7 Collection and analysis of closure data

The following section provides a summary of details on the physical and biological environment at Eastern Ridge mining operations, including:

- local climatic conditions and projected future climate change for the area;
- local physical conditions - topography, geology and hydrogeology, hydrology, seismicity and geotechnical data;
- local and regional information on flora, fauna, ecology, communities and habitats;
- local water resources details – type, location, extent, hydrology, quality, quantity and environmental values (ecological and beneficial uses); and
- soil and waste materials characterisation – soil structure and stability (e.g. erodibility), growth medium type and block modelling of waste materials; solubility, mobility and bioavailability of hazardous materials (e.g. radioactive materials, heavy metals and materials with potential to produce contaminated drainage).

Consistent with the adaptive management approach in the Closure Guidelines (EPA and DMP, 2015), BHP Billiton Iron Ore has commissioned a number of studies to inform relevant considerations during mine closure planning as described in the closure guideline, such as materials characterisation, consideration of contaminant pathways and potential impacts to environmental receptors. The studies and trials are progressive and will be refined over a number of years through stages of testing and field trials, data analysis and implementation planning. This information provides a basis to refine completion criteria and performance indicators for closure monitoring and performance.

The proposed preliminary closure management of Eastern Ridge mining operations is based on understanding the surrounding environment and the outcomes of monitoring and research trials.

7.1 Climate

7.1.1 Existing Climate

The Eastern Ridge mining operations are located in the Pilbara region of WA, which has an arid climate and experiences regular cyclonic activity during November to March. Characteristic climatic features of the region include seasonally low rainfall with high temperatures, high evaporation rates and a high daily temperature range.

Further information can be sourced from the closest operating Bureau of Meteorology (BOM) station at Newman (BOM station number 007176).

7.1.2 Climate change

The current climate change prediction information suggests a wide range of potential scenarios, for example, annual rainfall in 2070 may vary from 1990 by -50 mm to -25 mm. The CSIRO has predicted that the temperature would rise by 1 to 2 degrees by 2030 and from 3 to 4 degrees by 2070 when compared with 1990. Rainfall is anticipated to decrease on the whole overtime with a maximum drop of up to 50mm by 2070 (CSIRO 2013).

7.1.3 Knowledge Gaps

No knowledge gaps have been identified.

7.2 Overburden characteristics

Overburden materials at BHP Billiton Iron Ore sites are characterised at a high level based on their geological, geochemical, and physical characteristics. This characterisation process allows BHP Billiton Iron Ore to identify waste types and manage their disposal appropriately, including segregation and selective disposal of PAF overburden. This approach is consistent with the *Mine Closure and Completion Guideline* (Department of Industry, Tourism and Resources 2006) and *Managing Acid and Metalliferous Drainage Handbook* (Department of Industry, Tourism and Resources, 2007).

7.2.1 Geological overview

The regional geological sequence and stratigraphic descriptions are summarised below in Table 8 below.

The stratigraphic units that will be intersected throughout the Life of Mine and contribute to mine waste are presented within Table 9 below, along with estimated quantities (based on indicative mine planning forecast).

Table 8: Local stratigraphic table for the Eastern Ridge mining operations

Formation	Member	Mineralisation	Stratigraphy	Abbreviation
	Fault Zone Material	Unmineralised	Fault gouge.	F
	Dykes / Sills	Unmineralised	Dolerite.	K
Tertiary Detritals	Surface Scree	Mineralised		SZ
	TD3	Mineralised	Most recent detrital materials (Pliocene age).	TD3
	TD2	Mineralised	CIDs and clays.	TD2
	TD1	Mineralised	Hematite siltstone and conglomerate	TD1
Boolgeeda Iron Formation		Unmineralised	Three units of a lower shaley BIF, a middle BIF with minor shales and an upper unit of mainly interbedded BIF and shale.	HO
Woongarra Volcanics		Unmineralised	A lower rhyolite, a median unit comprising BIF, dolerite and shale, and an upper rhyolite.	HW
Weeli Wolli Formation (WW)	Weeli Wolli Dolerite	Unmineralised	Intruding dolerite sills.	HE
	Weeli Wolli Iron	Mineralised	Alternating sequence of BIF, shaley BIF and shale.	HJ
Brockman Iron Formation	Yandicoogina Shale	Mineralised	Sequence of inter-bedded chert and shale.	Y
	Joffre Member	Mineralised	Planar-bedded to poddy BIF with only minor shale interbeds.	J
	Whaleback Shale	Mineralised	Upper zone of meso-bands of chert and shale and a lower zone of alternating macro-bands of shale and BIF.	W
	Dales Gorge Member	Mineralised	Planar bedded assemblage of alternating BIF and shale macro-bands.	D
Mt McRae Shale		Mineralised	Alternating BIF with shales, dolomitic shales, carbonaceous shales and chert.	R
Mt Sylvia Formation		Mineralised	Three prominent BIF / chert units separated by inter-bedded cherts and shales.	S
Wittenoom Formation	Bee Gorge Member	Unmineralised	Alternating beds of turbiditic calcareous shales with minor cherts, volcanoclastics and BIF. The lower member is more shaley.	OD
	Shaley Bee Gorge Member	Unmineralised		OC
	Paraburdoo	Unmineralised	Dolomite with minor chert bands	OB
	West Angela 2	Mineralised	Shale, dolomite and dolomite shales. May show minor mineralisation.	WA2
	West Angela 1	Mineralised	Shale and banded iron formation (BIF).	WA1
Marra Mamba Iron Formation (M)	Mount Newman Member N3	Mineralised	Podded BIF with interbedded carbonates and shales.	MN - N3
	Mount Newman Member N2	Mineralised	Podded BIF with interbedded carbonates and shales.	MN - N2
	Mount Newman Member N1	Mineralised	Podded BIF with interbedded carbonates and shales.	MN - N1
	MacLeod Member	Mineralised	Shale and banded iron formation (BIF).	MM
	Nammuldi member	Mineralised	Chert rich shales and banded iron formation (BIF).	MU
Jeerinah Formation (JN)	Undifferentiated Shale	Unmineralised	Shales.	NX
	Undifferentiated Dolerite	Unmineralised	Dolerites.	XX or JNE

Table 9: Waste material to be removed from Eastern Ridge mining operations (above and below the pre-mining water table) by stratigraphy Note: Grey indicates contribution to waste balance for each deposit.

Stratigraphic Unit Abbreviation	Waste Quantity (% of total waste)								
	OB23	OB25 P1	OB25 P3	OB25 P4	OB24E AWT	OB24E BWT	OB25W Joffre AWT	OB25W Joffre BWT, D1, D2, D3, D4)	OB32E (AWT)
K	7%	0%	0%	0%	0%	0%	0%	0%	0%
SZ	29%	0%	31%	0%	0%	0%	6%	3%	0%
Z	4%	0%	0%	0%	0%	0%	0%	0%	0%
TD3	0%	0%	0%	0%	0%	0%	8%	1%	11%
TD2	0%	0%	0%	0%	0%	0%	5%	1%	22%
HE	0%	0%	0%	0%	0%	0%	3%	0%	0%
Y	0%	2%	2%	0%	0%	0%	14%	6%	0%
J6	0%	10%	5%	0%	0%	0%	21%	6%	0%
J5	0%	0%	3%	0%	0%	0%	4%	2%	0%
J4	0%	1%	0%	0%	0%	0%	3%	0%	0%
J3	0%	2%	0%	0%	0%	0%	7%	0%	0%
J2	0%	16%	2%	4%	0%	0%	19%	0%	0%
J1	0%	8%	0%	2%	0%	0%	6%	3%	0%
WU	0%	9%	1%	0%	0%	0%	0%	0%	0%
W	1%	0%	0%	16%	9%	0%	2%	21%	0%
D4	22%	19%	5%	36%	22%	3%	0%	25%	0%
D3	22%	18%	7%	27%	34%	14%	0%	15%	0%
D2	4%	12%	12%	15%	18%	5%	0%	9%	0%
D1	2%	2%	5%	0%	13%	57%	0%	5%	0%
RU	4%	0%	5%	0%	2%	19%	0%	1%	0%
RN	4%	0%	10%	0%	0%	1%	0%	0%	0%
S7	0%	0%	0%	0%	0%	0%	0%	0%	0%
S	0%	0%	10%	0%	0%	0%	0%	0%	0%
OB	0%	0%	0%	0%	0%	0%	0%	0%	2%
WA2	0%	0%	0%	0%	0%	0%	0%	0%	9%
WA1	0%	0%	0%	0%	0%	0%	0%	0%	11%
N3	0%	0%	0%	0%	0%	0%	0%	0%	10%
N2	0%	0%	0%	0%	0%	0%	0%	0%	15%
N1	0%	0%	0%	0%	0%	0%	0%	0%	10%
MM	0%	0%	0%	0%	0%	0%	0%	0%	10%
MU	0%	0%	0%	0%	0%	0%	3%	0%	0%
UN	1%	1%	0%	0%	0%	0%	0%	0%	0%
Total %	100%	100%	100%	100%	100%	100%	100%	100%	100%

7.2.1.1 Regional Stratigraphy

The Pilbara region comprises a portion of the ancient continental Western Shield that dominates the geology of WA. The Western Shield is comprised of pre-Cambrian, Proterozoic and Archaean rocks. The Pilbara Craton dates back to the Archaean, and includes some of the oldest rocks in the world. It is overlain by Proterozoic rocks deposited in the Hamersley and Bangemall Basins. The Eastern Ridge mining operations are located within the Hamersley Basin, which comprises the Fortescue Group (mafic- volcanics), Hamersley Group (Banded Iron Formation or BIF) and the Turee Creek Group of clastic meta-sediments (Figure 6).

Stratigraphy across Eastern Ridge is mainly of the Hamersley Group (~2,630 to 2,450 Ma) which is a 2.5 km thick sequence of predominantly deep water sediments with lesser turbidites and intrusives. Lithologies include BIF, hemipelagic shales, dolomite, chert, tuff and turbiditic volcanics. Since deposition, the Hamersley Group has undergone significant structural and geochemical alteration.

Situated adjacent to the Eastern Ridge mining operations is a broad, deeply incised alluvial palaeovalley that extends south of Orebody 25 and south and northeast of Orebody 23. The palaeovalley has been infilled with Tertiary to Recent alluvial sediments up to 90 metre (m) thick, comprising predominantly gravels, silts, clays, detritals and some zones of calcrete.

7.2.1.2 Orebody 23 Geology

Orebody 23 extends over an approximate 600 m strike length in the Dales Gorge Member of the Brockman Iron Formation on the north limb of a major vertically dipping anticline. The deposit is bounded to the east and west by splays of the Fortescue River Fault zone and to the north and west by dolerite dykes intruded along a north-northwest–trending strike slip fault within the Whaleback Shale Member of the Brockman Iron Formation. To the south, the Dales Gorge Member is conformably underlain by Mount McRae Shale and unconformably overlain by the palaeovalley alluvial sediments.

7.2.1.3 Orebody 24 Geology

The main Orebody 24 range consists primarily of outcropping Brockman Iron Formation. To the south the Dales Gorge Member is conformably underlain by the Mount McRae Shale and the Mount Sylvia Formation. Dolerite and BIF of the Weeli Wolli Formation occur to the north of Orebody 24.

Detrital cover is thin at Orebody 24 consisting usually of <1m of scree. There is deeper cover to the south and north of the deposit.

Orebody 24 has a moderate level of structural complexity in comparison to other Eastern Ridge and Homestead orebodies. The folding style is similar to Orebody 25, having a major role in the development of structures at Orebody 24.

The Orebody 24 is characterised by tight, sometimes isoclinal, anticline-syncline pairs with a north verging axial plane, attributed to the folding. Wavelength is between 100m to 1 km on average, with folding of bedding on the metre scale imitating the shape of the larger scale folding.

Well-described regional faulting occurs in close proximity to Orebody 24. The Whaleback Fault runs along an ENE-WSW strike to the south (Kneeshaw, 2008). The Whaleback Fault is a steep angled normal fault with around 1km vertical displacement. The Fortescue River Fault truncates the stratigraphy and Whaleback Fault east of Orebody 24, separating it from Orebody 23.

Acidic intrusions are well documented in mapping in close proximity to the Fortescue River Fault (e.g. Jones et. al, 1973; Zivkovic, 2014).

7.2.1.4 Orebody 25 Geology

The Orebody 25 area is structurally dominated by a large anticline, with Pit 1 developed in the south limb and anticline crest and Pit 3 in the overturned north limb (Kneeshaw, 2008). The majority of ore at Orebody 25 occurs in the Dales Gorge Member. Overlying the Dales Gorge Member is the Whaleback Shale Member, which, in turn, is overlain by the mineralised Joffre Member. To the south, the Dales Gorge Member is conformably underlain by the Mt McRae Shale and the Mt Sylvia Formation, which have been unconformably overlain by alluvial sediments.

7.2.1.5 Orebody 25 West Geology

Orebody 25 West forms a major east-west trending ridge that rises approximately 60m above the flats located to the north and south. The Orebody 25 West deposit geology comprises members of the Brockman Iron Formation (Yandicoogina Shale Member through to the Dales Gorge Member), the Mount McRae Shale, Mount Sylvia Formation, and the Wittenoom Formation (Bee Gorge Member). To the north, the Weeli Wolli Formation and Wongarra Rhyolite are also present. Tertiary Detrital cover overlies bedrock sequences off the ridge to the south and the north, however, the majority of the Orebody 25 West area is confined to the ridge itself. Orebody 25 West is structurally complex; the stratigraphy is overturned in places, tightly folded and faulted. The folding and faults are considered consistent with features along strike at Orebody 25 that have been truncated by the Whaleback Fault.

There are two proposed pits which are to be mined below the water table, here referenced as the Joffre and Dales 3 Pits.

The Joffre pit is located in the northern area of Orebody 25 West within a fault block bounded by a southerly-dipping thrust fault to the south and the Whaleback Fault to the north. The thrust fault places steeply to vertically dipping un-mineralised Dales Gorge Member units on top of overturned southerly-dipping mineralised Joffre units. The Whaleback normal fault dips approximately 45º to the south and has significant displacement where southerly-dipping Yandicoogina Shale Member of the Brockman Iron Formation has been downthrown onto older vertically-dipping Jeerinah Formation. Further to the north, the geology is stratigraphically continuous with the Marra Mamba Iron Formation and Wittenoom Formation present. Mineralisation is concentrated within the J6 and J3J5 units of the Joffre Member of the Brockman Formation.

The Dales 3 Pit is located in the western area of Orebody 25 West. Mineralisation is concentrated within the Dales Gorge Member and spans two fault blocks displaced by normal faulting. The southerly fault block has been downthrown approximately 40 m to the south, with bedding approximately horizontal in the vicinity of the proposed pit. In the northern fault block, the proposed pit is located on the downthrown side of the Whaleback Fault which truncates the southerly normal fault at depth and places Mount Sylvia, Mount McRae and Brockman Formation on top of vertically-dipping Jeerinah and Marra Mamba Formation stratigraphy. The base of the pit in the northerly fault block is generally co-incident with the Mt McRae / Dales Gorge boundary which dips approximately 45˚ to the north, towards the Whaleback Fault.

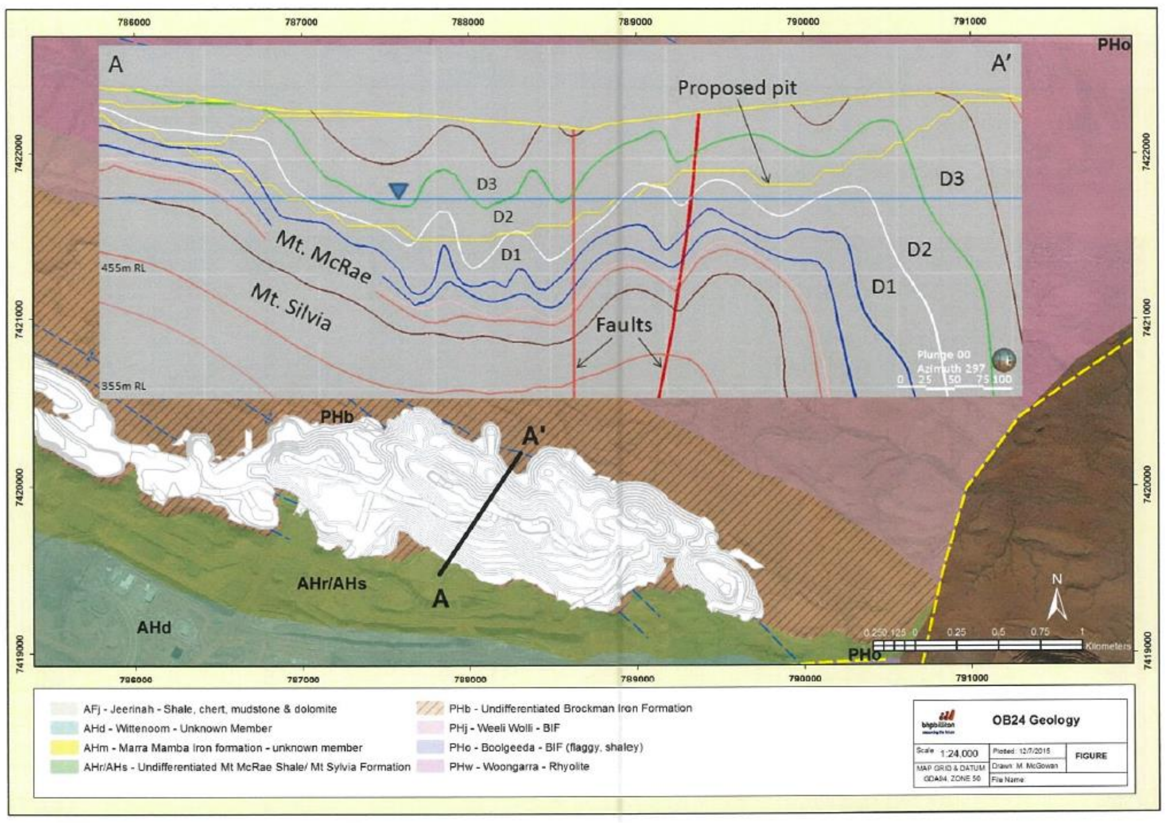
7.2.1.6 Orebody 25 West Geology

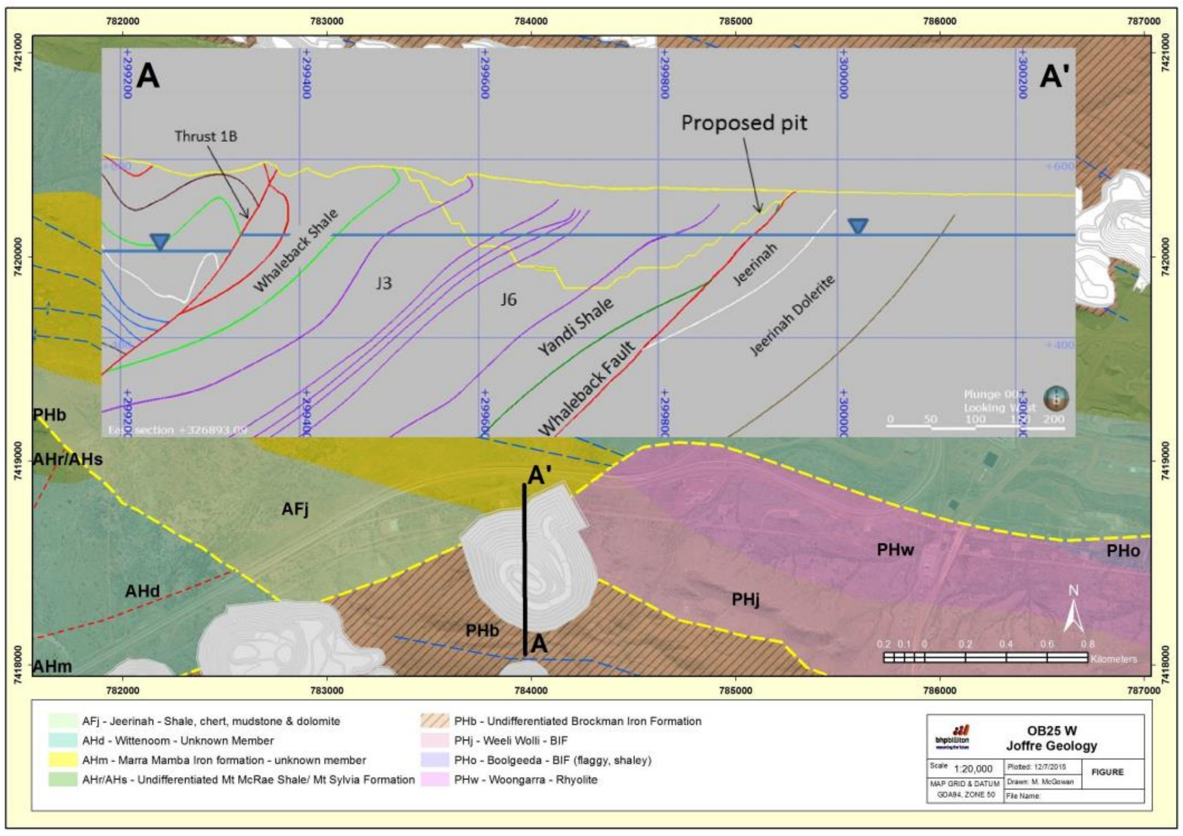
Overall, Orebody 32 is considered to be structurally complex. A major west-northwest/east-southeast trending normal fault, named Ali's Fault, dissects the central section of Orebody 32. Ali's fault separates a normal sequence of Marra Mamba Iron Formation to the south and an overturned recumbent fold of Marra Mamba Iron Formation with the Paraburdoo Dolomite at its core to the north.

At Orebody 32 the hardcap sequence was characterised by an increase in vitreous goethite and the presence of vugs and cavities. The average depth of the hardcap zone was 30 m below the ground level and the average thickness was 13 m. The hardcap zone is found deeper to the north of Orebody 32 where it is overlain by a thick sequence of tertiary detritals.

Mineralisation at Orebody 32 occurs within the N1, N2 and N3 units of the Mt Newman Member, with the highest grades found in the N1 and N3 units. Mineralisation was also found in some places within the MacLeod Member, the lower West Angeles Member and the Nammuldi Member. Thickness of enrichment was found to be variable throughout the deposit.

Three units of tertiary detritals occur at Orebody 32 East (TD1, TD2 and TD3). The detritals mostly occur on the flat plains in the northern, southern and eastern sections of the deposit around the edge of the outcropping Marra Mamba Iron Formation. The detrital sequence extends up to 60 m depth in the south and east of the area and has an average thickness of 15 m.





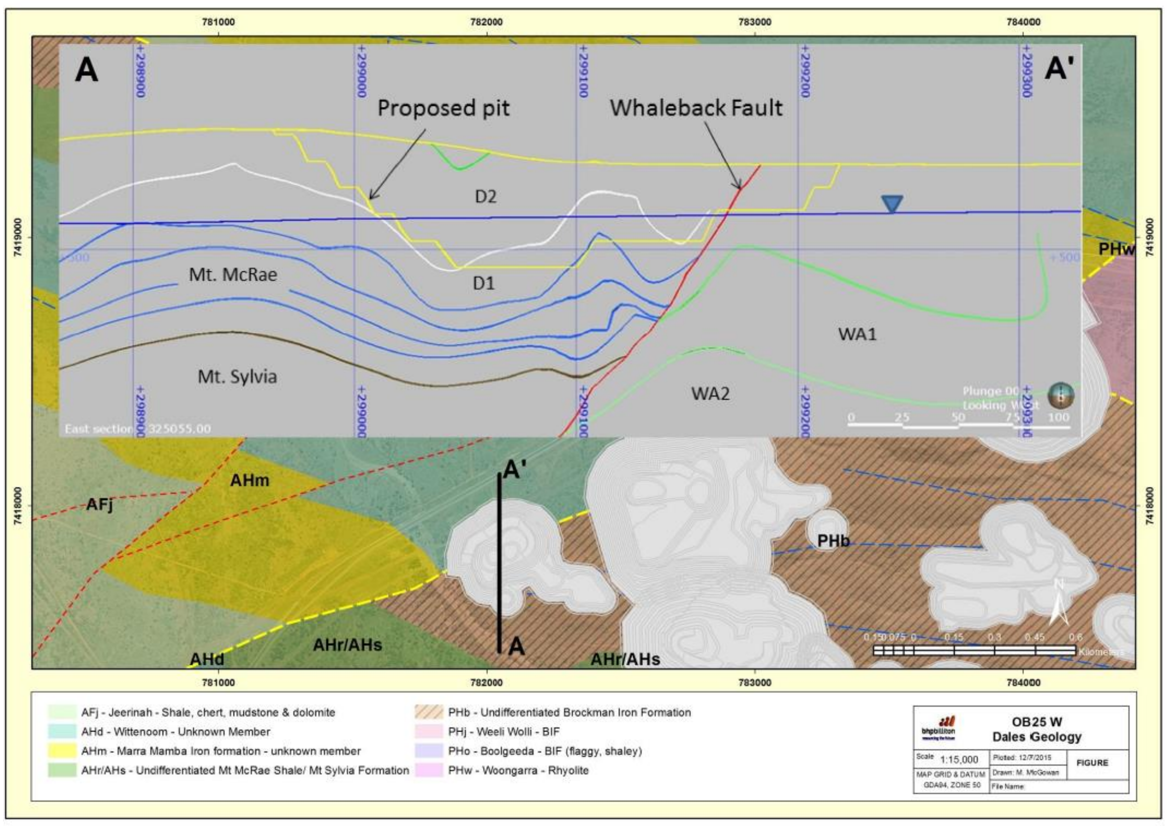


Figure 6: Orebody 24, 25 West geology (as adapted from BHP Billiton Iron Ore, 2015e)

7.2.2 Volume and availability

Table 10 lists the estimated total quantity of overburden at the Eastern Ridge mining operations.

Table 10 Overburden balance at Eastern Ridge mining operations

Schedule/Balance Element Site Overburden Balance)	Estimated Total Quantity (million bcm)
Current overburden volume	114
Total overburden [predicted at LOM] remaining in pits	102.1
Backfill requirements OB23	6
Backfill requirements OB25P3	39
Backfill requirements OB25P1	2.8
Total backfilling requirement	47.8
Surplus overburden post-backfill	**168.3**

Management of overburden surplus is addressed in Section 8.4.4.

7.2.3 Acid and Metalliferous Drainage Geochemistry

BHP Billiton Iron Ore has developed procedures for classifying of PAF material that can be a contributing source of AMD. BHP Billiton Iron Ore classifies material according to the sulfur (S) content, stratigraphy, degree of oxidation, and other geochemical testing to characterise potential acid generation or metals release.

In accordance with the WAIO AMD Management Standard, AMD Risk Assessments were undertaken in 2014 and 2015 by SRK for the Eastern Ridge deposits, which addressed both current and proposed future mining operations. Assessments were completed for Orebody 23/25, Orebody 24 Below Water Table mining, Orebody 25 Above and Below Water Table Mining and Orebody 32 (SRK 2015a, b, c, d). These assessments are provided at Appendix C. This assessment incorporated information supplied by BHP Billiton Iron Ore, including: geochemical characterisation of geological materials, geological and mine planning data, and findings of surface water, groundwater and ecological studies.

For the purposes of the Preliminary AMD Assessment, material was classed as potentially acid forming (PAF) based on a sulfur threshold approach, irrespective of the material lithology or weathering state. Materials with total sulfur content above the threshold are considered to be PAF. The sulfur cut-off approach is considered to be conservative as this approach allows no credit for neutralising potential that may be present within the materials. Two sulfur thresholds have been assessed: 0.1 and 0.2%wt sulfur.

Potential sources of PAF were assessed within:

- overburden/waste
- wall rock, and
- ore stockpiles (including high-grade, low-grade/blend grade ore)

The findings of the AMD Risk Assessment are summarised Table 11 and Table 12.

Table 11Table 11: Summary of AMD Risk Assessment findings at Eastern Ridge mining operation

Orebody	Orebody 23	Orebody 24 East	Orebody 25 Pit 3	Orebody 25 Pit 4	Orebody 25 Pit 1	Orebody 25 West	Orebody 32E[5]
Ore Type	Brockman	Brockman	Brockman	Brockman	Brockman	Brockman	Marra Mamba
Current Status	–Mining Complete –On-going groundwater abstraction	–Mining AWT –Proposed BWT mining –Proposed dewatering	–Current Mining –Active dewatering	– Current Mining – No dewatering	–Current Mining –Active dewatering	– Proposed mining –Proposed dewatering	– Proposed mining
AMD Assessment[1]	–Low potential for AMD from OSAs –Low to negligible potential for AMD from ore stockpiles –Low potential for AMD from pit wall run-off – Pitwall PAF material forms isolated hotspots, mostly on the southern wall.	Potentially 1.5 Mt of PAF waste material at base of the pits	–Low potential for AMD from pit wall runoff –Low to negligible potential for AMD from ore stockpiles –Low potential for AMD from OSA's –PAF pitwall exposure is concentrated on or near the pit floor, with isolated hot spots near the pit crests.	–Very low potential for AMD from OSAs –Negligible potential for AMD from ore stockpiles –Low potential for AMD from pit wall run-off	–Very low potential for AMD from OSAs –Negligible potential for AMD from ore stockpiles –Low potential for AMD from pit wall run-off	–Low to negligible potential for AMD from OSA's –Negligible potential for AMD from ore stockpiles –Low potential for AMD from put wall run-off	–Low potential for AMD from OSAs –Low potential for AMD from ore stockpiles –Low potential for AMD from pit wall run-off
Key PAF Lithologies [1,3]	–Surface Scree –Colonial Chert –McRae Shale	– Joffre Member – McRae Shale – Mt Sylvia Formation	–Surface Scree –Joffre Member –Whaleback Shale – Dales Gorge (D2, D3, D4) –Colonial Chert –Mt McRae Shale –Mt Sylvia	– Joffre Member (J1) –Whaleback Shale – Dales Gorge (D4)	– Whaleback Shale –Dales Gorge (D2, D3, D4)	–Tertiary Detritals – Yandicoogina Shale –Joffre Member –Whaleback Shale –Dales Gorge Member	–Tertiary Detritals
ANC Lithologies [3]	Tertiary Sediments	None Identified	Surface Scree	None Identified	None Identified	Tertiary Detritals	None Identified
PAF Waste (tonnes) [2, 4]	~0.05 to 0.21MT or 0.4%-1.7% (23,630-100,430 m^3)	~0.8MT to 1.5MT or 0.6-1.2% AWT ~(355,449 to 710,898 m^3) 0.08MT- 0.11MT or 1.4%-2% BWT (37,237 to 53,196 m^3)	~0.5MT to .1.1MT or 2.5% to 5.9% (218,029 to 514,548 m^3)	~ 0.33MT to 0.78MT or 0.5% to 1.2% (155,631 to 373,514 m^3)	~0.32MT to 1.2MT or 0.4% to 1.5% (152,324 to 571,214 m^3)	~4,500-12,500 tonnes or 0.02-0.07% Phase 1 (Joffre AWT) 22,.300 tonnes (based on 0.1% S) (no PAF using 0.2% S) or 0.7% volume (10,600 m^3) (Phase 2 (Joffre BWT, sub-pits D1, D2, D3, D4) -	7,600 tonnes or 0.7% of waste volume (3,626 m3) (based on 0.1% S threshold; no PAF using 0.2% S threshold)
PAF material exposed in wall rock at closure [2]	~850-3,000m² or 0.3-1.1%	~54,000-74,000m² or 1.9-2.6% (AWT and BWT)	~4,000-47,000m² or 0.3% to 3.2%	~9,000-32,000m² or 0.5-1.8%		~600-1,300m² or 0.2-0.4% exposed. Joffre AWT: 1,600-6,500 m^2 or 0.11 to 0.45% exposed Joffre BWT, sub-pits D1, D2, D3, D4) -	No exposed PAF identified using 0.1 or 0.2% S thresholds (Limited sampling density to date)
Pathways	–OSAs/stockpiles seepage –Surface run-off –Percolation into groundwater	–OSAs/stockpiles seepage –Surface run-off –Percolation into groundwater	–OSAs/stockpiles seepage –Surface run-off –Percolation into groundwater	–OSAs/stockpiles seepage –Surface run-off –Percolation into groundwater	–OSAs/stockpiles seepage –Surface run-off –Percolation into groundwater	–OSAs/stockpiles seepage –Surface run-off –Percolation into groundwater	–OSAs/stockpiles seepage – –Percolation into groundwater
Receptors	– Fortescue River – Ethel Gorge – Homestead Creek – Ophthalmia Dam – Newman Water Reserve and associated bore fields	– Fortescue River – Ethel Gorge – Homestead Creek – Ophthalmia Dam – Newman Water Reserve and associated bore fields	– Fortescue River – Ethel Gorge – Homestead Creek – Ophthalmia Dam – Newman Water Reserve and associated bore fields	– Fortescue River – Ethel Gorge – Homestead Creek – Ophthalmia Dam – Newman Water Reserve and associated bore fields	– Fortescue River – Ethel Gorge – Homestead Creek – Ophthalmia Dam – Newman Water Reserve and associated borefields	– Fortescue River – Ethel Gorge – Homestead Creek – Ophthalmia Dam – Newman Water Reserve and associated bore fields	– Fortescue River – Ethel Gorge – Homestead Creek – Ophthalmia Dam – Newman Water Reserve and associated bore fields

Notes:
[1] : based on SRK preliminary AMD Risk Assessments
[2] : range based on 0.1% S cut off to 0.2% sulfur cut off
[3] detailed acid-base accounting suggests that in the case of Surface Scree, because significant ANC can be present, some of the high sulfur material may be non-acid forming (NAF). It should be noted that materials with sulfidic sulfur combined with significant ANC, though not likely to generate acid conditions, may generate saline drainage.
[4] : Density of 2.1 t/m^3 has been used to calculate tonnages from volumes (m^3)
[5] The dataset assessed was limited (based on 100m x 200m drillhole spacing)

7.2.3.1 Geochemical Characterisation

Since 2012, over 200 samples have been collected from 14 lithological units from Orebody 23, Orebody 25 Pit 3, and Orebody 25 West. The samples have undergone a first phase of static geochemical tests. The data generated from the current waste geochemical characterisation programme has been interpreted by SRK Consulting and can be summarised as follows (SRK 2015e).

- The majority of samples (193) contained low to negligible total sulfur (<0.05%). Samples with higher total sulfur (between 0.1% and 10.5%) were from the Dykes/Sills, Mt McRae Shale, Surface Scree and Wittenoom lithologies. The highest sulfur content was a Mt McRae Shale sample from a drill-hole located along the Orebody 23 access ramp. Where significant sulfur was present, the sulfur speciation was dominated by sulfide sulfur.
- The acid neutralising capacity (ANC) was generally low (<10 kgH_2SO_4/t). Samples that contained high ANC (>100 kgH_2SO_4/t) were from the Mount Sylvia (S), Surface Scree (SZ), Wittenoom (OB, OD) and Tertiary Sediment (T) lithologies.
- Using the AMIRA classification scheme, most samples were classed as non-acid forming (NAF). Potentially acid forming (PAF) classed samples were identified in the surface scree (SZ), Colonial Chert (D1), Mt McRae Shale units (R, RU, RN), Dykes/Sills (K) and Wittenoom (OB, OD) units.
- Trace elements that were enriched with respect to crustal averages in one or more samples were Ag, As, Bi, Cd, Fe, Mn, Mo, Re, S, Sb, Se, Te and W. Of these, only Fe and Se were detected in leach testing. Generally leach testing gave circum neutral leachates and the majority of trace elements leached at concentrations that were close to or below detection limits. Acidic leachates (pH 3.5 to 4.2) were observed for two Dykes/Sills samples and one Mt McRae Shale sample.
- Material from the Dales Gorge and Joffre lithological groups pose a low risk of AMD and are most likely to be geochemically ‘inert’, i.e. samples were NAF and leached low/negligible concentrations of major and trace elements. Mt McRae Shale and Surface Scree material may not be completely ‘inert’ in that these materials appear more likely to generate saline drainage than other materials tested.

Summary statistics obtained for the SRK programme (Orebody 23 and Orebody 25 samples) gave good agreement with data generated from an earlier GHD investigation of over 250 samples from Orebody 24 (GHD, 2013). This would suggest that within the Eastern Ridge area, samples from equivalent lithologies may have similar geochemical properties.

The current geochemical characterisation programme is ongoing and includes:

- additional samples from Orebody 23, Orebody 24 Orebody 25 Pit 3, and Orebody 25 West as well as Orebody 32;
- carbon-speciation test work – to determine proportion of carbon present in an organic and/or inorganic form and provide insights into the nature of minerals contributing to the ANC;
- acid-buffering characteristic curves – to provide insights into the percentage of ANC that is readily available to neutralise acidity;
- mineralogical assessment (quantitative X-ray diffraction) – to determine the mineralogical composition of samples;
- supplemental leach tests – to examine leaching behaviour of metals and other solutes under a wider range of geochemical conditions;
- kinetic testing using AMIRA free draining columns – to provide data about the rates of acid generation, acid neutralisation and metal release; and
- saturated column test work – to provide data about the leaching potential of materials that could be used as backfill below the water table in mined out voids.

The results of this work continue to inform the refinement of closure management strategies for the Eastern Ridge mining operations. Assessment of AMD risk associated with mine voids post closure is provided in Section 7.8.3.2

7.2.4 Physical characteristics

As discussed in Section 7.2.1, the deposits located at the Eastern Ridge mining operations can be differentiated into two different geological formations, named the Brockman and Marra Mamba formations after their dominant geologies. Within these formations materials are broadly defined in terms of geological stratigraphic units. The proportion of the waste component associated with the different formations and detailed in Table 12.

Management of overburden physical characteristics is addressed in Section 8.4.1.

Table 12: Waste proportions Marra Mamba and Brockman

Deposit*	Total Waste Volume (Mm3)	Proportion of Eastern Ridge Total Waste	Marra Mamba proportion (%)	Brockman proportion (%)
Orebody 23	7.4	3%	0%	100%
Orebody 24	95.5	44%	0%	100%
Orebody 25	84.7	39%	0%	100%
Orebody 25 Pit 3	4.7	5%	0%	100%
Orebody 25 West	16.7	8%	0%	100%
Orebody 32 AWT	12	6%	100%	0%
TOTAL	**216.3**	**100%**		

*includes historically mined and future waste estimates

Material characterisation and field trials have been undertaken on waste types from both the Marra Mamba and Brockman formations and the associated stratigraphic units to further understand the erosion characteristics (Landloch 2013).

Analysis has included physical modelling including rainfall simulation and overland flow undertaken within laboratory conditions using predicted rainfall events based on local rainfall data. Laboratory methods including rainfall simulation and overland flow over a range of gradients have been undertaken resulting in quantification of:

- Interrill erodibility (Ki).
- Rill erodibility (KR)
- Critical Shear (tc)
- Effective Hydraulic conductivity (Ke)

The data has then been used in numerical modelling to assess how well a specific waste rock type (or blends of waste types) behaves under surface flow conditions. Numerical modelling tools of Water Erosion Prediction Project (WEPP) model and SIBERIA landform evolution model and the Revised Universal Soil Loss Equation (RUSLE) have been used.

Outcomes of the tests show variability in the parameters derived as illustrated in Figure 7.

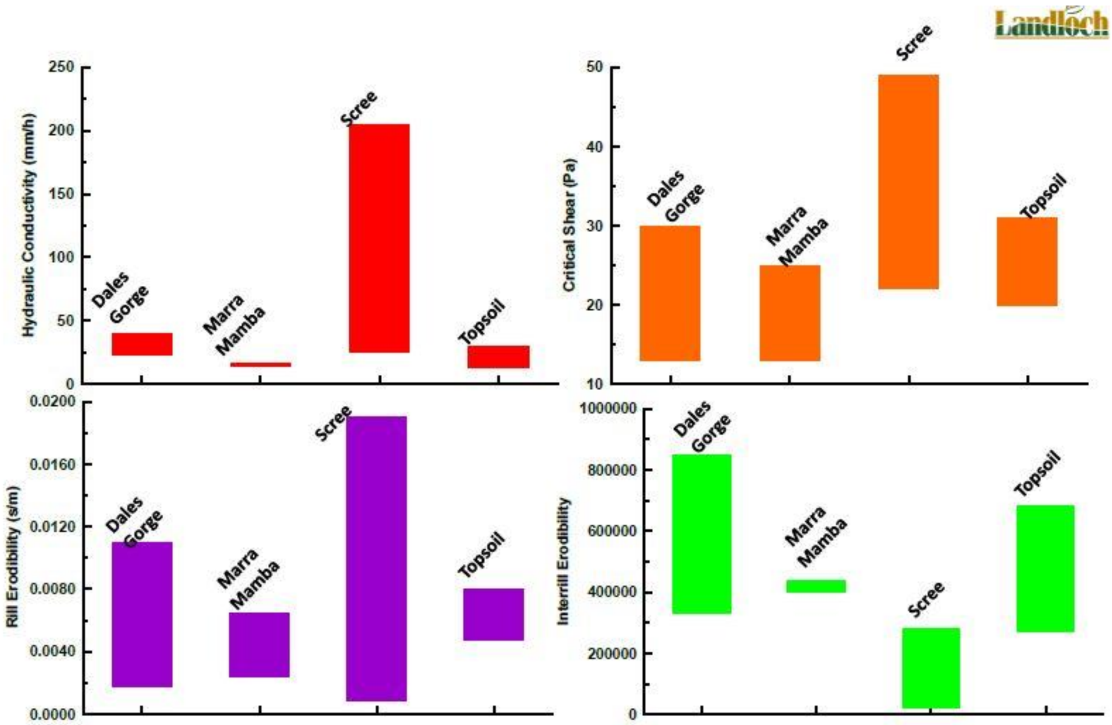


Figure 7: Variability in WEPP erodibility parameters for wastes and soils BHP Billiton Iron Ore Operations

In addition, field erosion trials located at other BHP Billiton Iron Ore sites (Mining Area C) are being used to collect data and calibrate the WEPP model predictions. The field trials will run for a number of years. Preliminary assessment of the existing data shows that WEPP is predicting runoff satisfactorily and reasonable agreement exists between measured and predicted cumulative erosion rates (Landloch, 2014).

SIBERIA modelling has analysed the performance of alternative landform design options including:

- Design profiles (linear slopes, concave slopes and bench and berm designs);
- Landform heights and angles; and
- Waste types including mixes (i.e. rockier material, growth media).

Outcomes of modelling corroborate that erosion is a function of the rock size distribution (well graded), slope grade and height. The application of concave slopes and augmentation of addition rock percentage to poorer performing waste material both successfully increased performance.

Marra Mamba Deposits

The major stratigraphic units that present the vast majority of the Marra Mamba style deposits can be broadly classified as Detrital, Mount Newman and West Angela waste materials.

Work to date has identified that the majority of the wastes associated with the Marra Mamba deposits, need to be considered highly erodible, therefore particular attention to the OSA design and construction techniques used to provide a stable landform will need specific management.

However, there can be a high degree of variability between material from similarly classified geological units from other locations.

Detritals can contain high proportions of clay rich materials or high levels of coarse fragments, significantly altering their response to erosive forces.

Orebody 32 introduces a Marra Mamba operation to the Eastern Ridge mining operations.

Brockman Deposits

The Brockman deposits contain high proportions of Dales Gorge and Joffre materials. The material characterisation work associated with the Brockman waste types has shown that the material is significantly less susceptible to surface erosion than the Marra Mamba materials. Opportunities exist to stabilise the exterior surfaces of the Marra Mamba OSA's to through combination with more competent waste types.

Orebodies 23, 25 and 25 West are all Brockman deposits.

Eastern Ridge mining operations landform assessments

Specific assessment have been undertaken for landform design at Eastern Ridge mining operations, analysing the currently available surface materials (mine waste samples on OSA outer surfaces and blends) that could potentially be used to create erosion resistant landforms (Landloch 2015, a,b). Materials were selected with preliminary screening for suitability through measuring rock content by screening, followed by analysis for chemical and physical properties, to evaluate erosion resistance and growth media suitability.

Analysis provides the required data to enable erosion resistant landforms to be created during the planned rehabilitation of Orebody 25 North West OSA and North OSA through optimising waste characterisation with slope profiles.

Management of overburden physical characteristics is addressed in Section 8.4.4.

7.2.5 Knowledge Gaps

The following knowledge gaps which have impacts on closure outcomes have been identified:

Geology:

- Limited geological data available for Orebody 32.

Acid and Metalliferous Drainage:

- Geochemical data gaps exist relating to understanding variability in material properties to improve confidence in predictions regarding the behaviour of waste rock and pit wall rock, and provide a basis for waste management designs.
- Fate of potential AMD in the context of regional flows.

Physical waste characteristics:

- The performance of final landform over design life is yet to be confirmed through 3D landform evolution modelling (SIBERIA) once the detailed design has been completed.
- Detailed closure landform designs (integrating all domains) to be developed based on outcomes of technical studies and assessments when there is less than two years to closure.
- Undertake further waste characterisation, modelling and analysis to refine the Waste Class classification and landform design on an ongoing basis.

Volume and availability of waste will be refined on an ongoing basis, as the mine plan is updated.

7.3 Slope stability and seismicity

A probabilistic seismic hazard assessment was conducted on selected BHP Billiton Iron Ore operations in the Pilbara in early 2012 (Meynink Engineering Consultants 2012). The assessment was based on area seismic sources as no evidence of recent fault activity was recognised close to the BHP Billiton Iron Ore operations in the Pilbara during the preliminary neotectonic observations. The observations show that an inferred segmented fault system appears to run across the site; however, there is no indication of recent fault activity. In the Australian context, the Peak Ground Acceleration values estimated from this study correspond to a low to moderate seismic hazard.

A preliminary assessment of slope stability to inform requirements of abandonment bunds has been undertaken. Areas that may require abandonment bunds include Orebody 25 Pit 3 northern wall, Orebody 25 Pit 1, Orebody 32 pit and the proposed Orebody 25 West Pits.

7.3.1 Knowledge Gaps

The following knowledge gaps which have impacts on closure outcomes have been identified:

- Detailed slope stability analysis to inform final abandonment bunds location for pit faces and mine pits remaining post closure.

7.4 Soil characteristics

A review of the soil profiles at the Eastern Ridge mining operations (Biota, 2001) found that the main soil types included skeletal soils and exposed rock on the ridges and hills, gravelly loams and skeletal soils on the scree slopes and sands and gravels in the drainage lines. The salinity of the soils was generally low with slightly higher values recorded in the subsoil of samples taken in the vicinity of Homestead Creek. The soil pH ranged from slightly acidic to slightly alkaline with alkalinity increasing with soil depth. While the organic carbon content and total nitrogen was low in all of the samples taken, these values are typical of the low-nutrient soils of the Pilbara, and are consistent with other studies conducted in the area.

In December 2013, BHP Billiton Iron Ore conducted a review of the soil requirements for mine closure against existing stockpiles. The review concluded that the Eastern Ridge mine site requires approximately 986,000 m^3 of soil for closure. Excluding all transport areas (haul roads, tracks etc.), the deficit has been estimated at approximately 530,000 m^3. A high-level topsoil balance based on the current life of mine plan is provided in Table 13 below.

Table 13 Eastern Ridge mining operations topsoil balance

Topsoil component	Volume (m3) x 1000
Current topsoil stockpiles	456[5]
Topsoil requirements for current open footprint	986[6]
Deficit based on current stockpiles	539

The suitability of soils at the Eastern Ridge mining operations and other BHP Billiton Iron Ore sites as growth media during rehabilitation has been assessed as part of the WAIO Growth Media Atlas. This involved testing potential growth media material along with analogue material for chemical, fertility and physical analytes. The collation of this data forms the basis for the WAIO Growth Media Atlas.

The WAIO Growth Media Atlas will inform rehabilitation planning. As new areas are identified for rehabilitation and more soil samples are collected, the Growth Media Atlas will continue to develop and expand. Reviewing the plant nutrition potential and structural attributes of specific growth media material compared to nearby analogue systems is used to inform rehabilitation planning and identify occasions where soil ameliorants or fertilisers may be required.

Management of Soils is addressed in Section 8.4.4.

7.4.1 Knowledge gaps

The following knowledge gaps which have impacts on closure outcomes have been identified:

[5] Last measured December, 2014

[6] Last measured December, 2013

- Limited information available on baseline soil mapping and descriptions which the Growth Media Atlas will continue to address and provide inputs to rehabilitation planning

7.5 Land systems

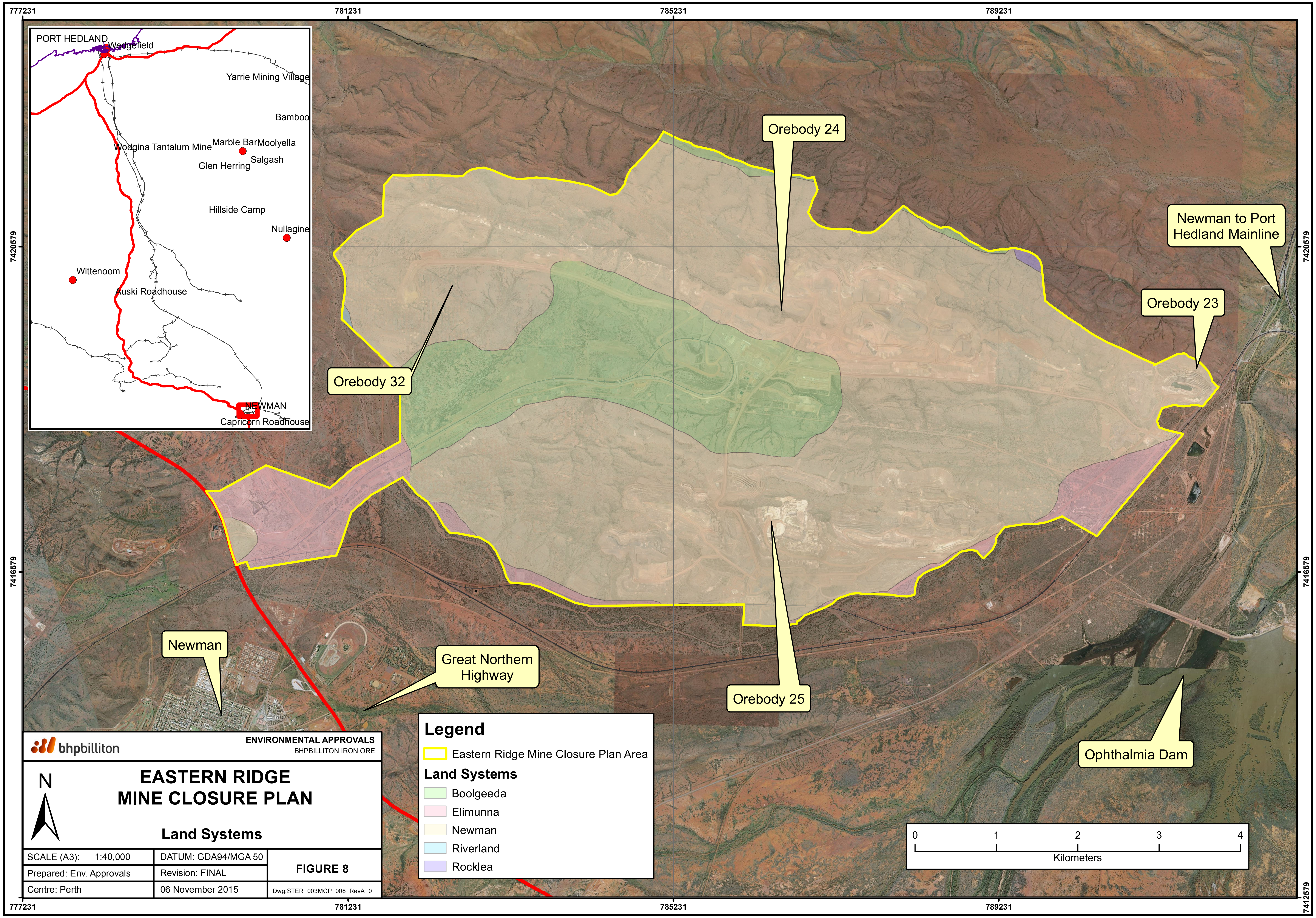
Land systems across much of the grazing and pastoral lands of WA were surveyed, described and categorised during a series of surveys conducted by the Department of Agriculture. The Project lies within the Pilbara Region, which was surveyed in the period between 1995 and 1999, by Van Vreeswyk *et al.* (2004), with the results published in Technical Bulletin No. 92. The descriptions of the land systems listed in Table 14 and illustrated in Figure 8 below are consistent with those described in Technical Bulletin No. 92.

Table 14: Land systems underlying the Eastern Ridge mining operations

Land System	Description	Percentage of Closure Area (%)
Boolgeeda	Stony lower slopes and plains below hill systems supporting hard and soft spinifex grasslands and mulga shrublands	17%
Newman	Rugged jaspilite plateaux, ridges and mountains supporting hard spinifex grasslands	75%
Elimunna	Stony plains on basalt supporting sparse acacia and cassia shrublands and patchy tussock grasslands.	7%
Rocklea	Basalt hills, plateau, lower slopes and minor stony plains.	0.1%
Riverland	Flood plains and major rivers supporting eucalypt woodlands, tussock grasslands and soft spinifex grasslands.	0.05%

7.5.1 Knowledge gaps

No knowledge gaps have been identified.



777231
781231
785231
789231
7420579
7416579
7412579
PORT HEDLAND
Wedgefield
Yarrie Mining Village
Bamboo
Wodgina Tantalum Mine
Marble Bar
Moolyella
Salgash
Glen Herring
Hillside Camp
Nullagine
Wittenoom
Auski Roadhouse
NEWMAN
Capricorn Roadhouse
Orebody 24
Newman to Port Hedland Mainline
Orebody 23
Orebody 32
Orebody 25
Newman
Great Northern Highway
Ophthalmia Dam
Legend
Eastern Ridge Mine Closure Plan Area
Land Systems
Boolgeeda
Elimunna
Newman
Riverland
Rocklea
0
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2
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Kilometers
bhpbilliton
ENVIRONMENTAL APPROVALS
BHPBILLITON IRON ORE
N
EASTERN RIDGE
MINE CLOSURE PLAN
Land Systems
SCALE (A3): 1:40,000
DATUM: GDA94/MGA 50
Prepared: Env. Approvals
Revision: FINAL
Centre: Perth
06 November 2015
FIGURE 8
Dwg:STER_003MCP_008_RevA_0

7.6 Vegetation

7.6.1 Regional flora and vegetation

The latest version of the Interim Biogeographic Regionalisation for Australia (IBRA7) divides Australia into 89 bioregions based on climate, geology, landform, native vegetation and species information (DoE, 2012) and includes 419 sub-regions. The bioregions and sub-regions are the reporting unit for assessing the status of native ecosystems and their level of protection in the National Reserve System.

The Eastern Ridge mining operations are located in the Pilbara bioregion, which consists of four sub-regions: Chichester, Fortescue, Hamersley and Roebourne. The mining operation is located in the Hamersley sub-region (PIL3), which is described as a mountainous area of Proterozoic sedimentary ranges and plateaux, dissected by gorges (basalt, shale and dolerite) (Kendrick 2001 as described by Onshore, 2015). It contains Mulga low woodland over bunch grasses on fine textured soils in valley floors, with *Eucalyptus leucophloia* over *Triodia brizoides* on skeletal soils of the ranges.

The Eastern Ridge mining operations are situated within the Hamersley Botanical District, which is part of the Eremaean Province (Beard 1990, as described in Onshore, 2015). It is dominated by tree and shrub - steppe communities consisting mainly of Eucalyptus and Acacia species. *Triodia pungens* and *Triodia wiseana* and some Mulga occur within valley areas and short grass plains occur on alluvia.

7.6.2 Local flora and vegetation

To date, a total of 13 flora and vegetation surveys have been completed within, or partly within, the Eastern Ridge mining operations (Onshore, 2015). Twelve vegetation associations have been identified and mapped within the Eastern Ridge mining operations (Figure 9). Vegetation condition within the operation area ranges from Completely Degraded to Pristine (Onshore, 2015).

7.6.3 Flora of Conservation Significance

No plant taxa gazetted as Threatened Flora (T) pursuant to subsection (2) of Section 23F of the *Wildlife Conservation Act, 1950* (WC Act) or listed under the *Environment Protection and Biodiversity Conservation Act, 1999* (EPBC Act) have been recorded in the Eastern Ridge mining operations (Onshore, 2015).

Four Priority flora taxa listed by the DPaW have previously been recorded within the mining operation (ENV, 2012; Onshore 2012, 2013, 2015) and are illustrated in Figure 10. These include:

- *Calotis latiuscula* (Priority 3); was recorded as one population in the floodplains of the western end of the mining operation. It occurs in a variety of habitats including rocky hillsides, floodplains, rocky creeks and river beds.
- *Eremophila magnifica* subsp. *veluntina* (Priority 3); occurs on hill crests, ridges hill slopes and rocky drainage lines throughout the Orebody 25 and Orebody 25 West mining areas. Plant density is variable, ranging from one to 100 plants per 10 m^2.
- *Goodenia nuda* (Priority 4); was recorded from two locations, both in the south-western corner of the Eastern Ridge mining operations which now represent cleared and disturbed areas.
- *Isotropis parviflora* (Priority 2); was recorded as one plant from the northern sector of the Eastern Ridge mining operations in 2004. During follow-up targeted surveys, botanists were unable to locate any evidence of *Isotropis parviflora* at the previous location point or from the wider study area. Given that *Isotropis parviflora* is a short-lived coloniser species, it has likely senesced and died at the site.

7.6.4 Threatened or Priority Ecological Communities

None of the 12 mapped vegetation associations at the Eastern Ridge mining operations are affiliated with Federal or State listed as Threatened Ecological Communities (TECs) or State listed Priority Ecological Communities (PECs) (ENV 2012; Onshore 2015).

There are three vegetation types within the mining operation area considered as Ecosystems at Risk as classified by Kendrick (2001). These include major ephemeral watercourses, valley floor and lower slope Mulga, and hilltop flora (Hamersley Range) (ENV, 2012). Additionally, Gorges represent areas of Special Value – Refugia (ENV, 2012).

7.6.5 Weeds and Declared Plants

Twenty-two introduced species have been recorded within the Eastern Ridge mining operations. None of these species are listed as a Declared Pest under the *Biosecurity and Agriculture Management Act 2017.*

7.6.6 Surface water dependent vegetation

Mulga vegetation occurring on floodplains in the Pilbara can be susceptible to altered surface water flows owing to the dense lateral rooting habit and the absence of a tap root (ENV 2012).

Four vegetation associations that support Mulga occur along minor and major drainage lines within the Eastern Ridge mining operations, two of which have been identified as potentially at risk from surface water flow alterations or reductions (Onshore 2015). If there is a significant reduction to surface water flows entering the drainage lines, there may be an impact on associated Mulga vegetation.

7.6.7 Groundwater dependent vegetation

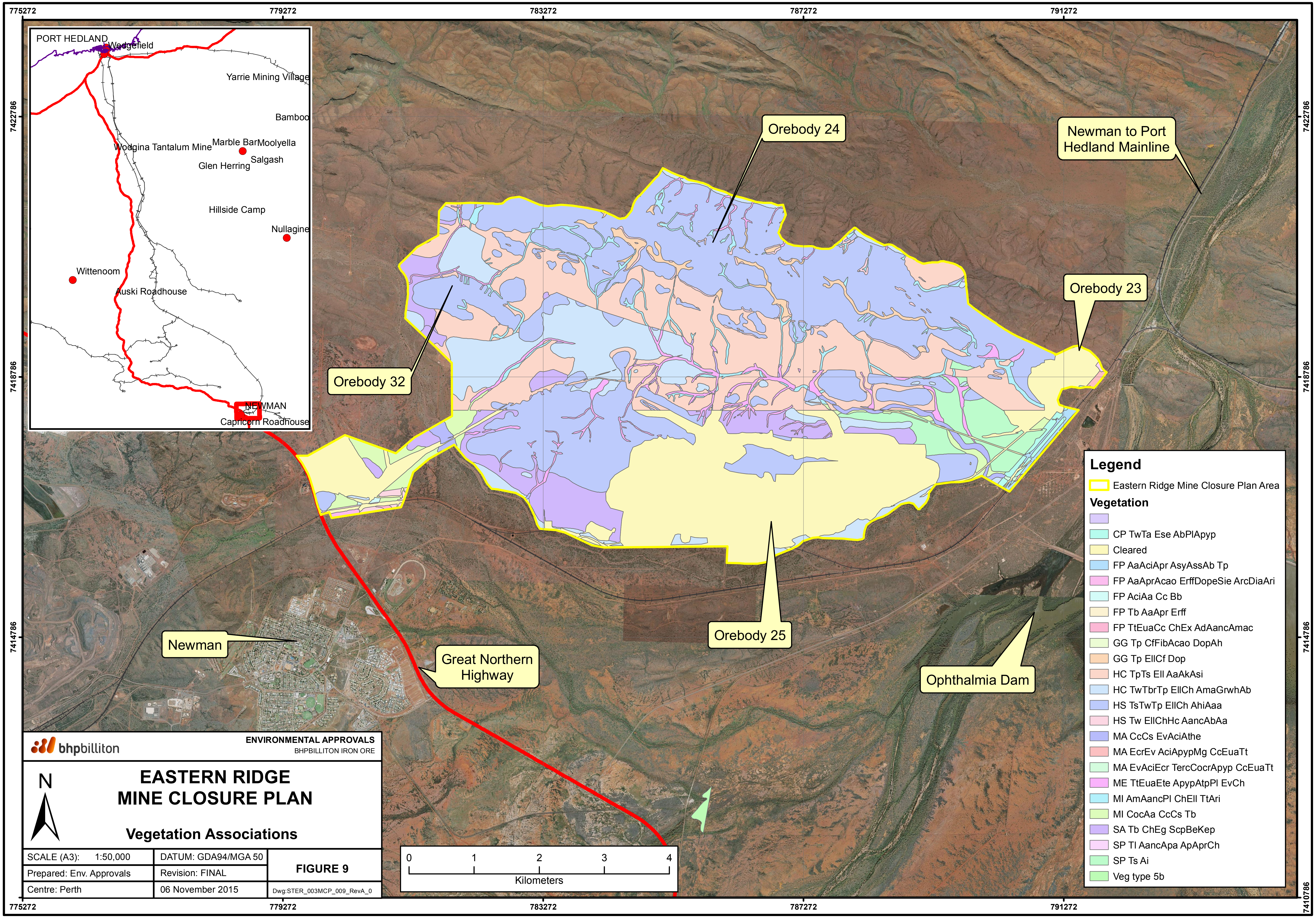
Two tree species, *Eucalyptus victrix* and *Eucalyptus camaldulensis* subsp. *refulgens,* have been identified as potentially at risk from groundwater drawdown at the Eastern Ridge mining operations (Onshore, 2015). Measurements of leaf water potential from riparian trees in the Homestead Creek system collected since 2009 suggest that both these species are likely to rely on vadose zone water and are unlikely to have groundwater dependence (AQ2, 2015). Two major receptors with the potential to support groundwater dependant vegetation (based on groundwater levels being modelled as within the 25 m bgl) have been identified surrounding the mining operations (Onshore, 2015); Homestead Creek (as well as adjacent floodplains and major tributaries); and Fortescue River (supporting the Ethel Gorge TEC).

The risk from cumulative groundwater drawdown to vegetation supporting the species *E. camaldulensis* subsp. *refulgens* and *E. victrix* is determined to be low during operations (Onshore, 2015), with the risk reducing to nil following the cessation of dewatering.

7.6.8 Knowledge Gaps

The following knowledge gaps has been identified:

- There is a current knowledge gap as to the known success in rehabilitation using *Eremophila magnifica* subsp. *velutina* material. The use of this material in progressive rehabilitation will be investigated.



775272
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PORT HEDLAND
Wedgefield
Yarrie Mining Village
Bamboo
Wodgina Tantalum Mine
Marble Bar
Moolyella
Salgash
Glen Herring
Hillside Camp
Nullagine
Wittenoom
Auski Roadhouse
NEWMAN
Capricorn Roadhouse
Orebody 24
Newman to Port Hedland Mainline
Orebody 23
Orebody 32
Orebody 25
Newman
Great Northern Highway
Ophthalmia Dam
Legend
Eastern Ridge Mine Closure Plan Area
Vegetation
CP TwTa Ese AbPlApyp
Cleared
FP AaAciApr AsyAssAb Tp
FP AaAprAcao ErffDopeSie ArcDiaAri
FP AciAa Cc Bb
FP Tb AaApr Erff
FP TtEuaCc ChEx AdAancAmac
GG Tp CfFibAcao DopAh
GG Tp EllCf Dop
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HC TwTbrTp EllCh AmaGrwhAb
HS TsTwTp EllCh AhiAaa
HS Tw EllChHc AancAbAa
MA CcCs EvAciAthe
MA EcrEv AciApypMg CcEuaTt
MA EvAciEcr TercCocrApyp CcEuaTt
ME TtEuaEte ApypAtpPl EvCh
MI AmAancPl ChEll TtAri
MI CocAa CcCs Tb
SA Tb ChEg ScpBeKep
SP Tl AancApa ApAprCh
SP Ts Ai
Veg type 5b
0 1 2 3 4
Kilometers
bhpbilliton
ENVIRONMENTAL APPROVALS
BHPBILLITON IRON ORE
N
EASTERN RIDGE
MINE CLOSURE PLAN
Vegetation Associations
SCALE (A3): 1:50,000
DATUM: GDA94/MGA 50
Prepared: Env. Approvals
Revision: FINAL
Centre: Perth
06 November 2015
FIGURE 9
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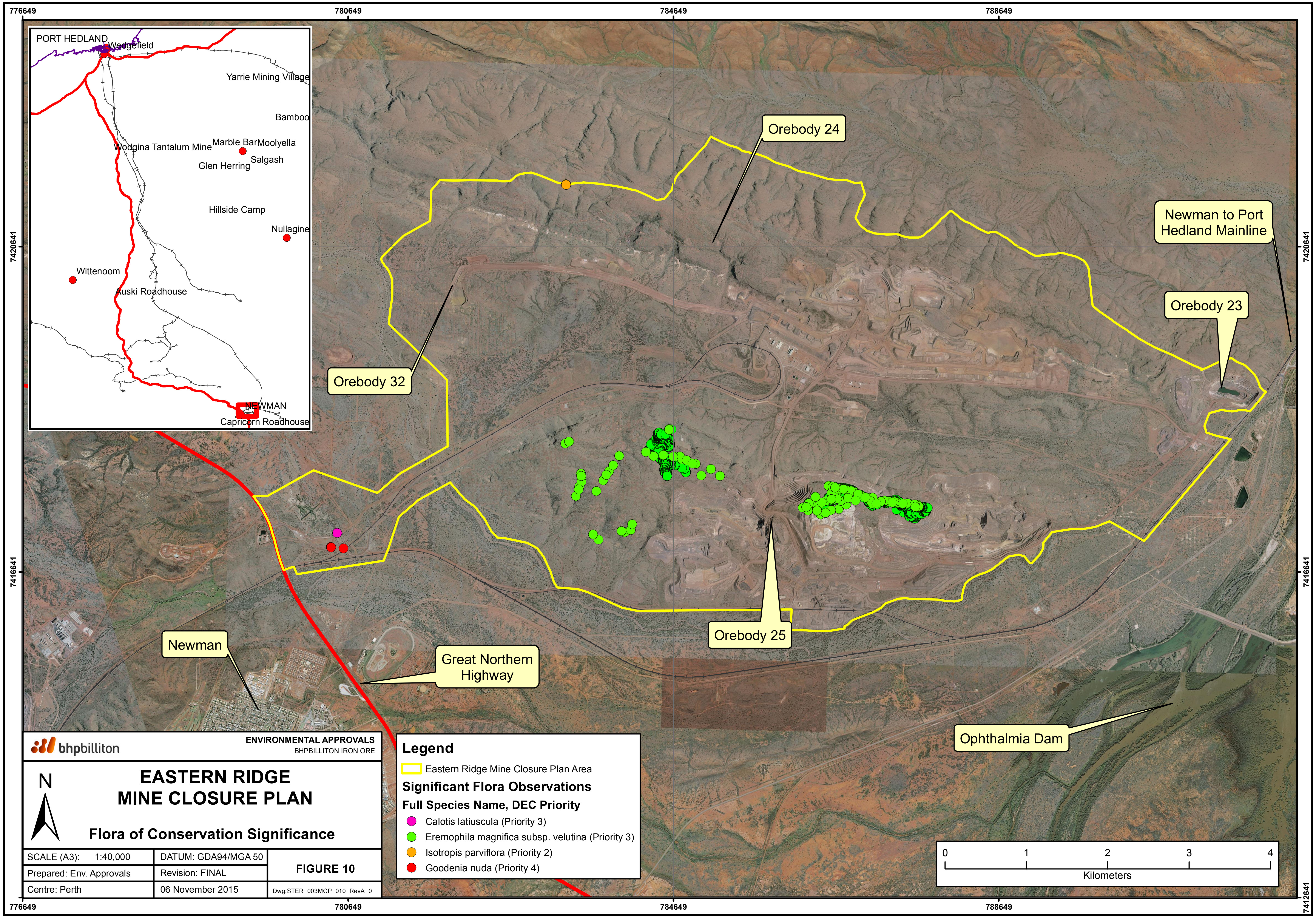
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bhpbilliton
ENVIRONMENTAL APPROVALS
BHPBILLITON IRON ORE
EASTERN RIDGE
MINE CLOSURE PLAN
Flora of Conservation Significance
N
SCALE (A3): 1:40,000
DATUM: GDA94/MGA 50
Prepared: Env. Approvals
Revision: FINAL
Centre: Perth
06 November 2015
FIGURE 10
Dwg:STER_003MCP_010_RevA_0
Legend
Eastern Ridge Mine Closure Plan Area
Significant Flora Observations
Full Species Name, DEC Priority
Calotis latiuscula (Priority 3)
Eremophila magnifica subsp. velutina (Priority 3)
Isotropis parviflora (Priority 2)
Goodenia nuda (Priority 4)
0
1
2
3
4
Kilometers