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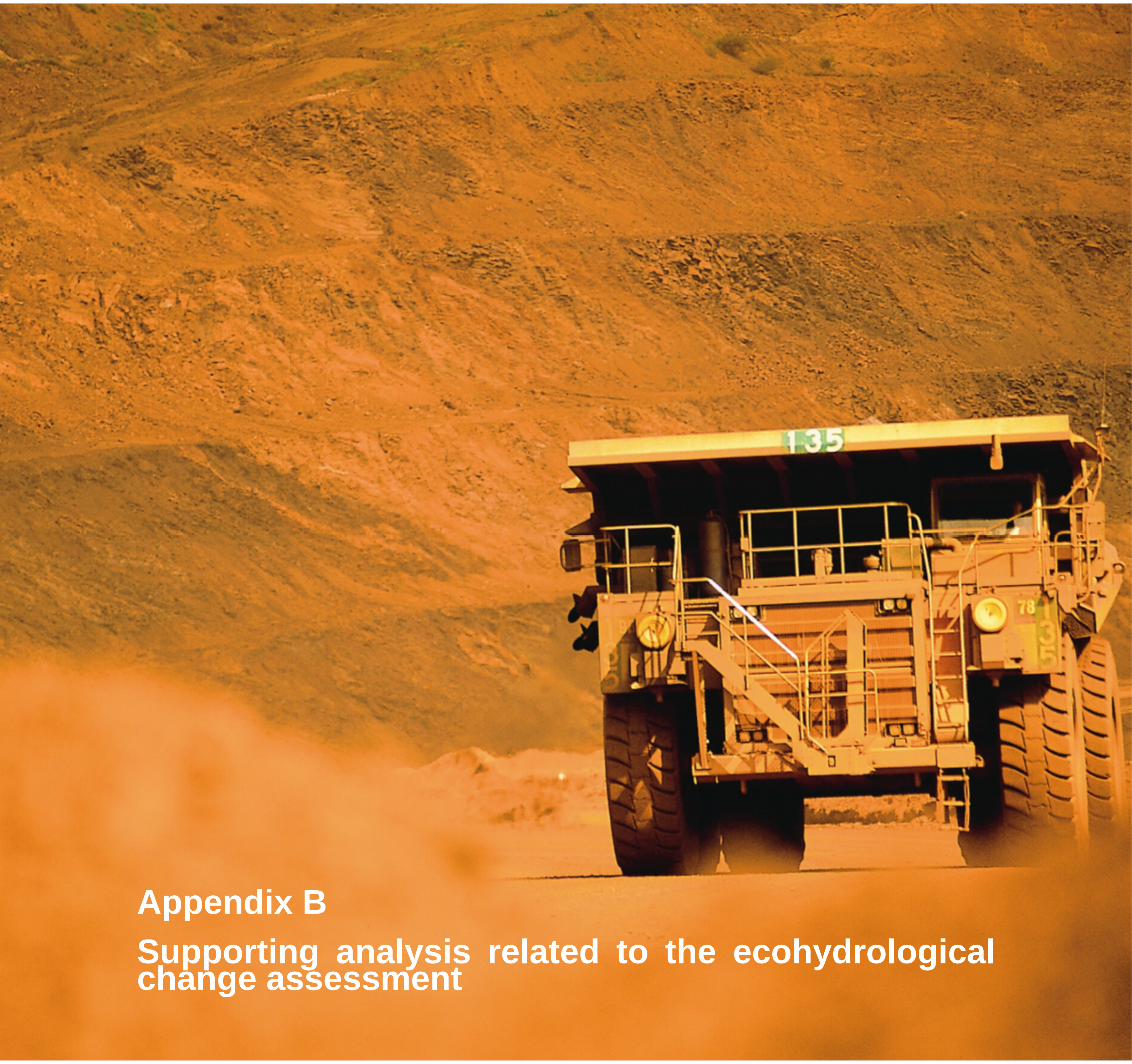

Appendix B

Supporting analysis related to the ecohydrological change assessment

Executive summary

BHP Billiton Iron Ore has undertaken a Strategic Environmental Assessment (SEA) of its proposed mining operations within the Pilbara Expansion. The completion of the ecohydrological conceptualisation and change assessment involved the development and application of new methodologies. This document provides detail on the supporting analysis that has been undertaken relating to hydroclimate variability, and the key threatening processes of groundwater drawdown, reduced catchment area on surface water availability, surplus water, AMD source potential and change in the regional groundwater resource.

Document information

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1. Introduction

BHP Billiton Iron Ore is undertaking a Strategic Environmental Assessment (SEA) for the Pilbara Expansion, which comprises construction and operation of a number of new operational iron ore hubs, expansion of existing operational iron ore hubs, and capacity upgrades to the main Newman to Port Hedland rail line and associated spur lines to existing and proposed hubs. As part of the SEA, BHP Billiton Iron Ore has undertaken an ecohydrological change assessment related to its current operations (baseline conditions), as well as proposed operations associated with 30% development and full development change scenarios. The change assessment provides a framework for evaluating the potential effects of hydrological change resulting from the Pilbara Expansion, and also cumulative change associated with third party operations.

The change assessment considers the effect of the Pilbara Expansion on groundwater and surface regimes associated with landscape-scale ecohydrological elements and ecohydrological receptors[1]. A number of key threatening processes contributing to ecohydrological change are identified and evaluated including groundwater drawdown, reduced catchment area on surface water availability, surplus water, AMD potential and change within the regional groundwater resource. As part of the assessment, the inherent hydroclimatic variability of Pilbara landscapes and the resistance and resilience of ecosystem elements in response to this variability has also been considered[2].

This document provides detail on the supporting analysis that has been undertaken relating to:

- Characterisation of hydroclimatic variability, and
- Development of methodologies for evaluating ecohydrological change potential associated with each of the key threatening processes[3]

This information constitutes supporting information for the methodology descriptions provided in the ecohydrological change assessment report (Rev F).

1 Defined as ecological assets with a high level of hydrological dependency and connectivity.

2 Resistance is the property of communities or populations to remain "essentially unchanged" when subject to disturbance (Levin, 2009). Resilience is the capacity of a system to absorb shocks and disturbances and retain the same level of fundamental functions (Mori *et al*., 2012)

3 'Ecohydrological change potential' has been adopted as a precautionary measure of the potential for hydrological change to cause material environmental change in the absence of targeted management.

2. Hydroclimatic variability

2.1 Climate variability

The annual rainfall variability was assessed using the long-term rainfall record from the Scientific Information for Land Owners (SILO) enhanced climate database. The SILO database contains the historical climate records for Australia and provides daily datasets for a range of climate variables from 1 January 1889 to current. This data is suitable for a variety of applications. The database is hosted by the Science Delivery Division of the Queensland Government Department of Science, Information, Technology, Innovation and the Arts (DSITIA). Data can be obtained from the Long Paddock website hosted by the Queensland Government (https://www.longpaddock.qld.gov.au/silo/).

The SILO datasets are constructed from observational records provided by the Bureau of Meteorology. Raw data, which may contain missing values, is processed to derive datasets which are both spatially and temporally complete. The methodology used for spatial interpolation of the climate data is described by Jeffrey *et al* (2001). Additional references to the SILO interpolation techniques, comparisons and reviews are provided on the SILO website at (https://www.longpaddock.qld.gov.au/silo/publications.html#Reviews)

For the purposes of the report, a SILO rainfall record has been obtained at Ethel Gorge (23°30'S, 119°30'E) from the "data drill" set, consisting of interpolated data available at any point on a 0.05' by 0.05' grid over mainland Australia. The SILO rainfall record was initially obtained to support the Ethel Gorge case study assessment; however, it also provides a representative and credible example of climate variability across the study area.

2.2 Streamflow variability

The variability in streamflow rates were assessed using actual streamflow records and interpolated streamflow rates. For the purpose of this assessment, streamflow records for the Upper Fortescue River at the DoW monitoring station No 708011 (23°24'04.9"S, 119°47'39.5"E) were used as a proxy for streamflow variability in the study area more generally. It is recognised that runoff coefficients vary between catchments within the study area, with further discussion on this variability in Appendices C to F. Despite the variability, streamflow rates across the study area tend to exhibit broadly similar characteristics; as such, the streamflow records for DoW monitoring station No 708011 are considered representative and credible of a large catchment area with no current mining activities.

Streamflow records for DoW station No 708011 spanning the period 1981 through to the present were used in the streamflow analysis. There was some additional analysis undertaken to obtain an interpolated streamflow record for the SILO rainfall record (1889 to current), which involved:

- Graphical comparing annual rainfall against annual streamflow rates for the streamflow record between 1981 and 2013 (Fig. 1). Both rainfall and streamflow rates are expressed in terms of a rainfall year that extends between 1 July and 30 June.
- Regression analysis to represent streamflow rates as a function of yearly rainfall. The best fit was obtained by applying a second-order polynomial function through the data record. Figure 1 shows the second-order polynomial fit, the derived expression and the coefficient of determination (R-squared) value for the regression relationship.
- The upper boundary was derived by applying a multiplication factor of 1.5 to the best fit and the lower boundary by applying a multiplication factor of 0.5 to the best fit. The boundaries represent a confidence limit of 81%.

- The resultant equation was used to derive streamflow rates at DoW station No 708011 for the remaining SILO rainfall dataset between 1889 and 1980. The interpolated streamflow rates contain error bars providing a measure of uncertainty associated with the analysis.

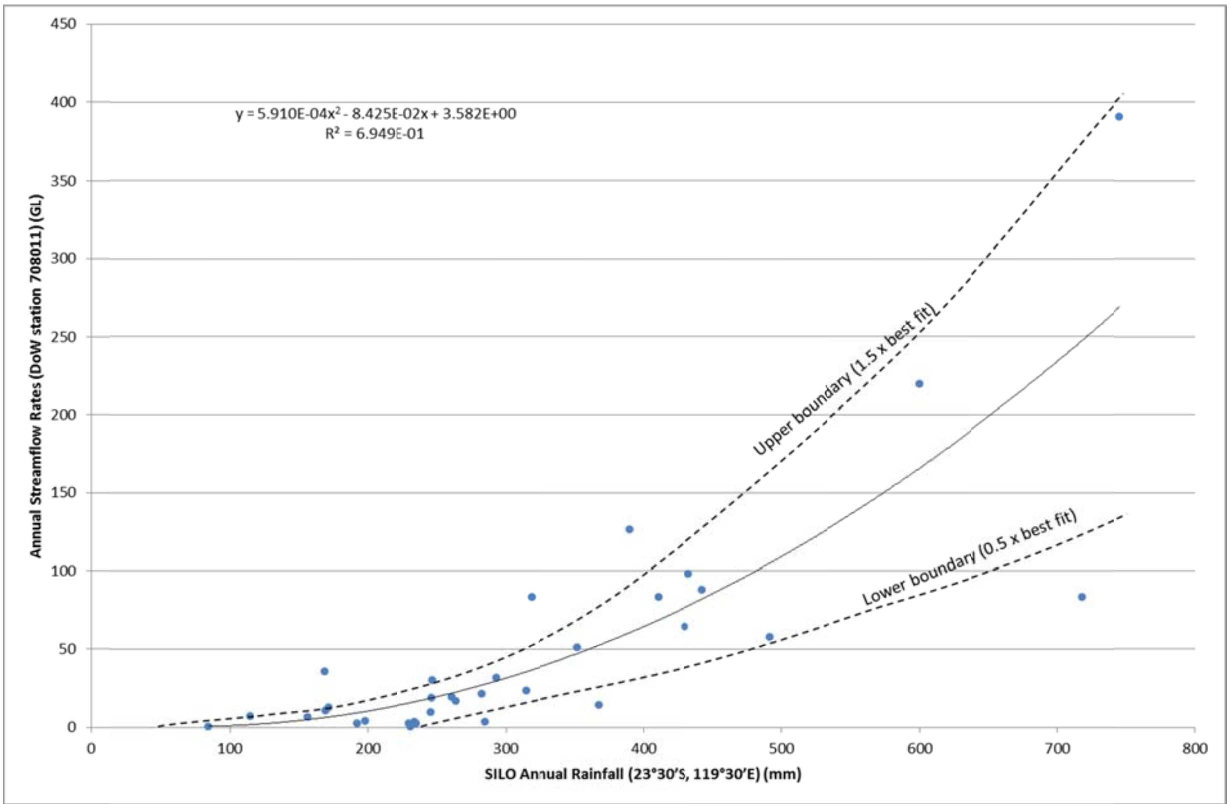


Figure 1. Relationship between rainfall and streamflow rates

2.3 Groundwater level variability

Groundwater levels were obtained from BHP Billiton Iron Ore's Water Database, which is a centralised database used to store and manage water data for all mining operations. Monitoring bores for the analysis of groundwater level variability were selected using the following criteria:

- The monitoring bores are not to be located in an area where groundwater levels are influenced by dewatering, abstraction, injection and/or infiltration. As a result, only up-gradient monitoring bores were considered;
- The monitoring bores are to contain more than 20 years of data representing and reflecting long-term groundwater variability; and
- Data is to be continuous with minimal data gaps.

Upgradient monitoring bores were also identified from the triennial aquifer reviews for the various operations over the period 2010 to 2013. Groundwater level data for these monitoring bores were obtained from the water database and assess for completeness.

The data evaluation resolved that only up-gradient monitoring bores in the Yandi and Ophthalmia Borefield have sufficient periods of groundwater level data. The following monitoring bores were selected for the analysis:

- HEOP0445M (Ophthalmia Borefield);
- HEOP0489M (Ophthalmia Borefield); and
- HYW0003M (Yandi mining area).

It should be noted that HYW0003M has been influenced by dewatering since 2006, with records from this time forwards not considered in the analysis.

The hydrographs were normalised with groundwater levels being set at 520 m AHD as at 18 January 1994, in order to provide a suitable comparison of relative groundwater level changes. The normalisation date is associated with a period of relatively low groundwater fluctuations and where accurate groundwater levels were available for all three monitoring bores.

3. Depth to groundwater

A depth to groundwater contour map of the study area was developed as part of the stygofauna habitat assessment. The methodology for developing the groundwater map is provided in a memorandum to BHP Billiton Iron Ore (RPS, 2014e).

The study comprised a detailed interpretation of the regional groundwater level contours based on a thorough review of all available groundwater level data as maintained in the BHP Billiton Iron Ore ioWater database, as well as public domain groundwater level data.

The interpreted regional groundwater surface was then subtracted from a digital terrain model to estimate the depth to groundwater level. The analysis included a comprehensive review process to ensure the estimated groundwater depth was consistent with the topographical setting.

The depth to regional groundwater data contours shows a clear correlation with the groundwater ecohydrological sensitivity map which was developed based on ecohydrological units (EHUs). Deep groundwater levels (>30m) are typically associated with the upper landscape units (EHUs 1, 2, 3 and 4, corresponding to low groundwater sensitivity). Shallow groundwater levels (<10m) are associated with the lower landscape units (EHUs 7, 8 and 9, corresponding to high groundwater sensitivity). There are exceptions such as deep groundwater levels which do occur in some lower landscape units, for example in the Jimblebar mining area.

Because of the good correlation between depth to regional groundwater levels and EHUs, the groundwater ecohydrological sensitivity map was developed based on EHUs, to be consistent with the approach and methodology of the Ecohydrological Change Assessment. It is noted though that deep groundwater levels do occur in some lower landscape units and the groundwater sensitivity map is therefore precautionary.

4. Groundwater drawdown

The key aspects for determining hydrological change associated with groundwater drawdown were:

- Generic mine types, determining the hydraulic connectivity with the regional aquifers; and
- Groundwater drawdown extent, considering the spatial extent of regional aquifer systems.

3.1 Generic mine types

Hydraulic connectivity between orebody aquifers and the regional groundwater system is an important factor in determining the magnitude of mine dewatering, and its potential influence on key ecological receptors (Fig. 2). The current and proposed orebodies were categorised into generic mine types with consideration of ore type, extent of the orebody aquifer below the watertable, and the likely degree of hydraulic connection with the regional aquifer and these are described in more detail in Appendices C to F. Distinct models were also created for channel-iron deposit (CID) orebodies to address their linear shape and connectivity with surface water features.

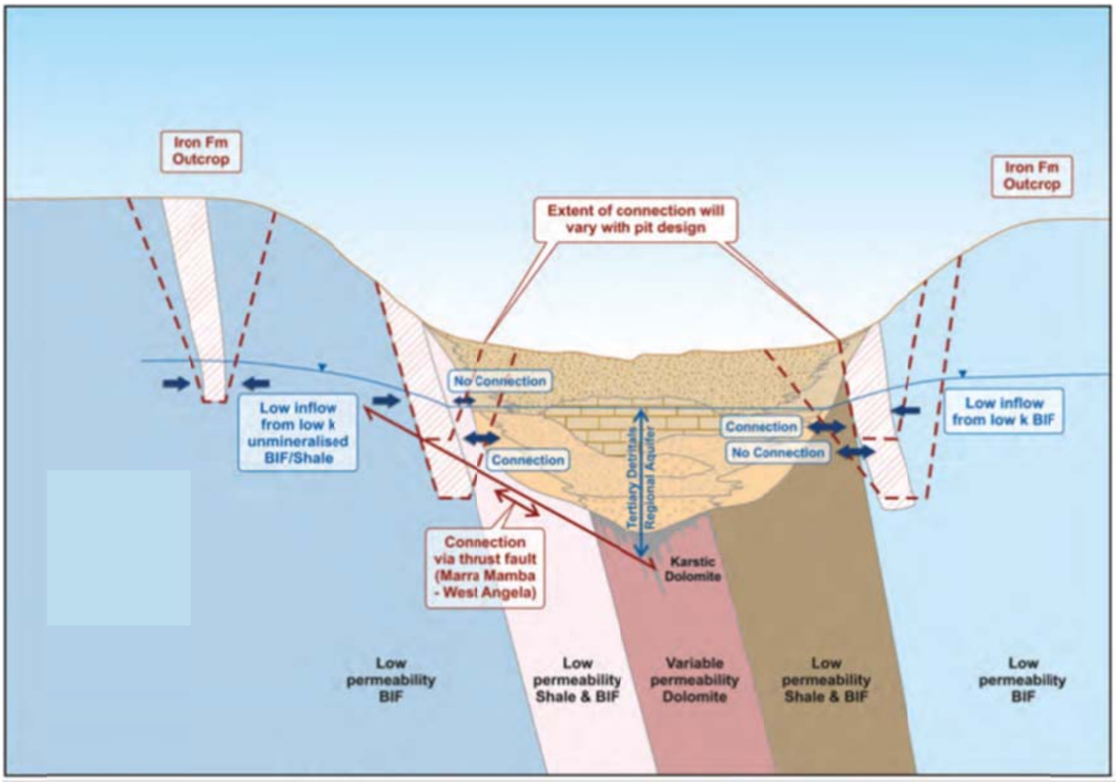


Figure 2. Schematic figure showing regional aquifer / groundwater system and likely connectivities (*from* RPS, 2014a and 2014b)

The key hydrogeological relationships and connectivities for each generic mine type are summarised in Table 1. The typical landscape setting and potential connectivity pathways for the generic mine types are schematically shown on Figures 3 and 4.

Table 1. Generic mine types used in the change assessment

Generic mine type	Hydrogeological connectivity	Potential considerations
Above the watertable (AWT)	Orebodies in upland areas with deep groundwater levels and no connectivity with groundwater. No mine dewatering is required.	No potential for drawdown impacts on sensitive receptors owing to lack of connection. Operations often have a water deficiency and may require additional water supply from other surplus areas or dedicated borefields.
Isolated or disconnected	Orebodies in upland areas surrounded by low-permeability lithologies. Inflows are minimal (<2 ML/day) with groundwater drawdown being restricted and localised.	There is limited potential for drawdown impacts on sensitive receptors owing to limited hydraulic connection. Operations often have a water deficiency and may require additional water supply from other surplus areas or dedicated borefields.
Partially connected	Orebodies along valley margins with the valley side pit wall intersecting thinly-saturated Tertiary detritals or geological structures providing limited hydraulic connection. Dewatering rates will typically be between 2 and 10 ML/day with minor groundwater drawdown extending into the regional aquifer.	There is limited potential for drawdown impacts on sensitive receptors owing to limited connection. Operations may be either water deficit or surplus. In most cases, water supply will be locally used within operations. Excess dewatering water may require management.
Connected	Orebodies within valleys with pit walls intersecting	Mitigation measures may also be necessary

	saturated Tertiary detritals providing significant hydraulic connection. Dewatering rates between 10 and 20 ML/day with groundwater drawdown extending several kilometres into the regional aquifer.	to minimise potential impacts at sensitive receptors. Operations often have a significant water surplus requiring management.
Fully connected	Orebodies within valley with most pit walls intersecting saturated Tertiary detritals and Paraburdoo dolomite resulting in in a high degree of hydraulic connection. Dewatering rates may be substantial, typically exceeding 20 ML/day, with groundwater drawdown extending more than 5 km into the regional aquifer.	Mitigation measures may also be necessary to minimise potential impacts at sensitive receptors. Operations often have a large water surplus requiring management.
Connected Channel Iron Deposits	CID orebodies within palaeochannel systems that form linear aquifers, which are in hydraulic connection with other aquifers (calcrete or alluvium). They are in hydraulic connection with surface water features that may have sensitive riparian communities. Dewatering rates may exceed 20 ML/day and groundwater drawdown may extend along the aquifers resulting in drawdown in the overlying aquifers.	Mitigation measures may also be necessary to minimise potential impacts at sensitive receptors. Operations often have a large water surplus requiring management.
Disconnected Channel Iron Deposits	CID orebodies within palaeochannel systems that form linear aquifers surrounded by low-permeability lithologies. They are *not* in hydraulic connection with surface water features and are *disconnected* from sensitive riparian communities. Dewatering rates may exceed 20 ML/day and groundwater drawdown may extend along the aquifer; but not resulting in change in shallow, overlying aquifers.	There is limited potential for drawdown impacts on sensitive receptors owing to limited connection. Operations often have a large water surplus requiring management.

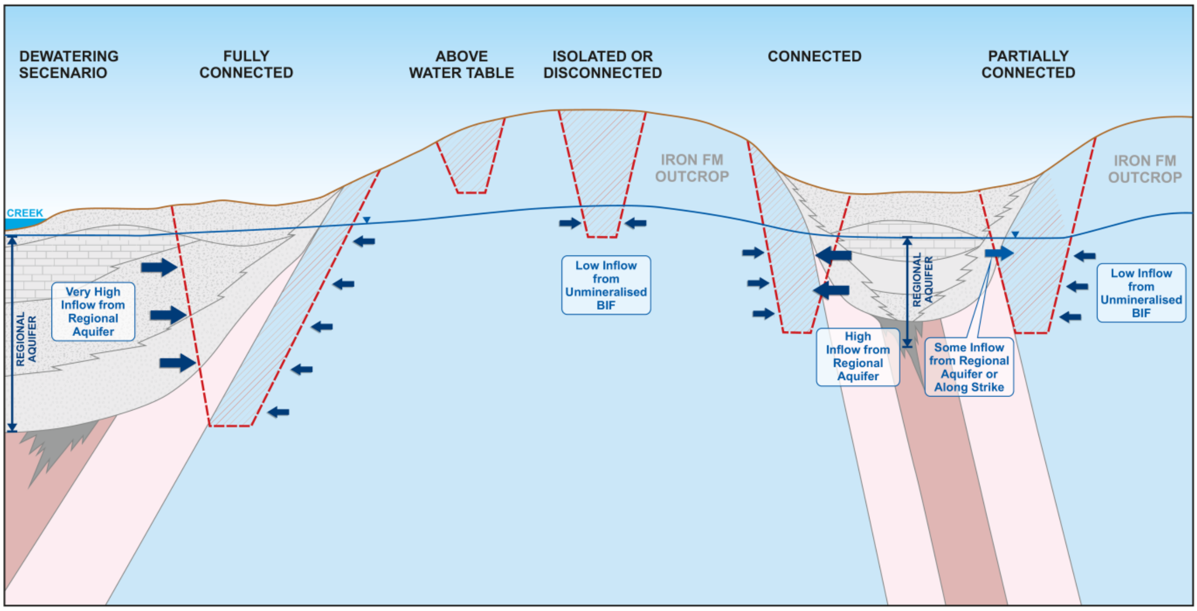


Figure 3. Generic mine types for Marra Mamba and Brockman deposits (*from* RPS, 2014a and 2014b)

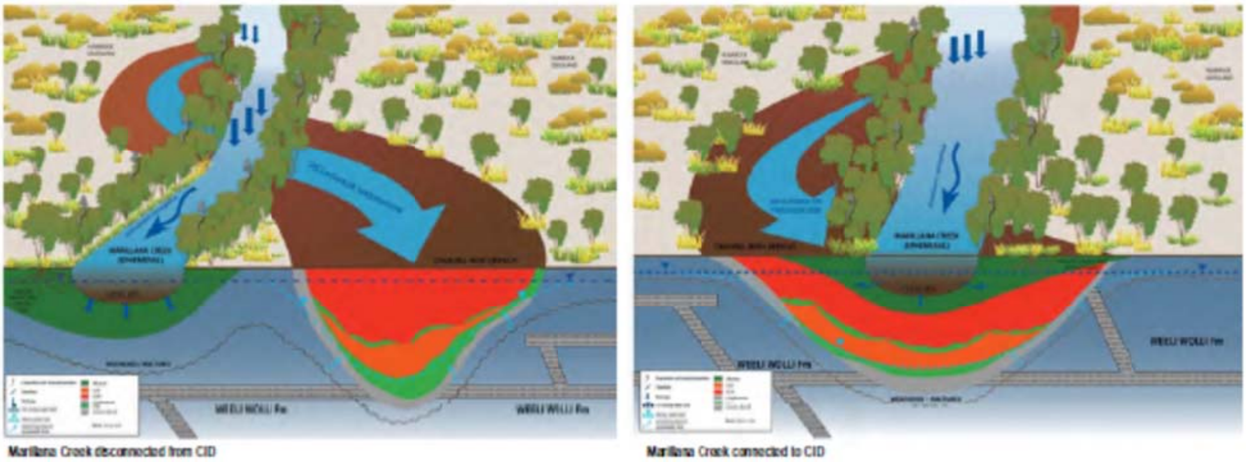


Figure 4. Generic mine type for channel-iron deposits (*from* Golder Associates, 2014)

3.2 Groundwater drawdown extent

The groundwater drawdown extent (or footprint) was defined to include areas where groundwater levels are predicted to decline by greater than 1 m relative to the 'no disturbance' baseline. Drawdown of 1 m is precautionary and should be considered in the context of natural groundwater fluctuations, the level of uncertainty associated with drawdown predictions and precedent in Western Australian environmental impact assessments in the Pilbara region.

The current (or baseline conditions) drawdown extent at 2014 is based on observed changes in watertable from groundwater monitoring and numerical modelling. RPS (2014) developed an analytical approach to determine the extents of groundwater drawdown associated with 30% development and full development scenarios respectively.

3.2.1 Current drawdown extents

The 1 m drawdown extent around the current BHP Billiton Iron Ore operations was based on observed measurement or calibrated model runs. There are existing numerical models for the Yandi operations, Central Pilbara operations, Ethel Gorge area and Jimblebar operations that are continually being updated as new information becomes available.

The groundwater drawdown extent for Whaleback is based on monitoring data presented in the 2013 triennial aquifer review and 2014 annual aquifer review. Groundwater drawdown around the Whaleback mine has reached equilibrium and has not significantly expanded over the last number of years.

Groundwater drawdown estimates associated with third-party operations are based on publicly-available information. Both Rio Tinto Iron Ore (RTIO) and Fortescue Metal Group (FMG) carried out numerical modelling as part of their Public Environmental Reviews and predicted groundwater drawdowns were presented in the appendices of their reports.

The 1 m drawdown extent for Yandicoogina (RTIO, 2011), Hope Downs 4 (HDMS, 2000), Cloudbreak (FMG, 2010b and FMG, 2014) and Christmas Creek (FMG, 2010a) were digitised from the reports. Groundwater drawdown for Hancock Roy Hill (2 m drawdown only) was presented as part of the cumulative impact assessment for the Cloudbreak operations (FMG, 2010b). The drawdown for Hope Downs 1 was based on the *Central Pilbara Groundwater Study* (Johnson and Wright, 2001)

3.2.2 Estimated extents for 30% and full development change scenarios

The estimation of groundwater drawdown is based largely on the generic mine type, as detailed in Section 3.1. For each generic mine type, an analytical approach was adopted to approximate the key hydrogeological processes that influence dewatering volumes. This approach is a modified version of the method developed by Cashman & Preen (2013) and provides a reasonable approximation of the groundwater flow field related to a mine by taking into consideration:

- circular or square pits as effectively large-diameter wells with a radius that provides an equivalent surface area to the average below watertable area of the pit. The groundwater flow field for such pits can be approximated using radial flow equations; however, such pits are rare across BHP Billiton Iron Ore's existing and proposed operations; and
- pits developed along a strike-axis which are rectangular in shape, the long walls were approximated by parallel flow effects and pit ends were approximated by radial flow effects. The majority of BHP Billiton Iron Ore's current and proposed operations are within this category.

  The following equations were applied to the evaluation of the flow fields summarised above:

- radial flow has been assessed using the Thiem Equation for unconfined radial flow (Thiem 1906).
- the radius of influence of dewatering will extend over time as a function of aquifer parameters and time only (i.e. the radius of influence is independent of dewatering discharge). The expansion of the radius of influence has been assessed with the Cooper Jacob Equation (Cooper and Jacob, 1946) with the adoption of an appropriate aquifer storage value, as suggested by Cashman and Preene (2013), to reflect semi-confined conditions experienced in most of the Pilbara.
- parallel flow was assessed using the Darcy Equation; whereas, the zone of influence was assessed using a modified form of the Darcy equation as presented in Cashman and Preene (2013), and Armstrong (undated).
- For both radial and parallel flow, the expansion of the zone of influence has been calculated for annual increments for a maximum of ten years (i.e. the area affected by dewatering increases for each year mining occurs below the water table for ten years). Where dewatering continues beyond ten years, the area affected by dewatering after 10 years is considered the maximum extent of drawdown.
- Both equations that have been used to estimate flow rates (Theim for radial flow and Darcy for parallel flow) assume steady-state conditions. Thus, once the zone of influence has been calculate for a one year increment, steady-state conditions were assumed for that year. This means dewatering rates and the zone of influence expand as a series of discrete annual steps rather than continuously.
- The steady-state equations described above were then used to calculate where 1 m drawdown would occur. The estimate of the extent of the 1m drawdown zone was corroborated against dimensionless nomograms describing the ratio of drawdown and distance from the mine as described by Rao (1973) for parallel flow, and Powrie and Preene (1994) for radial flow.

The method is summarised in Figure 5 (RPS, 2014c).

Aquifer parameters used in these equations are consistent with the hydrogeology of each key element:

- regional aquifer along-strike transmissivity of 1200 m^2/day representing the dolomite/valley-fill aquifer;

- alluvial aquifer/hanging wall transmissivity 25, 50 and 250 m^2/day (medium, high and very high cases with transmissivity varying largely as a function of pit wall saturated thickness and geology - this is also used to estimate the across-strike transmissivity of the regional aquifer);
- basement transmissivity of 5 to 7 m^2/day reflecting the low permeability;
- storage coefficient is assumed to be 0.05 for all geological units subjected to dewatering; and
- estimated dewatering pumping takes account of:
- pumping of groundwater stored within the orebody;
- inflow to the orebody through the foot and hanging walls (using the transmissivity for the foot and hanging walls); and
- inflow at the pit ends was approximated by radial flow equations (using a transmissivity that is the harmonic mean of the along-strike and across-strike transmissivity for the regional aquifer).

The zone of influence of pumping (which is a function of time) and the propagation of the 1 m drawdown contour develops as a function of both time and discharge. The 1 m contour has been adopted as an indicator of significant change to the hydrogeological regime.

The overall schedule of dewatering, years below the watertable and so forth are based on the SEA full development mine schedule. The 'typical mine' is based on an active mining area below the watertable of 300 m by 2000 m with a vertical rate of advance of 12 m/year. This approach takes no account of advanced dewatering.

A water balance was also calculated at the whole of mining-area and orebody level. Water demands for each operation are obtained from the LoA and based on BHP Billiton Iron Ore's operating experience in terms of water abstracted (kL) per tonne of ore production. Dewatering estimates derived from the analytical approach are consistent with dewatering volumes presented in the Central and Eastern Pilbara conceptualisations (RPS, 2014a and 2014b).

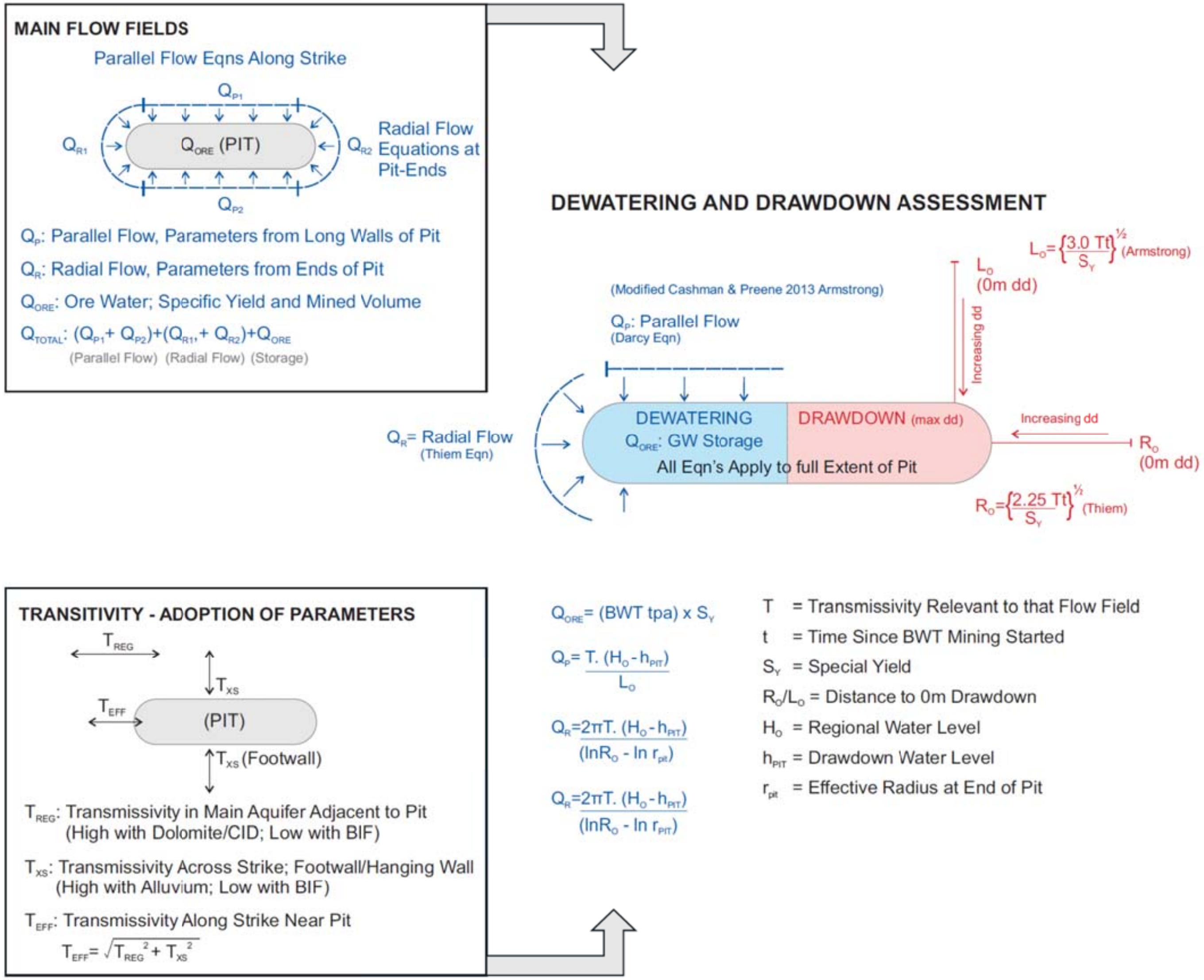
The methodology did not considered the need for additional water supply pumping in areas of water deficit, as there may be potential opportunities for integrated water supply across the region and between mining areas. Similarly, there was no consideration for the possible artificial recharge of surplus water.

There was no account of water level recovery following the cessation of dewatering, owing to the high complexity of recharge processes. In general, groundwater recharge rates are likely to be modest (other than in proximity to Ophthalmia Dam) and therefore natural water level recovery is likely to be slow suggesting timescales of many decades to centuries. Despite water levels around pits rebounding quickly as the watertable equilibrates, recovery is unlikely reach pre-mining levels requiring centuries for natural recharge processes to gradually replenish the catchment. However, areas of ecohydrological significance are likely to receive preferential recharge through surface water infiltration along creek lines and may be expected to recover more quickly than catchment-scale systems.

The inclusion of water storage replenishment, short and long-term water level recovery and footprint reduction was too complex for the adopted analytical approach; however, this will be better assessed using a numerical modelling approach as part of ongoing validation studies under the adaptive management framework. This would also include the assessment of potential closure scenarios and management options in the context of integrated water management. As such, the groundwater drawdown extent presented for the full development scenario is considered inherently precautionary.

Verification

The analytical approach was verified with respect to four existing mines (Orebodies 23 and 25; Deposits C and E in the MAC mining area) that have detailed observations and/or predictions of drawdown from a numerical model. The comparison between analytical extent of 1 m drawdown and numerical modelling are shown in Figure 5 for Orebodies 23 and 25, and Figure 6 for the MAC mining area. While there are constraints in the degree of detail using the analytical approach, the overall extent affected by at least 1 m of drawdown is of a similar order of magnitude when comparing both methods.



Parameter	CPH/EPH	Fortescue	Marillana
Max Discharge (ML/d)			
Fully Connected (very high)	<38	<48	<41
Connected (high)	<20	<30	<12
Part Connected (moderate)	<14	<23	<6.3
Not Connected (low)	<3.5	<10	<3.5
Transmissivity (m^2/d)			
T_reg (Fully Connected)	1200	700	2000
T_reg (Connected)	1200	700	2000
T_reg (Part Connected)	1000	500	50
T_reg (Not Connected)	7	100	7
T_xs (Fully Connected)	250	700	150
T_xs (Connected)	50	200	1
T_xs (Part Connected)	25	100	20
T_xs (Not Connected)	5	50	5
T_xs_fw (Fully Connected)	5	10	1
T_xs_fw (Connected)	5	10	1
T_xs_fw (Part Connected)	5	5	5
T_xs_fw (Not Connected)	5	5	5
Storage Coefficient	5%	5%	5%
Annual dewatering (m)	15	8	8
Strike length of active dewatering (each pit) (m)	2000	2000	2000 - 8000

Notes:
- Discharge based on RPS, Golder and MWH assessments
- Hydrogeological setting from RPS, Golder and MWH assessments
- All calcs based on generic mines with above parameters
- Assessment shuould be considered scaling exercise / risk identification
- Assessment is NOT a drawdown prediction
- T_xs_fw used for low k basement typically in footwall

- Drawdown estimates are steady-state based on calculated R_o/L_o
- R_o/L_o steady-state estimate of distance to 0m drawdown
- R_o/L_o increase as function of time (calculated for each year of BWT mining)
- Thus dewatering progresses as a series of stepped (annual) steady state estimates
- R_o/L_o/Dewatering allowed to increase for up to 10 yrs - constant thereafter

Figure 5. Groundwater drawdown: Method outline and equations

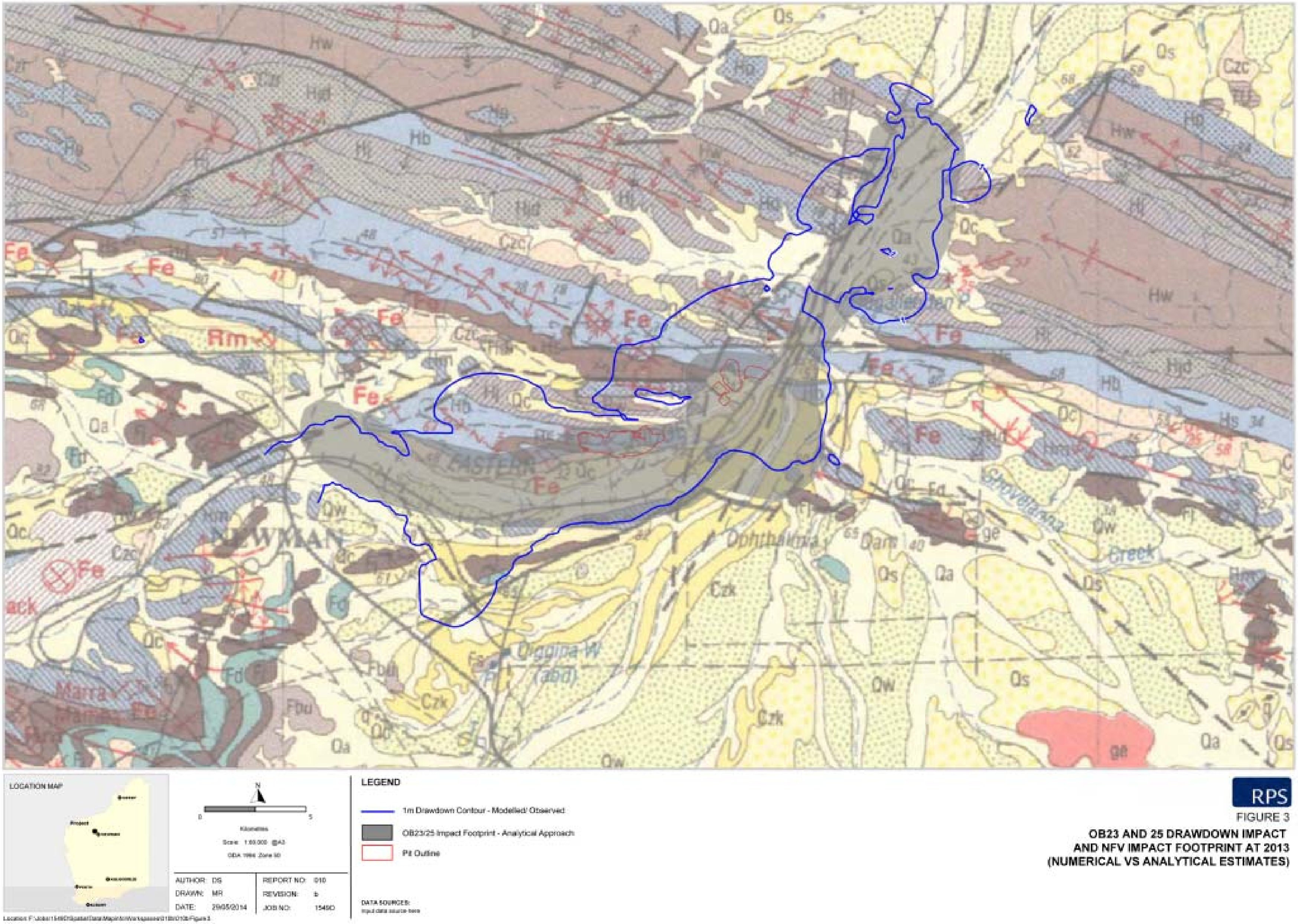


Figure 6. Drawdown extent verification surrounding Orebodies 23 and 25

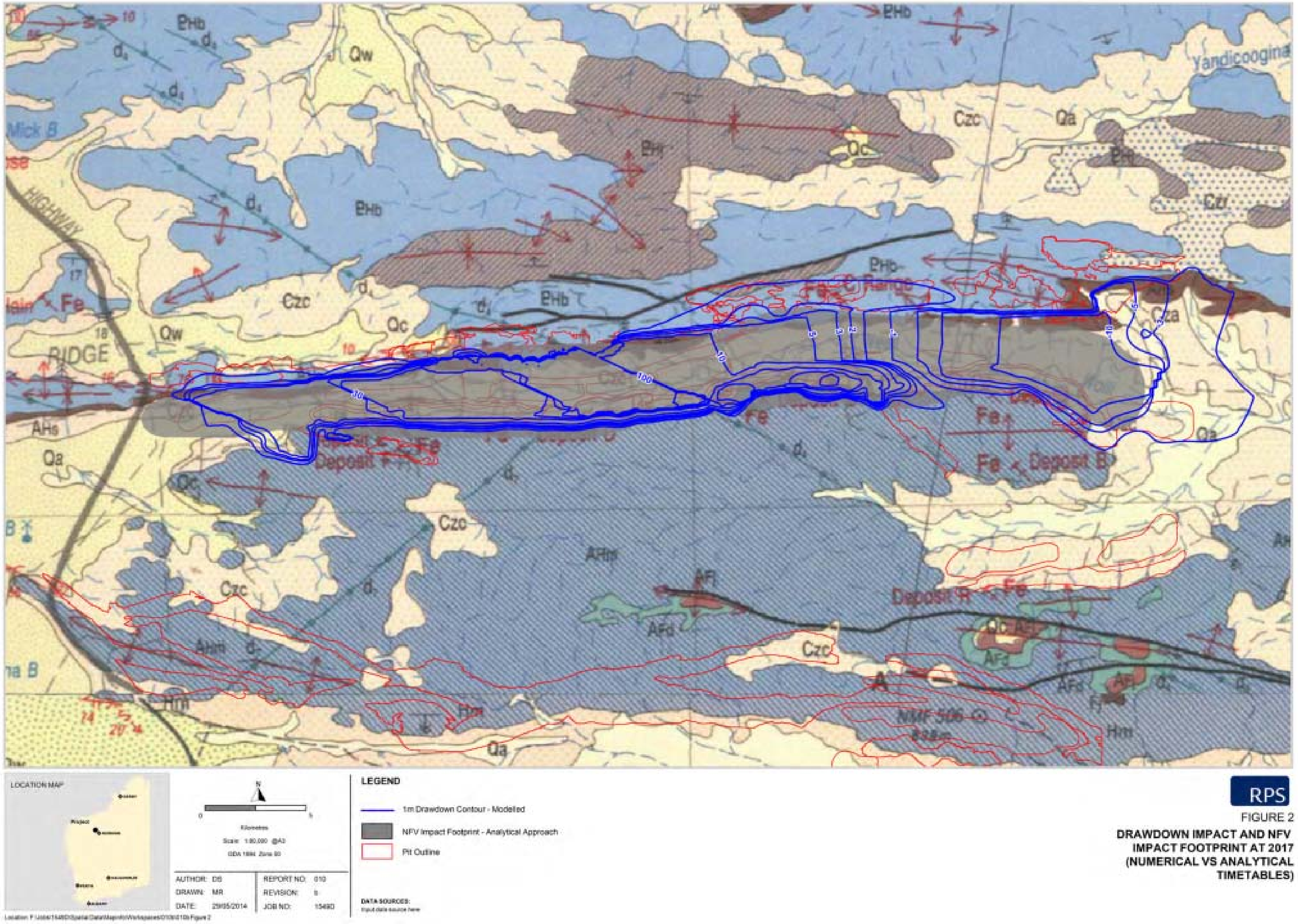


Figure 7. Drawdown extent verification at MAC mining area

5. Surface water availability

4.1 Drainage and catchment delineation

The delineation of the drainage network and catchment was derived from terrain analysis using the ArcHydro add-on to Spatial Analyst within ArcGIS. Both delineations were processed using the 5 m DEM (Digital Elevation Model) provided by BHP Billiton Iron Ore, and 30 m DEM (Version 1.0) provided by Geoscience Australia.

4.2 Extent of disturbance footprint

The mine disturbance footprints for the current (or baseline) operations, and proposed 30% and full development scenario operations under the Pilbara Expansion were used to approximate reduction in the surface water regime. It was assumed that any reduction could be directly related to the mining footprint area that intercepts and prevents flow from discharging downstream.

A GIS approach, using ArcGIS Spatial Analyst, was undertaken to map the extent of downstream shadowing associated with the mining footprint. The following key rules were applied to downstream shadowing of the aggregated footprints:

- In general, the catchment area of each drainage line (identified through GIS-based terrain analysis) which originated or crossed the aggregated mining footprint was assigned as the candidate shadow area (Fig. 7). Since any upstream inflows were assumed to be rerouted 1 km downstream of the aggregated footprint, the candidate shadow area was clipped 1 km downstream of that footprint.
- If the candidate catchment did not extend all the way to a distance of 1 km downstream (i.e. the catchment is quite small), the shadow area was extended by including the next downstream catchment until it reached the 1 km buffer (see Fig. 7, right part).

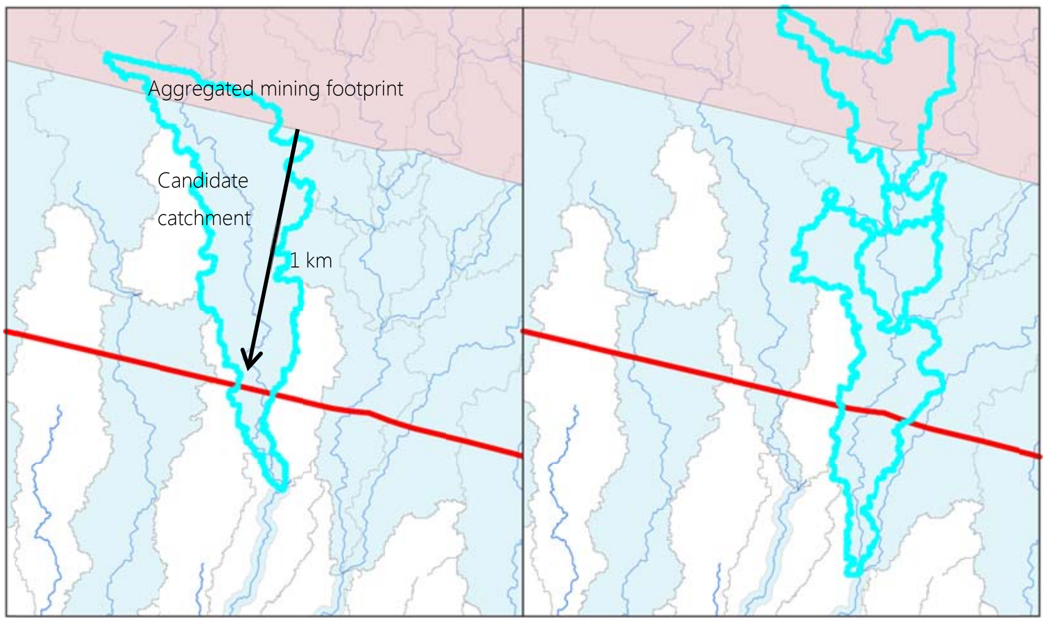


Figure 8. An example of a candidate catchment area downstream of the footprint (shaded pale red)

- In the drainage lines representing potential creeks downstream of the selected shadow catchment, a 25 m buffer was applied to the drainage line which continued in a downstream direction until its confluence with other drainage lines and ultimately to the terminal receptor such as Fortescue Marsh or Coondewanna Flats (Fig. 8).

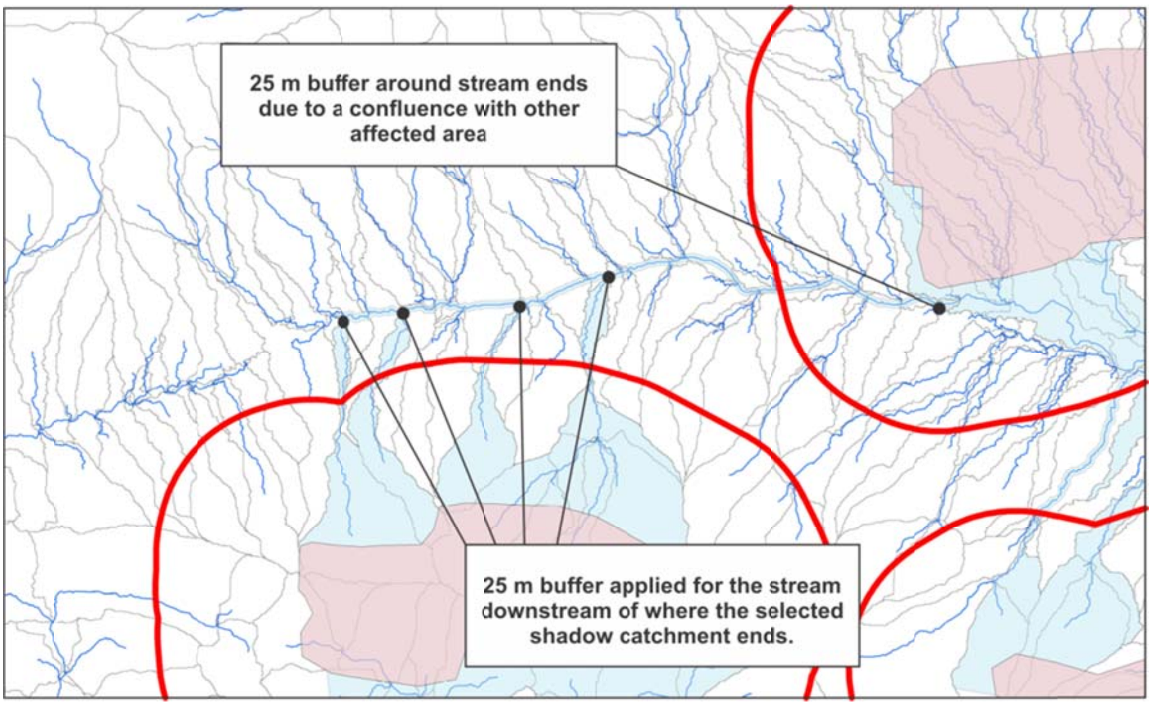


Figure 9. Drainage lines affected by mining footprints are represented by 25 m buffer along the lines

- Small catchments the intersection of which with the footprint was insignificant, are not included as part of the impact shadow area (Fig. 9).

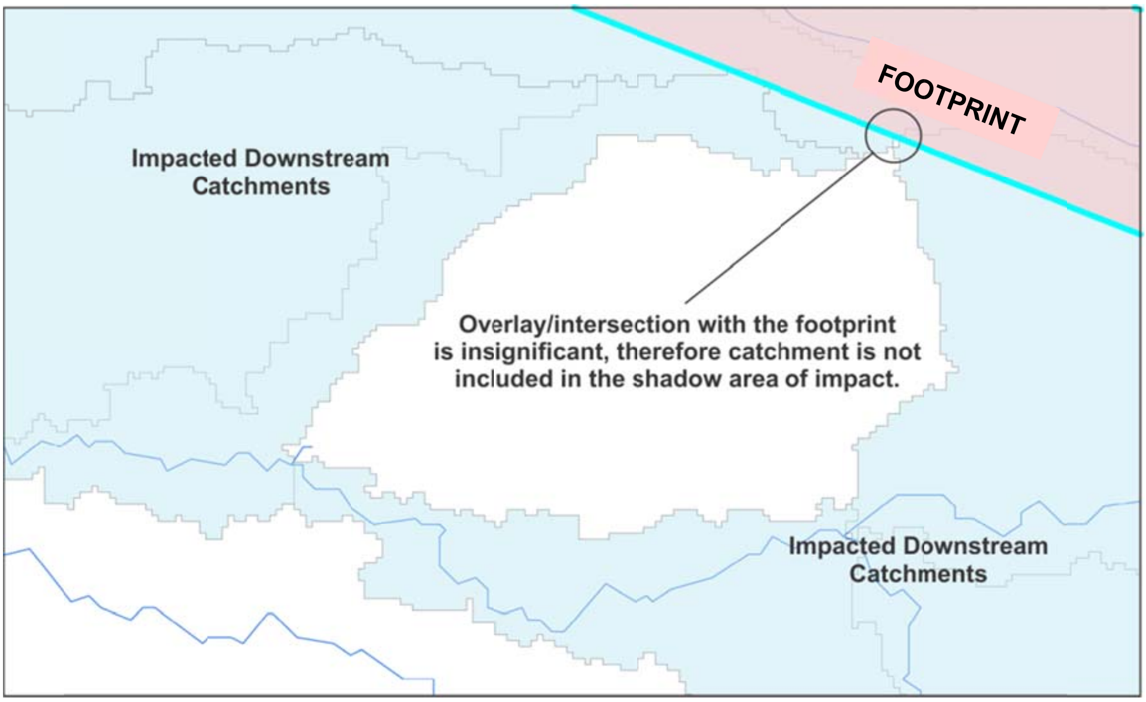


Figure 10. Minor intersection with the mining footprint

- In a number of cases the upper reaches of impacted catchments also extend upstream of the footprint. These are not considered to be part of the impact areas, as it is assumed flow from these areas will be diverted around the footprint (Fig. 10).

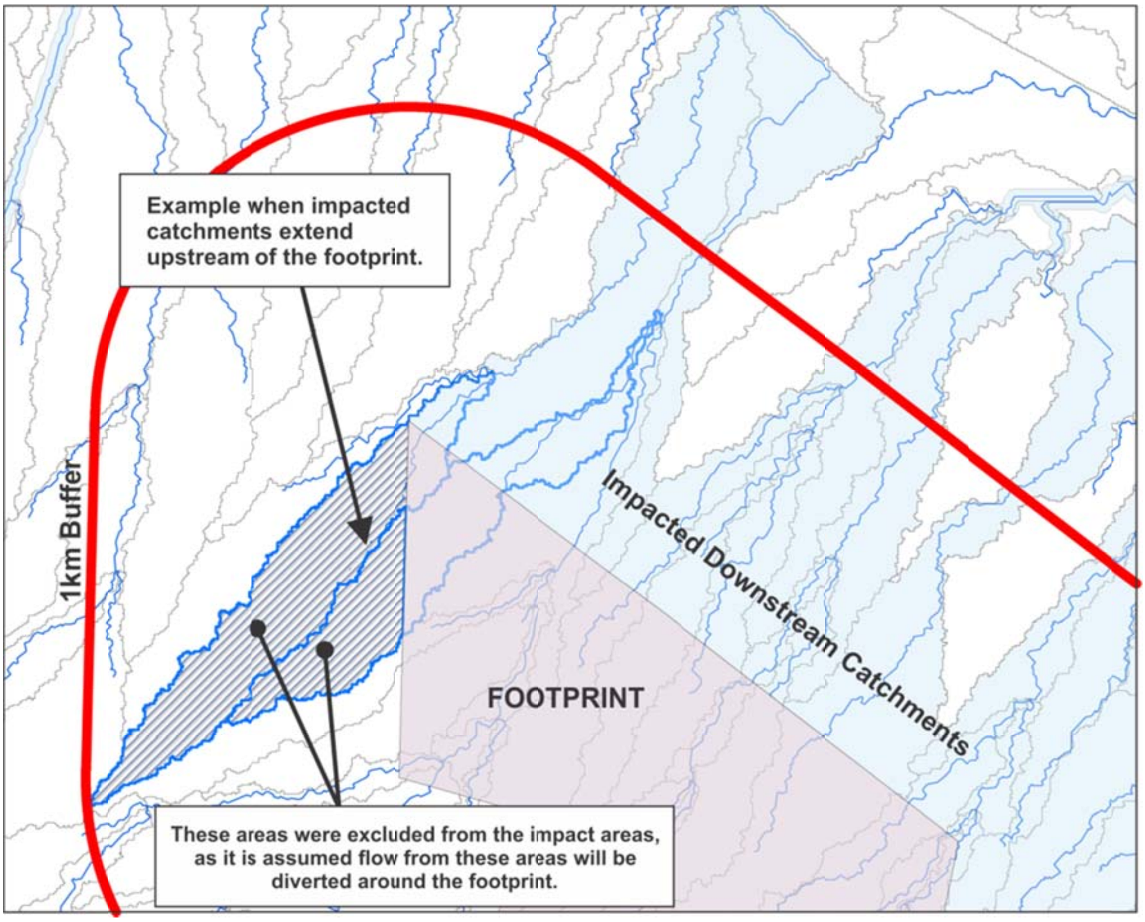


Figure 11. Catchment that extends both upstream and downstream of the mining footprint. Note: The upstream portion is not part of the candidate catchment shadow

A number of site-specific and special cases required adjustment and reinterpretation of the drainage network, including:

- The BHP Billiton Iron Ore railway corridor forms a distinct topographic feature in the 5 m DEM that skewed the derived drainage network. The major drainage features were manually adjusted to reconnect the drainage line upstream and downstream of the railway – this was validated against aerial photographs and Google Earth imagery.
- Within the 30 m DEM-H coverage, some drainage lines required adjustment. This was notably in the eastern part of the Fortescue Marsh and Fortescue River Valley, as there was an inaccurate depiction of the drainage network in flat-lying areas. Aerial photography and Google Earth imagery were used to better represent the drainage network.

4.3 Level of hydrological change

A statistical analysis of runoff volumes was undertaken to determine potential reduction in flow volumes in the context of natural variations at Coondewanna Flats (RPS, 2014). Despite this analysis being hindered by the lack of site-specific gauging data and highly-variable nature of runoff in the Pilbara, it did provide some insight into possible levels, or thresholds, for potential hydrological change.

RPS (2014d) suggested that a reduction in catchment runoff volume of less than 10% would be unlikely to be noticeable or measureable. Taking a more conservation approach, it was considered that less than 5% reduction in catchment runoff would have no material effect on inflow volumes to key ecological receptors. For the purpose of this change assessment, areas that experienced less than 5% reduction in surface water availability are considered to have no potential for hydrological change as this is within the error range of current measurement systems and an order of magnitude lower than natural variations.

The determination of the upper limit or threshold for high-level change requires further hydrological studies. The analysis by RPS (2014) showed that the 5 year moving average runoff value has a standard deviation of around 50% suggesting the natural system experiences wide variation in surface water flows.

The limited data on the response to variation in flow required a precautionary level of a 20% change to be adopted as the high classification of hydrological change for surface water. As there was no quantitative rationale for further segregation between 5% and 20% reduction in surface water availability, these areas have been rated as having a low hydrological change (Table 2).

Table 2. Hydrological change associated with reduction in surface water availability

Reduction in surface water availability (% catchment area affected)	Hydrological change
0 to 5	None
5 to 20	Low
>20	High

4.4 Extent of hydrological change

The degree of surface water change is expressed as a ratio of disturbance area and the upstream contributing catchment (footprint and downstream shadow catchment) areas inclusive of the 1 km buffer area. The footprint area includes open pits and OSAs, but does not consider infrastructure corridors such as railroads.

A high degree of change was assigned to areas up to 1 km downstream of mining disturbance areas, based on the assumption that water from the upper catchment is diverted and returned to the downstream catchment at a distance of 1 km down-gradient being consistent with business-as-usual management practices. Further downstream, the degree of change was expressed as the ratio of ground disturbance area to catchment area.

The following approach was applied in assigning degree of surface water change:

- Surface water change of all major water features (Fortescue Marsh, Lake Robinson, and effect of the Ophthalmia Dam) was calculated based on impacted areas.
- Surface water change classification for some catchments downstream of impacted footprints was based on visual estimation of the footprint area versus upstream catchment areas (if it was clear that the footprint was much smaller than the feeding catchment). When this was not the case, an estimate was applied based on GIS-based determination of the size of the feeding upstream catchment and the size of the affected area (footprint plus downstream shadow catchments within 1 km buffer around the footprint).
- Points along the downstream creeks and streams where surface water impact changes from high to moderate and/or moderate to low were preferably based on locations where larger tributaries with low surface water change connected to the given drainage. If no such point was identifiable, a one-third rule was applied.

The process of assigning the degree of surface water change was:

- Assign a "high" degree of surface water change to the disturbance area and 1 km downstream of the disturbance area
- Assume that water from the upper catchment will be diverted and into the downstream catchment 1 km downstream of the disturbance area
- Classify the surface water change at 1 km downstream of the disturbance area -> *footprint area + downstream shadow catchment within 1 km buffer/upper catchment area*
- Where the degree of surface water change is "none" assign "none" to the remainder of the downstream creek lines
- Where the degree of surface water change is low or high, do the following
    - o Evaluate the degree of surface water change at the downstream portion of the catchment,
    - o Identify the point where degree of surface change changes from high to low or low to none, and
    - o Scale the high/low/no degree of change along the downstream creek length.

5. Surplus water

5.1 Background

BHP Billiton Iron Ore currently operates two main surplus water management schemes namely:

- Release of surplus water from the Whaleback and Eastern Ridge mining areas to Ophthalmia Dam MAR scheme, and
- Release of surplus water from the Yandi mining area to the Marillana Creek.

There are also a number of surplus water management trials including:

- MAR through groundwater injection bores at Jimblebar mining area,
- MAR through groundwater injection bores at MAC mining area, and
- Release of surplus water from the Jimblebar mining area into Jimblebar Creek.

In addition to the BHP Billiton Iron Ore Operations, a number of third party mining operations are also producing surplus water, which is being managed by means of controlled release to the surface water environment (e.g. RTIO's Hope Downs 1 and Yandicoogina mining areas) and by means of groundwater injection bores (e.g. FMG's Cloudbreak and Christmas Creek mining areas). HPPL's Roy Hill is planning to manage surplus water through evaporation ponds.

Ophthalmia Dam MAR surplus water management scheme

The Ophthalmia Dam MAR surplus water management plan comprises the managed release of surplus water from a number of operations to the Ophthalmia Dam and four recharge ponds, from where the water infiltrates and recharges the underlying aquifers. The surplus water management plan has been in operation since 2006, has historically received surplus water from OB23 and currently receives surplus water from OB25 and Whaleback operations. The surplus water volume for FY 2013 was 8 GL. BHP Billiton Iron Ore is planning to manage surplus water from other operations in the Eastern Pilbara region within the Ophthalmia Dam MAR surplus water management scheme, including OB31 and Jimblebar mining area.

Marillana Creek surplus water management scheme

The Marillana Creek surplus water management plan comprises the controlled release of surplus water from the Yandi mining area to the ephemeral Marillana Creek. The surplus water management plan has been in operation since 1991 and surplus water is currently being discharged at the Central and Eastern Discharge Points. Surplus water is released directly in the creek where it ponds on the creek bed before infiltrating and recharging the underlying aquifers.

5.2 Methodology

Indicative water balances were developed for each of the BHP Billiton Iron Ore deposits to identify which operations are likely to have a water deficit (water negative) and those likely to have surplus water (water positive) over the development of the Pilbara Expansion. Water balances were developed at the mining area scale in recognition that deficit and surplus water regimes are managed between operations following normal business management practices.

The water balances were developed based on the best available information including:

- Detailed water balance studies supported by numerical hydrological modelling for active mine sites;
- Conceptual water balance studies supported by indicative mine plans but only conceptual understanding of the hydrological system (30% development scenario); and
- Conceptual water balance studies supported by conceptual mine plans and understanding of the hydrological system (full development scenario).

The water balance for each operation was calculated as:

Water balance (surplus or deficiency) = Inflows (Abstraction) - Outflows (Usage)

Positive values indicate water surplus operations for the specific time period; whereas, negative values indicate deficiencies and additional water will be required to meet demand.

5.2.1 Groundwater abstraction

Dewatering requirements were estimated as part of the analytical approach used to determine hydrological change associated with groundwater drawdown for the respective operations. Groundwater abstraction, represented as inflow into the pits, was considered in terms of inflow rate for a ‘generic mine type’ (Section 3.1) and the number of years of active below-the-watertable mining.

The inflow rates for the different generic mine types were assigned as follows:

- Isolated - less than 2 ML/day,
- Partially connected - 2 to10 ML/day,
- Connected - 10 to 20 ML/day, and
- Fully connected - more than 20 ML/day.

There was no account of the need for additional water supply options, where water balance indicate water deficit; impacts from artificial recharge in nearby aquifers; and advanced dewatering.

5.2.2 Groundwater usage

Groundwater usage was estimated based on the typical water demand of a mining operation, in terms of total material movement and ore movement. There was no consideration of water demand related to ore beneficiation (as no beneficiation has been incorporated in the SEA LoA mine schedule) and construction water supplies. Water demand has therefore been attributed as follows:

- 48 ML/yr per Mtpa for ore processing, and dust suppression of the stockyard and train load-out; and
- 18 ML/yr per Mtpa for total movement associated with dust suppression at the mine, and water supplies for the village and workshop.

Water balances were developed for each of the mining areas considering the dewatering water usage requirement for each of the proposed orebodies.

5.2.3 Third-party estimates

The surplus water estimates for third-party operations were derived from public available information as follows:

Surplus water = predicted dewatering rates - operations water requirements

The details of third party abstraction and demand, obtained from a range of publicly-available references, are summarised in Table 3.

Table 3. Surplus water estimates for third party operations

Operations	Operator	Region	2014 Dewater	2014-2030 Dewater	Water Demand (GLyr)	Reference based on	Comments
Christmas Creek	Fortescue Metals Group	Fortescue Marsh	29.3	N/A	7.5	Hydrogeological Assessment (FMG, 2010)	
Christmas Creek Expansion	Fortescue Metals Group	Fortescue Marsh	0	110	25	Referral of revised proposal (FMG, 2013)	No schedule for dewatering is provided. Assumed revised dewatering and water requirement rates apply to 2020 conditions – likely overstated. MAR not considered in assessment
Cloudbreak Injection Increase	Fortescue Metals Group	Fortescue Marsh	99	66	10	Hydrogeological assessment (FMG, 2013)	MAR not considered in assessment. Increased dewatering rates due to recirculation from MAR not considered in assessment
Hope Downs	Hamersley Hope Management Services	Central Region	40	36	6	Estimate based on Johnson and Wright (2001)	
Hope Downs 4	Hamersley HMS Pty Ltd	Fortescue Marsh	2.8	8.9	3.6	PER (Strategen, 2010)	
Iron Valley	Iron Ore Holdings	Marillana Creek	0	0	N/A		No dewatering anticipated – AWT mining
Koodaideri	Rio Tinto Iron Ore	Fortescue Marsh	0	N/A	6	PER (RTIO, 2013)	No dewatering estimates stated in PER – assumed water deficit as large part of mine will be AWT
Marillana	Brockman Resources	Fortescue Marsh	0	7.3	7.3	LOM water balance (Aquaterra, 2010)	Assumed mining will commence in 2016
Nyidinghu	Fortescue Metals Group	Fortescue Marsh	0	0	10	Referral (FMG, 2012)	No dewatering anticipated – AWT mining
Roy Hill	Hancock Prospecting	Fortescue Marsh	0	7.5	5.5	Stage 1 PER (Roy Hill, 2009)	Dewatering for Stage 2 (year 11) increase to 22 GL/a
Yandicoogina	Pilbara Iron	Marillana Creek	9.5	9.5	1.0	Groundwater management Plan (Pilbara Iron, 2006)	No predicted dewatering rates included in document. Dewatering estimates based on schematic water management plan
Yandi JSW Oxbow	Rio Tinto Iron Ore	Marillana Creek	13.4	13.4	4.0	PER (RTIO, 2011)	Only cumulative dewatering over 12 years provided – used average for “Option 1 (161 GL over 12 years”. Water demands based on statement “about 30% of dewatering will be used for dust suppression, potable supply and processing”
West Angelas	Robe River Mining	Central Pilbara	N/A	N/A	6	PER (EPA, 1999)	Assumed water deficit operation as water requirements are met from borefield
Yandi Pocket Billiard South	Rio Tinto Iron Ore	Marillana Creek	30	30	N/A	Referral (RTIO, 2014)	Total for Yandicoogina 53 GL/a with 83 GL/a over 2 years

6. Acid and Metalliferous Drainage (AMD)

6.1 Risk assessment fundamentals applied to AMD risk assessment

A risk assessment is the process used to evaluate the likelihood that adverse ecological effects may occur or are occurring as the result of exposure to one or more stressors, such as AMD. Risk assessments provide a framework for integrating and presenting scientific data and conclusions about:

- Source of stressors - contaminants and/or physical effects that are present,
- Pathways - the adverse influence of stressors on receptors, and
- Receptors - environmental receptors (i.e. groundwater, surface water bodies, flora and fauna) that are affected by the stressors.

A risk can only occur if at any point in time sources and receptors are linked by pathways.

The assessment of potential AMD impacts was based upon a conceptual understanding of the factors that contribute to overall AMD risk. The assessment is concerned principally with the assessment of the source term in the source-pathway-receptor model. At this time, uncertainties around pathways and receptors preclude their inclusion in the regional model. This is in part due to the iterative nature of risk assessment and selection of appropriate overburden management strategies, which are in part based upon the outcomes of the source risk assessment process.

Many deposits do not have the planning details for pathways and receptors to be characterised at this time, or data in support of the characterisation is currently being gathered, or data is not yet in a suitable format for inclusion in this preliminary risk assessment. These uncertainties are currently being addressed as part of BHPBIO's overarching ecohydrological change assessment.

The AMD risk assessment specifically assesses the likelihood of encountering potentially acid forming (PAF) mine overburden, or exposed PAF surfaces within the excavated mine voids. Such material is likely to present as high risk material in AMD assessment in terms of leaching of constituents of interest particularly acidity, metals and salinity. PAF material is therefore of particular interest as when disturbed it presents the source of risk for potential ecohydrological change.

The characteristics of disturbed geological material that were considered to be the basis of AMD risk were:

- leachable content of AMD in the source term, and
- potential for leaching to occur based on the materials properties.

The characteristics of the material may be divided into the following key attributes of the material and the disturbance created when the material is mined (Table 4).

Table 4. Factors controlling consequence and likelihood of AMD risk

Consequence Term – Leachable Content	Likelihood Term – Release Potential
Magnitude of disturbance (tonnes)	Residual reactivity (degree of in-situ weathering, qualitative assessment)
Leachable solid concentration of COI (mg/kg)	Change in environment (undisturbed to disturbed condition, qualitative assessment) Kinetics of release (mg/y, or qualitative assessment)

Note that COI = constituent of interest to AMD studies (e.g. metals, sulfate).

A conceptualisation of these factors may be combined into an overall source term risk assessment, as shown in Figure 11. For the purposes of this preliminary assessment, a detailed assessment of reactivity and kinetics of release is not possible; rather it is assumed that the reactivity and kinetics of release will be influenced by the degree of weathering only. Figure 12 shows the simplified conceptual model of the risk assessment.

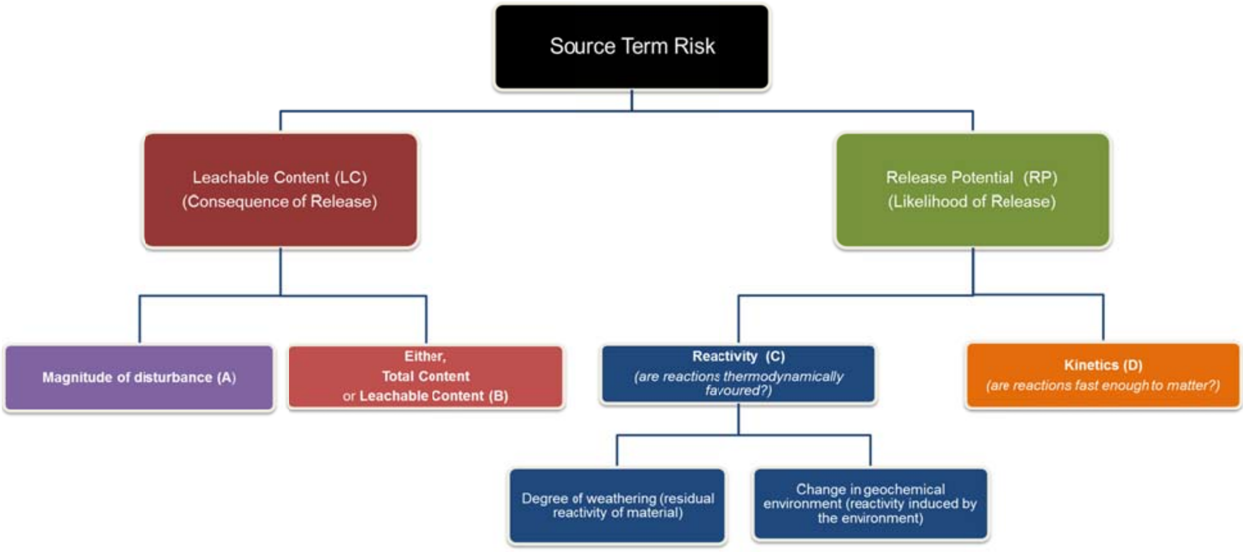


Figure 12. Conceptualisation factors that contribute to source term risk

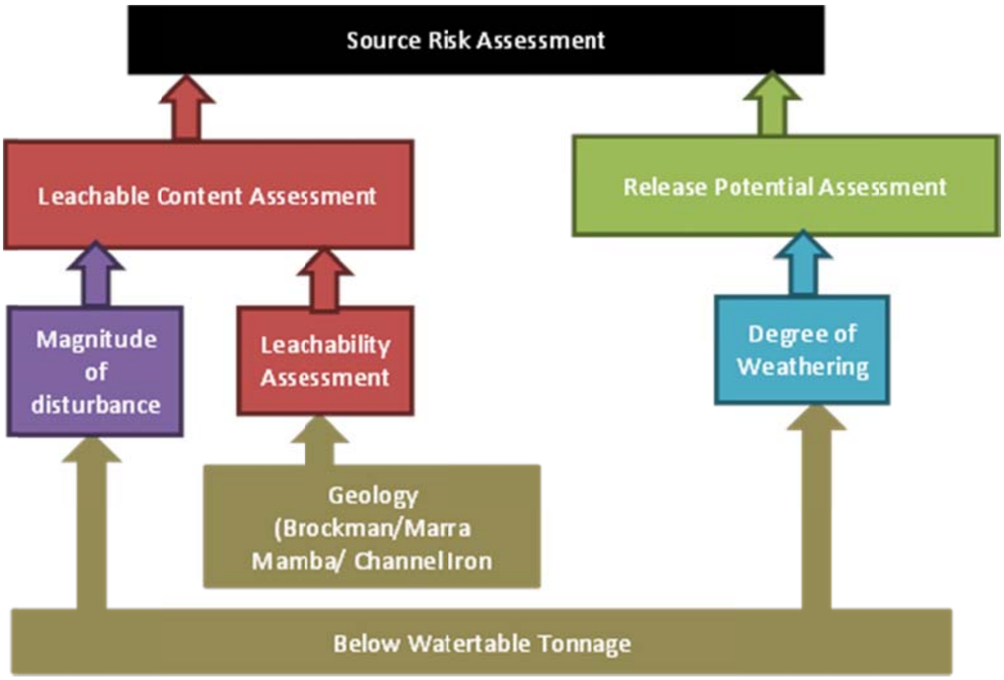


Figure 13. Conceptualisation of inputs for preliminary source term risk assessment

6.2 Input data

Input data available for use in the risk assessment were:

- deposit type (BKM, MM, CID),
- tonnes of material mined,
- ore and overburden classifications,
- preliminary PAF classifications, based upon total sulfur content of 0.2% S from assay, and
- information on whether material was mined from above or below the watertable.

6.3 Additional supporting information

Site and area specific AMD risk assessments have been undertaken across existing BHP Billiton Iron Ore operations to assess the likelihood of AMD generation. Summary outcomes of these studies are outlined in Table 5.

Table 5. Key attributes and measures of AMD source risk

Attribute	Significance	Measure applied to strategic review
Magnitude of disturbance.	For similar rock types, a larger magnitude of disturbance will produce a larger quantity of overburden and exposed pit will rock, with potentially leachable and reactive content, compared to a deposit with a smaller magnitude of disturbance.	Tonnage of mined material (overburden and ore); providing a measure of the quantum of overburden that will remain on site and the scale of the mine void wall exposure.
Leachability of constituents of concern (acidity, salinity, elements of environmental importance).	Rock types vary in their chemical content and the leachability of those chemicals.	Iron ore resources are categorised into three primary host rock types (Brockman, Marra Mamba or Channel Iron Deposit); these rock types have varying chemical content and leachability (e.g., Brockman deposits can be associated with Mount McRae Shale which may be highly reactive and leachable).
Reactivity of disturbed material (degree of weathering).	Unweathered (unoxidised) mined overburden and exposed pit wall rock is more reactive than weathered (oxidised) material, having a greater potential for release of acid, metals and dissolved salts.	Tonnage of below watertable mined material; overburden and exposed pit wall rock from below the watertable is generally unweathered (unoxidised).

The studies also provided a useful validation of likely ratings by analysing the percentage of material classified as PAF within the existing mining models with respect to the different host rock types. The following AMD risk assessments were considered as part of the assessment:

- Earth Systems (2013) - Preliminary Acid and Metalliferous Drainage Risk Assessment for Orebodies 17 / 18 Mining Operations;
- Earth Systems (2014) - Preliminary AMD Risk Assessment at Orebody 19;
- Earth Systems (2014) - Preliminary AMD Risk Assessment at Orebody 31;
- ERM (2012) - Jimblebar Hub: Preliminary Acid and Metalliferous Drainage Risk for the Development of the South Jimblebar, Hashimoto, and Wheelarra Hill Deposits, Pilbara, WA;
- GHD (2014) - Draft Yandi Operations Preliminary Risk Assessment for Acid and Metalliferous Drainage;
- Klohn Crippen Berger (2014) – MAC mining area, Preliminary AMD Risk Assessment;

- SRK (2013) - Orebodies 29, 30 and 35: Preliminary Acid and Metalliferous Drainage Risk Assessment; and
- SRK (2014) - Draft Orebodies 23 and 25: Preliminary Acid and Metalliferous Drainage Risk Assessment.

6.4 Generation of risk criteria and variables for the risk assessment

Following a review of the available data, supporting evidence and following expert peer review (Golder, 2014); the assessment of AMD risk considered two key risk criteria/variables:

- tonnage of material disturbed below the watertable (as a proxy for total leachable content, or consequence)
- host deposit type (as a proxy for relative PAF/high AMD risk, or likelihood).

The rational for the use of each variable, and the scaling used to define the 'significance' of each variable is described below.

Leachable content was assessed to be a function of the magnitude of disturbance of the material of interest and the leachable content of AMD (concentration) in the source the material. This is likened to the consequence term of a risk assessment (Table 8).

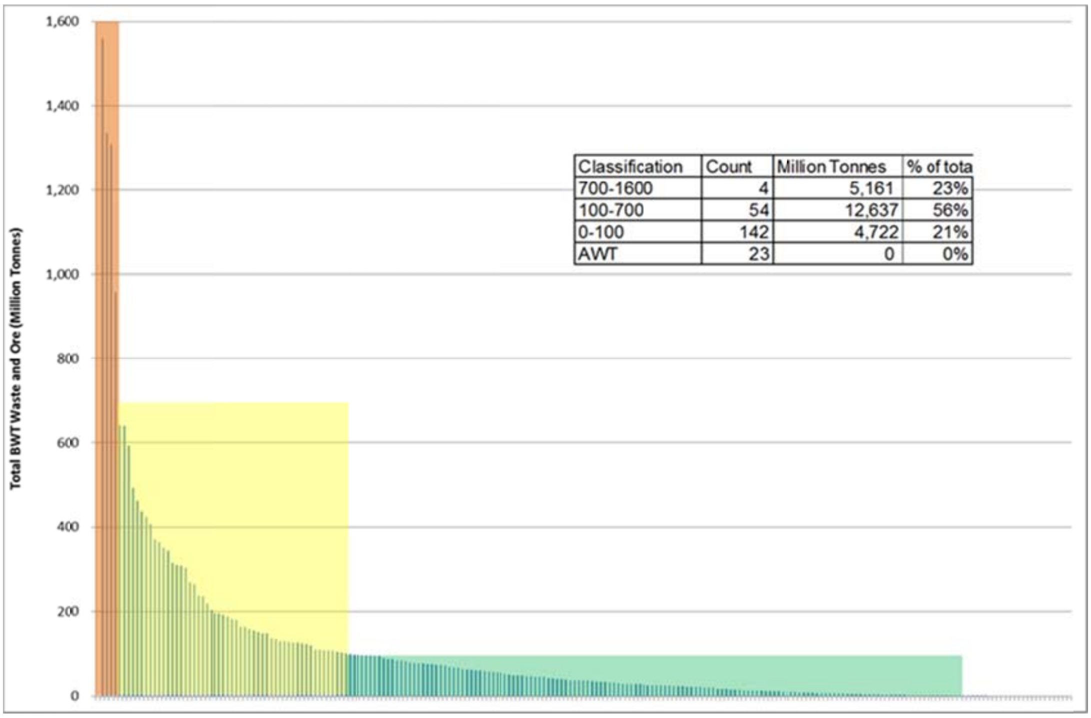
No assessment of relative leachability of rock type was included, because data is currently not available at the regional scale. The leachable content of PAF material is assumed to be sufficiently high to merit the assumption of high source-term risk in AMD risk assessments. Therefore the scalar for leachable content of PAF material is based upon the tonnage of disturbed material (ore and overburden) only.

The leachable content of the rock is reduced by the degree to which the material has already leached in situ, termed the degree of weathering. An assumption that weathered material contains markedly less leachable content than fresh, unweathered material has been made. Material in the oxidised zone / weathered zone; therefore, has been assumed to represents lower risk material in AMD risk assessments; this is based on the general trends in AMD studies of overburden. The assessment of magnitude of disturbance therefore considers tonnages of ore and overburden mined below the watertable only as the consequence term.

The degree of weathering was approximated from the pre-mining condition with respect to the watertable - material from below the watertable was used as a proxy for un-weathered, and therefore material with higher AMD risk.

6.5 Derivation of the significance scale for magnitude of disturbance

The below watertable tonnages for all deposits with available information were collated and are displayed in Figure 13.



Classification	Count	Million Tonnes	% of tota
700-1600	4	5,161	23%
100-700	54	12,637	56%
0-100	142	4,722	21%
AWT	23	0	0%

Figure 14. Frequency distribution of below watertable tonnages for all deposits.

The population was divided into three groups and the risk significance categories being assigned as shown in Table 6.

Table 6. Magnitude of disturbance of unweathered material

Magnitude of disturbance and degree of weathering	Tonnage of ore and overburden mined below watertable (Mt)
Large	> 700
Moderate	100 - 700
Small	< 100

6.6 Rationale for use of host geology as a proxy for (or 'likelihood of release')

An estimate of leaching potential has been derived from information on the host rock type of each iron ore deposit.

An assessment of the proportion of PAF classified ore and overburden material was made for each host rock type (BKM, MM, CID). The assessment revealed that a relationship exists between host rock type and the proportion of PAF classified material associated with it.

At the current time the significance scale for host geology is based upon a review of all available data for the proportion (%) of PAF material logged in WAIO mine models. This has been used as a proxy for leachability of the overburden generated from it in terms of the release of constituents of concern (e.g. metals, sulfate). The validity of the proxy is based on two main assumptions:

- a particular deposit type generates different magnitudes of AMD risk, based on the amount of PAF classified material likely to be disturbed
- potentially acid forming (PAF) material is likely to represent high AMD risk material since leachability of constituents of concern (e.g. metals, sulfate) are enhanced under acidic conditions.

The deposit type has been used to provide an estimate of the proportion of PAF material that will be present.

6.7 Derivation of the significance scale for host geology

The review of data from the WAIO mine models provided information on which a significance scale for percentage (%) of PAF material could be based. The data is displayed in Figure 14.

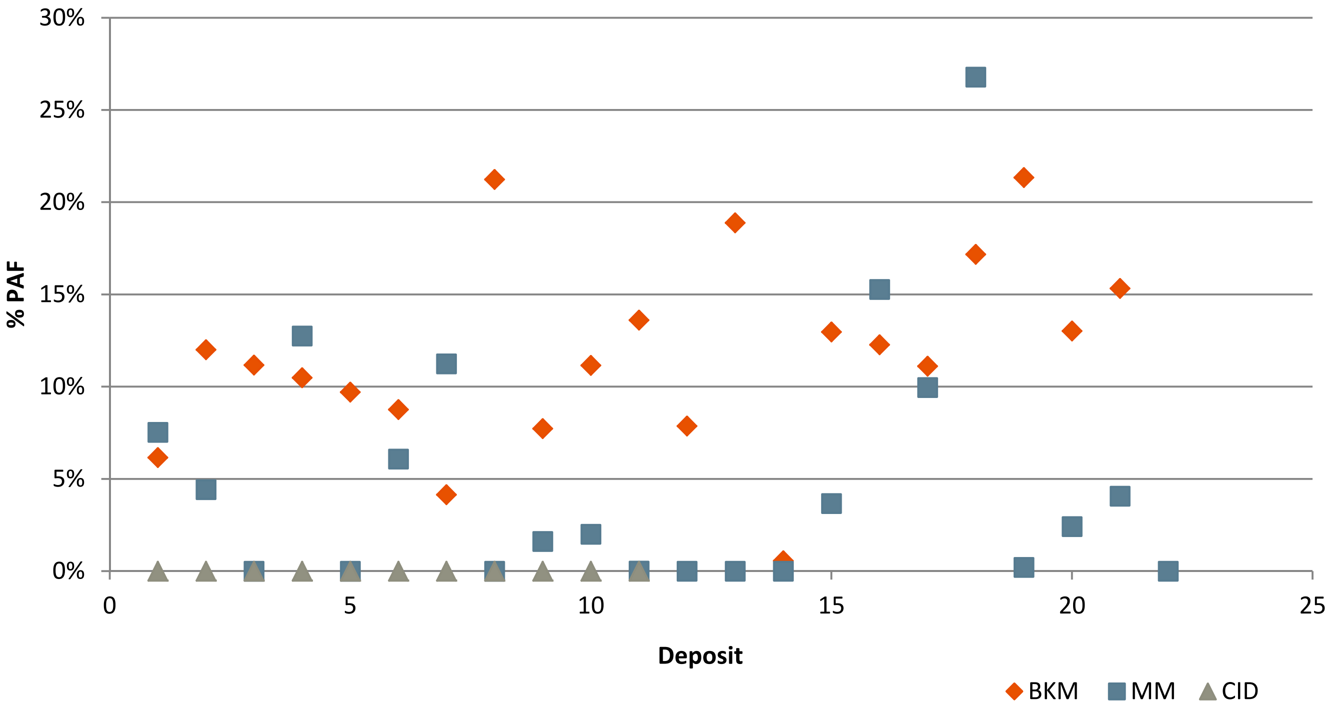


Figure 15. Relationship between % PAF material and host geology of deposit.

From the data review, the following conclusions were drawn for the likelihood of encountering PAF overburden and summarised in Table 7.

- Brockman Formation: Range of PAF in AMD risk assessments were 0.03 to 6% (most mines will have Possible AMD potential)
- Marra Mamba Formation: Range of PAF in AMD risk assessments were 0.3 to 6% (most mines will have Unlikely AMD potential)
- CID: Range of PAF in AMD risk assessments were 0 to 0.01% (most mines will have Rare potential)

Table 7. PAF characteristics of host rock geology

Likelihood of acid generation	Descriptor	Host rock geology
High	May happen	Brockman
Medium	May happen sometime	Marra Mamba
Low	May happen in extreme circumstances	Channel Iron Deposit

7. Ability to manage potential pit lake impacts through backfilling

7.1 Background

As part of normal business overburden optimisation, a portion of overburden is typically placed in the mine void, which is referred to as infilling. Provided that is does not interfere with the mining operations, infilling is typically more economical than placing the overburden outside the mine pit (referred to as ex-pit overburden). The proportion of normal business infilling varies from pit to pit and depends on many factors such as the geometry of the mine void and mine scheduling, but typically, between 30% and 60% of overburden material are used for infilling.

After the cessation of dewatering operations, groundwater levels will recover to pre-mining groundwater levels. In many cases, normal business infilling will be at an elevation higher than pre-mining groundwater levels and as a result, there will be no potential for pit lake development. In other cases, normal business infilling will be at an elevation lower than pre-mining groundwater levels and the natural recovery of groundwater levels will result in the formation of a pit lake.

Backfilling, in addition to normal business infilling, may be considered to meet closure objectives. One of the closure objectives could be the prevention of pit lake formation if there is a potential for unacceptable impact on the environment.

A detailed understanding of the source, pathway and receptor components are required to assess the potential pit lake impacts. Similar to the AMD assessment, many deposits do not have the planning details for pathways and receptors to be characterised at this time, or data in support of the characterisation is currently being gathered, or data is not yet in a suitable format for inclusion in this preliminary risk assessment. These uncertainties are currently being addressed as part of BHP Billiton Iron Ore's overarching ecohydrological change assessment

The pit lake assessment is concerned principally with the assessment of the source term in the source-pathway-receptor model. For the purposes of the study, BHP Billiton Iron Ore assessed the ability to manage potential pit lake impacts through backfilling, in addition to normal business infilling.

For many of the proposed pits where there is a potential for pit lake formation, there are enough ex-pit overburden material to backfill the mine void to an elevation above pre-mining groundwater levels. For others, there may be insufficient ex-pit overburden material to backfill the mine to above groundwater levels and overburden from other parts of the mining area may be used for backfilling to meet mine closure objectives. In some cases, there may be insufficient overburden across the whole mining area to backfill mine voids to above pre-mining groundwater levels.

Based on the above, BHP Billiton Iron Ore identified five categories in terms of the ability to manage potential pit lake impacts through backfilling (Table 8).

Table 8. Ability to manage potential pit lake impacts through backfilling

Category	Description	Potential for pit lake formation
Above the watertable mine voids.	Mining will only occur above the watertable and the watertable will not be intercepted during mining.	No potential for pit lake formation.
Infilled pit void through normal business overburden scheduling.	Mining will take place below the watertable, but the mine void will be infilled with overburden to an elevation above pre-mining water levels through normal business overburden scheduling.	No potential for pit lake formation through normal business overburden scheduling.
Adequate ex-pit overburden available to infill pit void.	Mining will take place below the watertable and normal business infilling will be to an elevation below the pre-mining water levels. However, there is adequate ex-pit overburden material to infill the mine void to above pre-mining water levels if required to meet the closure objectives.	Potential for pit lake formation. Sufficient ex-pit overburden is available to backfill the mine void and prevent pit lake formation, if required to meet the closure objectives.
Mining area based overburden scheduling required to backfill pit void.	Mining will take place below the watertable and normal business infilling will be to an elevation below the pre-mining water levels. Mining area based overburden scheduling is required to infill the mine void to above pre-mining water levels if required to meet the closure objectives.	Potential for pit lake formation. Mining area based overburden scheduling is required to infill pit void and prevent pit lake formation, if required to meet the closure objectives.
Insufficient overburden available in mining area to backfill pit void.	Mining will take place below the watertable and normal business infilling will be to an elevation below the pre-mining water levels. There is not adequate overburden in the mining area to infill the mine void to above pre-mining water levels if required to meet the closure objectives.	Potential for pit lake formation. There is not adequate overburden in the mining area to prevent pit lake formation.

In the context of BHP Billiton Iron Ore pit lake management framework, increased management focus is required at mining areas where there is not adequate overburden material available to infill / backfill mine voids and prevent the formation of pit lakes, if required to meet the closure objectives.

7.2 Methodology

Input data available for use in the assessment were:

- tonnes of material mined at each deposit,
- ore and overburden classifications,
- BWT and AWT classifications, and
- Density of the ore and overburden at each of the deposits.

Figure 15 shows the conceptualisation of the methodology applied to assess the ability to manage potential pit lake impacts through infilling.

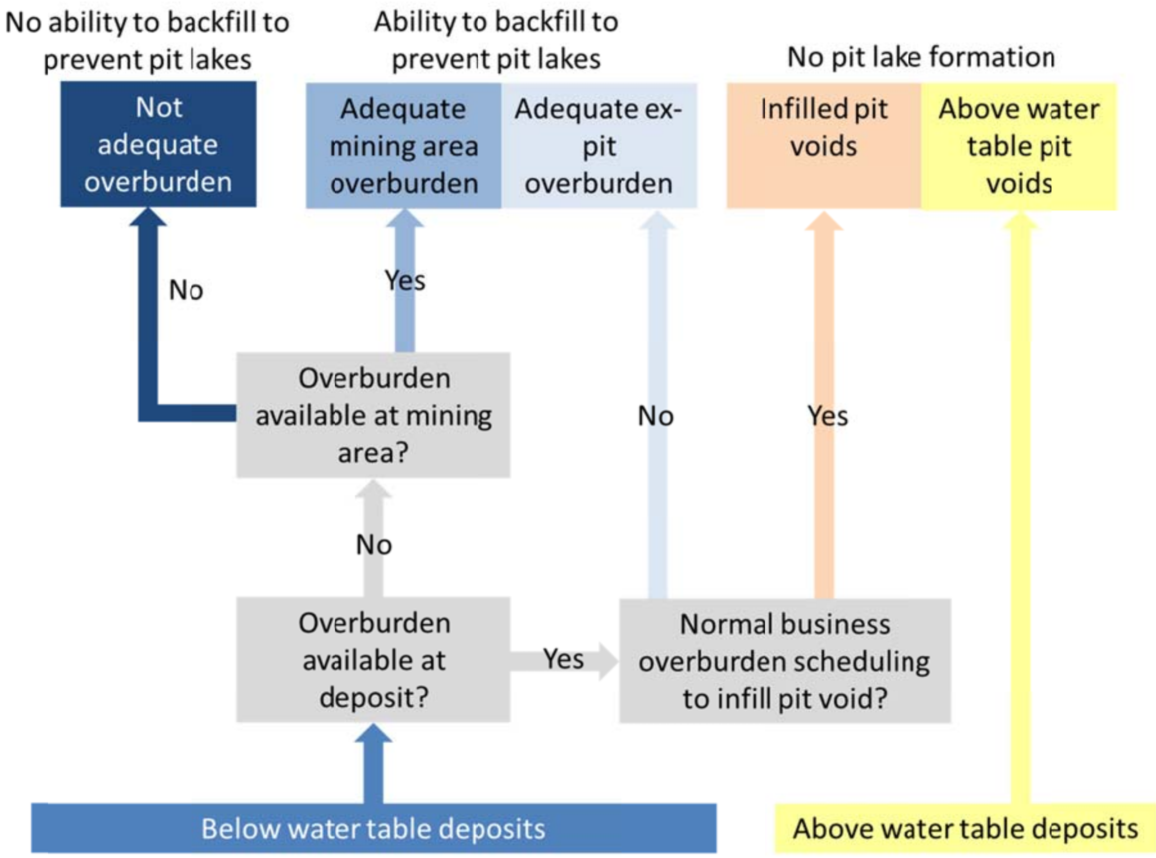


Figure 16. Conceptualisation for the ability to manage pit lakes through infilling

Each deposit was classified as either below watertable (BWT) or above watertable (AWT) deposits. AWT deposits were categorised as AWT mine voids with no potential for pit lake formation.

For BWT classifications, an assessment was made whether there is adequate overburden material at each of the deposits to infill or backfill the mine void to above pre-mining groundwater levels (i.e. the total overburden volume should be greater than the BWT mine void volume):

$$overburden\ volume > BWT\ mine\ void\ volume$$

The overburden volume was estimated as follows:

$$overburden\ volume = \frac{total\ overburden\ tonnage}{overburden\ density} \times bulking\ factor$$

The bulking factor takes in consideration that the overburden comprises broken material and has therefore a larger volume compared to the *in-situ* material. A 30% bulking factor was adopted for this assessment, i.e. the overburden volume is 1.3 times greater than the in-situ material volume.

The BWT mine void volume was calculated as follows:

$$BWT\ mine\ void\ volume = \frac{BWT\ overburden\ tonnage}{overburden\ density} + \frac{BWT\ ore\ tonnage}{ore\ density}$$

Where the overburden volume is greater than the BWT mine void volume, an assessment was made on whether the mine void will be infilled through normal business overburden scheduling:

$$Overburden\ volume = infill\ factor \times overburden\ volume$$

The infill factor for normal business practices was based on known infill volumes from current operations and planned infill and backfill volumes for future pits. In practice the infill factor varies between 30% and 60% of the total overburden volume and depends on many factors such as pit geometry, mining scheduling, overburden scheduling and other factors. For the purpose of this assessment, an averaged infill factor of 45% was adopted.

Where the overburden volume is less than the BWT mine void volume, there is insufficient volumes of overburden at the deposit scale to infill the mine void to above pre-mining water levels. A further assessment was made to assess whether there is adequate overburden material at the mining area scale to infill the mine void to above the pre-mining water levels.

$$overburden\ volume\ at\ mining\ area\ > BWT\ mine\ void\ volume\ at\ mining\ area$$

Where the overburden volume from all the mines in the mining area is greater that the BWT pit void volume for all the mine voids in the mining area, there is sufficient overburden material to infill the pits to above pre-mining water levels and mining area based overburden scheduling is required to backfill the pits.

The SEA mine schedule, on which the change assessment is based, is indicative only and does not purport to contain all information relevant to future project development. The project mine schedule is subject to ongoing resource definition, mine planning design and other future events, the outcome of which is uncertain and cannot be assured. The actual mining and overburden schedule may vary materially from this indicative mine schedule. However, for the purpose of a strategic high-level assessment, the methodology employed is deemed fit-for-purpose.

Figure 16 shows the categories of mine voids and the ability to manage pit lakes through infilling or backfilling. It is estimated that between 35% and 60% (average of 55%) of all mine voids associated with the project will be either above the watertable, or will be infilled through normal business overburden scheduling. A further 25% to 50% (average 30%) of mine voids can be infilled to prevent the formation of pit lakes, if required by the closure objectives, either using ex-pit overburden or through overburden scheduling at a mining area scale.

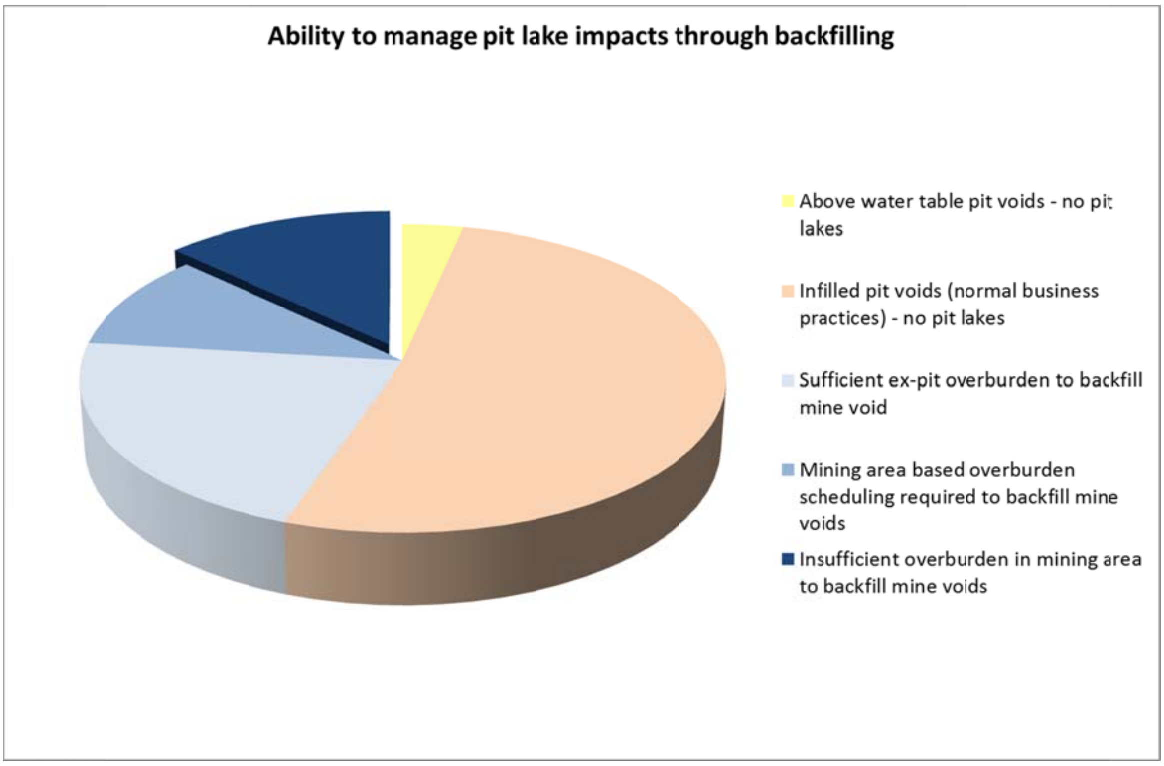


Figure 17. Categories of mine voids and ability to infill to prevent the formation of pit lakes

8. Regional change in groundwater resources

Consumptive water use in the Pilbara is largely dependent on the development and utilisation of groundwater resources. Most groundwater abstraction is related to mine dewatering and is primarily used for ore processing, beneficiation and dust suppression.

There are substantial stored groundwater resources within the regional aquifer comprising saturated detrital and weathered dolomite of the Wittenoom Formation. Outside of this regional aquifer, groundwater resources are highly localised within fractured and mineralised zones that are more difficult to estimate at a regional scale. As groundwater recharge is intermittent, variable and site-specific, it is readily exceeded by groundwater abstraction resulting in progressive depletion of groundwater storage at a catchment level.

A methodology was developed to provide a regional appreciation of groundwater storage depletion on groundwater resources. The measure of storage depletion considers volumetric change within the groundwater resource. This provides an order-of-magnitude understanding rather than a site-specific impact, as this is addressed in the groundwater drawdown approach (discussed in Section 3.1).

8.1 Stored groundwater resources

Stored groundwater resources were estimated for the regional aquifer using the areal extent multiplied with a saturated thickness of 50 m and a specific yield of 0.05 (or 5%). The areal extent of the regional aquifer was based on aquifer mapping by RPS (2014a and 2014b), as well as 1:250 000 geological data obtained from Geological Survey of Western Australia. The additional data was required to delineate the aquifer in the Fortescue Marsh and Marillana Creek Regions. The saturated thickness was determined from interpreted cross sections in RPS (2014a and 2014b), and MWH (2014a); while, the specific yield was estimated from aquifer parameters provided in the same reports.

Groundwater storage in the regional aquifer for each region is provided in Table 9. This estimate is only related to the regional aquifer and is considered conservative with respect to stored groundwater resources across the entire development area.

Table 9. Groundwater storage in the regional aquifer

Region	Regional aquifer area (km^2)	Regional aquifer storage (GL)
Central Pilbara	1039	2 600
Eastern Pilbara	1873	4 700
Fortescue Marsh	5360	13 400
Marillana Creek	523	1 300
Total		22 000

8.2 Change in groundwater storage

The change in groundwater storage has been assessed in terms of a water balance with inflows associated with recharge and 50% return of surplus water, and outflows associated with dewatering abstraction and any additional water required to address deficiencies. This can be summarised as:

Change in storage = Inflows (Recharge + 50% Surplus) - Outflows (Dewatering Abstraction + Deficiency)

Using this approach, a positive change in groundwater storage indicates that the groundwater resource will not be impacted but rather has potential for additional recharge or inputs; whereas, a negative change suggests groundwater storage depletion. This storage depletion in each region has been expressed in terms of a percentage change with respect to regional aquifer storage for 2014 (baseline conditions) to 30% development scenario and 2014 (baseline conditions) to full development scenario.

A summary of the methodology used to estimate the individual components of the water balance is provided below.

8.2.1 Groundwater recharge

Despite the intermittent and variable nature of groundwater recharge, there has been an attempt to determine likely volume of recharge contribution. This approach utilised data from the water balance calculations detailed in RPS (2014a and 2014b) for Central and Eastern Pilbara regions, and MWH (2014b) for Fortescue Marsh region. Whereas, recharge estimation for the Marillana Creek region was determined using a streamflow infiltration approach owing to an inconsistent methodology applied by Golder Associates (2014).

Groundwater recharge was only included in the water balance for years when there was active mining in the respective area. It was estimated for the different regions as follows:

Central Pilbara

RPS (2014a) suggested that diffuse groundwater recharge from rainfall was minimal and that only recharge associated with streamflow events in key receiving areas could be estimated. They estimated groundwater recharge associated with Coondewanna Flat at 2.8 GL/yr and Weeli Wolli Spring at 2.7 GL/yr.

Eastern Pilbara

Groundwater recharge in the Eastern Pilbara region occurs in a number of ways. Based on the water balance in RPS (2014b), there is direct recharge along Fortescue River and Homestead Creek of 5 GL/yr for both systems; seepage from Ophthalmia Dam is 18.25 GL/yr; discharge to the infiltration ponds is 3.6 GL/yr; and diffuse recharge throughout the broader catchment is 0.7 GL/yr.

Marillana Creek

The water balance for Marillana Creek by Golder Associates (2014) utilised a different methodology of recharge estimation and was considered not representative. It was decided that groundwater recharge could be estimated using an infiltration approach that has been previously used for Marillana Creek (BHP Billiton, 2014b). Recharge was estimated at 1.8 GL/yr, based on a 10 m aquifer width multiplied by a 44 000 m aquifer length, four days of infiltration and an infiltration rate of 1 m/day.

Fortescue Marsh

The water balance presented in MWH (2014a) suggested there is 21 GL/yr of groundwater throughflow from the Chichester Range (over a 170 km length) and 7 GL/yr of groundwater throughflow from the Hamersley Range (over a 125 km length) that contributes towards Fortescue Marsh. Groundwater throughflow can be considered as a proxy for groundwater recharge, as it represents groundwater infiltration at the margins and coincides with the proposed mining areas.

As the proposed Roy Hill operation covers 42 km long of the Chichester Range, recharge can be estimated at 5.2 GL/yr being 42 km of the 170 km multiplied by 21 GL/yr. Using the same approach for the proposed operations along the Hamersley Range, groundwater recharge related to Marillana is 1.1 GL/yr (being 20 km of the 125 km multiplied by 7 GL/yr); Mindy is 1.1 GL/yr (20 km) and Coondiner is 0.6 GL/yr (10 km).

8.2.2 Groundwater abstraction

Annual volumes of groundwater abstraction were determined for each region using the approach outlined in Section 5.2.

8.2.3 Water surplus and deficiency

Annual volumes of water surplus and deficiency were determined by deducting groundwater abstraction from groundwater usage. Situations of surplus water occur where abstraction is greater than usage, and the reverse is the case for periods of water deficiency. These periods of water deficiency represent an outflow or loss from the water balance, and suggest that an additional water source will be required.

8.2.4 Third-party requirements

The water demand related to existing and proposed third-party operations were determined from publically-available reports and documents. Table 10 details the likely water requirements for these third-party operations and length of abstraction to provide an estimate of water demand for the periods for 2014 (baseline conditions) to 30% development scenario and 2014 (baseline conditions) to full development scenario. The estimates were used to provide a cumulative perspective on potential change in the regional groundwater regime throughout time.

Table 10. Estimated water demand for third-party operations - 2014 (baseline conditions) to 30% development scenario and 2014 (baseline conditions) to full development scenario

Operations	Operator	Region	Water Requirement (GL/yr)	Year of closure	Depletion - 2014 to 30% development (GL)	Central Pilbara region	Fortescue Marsh region	Marillana Creek region	Depletion - 2014 to full development (GL)	Central Pilbara region	Fortescue Marsh region	Marillana Creek region
Christmas Creek	FMG	Fortescue Marsh	7.5	2018	30		30		30		30	
Christmas Creek Expansion	FMG	Fortescue Marsh	25	2026	300		300		300		300	
Cloudbreak Injection Increase	FMG	Fortescue Marsh	10	2025	110		110		110		110	
Hope Downs 1	HDMS	Central Pilbara	6	2026	72	72			72	72		
Hope Downs 4	HDMS	Fortescue Marsh	3.6	2031	0		0		0		0	
Iron Valley	IOH	Marillana Creek	n/a					0	0			0
Koodaideri	RTIO	Fortescue Marsh	6	2044	96		96		180		180	
Marillana	BRL	Fortescue Marsh	7.3	2034	116.8		116.8		146		146	
Nyidinghu	FMG	Fortescue Marsh	10	2034	160		160		200		200	
Roy Hill	HPPL	Fortescue Marsh	5.5	2034	88		88		110		110	
Yandicoogina (including Oxbow and Billiards)	RTIO	Marillana Creek	30	2032	480			480	540			540
West Angelas	RTIO	Central Pilbara	6	2028	84	84			84	84		
Totals					**1536.8**	**156**	**900.8**	**480**	**1772**	**156**	**1076**	**540**

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