina post mining water level contour map (2008)

9. SUMMARY AND RECOMMENDATIONS

The immediate response of groundwater levels in the CID aquifer to the flow regimes in both Marillana and Weeli Woolli Creeks suggest a direct connection between surface and groundwater. The long record of water level monitoring (1974-2009) shows the impact of mining at Yandicoogina is limited to 12km down gradient from Junction Central mining area. The water level record in the CID beyond this point does not show change since monitoring started in 1991.

Similarly, the observed chloride (Cl) concentrations used as a proxy to salinity, monitored since 1998 in the CID groundwater show limited increase due to discharge to surface water. The Cl concentration of the CID groundwater has increase by ~20% from 70mg/L to 90mg/L in the up stream section west of JC mining area and from 120mg/L to 150mg/L down gradient of the JC mining area. This represents water loss to evaporation and evapotranspiration of ~20% as calculated from chloride and water mass balance along Marillana Creek. The remaining surface water flow recharges back to the CID and alluvium aquifers.

The impact of increased leakage has been observed in most monitoring bores. This has resulted in increased dewatering volumes from bore fields and sumps at JC and JSE. The estimated average seepage losses range from 5 to 10GL/a depending on the variation in hydraulic properties of the saturated thickness and cross sectional area of the underlying alluvium.

The discharge of 4.5ML/d by RTIO up stream of MR19 sampling site at DO3 is contributing leakage to the CID aquifer up stream of JSE. Assuming similar rates of discharge loss to that along JSW from the BHPB discharge outlet, approximately 2ML/day of this discharge volume is eventually recycled through the dewatering bores at JSE.

The lowest Cl concentration measured in the Yandicoogina site, occurs 12km down gradient from the JC mining area. The 10 year consistent record of Cl concentration of 45mg/L in the CID aquifer adjacent to the Weeli Woolli Creek which is 65% less than that measured at JSE area suggest that the groundwater is diluted by fresh recharge along the creek. The ~60% dilution of Cl in the CID aquifer also suggests that the groundwater system along the Weeli Woolli Creek is dominated by vertical flow (recharge) rather than horizontal flow (CID through flow).

Although, the 30 year water level record and 10 years of major ion concentration record show significant impact on a local scale in terms of disturbance to the natural groundwater system, the observations and analysis suggests to date, that the impact on water quality and quantity is limited to 12km from the JC mining area. Therefore, the down stream impact of mining at Yandicoogina on water quality and quantity down stream of 12km at worst is minimal and at best is non existent.

The main results of this study indicate that dewatering volumes can be reduced if the discharge outlets are relocated to points down stream of the active mining operation. The relocation of the discharge outlet DO3 and DO5 from the current locations to down stream of JSE pit can reduce the leakage volume by 80%. The relocation of the BHPB discharge outlet would greatly reduce the required dewatering for mining below watertable at JSW.

It is likely the removal of surplus dewatering water would have a detrimental impact on the vegetation along Marillana Creek over time as dewatering is affected; however this would be mitigated by intermittent creek flow events following rainfall.

The results also indicate it is highly unlikely that mining of Billiards deposits would be feasible whilst Hope Downs 1 discharge was occurring upstream in Weeli Wolli Creek without substantial pumping as a result of re-circulation. This should be accounted for within the business Strategic Production Planning for Yandicoogina output.

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