Western Australia Iron Ore

Mining Area C Southern Flank Proposal

Hydrological Impact Assessment and Water Management Summary

Contents

Note to Reader:

This document sets out the BHP Billiton Iron Ore assessment of groundwater and surface water related impacts associated with the Mining Area C Southern Flank Proposal. When discussing areas within the Proposed Mining Area C Development Envelope the following terms will be used:

- **North Flank** – refers to the existing approved mining operations at Mining Area C. This includes all pits within in the *Approved Mining Area C (Northern Flank) Development Envelope* as defined in PER document.
- **South Flank** – refers to the proposed mining operations within the South Flank valley. This includes all pits included in the *Proposed Southern Flank Development Envelope* as defined in PER document.

- **Mining Area C (MAC) Combined Operations** – refers to the combined North Flank and South Flank mining operations. This includes all pits included in the *Proposed Mining Area C Development Envelope* as defined in PER document.

1 Introduction

1.1 Context of this assessment

This hydrological change assessment has been carried out to inform and support the Mining Area C Southern Flank Proposal. The proposal includes continuing existing operations at North Flank and development of the new satellite deposits at South Flank (Vista Oriental, Grand Central and Highway). The proposal is located approximately 100 km north-west of the town of Newman. The regional location of the proposal is shown in Figure 1, with the location of the South Flank deposits shown in Figure 2.

This assessment builds on existing work carried out to support previous North Flank assessments and makes use of additional investigations and modelling to assess the additional hydrologic change of the proposal. This was completed as part of the broader environmental impact assessment to establish the range of potential changes in surface and groundwater conditions which may result from the proposal. As per previous assessments, impacts have been assessed for the Central Pilbara catchment with an updated understanding of the South Flank valley being provided by additional field investigations and modelling.

The proposal includes the development of new satellite ore bodies at South Flank known as Vista Oriental, Grand Central and Highway, which are located approximately 8 km to the south of the existing North Flank operations (Figure 2). The proposal includes the requirement for additional ground disturbance not assessed as part of the original proposal (including existing approved North Flank operations and the development of the proposed new satellite deposits at South Flank). The operation is likely to have a nominal throughput of up to 150 Million tonnes per annum (Mtpa) over a mine life of approximately 30 years. Conventional open pit mining methods will continue to extract ore from the existing approved North Flank deposits and the proposed South Flank deposits, which are located approximately eight kilometers south of existing processing facilities at North Flank. Incremental mining activity will be supported by the construction of new infrastructure as follows:

- 2 additional crushing facilities at Highway and Vista Oriental
- Overland conveyors to existing Ore Handling Plant (OHP) at North Flank
- Upgrades to North Flank OHP and Rail facilities.

The continued development of below water table mining operations and the interception of surface water flow volumes formed the basis for assessment of the potential threatening processes. The indicative mine schedule used in the assessment reflected the South Flank life of mine schedule. Approximately 8% of the material in the additional satellite deposits are below water table with 50% of below water table ore occurring in the Highway orebodies in the west of the project area.

The assessment also recognises the temporal and spatial variance in water balance outcomes and cumulative effects from other mining activities, and predicts changes to hydrological condition which could eventuate owing to a range of possible mine schedules, development sequences and mine closure strategies.

The assessment considered the following hydrological change aspects at key water dependent receptors (Coondewanna Flats, Weeli Wolli Springs and Ben's Oasis) and also the water resource:

- Groundwater level
- Groundwater quality
- Surface water flow volume and persistence
- Surface water quality

The assessment was completed in context to the broader adaptive management approach for the upper Weeli Wolli catchment which focuses on the key water dependent receptors, including the water resource and importantly considers impact in relation to outcome based thresholds which have been already adopted for the key assets. The approach allows for the progressive development of scientific knowledge and therefore sets precautionary thresholds and objectives which reflect this level of technical knowledge, including the application of preventative and mitigating controls.

As many preventative controls are already in place to mitigate impacts under the existing Mining Area C Life of Project Environmental Management Plan (EMP Revision 6) (BHP Billiton Iron Ore 2015) and the Mining Area C Closure Plan (BHP Billiton Iron Ore 2014), the outcomes and impact predictions do recognise some of these controls, such as a water supply being sourced from proactive dewatering areas and managed aquifer recharge (MAR) to offset the potential impacts from groundwater abstraction activities.

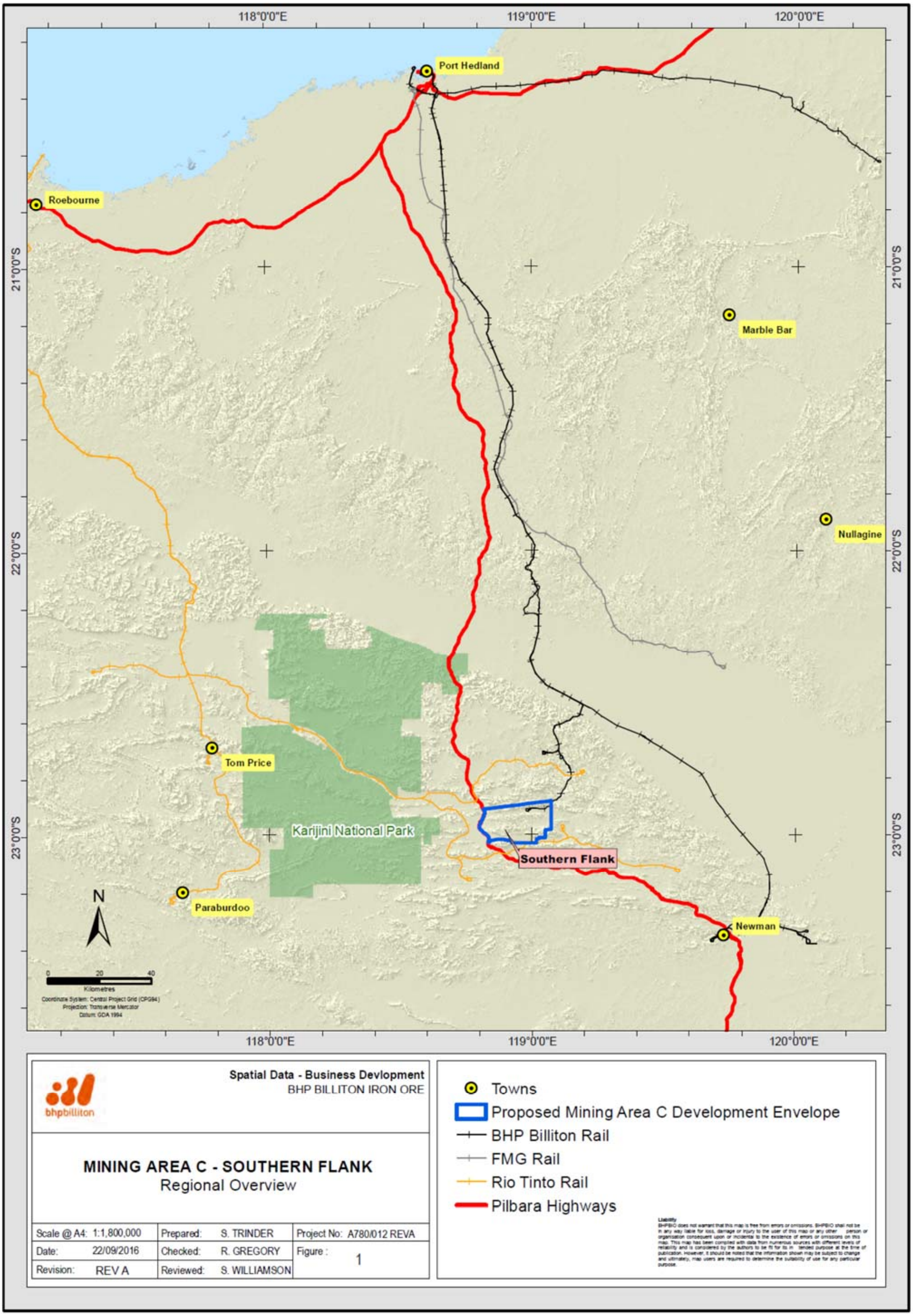


Figure 1: South Flank project location and regional overview

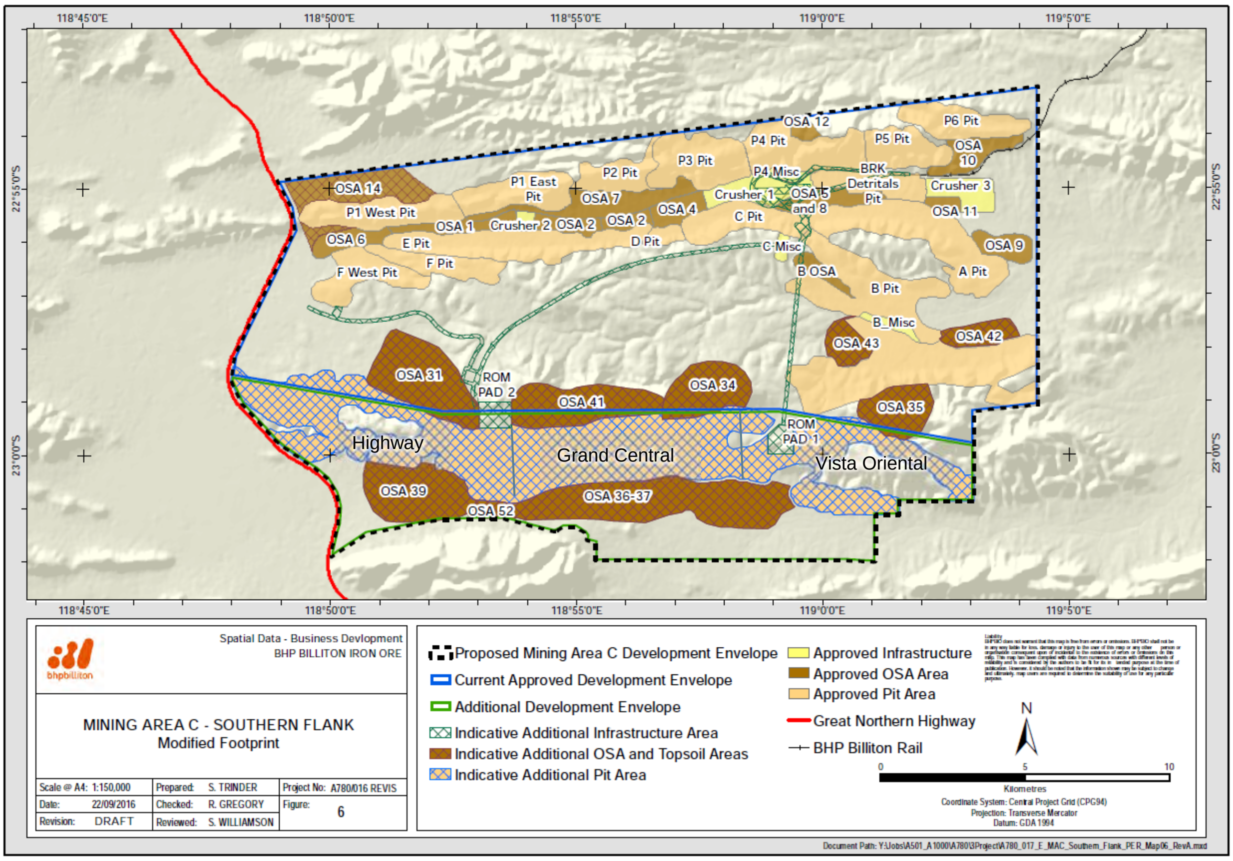


Figure 2: Mining Area C North Flank and South Flank locations

2 Regional water management approach

The strategic approach to site water management is currently outlined in the EMP Revision 6 (BHP Billiton Iron Ore 2015). As part of this proposal the water management aspects of the EMP have been moved into an updated Central Pilbara Water Resource Management Plan (BHP Billiton Iron Ore 2016d) which will be used to manage impacts to key water dependent receptors.

To meet our commitments and obligations, a regional water management strategy (with underlying catchment plans) has been developed to provide a regionally consistent methodology for identifying and managing water related environmental and community risks, considering:

- Hydrological changes (baseline, current and future conditions of groundwater, soil moisture and surface water) resulting from BHP Billiton Iron Ore dewatering operations.
- Receiving receptors (water resources, environment, social and third-party operations), identified value and hydrological dependency (groundwater, soil moisture and/or surface water).
- Potential impacts (predicted and actual) attributable to BHP Billiton Iron Ore mining activities.
- Required risk-based adaptive management techniques that are feasible (tested and practicable) to mitigate potential impacts to acceptable levels during operations and closure.

The regional water management approach iteratively collates the key findings of eco-hydrogeological technical studies to inform the required adaptive management to enable achievement of outcome-based objectives. The adaptive management is risk based and is expected to proactively counteract, mitigate or manage potential impacts (both predicted and actual) to an acceptable level.

The approach addresses the overall water catchment management area and the specific BHP Billiton Iron Ore operations within the catchment (Central Pilbara, Mining Area C Hub). It applies catchment scale water management principles, allows for future approval processes and will simplify and provide transparency on water management criteria, risks, controls and water licenses.

The regional water management approach requires that specific regulatory commitments are linked to outcome-based objectives and adaptive management methods for significant receptors if impacted by BHP Billiton Iron Ore operations. The BHP Billiton Iron Ore adaptive management process for water in the Pilbara is detailed in Figure 3.

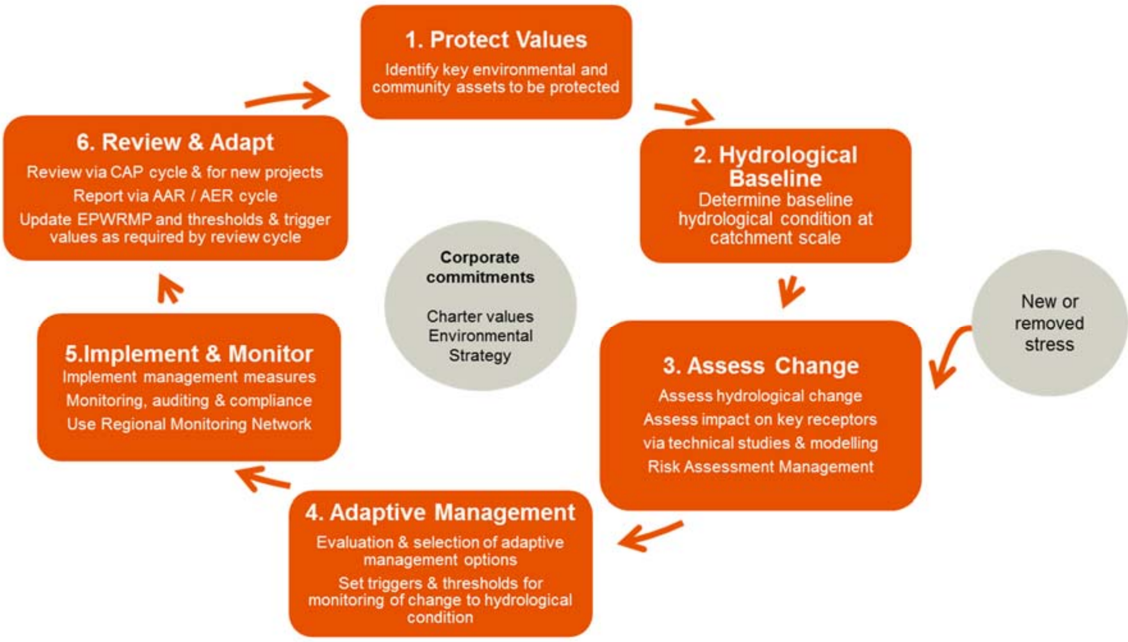


Figure 3: The adaptive management approach implemented for water resources within the Pilbara.

3 Impact assessment references

This document summarises elements from various work programs completed to support environmental approvals for both North Flank and South Flank and recent technical assessments carried out to improve the level of water and ecological knowledge. The supporting document structure is provided in Appendix C. The reports completed as part of the assessment are referenced as follows:

1. Conceptual hydrogeology –
   Hydrogeological Assessment for Mining Area C (RPS 2014a).
   South Flank Hydrogeological Investigation Summary (BHP Billiton Iron Ore, 2016a)
2. Surface water change assessment –
   - Mining Area C Environmental Management Plan Revision 6 Surface Water Assessment, (RPS 2014).
   - South Flank Surface Water Environmental Impact Assessment (MWH, 2016)
3. Predicted water levels and groundwater change assessment –
   - Hydrogeological Assessment for Mining Area C (RPS 2014a).
   - South Flank Numerical Groundwater Modelling (BHP Billiton, 2016b)
   - Juna Downs Injection Modelling (BHP Billiton, 2016c)
   - Juna Downs MAR Scheme Ecohydrological Monitoring Framework (AQ2, 2016b)
   - Coondewanna Flats Eco-Hydrology Review and Conceptual Model (AQ2, 2015).
   - Coondewanna Flats Ecohydrological Conceptualisation (AQ2, 2016).

4 A summary of water effecting activities and threatening processes

The project scope and mine plan schedule included in the proposal is summarised in the Mining Area C Southern Flank Proposal and assumes mining continues until 2054. The following water effecting activities have been assessed as part of the hydrological change assessment and presented in Figure 4:

Dewatering - Dewatering is a key mining activity that will be required to access below water table ore and includes the Highway Pushbacks 1, 3, 5 , Grand Central Pushbacks 12, 13, 14, 15, 16, 19 and Vista

Oriental Pushbacks 20, 21, 22, 23, 25, 27, 28. The lowering of groundwater levels during mine dewatering activities results in a propagation of drawdown and the modification of the hydrological conditions away from the orebody aquifers and more regionally towards the key receptors of Coondewanna Flats, Weeli Wolli Spring and Ben's Oasis.

Water Supply Drawdowns - A water supply borefield will be required if mine dewatering volumes fall below water demand volumes. Water supplies for MAC Combined Operations will continue to be delivered from dewatering and proactive dewatering activities with surplus transferred between North Flank and South Flank where feasible. Additional water supply will be sourced from the Camp Hill borefield located 15 km west of North Flank (previously assessed as part of the EMP Rev 6 Proposal).

Reduced Surface Water Availability - Surface water flow and runoff will be intercepted and diverted to prevent inflow and inundation of the open pits, and to prevent flooding of infrastructure. Proposed pit and overburden storage area (OSA) developments have the potential to impact surface water resources by:

1. changing local surface water flow patterns,
2. affecting surface water runoff volumes and quality,
3. increasing the risk of erosion and sedimentation, or
4. introducing contamination to the subsurface from chemicals.

Surface water within the Upper Weeli Wolli catchment either drains east towards Weeli Wolli Creek or west to Coondewanna Flats.

Management of surplus water - The discharge of surplus mine water will occur during periods when the mine water demand is less than the dewatering rate. The release and discharge of surplus mine dewatering can alter groundwater levels, impact riparian tree health and change water quality. MAR (through infiltration and injection) is the preferred method of surplus management. MAR injection at Camp Hill was assessed as part of the previous EMP proposal and an additional MAR injection scheme at Juna Downs is presented as part of the CPWRMP. The ongoing MAR at North Flank (currently located at A Deposit) appears to be a feasible alternative to mitigating drawdown at a key receptor.

The storage and handling of waste products - The inappropriate handling and management of soluble waste materials has the potential to alter surface and groundwater quality.

Pit void - The backfilling of pit voids to above pre-mining water is an option available as part of the mine closure strategy and will be considered where unacceptable impacts to water quality or quantity are likely as a result of pit lakes. Using this outcome based management strategy will mitigate the risk of pit lakes as a water effecting activity. Once dewatering ceases the recovery of the water level to pre-mining levels is slower than the rate of drawdown and in some instances may take centuries.

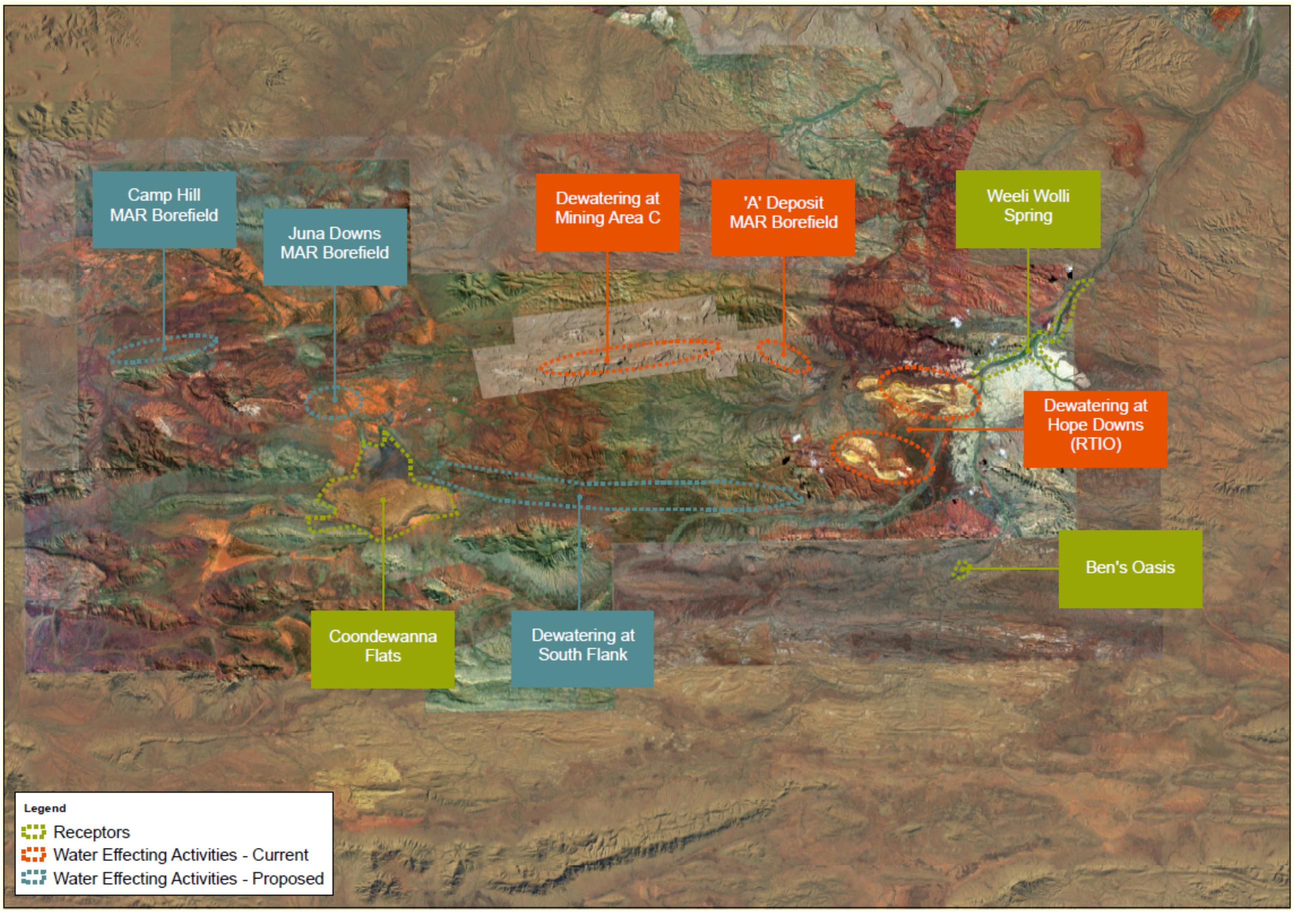


Figure 4: Water effecting activities associated with the Southern Flank Proposal.

5 A description of the assets of value

The water dependent receptors which could potentially be impacted from changes in hydrological conditions associated with the proposal development have been established based on depth to groundwater monitoring, surface water flow and inundation mapping and vegetation mapping over multiple years. The primary water dependent receptors identified are:

1. The Water Resource (surface and groundwater)
2. Coondewanna Flats (including Lake Robinson)
3. Weeli Wolli Spring (including Ben's Oasis)

The locations of the assets are presented on Figure 4 and a detailed description of the environmental receptors and hydrological dependency is detailed in the Strategic Environmental Approval (SEA) Ecohydrological Change Assessment report (BHP Billiton Iron Ore, 2015). An updated assessment of hydrological dependency for Coondewanna Flats (AQ2, 2016) has been completed as part of this EIA.

5.1 Water resources and conceptual model

The hydrogeology and water resources of the Central Pilbara region are summarised in the SEA Ecohydrological Change Assessment report (BHP Billiton Iron Ore, 2015c). Three primary water resource aquifers exist within the Upper Weeli Wolli catchment including 1) the orebody aquifer developed through mineralisation of the banded iron formation, 2) the Wittenoom dolomite which is located within the topographic low areas and 3) the overlying alluvial tertiary detritals and calcretes. The aquifer yields, permeability and storage volumes vary laterally and vertically through each aquifer unit and the hydraulic connection between the systems is considered to be variable and constrained by structural controls, mineralisation and vertical permeabilities.

Figure 5 shows the updated conceptual groundwater model, showing recharge and discharge areas, groundwater flow directions and the locations of dolomite dykes within the catchment.

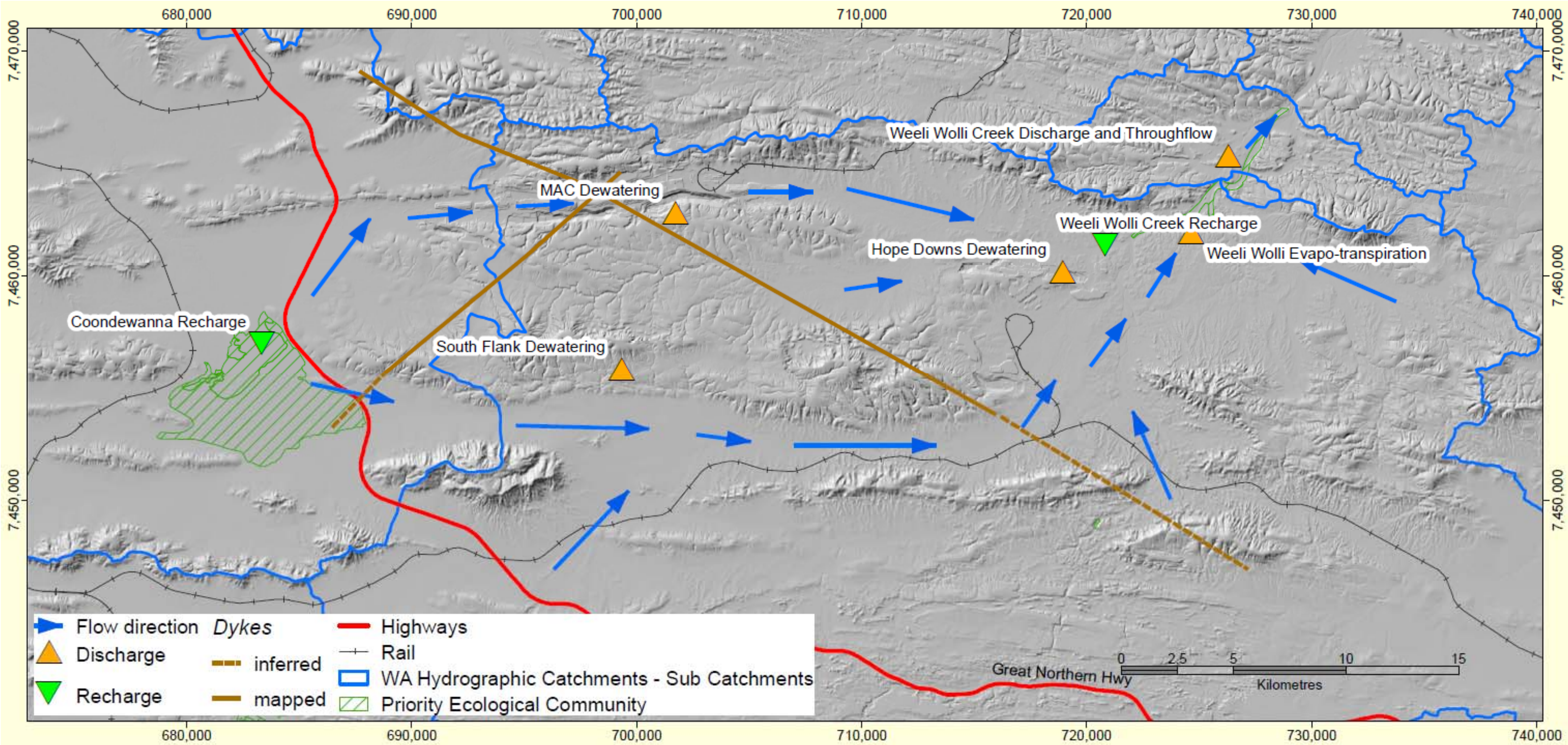


Figure 5: Conceptual Groundwater flow within Project area.

Groundwater flow in the catchment flows broadly from west to east, following the dolomites and sedimentary units located in the valleys. Structural elements such as dykes and fault systems are known to intersect the dolomite and create local, leaky barriers to groundwater. While some of these dykes have been mined through in North Flank, none of the South Flank pit designs intersect any dykes below water table.

Recharge primarily occurs in the Coondewanna Flats area as a result of ponding in Lake Robinson after large rain events. A small proportion of recharge takes place across the remainder of the catchment, associated with seasonal flow in Weeli Wolli creek and diffuse rainfall recharge occuring in areas with exposed bedrock.

Discharge is dominated through outflow at Weeli Wolli springs and groundwater throughflow beneath the springs. Evaporation and transpiration through vegetation usage of groundwater, particularly around Weeli Wolli Springs, accounts for the remainder of groundwater outflow from the catchment.

The natural water balance for the Upper Weeli Wolli catchment is estimated to be made up of inflows and outflows of around 12.4 ML/d. Of the total volume abstracted as part of the proposed mining activities between 50% and 70% is predicted to be from aquifer storage and the remainder from through flow.

5.2 Coondewanna Flats

Coondewanna Flats is a Priority Ecological Community (PEC) (Onshore Environmental, 2015) located about 18 km south west of BHP Billiton Iron Ore's North Flank operations. The Great Northern Highway passes to the east of the Coondewanna Flats boundary and Rio Tinto's West Angelas to Cape Lambert rail line passes to the west. Lake Robinson is an ephemeral shallow lake which forms within Coondewanna flats during the wet season.

Coondewanna Flats is an internally-draining surface water feature and has a catchment area of approximately 866 km^2. The flats occur within an intermontane area bound by hills of Mt Robinson and The Governor to the east and south, and Packsaddle and Mount Meharry to the north and west.

Surface water flows towards the flats from the north, west and south. Surface water runoff accumulates on the flats before being lost to evaporation or infiltrating into the Tertiary detrital, where it replenishes soil water in the unsaturated zone and contributes to groundwater recharge. Lake Robinson occurs within a topographic low at the north-eastern extent of the flats and is one of the terminus areas for catchment runoff. It supports distinct *Eucalyptus victrix* woodland vegetation communities. The surrounding flats are characterised by poorly-defined drainages with Mulga woodland vegetation and occasional scattered Eucalypts.

The depth to groundwater beneath the Coondewanna Flats is about 20 mbgl (AQ2, 2016) suggesting that interaction between the groundwater system and terrestrial ecosystems is unlikely. Ongoing studies on the hydrology and vegetation water use have found that vegetation communities are highly likely to be dependent on the surface water regime of the flats.

Environmental values

Coondewanna Flats (including Lake Robinson) includes several vegetation communities with ecological value and is listed by the Department of Parks and Wildlife (DPaW) as a Priority Ecological Community (PEC) (Onshore Environmental 2015). The Coolibah-lignum flats: *Eucalyptus victrix* over *Muehlenbeckia* community is described by DPaW as:

> Woodland or forest of *Eucalyptus victrix* (Coolibah) over thicket of *Muehlenbeckia florulenta* (lignum) on red clays in run-on zones. Associated species include *Eriachne benthamii, Themeda triandra, Aristida latifolia, Eulalia aurea* and *Acacia aneura*. A series of sub-types have been identified:
>
> - Tussock grassland of *Eriachne benthamii, Eulalia aurea* and *Themeda triandra* with open woodland of Eucalyptus victrix over open shrubland of *Duma florulenta* on orange brown loamy clay on alluvial plains. This vegetation type is confined to the Lake Robinson depression, occupying an area of about 570 ha and corresponding with the Priority 1 PEC;

- Open forest of *Acacia aptaneura* and *Eucalyptus victrix* over open tussock grassland of *Eulalia aurea* and *Eriachne benthamii* with open shrubland of *Duma florulenta* on red brown clay loam on alluvial plains. This vegetation type is widespread across the Flats (mapped area about 2,000 ha) and corresponds with the Priority 3 PEC; and
- Closed forest of *Eucalyptus victrix* and *Acacia aptaneura* and over open tussock grassland of Eriachne benthamii and Eulalia aurea with open shrubland of *Duma florulenta* on red brown clay on low-lying plains. This vegetation type occurs as a mosaic of discrete patches, ranging in size from about 0.5 ha to 10 ha, within AaEv EaEb Mf (total mapped area about 130 ha) and corresponds with the Priority 3 PEC.

Ecohydrological conceptualisation

- Surface water runoff from surrounding catchments is attenuated in the internally-draining, low-relief landscape of the flats. It principally accumulates in the Lake Robinson area but extends more widely across the flats during large flooding events.
- Anecdotal evidence indicates that surface water flow into Coondewanna Flats occurs every three in four years and is an important process for replenishing soil moisture in the unsaturated profile.
- Beneath the flats, an unconfined calcrete aquifer is present at a depth of 20 to 30 mbgl. It is overlain by largely unsaturated Tertiary detrital and underlain by low to high permeability dolomite of the Wittenoom Formation. This dolomite forms part of a regional groundwater flow system that ultimately reaches Weeli Wolli Spring.
- Groundwater recharge is associated with the infiltration of ponded surface water runoff in Lake Robinson. Recharge events are estimated to occur once in every four years. RPS (2014a) estimated that annual average recharge rate is about 10 ML/d over the broader Coondewanna Flats area. The Coondewanna Flats is considered an important groundwater recharge area for Upper Weeli Wolli catchment, supporting 75% of the catchment recharge.
- Groundwater discharge occurs as outflow to the South Flank and North Flank Valleys, which hydraulically connect the Coondewanna and Weeli Wolli Spring catchments.

Ecosystem components

- *E. victrix* on Coondewanna Flats rely on stored soil moisture to meet their water requirements, which is replenished by surface water inflow. Studies indicate these trees are able to obtain soil moisture for prolonged periods from horizons within the unsaturated zone above the watertable (Astron, 2014). The *E. victrix* woodlands at Coondewanna Flats are considered unlikely to rely on groundwater.
- The surface water dynamics of Coondewanna Flats are likely to influence bud-set, flowering, seed production and seedling recruitment of the *E. victrix*. However, further investigations are necessary to understand the relationship between flooding regimes and the reproductive cycle of the woodland trees.
- Mulga is a shallow-rooted species with xerophytic adaptations to drought stress. Water use requirements of the Mulga communities on the flats are most likely met by soil water in surface layers (up to 5 mbgl), which is replenished by rainfall and runoff.
- The Lake Robinson waterbody is ephemeral but may persist for several months.

Ongoing investigations into water requirements for Coondewanna Flats priority communities suggest that the vegetation assemblage is unlikely to rely on groundwater to meet water requirements (AQ2, 2016). Field investigations at the PEC were evaluated using a framework for groundwater dependence that incorporated direct measurement of groundwater use by vegetation, tree water use physiology and water balance for the system. The following findings indicated that the soil moisture reservoir beneath the flats, fed by surface water runoff rather than groundwater, is likely to be the sustaining water source for this community:

- Basal area per hectare indicative of a water limited community

- Symptoms of drought stress during dry season observed in leaf water potential measurements
- Matric potential indicating water access above 18m
- Size of soil moisture reservoir and surface water replenishment regime
- Depth to groundwater (>20m)

Mulga and Muehlenbeckia are vadophytic and may not rely on groundwater to meet plant water requirements owing to deep water levels (>15 m) and seasonal surface water inundation (AQ2, 2016). Coolibah trees are considered to rely on the soil water reservoir to meet plant water needs with a low likelihood of facultative dependence on groundwater. It is likely that the surface water regime at Coondewanna Flats supports these vegetation communities via soil moisture replenishment by periodic infiltration and inundation in some place and of surface water drawdown into the unsaturated zone.

While none of these indicators are conclusive in isolation, taken together, and in the absence of any contraindicative data, they show a low likelihood that groundwater drawdown will impact this community.

As a result of these findings, this assessment suggests that the Condition 5 of Ministerial Statement 491, of the Mining Area C Life of Project EMP Revision 6 (BHP Billiton Iron Ore 2015) containing the requirement for two water level investigation triggers for Coondewanna Flats be modified to remove the investigation triggers for change in water level at GWB0039M.

A precautionary approach will be maintained in the management of groundwater and for the purpose of this assessment, the vegetation will be assumed to be partly dependent upon groundwater resources and that a change in water level and hydrological conditions will require monitoring and investigation. These measures are inherently precautionary and have been committed to as triggers for further investigation within the CPWRMP.

5.3 Weeli Wolli Spring

Weeli Wolli Spring is located approximately 14 km east of North Flank and comprises an area where surface water and groundwater flows discharge from the Upper Weeli Wolli Creek catchment. The spring occurs where groundwater flow is constrained through a gorge in Wildflower Range. The creek and surrounding floodplain area support permanent pools and riparian woodlands.

A shallow groundwater system with extensive areas of calcrete is present up-gradient of the spring. Downstream of the Weeli Wolli gorge, the creek flows via a narrow channel past the confluence with Marillana Creek and ultimately into the Fortescue River Valley.

The spring's natural function is currently being impacted from Rio Tinto Iron Ore (RTIO) Hope Downs operations and is maintained through artificial discharge through a series of spigots.

Environmental values

The Weeli Wolli Spring area is recognised as having multiple ecological values that collectively contribute to its DPaW listing as a Priority 1 Ecological Community. The community is described by DPaW as:

> "Fringing forest or tall woodland of Silver Cadjeput (*Melaleuca argentea*) and River Red Gum (*Eucalyptus camaldulensis)* over trees of Coolibah (i) and a dense shrub layer dominated by wattles, in particular Pilbara Jam (*Acacia citrinoviridis*)"

There are several species of conservation interest including one named after the spring (*Stylidium weeliwolli*). This area supports the true phreatophyte *Melaleuca argentea* which is highly sensitive to groundwater drawdown (Onshore Environmental 2015). *Eucalyptus camaldulensis* and *E. victrix* are considered to be facultative phreatophyte species.

An unusual and diverse aquatic fauna assemblage occurs in a series of permanent pools up gradient of the spring associated with the shallow groundwater system. The permanent discharge from Weeli Wolli Spring is an uncommon habitat for the Pilbara and may function as a refuge for mesic-adapted fauna. A relatively high diversity of stygofauna is associated with the calcrete and alluvial aquifer system.

The creek valley at Weeli Wolli Spring supports a diverse bird assemblage (over 60 species) and very rich microbat assemblage including the Ghost bat (*Macroderma gigas*), a State listed species. The permanent pools provide a water source and foraging habitat for microbats.

In 2014, the Weeli Wolli Spring PEC was updated by the DPaW to also include Ben's Oasis, an area located about 20 km further upstream and south of Weeli Wolli Spring. Ben's Oasis is a name that is locally used by BHP Billiton Iron Ore. At this location, the vegetation is concentrated along a relatively narrow creek channel adjacent to some surface water pools. There is very little documented information about the geology, hydrology and ecology of Ben's Oasis.

Ecohydrological conceptualisation

Surface flow at Weeli Wolli Spring is a combination of spring baseflow supported by groundwater discharge, as well as seasonal surface water inflows.

On average, the area experiences two surface water flow events each year. Local infiltration of the surface water results in recharge to the shallow groundwater system.

The local groundwater system comprises an unconfined aquifer sequence including calcrete and detrital which is hydraulically connected to the regional dolomite aquifer. Groundwater is shallow being less than 10 mbgl and becoming shallower towards the spring. As the aquifer thins and narrows towards Weeli Wolli Spring, groundwater flow is concentrated and discharged over near-surface basement as baseflow.

The water balance (AQ2, 2016) identifies that the pre-mining groundwater throughflow from the upstream catchment was about 10 ML/day. Additional recharge of approximately 2.5 ML/d occurs within Weeli Wolli Spring area. Discharge occurs as spring baseflow (7.2 ML/day), evapotranspiration (1.5 ML/day) and groundwater throughflow in the shallow aquifer (3.6 ML/day).

Ecosystem components

The Weeli Wolli Spring area hosts a PEC comprising groundwater-dependent vegetation, permanent pools supporting a range of fauna, and a diverse stygofauna community. There is up to 30 m of saturated calcrete that provides the main stygofauna habitat.

A number of permanent pools upgradient from Weeli Wolli Spring (sustained by the shallow groundwater regime) provide aquatic habitat, and a permanent water source for terrestrial fauna and avifauna.

No information is available regarding groundwater levels or seasonal variation at Ben's Oasis. At present, there is insufficient information to formulate a conceptual ecohydrological model for Ben's Oasis.

6 A description of the predicted water balance range

6.1 Dewatering volumes and profile

Dewatering is the key water activity which influences the mine site water balance and the extent of potential groundwater impacts.

With the addition of South Flank dewatering the MAC Combined Operations water balance moves towards neutral with increased demand from the new operations absorbing surplus water from North Flank and the dewatering requirements at South Flank providing water supply in the later years of the combined mine life.

First below water table ore at South Flank is currently scheduled in 2026 and dewatering rates will fluctuate throughout the life of the mine reflecting the relatively low volume of below water table material. The bulk of dewatering will be required between 2030 and 2050 with proactive dewatering of future deposits used to supplement supply requirements across the two operations. Modelled maximum dewatering rates at South Flank are expected to be from 20-60 ML/d during peak periods with an average background range between 11 and 20 ML/d. These rates are additional to previously assessed dewatering rates for North Flank as presented in the 2015 EMP Rev 6 proposal.

The range of dewatering volumes estimates for South Flank are broad which reflects the underlying uncertainties considered in the groundwater modelling. The key source of uncertainty for dewatering volumes is connection to high storage, high K regional aquifers. This uncertainty will reduce over time, most notably once the aquifers in and around the deposit are accessed for dewatering and water supply.

Dewatering at MAC Combined Operations is likely to be required until 2047 with several peaks associated with larger dewatering requirements in specific pushbacks. The annual predicted dewatering rate is presented in Figure 6. The dewatering rate is dependent upon the rate of below water table mining, the mining sequence and the deposit being mined at any one time, plus the cumulative effects from Hope Downs. It is recognised that the indicative mine schedule could change and as a result the maximum dewatering rates and periods of dewatering may vary accordingly.

To allow for this uncertainty and the resulting temporal variance in water levels, volumes and potential impacts, an adaptive management approach has been adopted under Condition 5 of Ministerial Statement 491 and is outlined within the Central Pilbara Water Resource Management Plan (BHP Billiton Iron Ore 2016). The approach considers a range of potential water balance scenarios and associated drawdowns based on a range of dewatering rates, and sets outcome based thresholds at the key receptors. These conditions are supported by practicable and feasible mitigation measures which can be implemented to address the range of predicted hydrological changes.

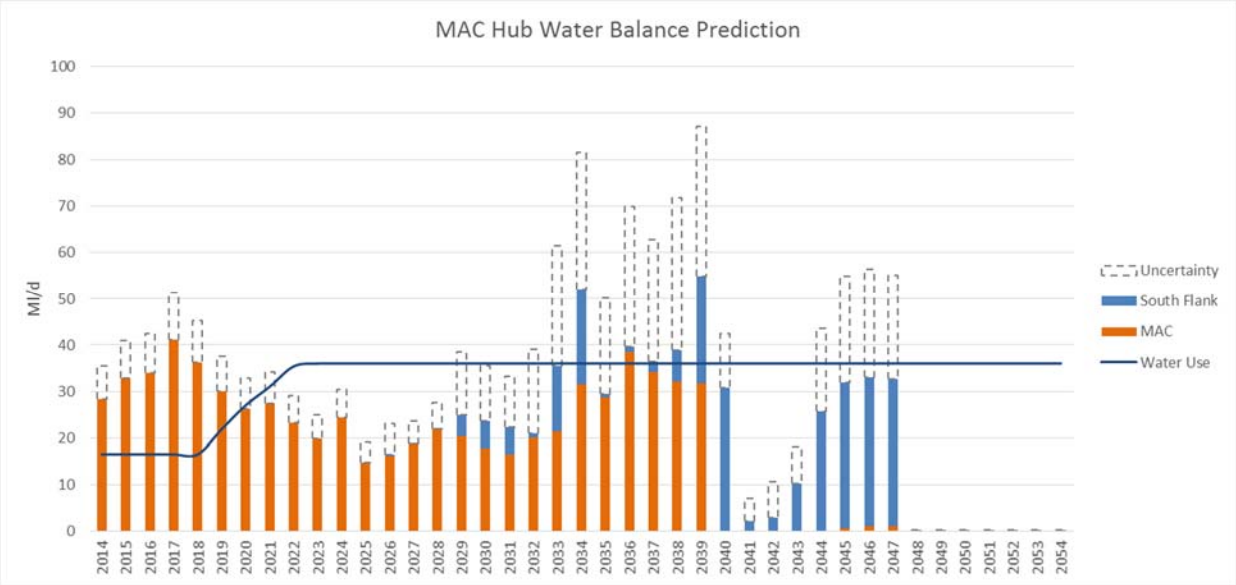


Figure 6: Combined Mining Area C water balance showing annual dewatering estimates compared with water demand

6.2 Water demands

Future water supplies for the South Flank are required for either 1) production demands or 2) potable supply. The projected daily annual production water demand for the MAC Combined Operations is estimated to peak at 35 ML/d from 2022 and remains around this volume until production ramps down around 2054. Daily peak demands could be as high as 40 ML/d and as low as <5 ML/d during rain periods. Potable demands are estimated to be considerably less at around 3 ML/d.

Production water supplies will be delivered from dewatering activities. Early dewatering of pits may be used to maintain water suppy where required. If dewatering rates drop below the water demand, an alternative water supply borefield will be developed. The Camp Hill borefield has been previously assessed as part of the EMP Revision 6 proposal for both water supply and MAR purposes. Alternative supply options such as sourcing water from third party surplus will be considered where practicable.

6.3 Surplus water management

Surplus water will continue to be managed with reference to the guidance of the Department of Water, Use of Mine Dewatering Surplus (2013). Up until 2040, dewatering rates are expected to be near to or greater than water demands resulting in a net water surplus in most years.

Surplus water will continue to be managed under the CPWRMP and will be preferentially returned to ground through injection into MAR borefields to meet BHP Billiton Iron Ore's sustainability objectives and minimise impacts to the water resource. It is currently planned to operate MAR schemes in four areas including the existing A Deposit MAR borefield (until 2017), infiltration ponds, Juna Downs borefield, plus the proposed Camp Hill borefield area. Some of the surplus water injected to the aquifer at Juna Downs and Camp Hill may subsequently be abstracted once dewatering rates fall below demand requirements. Further investigations may identify other preferred options for the future location of a MAR borefield.

Injection of surplus water volumes may also be used to mitigate potential drawdown impacts to environmental receptors. Other surplus water management options, such as the discharge to creeks or drainage lines have not been assessed but could be considered appropriate once other more sustainable water management options have been exhausted and the potential impacts can be managed.

6.4 Surface water diversion

The upper portions of some small ephemeral creeks would be intercepted by the proposed South Flank pits. Natural runoff loss from the interception of these upper creeks plus loss from the OSA and the operational footprint for the MAC Combined Operations catchment is estimated at a maximum 50%. This overall net reduction to the primary drainage areas of Weeli Wolli creek and Coondewanna has been assessed to determine whether the loss is significant (MWH, 2016) and is detailed in Section 7.1. Changes to the Coondewanna and Weeli Wolli (including Pebble Mouse Creek) catchments as a result of this proposal are considered small with a net reduction in the Fortescue catchment of 2%. The potential impacts from increased sediment load and changes to water quality resulting from water waste rock interaction are also addressed as part of the assessment.

6.5 Pit voids management

As per the EMP Revision 6 proposal, existing pits below water table at Northern Flank will be backfilled during operations as part of a waste management program and also post operations to a level which prevents impacts to water quality and allows for aquifer recovery at the key receptors. The requirements for backfill at South Flank will be assessed as part of the closure planning process where impacts to water quality and throughflow are considered to be a risk. The proposed approach to waste management and pit void backfilling is documented in the Mining Area C Closure Plan (BHP Billiton Iron Ore, 2014).

7 Change assessment

7.1 Methodology

Changes in Groundwater levels - To predict the range of possible changes in hydrological conditions resulting from groundwater abstraction during operations and post closure, a number of regional numerical groundwater models have been developed which simulate past and future abstraction and predict temporal and spatial hydrological changes (BHP Billiton Iron Ore, 2016b). The models are regional in extent, covering the entire upper Weeli Wolli catchment and the key environmental receptors of Coondewanna, Weeli Wolli and Ben's Oasis.

The models represent an updated conceptualisation of the hydrogeology (BHP Billiton Iron Ore, 2016a) and simulate MAC Combined Operations dewatering activities referenced within the proposed EMP Revision 6 scope. Cumulative effects from Hope Downs groundwater activities have also been included.

Multiple numerical models were developed to predict the range of change as the groundwater system is complex and covers a large area, and some of the major influences on these outcomes are open to multiple interpretations. While aquifer responses to North Flank and Hope Downs dewatering have been monitored, dewatering of the South Flank deposits, a previously unstressed system, added additional uncertainty, in particular the extent of connectivity between South Flank pits and the regional dolomite aquifer system.

To counter this uncertainty the approach was taken to develop multiple models where key modelled parameters were allowed to vary, in particular those relating to the regional and orebody aquifers and the connection between them. The initial model set comprised 2000 variants, of these 192 calibrated with sufficient confidence to be used in the assessment. The resulting outputs are presented as a range of drawdown responses as a result of dewatering from proposed operations at South Flank, as well as cumulative response from other operations.

The outputs have been presented as series of percentile bands for both drawdown and abstraction volumes. Percentile cutoffs at 20% (P20) and 80% (P80) have been used for the purposes of informing environmental impact assessment. In this case, low percentiles represent a smaller drawdown footprint and dewatering requirement while the high percentiles represent a larger drawdown footprint and dewatering requirement.

The predicted drawdown due to dewatering activities in the catchment is presented in terms of a range between the 20th and 80th percentiles (P20 to P80) of model outcomes. The range of outcomes are a consequence of variations made to the key model inputs of regional connectivity and hydraulic parameters. The range is not intended to represent confidence intervals rather that the most likely prediction lies somewhere within the P20 to P80 range at most locations within the catchment.

Importantly, previous modelling results and field monitoring fall between the 20th and 80th percentile of the model outputs in key areas, demonstrating that this approach is both consistent with previous work and calibrates to measurements from the catchment.

The benefit of this approach is that the models allow an assessment of the potential range of predictive outcomes that reflect the technical uncertainty, particularly with regards to the propagation of drawdown from MAC Combined Operations to key receptors at Weeli Wolli Creek, Ben's Oasis and Coondewanna Flats.

The approach is consistent with BHP Billiton Iron Ore's overarching regional adaptive management approach and is appropriately precautionary, whereby it provides a spectrum of hydrological conditions considering the range of uncertainty to establish whether the groundwater system can be managed using practicable and tested mitigation options. The models are furthermore used to establish whether the range of probable hydrological conditions can be maintained within the outcome based thresholds established for the key receptors during operations or post closure.

Changes to Surface Water flow Volumes – An analytical approach was used to estimate the potential loss or gain of water volumes owing to landform changes and diversions. The volumes were based on a percentage of catchment area loss. In some instances there was a small catchment gain owing to the change to drainage lines near catchment divides. The percentage of change was then compared in relation to the overall catchment flow change and assessed as to whether this was significant. Changes in runoff volumes were then assumed to be directly proportional to the percent change in catchment area. For example, a 1% reduction in catchment area is assumed to result in a 1% reduction in runoff volume.

Changes to Water quality – A preliminary Acid and Metalliferous Drainage (AMD) Risk Assessment has been completed to support the proposal which, in part, assessed potential changes to local water quality (BHP Billiton 2016e). The assessment showed there is a low presence of primary AMD source material within the South Flank ore and surrounds and that AMD is a low risk for the proposal.

It is possible for AMD to report to groundwater and surface water from overburden storage areas and backfilled pits, if potentially acid forming (PAF) material is left unmanaged; while it is unlikely for AMD to migrate from pit lakes or pit voids. The expected likelihood of water quality degradation is even lower because PAF material management measures are routinely applied.

There is a potential for leachate or runoff from waste rock stored in OSAs to be somewhat saline, and short-term pulses of salinity in contact waters are possible.

Within pit voids that extend partially below the post-closure water table, initial deterioration of water quality may occur due to leaching of wall rock in the dewatering cone and, if pits are backfilled, reaction of backfilled materials not in geochemical equilibrium with groundwater.

7.2 Regional water resource impacts

Introduction

The impact to water resources in the Upper Weeli Wolli catchment area from the proposed South Flank mining activity are predicted to be most significant in the groundwater aquifers and surface water flow system in the vicinity of the dewatering activities and within the mine footprint. Cumulative impacts are predicted to be most significant in the lower Weeli Wolli catchment due to the combined effect of Hope Downs and MAC Combined Operations water management activities in this area and the recovery of the groundwater system throughout the catchment is likely to take decades to centuries. Predicting the cumulative impacts is highly uncertain, relying on a number of significant assumptions associated with the future water management strategy at Hope Downs.

Changes to Surface Water

Surface water flow is an important contribution of stream flow and groundwater recharge in the Coondewanna Flats and Weeli Wolli Spring areas. An impact assessment of changes to the catchment resulting from the South Flank Proposal has been carried out (MWH, 2016). The assessment indicates that the extent of surface water interference to the natural system from the proposed South Flank activities will be minimal due to the diversion of creeks and channel flow. The loss of surface water volume from the system owing to South Flank water effecting activities occurs immediately in the mine footprint area which is located in the upper catchment some distance from the primary recharge features and key surface water dependent ecosystems such as Coondewanna Flats, Pebble Mouse Creek and Weeli Wolli Creek.

Impacts to the surface water flow volume and quality is not expected to be significant owing to the continued use of preventative controls such as protection bunds and sedimentation ponds. No creek diversions are planned for the South Flank operations. The subsequent downstream impacts to aquifer recharge and riparian vegetation in the areas of Weeli Wolli and Coondewanna are considered to be insignificant and within natural variance.

The interception and effective removal of surface water from which would ultimately discharge or infiltrate into the Weeli Wolli Spring region is an additional 3.5% of the volumes (total of 6.2% for MAC Combined Operations) and is considered to be insignificant in comparison to the disruption which has occurred owing to mining in the lower catchment. For Coondewanna, the volume of surface water flow would decrease by 5% (total of 6.9% for MAC Combined Operations).

Changes in Regional Groundwater Levels

The previous groundwater impact assessment submitted with the EMP Rev 6 proposal presented a cumulative groundwater drawdown from North Flank and Hope Downs operations following completion of mining in 2054 which is shown in Figure 7 (RPS, 2014).

Results of the recent modelling for 2054 (Figure 8) are comparable with the 2014 model and show increased drawdown south and west of the South Flank deposits. The cumulative drawdown footprint is similar in the North Flank valley and in the lower catchment.

In addition, maximum drawdown footprints have been used to show the highest drawdown at any given point in the model run rather than at a particular point in time. This gives an indication of where the maximum change in the aquifer will take place over the course of the mine life and has also been used to inform hydroecological assessments.

These footprints have been produced for South Flank only (Figure 9) and as a cumulative picture including both MAC Combined Operations and Hope Downs (Figure 10).

Figure 7: 2054 Drawdown Footprint from EMP Rev 6 Proposal

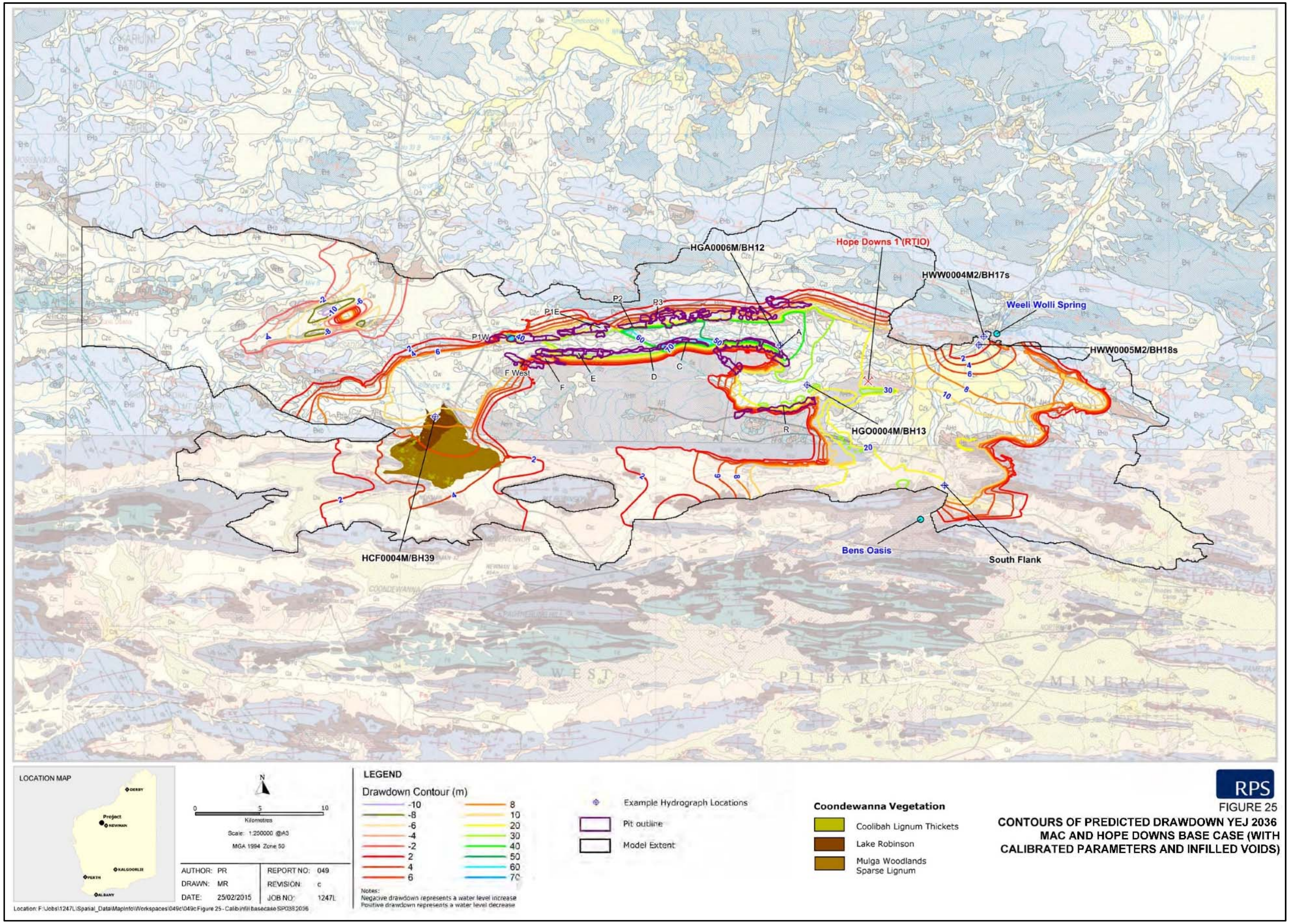


Figure 8: Cumulative drawdown in 2054

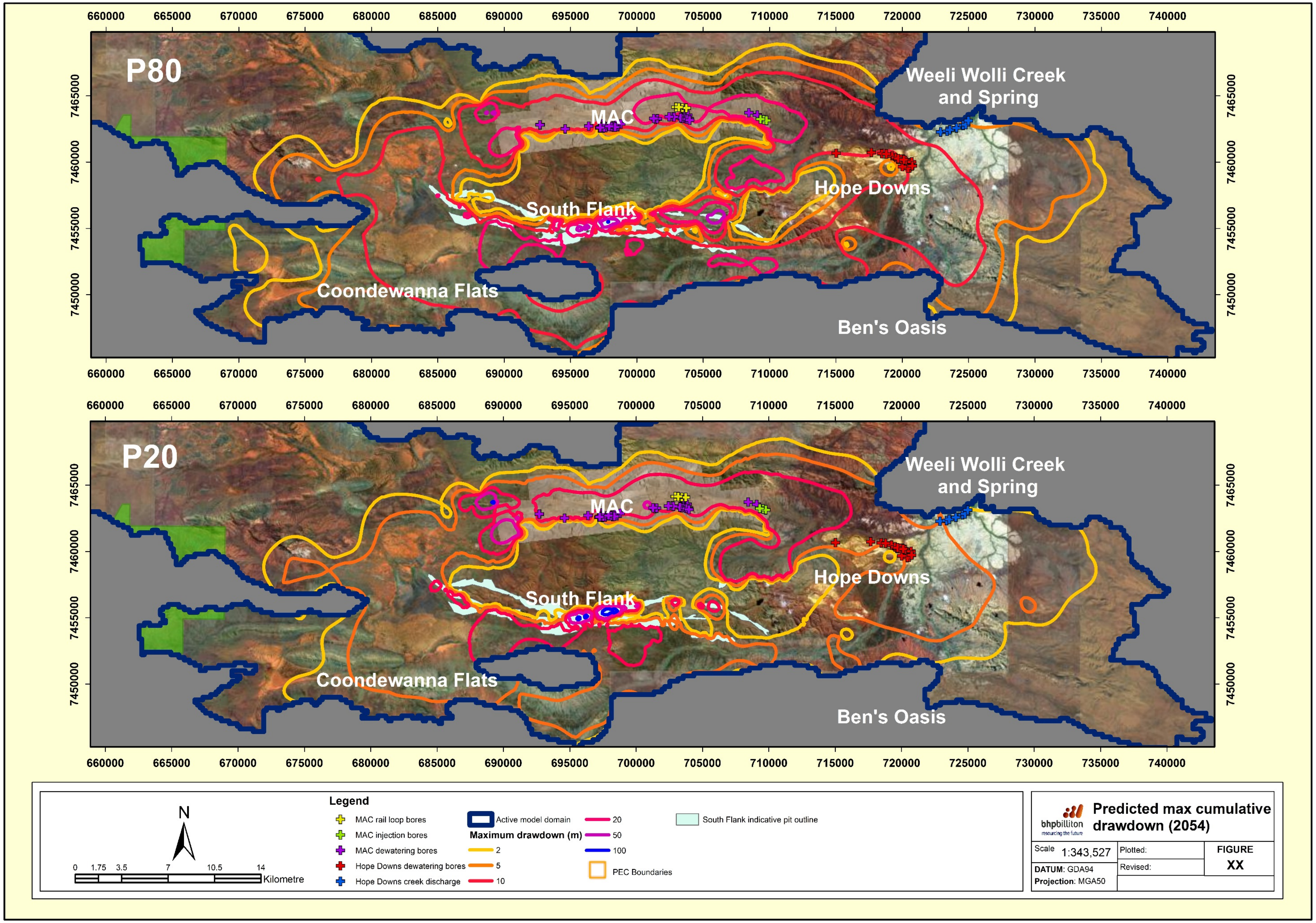


Figure 9: South Flank Only P80 and P20 drawdown scenarios

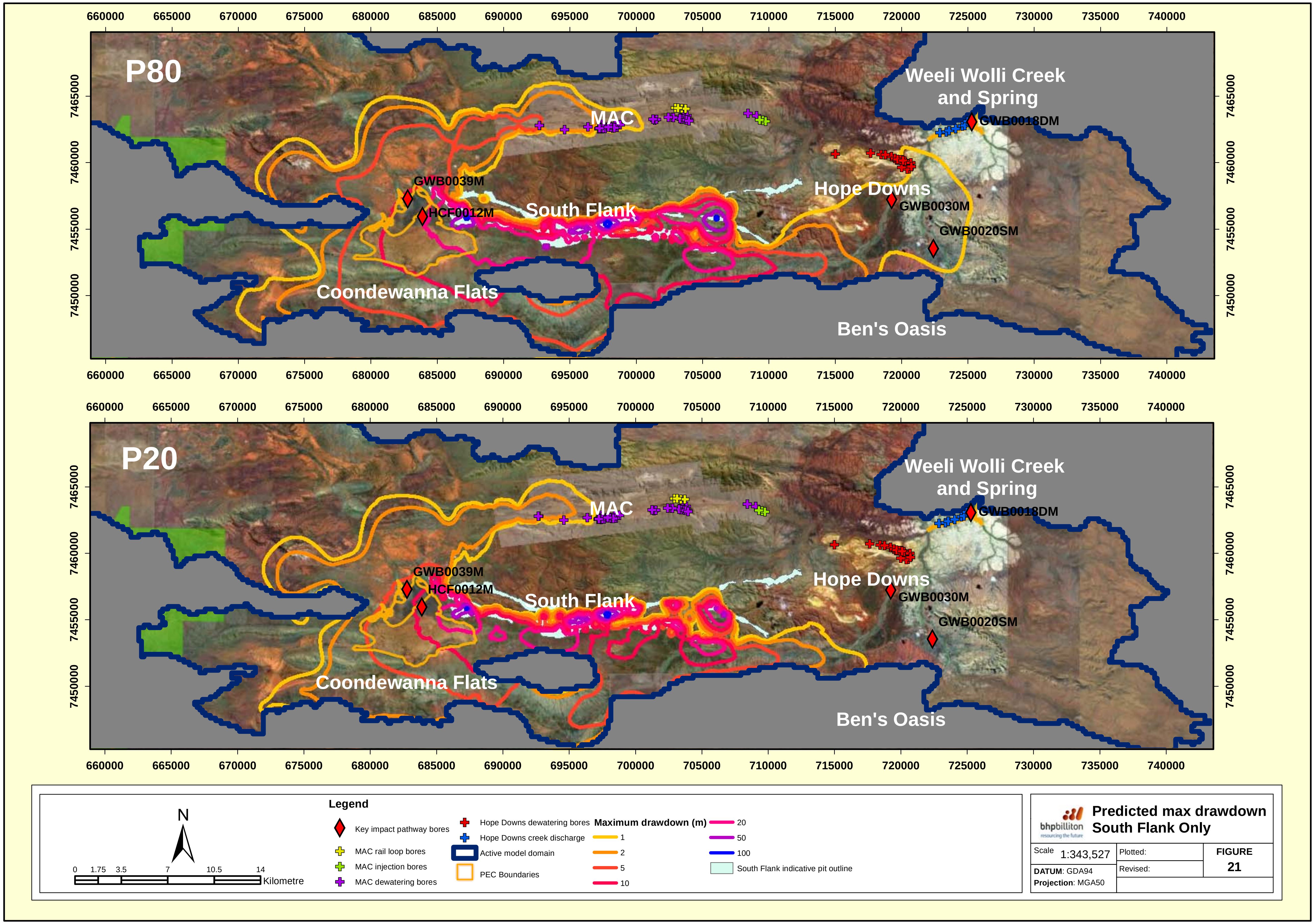
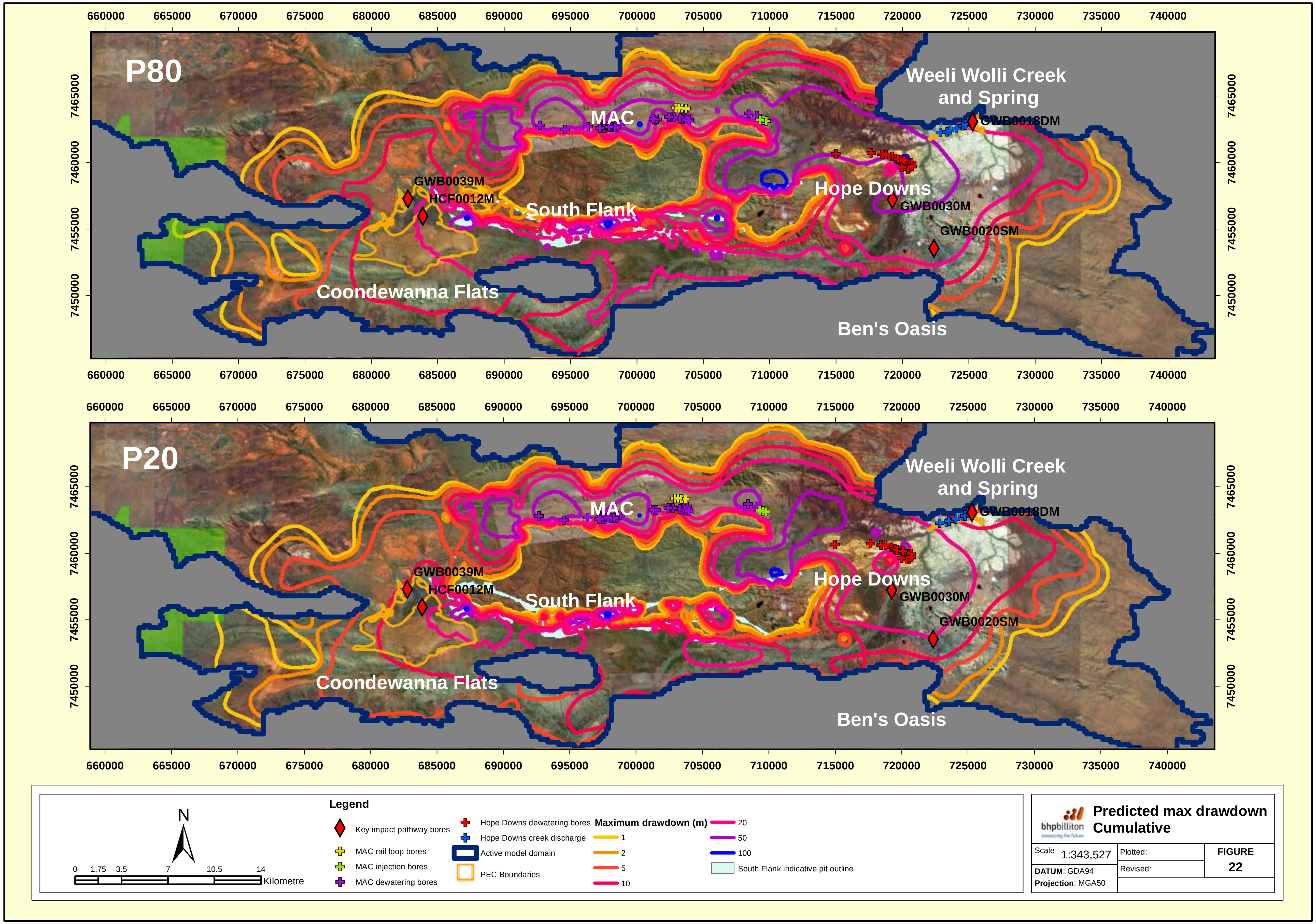


Figure 10: Cumulative P80 and P20 drawdown scenarios



The South Flank only footprint (Figure 9) shows drawdown greater than 10m is limited broadly to the Pebble Mouse Creek valley and the south-eastern areas of Coondewanna Flats. Drawdown of less than 10m extends beyond the Proposed Southern Flank Development Envelope mostly to the south and west beneath Coondewanna Flats with drawdown of between 1 and 2m extending to the east into the Weeli Wolli valley. The extent of migration of drawdown to the east is more uncertain, but is not expected to exceed 1 m at either Weeli Wolli Spring or Ben's Oasis.

The cumulative P80 footprint including all operations in the catchment shows that groundwater within the entire catchment area will be affected to some extent from the activities at MAC Combined Operations and Hope Downs. Drawdown is concentrated on dewatering borefields and is predicted to propagate out from the Marra Mamba orebodies in an east-west direction following the higher transmissivity Wittenoom dolomite and detrital aquifers. The extent of drawdown associated with dewatering Brockman deposits in the North Flank Packsaddle range is considered to be less significant owing to low permeability rocks (shale and banded iron formation (BIF)) constraining the drawdown extent.

The net change to the drawdown due to South Flank operations is an increased depth of drawdown in the south western section of the model domain, primarily beneath Coondewanna Flats.

Although groundwater drawdown attributed to MAC Combined Operations activities could extend >10 km west and east of from the mine, the resulting impacts to the groundwater resource and groundwater dependent ecosystem are considered to be manageable. However it is recognised that the aquifer water levels will be lowered by up to 100 m immediately in the vicinity of the mines during and for the recovery period following dewatering activities.

This water level change is predicted to extend preferentially towards Coondewanna Flats with a smaller, and much later, change predicted at Weeli Wolli Spring. The extension of drawdown from MAC Combined Operations to Ben's Oasis is considered unlikely owing to geological controls and catchment boundary features. It is predicted that with pit backfill at both North Flank and Hope Downs, the groundwater systems could recover within 1 m of the pre-mining water levels within around 300 years.

Groundwater levels are expected to rise and fall in the vicinity of the Juna Downs and Camp Hill borefields as the areas are used for surplus MAR and subsequently as Camp Hill is used as a water supply borefield. Operational borefield management and design will ensure that groundwater drawup does not result in impacts to local ecosystems during surplus injection. The aquifer drawdown effects from Camp Hill are predicted to be isolated from the mine dewatering area of influence owing to the ridge of low permeability BIF and shale separating the areas.

Changes in Water Quality – Geochemical testing and AMD risk assessments (BHP Billiton Iron Ore, 2016e) have identified that the potential for impacts to water quality are considered to be low, primarily owing to the low proportion of acid generating material, the high proportion of acid consuming material and the planned backfill and waste management program during and at the end of mining.

The application of sedimentation ponds which will be installed at the margins of the mining area will reduce the likelihood of a degradation of surface water resources and impacts to flora and fauna.

Waste management and the storage of chemicals will continue to be considered in context to the existing standard management practices and therefore is unlikely to have a discernable impact to water quality.

7.3 Impacts to Coondewanna Flats

Impacts to Coondewanna Flats PEC owing to changes in hydrological conditions associated with mining activities at MAC Combined Operations will be controlled with preventative water management activities with residual impact risks managed using the mitigation measures outlined in the CPWRMP and Mine Closure Plan.

The changes to hydrological conditions at Coondewanna are primarily expected to be associated with falling groundwater levels as a result of dewatering the western deposits at both South Flank and North Flank, and to a lesser extent through dewatering of the eastern Marra Mamba deposits in these areas. Changes in surface water volumes are not considered to impact the PEC values as outlined above.

The previous forecast drawdown range at Coondewanna presented in the EMP Rev 6 model was between 6 and 9.5m by 2036. This drawdown was attributed to dewatering of the western Marra Mamba deposits at North Flank with a minor contribution from dewatering the eastern Marra Mamba pits.

Dewatering at South Flank is predicted to result in an additional 6 to 16m of drawdown by 2047. The majority of this drawdown will come from dewatering the Highway deposit at the western end of South Flank.

The cumulative model shows that, without mitigation, total drawdown would be between 10 and 22 m in the central area of Coondewanna Flats by 2047 at which point water levels begin to recover (Figure 11). The rate of change is estimated to be up to 3 m/year. The rate and extent of drawdown is dependent upon the hydraulic connection between the Highway deposits at South Flank and the dolomite aquifers to the west. Timing of maximum drawdown at Coondewanna is associated with two deep pits at Highway, one of which extends approximately 160m below water table.

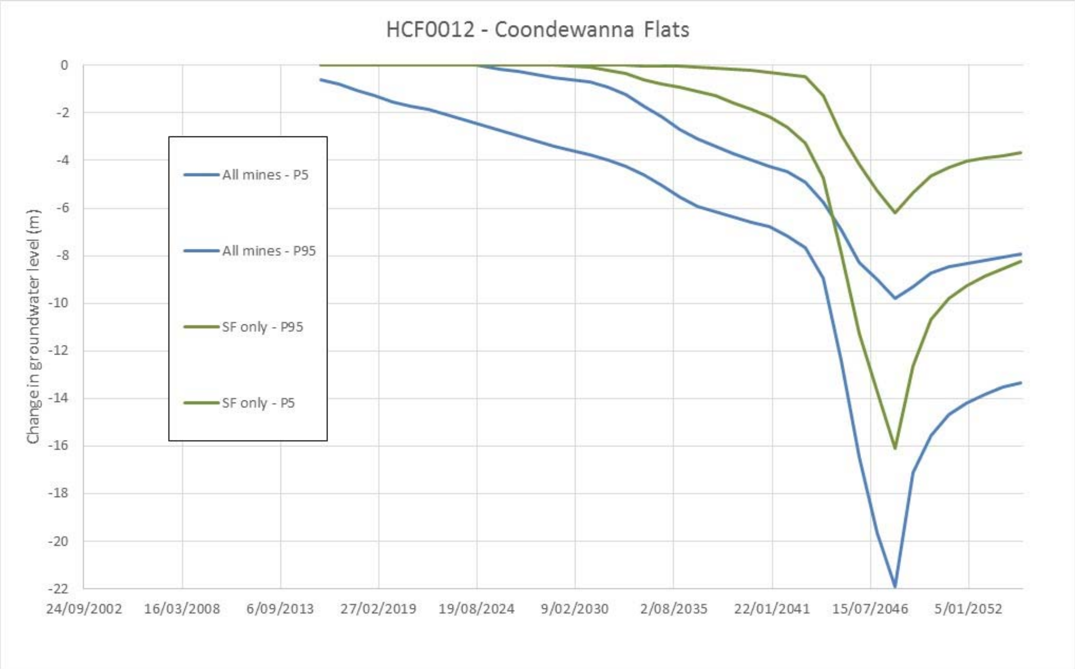


Figure 11: Predicted drawdown and recovery at HCF0012.

Uncertainty remains about the hydraulic behavior of a dolerite dyke which passes through the Highway deposits although, given the measured 30m water level drop across the dyke, there is potential that this structure will modify propagation of drawdown from dewatering of the eastern South Flank deposits. This will continue to be evaluated during though further investigations and during operations with findings reflected in future assessments (BHP Billiton Iron Ore, 2016a).

As outlined in Section 5.2, Coondewanna is considered unlikely to be dependent on groundwater and the change in hydrological conditions outlined above is therefore unlikely to result in an impact to the PEC. However, a precautionary management approach will continue to be adopted for Coondewanna and monitoring and investigation thresholds will continue to be applied.

Planned injection of surplus water at the Juna Downs MAR scheme has the potential to offset dewatering induced drawdown at Coondewanna Flats. However, there is also potential that the resulting groundwater draw-up may impact the PEC by raised groundwater levels in the root-zone of the vegetation community. An assessment of the groundwater changes due to injection has been modelled and the results are presented in Appendix A. Ecological risks to the PEC as a result of mounding have been assessed and are presented in Appendix B. Upper water level targets and thresholds have been established based on these assessments and are presented in the CPWRMP along with ecological indicators to prevent detrimental changes at the PEC. The risk to the PEC as a result of injection is considered to be manageable.

7.4 Impacts to Weeli Wolli Spring (including Ben's Oasis) and Stygobionts

The extent of groundwater change and surface water interception from South Flank activities at Weeli Wolli Spring will be monitored and managed using the mitigation measures outlined within the CPWRMP.

Combined surface water flow interception which contributes to Weeli Wolli creek flow will be around 6.2% and this is considered to present a low risk in terms of change of hydraulic function and impact. There are no changes to the surface water catchment for Ben's Oasis.

The previous forecast residual drawdown at Weeli Wolli Spring presented in the EMP Rev 6 model was around 1.6m at GWB0018 in 2054. This drawdown occurred following closure of Hope Downs and was attributed to the combined impacts of Hope Downs and North Flank dewatering. Maximum drawdown at GWB0018 was modelled to be between 6 and 7 meters in 2026 and coincides with the conclusion of Hope Downs dewatering.

Dewatering at South Flank is predicted to contribute between 0.2 and 0.5m of drawdown at GWB0018 in 2054. This drawdown is modelled to occur following the end of aquifer replenishment and mitigation actions at Hope Downs (Figure 12).

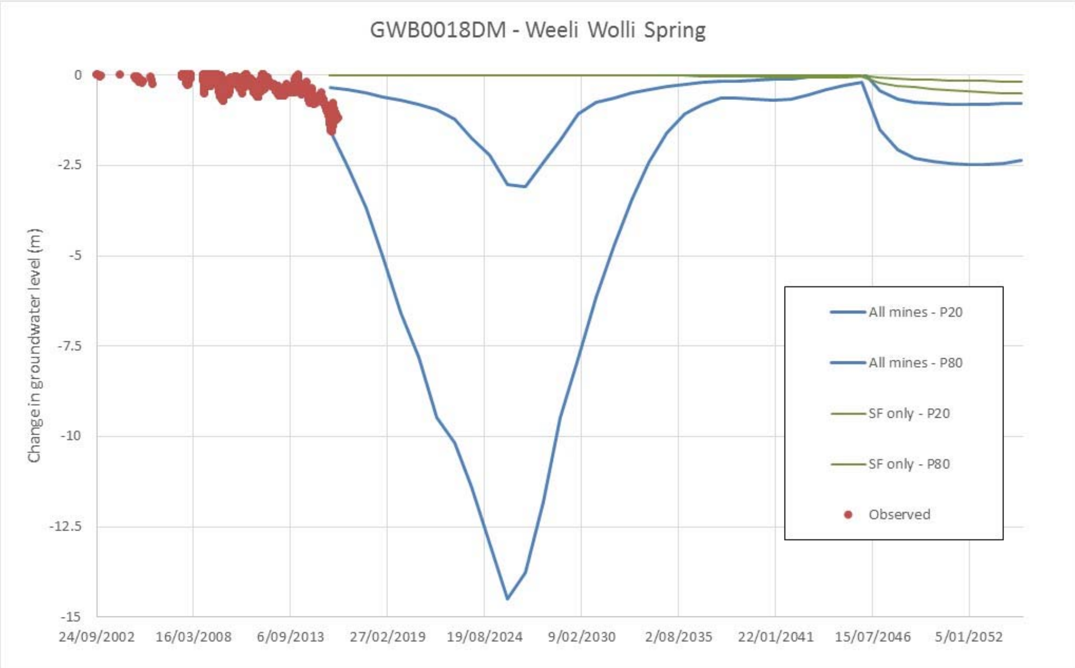


Figure 12: Predicted drawdown and recovery at GWB0018

Cumulative groundwater drawdown from dewatering activities shows a more significant change, whereby water levels are significantly reduced in the Weeli Wolli spring area. This drawdown, which shows a range of 3 to 14m, is associated predominantly with abstraction from Hope Downs. The timing and success of Hope Downs closure plans to recover groundwater levels will also influence the water level and potential for a continued impact at Weeli Wolli Spring.

Following closure of Hope Downs the combined cumulative impacts show a range of 1 – 2.5m of maximum drawdown at 2054 with a median drawdown of 1.75m which is similar to the previously assessed change of 1.6m. Ecological changes are unlikely up to the median value, with drawdown unlikely to impact key water dependent species within the PEC. Changes in groundwater availability are considered to become significant for *Melaleuca argentea* if drawdown is sustained at 2.5m with a subsequent reduction in numbers and would likely result in the population contracting to the east. Reductions in flow volumes from the spring are also likely if drawdown is in the upper end of the range.

Use of the ranged drawdown assessment has identified potential impact scenarios which were not previously considered, providing the opportunity to investigate, monitor and incorporate these scenarios into catchment management plans.

These impacts represent an unmitigated scenario and occur towards the outside of the modelled drawdown envelope. If these changes appear likely as a result of BHP Billiton Iron Ore activities then they are within the range of management and mitigation.

There is considerable uncertainty around potential groundwater changes at Ben's Oasis due to a lack of geological knowledge and monitoring data in that area of the catchment. Due to this uncertainty it was not considered practical or informative to extend the model domain to include Ben's Oasis.

The modelling shows that drawdown from South Flank dewatering is likely to be minimal at Ben's Oasis. The P20 to P80 models at GWB0020M reproduce the observed drawdown very well at this location, and the predictions suggest that a maximum of between 1 and 2 m will occur due to South Flank (Figure 13). This location is about 7.5 km away from Ben's Oasis along the conceptual flow path, so drawdown at the receptor itself will be very much smaller than this (i.e. likely measured in centimeters). Modelling of the South Flank only P80 case shows the 1m drawdown contour from South Flank dewatering does not extend to Ben's Oasis (Figure 9).

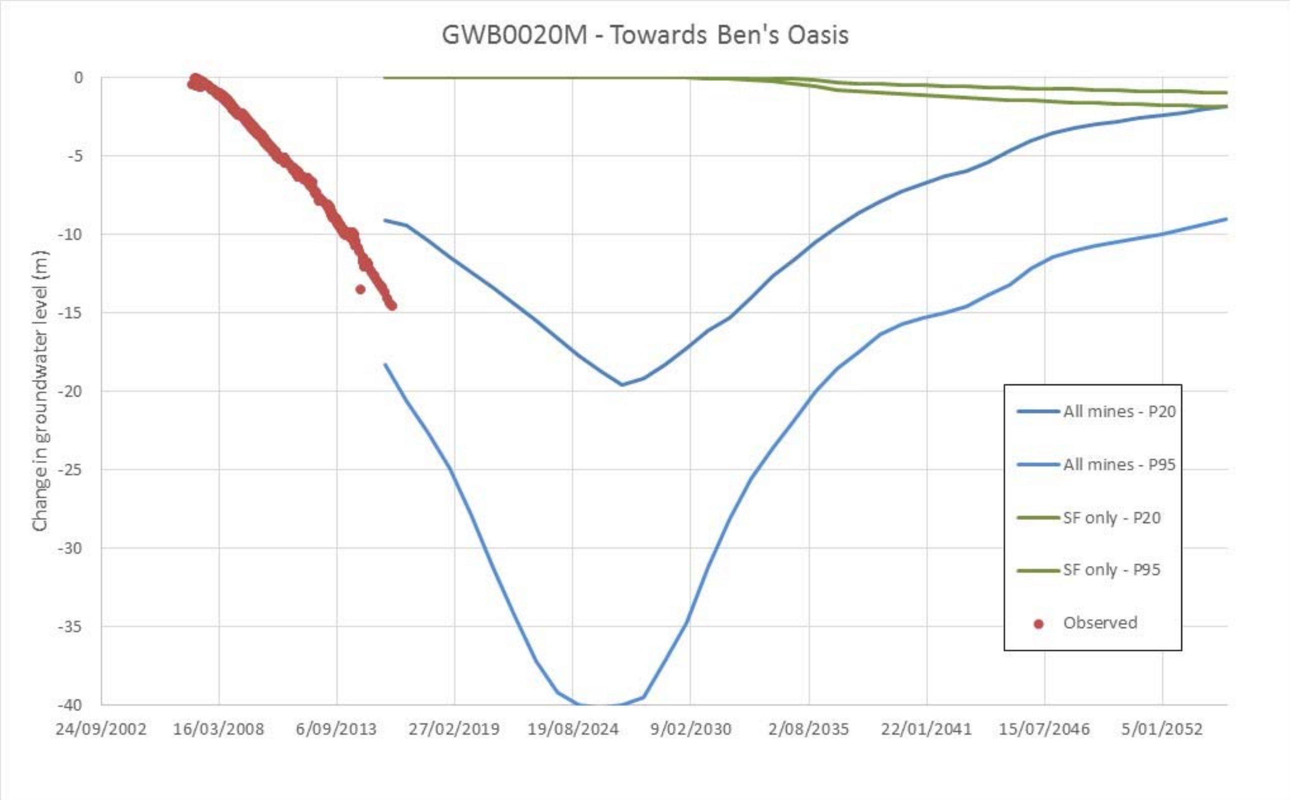


Figure 13: Modelled drawdown and recovery at GWB0020

Cumulative drawdown however will be significant in this area. As of 2016 observed drawdown at GWB0020M was already 15 m. Monitoring data shows that this originates from dewatering of Hope Downs and is predicted to increase to between 20 and 40 m by 2025 which will dominate the cumulative drawdown in this area. Without contemporary observation data and more geological knowledge it is hard to predict to what extent this will effect Ben's Oasis.

7.5 Uncertainties and Further work

A number of regions included within the groundwater model have poor coverage by groundwater monitoring and uncertainty in the behavior of the underlying geological units. Some of these areas additionally fall outside BHP Billiton Iron Ore tenure. The resulting assumptions used in this assessment may change over time as understanding in these areas improves.

Groundwater modelling to support this EIA was based on a conceptual model that links recharge at Coondewanna Flats with spring flow at Weeli Wolli Spring via regional aquifers. Based on recent and historic observations, BHP Billiton Iron Ore considers that a number of alternative conceptualisations may exist that both explain the observed catchment behavior and potentially modify the extent of connectivity between aquifers in the system. Investigations to support alternative conceptualisations are ongoing and will develop over coming years.

The groundwater modeling also presents an unmitigated assessment of drawdown and the application of management measures outlined in Section 9, informed by an adaptive management process, is likely to result in reduced impacts at key receptors. As such the impacts outlined in this report is considered a conservative and precautionary assessment of potential impacts resulting from the proposal.

8 Regional Cumulative Effects

As highlighted above, the predictive groundwater models have also included the activities of other mining operators within the Upper Weeli Wolli catchment.

The predicted further downstream impacts outside the Weeli Wolli upper catchment (lower Weeli Wolli catchment and ultimately the Fortescue Marsh) from the MAC Combined Operations are considered to be manageable.

Changes to the groundwater and surface water discharge volumes and contributing flows to the downstream and adjoining catchment discharge points from MAC Combined Operations activities are estimated at between 6% and 7% and typically will continue to be masked by the extent of water affecting activities from mining operations between Weeli Wolli Spring and Fortescue Marsh.

9 Management Options

The Central Pilbara Water Resource Management Plan (CPWRMP) outlines the range of water management alternatives and hydrological thresholds which are currently being applied as a part of the adaptive management controls to mitigate and prevent impacts from the proposed mining activities to the key receptors, such as the water resource, Weeli Wolli Spring and Coondewanna Flats. The proposed CPWRMP and associated Mine Closure Plan define the following practicable and feasible water management options to manage impacts:

1. Proactive dewatering volumes will continue to be used as a process supply when dewatering rates fall below water demand requirements. The predicted water balance indicates that this is likely to occur at various stages between 2025 and 2040. The activity will see dewatering water being preferentially abstracted and used over a stand-alone water supply borefield, ultimately reducing the long term drawdown on the water resources.
2. Consistent with the Department of Water Mine Water Management Guidelines (DoW, 2013), and where practicable and feasible, surplus groundwater will continue to be preferentially returned to the aquifer through MAR. The practice will be used to reduce the extent and duration of groundwater drawdown and mitigate the impact to water resources. However, it is recognised that there are practicable and aquifer limitations with MAR and some surface water discharge maybe explored at a later date.
3. Surplus water is planned to be introduced into the proposed Juna Downs and Camp Hill borefields from about 2017 onwards, effectively storing water into the dolomite and alluvial aquifers. Subsequently, the MAR borefield may be used for water supply. Additional locations for the development of MAR borefields may be considered.
4. Surface water will continue to be diverted around the mining footprint to the extent practicable to minimise the loss of surface water flow in the natural drainage systems. Sediment ponds will continue to be installed at the margins of the deposits (east and west) to retain runoff and settle sediment prior to discharge into natural drainage features which ultimately flow into Coondewanna Flats and Weeli Wolli Spring PECs.
5. Backfilling of below water table mine voids will be considered for where risks to water quality and quantity are considered unacceptable.

In addition to preventative controls, a number of mitigating controls have been tested and proposed to prevent impacts to the key receptors, including:

Coondewanna Flats - The change in hydrological conditions at Coondewanna Flats is predicted to be between 10 and 22 m by the end of combined mining activities in 2054. The net change or rate of change in water levels is considered unlikely to result in an impact to the PEC (AQ2, 2016). However, as outlined previously, a precautionary approach to impact management will be applied using hydrological change thresholds for drawdown until ecological thresholds can be established. The hydrological thresholds are outlined in the CPWRMP. In the event that water levels fall below the investigation thresholds, a review will be completed of the hydrology and potential impacts and the finding discussed with the various Regulators. If following the review the risk of impact is considered likely, mitigation controls will be implemented.

The mitigating controls proposed in the CPWRMP include infiltration and injection of water into the aquifer between the aquifer stress (dewatering) and the receptor margins to maintain hydraulic heads at Coondewanna Flats. Groundwater modelling predicts that infiltration rates at Coondewanna of up to

15 ML/d until 2041 may be required to offset the drawdown from mine dewatering activities. The planned injection of surplus water at Juna Downs will test aquifer capacity and the effectiveness of this scheme in mitigating drawdown.

Weeli Wolli Spring - Mitigating controls and hydrological thresholds or triggers to address MAC Combined Operations proportion of impacts to Weeli Wolli Spring have not been considered in the CPWRMP. Over the next 20 years Hope Downs will predominantly continue to impact the spring and any long term effects from MAC Combined Operations are considered to be comparatively small and ultimately will depend upon the success of Hope Downs closure. However, the potential impacts will be reviewed annually as part of the groundwater operating strategy (GWOS) and annual aquifer review (AAR) reporting within the adaptive management framework. The findings from the annual review will inform the routine updates of the Mine Closure Plan (nominally every 5 years) and where necessary controls implemented as more monitoring data is made available.

10 References

AQ2, 2015. Coondewanna Flats Eco-Hydrology Review and Conceptual Model. AQ2 Pty Ltd, Perth, Western Australia

AQ2, 2016. Coondewanna Flats Ecohydrological Conceptualisation. AQ2 Pty Ltd, Perth, Western Australia

AQ2, 2016a. Juna Downs MAR Scheme Ecohydrological Monitoring Framework. AQ2 Pty Ltd, Perth, Western Australia

BHP Billiton Iron Ore, 2014. Mining Area C Closure Plan. BHP Billiton Iron Ore Pty Ltd, Perth, Western Australia.

BHP Billiton Iron Ore, 2015. Mining Area C Life of Project Environmental Management Plan (EMP Revision 6). BHP Billiton Iron Ore Pty Ltd, Perth, Western Australia.

BHP Billiton Iron Ore, 2015a. Hydrological Change Assessment – Mining Area C. BHP Billiton Iron Ore Pty Ltd, Perth, Western Australia.

BHP Billiton Iron Ore, 2015c. Strategic Environmental Approval Ecohydrological Change Assessment, BHP Billiton Iron Ore Pty Ltd, Perth, Western Australia.

BHP Billiton Iron Ore, 2016a. South Flank Hydrogeological Investigation Summary. BHP Billiton Iron Ore Pty Ltd, Perth, Western Australia.

BHP Billiton Iron Ore, 2016b. South Flank Numerical Groundwater Modelling. BHP Billiton Iron Ore Pty Ltd, Perth, Western Australia.

BHP Billiton Iron Ore, 2016c. Juna Downs Injection Modelling. BHP Billiton Iron Ore Pty Ltd, Perth, Western Australia.

BHP Billiton Iron Ore, 2016d. Central Pilbara Water Resource Management Plan. BHP Billiton Iron Ore Pty Ltd, Perth, Western Australia.

BHP Billiton Iron Ore Pty Ltd, 2016e. Preliminary Southern Flank AMD Risk Assessment. BHP Billiton Iron Ore Pty Ltd, Perth, Western Australia.

Department of Water, 2013. Strategic Policy 2.09: Use of mine dewatering surplus, Perth Western Australia.

Klohn Crippen Berger, 2014. Mining Area C Preliminary Acid and Metalliferous Drainage Risk Assessment. Perth, Western Australia

MWH, 2016. South Flank Surface Water Environmental Impact Assessment. MWH, Perth, Western Australia

Onshore Environmental, 2015. Mining Area C Flora and Vegetation Environmental Impact Assessment, Perth, Western Australia.

RPS, 2014. Mining Area C Environmental Management Plan Rev 6 Surface Water Assessment. RPS, Perth, Western Australia

RPS, 2014a. Hydrogeological Assessment for Mining Area C. RPS, Perth, Western Australia

Appendix A

Juna Downs Injection Modelling

3 August 2016

Contents

Introduction

BHP Billiton Iron Ore (BHPBIO) is investigating the feasibility of injection of surplus water from Mining Area C (MAC) into the regional dolomite aquifer between MAC and Coondewanna Flats, in an area known as Juna Downs (Figure 1).

The surplus volume is relatively uncertain, so the investigations are being based on an upper value of 20 ML/d (~230 L/s), which is estimated to be the maximum receiving capacity of the receiving aquifer system, based on current information. The injection time period is based on a nominal period of 18 years, equivalent to starting injection in July 2016 and continuing to the end of surplus in June 2034.

Objectives

The objective of this study is to predict the increase in groundwater levels in the area of Coondewanna Flats in response to long term injection of surplus dewatering water into the regional dolomite aquifer around Juna Downs. This information will be used to support environmental approvals for the Juna Downs Managed Aquifer Recharge (MAR) borefield.

Previous Modelling

BHPBIO first developed a numerical groundwater flow model for this area in 1997. Since then, the model has been updated and improved several times, with the most recent update having been undertaken in 2015 (RPS, 2015). This model includes Coondewanna Flats, the North Flank and South Flank Valleys (including MAC and Hope Downs) and the Weeli Wolli Spring and Creek systems. The model domain is shown in Figure 1. The model was used to support the MAC Environmental Management Plan Revision 6 (EMP Rev6) submission and was calibrated against a significant amount of time variant groundwater observations in these areas.

Modelling Strategy

Previous modelling has shown that drawdown is likely to occur in the area of Coondewanna Flats and Juna Downs in response to dewatering at MAC. It was therefore necessary to take into account the impacts of dewatering when assessing the response of the system to injection, especially given that the source of the injected water is that which is causing the drawdown.

Apart from some changes to the dolomite aquifer extent (which are described below), the strategy was to use the model exactly as it was used during MAC EMP Rev6. This means that the simulated dewatering at MAC is consistent with the existing and approved dewatering plan.

Model Updates

Since the last model revision, additional drilling has been undertaken in the Juna Downs area. This has shown that the extent of the dolomite is greater than depicted in the model. Figure 2 shows the locations of bores that have intercepted dolomite and the extent of the dolomite in the existing model. The figure also shows how the dolomite extent has been expanded to accommodate this new data. The historical calibration model was re-run with this change and the results compared against the original calibration (Figure 3). The hydraulic parameters assigned to the dolomite were unchanged. The comparison shows that these changes have no effect on the calibration outcomes of the model.

Model Set-Up

The majority of model settings are unchanged from those used during MAC EMP Rev6 (see RPS, 2015). For example; the model grid, layers, hydraulic parameters, simulation time, stress periods, numerical solver settings and dewatering settings for MAC and Hope Downs are unchanged.

To allow for the simulation of injection, the following settings were used:

- Injection at the five indicative sites was simulated with the Modflow Well Package. Each well was assigned an injection rate of 4 ML/d (20 ML/d in total).
- The model was run for the injection period only, from 1/07/2016 to 30/06/2034.
- The MAC EMP Rev6 model included injection of MAC surplus water to Camp Hill. This was removed.

Three model scenarios were run to provide the outputs required:

a) A “no mining” scenario. No groundwater stresses included other than the natural recharge and discharge processes.

b) A mining scenario. As (a) but with dewatering at MAC as per the EMP Rev6 mining schedule.

c) A mining and injection scenario. As (b) but with injection at Juna Downs included.

The three scenarios would allow for analysis of the effects of injection both in isolation from, and combined with, mining related drawdown (i.e. injection only effects are shown by the difference in predicted water levels in scenarios (b) and (c)).

The hydraulic parameters of the key hydrostratigraphies in terms of the model objectives are shown in Table 1.

Table 1. Hydraulic parameters of stratigraphy around and to the north east of Coondewanna Flats

Hydrostratigraphy	Hydraulic conductivity (m/d)	Kh / Kv	Specific Yield (%)
Dolomite aquifer	18.0	1.5	0.5
Alluvials	0.2	1	10
Calcrete	20.0	1	10
Mt Sylvia and Bee Gorge	0.1	1	0.1

Results

The results of injection modelling are provided as:

- Contours of depth to groundwater after 18 years of injection (in June 2034), with concurrent MAC dewatering (Figure 5). For comparison, contours of the current (May 2016) observed depth to groundwater are shown in Figure 4. These represent the “baseline” conditions.
- Contours of change in groundwater levels after 18 years of injection, with and without the influence of concurrent MAC dewatering (Figures 6 and 7)

- Hydrograph of groundwater level at observation bore BH39 (Figure 8)
- Contours of change in regional groundwater levels after 18 years of injection, without the influence of MAC dewatering (Figure 9)

These show that:

- The net change in groundwater levels at Coondewanna Flats after 18 years of injection of 20 ML/d to the Juna Downs borefield and continued dewatering at MAC, is a rise of between 5 and 8 m. This brings the groundwater level to within a minimum of about 14 and 16 m of the ground surface.
- Levels predicted at BH39 show a relatively rapid rise with time (roughly 0.5 m per year) over the first 10 years of injection. Levels peak about this time (at about 672 mRL, compared to a surface elevation of 688 mRL), then plateau and fall slightly as drawdown from MAC dewatering begins to increase in this area.
- The results with and without MAC dewatering show that injection contributes a rise in groundwater levels of about 10 to 15 m around the borefield and Coondewanna Flats.
- Around the borefield itself, groundwater levels remain in excess of 20 m below the ground surface throughout the injection period due to deeper baseline ground water levels.
- After 18 years, injected water is predicted to migrate preferentially to the south of the injection borefield. Whilst mounding of over 6 m is predicted up to 7 km west of the borefield, groundwater levels at the boundary between BHPBIO tenure and Karijini National Park are predicted to increase by less than 1 m.

Conclusions

Operation of an MAR borefield at Juna Downs at the maximum proposed rate of 20 ML/d for a period of 18 years leads to development of a groundwater mound which propagates throughout the Juna Downs and Coondewanna Flats area.

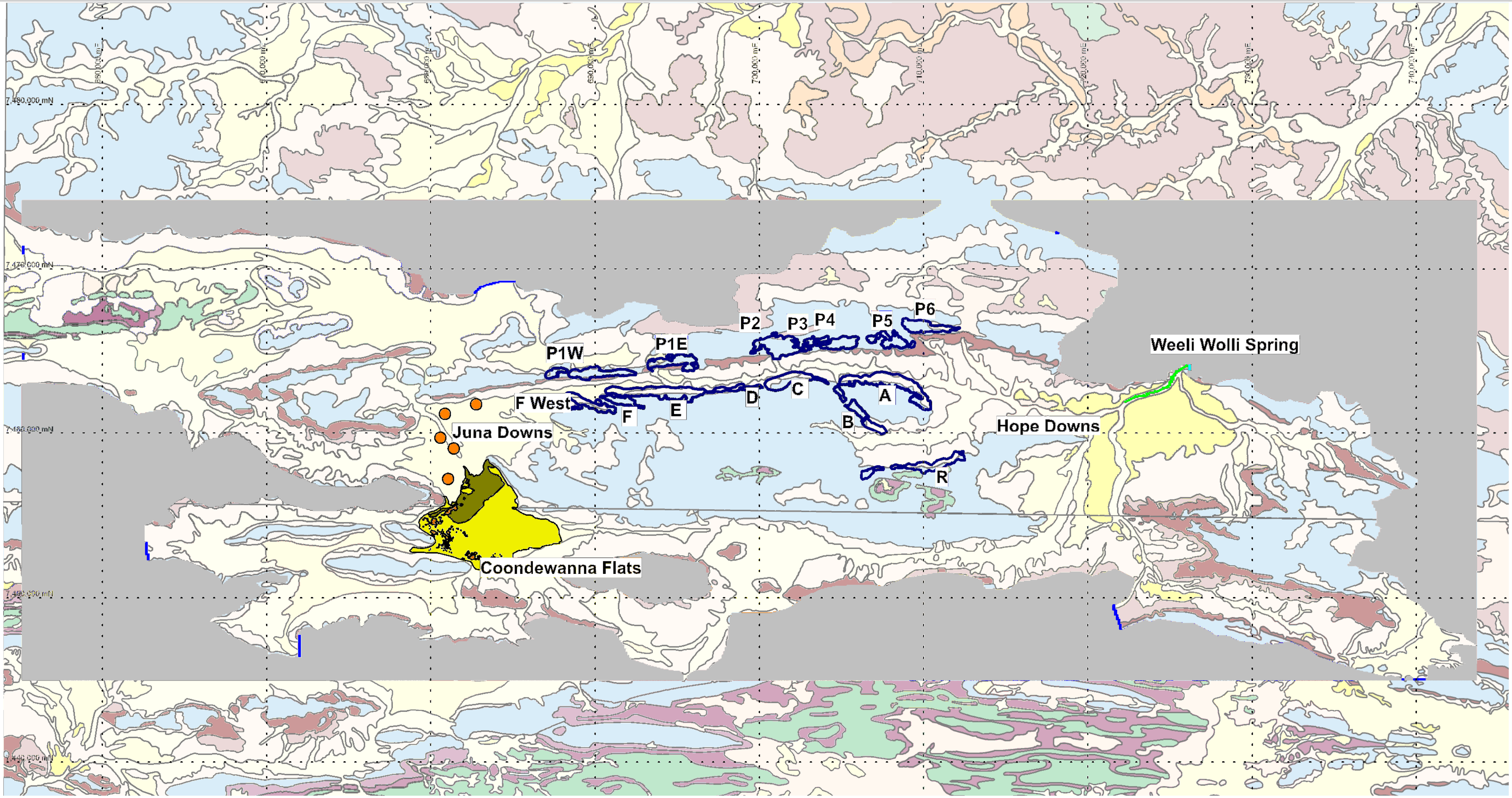
Based on the current conceptual hydrogeological model (and corresponding numerical model set-up), which includes drawdown from MAC extending into the Coondewanna Flats area, the result is a net increase in groundwater levels of between 5 and 8 m. This corresponds to a minimum depth to groundwater of 14 to 16 m in the north-eastern part of the Flats.

If dewatering drawdown from MAC ultimately does propagate westwards outside the North Flank Valley, the maximum predicted rise in groundwater levels beneath Coondewanna Flats increases to between 10 and 15 m, with a corresponding minimum depth to groundwater of about 7 m.

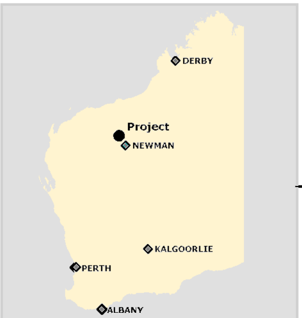
References

RPS, 2015. Hydrogeological Assessment for Mining Area C. RPS, Perth, Western Australia

Figures



LOCATION MAP



LEGEND

- MAC Pit Ouline
- No Flow Boundary
- Constant Head Boundary
- General Head Boundary
- Stream Boundary

Coondewanna Vegetation

- Coolibah lignum thickets
- Lake Robinson
- Mulga Woodlands Sparse Lignum
- Juna Down Injection Bore

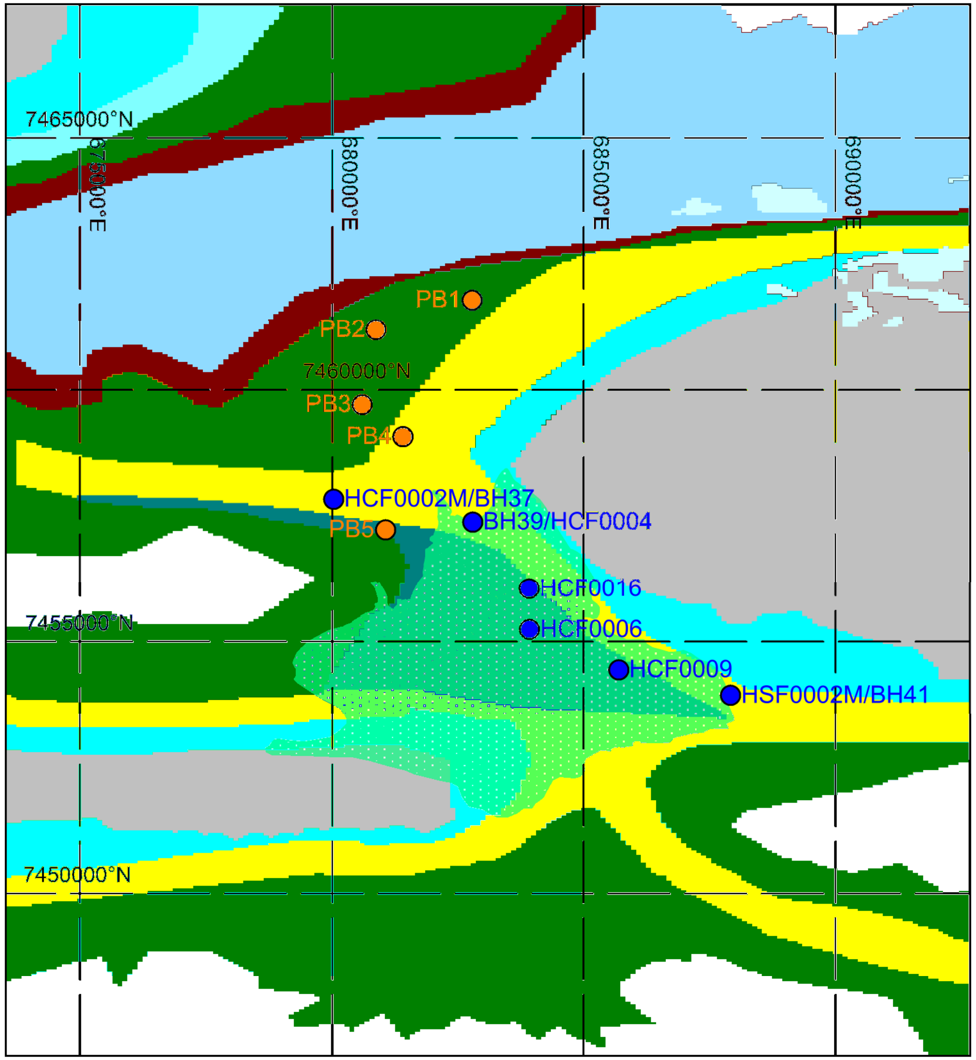
N

0 5 10 km

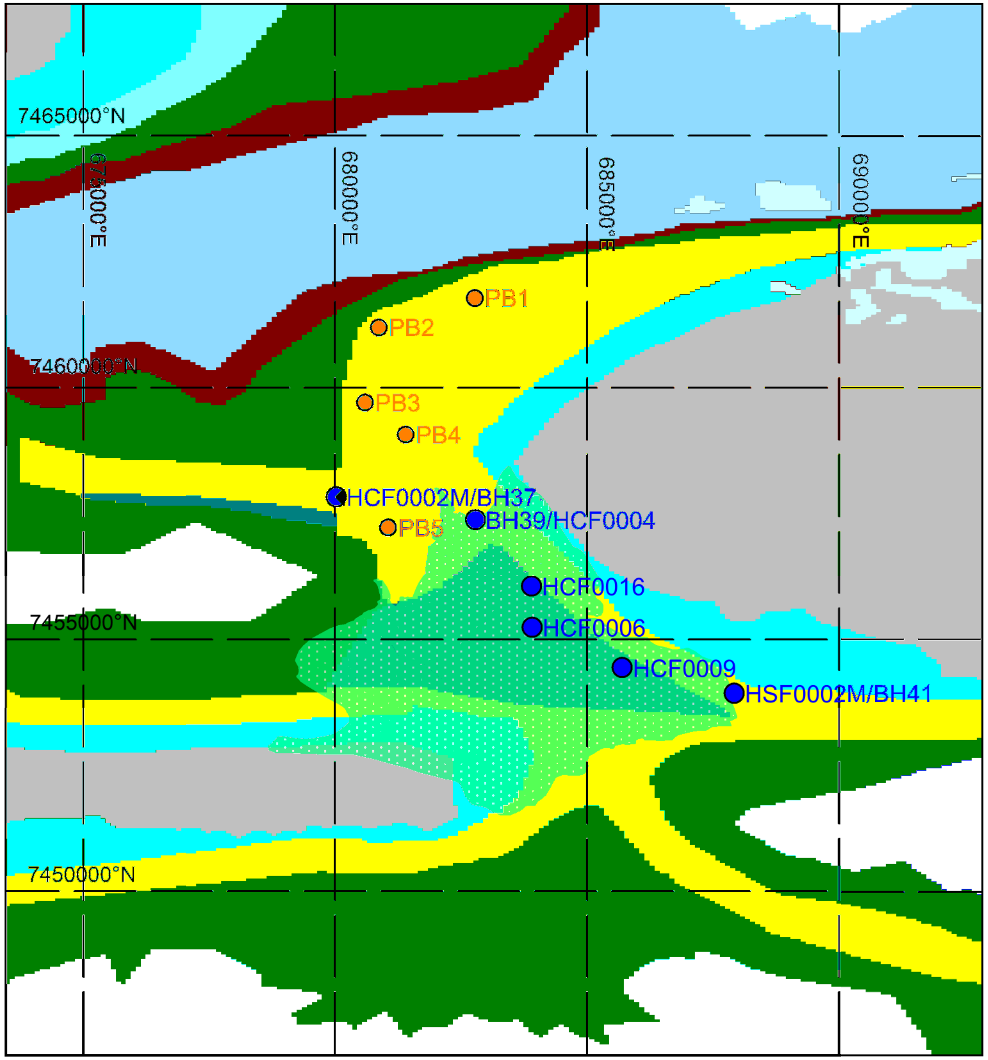
Scale 1:325,000

AUTHOR:	KR	REPORT NO:	...	**NOTES & DATA SOURCES:** Coondewanna vegetation distribution provided by BHPB MGA 1994 Zone 50 Scale 1:325,000 at A4	FIGURE 1 **LOCATION, MODEL EXTENT & BOUNDARY CONDITIONS**
DRAWN:	KR	REVISION:	B		
DATE:	9 June 2016	JOB NO:	082B		

Location:f:\082B\4. GIS\Workspaces\Report Figures\Base Map and Model Grid.WOR



PREVIOUS DOLOMITE AQUIFER EXTENT



REVISED DOLOMITE AQUIFER EXTENT

LOCATION MAP

LEGEND

Modelled Hydrostratigraphy (Layer 3)

- Unmineralised Brockman
- Mt McRae Shale
- Mt Sylvia and Bee Gorge
- Bee Gorge
- Paraburdoo Dolomite
- West Angela Shale
- Unmineralised Marra Mamba
- Mineralised Brockman / Marra Mamaba
- Coondewanna Flats
- Juna Downs Injection Bore
- Bore Used for Model Calibration

N

0 3 6 km

Scale: 1:150,000

AUTHOR:	KR	REPORT NO:	...
DRAWN:	KR	REVISION:	B
DATE:	10 June 2016	JOB NO:	082B

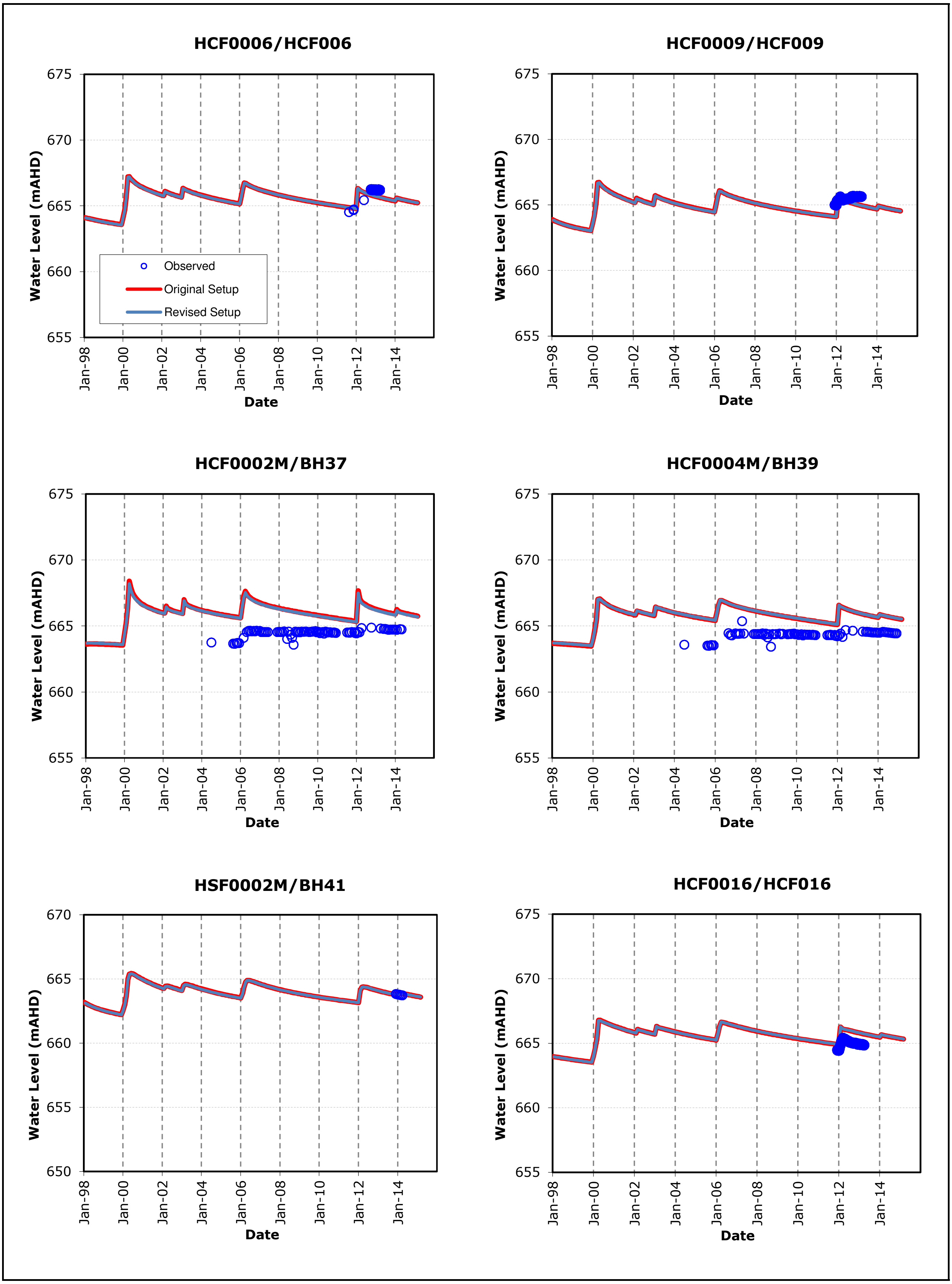
NOTES & DATA SOURCES:

Modelled aquifer parameter distribution from BHPB regional model, updated in April 2016.
MGA 1994 Zone 50
Scale 1:150,000 @ A4

FIGURE 2

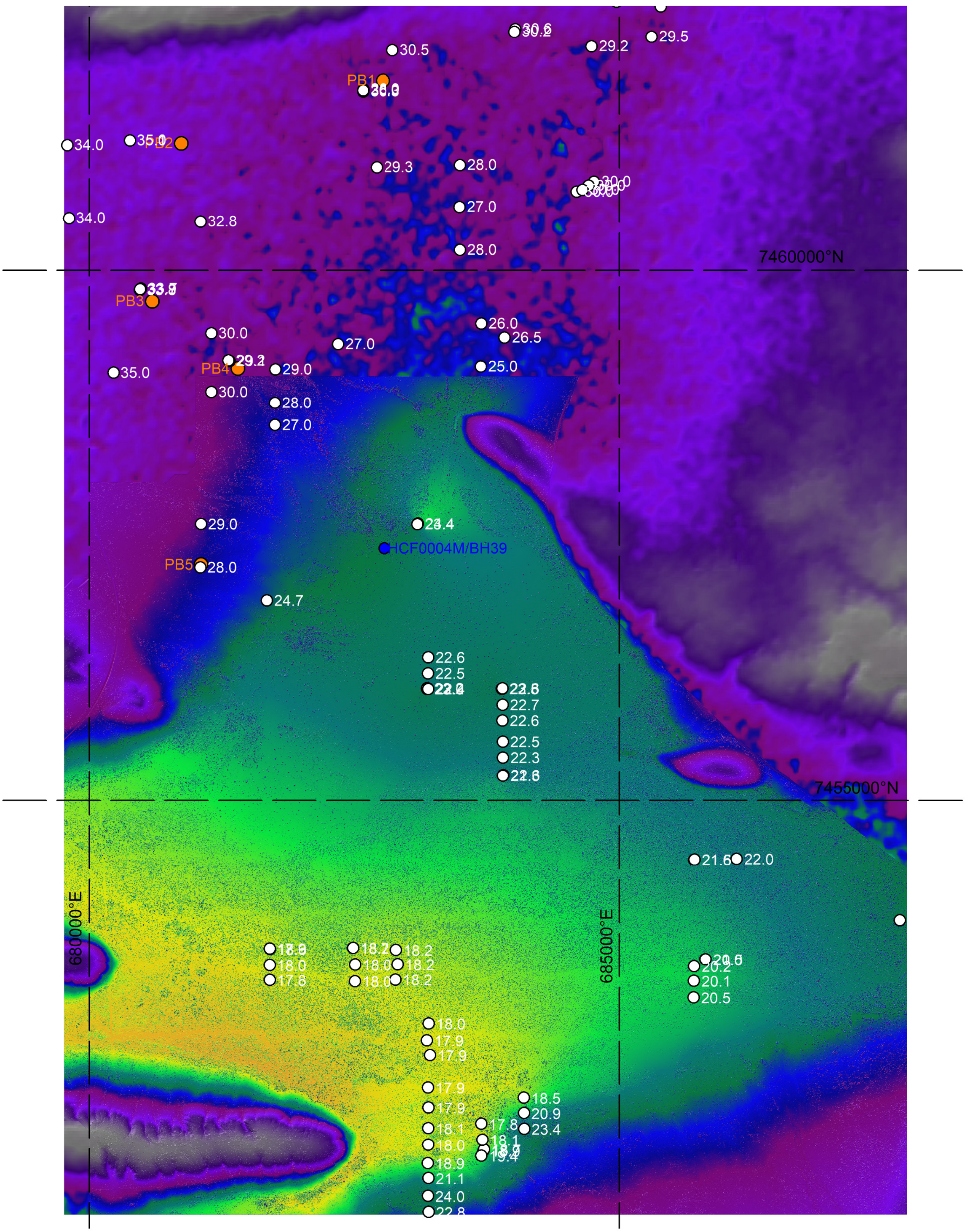
INJECTION BORES & MODELLED DOLOMITE EXTENT

Location: F:\082B\4.GIS\Workspaces\Report Figures\K distribution old and new.wor



CALIBRATION HYDROGRAPHS COONDEWANNA FLATS AREA FIGURE 3

F:\082B\2.TECH\Modelling\Results\UncertOpsF Cal April\[April calibration uncertainty Calibration Hydrographs R5 for BHPB.xlsm]Figure 3



LEGEND

Depth to Water (m)

12	18	24	30	100
14	20	26	40	400
16	22	28	50	

Juna Downs Injection Bore
Monitoring Bore
24.0 Measured Depth to Water (m)

0 1 2 km
Scale: 1:50,000

AQ2

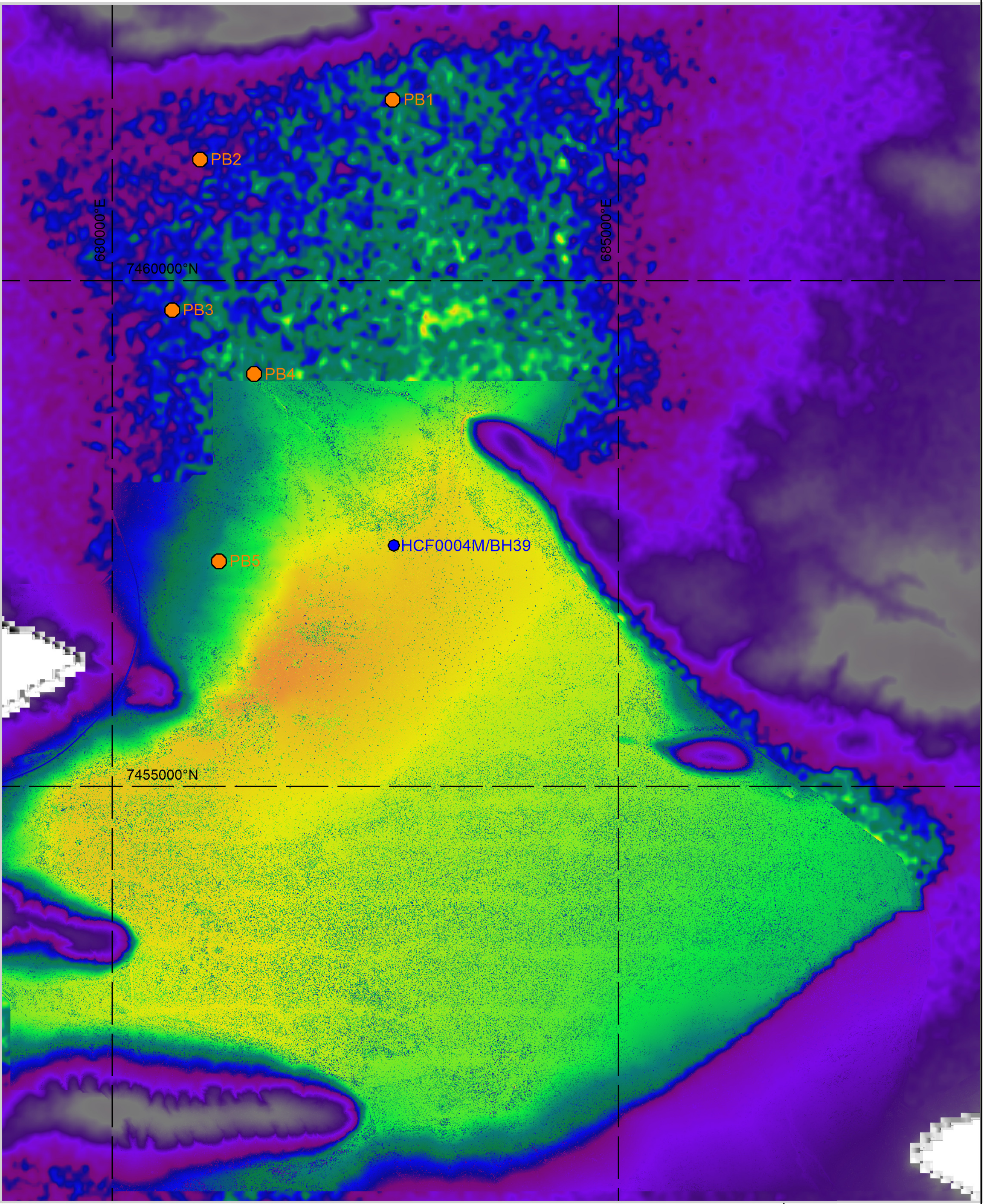
FIGURE 4
OBSERVED DEPTH TO GROUNDWATER (MAY 2016)

AUTHOR: KR
DRAWN: KR
DATE: 12 June 2016

REPORT NO: ...
REVISION: B
JOB NO: 082B

NOTES & DATA SOURCES:
Depth to water calculated from recent groundwater monitoring and composite ground surface (Coondewanna Lidar and SRTM)
MGA 1994 Zone 50
Scale 1:50,000 @ A4

F:\082B\4.GIS\Workspaces\Report Figures\current depth to water.WOR



LEGEND

Predicted Depth to Water (m)

12	20	28	100
14	22	30	400
16	24	40	
18	26	50	

0 1 2 km

Scale: 1:50,000

Juna Downs Injection Bore

Monitoring Bore

AQ2

AUTHOR: KR

DRAWN: .KR

DATE: 12 June 2016

REPORT NO: ...

REVISION: B

JOB NO: 082B

NOTES & DATA SOURCES:

Ground surface from composite LIDAR and SRTM

Predicted water levels from MAC regional model

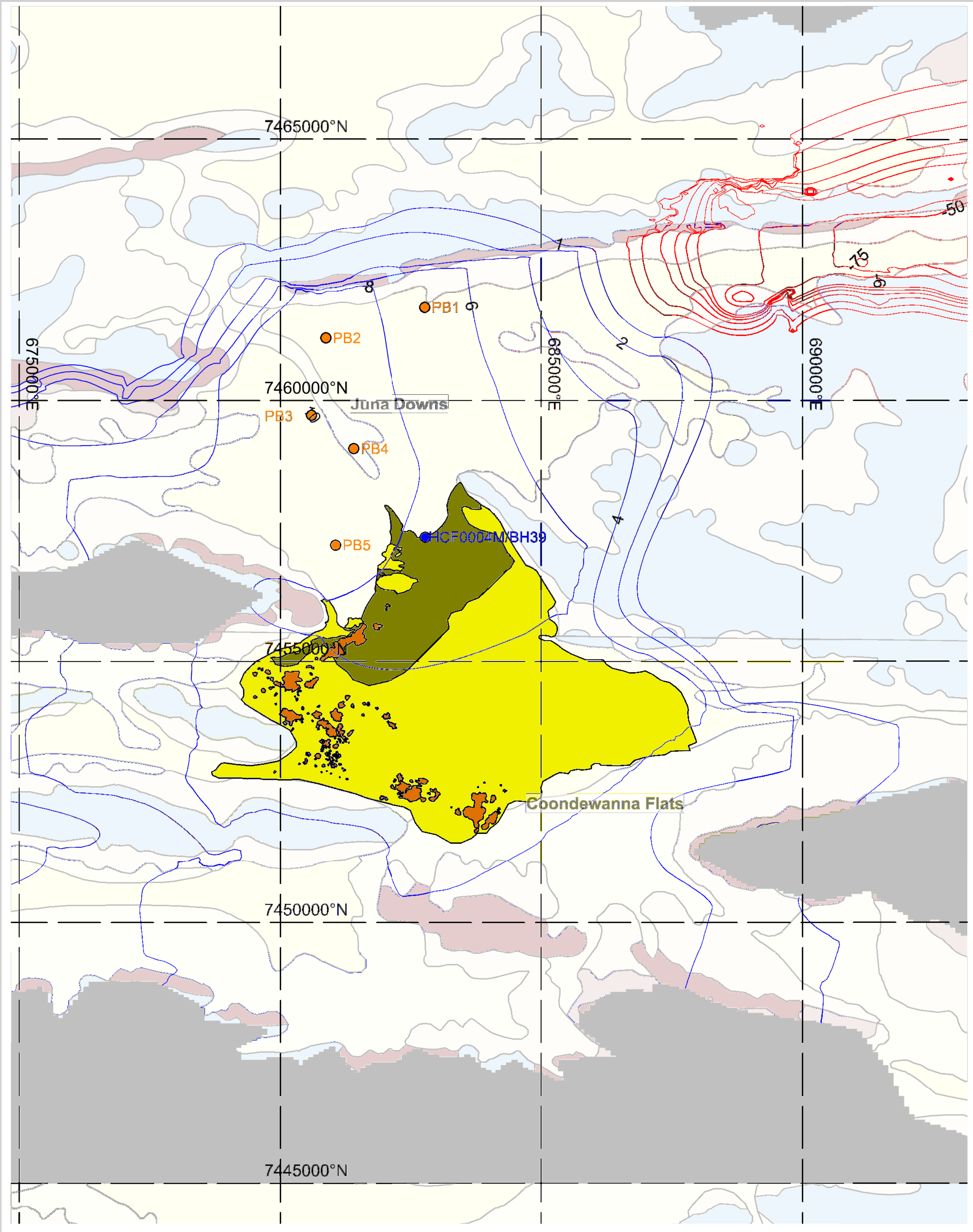
MGA 1994 Zone 50

Scale 1:50,000

FIGURE 5

PREDICTED DEPTH TO WATER YEJ2034 WITH MAC, HOPE DOWNS & INJECTION (20ML/D)

F:\082B\4.GIS\Workspaces\Modelling Figures\Ground Surface Update\depth to water coond with dev sp59.WOR



LEGEND

Water Level Decrease (m)
Water Level Increase (m)

Coondewanna Vegetation

Coolibah lignum thickets
Lake Robinson
Mulga Woodlands Sparse Lignum

Juna Downs Injection Bore
Monitoring Bore

N

0 2 4 km

Scale: 1:100,000

AQ2

FIGURE 6

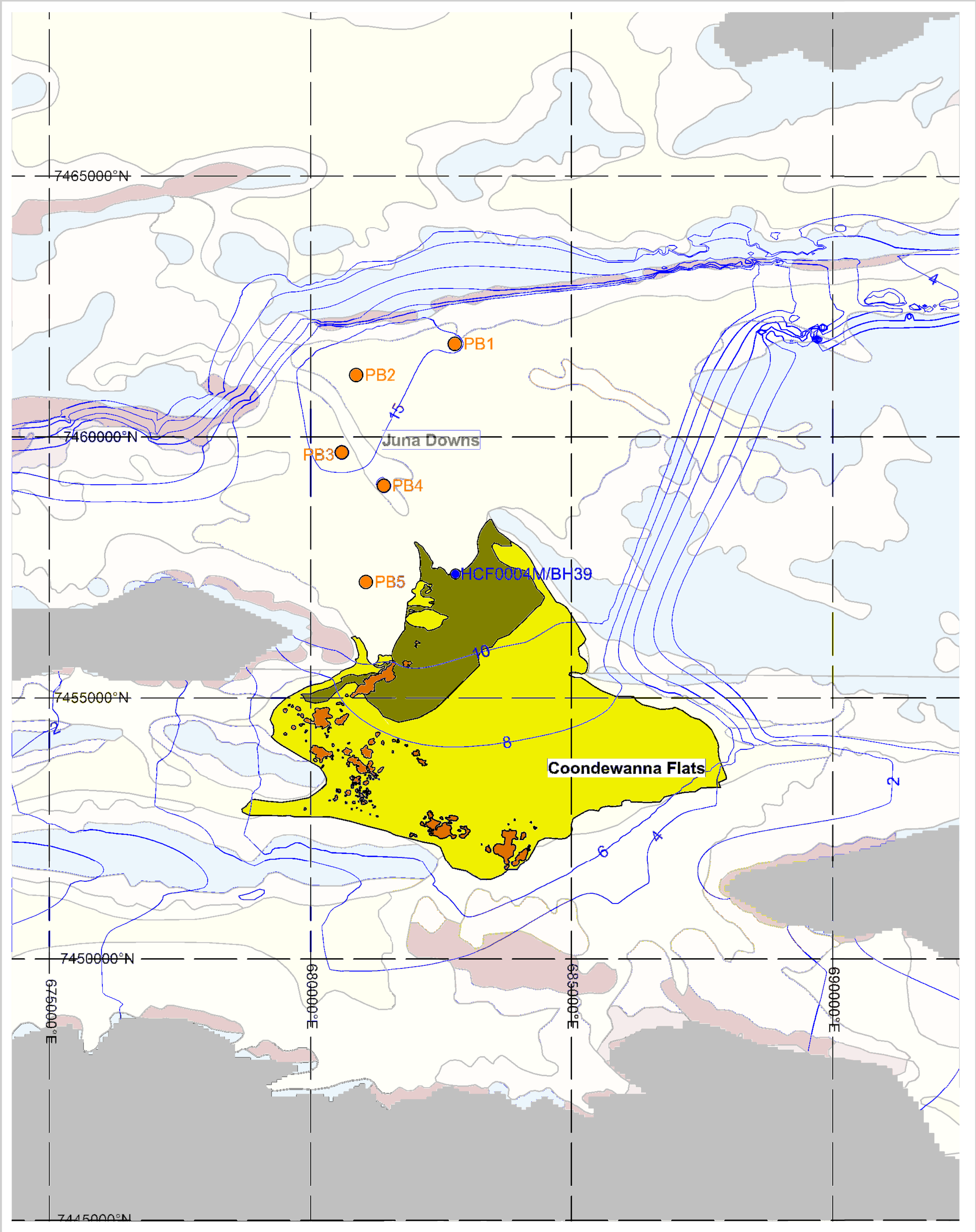
CONTOURS OF PREDICTED WATER LEVEL CHANGE WITH MAC, HOPE DOWNS AN INJECTION (20ML/D)

AUTHOR:	KR	REPORT NO:	...
DRAWN:	KR	REVISION:	B
DATE:	11 June 2016	JOB NO:	082B

NOTES & DATA SOURCES:

Negative water level change represents a water level decrease.
Positive water level change represents a water level increase.
MGA 1994 Zone 50
Scale 1, 100,000 @ A4

F:\082B\4.GIS\Workspaces\Report Figures\Base Map and Model Grid No dev minus dev portrait.WOR



LEGEND

Water Level Increase (m)

Coondewanna Vegetation

- Coolibah lignum thickets
- Lake Robinson
- Mulga Woodlands Sparse Lignum
- Juna Downs Injection Bore
- Monitoring Bore

0 1 2 km

Scale: 1:100,000

AQ2

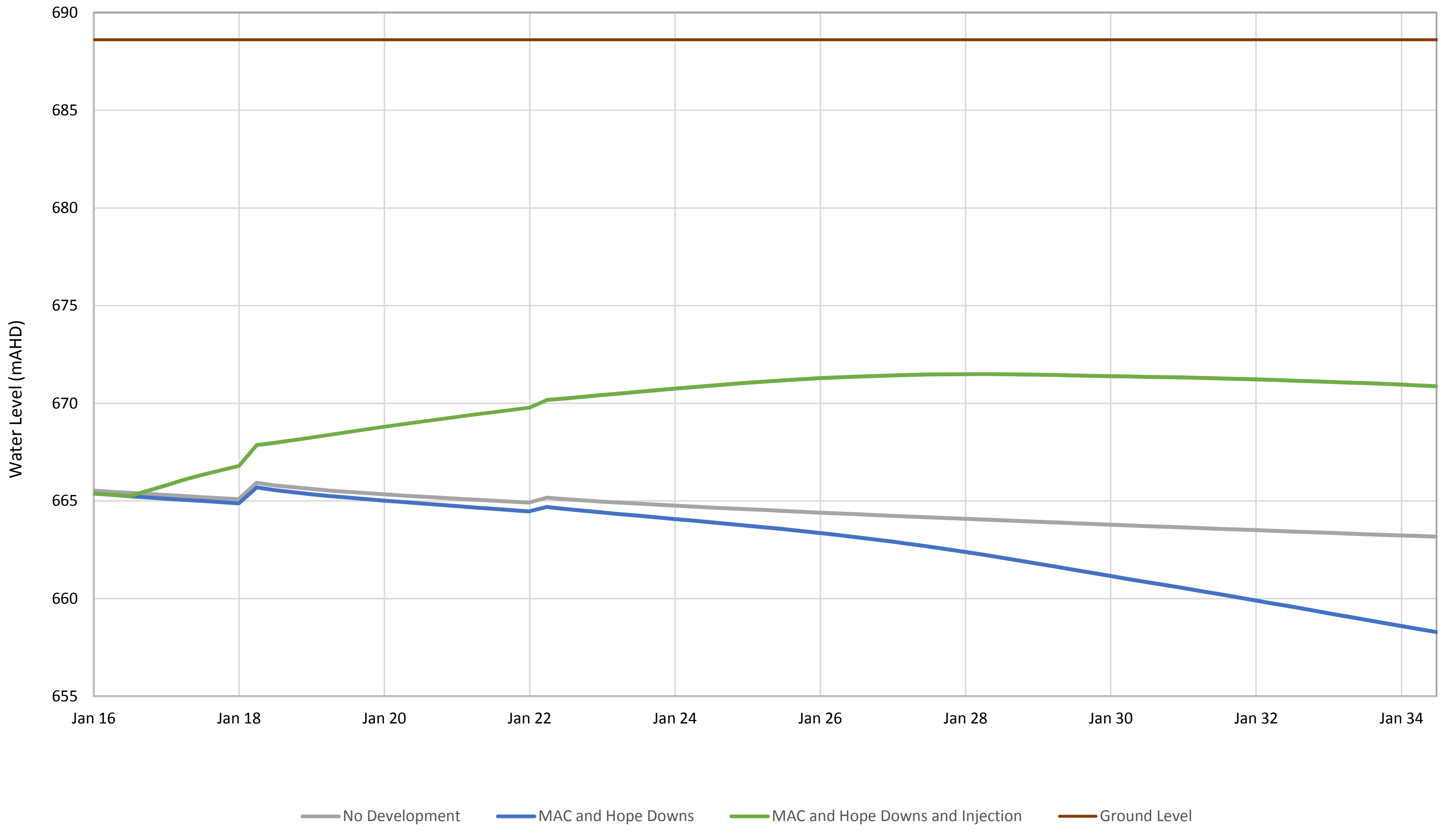
FIGURE 7

CONTOURS OF PREDICTED WATER LEVEL CHANGE YEJ2034 DUE TO INJECTION ONLY

AUTHOR:	KR	REPORT NO:	...
DRAWN:	KR	REVISION:	B
DATE:	12 June 2016	JOB NO:	082B

NOTES & DATA SOURCES:
Negative water level change represents a water level decrease.
Positive water level change represents a water level increase.
MGA 1994 Zone 50
Scale 1:100,000 @ A4

F:\082B\4.GIS\Workspaces\Report Figures\Base Map and Model Grid dewater minus dewater and injection portrait.WOR



AQ2

PREDICTED WATER LEVELS AT BH39/HCF0004M FIGURE 8

F:\082B\2.TECH\Modelling\Results\UncertOpsF Cal April\cal 3\[bh39 predicted water levels.xlsx]Figure 8

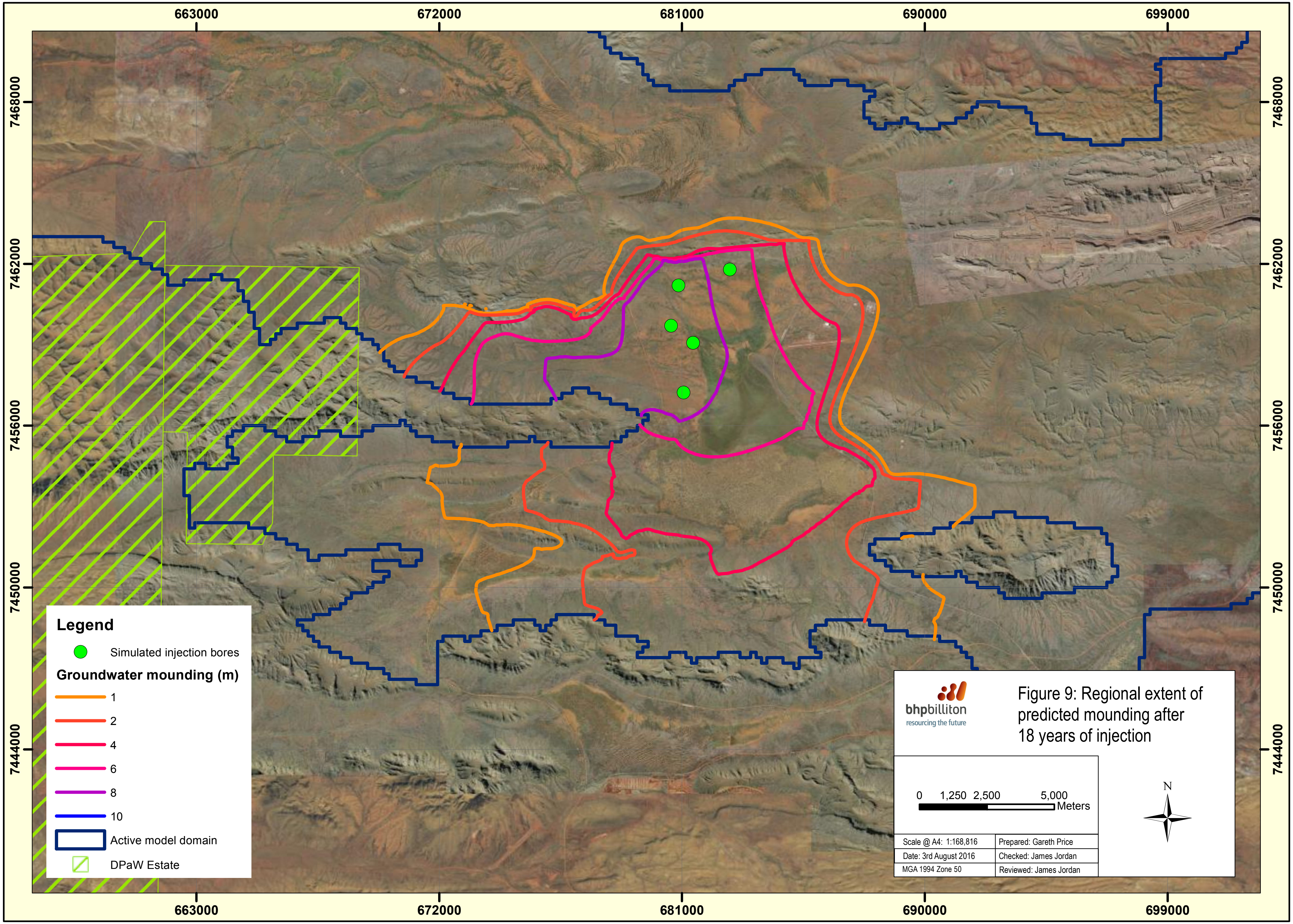


Figure 9: Regional extent of predicted mounding after 18 years of injection

Appendix B

Level 4, 56 William Street
Perth WA 6000
PO Box 976
South Perth 6951
Western Australia
Tel +61 8 9322 9733
www.aq2.com.au

AQ2 Pty Ltd
ABN 38 164 858 075

Memo

To	James Jordan	**Company**	BHPB
From	Dan Huxtable (Equinox Environmental) Duncan Storey (AQ2)	**Job No.**	011F
Date	09/09/2016	**Doc No.**	003d
Subject	Juna Downs MAR Scheme Ecohydrological Monitoring Framework		

James,

We are pleased to present the following assessment of ecohydrological monitoring requirements associated with the proposed managed aquifer recharge (MAR) scheme servicing Mining Area C.

1. INTRODUCTION

BHP Billiton Iron Ore (BHPB) is seeking to implement a managed aquifer recharge (MAR) scheme to dispose of surplus water produced at Mining Area C, located 100 kilometres northwest of Newman. Surplus water is generated by orebody dewatering during mining below the water table. The MAR water transfer system will include a series of injection bores located in a broad valley landscape to the west of Mining Area C, in an area known as Juna Downs.

MAR has advantages over other surplus water disposal options, such as direct discharge to surface drainages, by virtue of having a small surface disturbance footprint. However, as MAR effectively replenishes groundwater systems at much higher rates than natural recharge processes, it will elevate groundwater levels (i.e. create a groundwater 'mound') in a zone proximal to the injection bores for a period of time. BHPB has completed a modelling study that predicts the progression and extent of the MAR groundwater mound over the nominal 18-year operating life of the MAR scheme (2016-2034).

The predicted zone of groundwater mounding intersects the Coondewanna Flats (the Flats), an area of broad flats and closed depressions containing Mulga (*Acacia aptaneura*) woodlands and two unusual Western Coolibah (*Eucalyptus victrix*) woodland vegetation communities that are listed as Priority Ecological Communities (PECs) by the Department of Parks and Wildlife (DPaW 2015). The PECs constitute an environmental receptor.

This memo describes the potential response of the PEC vegetation communities of the Flats to groundwater mounding caused by the MAR scheme. It specifically addresses tasks completed by AQ2 and Equinox addressing the agreed scope of work[1], including:

- Defining the mechanism for potential impacts of the MAR scheme using an ecohydrological conceptualisation previously developed for the study area.
- Proposing an environmental monitoring framework for the MAR scheme including adaptive management triggers and thresholds.

Applied
Hydotechnics

Hydrogeologists
Modellers
Engineers

[1] As per AQ2_JobCost_revA_28-04-16

2. ENVIRONMENTAL SETTING

An overview of the study area is provided in Figure 1.

The Coondewanna Flats occupy an area of about 36 km^2 and are bounded by hills and ranges including Mt Robinson and The Governor to the east and south respectively, Packsaddle and Mt Meharry to the north and west respectively, and Newman 18 to the south west. Topographic elevations range between 690 m AHD near the margins of the Flats to 686 mAHD at the lowest points, whilst the surrounding hills rise to over 1,200 mAHD. The Flats constitute the terminus of an internally draining catchment extending to the west with an overall catchment area of approximately 860 km^2

The hydrostratigraphy of the Flats includes low to moderate permeability Tertiary detritals overlying an unconfined aquifer comprising calcrete and dolomite. The calcrete layer is extensive at a depth of about 16 to 20 mbgl. This is underlain by low to high permeability basement of the Wittenoom Formation. The water table occurs at a depth of approximately 18-24 mbgl; with the shallowest depth to water corresponding with the lowest elevation portion of the Flats near the south west margin. Groundwater level gradients across the Flats are low, however aquifer connectivity across the surface water catchment divide enables groundwater outflow into the North Flank and South Flank valleys to the east. A southwest-northeast trending dyke acts as a partial (low flow) groundwater flow barrier near the eastern edge of the Flats (AQ2 and Equinox 2016a).

The vegetation of the Flats includes the following associations mapped by BHPB botanical consultants (Onshore Environmental 2014; Astron 2011):

- EbEaTt Ev Mf - Tussock grassland of *Eriachne benthamii*, *Eulalia aurea* and *Themeda triandra* with open woodland of *Eucalyptus victrix* over open shrubland of *Duma florulenta* on orange brown loamy clay on alluvial plains. This vegetation type is confined to the Lake Robinson depression, occupying an area of about 570 ha and corresponding with the Priority 1 PEC;

- AaEv EaEb Mf - Open forest of *Acacia aptaneura* and *Eucalyptus victrix* over open tussock grassland of *Eulalia aurea* and *Eriachne benthamii* with open shrubland of *Duma florulenta* on red brown clay loam on alluvial plains. This vegetation type is widespread across the Flats (mapped area about 2,000 ha) and corresponds with the Priority 3 PEC;

- EvAa EbEa Mf - Closed forest of *Eucalyptus victrix* and *Acacia aptaneura* and over open tussock grassland of Eriachne benthamii and Eulalia aurea with open shrubland of *Duma florulenta* on red brown clay on low-lying plains. This vegetation type occurs as a mosaic of discrete patches, ranging in size from about 0.5 ha to 10 ha, within AaEv EaEb Mf (total mapped area about 130 ha) and corresponds with the Priority 3 PEC.

The remainder of the Flats area (about 900 ha) includes a mix of vegetation types including hummock grasslands (*Triodia* sp.) and low open forests and woodlands of *Acacia aptaneura* and other *Acacia* species. These are principally distributed around the periphery of the Flats.

BHPB's Mining Area C includes eight designated Marra Mamba orebodies with seven extending below the watertable; eleven Brockman orebodies with four extending below the watertable; and a Tertiary detritals deposit being above the watertable (RPS 2015). Construction of the mine started in 2001, mining started in 2003 and dewatering at two Marra Mamba orebodies (C and E Deposits) started in 2010. Initially all abstracted water was used for dust control; however more recently abstraction volumes have exceeded operational requirements necessitating the development of surplus disposal options.

The proposed MAR injection bores will be located in the Juna Downs area, which is immediately north of Coondewanna Flats. The final configuration of the injection borefield (i.e. exact location and number of bores) is yet to be determined. The study area includes a network of existing monitoring bores, including five that are monitored regularly as part of the Mining Area C groundwater operating strategy[2] (GWOS).

---

[2] Bore IDs GWB0037, GWB0038, GWB0039, GWB0041 and HCF0032

3. THE COONDEWANNA FLATS RECEPTOR

A detailed ecohydrological conceptualisation of the Coondewanna Flats was developed by AQ2 and Equinox in 2015, drawing on numerous hydrological and ecological investigations completed by BHPB over the past decade (AQ2 & Equinox 2016a).

In summary, the Flats include the following discrete ecohydrological system elements:

- Woodland vegetation communities dominated by *A. aptaneura* and *E. victrix*, with a total area coverage of approximately 3,600 ha within a boundary defined by the 690 mAHD land surface contour;
- Soil Water Reservoir - water resources contained in the unsaturated zone (vadose zone), consisting of deep, fine textured sediments; and
- Groundwater Reservoir - groundwater resources contained in the saturated alluvial aquifer and underlying dolomite aquifer beneath the vadose zone.

The system elements are linked to each other and the broader environment, through a series of key processes, outlined as follows:

- Periodic inundation of the Flats by flood waters generated from the surrounding catchment, as dictated by climatic conditions;
- Local scale redistribution of surface water within the Flats as mediated by micro-topography. Areas of focussed surface water accumulation occur at the Lake Robinson depression and near the southwest margin of the Flats;
- Infiltration of water into the soil profile during flood events; based on available climatic data, this water replenishes both soil water (≈ 3 in 4 years) and the groundwater system less frequently (≈ 1 in 4 years);
- Water uptake from the soil profile by tree root systems and release to the atmosphere (i.e. the process of transpiration).

  Of key importance, the deep sediments provide significant inter-annual plant available water storage for the major tree species. *E. victrix i*s a deep rooted species which may extract soil water at depths of up to approximately 15 mbgl. In doing so it adopts a drought avoidance strategy, by maintaining access to relatively moist soil throughout the year. In contrast *A. aptaneura* has a shallow root system (i.e. roots confined to the upper 5 m of the soil profile). This species adopts a drought tolerance strategy, by becoming quasi-dormant during prolonged dry conditions;
- Additional loss of soil moisture to the atmosphere via transpiration by under-storey vegetation (i.e. shallow rooted tussock grasses and *D. florulenta)*, bare soil evaporation and direct evaporation from transiently ponded water; and
- Outflow of groundwater from Coondewanna Flats to the east, into the North and South Flank Valleys respectively. Note that there is minimal lateral inflow of groundwater to the flats from the surrounding landscape due to low hydraulic gradients.

A diagrammatic description of the major system elements and processes is shown in Figure 2.

4. ASSESSMENT OF GROUNDWATER MOUNDING

In order to predict the likely increase in groundwater levels in the Coondewanna Flats area in response to long term injection of surplus dewatering water into the regional dolomite aquifer at Juna Downs, groundwater modelling has been undertaken using the existing Central Pilbara numerical groundwater model developed by BHPB. The modelling was based on the injection of 20 ML/d for a period of 18 years (nominally 2016-2034) at five indicative locations at Juna Downs (shown in Figure 3).

Key findings from the modelling work are:

- The net change in groundwater levels at Coondewanna Flats after 18 years of injection to the Juna Downs borefield and continued dewatering at MAC, is a rise of between 5 and 8 m, as shown in Figure 4. This brings the groundwater level to within a minimum of about 14 and 16 m from the ground surface.
- Groundwater levels at GWB0039 (located near the edge of the flats, on the northwest margin of Lake Robinson – see Figure 4) show a relatively rapid rise with time (roughly 1 m per year) over the first five years of injection. When dewatering drawdown from MAC starts to increase in this area, levels begin to plateau between five and 10 years at about 672 mRL (where surface elevation is about 689 mRL i.e. depth to groundwater about 17 mbgl), then fall slightly. In the

injection-only scenario, groundwater levels continue to rise after five years injection but at a lower rate of around 0.5 m per year. Time series predictions of groundwater levels at GWB0039 are shown in Figure 3.

- Around the borefield itself, groundwater levels remain in excess of 20 m below the ground surface throughout the injection period due to deeper baseline ground water levels.

Full details of the modelling work undertaken can be found in the Juna Downs Injection Modelling Report (BHPB, 2016).

5. POTENTIAL MECHANISMS OF IMPACT ON VEGETATION HEALTH

The scope for elevated groundwater levels to affect vegetation water uptake and plant health depends on the degree of interaction between groundwater and plant root systems. This requires consideration of:

- The depth that plant roots extend into the soil profile;
- The potential for the water table to intersect the zone of plant roots; and
- The response of plants to partial root zone inundation.

These aspects are explored in the following sections.

5.1 PLANT ROOT SYSTEMS

Plant roots provide absorption sites for the extraction of water and nutrients from the soil, in addition to physically anchoring and stabilising above ground vegetation. The ability of root systems to locate and extract soil water is a key factor influencing the movement of water through the soil-plant-atmosphere continuum (SPAC).

In many environments water is the key limiting factor for plant growth. Plants respond by configuring their root systems to inputs of water to the soil profile (Hodge et al. 2009). In most situations the major input is from the surface (i.e. deriving from rainfall or run-off). Surface soil layers wet up after rainfall events and then progressively dry out. Percolation of water into deeper soil layers occurs less frequently following larger rainfall events. As it is energetically and ecologically efficient for plants to preferentially use shallow soil water, deeper sources are only accessed during prolonged dry periods when shallow soil water becomes depleted. Groundwater use is uncommon and typically restricted to environments with relatively shallow water tables (<10 mbgl), low rainfall (i.e. small surface water inputs) and low water storage capacity of overlying soil layers (i.e. soils with low plant available water per unit volume of soil, which are prone to rapidly drying out) (Thomas 2014 and references therein).

Global synthesis of plant root distribution data indicates that for most species about 50% of the root biomass occurs in the first 0.8 m of soil, 95% in the first 2 m, and only a minor percentage (if any) in deeper soil layers (Schenk 2008; Schenk & Jackson 2002, 2005). However, particularly in seasonally water limited environments, some woody plants develop relatively deep and expansive root systems in order to avoid periodic drought stress (Schenk and Jackson 2002; Maeght et al. 2013). By accessing deep soil water reserves and/or groundwater, these plants can maintain healthy water status even during prolonged dry conditions. Even where they occur, deep roots generally only constitute a small fraction of the overall root system biomass; although they may have disproportionate functional importance for drought stress avoidance (Maeght et al. 2013).

Many eucalypts adapted to arid areas have dimorphic root systems, with both shallow lateral roots and a large taproot capable of penetrating to considerable depth (Knight 1999 and references therein). They are also able to maintain relatively low xylem matric potentials and regulate water use via stomatal closure and leaf shedding. These traits confer an ability to opportunistically access shallow soil water resulting from episodic rainfall or run-on events, along with deeper soil water and in some situations groundwater; thereby contributing to favourable water status and continuous water use throughout the year. The major floodplain and riparian Eucalypt species in the Pilbara region (*E. camaldulensis* subsp. *refulgens* and *E. victrix*) fall into this category (Mensforth et al. 1994; Burgess et al. 2001; Colloff 2014; Pfautsch et al. 2014; Knight 1999; Florentine 1999). In contrast, many other perennial xerophytic species that are widespread in Pilbara landscapes have shallow root systems. These species tolerate drought stress by drastically reducing their water use under dry conditions and maintaining very low stem water potentials. Examples include spinifex grasses (*Triodia* sp), members of the Mulga complex (*Acacia aneura* and closely related taxa) and other *Acacia* species (Grigg 2009; Eamus et al. 2013; Page et al. 2011).

It is important to note that plant root systems may respond dynamically to changes in water availability (Brunner et al. 2015). For example, many species exposed to drought develop deeper or more expansive roots systems to help meet their water use demands. Plants may be quite adaptable to gradual changes to source water, linked to natural processes affecting their habitat, but susceptible to rapid changes that exceed the capacity of their root systems to adjust. Particularly in mature trees, over-investment in a particular root structure could increase vulnerability if the root system is rendered functionally ineffective by changes to the hydrological regime.

BHPB has undertaken detailed studies of tree water use at Coondewanna Flats (summarised in AQ2 and Equinox 2016a); including measurements of leaf water potential, sap flow and soil moisture. This work also included measurement of chloride distribution in the vertical soil profile, which provides information on zones of preferential water uptake by tree roots. The findings suggest that at Coondewanna, the roots systems of mature *E. victrix* trees may extend up to approximately 15 m below the surface, whilst those of *A. aptaneura* and *D. florulenta* are confined to the upper 5 m of the profile. In all cases the plant roots are concentrated at depths above the water table, suggesting that groundwater is not a plant available water source. Although exhibiting a seasonal pattern of water use, with declines corresponding with dry periods, *E. victrix* trees maintain leaf water potential above -5 MPa indicating permanent access to relatively moist soil (below 5 m from the surface). In contrast *A. aptaneura* experiences periods of extreme water deficit (leaf water potential less than -5 MPa) during prolonged dry conditions.

Based on the above, the maximum predicted increase in groundwater levels associated with the MAR scheme could potentially create a connection between the deep roots of mature *E. victrix* trees and the groundwater system. This could occur via direct saturation of roots or interaction with the capillary fringe immediately above the water table. Note that based on a numerical modelling study of soil water hydraulics at Coondewanna (AQ2 & Equinox 2016a), capillary rise is likely to be confined to within 1 m of the water table.

Due to their shallow roots systems *A. aptaneura* trees and understorey species will not be affected by the predicted increase in groundwater levels associated with the MAR scheme.

5.2 PLANT RESPONSES TO FLUCTUATING WATER LEVELS

5.2.1 Waterlogging in the root zone

Plants roots require oxygen to support metabolic processes. Without specialised adaptations, root systems exposed to prolonged waterlogging will become seriously injured or die within days to weeks (Pessarakli 2005; Kozlowski 1997). This process, often referred to as 'root pruning', also impairs physiological recovery following improved aeration of the profile (e.g. upon drainage following flooding). Depending on the proportion of the root system affected, the abrupt reduction in the plant's water uptake apparatus makes it more susceptible to subsequent water deficits. The decrease in root-to-shoot ratio impairs soil water and nutrient extraction and inhibits subsequent recovery and growth. Especially in the case of large trees, severe root pruning can also increase vulnerability to toppling by wind or flood waters.

Regularly fluctuating groundwater levels in the vegetation root zone presents a challenge for plants due to repeated occurrence of anoxia hampering or preventing deep root formation (Naumberg et al. 2005). In general, it is likely that the roots of groundwater using (i.e. phreatophytic) plants undergo cycles of root trimming and elongation as water tables rise and fall (Canham et al. 2012). However, factors affecting the rate of root growth in such environments remain relatively poorly studied. Plants may be quite adaptable to gradual changes in water levels, linked to natural processes affecting their habitat, but susceptible to more rapid changes associated with artificial modifications. Large woody roots are reported to persist under waterlogged conditions more effectively than non-woody roots (Kozlowski 2002); which suggests that mature trees may have a higher tolerance than juveniles to short and medium term water level fluctuations.

Root system architecture established under historical water regimes is likely to be important for tree adaptability to elevated water tables (Jurskis & Turner 2002); and also the growth stage of the tree. In a study of artificially induced water table fluctuations on riparian groundwater using vegetation in Arizona, Shafroth et al. (2000) measured increased tree mortality at sites with a history of shallow, stable water tables in comparison to sites with a wider range of water table fluctuations. In the former case the trees had configured the majority of their root systems to a narrow layer corresponding with the groundwater capillary fringe; whilst in the latter case the root system was more widely distributed. The severity of these effects was related to the water storage capacity of the unsaturated profile, with a lesser degree of health decline on finer-textured soils with greater soil moisture buffering capacity.

It is reasonable to expect that the effects of waterlogging will be less severe if only a portion of the root system is subject to saturation, and that plant recovery from stress will be more rapid following the return to unsaturated conditions. This has been documented in anthropogenic crop species (e.g. Malik et al. 2002; Dresbøll at al. 2013) but has been subject to limited study in woody riparian species. In a recent conference presentation, Argus et al (2014) reported that *E. camaldulensis* and *E. victrix* trees located on the banks of Weeli Wolli Creek adjacent to the main river channel (i.e. ground surface slightly elevated above the river channel) displayed no symptoms of health decline in association with prolonged saturation of the channel, whilst measurable decline (although not mortality) was observed in trees growing in the fully saturated channel. These findings suggest that for the trees on the banks, a significant proportion of the tree roots were in the surficial layers that remained oxygenated.

5.2.2 Augmented water supply

Vegetation water use tends towards a dynamic equilibrium with plant available water, as supported by long term observations of vegetation structural characteristics including leaf area index and stand basal area (e.g. Doody et al. 2015; Horner et al. 2009). Leaves comprise the connection between root water uptake and the atmosphere, and leaf area is strongly correlated with plant water use at individual plant and stand scales (Zeppel 2013; O'Grady et al. 2011). Plants transpire water in order to fix carbon from the atmosphere via the process of photosynthesis. In general terms, the more water plants transpire the faster they will grow.

Whilst prolonged root zone inundation is problematic for many plants, the connection of root systems to groundwater can provide an additional water source to augment soil water. Where root systems are not significantly compromised, or plants are able to adjust to the altered groundwater regime, higher rates of plant water use are able to be sustained. This can manifest in various structural responses including an increase in leaf area index, higher rates of transpiration and faster growth rates. Over longer periods plant density may increase (depending on species life history). With respect to plant water status, the availability of groundwater is likely to enable high leaf water potentials to be maintained during dry periods relative to trees without access to groundwater.

Conversely, if groundwater subsequently becomes unavailable to vegetation structural adjustments will occur in the opposite direction (i.e. reduced leaf area index, lower growth rates). Many Eucalypts respond to short term drought stress by stomatal regulation of water use (i.e. decreased transpiration). Over longer periods leaf area may be reduced via leaf shedding or in more extreme cases branch severing. In extreme cases, drought stress may cause individual tree deaths as part of stand level adjustment to lower water availability - a process commonly referred to as 'self thinning'. Rapid and significant changes in groundwater levels are more likely to induce measurable vegetation stress than more gradual changes.

In a recent study of the effect of fluctuating groundwater levels on *E. victrix* trees along Weeli Wolli Creek, Pfautsch et al. (2014) provide evidence of higher water use by trees in areas where water levels had been increased from 16 mbgl to 7 mbgl compared with sites where the depth to groundwater had not changed. Notably the health of *E. victrix* trees exposed to prolonged and substantial groundwater drawdown (8 mbgl to 19 mbgl) was unaffected, suggesting that these trees source the majority of their water from surface derived inputs but can utilise groundwater opportunistically when it is available.

5.2.3 Tree response conceptual model

Through synthesis of the preceding discussion, the conceptual model developed by Naumburg et al. (2005) provides a useful framework for considering potential responses of *E. victrix* to fluctuating groundwater levels at Coondewanna Flats caused by the proposed MAR scheme (Figure 5). The application of this model is summarised diagrammatically in Figure 6. Key conclusions are:

- Implementation of the MAR scheme is predicted to progressively increase groundwater levels underlying stands of *E. victrix* trees on Coondewanna Flats.
- Based on the predicted maximum extent of groundwater mounding, the lower portion of the root systems of some mature *E. victrix* trees could become exposed to groundwater for a period of time. In such cases tree water status (as measured by leaf water potential) may increase relative to unaffected trees, particularly during prolonged dry conditions. Where trees have sustained access to groundwater leaf area, tree water use and growth rates may increase.
- The majority of the tree root systems will remain unaffected. However, pruning of the deeper roots may occur if they are exposed to frequently saturated soils. The trees may reconfigure their root systems to some extent to exploit the groundwater resource.
- At the conclusion of the operational phase of the MAR scheme groundwater levels will progressively decline.
- Trees with root system that were brought into connection with the groundwater system will become disconnected from groundwater. In such cases tree water status may decline during prolonged dry conditions; potentially with associated decreases in leaf area, tree water use and

growth rates. More extreme adjustments including canopy die back are unlikely but possible. The trees will gradually re-adjust to the surface driven hydrological regime.

6. PROPOSED ECOHYDROLOGICAL MONITORING AND ADAPTIVE MANAGEMENT FRAMEWORK

6.1 HISTORICAL INFORMATION AND EXISTING MONITORING

BHPB undertakes regular monitoring of groundwater levels in the study area, as part of existing compliance requirements for Mining Area C. Regularly monitored bores in the study area include GWB0037, GWB0038, GWB0039, GWB0041 and HCF0032.

BHPB does not have a program of ongoing vegetation monitoring in the study area, however considerable campaign based data has been collected in association with ecohydrological investigations completed in the period 2012-2014 (Astron 2014; URS 2014). This historical work is summarised in Table 1 and further described in AQ2 and Equinox (2016a).

The locations of leaf water potential measurements collected by Astron are suitable for inclusion in future monitoring programs at Coondewanna Flats. Leaf water potential provides an important leading or 'real time' measure of plant water status, and has been adopted as a key parameter in BHPBs riparian vegetation monitoring programs across its Pilbara operations. Interpretation of leaf water potential measurements includes consideration of relationships between predawn leaf water potential (ΨPD) and midday leaf water potential (ΨMD) described by the following formula:

$$\text{Ecological Rehydration Index (ERI)} = \frac{(\Psi\text{MD} - \Psi\text{PD})}{\Psi\text{MD}}$$

ERI values superimposed on plots of ΨPD against hydraulic gradient (i.e. ΨMD – ΨPD), in combination with empirically developed species specific ΨPD thresholds, provide information on the drivers of plant water status (AQ2 and Equinox 2016b). Four ERI zones have been defined based on the analysis of pooled BHPB monitoring data across all Pilbara operations:

- Zone 1: Potential Groundwater Use; characterised by high levels of rehydration (ERI >≈0.7) and ΨPD values above the species-specific upper thresholds. Changes in water status of trees within this zone could correlate with either groundwater availability or vadose-zone water availability (wet soil), depending on the actual source of tree-water.
- Zone 2: Vadose-water Use – high water availability; characterised by high levels of rehydration (ERI >≈0.7) and ΨPD values below the species specific upper thresholds. Changes in water status of trees within this zone are expected to correlate vadose-zone water availability.
- Zone 3: Vadose-water Use – constrained water availability; characterised by moderate levels of rehydration (ERI between about 0.3 and 0.7). Changes in water status of trees within this zone are expected to correlate with vadose-zone water availability.
- Zone 4: Vadose-water Use – limited water availability (drought stress); characterised by low levels of rehydration (<≈0.3). Changes in water status of trees within this zone are expected to correlate with vadose-zone water availability.

An ERI baseline is developed from time series trajectories of individual trees and stands of trees within and between these zones (refer to Figure 7 for a graphical example). Derived ERI values for *E. victrix* trees at the Flats, based on the measurements made by Astron (2014), suggest a reliance on vadose soil water (i.e. ERI zones 2, 3 and 4). *E. victrix* ΨPD values varied across the measured sites on the Flats (between -0.2 to -2.1 Mpa), but in most cases were between -1 MPa and -2 MPa. Midday leaf water potential (ΨMD) ranged between -2.7 MPa and -4.6 MPa. ΨMD was generally higher (i.e. less negative) in April 2014 compared to November 2013, although the difference was relatively small. The higher ΨMD values in April 2014 correspond with the replenishment of soil water following summer rains in 2014.

Other relevant vegetation health parameters included in BHPBs riparian vegetation monitoring programs across its Pilbara operations include:

- Crown condition score (CCS) - Crown condition refers to the physical status of the upper part of the tree containing the leaves and branches. Visual assessments of canopy condition based on qualitative scoring systems can provide cost effective, informative data on tree condition. A ground based visual health assessment method for evaluating the health of riparian eucalypts (Souter et al. 2009; 2010) has been adapted for use in the Pilbara region by BHPB; however similar methods based on remote sensing imagery are a viable alternative. CCS is a lagging indicator, as visual changes to the canopy may take weeks or months to manifest following a stress event.

- Diameter-at-breast-height over-bark (DBH) - The standard method of measuring the stem diameter of forest trees, measured at 130 cm above ground level. Time series measurements of DBH can provide an indication of biomass growth rates between successive sampling events. Growth increments can be related to climatic variables such as rainfall metrics to provide insights into relationships between growth rates and plant water use; and therefore constitute a lagging indicator of plant water availability.

  Note that DBH measurements of *E. victrix* trees at Coondewanna Flats were collected by Astron (2014), and some additional measurements made by Dan Huxtable (Equinox) in 2015 (AQ2 and Equinox 2016). These data constitute an initial growth baseline.

6.2 BHPBS WATER RESOURCE MANAGEMENT STRATEGY

BHPB has developed a Water Resource Management Strategy (Water RMS) applicable to all iron ore operations in the Pilbara (Figure 8). The Water RMS provides an adaptive management approach for water-related aspects of BHPBs activities, and can be flexibly applied to a wide range of strategic and operational water management scenarios.

An overarching water management objective is to proactively avoid and/or minimise environmental impact through implementing preventative controls on a regional scale, as part of 'business as usual' activities. The Water RMS supports sustainable water resource management by framing options for mitigating and/or minimising operational impacts on surface water and groundwater; and setting outcome-based conditions for managing water assets within catchment scale water management plans. This approach is consistent with the Department of Water's (DoW) guidance in the Western Australian Water in Mining Guideline (DoW 2013), and reflects the water management hierarchy advocated in the guideline. In the context of the strategy, water assets are considered to include environmental receptors with strong ecohydrological connections with surrounding landscapes.

Adaptive management within the Water RMS is staged, iterative and responsive to the specific water requirements of environmental receptors. Decision making is based on the development of baselines, assessment of hydrological changes (predicted and actual), prediction of impacts on receptors, monitoring of change, and evaluation of the outcomes of management actions where applied. Management approaches are progressively developed and refined, as informed by accumulated scientific knowledge and measured outcomes. The key elements of this approach are further articulated in Figure 9.

The Water RMS is underpinned by a risk-based approach that considers scientific uncertainty and outcome-based objectives. Early warning triggers and thresholds are selected to ensure that monitoring is targeted to relevant hydrological change processes and ecosystem responses, in order to mitigate and manage potential impacts on receptors. In the early stages of the process, these triggers and thresholds are typically conservative and precautionary reflecting incomplete scientific knowledge. As scientific understanding becomes more complete, often involving a transition from regional or catchment-scale to site-specific interpretative investigations, the level of uncertainty reduces with management triggers and thresholds being iteratively refined.

In this case, several site-specific ecohydrological investigations have been undertaken at Coondewanna Flats and initial triggers and thresholds can therefore be set, with a relatively high degree of confidence, based on available scientific data.

6.3 APPLICATION OF ADAPTIVE MANAGEMENT TO COONDEWANNA FLATS

Consistent with BHPBs adaptive management framework, the management objective relating to the MAR scheme is to conserve the environmental values of the Coondewanna PECs. Relevant elements of the approach include:

- Development of a baseline for *E. victrix* water status and tree health, based on monitoring parameters targeting anticipated tree responses to modified groundwater levels (as per Figure 6).

  As stated previously, the predicted increase in groundwater levels associated with the MAR scheme is not expected to affect *A. aptaneura* trees and understorey species, on the basis that there will be no interaction between groundwater and their shallow root systems.

- Identification of management triggers - defined to provide the point at which water management options must be considered and implemented to avoid potential impact to an environmental receptor. The triggers are intended to operate sufficiently early to allow investigation into the cause of change and, if required, water management options to be put in place well before a threshold values for the environmental receptor is reached.

- Identification of management thresholds - that provide a basis for evaluating whether a hydrological change has resulted in an impact to an environmental receptor as a result of BHPB operations. Thresholds are intended to represent system 'tipping points' resulting in a transition to a less desirable state. If a threshold is crossed, management actions are necessary to prevent further system change and may also entail remedial actions.

Based on the potential tree responses described in Section 5, suggested monitoring parameters, triggers and thresholds for *E. victrix* trees are summarised in Table 2 and described below.

Unless groundwater levels rise to <15 mbgl, the suggested vegetation monitoring program includes rapid and low cost CCS and DBH measurements at three locations (Figure 10):

- Near bore HCF0032 incorporating Astron (2014) site 15;
- Near Bore HCF0045, incorporating Astron (2014) site 20; and
- Near Bore HCF0044, incorporating Astron (2014) site 12.

It is recommended that 18 trees are selected to be monitored at each location, including the trees originally measured by Astron (2014), to provide adequate statistical power for trend analysis. It is recommended that measurements commence in November 2016 (dry season), with ongoing bi-annual (dry season and wet season) measurements. A preliminary baseline for CCS and DBH will be determined from the first 3-years of measurements, during which time the trees are not anticipated to be exposed to any significant groundwater level changes caused by the MAR scheme.

A rise of groundwater levels to within 15 m of the surface in any of bores GWB0039, HCF0032, HCF0044 and/or HCF0045 triggers the measurement of leaf water potential on a bi-annual basis at each of vegetation health monitoring sites 12, 15 and 20 (i.e. in addition to ongoing CCS and DBH measurements). This will enable the ERI assessment tool to be applied and hence evaluation of the effect of elevated groundwater levels on plant water status. It is recommended that 6 trees are selected to be monitored at each location, including the trees originally measured by Astron (2014). This represents a compromise between statistical power to detect trends and the practical collection of leaf water potential measurements.

Measurements of leaf water potential obtained during the first 3 years of elevated water tables (i.e. after the 15 mbgl trigger has been exceeded) will constitute a preliminary baseline against which future measurements during operation and following cessation of the MAR scheme will be compared. If leaf water potential values occur outside the ERI baseline then an investigation into the potential causes of ERI change will be undertaken. If the ERI change is linked to changes in groundwater levels then measures to limit the potential for negative impacts on tree health should be developed, based on the conceptual model of ecosystem response.

A decline in tree health is indicated by CCS values falling below the established baseline. If this occurs after the 15 mbgl trigger has been exceeded, a review of the potential causes of tree health decline, including natural causes (e.g. climate sequence) and the MAR scheme will be undertaken. Sustained canopy decline (defined as CCS below baseline for three or more consecutive measuring events and/or the death of any monitored tree) constitutes a management threshold. If this occurs, the following response actions are recommended:

- Review the potential causes of tree stress/death;
- Review the conceptual model of ecosystem response to change;
- If the response is linked to groundwater level change caused by the MAR scheme, instigate measures to limit further change.
- Identify any requirements for remedial actions in consultation with regulatory agencies.

7. CORROLARY

The preceding discussion provides:

- An overview of the ecohydrological conceptualisation of Coondewanna Flats;

- A description of the potential effects of the Mining Area C MAR scheme on groundwater levels and the Coondewanna Flats vegetation communities. It is considered that the deep rooted species *E. victrix* could potentially be responsive to groundwater mounding caused by the MAR scheme; and
- A suggested environmental monitoring program targeted to the conceptual understanding of the ecohydrological system, based on practical and cost effective methods.

The proposed monitoring program has been designed to build on existing Mining Area C environmental monitoring activities, and is consistent with BHPBs adaptive management approach and vegetation monitoring methods applied across the company's Pilbara operations more broadly.

Regards

Dan ***Duncan***

Consulting Ecologist Consulting Hydrogeologist

REFERENCES

AQ2 & Equinox 2016a, *Coondewanna Flats Ecohydrological Conceptualisation*, unpublished report to BHP Billiton Iron Ore Pty Ltd, January 2016, AQ2 Pty Ltd, Perth

AQ2 and Equinox 2016b, *Ecological Rehydration Index and the Determination of Groundwater Use by Riparian Vegetation,* unpublished report to BHP Billiton Iron Ore Pty Ltd, May 2016, AQ2 Pty Ltd, Perth

Argus RE, Page GFM and Grierson PF 2014, 'Impacts of artificial inundation of ephemeral creek beds on mature riparian eucalypts in semi-arid northwest Australia', *Geophysical Research Abstracts*, GU General Assembly held 27 April - 2 May 2014, Vienna (publication pending)

Astron 2014, Coondewanna Flats Ecohydrological Study Ecological Water Requirements of Vegetation Report, unpublished report to BHP Billiton Iron Ore Pty Ltd, Astron Environmental Services, Perth

Astron 2011, Coondewanna Flats Flora and Vegetation Assessment, unpublished report to BHP Billiton Iron Ore Pty Ltd, Astron Environmental Services, Perth

BHPB 2016, *Juna Downs Injection Modelling Report*, Unpublished report prepared by BHP Billiton Iron Ore, Perth

Brunner I, Herzog C, Dawes MA, Arend M and Sperisen C 2015, 'How tree roots respond to drought', Frontiers in Plant Science, vol. 6, doi 10.3389/fpls.2015.00547

Burgess SSO, Adams MA, Turner NC, White DA and Ong CK 2001, 'Tree roots: conduits for deep recharge of soil water', *Oecologia*, vol. 126, pp: 158 – 165

Canham CA, Froend RH, Stock WD and Davies M 2012, 'Dynamics of phreatophyte root growth relative to a seasonally fluctuating water table in a Mediterranean-type environment', *Oecologia*, vol. 170, pp: 909–916

Colloff MJ 2014, *Flooded Forest and Desert Creek – Ecology and History of River Red Gum*, CSIRO Publishing, MelbourneDoW 2013

Doody TM, Colloff MJ, Davies M, Koul V, Benyon R and Nagler PL 2015, 'Quantifying water requirements of riparian river red gum (*Eucalyptus camaldulensis*) in the Murray-Darling Basin, Australia - implications for the management of environmental flows', *Ecohydrology*, DOI: 10.1002/eco.1598

DoW 2013, *Western Australian water in mining guideline*, Water licensing delivery series Report No. 12, Department of Water, Perth

DPaW, 2015, *Priority Ecological Communities for Western Australia*, Version 23, 3 December 2015, Species and Communities Branch, Department of Parks and Wildlife, Perth

Dresbøll DB, Thorup-Kristensen K, McKenzie BM, Dupuy LX and Bengough AG 2013, 'Timelapse scanning reveals spatial variation in tomato (*Solanum lycopersicum* L.) root elongation rates during partial waterlogging', *Plant and Soil*, vol. 369, pp: 467 - 477

Eamus D, Cleverly J, Boulain N, Grant N, Faux R and Villalobos-Vega R 2013, 'Carbon and water fluxes in an arid-zone Acacia savanna woodland: An analyses of seasonal patterns and responses to rainfall events', *Agricultural and Forest Meteorology*, vol. 182-183, pp: 225 – 238

Florentine SK 1999, Ecology of *Eucalyptus victrix* in grassland in the floodplain of the Fortescue River, PhD Thesis, Curtin University of Technology, Perth

Grigg A 2009, 'An ecophysiological approach to determine problems associated with mine site rehabilitation: a case study in the Great Sandy Desert, north-western Australia', PhD Thesis, School of Plant Biology, University of Western Australia, Perth

Hodge A, Berta G, Doussan C, Merchan F and Crespi M 2009, 'Plant root growth, architecture and function', *Plant Soil*, vol. 321, pp: 153–187

Horner GJ, Baker PJ, MacNally R, Cunningham SC, Thomson JR and Hamilton F 2009, 'Mortality of developing floodplain forests subjected to a drying climate and water extraction', *Global Change Biology*, vol. 15, pp: 2176–2186

Jurskis V and Turner J 2002, 'Eucalypt dieback in eastern Australia: a simple model', *Australian Forestry*, vol. 65, pp: 87 – 98

Knight JH 1999, 'Root distributions and water uptake patterns in Eucalyptus and other species' In: Landsberg, J.J. (Ed.), *The Ways Trees use Water*. Water and Salinity Issues in Agroforestry No. 5. Rural Industries Research and Development Corporation, Publication Number 99/37, Barton, ACT, pp. 55– 85, 1999

Kozlowski TT 2002, 'Physiological-ecological impacts of flooding on riparian forest ecosystems ', *Wetlands*, vol. 22, pp: 550 – 561

Kozlowski TT 1997, 'Responses of woody plants to flooding and salinity', *Tree Physiology*, vol. 17, pp: 13 – 21

Maeght J, Rewald B and Pierret A 2013, 'How to study deep roots and why it matters', *Frontiers in Plant Science*, vol. 4, pp: 1 - 14

Malik AI, Colmer TD, Lambers H and Schortemeyer M 2002, 'Changes in physiological and morphological traits of roots and shoots of wheat in response to different depths of waterlogging', *Functional Plant Biology*, vol. 28, pp: 1121 – 1131

Mensforth LJ, Thorburn PJ, Tyerman SD and Walker GR 1994, 'Sources of water used by riparian Eucalyptus camaldulensis overlying highly saline groundwater', *Oecologia*, vol. 100, pp: 21–28

Naumburg E, Mata-Gonzalez R, Hunter RG, McLendon L and Martin DW 2005, 'Phreatophytic vegetation and groundwater fluctuations: a review of current research and application of ecosystem response modeling with an emphasis on great basin vegetation', *Environmental Management*, vol. 35, pp: 726-740

O'Grady AP, Carter JL and Bruce J 2011, 'Can we predict groundwater discharge from terrestrial ecosystems using eco-hydrological principals?', *Hydrol. Earth Syst. Sci. Discuss.*, vol. 8, pp: 8231–8253

Onshore Environmental 2014, *Consolidation of Regional Vegetation Mapping BHP Billiton Iron Ore Pilbara Tenure*, Unpublished report for BHP Billiton Iron Ore, Onshore Environmental Consultants Pty Ltd,

YallingupPage GFM, Cullen LE, van Leeuwen S & Grierson PF (2011), 'Inter- and intra-specific variation in phyllode size and growth form among closely related Mimosaceae Acacia species across a semiarid landscape gradient', *Australian Journal of Botany*, vol. 59, pp: 426-439

Pessarakli M (Ed.) 2005, *Handbook of Photosynthesis*, Second Edition, CRC Press

Pfautsch S, Dodson W, Madden S and Adams MA 2014, 'Assessing the impact of large-scale water table modifications on riparian trees: a case study from Australia', *Ecohydrology*, DOI: 10.1002/eco.1531

RPS 2015, *Ecohydrological conceptualisation of the Central Pilbara region*, unpublished report to BHP Billiton Iron Ore Pty Ltd, September 2015, RPS Group, Perth

Schenk HJ 2008, 'The Shallowest Possible Water Extraction Profile: A Null Model for Global Root Distributions', *Vadose Zone Journal*, vol. 7, pp 1119 – 1124

Schenk HJ and Jackson RB 2005, 'Mapping the global distribution of deep roots in relation to climate and soil characteristics', *Geoderma*, vol. 126, pp:129–140.

Schenk HJ and Jackson RB 2002, 'Rooting depths, lateral root spreads and below-ground/above-ground allometries of plants in water-limited ecosystems', *J. Ecol.*, vol. 90, pp: 480–494

Shafroth PB, Stromberg JC and Patten DT 2000, 'Woody riparian vegetation response to different alluvial water table regimes', *Western North American Naturalist*, vol. 60, pp: 66 – 76

Souter NJ, Cunningham S, Little S, Wallace T, McCarthy B and Henderson M 2010, 'Evaluation of a visual assessment method for tree condition of eucalypt floodplain forests', *Ecological Management and Restoration*, vol. 11, pp: 210–214

Souter N, Watts RA, White MG, George AK and McNicol KJ 2009, 'Method manual for the visual assessment of Lower River Murray River Floodplain trees – River Red Gum *(Eucalyptus camaldulensis)'*, Technical Note 2009/25, Department of Water, Land and Biodiversity Conservation, Adelaide

Thomas FM 2014, 'Ecology of Phreatophytes', *Progress in Botany*, vol. 75, pp: 355 – 375

URS 2014a, Report – Coondewanna Flats Phase II Water Assessment, unpublished report to BHP Billiton Iron Ore Pty Ltd, URS Australia, Perth

URS 2014b, Report – Coondewanna Flats Phase III Water Assessment, unpublished report to BHP Billiton Iron Ore Pty Ltd, URS Australia, Perth

Zeppel M 2013, 'Convergence of tree water use and hydraulic architecture in water-limited regions: a review and synthesis', *Ecohydrology*, vol. 6, pp: 889–900

FIGURES and TABLES

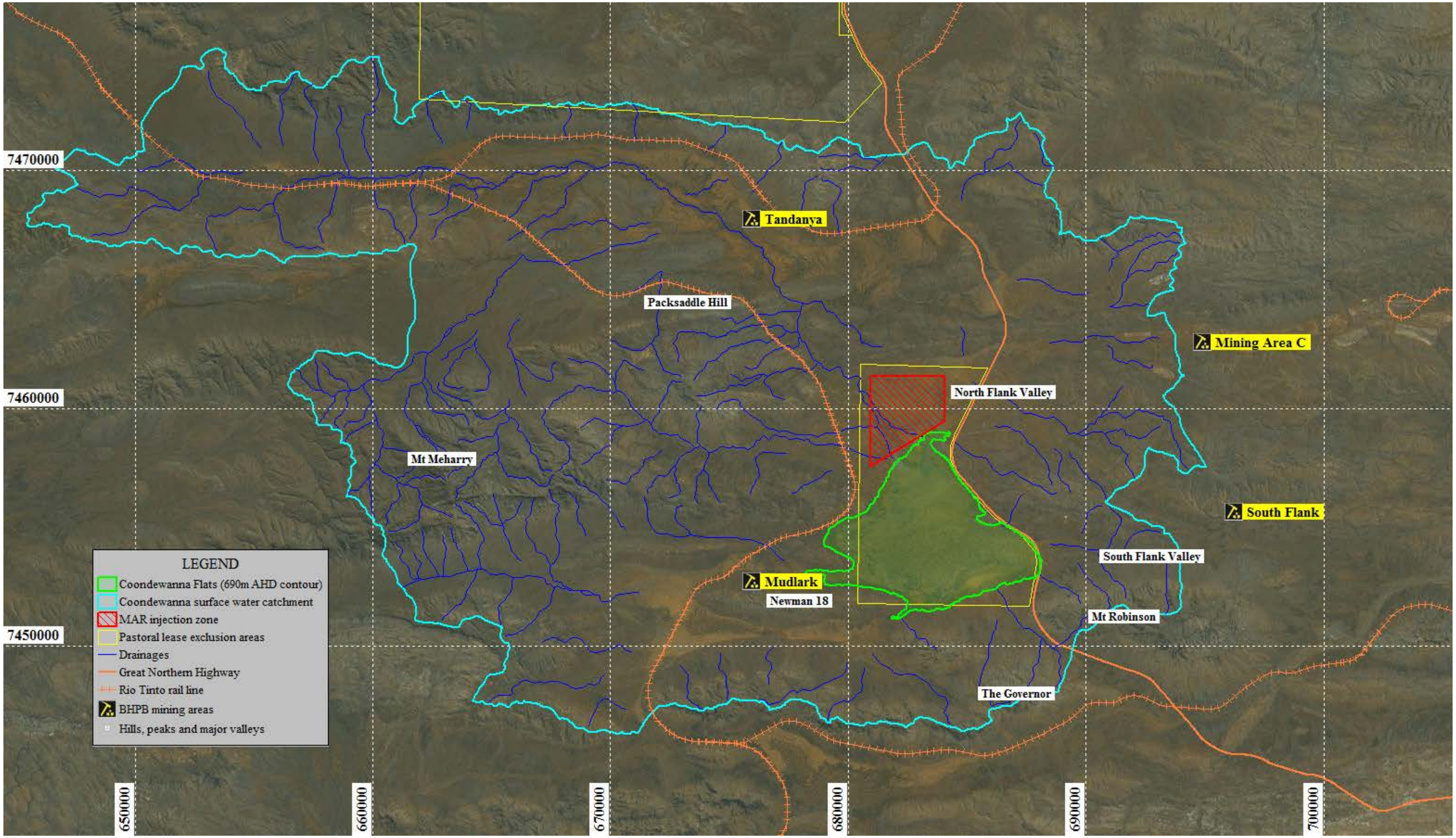


Figure 1 Overview of the study area

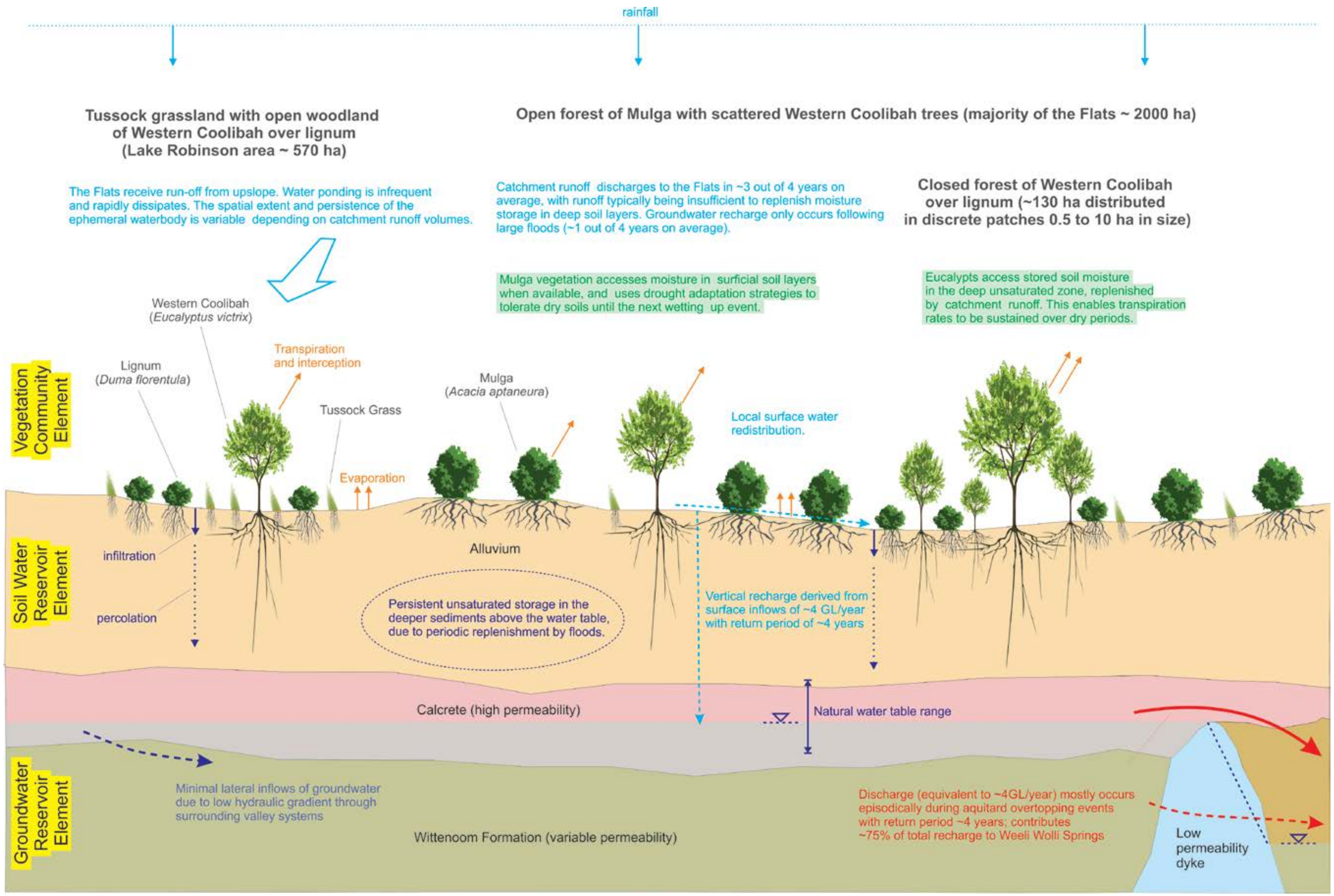


Figure 2 Ecohydrological conceptualisation of Coondewanna Flats

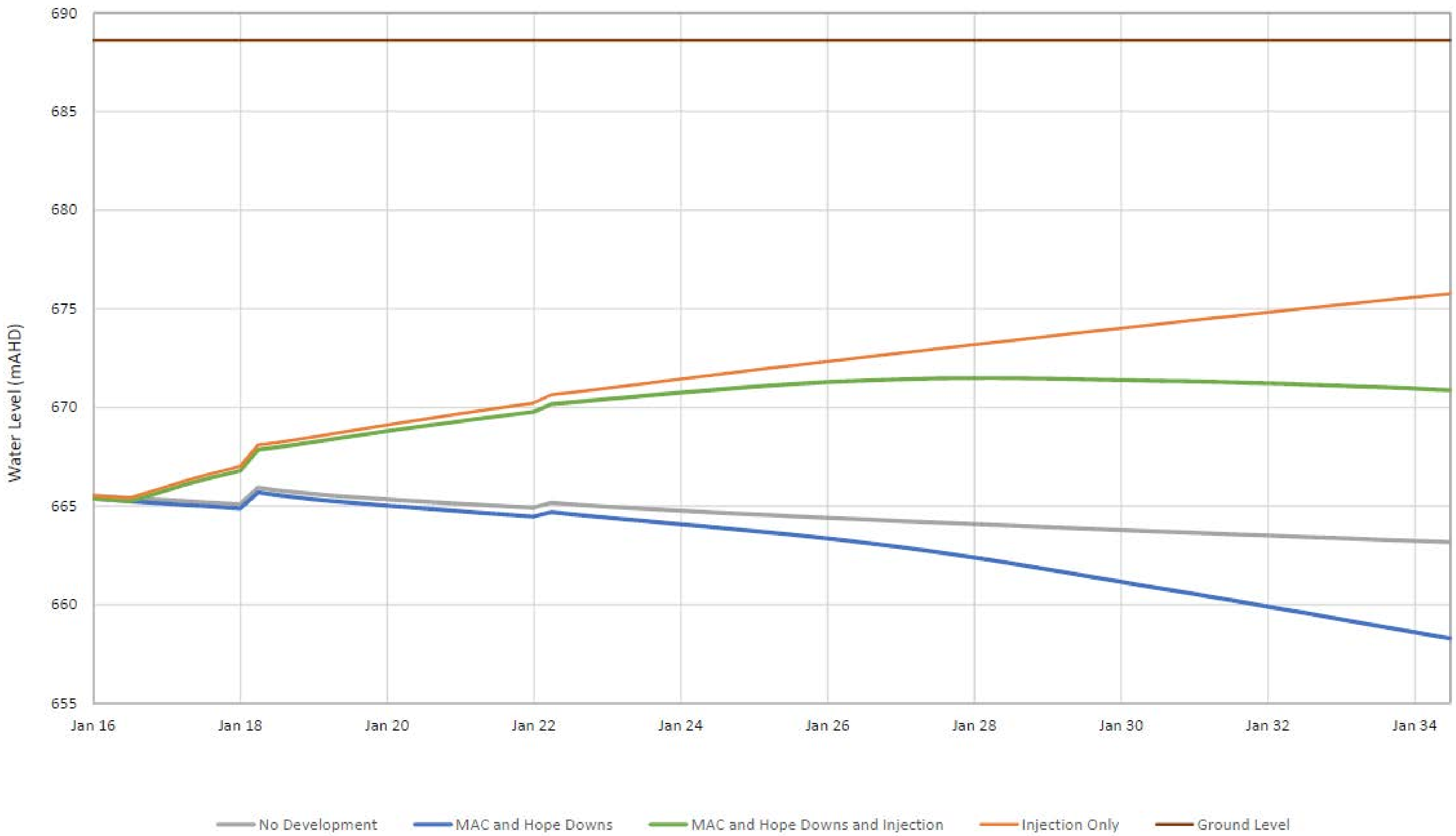


Figure 3 **Time series predictions of groundwater level at GWB0039, showing the progression of groundwater mounding**

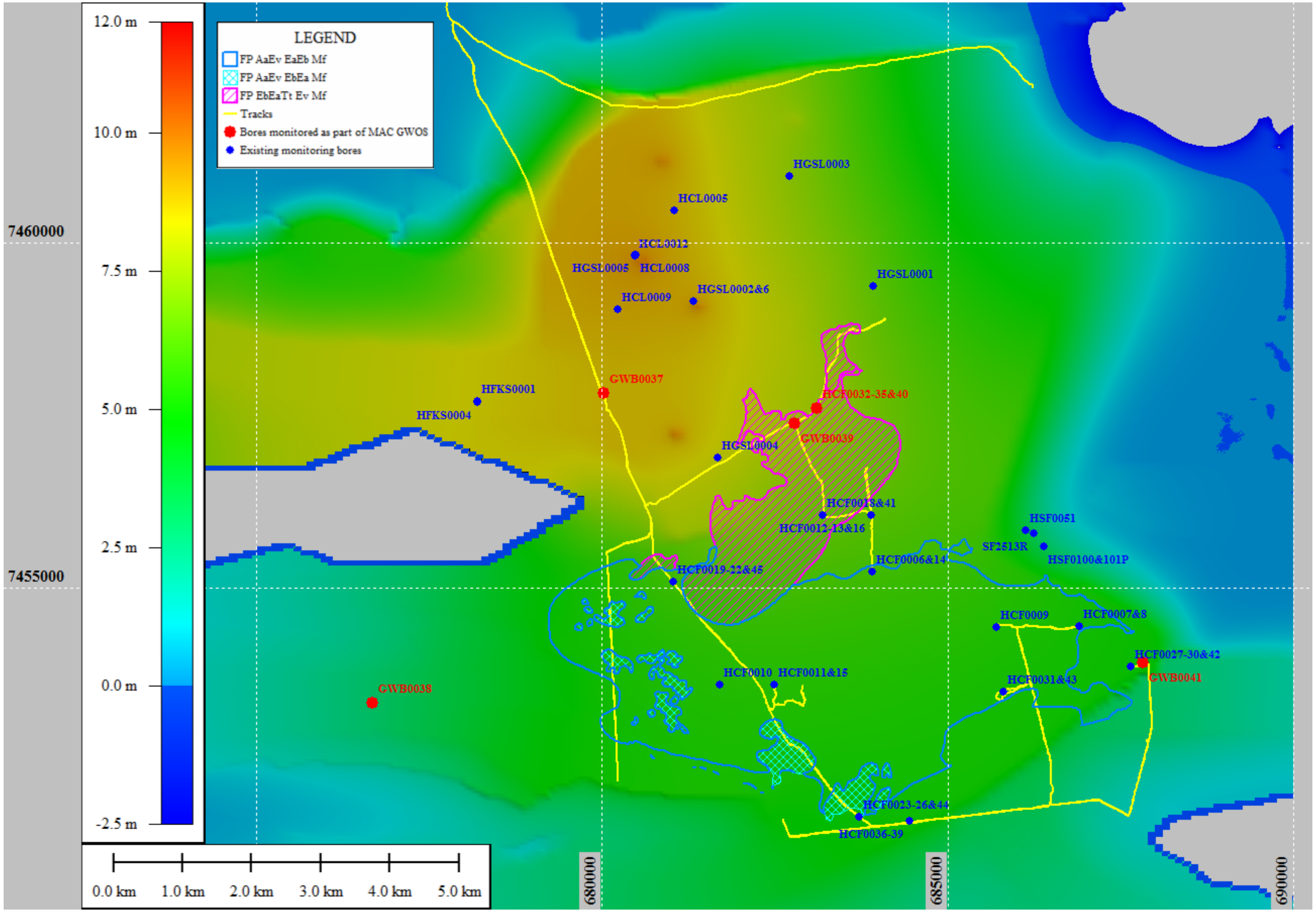


Figure 4 Predicted groundwater level rise (relative to pre-disturbance water levels) associated with the Mining Area C MAR scheme. Monitoring bores and major vegetation types (Priority Ecological Communities) are also shown.

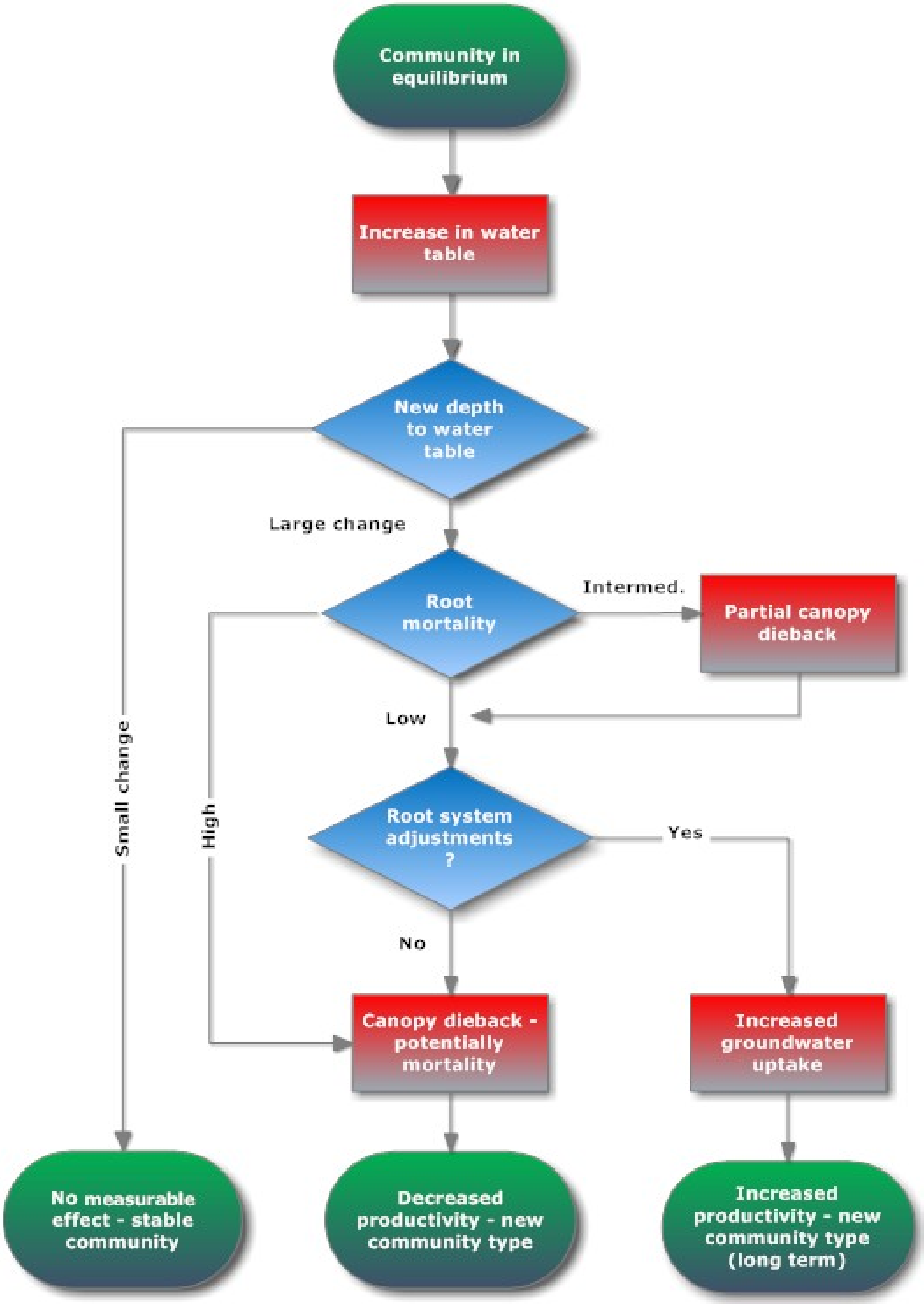
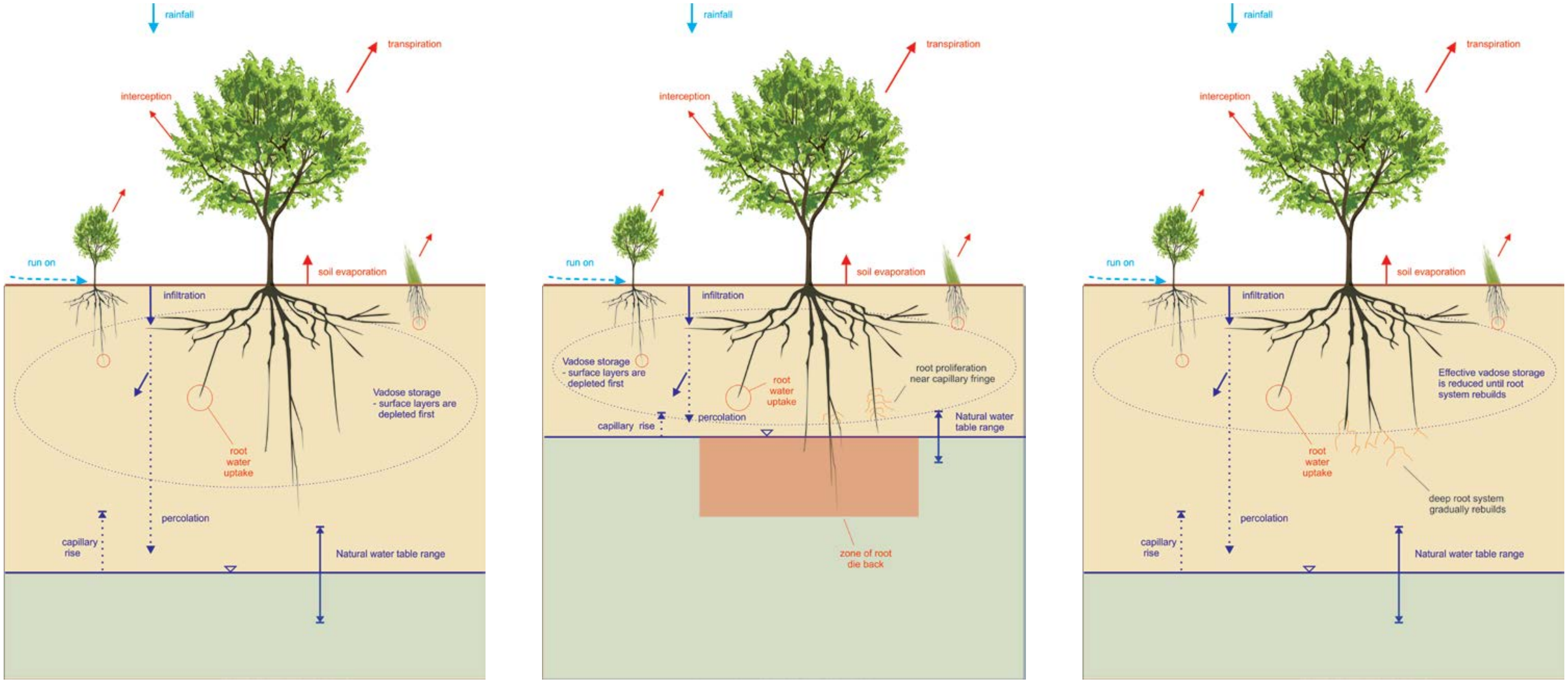


Figure 5 **Simplified conceptual model of the effects of a rising watertable on a vegetation community (adapted from Naumburg et al. 2005).**



Case 1 – Pre-disturbance

- Vegetation is disconnected from groundwater.
- The deep soil profile stores large quantities of plant available water, periodically replenished by floods and progressively depleted during protracted dry conditions.
- Mature tree roots extend to up to 15 mbgl.

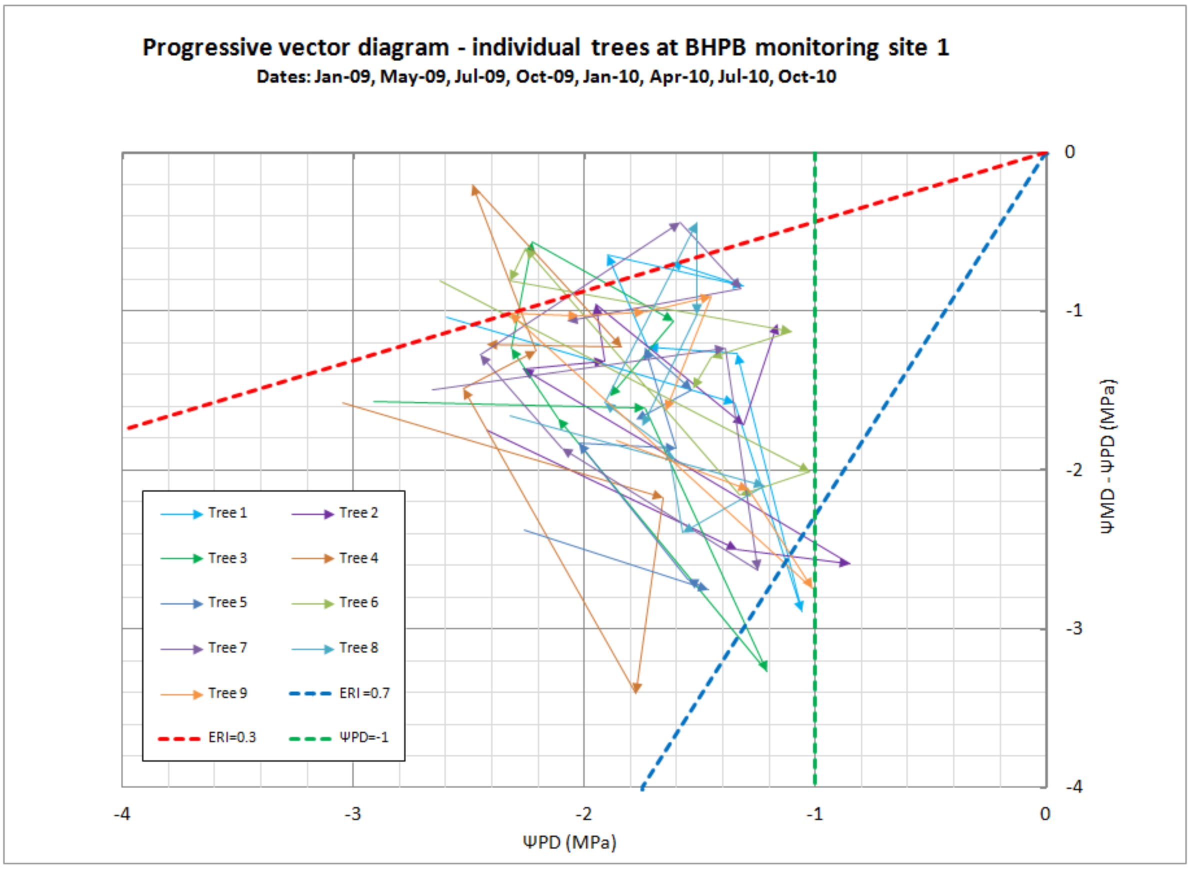
Case 2 – elevated water table

- Groundwater intersects lowest portion of mature tree root systems.
- Majority of root system remains unaffected. Root pruning may occur in zone >12 mgbl.
- Trees gradually reconfigure root systems to exploit capillary fringe water. A proportion of water is still sourced from shallower soil layers.
- Increased foliage density, tree water use and growth.

Case 3 –water table recedes

- Tree roots become disconnected from groundwater.
- Trees gradually reconfigure root systems to exploit soil water resource.
- Reduced tree water use and growth.
- Potential for leaf shedding and canopy dieback in some trees, particularly if water level decline corresponds with protracted dry conditions. However this is unlikely given that ample vadose storage will be maintained.

Figure 6 Potential response of *Eucalyptus victrix* to the effects of modified water table depth associated with the proposed Mining Area C MAR scheme



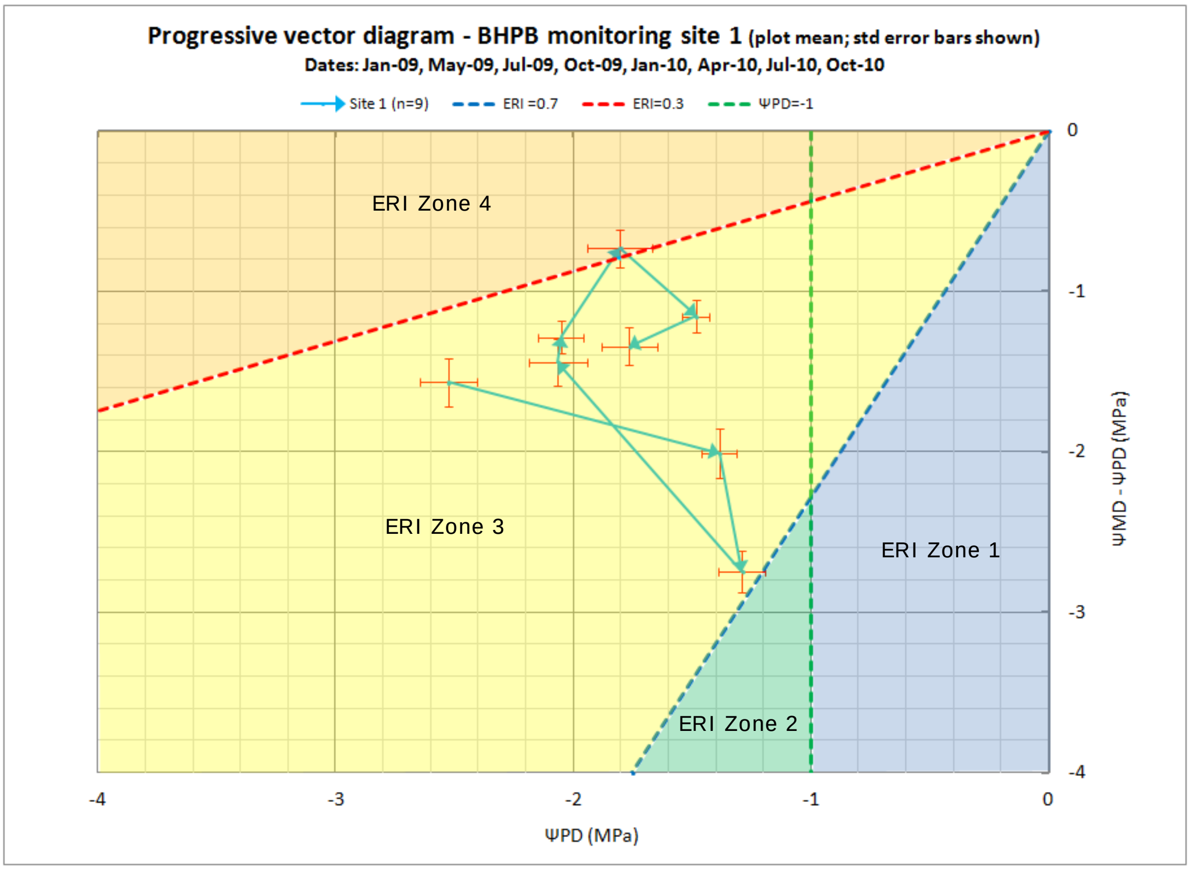


Figure 7 An example of an ERI baseline developed using time series leaf water potential measurements from riparian Eucalypts

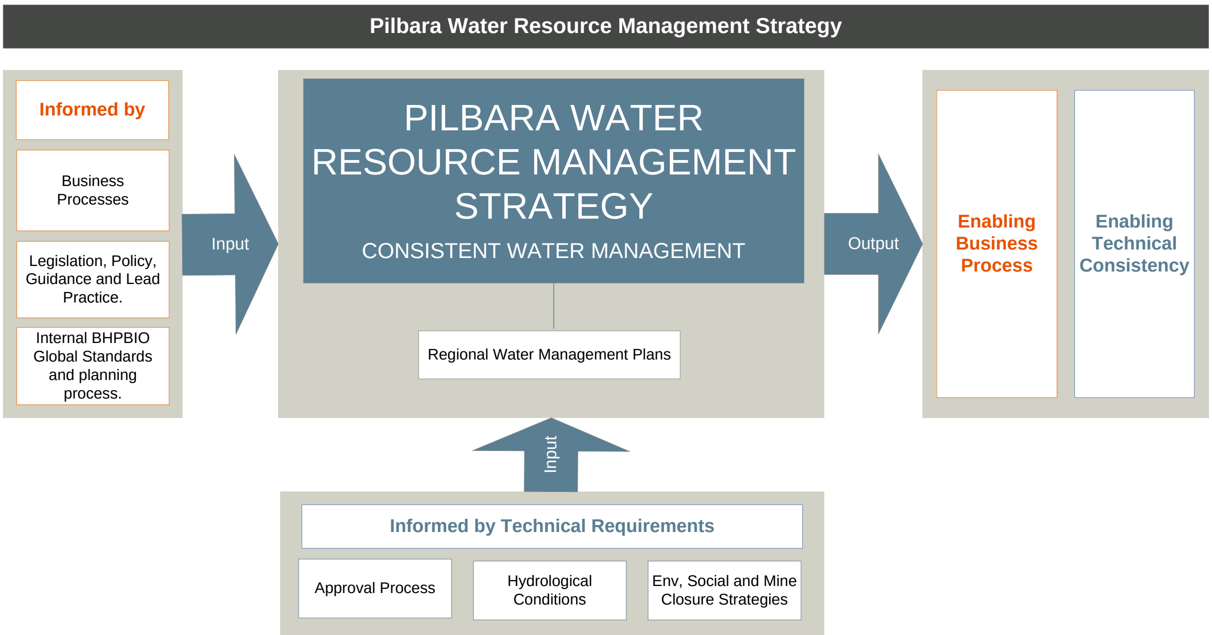


Figure 8 BHPBs Water Resource Management Strategy

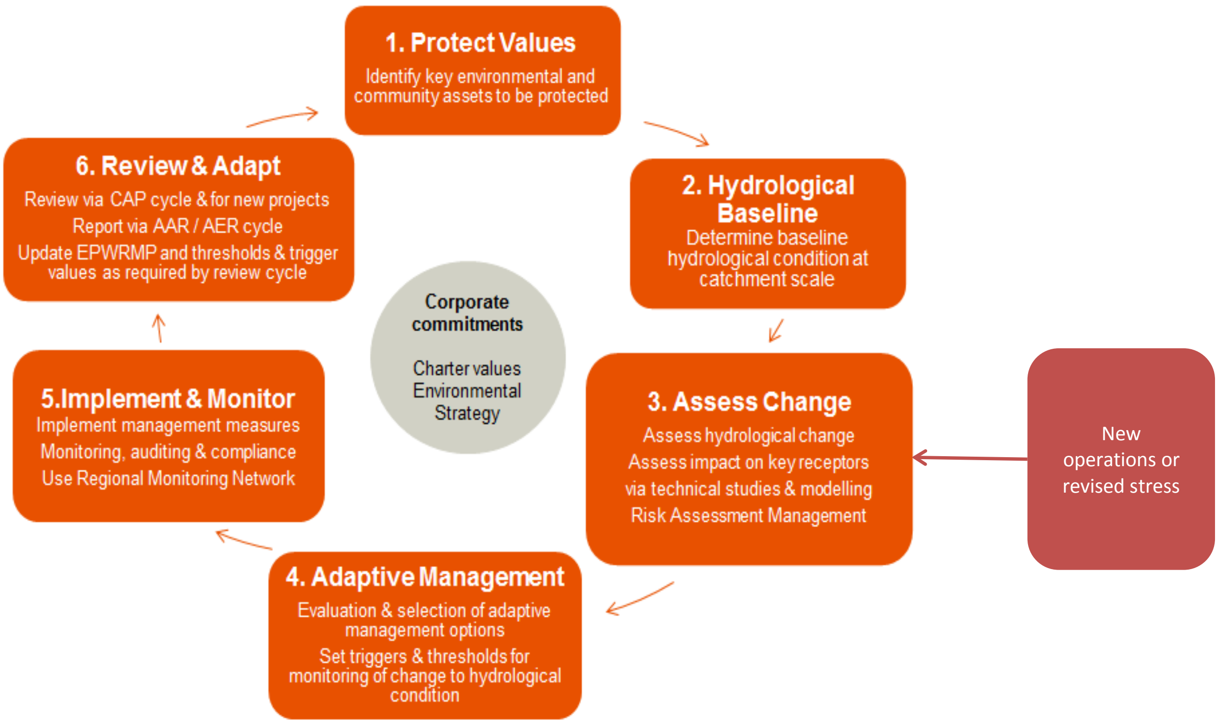


Figure 9 BHPB's adaptive management approach

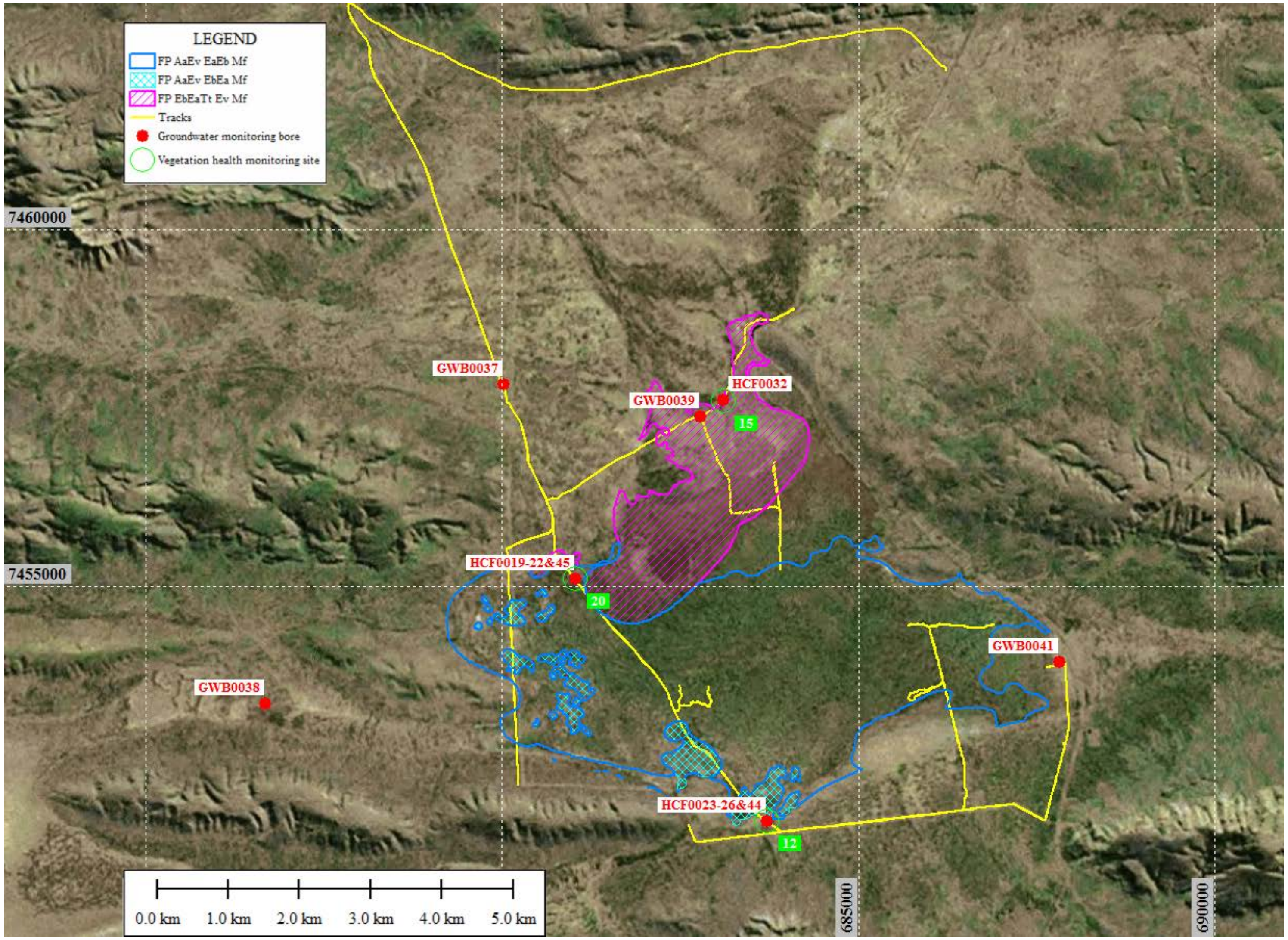


Figure 10 Recommended monitoring locations (groundwater levels and vegetation health) for the management of *E. victrix* trees at Coondewanna Flats

Table 1 Summary of ecohydrological studies completed at Coondewanna Flats in the period 2012-2014

Measurement / Metric	Timing / Frequency	Source	Application / Focus
Counts of live and dead trees, saplings and seedlings of E. victrix and A. aptaneura within circular plots (25 m radius) proximal to the target drill pads[1]. Visual estimates of the percentage understorey cover (to the nearest 5%) of native plants, weeds, litter and bare ground were also made.	Apr-14	Astron	Riparian Vegetation Community
Descriptive plant traits including stem diameter, crown dimensions and height for each 'focus' plant.	Measured once in either November 2013 and April 2014	Astron	Riparian Vegetation Community
Health status of 'focus' plants based on visual assessment techniques suitable for each species.	November 2013 and April 2014 for each 'focus' plant	Astron	Riparian Vegetation Community
Sapwood samples were obtained from a separate group of six *E. victrix* trees and five *A. aptaneura* trees sampled from random locations adjacent to access tracks across the study site. This provided the basis for developing an allometric relationship between sapwood area and DBH over bark for each species.	Apr-14	Astron	Riparian Vegetation Community
Projected foliar cover (PFC) of *E. victrix* and *A. aptaneura* was measured using the digital canopy photography (DCP) method of MacFarlane et al. (2007a; 2007b). Photo points were permanently marked with capped steel pegs to allow repeated measurements.	November 2013 and April 2014 for each 'focus' plant.	Astron	Riparian Vegetation Community
Leaf water potential was measured at predawn and midday using a pressure chamber. Three subsample measurements were obtained for each plant from separate shoots (containing 3 to 10 leaves) severed from the mid-canopy.	November 2013 and April 2014 for each 'focus' plant.	Astron	Riparian Vegetation Community
Leaf turgor loss point was also determined for *E. victrix* and *A. aptaneura* from the analysis of pressure volume (PV) curves, from a separate set of trees sampled at the study site.		Astron	Riparian Vegetation Community
Sap flow was measured in eight *E. victrix* and seven *A. aptaneura* trees using the Heat Ratio Method (HRM) of Burgess et al. (2001). This was used in combination with sapwood area estimates to calculate sap flux density (SFD, $cm^3\ cm^{-2}\ h^{-1}$)	Continuous (half hourly). Trees at pads 11, 12, 13, 14, 16, 20 and 22 were instrumented in June 2013, while trees at pads 15 and 17 were instrumented in November 2013. Data presented in the Astron (2014) report is from the dates of installation until 22 April 2014.	Astron	Riparian Vegetation Community
Stable isotopes in plant stem tissue water. This complemented the sampling of groundwater, rainwater and soil for stable isotopes by URS (2014) (refer to Section 2.2.1).	14 November 2013 and 27 April 2014	Astron	Riparian Vegetation Community
Physical properties of soil/geology. Drilling 13 monitoring bores to provide geological descriptions of saturated and unsaturated zones. Analysis of selected samples for Particle Size Distribution and Bulk Density. Samples cored with Sonic Rig	2 Campaigns: November 2013 (7 bores) and May 2014 (6 bores)	URS	Soil and Groundwater Reservoirs
Soil Chemsitry - major ions and salinity	2 Campaigns to identify seasonal change: Dry season - November 2013 (7 bores) and Wet season - May 2014 (6 bores)	URS	Soil Water Reservoir
Soil Water Chemistry - major ions and stable isotopes from samples extracted during drilling.	2 Campaigns to identify seasonal change: Dry season - November 2013 (7 bores) and Wet season - May 2014 (6 bores)	URS	Soil Water Reservoir
Soil Moisture Content - measured in the field on selected samples during drilling using Decagon soil moisture probe; selected samples subject to laboratory measurement; measured in-situ soil moisture sensors installed in bores 9 bores at 3 sites - 3 at each site between 0.4 and 4m depth	2 Campaigns to identify seasonal change: Dry season - November 2013 (7 bores) and Wet season - May 2014 (6 bores). Installed soil moisture probes continuous data 11/11 - 4/14	URS	Soil Water Reservoir
Soil Matric Potential based on 'filter paper method' on selected samples collected during drilling	2 Campaigns: November 2013 (7 bores) and May 2014 (6 bores)	URS	Soil Water Reservoir
Groundwater Levels - installation of additional loggers and collection of data from loggers installed in existing bores		URS	Groundwater Reservoir
Groundwater Chemistry - major ions and stable isoptopes from samples collected during drilling and testing	2 Campaigns: November 2013 (7 bores) and May 2014 (6 bores)	URS	Groundwater Reservoir
Aquifer hydraulic properties - slug tests on groundwater monitoring bores.	2 Campaigns: November 2013 (7 bores) and May 2014 (6 bores)	URS	Groundwater Reservoir

Table 2 Suggested monitoring parameters, triggers and thresholds for the management of *E. victrix* trees at Coondewanna Flats

Potential response to modified system	Relevant monitoring parameters	Locations	Frequency	Triggers and thresholds
Groundwater mounding	Depth to water table	Currently monitored bores: GWB0037, GWB0038, GWB0039, GWB0041 and HCF0032. Additional bores: HCF0044 and HCF0045	Continuous (as per existing methods)	Trigger: GW level <15 mbgl in any of the following monitoring bores: GWB0039, HCF0032, HCF0044 and HCF0045. Respond by commencing LWP measurements.
Change in water status	Leaf water potential (LWP)	6 trees[3] at each of Astron (2014) sites 12, 15 and 20	Biannually (wet season and dry season[4]) – if triggered	Triggered if GW level <15 mbgl in any of bores GWB0039, HCF0032, HCF0044 and HCF0045. Preliminary ERI baseline to be determined from the first 3-years of measurements (as above). Post first 3-years of measurements: ERI outside baseline; respond by reviewing potential causes of ERI change. If linked to GW level change instigate measures to limit potential negative impacts on tree health based on conceptual model of ecosystem response.
Leaf area increase/decrease Leaf shedding Canopy dieback	Crown condition score (CCS)	18 trees at each of Astron (2014) sites 12, 15 and 20	Commencing in 2016.Biannually (wet season and dry season[4])	Preliminary baseline (range) to be determined from the first 3-years of measurements (i.e. 2016-2019). Post-2019: CCS declines below baseline and GW level trigger reached; respond by reviewing potential causes of decline. Threshold: Sustained canopy decline (defined as CCS below baseline for three or more consecutive measuring events at any site) or death of any monitored tree; respond by reviewing potential causes of tree stress/death and conceptual model of ecosystem response to change. If linked to GW level change instigate measures to limit further change. Identify any requirements for remedial actions in consultation with regulatory agencies.
Growth rate	Diameter at breast height (DBH)	18 trees at each of Astron (2014) sites 12, 15 and 20	Commencing in 2016.Biannually (wet season and dry season[4])	Preliminary baseline to be determined from the first 3-years of measurements. Provides supporting information for response interpretation and trend analysis.

[3] Being a subset of trees from which CCS and DBH measurements are collected.
[4] Nominally November (dry season) and April (wet season) of each year.

Appendix C

Southern Flank Hydrological Studies and Supporting Documents