Appendix K Threatened flora report forms

Department of Parks and Wildlife

Threatened and Priority Flora Report Form

Version 1.2 August 2013

Please complete as much of the form as possible.
For information on how to complete the form please refer to the Threatened & Priority Flora Report Form (TPRF) manual on the DPaW website at http://www.dpaw.wa.gov.au/

TAXON: Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301) **TPFL Pop. No:**

OBSERVATION DATE: 06/08/2015 **CONSERVATION STATUS:** P3 New population ☒

OBSERVER/S: Sarah Dalgleish and Joel Collins **PHONE:** (08) 9227 1070

ROLE: Botanist and Senior Botanist **ORGANISATION:** Eco Logical Australia

DESCRIPTION OF LOCATION (Provide at least nearest town/named locality, and the distance and direction to that place)**:**

90 km east of Tom Price within Boolgeeda Creek (a tributary of Duck Creek)

30 km west of Brockman 4 mine site

Reserve No:

DISTRICT: Pilbara Region **LGA:** Shire of Ashburton Land manager present: ☐

DATUM: GDA94 / MGA94 ☒ AGD84 / AMG84 ☐ WGS84 ☐ Unknown ☐

COORDINATES: (If UTM coords provided, **Zone** is also required)
DecDegrees ☐ DegMinSec ☐ UTMs ☒
Lat / Northing: 7496090
Long / Easting: 485652
Zone: 50

METHOD USED: GPS ☒ Differential GPS ☐ Map ☐
No. satellites: Map used:
Boundary polygon captured: ☐ Map scale:

LAND TENURE:
Nature reserve ☐ Timber reserve ☐ Private property ☐ Rail reserve ☐ Shire road reserve ☐
National park ☐ State forest ☐ Pastoral lease ☒ MRWA road reserve ☐ Other Crown reserve ☐
Conservation park ☐ Water reserve ☐ UCL ☐ SLK/Pole ______ to ______ Specify other: ______

AREA ASSESSMENT: Edge survey ☐ Partial survey ☐ Full survey ☒ Area observed (m²): 3,280,000

EFFORT: Time spent surveying (minutes): 2,400 No. of minutes spent / 100 m^2: 13.6

POP'N COUNT ACCURACY: Actual ☐ Extrapolation ☐ Estimate ☒

Count method: (Refer to field manual for list) Actual

WHAT COUNTED: Plants ☒ Clumps ☐ Clonal stems ☐

TOTAL POP'N STRUCTURE:	**Mature:**	**Juveniles:**	**Seedlings:**	**Totals:**
Alive	2,837			
Dead				

Area of pop (m²): 3,280,000

Note: Pls record count as numbers (not percentages) for database.

QUADRATS PRESENT: No. ______ Size ______ Data attached ☐ Total area of quadrats (m²): ______

Summary Quad. Totals: Alive				

REPRODUCTIVE STATE: Clonal ☐ Vegetative ☐ Flowerbud ☐ Flower ☒
Immature fruit ☐ Fruit ☐ Dehisced fruit ☐ Percentage in flower: ______%

CONDITION OF PLANTS: Healthy ☒ Moderate ☐ Poor ☐ Senescent ☐

COMMENT:

THREATS - type, agent and supporting information: E.g. clearing, too frequent fire, weed, disease. Refer to field manual for list of threats & agents. **Specify agent** where relevant. **Rate current and potential threat impact:** N=Nil, L=Low, M=Medium, H=High, E=Extreme **Estimate time to potential impact:** S=Short (<12mths), M=Medium (<5yrs), L=Long (5yrs+)	**Current impact (N-E)**	**Potential Impact (L-E)**	**Potential Threat Onset (S-L)**
• Weeds Numerous species including*Acetosa vesicaria (Ruby Dock), *Argemone ochroleuca subsp. ochroleuca (Mexican Poppy), *Cenchrus ciliaris (Buffel Grass), *Flaveria trinervia (Speedy Weed), *Malvastrum americanum (Spiked Malvastrum), *Setaria verticillata (Whorled Pigeon Grass), *Sonchus oleraceus (Common Sowthistle) and *Vachellia farnesiana (Mimosa Bush).	L	L	L
• Stock Cattle	L	L	L

Please return completed form to **Species And Communities Branch** DPaW,
Locked Bag 104, BENTLEY DELIVERY CENTRE WA 6983
RECORDS: Please forward to **Flora Administrative Officer,** Species and Communities Branch.

Record entered by:________________________ **Sheet No.:**____________ **Record Accepted in Database** ☐

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Department of Parks and Wildlife

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•			
	______	______	______

HABITAT INFORMATION: (Check more than one box for combinations or where necessary)

LANDFORM:	ROCK TYPE:	LOOSE ROCK:	SOIL TYPE:	SOIL COLOUR:	DRAINAGE:
Crest ☐	Granite ☐	(on soil surface; e.g. gravel, quartz fields)	Sand ☒	Red ☒	Well drained ☐
Hill ☐	Dolerite ☐	0-10% ☐	Sandy loam ☐	Brown ☒	Seasonally inundated ☒
Ridge ☐	Laterite ☐	10-30% ☐	Loam ☐	Yellow ☐	Permanently inundated ☐
Outcrop ☐	Ironstone ☒	30-50% ☐	Clay loam ☐	White ☐	Tidal ☐
Slope ☐	Limestone ☐	50-100% ☒	Light clay ☐	Grey ☐	
Flat ☐	Quartz ☐		Peat ☐	Black ☐	
Open depression ☐					
Drainage line ☒	Specify other:		Specify other: Alluvial clay plain and river rock	Specify other:	Specify other:
Closed depression ☐					
Wetland ☐					

Specific Landform Element: (Refer to field manual for additional values)

Creek

CONDITION OF SOIL:

Dry ☐ Moist ☒ Waterlogged ☐ Inundated ☐ Cracked ☐ Saline ☐ Other:

VEGETATION CLASSIFICATION:* E.g. **1**. Banksia woodland (B. attenuata, B. ilicifolia); **2**. Open shrubland (Hibbertia sp., Acacia spp.) **3**. Isolated clumps of sedges (Mesomelaena tetragona)	1. Eucalyptus victrixand E. camaldulensis woodland
	2. Acacia citrinoviridis low open woodland
	3. *Cenchrus ciliaris scattered tussock grasses over Triodia epactia scattered hummock grasses
	4.
ASSOCIATED SPECIES: Other (non-dominant) spp	Acacia pyrifolia
	Petalostylis labicheoides
	Melaleuca glomerata

* Please record up to four of the most representative vegetation layers (with up to three dominant species in each layer). Structural Formations should follow 2009 *Australian Soil and Land Survey Field Handbook* guidelines – refer to field manual for further information and structural formation table.

CONDITION OF HABITAT: Pristine ☐ Excellent ☐ Very good ☒ Good ☐ Degraded ☐ Completely degraded ☐

COMMENT: Vegetation condition ranged from Poor to Very Good due to varying prevalence of weeds and grazing

FIRE HISTORY: **Last Fire:** Season/Month: ______ Year: ______ **Fire Intensity:** High ☐ Medium ☐ Low ☐ No signs of fire ☒

FENCING: Not required ☒ Present ☐ Replace / repair ☐ Required ☐ Length req'd: ______

ROADSIDE MARKERS: Not required ☒ Present ☐ Replace / reposition ☐ Required ☐ Quantity req'd: ______

OTHER COMMENTS: (Please include recommended management actions and/or implemented actions - include date. Also include details of additional data available, and how to locate it.)

Full dataset attached of individual plant locations

Please return completed form to **Species And Communities Branch** DPaW,
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Record entered by:______________________ **Sheet No.:**______________ **Record Accepted in Database** ☐

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DRF PERMIT/ LICENCE No: SL011393 and SL011387

Note if only observing plants (i.e. no specimens or plant matieral is taken) then no permit/licence is required. For further information on permit and licening requirements see the Threatened Flora and Wildlife Licensing pages on DPaW's website. Any actions carried out under licence/permit should be recorded above in the OTHER COMMENTS section.

SPECIMEN: Collectors No: WA Herb. ☐ Regional Herb. ☐ District Herb. ☐ Other:

ATTACHED: Map ☐ Mudmap ☐ Photo ☐ GIS data ☒ Field notes ☐ Other:

COPY SENT TO: Regional Office ☐ District Office ☐ Other:

Submitter of record: Sarah Dalgleish **Role:** Botanist

Signature: [signature] **Date submitted:** 01 / 09 / 2015

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RECORDS: Please forward to **Flora Administrative Officer,** Species and Communities Branch.

Record entered by:____________________ **Sheet No.:**__________ **Record Accepted in Database** ☐

Taxon	No. individuals	Easting	Northing
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	8	482034	7495230
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	25	482058	7495220
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	4	482078	7495190
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	5	482107	7495170
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	2	482206	7495210
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	5	482266	7495190
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	4	482322	7495170
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	3	482435	7495210
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	35	482451	7495180
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	6	482653	7495180
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	21	482913	7495200
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	1	483119	7495220
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	10	483233	7495210
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	10	483225	7495180
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	10	483272	7495210
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	4	483351	7495150
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	12	483472	7495050
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	5	483260	7495010
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	5	483246	7495020
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	3	483151	7495050
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	2	483080	7495000
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	22	483041	7494980
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	10	482821	7495100
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	14	482558	7495150
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	5	482488	7495130

Taxon	No. individuals	Easting	Northing
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	1	482152	7495060
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	7	484844	7494670
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	8	484848	7494760
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	12	485096	7495020
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	8	485129	7495080
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	14	485308	7495370
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	10	485318	7495500
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	5	485302	7495590
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	20	485354	7495650
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	5	485392	7495680
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	5	485447	7495650
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	16	485483	7495660
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	15	485518	7495660
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	10	485509	7495700
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	15	485476	7495760
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	10	485419	7495770
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	22	485406	7495800
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	1	482088	7495280
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	1	482118	7495270
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	1	482118	7495270
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	1	482193	7495270
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	1	482209	7495280
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	1	482215	7495280
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	1	482215	7495280
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	1	482217	7495280

Taxon	No. individuals	Easting	Northing
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	1	482214	7495310
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	1	482253	7495270
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	1	482259	7495280
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	1	482265	7495270
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	1	482267	7495270
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	1	482267	7495270
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	1	482269	7495270
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	1	482281	7495300
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	1	482281	7495300
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	1	482281	7495300
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	1	482291	7495300
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	1	482295	7495300
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	1	482293	7495300
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	1	482291	7495310
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	9	482402	7495270
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	1	482463	7495260
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	1	482484	7495290
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	4	482488	7495290
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	34	482526	7495280
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	1	482523	7495320
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	1	482553	7495310
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	17	482559	7495330
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	1	482584	7495310
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	1	482620	7495290
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	1	482620	7495290

Taxon	No. individuals	Easting	Northing
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	1	482620	7495290
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	1	482626	7495320
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	4	482638	7495330
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	6	482639	7495340
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	1	482798	7495240
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	1	482967	7495240
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	1	482972	7495260
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	3	483223	7495370
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	1	483241	7495380
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	5	483615	7495190
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	3	483572	7495290
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	1	483503	7495370
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	1	482969	7495430
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	15	482932	7495430
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	7	482576	7495380
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	5	482513	7495380
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	3	482480	7495370
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	10	482468	7495370
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	2	482442	7495370
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	7	482441	7495390
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	10	482381	7495360
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	2	482056	7495340
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	2	481983	7495370
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	1	481929	7495280
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	1	483650	7494810

Taxon	No. individuals	Easting	Northing
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	1	483720	7494690
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	1	483735	7494680
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	3	483735	7494660
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	30	483737	7494640
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	2	483779	7494610
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	25	483797	7494550
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	1	483834	7494530
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	1	483845	7494520
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	1	483853	7494520
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	1	483868	7494500
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	3	483896	7494490
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	15	483915	7494480
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	20	484049	7494440
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	15	484100	7494450
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	15	484130	7494450
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	35	484159	7494450
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	10	484265	7494490
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	25	484460	7494530
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	45	484493	7494550
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	20	484532	7494570
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	10	484787	7494830
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	5	484797	7494860
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	13	484811	7494870
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	25	484841	7494920
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	20	484973	7495160

Taxon	No. individuals	Easting	Northing
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	2	485030	7495220
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	5	485064	7495220
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	30	485071	7495220
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	3	485109	7495310
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	3	485136	7495330
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	1	485137	7495370
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	9	485176	7495420
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	2	485246	7495460
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	1	485292	7495520
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	25	485359	7495670
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	1	485355	7495770
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	2	485387	7495790
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	2	485417	7495790
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	2	485431	7495790
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	10	485458	7495810
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	2	485450	7495840
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	5	485453	7495850
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	8	485451	7495860
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	1	485443	7495870
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	4	485451	7495900
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	1	485462	7495930
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	2	485494	7495950
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	2	485492	7495950
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	18	485492	7495970
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	5	485526	7495960

Taxon	No. individuals	Easting	Northing
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	1	485537	7495960
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	1	485531	7495980
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	8	485531	7496000
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	20	485536	7496020
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	1	485553	7496050
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	20	485601	7496140
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	20	485606	7496150
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	5	485616	7496170
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	20	485649	7496180
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	2	485516	7496050
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	1	485631	7496100
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	15	485652	7496090
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	5	485662	7496120
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	5	485659	7496180
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	2	485673	7496220
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	1	485678	7496230
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	5	485694	7496220
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	5	485709	7496210
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	1	485733	7496180
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	2	485757	7496190
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	2	485790	7496220
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	2	485793	7496210
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	1	485774	7496250
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	1	485760	7496280
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	1	485758	7496300

Taxon	No. individuals	Easting	Northing
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	1	485774	7496280
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	3	485838	7496260
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	1	485853	7496350
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	2	485861	7496340
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	5	485901	7496330
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	10	485884	7496370
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	2	485887	7496400
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	8	485892	7496440
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	15	485899	7496450
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	1	485954	7496400
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	5	486000	7496400
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	1	485999	7496470
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	11	485987	7496490
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	6	485979	7496500
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	4	485973	7496510
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	15	485973	7496540
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	1	486010	7496550
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	1	486016	7496550
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	1	486069	7496660
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	1	486096	7496690
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	1	486109	7496690
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	10	486141	7496700
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	1	486145	7496690
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	16	486145	7496670
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	1	486162	7496680

Taxon	No. individuals	Easting	Northing
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	18	486195	7496720
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	50	486173	7496740
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	1	486151	7496750
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	1	486104	7496780
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	5	486194	7496780
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	5	486238	7496840
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	25	486207	7496880
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	1	486194	7496900
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	7	486269	7496920
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	30	486308	7496950
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	30	486294	7496960
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	30	486282	7496980
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	5	486271	7497000
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	25	486317	7496990
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	45	486382	7497020
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	1	486396	7497020
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	7	486401	7497050
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	20	486392	7497070
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	5	486356	7497070
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	1	486351	7497100
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	3	486445	7497090
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	3	486461	7497110
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	4	486519	7497320
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	1	486582	7497400
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	30	486738	7497360

Taxon	No. individuals	Easting	Northing
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	3	486746	7497410
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	4	486725	7497480
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	4	486860	7497480
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	4	486865	7497560
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	1	486980	7497610
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	30	487040	7497680
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	10	487063	7497660
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	2	487101	7497660
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	2	487151	7497640
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	1	487369	7497700
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	30	487368	7497720
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	6	487387	7497760
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	1	487400	7497800
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	3	487429	7497790
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	2	487561	7497740
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	20	487756	7497770
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	25	487798	7497770
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	30	487995	7497670
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	1	488030	7497680
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	6	488151	7497650
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	1	488312	7497530
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	1	488341	7497520
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	2	488355	7497530
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	8	488369	7497510
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	30	488390	7497490

Taxon	No. individuals	Easting	Northing
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	3	488454	7497460
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	7	488473	7497450
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	10	488503	7497430
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	1	488558	7497400
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	7	488520	7497480
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	7	488490	7497480
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	2	488416	7497530
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	8	488396	7497540
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	25	488326	7497590
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	1	488266	7497610
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	1	488184	7497700
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	2	488154	7497720
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	2	488129	7497700
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	2	488099	7497710
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	5	488057	7497760
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	2	488041	7497770
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	2	488007	7497790
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	6	487992	7497820
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	2	487976	7497830
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	1	483600	7495010
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	2	483606	7495070
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	3	483621	7495140
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	5	483742	7494760
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	2	483847	7494640
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	2	483888	7494610

Taxon	No. individuals	Easting	Northing
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	3	483896	7494620
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	1	483921	7494590
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	1	483920	7494590
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	1	483929	7494580
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	1	483934	7494580
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	1	483995	7494560
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	1	484003	7494560
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	1	484005	7494550
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	1	484026	7494540
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	1	484031	7494530
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	1	484036	7494530
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	1	484384	7494580
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	12	485404	7495820
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	15	485444	7495820
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	4	485536	7495820
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	6	485575	7495800
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	8	485605	7495850
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	12	485618	7495900
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	4	485595	7496000
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	10	485655	7496030
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	12	485699	7496000
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	10	485735	7496020
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	20	485720	7496120
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	10	485793	7496130
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	10	485822	7496110

Taxon	No. individuals	Easting	Northing
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	15	485888	7496160
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	8	485909	7496230
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	10	485935	7496310
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	20	486021	7496430
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	5	486167	7496590
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	20	486149	7496650
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	25	486283	7496710
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	8	486364	7496800
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	6	486465	7496910
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	14	486473	7497000
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	15	486601	7497100
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	20	486700	7497220
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	40	486796	7497280
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	20	486858	7497310
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	8	486856	7497370
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	15	486984	7497500
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	35	487076	7497470
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	2	487478	7497620
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	1	487593	7497620
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	7	487745	7497620
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	15	487238	7497550
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	20	487269	7497610
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	20	487376	7497670
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	25	487475	7497650
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	20	487514	7497680

Taxon	No. individuals	Easting	Northing
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	8	487674	7497700
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	3	487838	7497620
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	20	488166	7497580
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	13	488309	7497510
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	3	488338	7497500
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	1	488406	7497400
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	2	488512	7497390
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	6	488871	7497220
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	10	489149	7497230
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	25	489153	7497260
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	10	489181	7497260
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	15	489222	7497270
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	14	489251	7497280
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	4	489270	7497350
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	5	483677	7494700
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	25	483743	7494650
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	3	483737	7494570
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	1	483859	7494420
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	1	483969	7494410
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	2	484045	7494370
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	15	484152	7494350
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	15	484335	7494400
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	20	484453	7494440
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	5	484529	7494500
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	8	484675	7494580

Taxon	No. individuals	Easting	Northing
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	5	484756	7494610
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	8	484768	7494710

ISO 14001 Environmental Management

AS/NZS 4801:2001 Occupational Health and Safety Management

ISO 9001 Quality Management

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Attachment 1: Flora and Vegetation Summary

The following provides a summary of the key flora and vegetation values of the Brockman Syncline 4 Marra Mambas Proposal area (Proposal area). For the purposes of this summary, the Proposal area aligns with the area defined by the 'Proposed Extension to Development Envelope' polygon in Figure 1. The flora and vegetation of Boolgeeda Creek is discussed separately at the end of this document.

The summary is taken mostly from the following survey reports, both of which are provided as attachments to this summary:

- Biota 2016, Brockman Syncline 4 – Marra Mambas Project Level 2 Vegetation and Flora Survey; and
- Ecological Australia 2015, Boolgeeda Creek – Riparian Vegetation Extension Area.

These reports should be referred to for further detail.

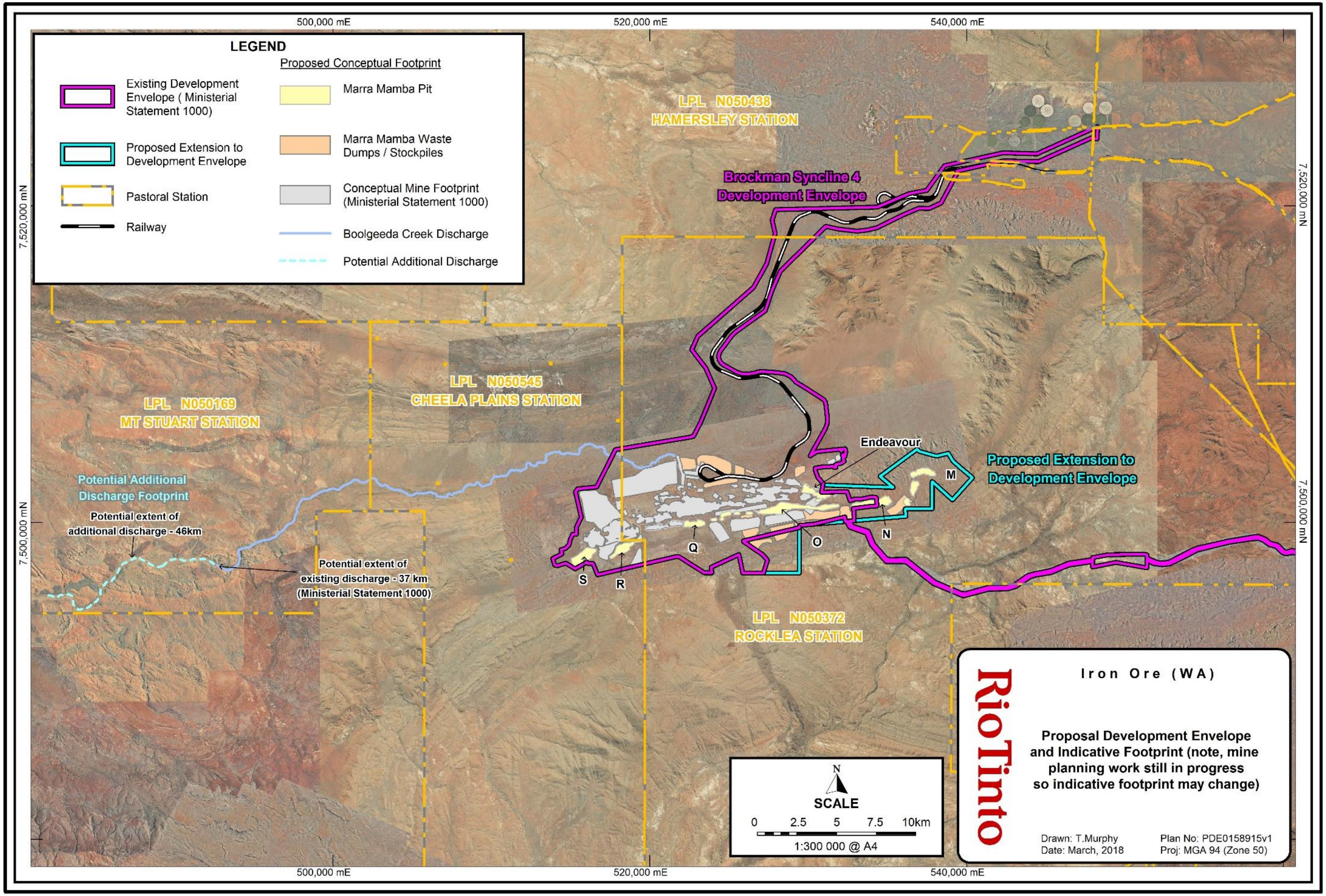

Figure 1: Proposal area

1. Flora and Vegetation Survey Effort

Report	Survey Area (ha)	Summary of Method and Key Results
Biota (2016) *Brockman Syncline 4 – Marra Mambas Project Level 2 Vegetation and Flora Survey* This survey report is provided	5,806	This survey covers the Proposal area and identified as 'study area' in Figure 2. Level 2 – single season in July-August 2015, consisting of 37 quadrats, 38 relevés and re-sampling 16 historic quadrats. Significant flora and vegetation recorded: • *Goodenia pedicellata* (P1), *Hibiscus* sp. Mt Brockman (E. Thoma ET 1354) (P1), *Sida* sp. Hamersley Range (K. Newbey 10692) (P1), *Hibiscus* sp. Gurinbiddy Range (M.E. Trudgen MET 15708) (P2), *Oxalis* sp. Pilbara (M.E. Trudgen 12725) (P2), *Pentapeltis trichodesmoides* subsp. *hispida* (P2), *Eremophila magnifica* subsp. *velutina* (P3), *Oldenlandia* sp. Hamersley Station (A.A. Mitchell PRP 1479) (P3), *Ptilotus subspinescens* (P3), *Triodia basitricha* (P3), *Acacia bromilowiana* (P4), *Goodenia nuda* (P4). • Several vegetation types considered to be of elevated significance.
Ecological Australia (2015) *Boolgeeda Creek – Riparian Vegetation Extension Area* This survey report is provided	302.7	This survey covers the Boolgeeda Creek along an additional 10 km stretch of the creek (beyond the original 41 km survey extent undertaken by Biota 2013c) that the surplus water discharge is predicted to extend (refer to Figure 1). Level 2 – single season August 2015, consisting of 15 quadrats and targeted searches for conservation listed species. Significant flora and vegetation recorded: • *Indigofera* sp. Bungaroo Creek (S. van Leeuwen 4301) (P3). • Major ephemeral water courses in the Pilbara are considered to be ecosystems at risk from various threatening processes.
Astron (2014) *Brockman Syncline Marra Mamba DP08/DP09 Biological Assessment*	194.8	This survey covers an area to the south of the Marra Mamba Pit O, mostly within the existing Development Envelope. This survey area covers some of the Proposal area. Targeted flora survey in September 2014, consisting of 14 relevés. Significant flora and vegetation recorded: • *Ptilotus subspinescens* (P3). • Three weed species. • No vegetation types of elevated significance.
Biota (2014) *Brockman 4 Eastern Edge Native Vegetation Clearing Permit Report*	337	This survey covers an area to the north of Marra Mamba Pit N. This survey area covers part of the Proposal area. Level 1 – single season plus targeted flora searches in July 2014, consisting of 14 quadrats and 6 relevés. Significant flora and vegetation recorded: • *Hibiscus* sp. Mt Brockman (E. Thoma ET 1354) (P1), *Sida* sp. Hamersley Range (K. Newbey 10692) (P1). • Two vegetation types considered to be of elevated significance.

Report	Survey Area (ha)	Summary of Method and Key Results
Biota (2013a) *Brockman Syncline 4 Marra Mamba Vegetation and Flora Survey*	942.8	This survey covers an area to the south of the Marra Mamba Pits O, Q, R and S. This survey area covers some of the Proposal area. Level 2 – single season in August-September 2012, consisting of 31 quadrats. Significant flora and vegetation recorded: • *Grevillea saxicola* (P3; previously *Grevillea* sp. Turee (J. Bull & G. Hopkinson ONS JJ01.01), *Ptilotus subspinescens* (P3). • No vegetation types of elevated significance.
Biota (2013b) *Mara Mamba West Native Vegetation Clearing Permit*	324.6	This survey covers an area of the western most extent of the existing Development Envelope. This survey area covers some of the Proposal area, specifically Marra Mamba Pit S. Level 1 – single season plus targeted flora searches in September 2013, consisting of 18 relevés. Significant flora and vegetation recorded: • *Hibiscus* sp. Mt Brockman (E. Thoma ET 1354) (P1), *Indigofera* sp. Bungaroo Creek (S. van Leeuwen 4301) (P3), *Goodenia nuda* (P4). • No vegetation types of elevated significance.
Biota (2013c) Brockman 4 Riparian Vegetation Mapping	1,301.3	This survey covers the Boolgeeda Creek along the 41 km stretch of the creek that the surplus water discharge is predicted to extend (predicted to extend 37 km from the discharge point). Level 2 – single season in August 2013, consisting of 17 quadrats and two releves. Significant flora and vegetation recorded: • *Peplidium* sp. Fortescue Marsh (S. van Leeuwin 4865) (P1), *Pentalepis trichodesmoides* subsp. *hispida* (P2), *Indigofera* sp. Bungaroo Creek (S. van Leeuwen 4301) (P3) and *Goodenia nuda* (P4). • Several riparian vegetation units considered to be of elevated significance.
Biota (2009) *A Vegetation and Flora Survey of Beasley River*	4,147.9	This survey covers an area to the south of the Proposal area, covering the Beasley River. This survey area adjoins the Proposal area. Level 2 – single season in May, September 2009, consisting of 35 quadrats. Significant flora and vegetation recorded: • *Ptilotus trichocephalus* (P4), *Indigofera* sp. Bungaroo Creek (S. van Leeuwen 4301) (P3), *Oldenlandia* sp. Hamersley Station (A.A. Mitchell PRP 1479) (P3), *Ptilotus subspinescens* (P3). • Several vegetation types considered to be of elevated significance.
Rio Tinto (2009) *Botanical Survey of the Brockman Syncline Southern Marra Mamba Deposits J, M & N*	619.2	This survey covers an area within the eastern most extent of the Proposal area. This survey area covers part of the Proposal area, specifically Marra Mamba Pits M and N. Targeted flora survey in June 2005, and April and May 2007.

Report	Survey Area (ha)	Summary of Method and Key Results
		Significant flora and vegetation recorded: • *Lepidium catapycnon* (P4 – previously threatened), and *Sida* sp. Hamersley Range (K. Newbey 10692) (P1 – previously *Sida* sp. Pilbara (S. van Leeuwen 4377)) • Three weed species. • No vegetation types of elevated significance.
Biota (2007) *A Vegetation and Flora Survey of the White Quartz Road Corridor, near Tom Price*	2,304.8	This survey covers an area to the south south-east of the Proposal area, covering the White Quartz Road corridor linking the Proposal area to the Western Turner Syncline area. This survey area adjoins the Proposal area. Level 2 – single season, plus targeted flora searches in May-June 2006, consisting of 20 quadrats. Significant flora and vegetation recorded: • *Ptilotus subspinescens* (P3; previously *Ptilotus* sp. Brockman (E. Thoma & A. Joder ER & AJ 145) (P1)), *Rostellularia adscendens* var. *latifolia* (P3), and a further two priority species no longer listed. • Eight weed species. • Several vegetation types considered to be of elevated significance.
Biota (2005) *A Vegetation and Flora Survey of the Brockman Syncline 4 Project Area, near Tom Price*	11,796	This survey was undertaken to support the environmental assessment of the original Brockman Syncline 4 development so covers most of the existing Development Envelope. This survey area covers some of the Proposal area. Level 2 – single season, plus targeted flora searches in February-March, April, May and June 2003 and October 2004, consisting of 49 quadrats and 2 relevés. Significant flora and vegetation recorded: • *Ptilotus subspinescens* (P3; previously *Ptilotus* sp. Brockman (E. Thoma & A. Joder ER & AJ 145) (P1)), *Eremophila magnifica* subsp. *magnifica* (P4), *Goodenia stellata* (P4), and a further three priority species no longer listed. • Several vegetation types considered to be of elevated significance.

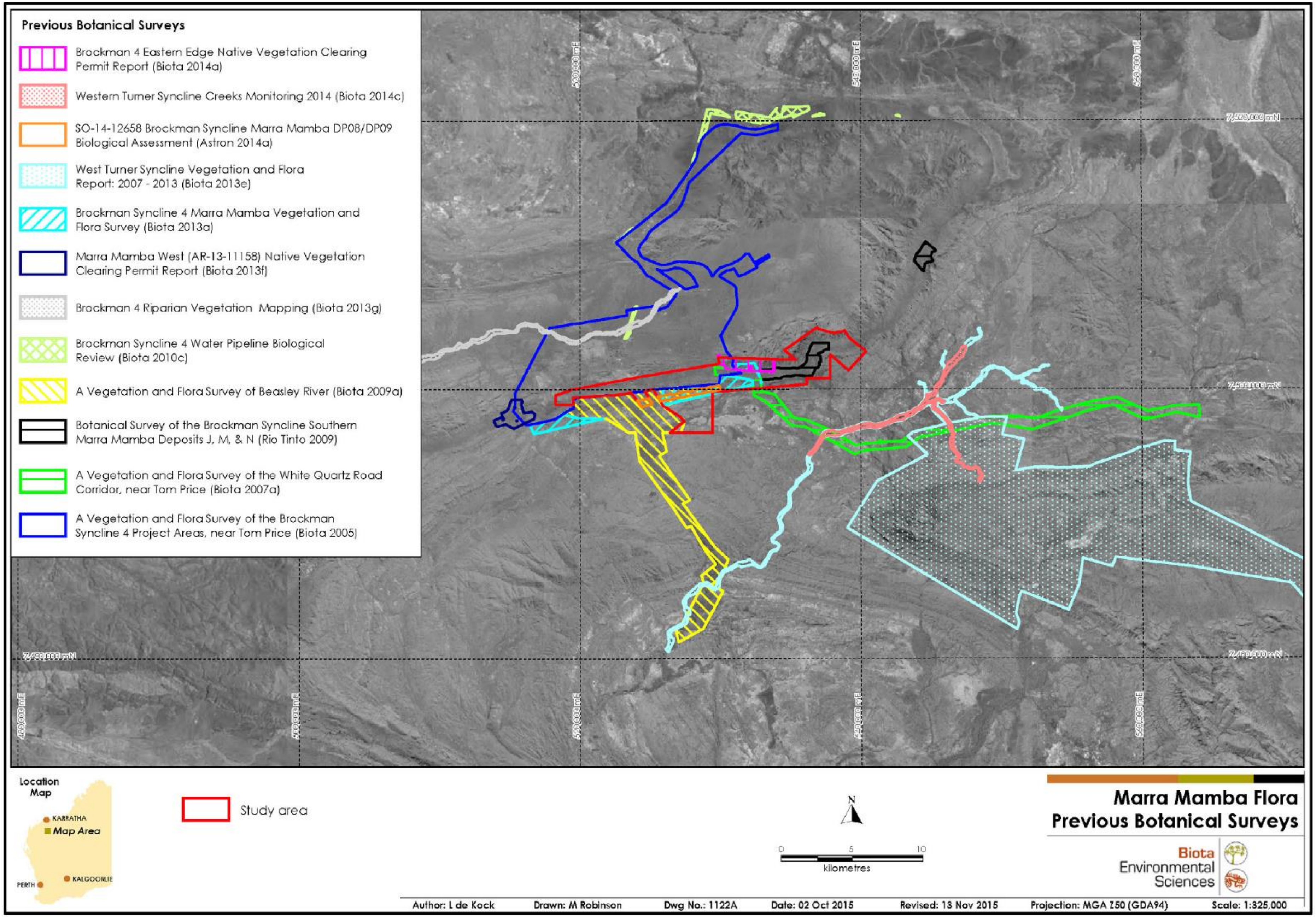

Figure 2: Locations of the key flora and vegetation surveys in the vicinity of the Proposal area (from Biota 2016)

2. Flora and Vegetation of the Proposal Area

2.1 Vegetation Associations

The predominant vegetation associations, as mapped by Beard (1975), occurring in the Proposal area are:

- Hamersley 82: Hummock grasslands, low tree steppe; snappy gum (*Eucalyptus leucophloia*) over *Triodia wiseana*; and
- Hamersley 567: Hummock grasslands, shrub steppe; mulga (*Acacia aneura* complex) and kanji (*Acacia inaequilatera*) over soft spinifex and *Triodia basedowii.*

Vegetation Association (as mapped by Beard 1975)	**Current Pre-European Extent (ha)**	**Proportion Remaining (%)**	**Extent in Proposal Area (ha)** (percentage of current pre-European extent)
82	2,177,573.90	99.43	627.66 (<0.03%)
567	776,823.96	99.66	1,938.29 (<0.3%)

2.2 Land Systems

The Proposal area intersects six Land Systems, as mapped by Payne *et al* 1998 and Department of Agriculture 2002:

Land System	**Description**	**Extent in Pilbara Region (ha)**	**Extent in Proposal Area (ha)** (percentage of regional extent of Land System)
Rocklea	Basalt hills, plateaux, lower slopes and minor stony plains supporting hard spinifex (occasionally soft spinifex) grasslands.	2,881,199	376.27 (0.01%)
Robe	Low limonite mesas and buttes supporting soft spinifex (and occasionally hard spinifex) grasslands	128,859	209.78 (0.16%)
Table	Low calcrete plateaux, mesas and lower plains supporting mulga and cassia shrublands and minor spinifex grasslands	20,645	101.8 (0.49%)
Wona	Level to gently undulating upland basaltic plains with gilgai microrelief and clay soils, relief up to 30m. Self-mulching clay plains on top of basalt hills; cassia short grass forb pastures in poor to excellent condition; no erosion	19,4821	196.84 (0.1%)
Newman	Rugged jaspolite plateaux, ridges and mountains supporting hard spinifex grasslands	1,993,741	396.08 (0.02%)
Platform	Dissected slopes and raised plains supporting hard spinifex grasslands	236,335	558.26 (0.14%)

2.3 Vegetation Types

Biota (2016) mapped 30 vegetation types as occurring in the Proposal area (refer also to Figure 3):

Vegetation Mapping Code	**Vegetation Description**	**Area mapped within Proposal Area (ha)** (percentage of Proposal Area)
Vegetation of creeklines and floodplains		
C1: EcAciCEc	*Eucalyptus camaldulensis* subsp. *refulgens* open woodland over *Acacia citrinoviridis* low open forest over **Cenchrus ciliaris* tussock grassland with *Triodia epactia* scattered hummock grasses	1.1 (0.04%)
C2: ExAciAbTeCEcTHt	*Eucalyptus xerothermica* open woodland over *Acacia citrinoviridis* low woodland over *Triodia epactia* very open hummock grassland with **Cenchrus ciliaris, Themeda triandra* tussock grassland	44.1 (1.7%)
C3: ElAciAbTe	*Acacia citrinoviridis*, (*Eucalyptus leucophloia* subsp. *leucophloia*) low open woodland over *A. bivenosa* tall shrubland over *Triodia epactia* open hummock grassland	19.1 (0.7%)
C4: ElAbTe	*Eucalyptus leucophloia* subsp. *leucophloia* scattered low trees over *Acacia bivenosa* shrubland over *Triodia epactia* hummock grassland	19.1 (0.7%)
C5: ElAciAtuAbTe	*Acacia citrinoviridis,* (*Eucalyptus leucophloia* subsp. *leucophloia*) low open woodland over *A. tumida* var. *pilbarensis, A bivenosa* tall shrubland over *Triodia epactia* open hummock grassland	0.4 (0.02%)
C6: ElChAtuPlTe	*Eucalyptus leucophloia* subsp. *leucophloia, Corymbia hamersleyana* scattered low trees over *Acacia tumida* var. *pilbarensis, Petalostylis labicheoides* tall open scrub over *Triodia epactia* open hummock grassland	1.2 (0.05%)
C7: ElAciAmoTe	*Acacia citrinoviridis,* (*Eucalyptus leucophloia* subsp. *leucophloia*) low woodland over *A. monticola* tall shrubland over *Triodia epactia* open hummock grassland	18.4 (0.7%)
C8: ElAmoAmAatTeTw	*Eucalyptus leucophloia* subsp. *leucophloia* scattered low trees over *Acacia monticola, A. maitlandii, A. atkinsiana* tall open scrub over *Triodia epactia, T. wiseana* open hummock grassland	22.3 (0.9%)
C9: AciAaTe	*Acacia ancistrocarpa,* (*A. citrinoviridis*) tall open shrubland over *Triodia epactia* open hummock grassland	7.1 (0.3%)
Vegetation of gorges, gullies and free faces		
G1: ElCfAciAapGbDpTe	*Eucalyptus leucophloia* subsp. *leucophloia, Corymbia ferriticola, Acacia citrinoviridis, A. aptaneura,* (*Grevillea berryana*) low woodland over *Dodonaea pachyneura* tall open shrubland over *Triodia epactia* very open hummock grassland	12.3 (0.5%)

Vegetation Mapping Code	**Vegetation Description**	**Area mapped within Proposal Area (ha)** (percentage of Proposal Area)
G2: ElCfAprAapDpTeERlm	*Eucalyptus leucophloia* subsp. *leucophloia, Corymbia ferriticola, Acacia pruinocarpa, A. aptaneura* low open woodland over *Dodonaea pachyneura* scattered tall shrubs over *Triodia epactia* very open hummock grassland with *Eriachne mucronata* open tussock grassland	57.7 (2.2%)
Vegetation of plains and broad valleys		
P1: ElTaTlo	*Eucalyptus leucophloia* subsp. *leucophloia* scattered low trees over *Triodia angusta, T. longiceps* hummock grassland	339.8 (13.2%)
P2: ElAsAbSENsppTbr	*Eucalyptus leucophloia* subsp. *leucophloia* scattered low trees over *Acacia synchronicia, A. bivenosa, Senna* spp. scattered shrubs over *Triodia brizoides* open hummock grassland	7.9 (0.3%)
P3: ElCdEgAatAexTw	*Eucalyptus leucophloia* subsp. *leucophloia, Corymbia deserticola* subsp. *deserticola* scattered low trees over *E. gamophylla* scattered low mallees over *Acacia atkinsiana, A. exigua* open shrubland over *Triodia wiseana* open hummock grassland	207.5 (8.1%)
Vegetation of hills		
H1: ElEgAmTw	*Eucalyptus leucophloia* subsp. *leucophloia* low open woodland over *E. gamophylla* low open mallee woodland over *Acacia maitlandii* open shrubland over *Triodia wiseana* hummock grassland	14.9 (0.6%)
H2: ElAmTw	*Eucalyptus leucophloia* subsp. *leucophloia* scattered low trees over *Acacia maitlandii* shrubland over *Triodia wiseana* open hummock grassland	15.2 (0.6%)
H4: ElTbr	*Eucalyptus leucophloia* subsp. *leucophloia* scattered low trees over *Triodia brizoides* hummock grassland	142.0 (5.5%)
H5: ElTe	*Eucalyptus leucophloia* subsp. *leucophloia* low open woodland over *Triodia epactia* open hummock grassland	207.4 (8.1%)
H6: ElAciAprTe	*Eucalyptus leucophloia* subsp. *leucophloia* scattered low trees over *Acacia pruinocarpa*, *A. citrinoviridis* tall open shrubland over *Triodia epactia* open hummock grassland	6.3 (0.2%)
H7: ElTw	*Eucalyptus leucophloia* subsp. *leucophloia* scattered low trees over *Triodia wiseana* open hummock grassland	218.1 (8.5%)
H8: ElTwTbt	*Eucalyptus leucophloia* subsp. *leucophloia* scattered low trees over *Triodia wiseana*, (*T. basitricha*) open hummock grassland	211.9 (8.3%)
H10: AiTbr	*Acacia inaequilatera* scattered tall shrubs over *Triodia brizoides* hummock grassland	89.7 (3.5%)

Vegetation Mapping Code	Vegetation Description	Area mapped within Proposal Area (ha) (percentage of Proposal Area)
H11: ElAmAatAexTw	*Eucalyptus leucophloia* subsp. *leucophloia* scattered low trees over *Acacia maitlandii, A. atkinsiana, A. exigua* open shrubland over *Triodia wiseana* hummock grassland	319.8 (12.5%)
H12: ElAiTw	*Eucalyptus leucophloia* subsp. *leucophloia* scattered low trees over *Acacia inaequilatera* scattered tall shrubs over *Triodia wiseana* hummock grassland	175.7 (6.8%)
H13: AciAbTw	*Acacia citrinoviridis* tall open shrubland over *A. bivenosa* open shrubland over *Triodia wiseana* very open hummock grassland	46.5 (1.8%)
H14: AbAeAaTw	*Acacia bivenosa, A. exigua, A. ancistrocarpa* tall open shrubland over *Triodia wiseana* hummock grassland	145.6 (5.7%)
H15: EsTw	*Eucalyptus socialis* subsp. *eucentrica* low open mallee woodland over *Triodia wiseana* open hummock grassland	22.5 (0.9%)
Snakewood/mulga complex		
A1: AxSIfSENsppTlo	*Acacia xiphophylla* tall shrubland over *Sida fibulifera,* (*Senna artemisioides* subsp. *oligophylla* x subsp. *helmsii, Senna* sp. Karijini (M.E. Trudgen 10392)) low shrubland over *Triodia longiceps* scattered hummock grasses	36.8 (1.4%)
A2: AxAapTspp	*Acacia xiphophylla*, (*A. aptaneura*) tall shrubland over *Triodia* spp. very open hummock grassland	22.1 (0.9%)
A3: AapAayTeTw	*Acacia aptaneura, A. ayersiana* low woodland over *Triodia epactia, T. wiseana* open hummock grassland	16.2 (0.6%)
A4: AapAciTeTw	*Acacia aptaneura, A. citrinoviridis* tall shrubland over *Triodia epactia, T. wiseana* open hummock grassland	26.6 (1.0%)

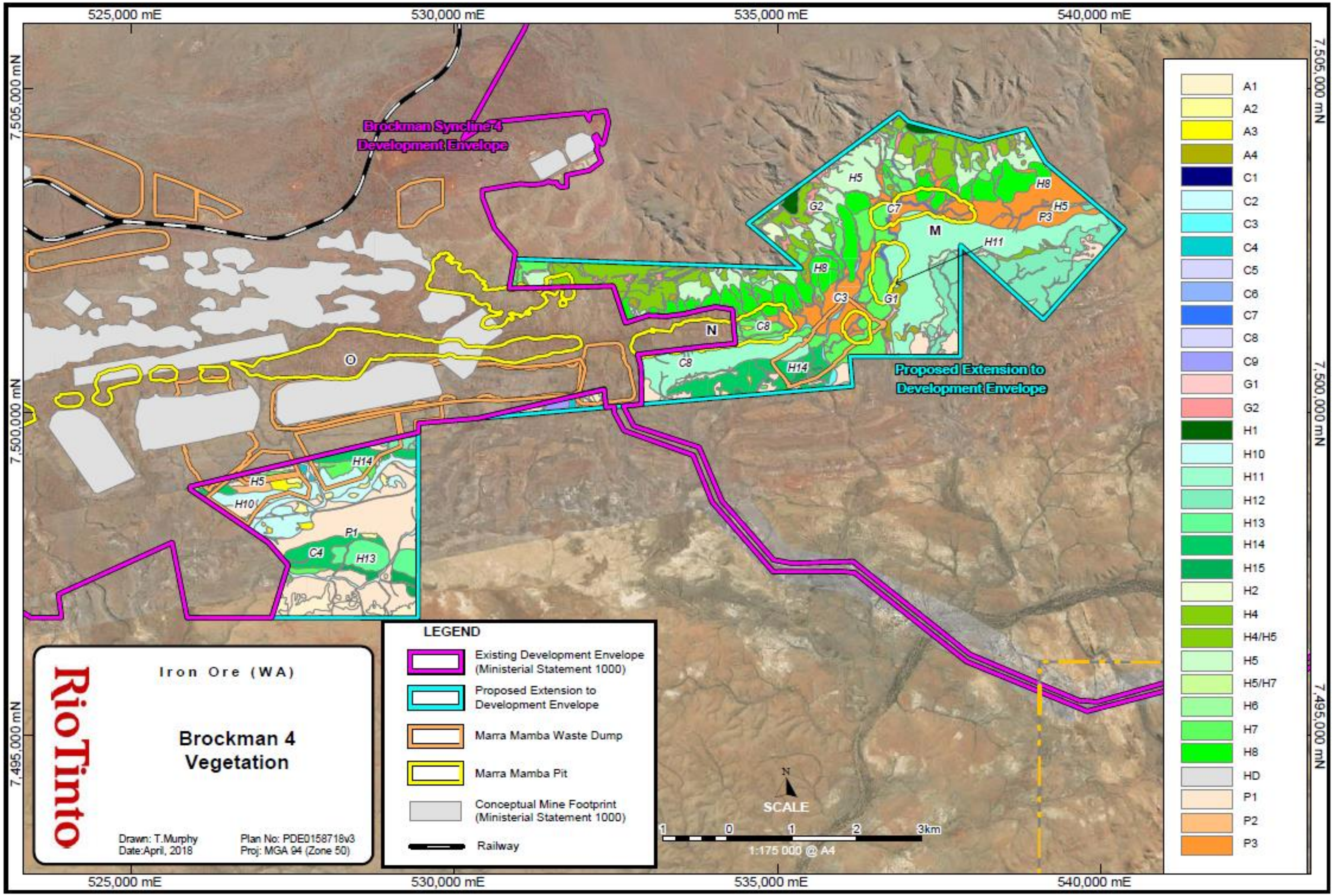

Figure 3: Vegetation mapping of the Proposal area

Several vegetation types were identified by Biota (2016) as being of elevated local significance:

- **Vegetation types G1 and G2:**

  The narrow rocky gully creeklines, walls of gorges and broad valleys and rocky faces were considered by Biota (2016) as restricted landforms, although common across the grater Brockman area. Approximately 70 ha of these two vegetation types associated with these landforms have been mapped in the Proposal area.

  The Proposal disturbance footprint (based on the current mine plan) within the Proposal area does not intersect these two vegetation types.

- **Vegetation type A1:**

  This vegetation was mapped in association with the Wona Land System and supported snakewood on plains with cracking clay. Approximately 37 ha of this vegetation type has been mapped in the Proposal area. The Wona Land System occurs primarily in the Chichester Range sub-region and as scattered occurrences in the Hamersley sub-region. The Priority Ecological Community (PEC) "Four plant assemblages of the Wona land system" is associated with this land system, however, no currently defined boundaries of the PEC are located within 30 km of the Proposal area. Approximately 197 ha of the mapped occurrence of the Wona Land System intersects the Proposal area (or 0.1% of the total Wona Land System mapped in the Pilbara region).

  The Proposal disturbance footprint (based on the current mine plan) within the Proposal area does not intersect the vegetation type A1 of the Wona Land System.

- **Vegetation type C1:**

  This vegetation type was mapped as occurring on a small tributary to the Beasley River. The condition of the vegetation was assessed as being in very poor condition due to the dominance of buffel grass (*Cenchrus ciliaris*) in the understorey. Approximately 1.1 ha of this vegetation type was mapped in the Proposal area.

  The Proposal disturbance footprint (based on the current mine plan) within the Proposal area does not intersect this vegetation type.

2.4 Vegetation Condition

At the time the Biota (2016) vegetation survey, the majority of the vegetation was assessed as being in Excellent to Very Good condition, noting the condition of some mapped representations of vegetation types C1 and C2 were assessed as being in Good to Very Poor condition.

2.5 Significant Flora

The following currently listed Priority (P) flora species have been recorded from within the combined Brockman Syncline 4 existing Development Envelope (Ministerial Statement 1000) and the proposed Development Envelope extension area (the Proposal area) (refer also to Figure 4):

Species	Conservation Ranking	A Total recorded population on Rio Tinto database (# individuals)	B Records within existing Development Envelope + proposed Development Envelope extension	Records potentially impacted by the Proposal (based on current mine plan – within existing Development Envelope + proposed Development Envelope extension)	
				# of individuals	% of total recorded in Rio Tinto database (A) % of total recorded within Development Envelope + proposed Development Envelope extension (B)
Goodenia pedicellata	P1	3,099	21	0	0
Hibiscus sp. Mt Brockman (E. Thoma ET 1354)	P1	6,710	145	0	0
Sida sp. Hamersley Range (K. Newbey 10692)	P1	2,904	330	0	0
Hibiscus sp. Gurinbiddy Range (M.E. Trudgen MET 15708)	P2	1,829	79	0	0
Oxalis sp. Pilbara (M.E. Trudgen 12725)	P2	253	53	0	0
Pentalepis trichodesmoides subsp. *hispida*	P2	602	1	0	0
Eremophila magnifica subsp. *velutina*	P3	3,147	1	0	0
Oldenlandia sp. Hamersley Station (A.A. Mitchell PRP 1479)	P3	1,674	953	1	0.06 0.1
Ptilotus subspinescens	P3	29,084	12,673	425	1.5 3.4
Triodia basitricha	P3	99,926	3,170	0	0
Acacia bromilowiana	P4	2,455	96	0	0
Goodenia nuda	P4	7,371	127	11	0.15 8.7

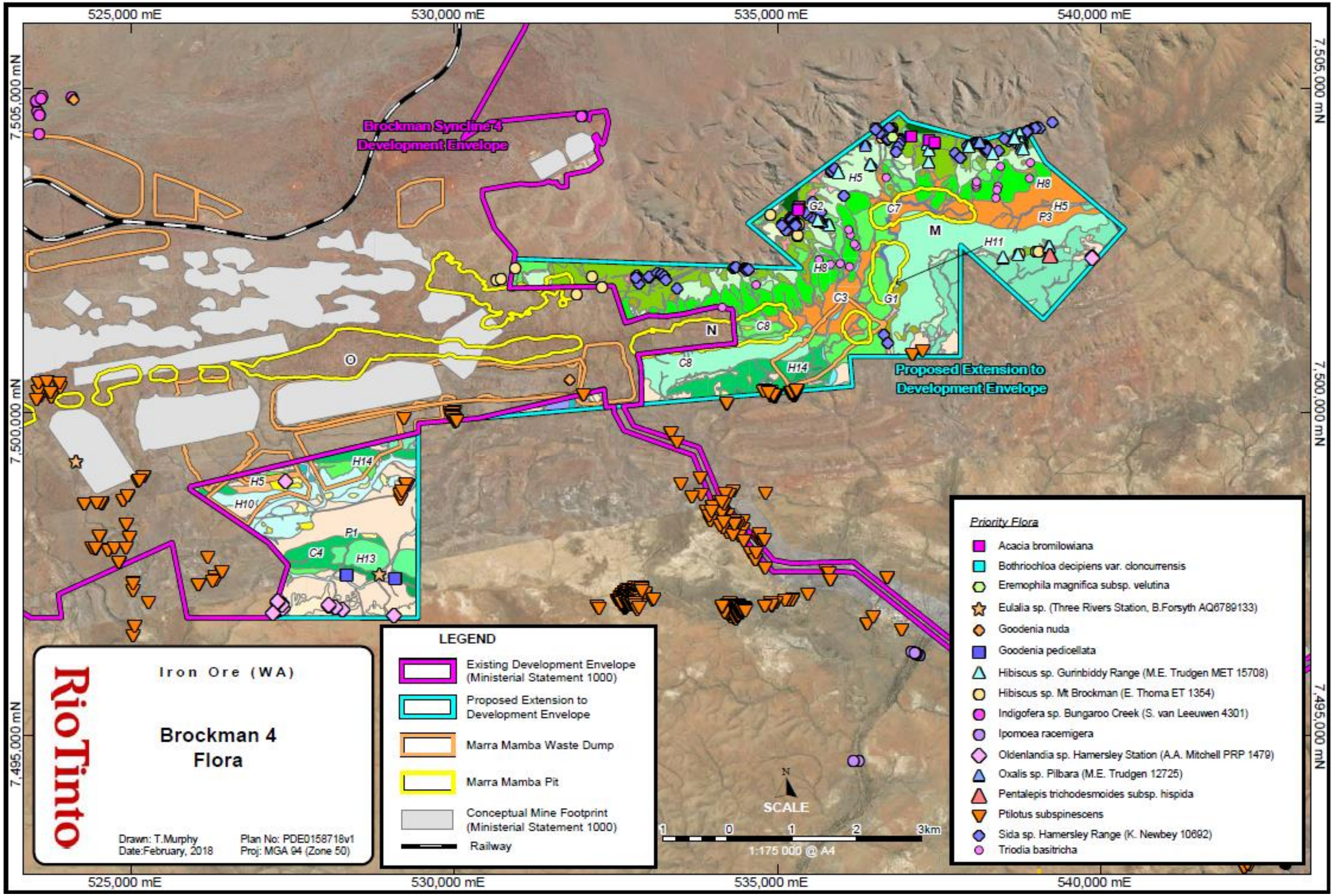

Figure 4: Conservation significant flora of the Proposal Area

3. Flora and Vegetation of Boolgeeda Creek (Discharge Creek)

3.1 Vegetation

Two dominant vegetation units were mapped by Ecological Australia (2015) in the additional 10 km stretch of Boolgeeda Creek (from approximately 40 km downstream of the surplus water discharge point to approximately 50 km downstream of the discharge point – covering the additional stretch of the creek that the cumulative surplus water discharge is predicted to extend – refer to Figure 1):

- F8: AciApyPlCEcTe – *Acacia citrinoviridis* open woodland over *A. pyrifolia, Petalostylis labicheoides* tall open shrubland over **Cenchrus ciliaris* open tussock grassland over *Triodia epactia* very open hummock grassland; and
- C7: EvEcAcimgCEcTe – *Eucalyptus victrix, E. camaldulensis* woodland over *Acacia citrinoviridis* low open woodland over *Melaleuca glomerata* tall shrubland over **Cenchrus ciliaris* scattered tussock grasses over *Triodia epactia* scattered hummock grasses.

The vegetation condition was assessed as ranging from Poor to Very Good.

The vegetation of the survey area is consistent with major ephemeral water course ecosystems considered to be 'at risk' from various threatening processes.

3.2 Significant Flora

One P3 taxon was recorded during the survey: *Indigofera* sp. Bungaroo Creek (S. van Leeuwen 4301). Approximately 2,837 individuals of this species were recorded from 352 locations during the survey (Ecological Australia 2015).

Rio Tinto

Water Resource Evaluation and Services

BS4 and BS4 MM - updated surplus dewater discharge into Boolgeeda Creek

January 2016

A baseline hydrology assessment of Brockman Syncline 4 (BS4) surplus dewater discharge into Boolgeeda Creek estimated that surplus discharge of 17.5 ML/d would result in a footprint extent of 37 km. As a result the BS4 operation has approval for the discharge of surplus water into Boolgeeda Creek up to a footprint extent in the creek of 37 km.

Development of the Brockman Syncline 4 Marra Mamba (BS4 MM) deposits below the water table will generate an increased volume of surplus water as a result of dewatering. To minimise environmental impacts that would arise from alternative discharge locations, it is proposed that the additional water is discharged into Boolgeeda Creek at the same location as the existing BS4 discharge.

Hydrogeological modelling to-date suggests that the potential peak surplus discharge into Boolgeeda Creek will be 35 ML/d; combined from BS4 and BS4 MM dewatering. Discharge extent modelling undertaken in this study estimated that the maximum footprint extent from this rate of discharge will be 46 km downstream of the discharge location. It is expected that water released into Boolgeeda Creek at 35 ML/d will be contained within the main channel.

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	Name	Signature	Date

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Contents page

Introduction

1. Issue

Surplus water is generated as a result of mining below the water table. The volume and rate of surplus water generation will be determined by the difference between the rate at which Rio Tinto and other parties can use the water and the rate of abstraction. Results from hydrogeological modelling (RTIO-PDE-0134681) (August 2015) suggests that the total surplus water discharge into Boolgeeda Creek required from Brockman Syncline 4 (BS4) and the development of Brockman Syncline 4 Marra Mamba (BS4 MM) will reach a combined peak rate of 35 ML/d.

Management of water on Rio Tinto sites follows its own strict environmental and water use standards. These standards align with the Western Australian State Government Department of Water hierarchy of disposal options informal regulatory guidelines (Bessan Consulting Services, 2007) that recommend (in order of preference):

- Use on site
- Transfer to another site or industrial location
- Reintroduction to aquifer(s) (e.g. discharge to mined out voids, passive reinjection)
- Controlled discharge to natural watercourses (e.g. irrigation, storage and periodic discharge)
- Uncontrolled discharge to natural watercourses

Currently there are no opportunities for reinjection of surplus water at BS4. Hydrogeological assessment indicates that there are no suitable local aquifers, with sufficient storage, where active reinjection via a borefield is feasible. In addition, the mine is currently in its expansion phase and no mined-out voids that could be used for passive reinjection exist.

Surplus water at BS4 is therefore managed in the following order:

- Security of supply for BS4 plant operations
- Transfer to other assets for beneficial use,
- Controlled discharge to surface drainage into Boolgeeda Creek

The intent of controlled discharge to local creeks is to recharge local groundwater aquifers adjacent to the abstraction area and to keep water on Country[1], while minimising the potential environmental and ecosystem impacts that can be introduced as a result of creating continuous shallow surface water flows in naturally ephemeral creeks. Ministerial Statement 1000 (**MS 1000**) authorises the discharge of surplus water from BS4 to Boolgeeda Creek with a maximum discharge footprint of 37 km from the point of discharge (as measured under natural no-flow conditions).

2. Objectives

The purpose of this study was to predict the hydrological reaction of Boolgeeda Creek to artificial discharge. The specific objectives of the assessment were:

[1] Country refers to ethnographic regions of significance to Indigenous Australian communities encompassing land, ecosystems and heritage values.

- To establish the **hydrological characteristics** of Boolgeeda Creek downstream of the discharge location. This was accomplished by reviewing the stream pattern, river/floodplain geometry, soil profile/geological logs, vegetation patterns and community distribution and other characteristics of the receiving creek to establish representative "reaches".
- To determine the **hydraulic characteristics** associated with different rates of water released into the system. This work was undertaken to determine the capacity and reaction (water movement) of the creek at different discharge rates.
- To establish the area over which the released water would be likely to travel; the **discharge footprint** or extent.

The results of this work will be used to inform the environmental impact assessment of increased discharge to Boolgeeda Creek that would result from the proposed simultaneous operation of BS4 and BS4 MM.

3. Introduction to hydroecology

The dearth of hydrological data in the Pilbara, especially related to small and medium sized catchments, their stream flow and rainfall distribution patterns, makes it impossible to use standard hydrology assessment methodologies to determine surface water flow characteristics in local Pilbara catchments. To overcome this limitation and to provide a methodology for estimating the potential flow conditions of artificial discharge into ephemeral Pilbara creeks, hydroecology techniques for evaluating water movement have been adopted.

Hydroecology is the inter-disciplinary study of the interactions between ecological processes and water movement. For the purpose of this study, information that could be extracted from the Pilbara landscape to help describe baseline hydrological characteristics, in the absence of historical stream flow or climate series data, included: vegetation patterns and communities in the riparian zone, pool location/absence and water quality, geomorphology of the creek bed, banks and floodplain, and soil/regolith geology properties and patterns (particularly as recorded in satellite remote sensing imagery). These catchment characteristics are subsequently used to define the inputs to the discharge modelling.

4. The modelling approach

4.1 Defining the discharge footprint

How creeks behave and where water moves and pools when it is artificially added to a creek system are dependent on many interconnected variables, including discharge volume, creek bed topography, alluvial/colluvial thickness, evaporation, evapotranspiration and recent rainfall. Thus creek behaviour will vary over time, with season and with changes in weather. This makes it difficult to map when and where changes to the system may occur and when those changes may impact other aspects of the creek ecology.

However, two important characteristics of the artificial discharge that can be quantified for a specified discharge rate in order to provide a basis for an assessment of the creek ecosystem reaction are (Figure 1):

- the minimum distance surface water will consistently flow along the surface of the creek bed, where the creek bed will be constantly saturated, and
- the maximum possible extent of surface water expression of any artificial discharge downstream of the location (maximum surface water inundation) or “discharge footprint”, where the creek bed may become saturated after a period of continuous discharge once steady state conditions are established but may not have constant surface water flow.

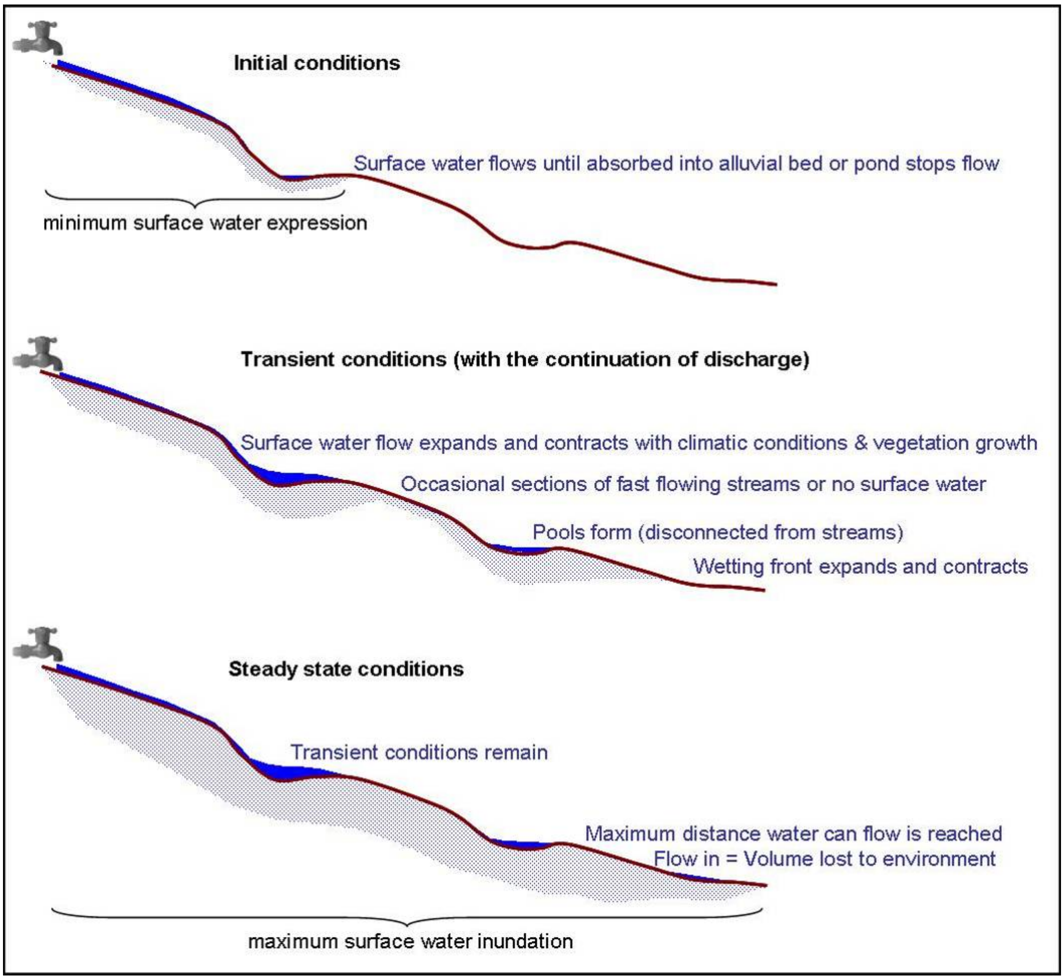
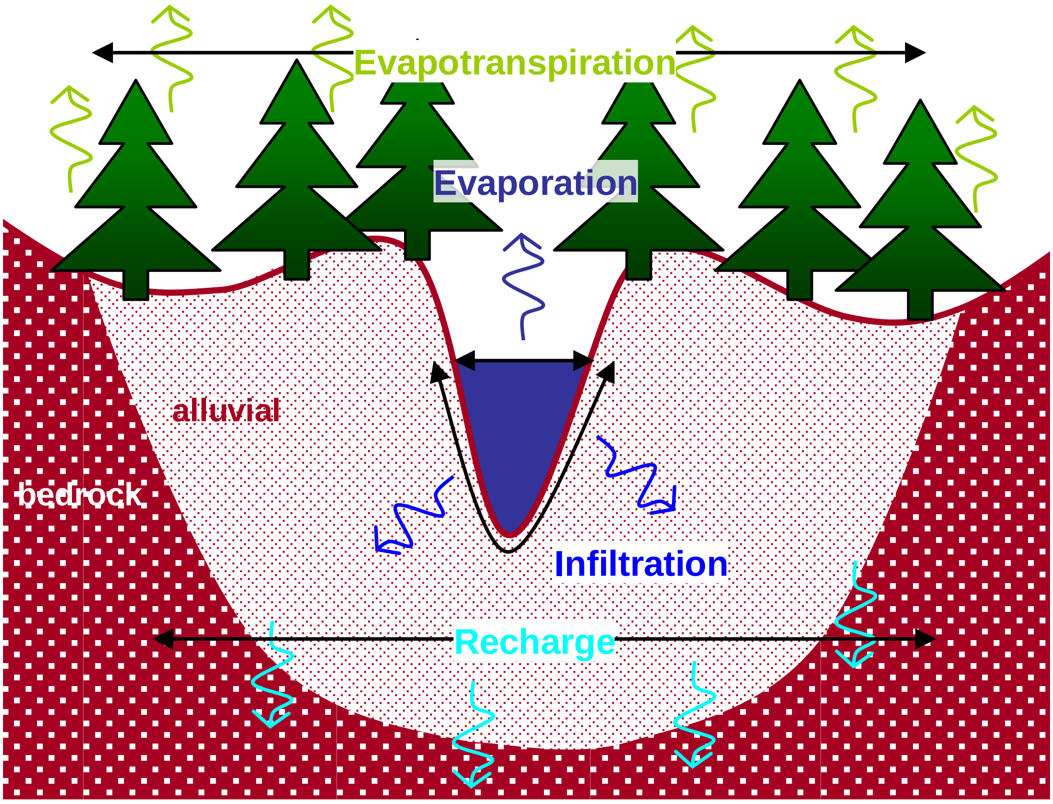


Figure 1: Reactions states to creek discharge.

As illustrated in the creek cross section in Figure 2, water discharged to a creek will flow along the surface of the creek, losing water via infiltration or evaporation; until the volume of water dissipates into the creek bed or is dammed by a small change in the creek bed topography (see Figure 1 – **initial conditions**).

As the creek bed becomes saturated, there is less room (pore space) for water to infiltrate into the creek bed. Infiltration rates will subsequently reduce as the wetting front moves through or around creek bed materials with lower porosity, i.e. clays, calcretes and even roots. When the volume of water flowing down the creek exceeds the volume of water removed from the creek via storage, recharge (loss beyond the root zone), evaporation and evapotranspiration, water will then start to flow across the creek bed again and the distance the surface water is seen to flow down the creek increases (see Figure 1 – **transient conditions**).

Water will also move obliquely through the creek bed, albeit at a slower rate, if the effort required for the water to move vertically is greater than the effort to move horizontally. This can be the case if the pore space rapidly decreases vertically, for example with buried clay lenses, calcrete or shallow bedrock, or if there is a preferential pathway (micro-scale) of higher porosity within the alluvial sediments, such as those generated by plant roots, sand seams or rock fractures. This oblique water movement, also referred to as through-flow or interflow, enables water to return to the surface as surface water flow when the depth to the buried barrier decreases or the creek bed slope suddenly increases (break-of-slope); creating streams, increasing stream flow and/or creating pools.



Water balance equation:

Footprint length (m) = discharge volume (m^3/s) / [evaporation x flow top width (m) + (evapotranspiration+recharge)(m/s) x riparian zone width (m)]

$$\text{Footprint length (m)} = \frac{\text{discharge volume } (m^3/s)}{\text{evaporation} \times \text{flow top width (m)} + (\text{evapotranspiration+recharge})(m/s) \times \text{riparian zone width (m)}}$$

$$\text{Surface water expression (m)} = \frac{\text{discharge volume } (m^3/s)}{\text{evaporation } (m/s) \times \text{flow top width (m)} + \text{infiltration } (m/s) \times \text{wetted perimeter (m)}}$$

Figure 2: Stylised water balance cross section and equations for estimating discharge impact.

Thus the degree of creek bed saturation, and the potential for water to be seen to flow over the creek bed, is influenced by creek bed topography and transient variations in climate, e.g. daily evaporation rates, seasonal evapotranspiration variations, rainfall and humidity. As a result, transient flow conditions dominate; such that the discharge may not be seen to continuously flow over the creek bed, although water may continue to flow through it.

Eventually, given relatively static environmental and atmospheric conditions, the system reaches equilibrium; when the volume of water entering the system is equal to the volume of water leaving the system through evaporation, evapotranspiration and losses beyond to root zone (recharge) (Figure 2). The length of the creek over which the discharged water is lost to the environment for these generalised “static” environmental and atmospheric conditions is described as the maximum[2] surface water inundation or ‘discharge footprint’ (see Figure 1 – **steady state conditions**).

[2] The minimum distance of surface water expression is differentiated from the distance of maximum surface water inundation through the use of surface infiltration rates instead of evapotranspiration and recharge rates.

4.2 Establishing the water balance inputs

Definitive spatial data and temporally varying climate, infiltration, evapotranspiration and soil information is generally not available for Pilbara creek tributaries. This makes it impossible to use two-dimensional or numerical models to accurately map catchment and creek response. As an alternative, an empirical methodology was developed employing the simple, conservative water balance equations from Figure 1 to estimate the length of the creek over which the discharge is lost to the environment.

Each branch of the creek below the discharge location is divided into sections or "reaches" with similar catchment characteristics. The reach length depends on the homogeneity of the system, but is expected to range between 1 and 10 km. Inputs such as evaporation, evapotranspiration and infiltration beyond the soil root zone (recharge) are then assigned to the reach based on measurable catchment characteristics or information inferred from the catchment characteristics.

4.3 Applying the water balance equations

The two water balance equations, the surface water expression and footprint length, are used to account for the different ways water moves and is removed from the creek. Under most circumstances the factors that limit water loss are associated with the creek bed infiltration rates, represented in the surface water expression, and the rate at which water can be lost beyond the root zone, akin to recharge, which is dependent on the hydrogeological characteristics of the subsurface geology and defined within the footprint length equation.

Both equations are applied to each reach. The equation which allows the smallest volume of water to be lost from the reach defines the maximum loss rate for the reach and is referred to as the limiting factor. Understanding the limiting factor for the reach can help to interpret the reaction of the creek to the discharge, as discussed in the subsequent section. The discharge rate for the next downstream reach is subsequently defined as the previous reach discharge rate minus the previous reach maximum loss rate. This process is continued down each reach until the equations show no flow remains on the surface (surface water expression converges to zero) and the total volume of water has been divested to the environment (footprint length converges to zero).

As illustrated by Figure 1, if there is a difference between the surface water expression distance and the footprint length, transient flow conditions are expected between the two measurements. Within the transient flow zone:

- The surface water expression will expand and contract with climatic conditions and vegetation growth as evaporation, transpiration and rainfall contributions change;
- Sections of fast flowing streams or no surface water flows may form; and
- Pools disconnected from surface water flows may be created.

The one dimensional water balance equations from Figure 2 are designed to provide a theoretical description of the annual average behaviour of the surplus discharged water as it moves down the creek.[3] As each reach is understood to encapsulate, as far as practicable, one ecosystem, interpretation of the degree of impact to the environment or the ecosystem can be primarily attributed on a reach by reach basis.

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[3] No calibration is undertaken using this methodology. This methodology is not recommended as a surrogate for monitoring discharge impacts.

The model is static such that the loss and gain rates are assumed to be sustained over the life of the discharge. If the rates are expected to change over the life of the discharge, a separate model with the different rates is required to demonstrate how the change influences the discharge footprint.

5. Interpreting impacts using the water balance model

5.1 Surface water – groundwater connectivity

The movement of surface water to groundwater aquifers has the potential to remove the largest volume of water from the creek. “In connected water resources[4], the flow of water between the surface water feature and the aquifer is called the *seepage flux*. The convention is that positive seepage flux indicates upwards groundwater flow to the stream.” Converse to seepage flux, recharge is positive when water volume is lost from the reach and negative when water is gained. (Note recharge is used in the mathematical equations employed in this study)

On a regional or creek system scale, surface water and ground water interactions are broadly described as (after Winter et. al., 1998):

- Gaining groundwater inflow (Figure 3) where seepage flux is positive. In the Pilbara gaining creek systems are characterised by permanent to semi-permanent water features such as pools or springs.
- Losing water to the underlying aquifer (Figure 4) where seepage flux is negative, however there is a connection (hyporheic zone) between the surface water and groundwater systems. In the Pilbara losing creek systems are characterised by semi-permanent pools, dense riparian vegetation, and shallow groundwater tables.
- Indirectly connected (or disconnected) losing stream (Figure 5) where seepage flux is negative with no hyporheic zone. In the Pilbara indirectly connected creek systems are characterised by the absence of surface water features and poorly defined riparian vegetation.

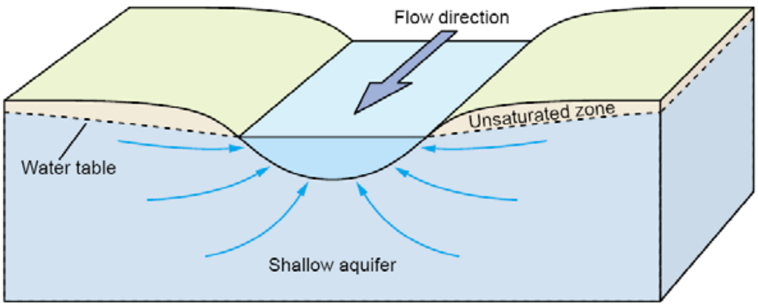

Figure 3: Schematic representation of surface water – groundwater interaction for a gaining system (after Winter et al., 1998).

[4] Sourced from http://www.connectedwater.gov.au/processes/index.html accessed 5 May 2010, defining a *connected water resource* as the combination of surface water feature(s), such as a river, estuary or wetland, and the groundwater system(s) that can directly interact in terms of movement of water.

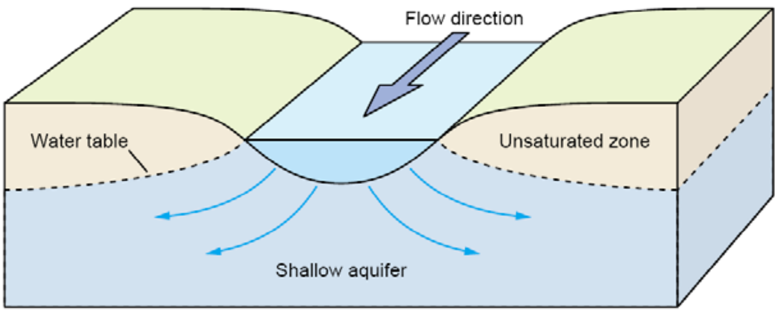

Figure 4: Schematic representation of surface water – groundwater interaction for a losing system with saturated connection (after Winter et al., 1998).

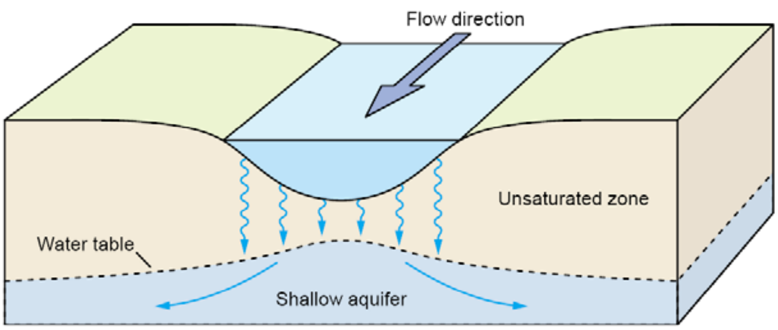

Figure 5: Schematic representation of surface water – groundwater interaction for an indirectly connected losing system demonstrating unsaturated connection with the groundwater aquifer (after Winter et al., 1998).

Some creek systems may always gain groundwater, or alternatively always lose water to groundwater. In most cases the water exchange direction varies significantly along a creek and water movement can alter in very short timeframes or seasonally in response to flooding or evapotranspiration (Winter et. al., 1998). Thus the average seepage flux condition is used to characterise the creek system.

5.2 Reach characterisation

In the ephemeral, flash flood prone creek systems of the Pilbara, the effect (or impact) of creek discharge[5] on a creek system is observed on a local scale, e.g. on scales less than the length of a reach. Thus it is necessary to characterise and predict the more complex, local scale behaviour of the water movement in order to appreciate and subsequently assess the impact of discharge within the discharge footprint.

On a local scale, water movement within a creek can be observed to:

- Flow over the creek bed (surface flow)
- Move in and out of creek bed and bank alluvial materials (interflow), changing the volume of surface flow without changing the total volume[6] flowing down the reach
- Gain volume from confined or unconfined groundwater aquifer discharge, changing water chemistry[7]

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[5] The rate water is discharged into creek as a result of groundwater abstraction activities is usually orders of magnitude less than the peak flow volume generated during the smallest of floods. However, the duration of the discharge can significantly exceed the natural stream flow duration.

[6] Total flow volume is the proportion of the original discharge plus any additional groundwater discharge defined as the input discharge rate for the reach.

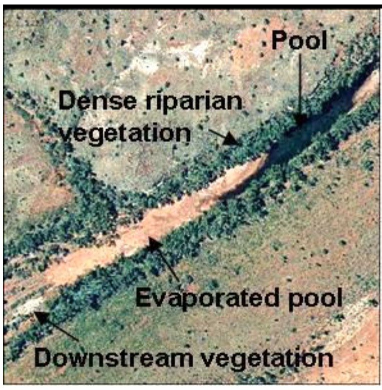
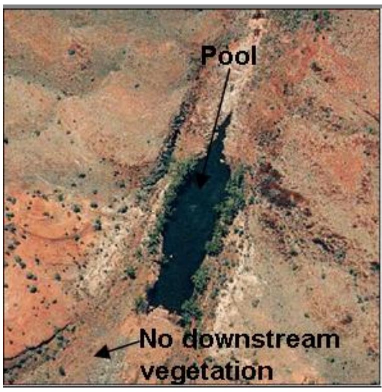
[7] Applicable when groundwater chemistry is different from surface water chemistry

- Mix with groundwater in the hyporheic zone, changing water chemistry[8] with or without changing total flow volume
- Lose volume to the atmosphere and riparian vegetation, or
- Lose volume to recharge into groundwater aquifers

These characteristics are identified as part of the reach characterisation and are represented in the water balance model through the input selection.

Within our model it is necessary to establish, often in the absence of monitoring data, whether a reach is gaining, neutral or losing to select the appropriate recharge rate from a wide selection of possible values (refer to Section 9 Hydrogeology). This is achieved through the interpretation of reach conditions, dominantly the interpretation of aerial photography. Building on the regional scale descriptions, Table 1 highlights the main interpretation triggers used to establish the recharge conditions for the reach. For interpretation of flow conditions in the Pilbara it is important that the aerial photography is taken during a dry season[9] to ensure pools visible in the imagery are semi-permanent to permanent.

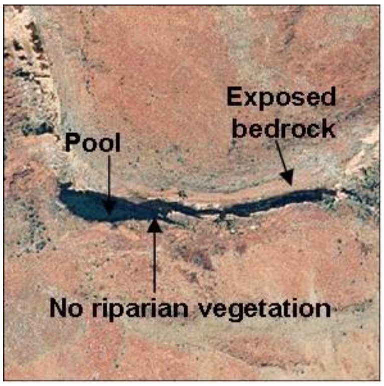
Table 1: Interpretation triggers for defining recharge conditions

Typical image	Condition description
	**Negative recharge** (Gaining system) Negative recharge rates typify systems where sufficient groundwater is contributed to the creek such that the water creates surface and/or subsurface flow. The reach is characterised by visible pools or algae deposits (where the pools have evaporated) surrounded by dense vegetation. Vegetation downstream of pool is located on local preferred flow pathways often creating rows of vegetation, indicating water is flowing away from pool or spring, moving subsurface. Bedrock geology is used to define the likely discharge (negative recharge) rate based on regional hydrogeology.
	**No loss/no gain** (Gaining system) No loss and no gain reaches within a gaining system represent reaches where there is only sufficient discharge to sustain vegetation adjacent to the pool or spring and balance evaporation rates. The water does not move away from the spring, such that there is no vegetation downstream. The pool evaporation and vegetation evapotranspiration rate for the reach are used to estimate the discharge rate, as these values are expected to be in equilibrium. Systems without pools but similar dense riparian vegetation due to shallow groundwater tables may also be classified as **No loss/no gain** (Losing connected system). In this case, groundwater is removed from the aquifer to sustain vegetation, at a rate equal to evapotranspiration rates. Thus although technically a losing groundwater system, the capacity to remove water from the reach is so limited as to be neutral.

[8] Applicable when groundwater chemistry is different from surface water chemistry

[9] Due to the sparse distribution of rainfall gauges it is usually impossible to define quantitatively when the last rainfall event occurred in any particular creek.

Table 1: Interpretation triggers for defining recharge conditions

Typical image	Condition description
	**No loss/no gain** (Losing indirectly connected system) No loss and no gain reaches are also established where the bedrock beneath the pool is an aquitard or aquiclude, limiting groundwater interaction. The absence of vegetation and the expose of bedrock near the pool suggest alluvial material in the reach is very thin if present, such that it is regularly saturated and/or unable to sustain vegetation. The water in the pool is sourced from creek flow and runoff, but may also be the terminus for an upstream spring. Water is removed slowly via evaporation only. Thus there is no recharge or discharge.
	**Positive recharge** (Losing connected system) Positive recharge rates may be attributed to losing connected systems, where vegetation patterns indicate there is a regular supply of groundwater within reach of the root zone, yet there are no signs of a permanent pool. The absence of permanent pools suggests there is storage capacity within the creek alluvial material, such that water can contribute to recharge. However, the presence of groundwater within the root zone suggests the loss rate will be limited. The recharge rate is based on a reduced bedrock geology representative regional hydrogeology rate. (Also see **No loss/no gain** - Losing connected system)
	**Positive recharge** (Losing indirectly connected system) Positive recharge rates represent losing systems where there is no evidence of groundwater influence on the reach vegetation patterns. This is the most common condition of ephemeral Pilbara creeks. Bedrock geology is used to define the likely recharge rate based on regional hydrogeology.

5.3 Predicting the response of surplus discharge

The maximum loss rate that can be sustained by a reach will be the minimum of the surface water infiltration plus evaporation rates or the recharge plus evapotranspiration rates. As discussed previously, this maximum loss rate is referred to as the limiting factor.

Water movement that is limited by surface infiltration is generally associated with indirectly connected losing reaches. Flow is generally constrained to the narrow geometry of the low flow channel. This limits the contact area with the creek alluvials (wetted perimeter), limiting the volume of infiltration.

While these conditions proportionally increase the distance over which the surface water flows will travel, this situation can produce the smallest impact to the environment. As water is contained within the low flow channel, an area characterised by the absence of vegetation, the sustained creek bed saturation is unlikely to impact the root zone of bank vegetation or waterlog topsoil which can lead to reduced plant vigour or vegetation death. Conversely, the additional water supply may increase plant available water resulting in increased vegetation vigour and recruitment.

When loss is limited by recharge and evapotranspiration, the factor limiting recharge is the vertical hydraulic permeability (k) of the subsurface geology. As a result of the subsurface vertical movement constraint, water movement constrained by subsurface geology is most likely to create the widest footprint. Infiltration impounded at the alluvial – bedrock interface forms a mound. From the developing subsurface mound, water moves in a direction independent of the surface flow direction, perpendicular from the surface flow direction if the creek alluvial materials are homogeneous or alternatively following preferential subsurface paths within the creek bed alluvials creating interflow. Depending on the local creek and flood plain morphology, interflow has the potential to move in and out of the creek bed as the alluvial storage volume increases and decreases. These conditions also have the potential to create transient pools away from the low flow channel in topographic lows in adjacent channels or billabongs (lows lying areas behind the creek banks) that share the same alluvial system.

Sustained discharge into ephemeral creek reaches under subsurface geological constraints is likely to produce the greatest degree of change in the reach. For example, the formation of permanent pools outside the low flow channel may reduce the vigour of plants sensitive to sustained saturated soil conditions. Conversely, in groundwater fed reaches and those where pools regularly form after rainfall, the sustained water supply may be within the range of the natural flow volume contributing to the creek system. As a result the pools formed and sustained may be within the natural system variability and are unlikely to have an impact on the reach. The additional discharge may even drought proof the reach, which could benefit the area.

As Pilbara creeks are generally ephemeral, whatever the behaviour of the discharge within the creek, creek bank materials and geometries do not generally take a form that is designed to stand up under sustained saturation, whether it is just the toe of the bank or the whole bank that is saturated. Thus sustained creek flow can result in bank degradation leading to collapse, which may be exacerbated by vegetation death due to saturated soil conditions. The collapsed banks will create a new local flow regime, as experienced naturally after flooding events, which may or may not impact the environment and local ecosystem. As it is impossible to determine the potential for bank collapse from the data available for this type of assessment, no further commentary on creek bank stability is provided.

6. Hydrology

Boolgeeda Creek catchment covers an area of approximately 1,650 km^2 and is a tributary of Duck Creek within the regional Ashburton River catchment (Figure 6). The headwaters for the Boolgeeda Creek catchment rise from the mountain ranges of Mount Brockman and the Hamersley Range. It is characterised by a braided, meandering creek dominated by multiple active and inactive flow channels within a broad valley. The creek becomes more defined when it enters a gorge system downstream of BS4 operation, before discharging into Duck Creek at Lawloit Range. The general absence of permanent and semi-permanent water features suggests it is a relatively dry system, typical of ephemeral creeks in the Pilbara.

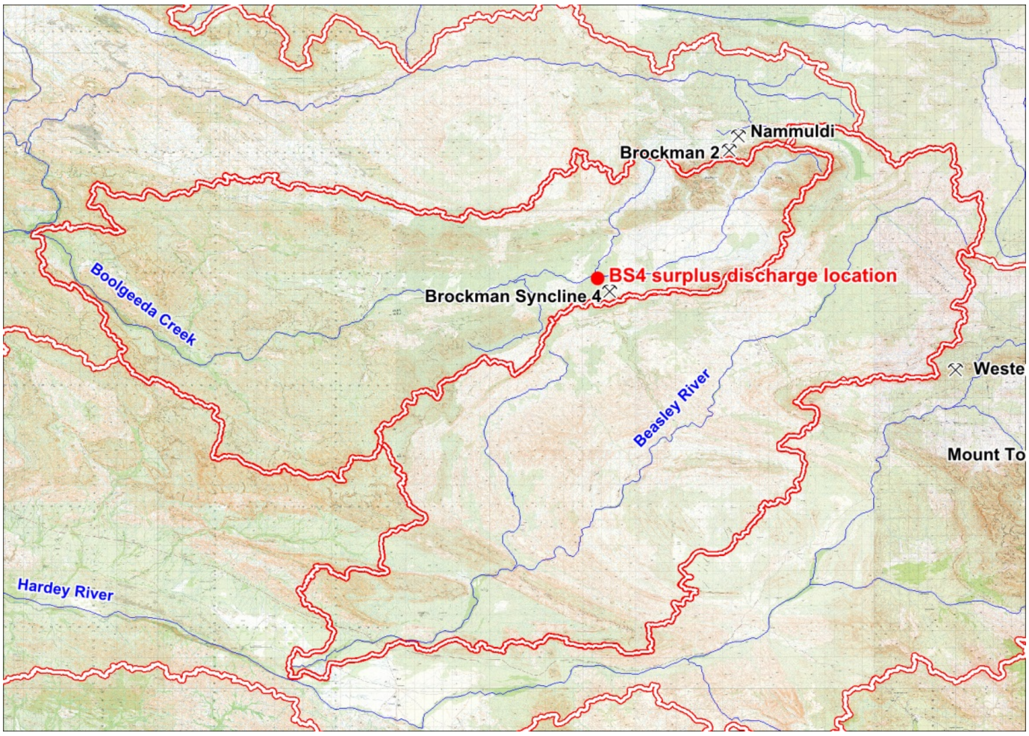


Figure 6: Boolgeeda Creek catchment showing the BS4 surplus discharge location

Boolgeeda Creek is characterised by active creek beds of coarse sand and gravel that are likely to be reworked during flow events. A comparison between the 2005 and 2006 aerial imagery[10] identifies locations where significant scouring and widening of the creek bed had occurred due to flooding (Figure 7). 2006 was a cyclone prone year with five cyclones passing through the Pilbara region between January and April: Daryl and Clare in January, Emma in February, Glenda in March and Hubert in April. Scouring along the creek bed had resulted in the loss of riparian vegetation, suggesting the flood water flows at high velocity (Figure 7). There is also photographic evidence of the development of new secondary flow channel following these flood events. This indicates the system is dynamic, and naturally capable of changing course and flow conditions.

[10] The 2005 aerial photograph originates from the RTIO database and was flown in November before the wet season; the 2006 aerial imagery is provided by Google Earth.

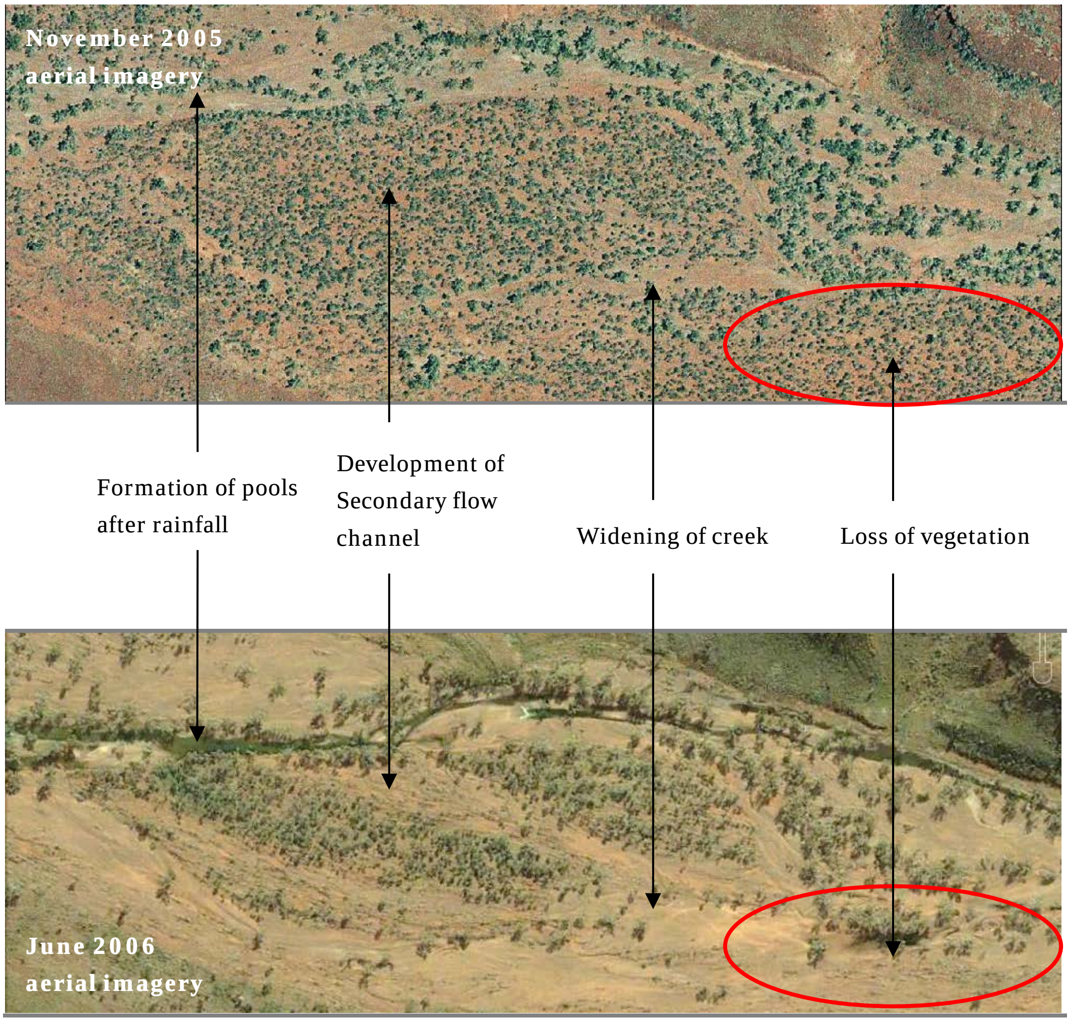


Figure 7: Comparison between 2005 and 2006 aerial imagery showing scouring and widening of the Boolgeeda Creek system following significant flood events

There are no permanent stream gauging stations in the Boolgeeda Creek catchment. The Index Flood method was used to estimate design flood quantiles in Boolgeeda Creek at the discharge location (MGA50 coordinates 521783E; 7504099N) for a comparison to the expected peak surplus discharge rates. The catchment area to the discharge location is 246 km^2 , with design floods for the 2 year and 100 year ARI events estimated to be 148 m^3/s and 3310 m^3/s, respectively. The expected peak surplus discharge of volume of 35 ML/d is equivalent to 0.4 m^3/s, which is several orders of magnitude lower than the most common flood events. It is therefore anticipated that the discharge will have negligible impact on flood events.

7. Rainfall

Using the Köppen climate classification scheme[11] based on temperature and rainfall, the Boolgeeda Creek catchment is described as grassland: hot (persistently dry). There are no local long term rainfall stations at the BS4 site. However, long term daily gridded rainfall data is available across Australia from the Bureau of Meteorology (BoM, 2012b). The gridded data is derived (weighted average) from recorded daily rainfall and is provided for areas with sides approximately 5km by 5km.

In the absence of long term recorded rainfall data from the BS4 site, BoM gridded data was considered to be suitable for use as an estimate of site rainfall. BS4 daily rainfall from 1906 to

[11] http://www.bom.gov.au/lam/climate/levelthree/ausclim/koeppen2.htm

2015 was obtained for the centroid of the site and used for rainfall analysis.

The long term mean annual rainfall for the BS4 is 362 mm, with a range of 94 mm to 849 mm illustrating the high inter-annual variability. A trend analysis of annual rainfall indicates a long term increasing trend of 1.2 mm/year, Figure 8. The trend increases substantially to 6.4 mm/year when considering only the last 20 years. A similar rising trend has been observed at multiple locations in the Pilbara region.

The Coefficient of Variation (CV) of annual rainfall, used as a measure of inter-annual variability, is calculated as the ratio of the standard deviation to the mean annual rainfall. The CV of annual rainfall for the BS4 study area was calculated as 0.42, which is within the range of 0.4 to 0.7 reported for the Pilbara by Ruprecht and Ivanescu (2000).

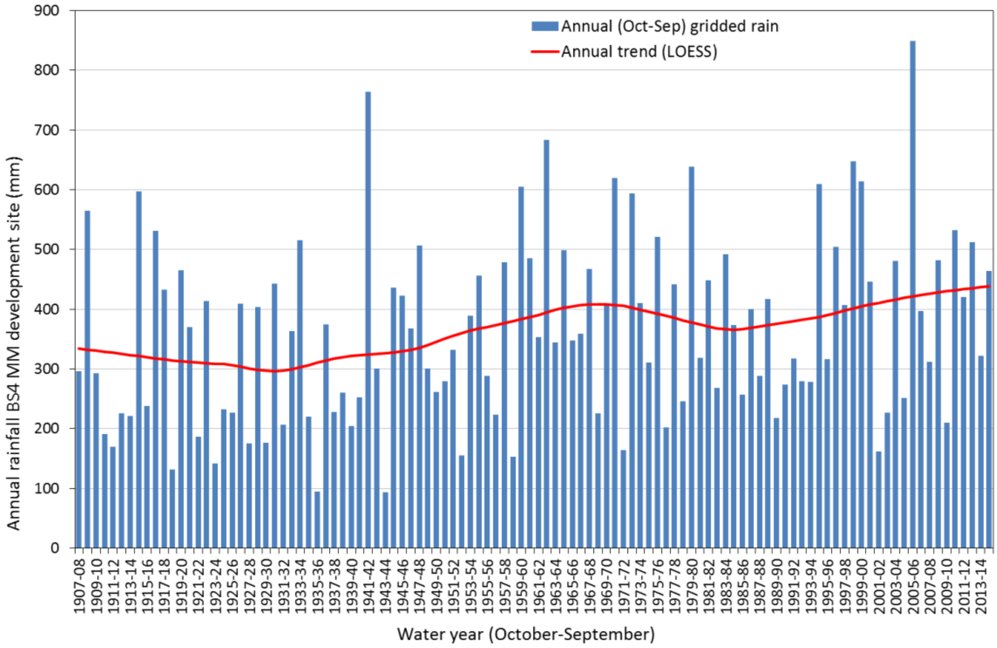


Figure 8: Trend for annual (Oct-Sep) rainfall, BoM gridded data BS4 site (526,735 mE / 7,501,841 mN)

Monthly rainfall statistics for BS4 are provided in Figure 9. The statistics show that rainfall is highly seasonal with an average of 74% of the annual total occurring between December and April. Rainfall is typically associated with tropical low pressure systems and thunderstorm activity from the monsoonal trough that develops over northern Australia during summer. Winters are typically dry and mild though winter rain events can occur in June and July as a result of tropical cloud bands that intermittently affect the area. The high seasonality of rainfall has resulted in the adoption of a “water year” for the purpose s of hydrological analysis. The water year in the Pilbara Region is typically defined from 1 October to 30 September with the reported year stated as the year in which the water year commences. For example, the 1950 water year refers to 1 October 1950 through 30 September 1951.

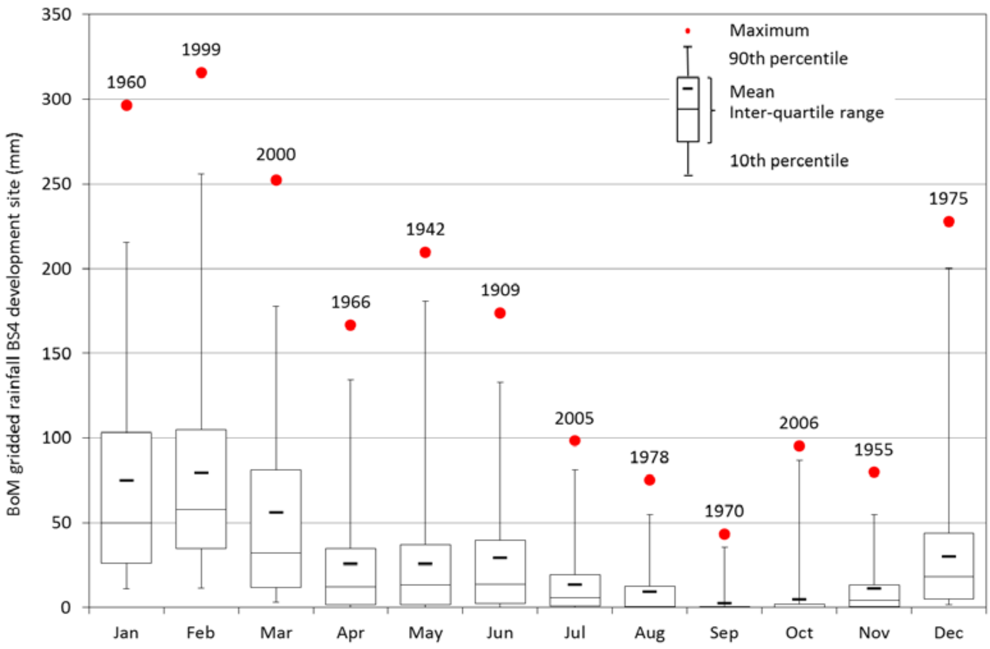


Figure 9: Monthly BoM gridded rainfall distribution for BS4 (526,735 mE / 7,501,841 mN)

Analysis of the daily gridded rainfall data indicates that rain events are infrequent and typically have low rainfall totals. Historically there are on average 38 rain days per year (rain greater than or equal to 1mm) with majority of these days occurring from December to March. The statistics for days with rainfall for the 107 year of record revealed; 73% of rainfall totals were less than 5 mm; 97% were less than 25 mm; 98% were less than 35 mm; and 1% of daily rainfall totals were greater than 50 mm, with an average of one day per year over 50 mm.

Table 2: 24 hour rainfall statistics BoM gridded data for the BS4 site (526,735 mE / 7,501,841 mN)

	Statistics for days when rain occurred			**Statistics for all days**		
Month	Maximum (mm)	Mean (mm)	Standard deviation (mm)	Mean days of rain per year >=1mm	Mean (mm) <10 mm only	Standard deviation (mm) <10mm only
January	137	6.2	12.8	8	2.3	2.5
February	93	6.4	10.8	8	2.4	2.6
March	144	5.9	12.5	6	2.1	2.4
April	133	4.9	10.3	3	2.0	2.4
May	98	5.2	10.1	3	2.0	2.3
June	97	5.7	11.2	3	1.9	2.4
July	51	3.9	6.9	2	1.8	2.3
August	42	4.3	7.0	1	1.9	2.3
September	32	2.7	4.7	0	1.8	2.4
October	55	4.0	8.3	0	1.5	1.8
November	79	3.5	7.2	2	1.7	2.0
December	122	4.4	8.8	4	2.1	2.4

8. Evaporation

The annual average evaporation (sheltered free water surface) rate recorded at BS4 is 1,914 mm/year, which exceeds the mean annual rainfall, keeping the landscape typically arid. The average annual pan evaporation for the region (from Department of Agriculture Western Australia, 2003) is approximately 3,400 mm.

The average point potential evapotranspiration (ET) rate estimated for the region by Bureau of Meteorology (BoM) is approximately 3030 mm/year. Point potential ET is the ET that would take place, under the conditions of unlimited water supply, from an area so small that the local ET effects do not alter local air mass properties. Based on the information provided by BoM, point potential ET may be taken as a preliminary estimate of evaporation from small water bodies such as shallow water storages, which may include surface water pools within a creek system.

It was appreciated that the point potential ET estimation by BoM would be the more appropriate measurement of evaporation under the circumstances of where there is an unlimited supply of water from surplus discharge. Hence the rate of 3030 mm/year was used to describe the annual average evaporation for the Boolgeeda Creek water balance model.

9. Hydrogeology

Scant information regarding the hydrogeology of the Boolgeeda Creek system was available for this assessment. In general geological features observed along the creek, identified in regional geology maps and extrapolated from geophysical data were used to infer hydrogeology characteristics from the Brockman Syncline 4 mine hydrogeology and subsequently deduce the groundwater movement associated with the creek.

Groundwater elevations along the Boolgeeda Creek valley were interpreted by Aquaterra in 2005 and groundwater level data are available from 2006/2007 to present from water bores located along or in vicinity of Boolgeeda Creek. The interpreted water table contours and bore locations, and groundwater level in 2005 (interpreted), 2006/2007 and January 2011 (actual bore data[12]) along the valley are illustrated in Figure 10 and Figure 11, respectively. The natural depth to groundwater table along the Boolgeeda Creek valley, adjacent to the BS4 operation, varies from approximately 21 m to 5 m below ground level. It can be seen that the 2006/2007 groundwater table was generally higher than the water table interpreted by Aquaterra in 2005. This may be attributed to the above average annual rainfall (in excess of 870 mm) recorded in the region in 2006 under the influence of significant cyclonic activities. However, the groundwater table has dropped, by approximately 2 – 3 m (based on January 2011 water level measurements), since 2006/2007 possibly due to water supply abstraction for the BS4 mine.

[12] Information extracted from the Rio Tinto Iron Ore (RTIO) Envirosys database.

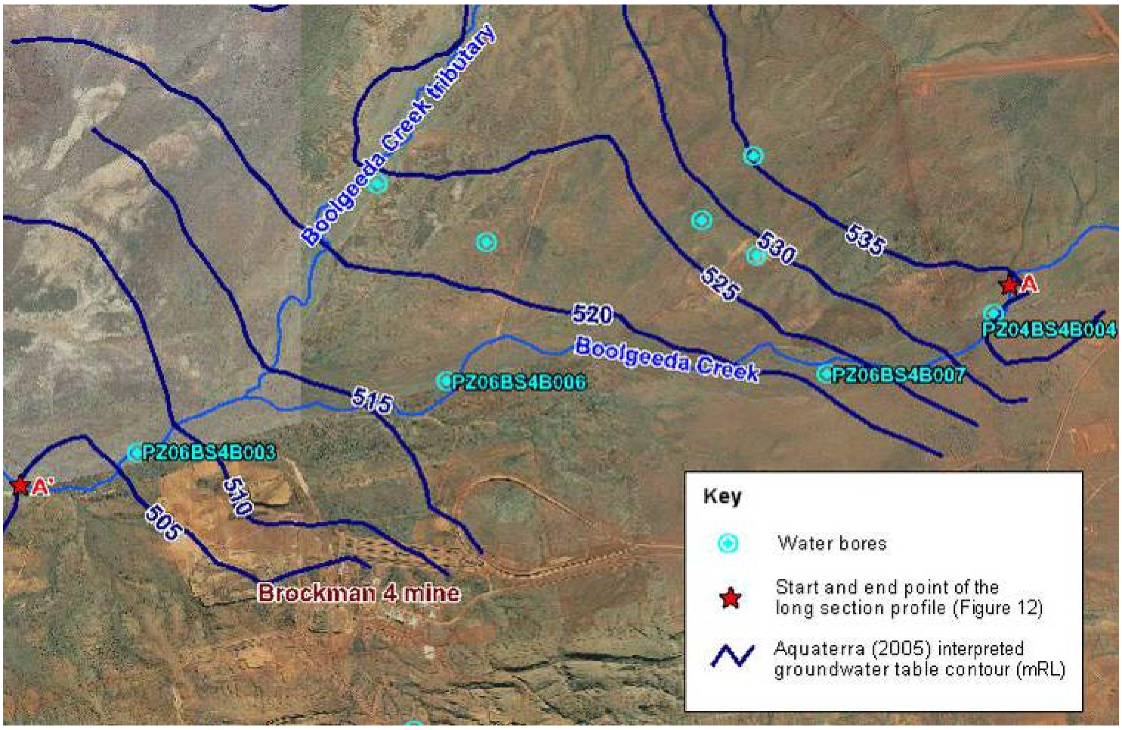


Figure 10: Groundwater level elevations and water bore locations within the Boolgeeda Creek Valley, adjacent to the BS4 (Brockman 4) mine operation

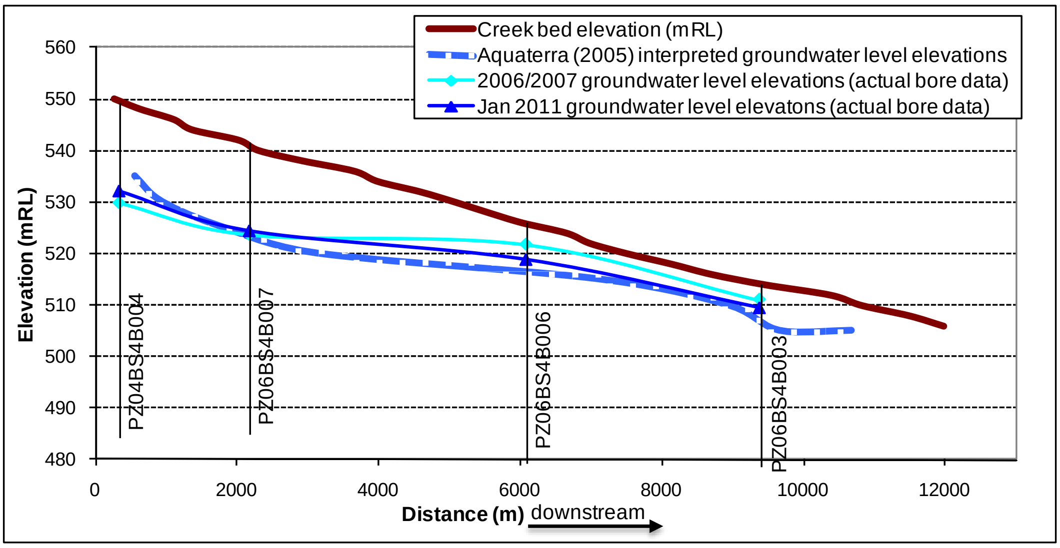


Figure 11: Groundwater level elevations along Boolgeeda Creek (interpreted by Aquaterra in 2005 and based on 2006/2007 and January 2011 water level measurements)

No information on hydrogeology was available for Boolgeeda Creek downstream from the BS4 mine. However it was observed from 1:250,000 geological mapping and remote sensing that the catchment is dominated by outcropping Boolgeeda Iron Formation and Woongarra Volcanics with Robe pisolitic mesas (Figure 12). These rock units are believed to be of low transmissivity but local aquifers may be encountered in fracture zones, which are characteristically more permeable.

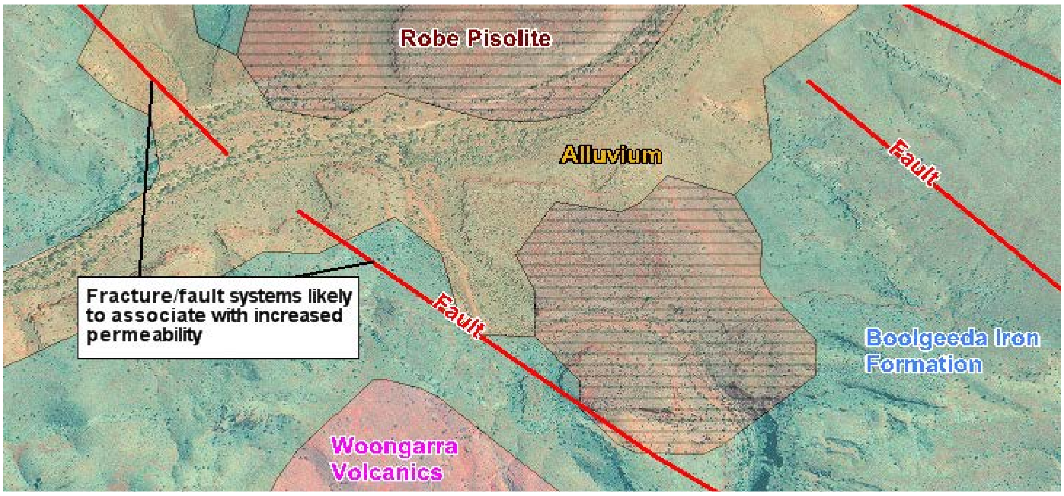


Figure 12: 1:250,000 geological mapping of Boolgeeda Creek downstream of the BS4 operation. Fracture/fault systems are found in this section of the creek, which are likely to associate with increased permeability.

10. Alluvium characteristics

Alluvial and colluvial regolith characteristics, used as a surrogate for detailed soil information, govern the infiltration rate and storage capacity of the creek. These characteristics also influence the type and densities of vegetation communities developed within and adjacent to the creek, and subsequently influence evapotranspiration within the system.

In general, the creek alluvium is comprised of gravel and sand deposits that are likely to be highly transmissive, facilitating rapid recharge during creek flows. The valley fill material within the Boolgeeda Creek valley, underlying the Quaternary alluvium/colluvium, is mainly made up of pisolite and clay. This unit is typically less than 20 m thick with no significant inflows/outflows of groundwater (Aquaterra, 2005). Hence, transient pools within the creek bed are likely to depend on rainfall, surface water and shallow alluvial interflow rather than regional groundwater. As the creek exits the valley and enters the gorge system downstream of the BS4 mine, the extent of the alluvial and colluvial deposits significantly decrease. It is expected that the thickness of these Quaternary deposits is also reduced. Further downstream towards the confluence with Duck Creek, the extent and potentially the thickness of the creek alluvium gradually increase.

11. Riparian vegetation

11.1 Mapped vegetation

Vegetation type, distribution and density can be related to the water availability, soil depth and condition, and the channel morphology of a creek system. Several vegetation and flora surveys have been conducted in the Boolgeeda Creek valley, but most are restricted to the BS4 project area and the rail and infrastructure corridor adjacent to the mine (Biota, 2005, 2007 and 2008). Biota in 2010 & 2013 extended the survey to include an extra 41 km section of Boolgeeda Creek down gradient from the BS4 mine. Further work by Ecological (2015) was completed in combination with various surveys by Biota, to extend riparian vegetation mapping a total of 51 km downstream from the discharge point. Riparian vegetation throughout the 51 km stretch develops with improving catchment availability, but is broadly dominated by open woodlands of *Eucalyptus victrix* (Coolibah) and *Eucalyptus camaldulensis* over *Acacia citrinoviridis* low open woodlands and *Acacia* and *Melaleuca* spp. tall open shrublands in the incised channel zones, and *Corymbia* and *Acacia* spp. low open woodlands over *Acacia* spp. tall open shrublands over tussock/open-tussock grasslands and open hummock grasslands on the adjacent floodplain zones.

In addition to information gathered from vegetation mapping surveys, field observations during a helicopter trip on 6 October 2010 and available land system mapping[13] were used to broadly characterise the local catchment riparian vegetation supported by the creek channel and banks.

While those species dominating local riparian vegetation in Boolgeeda Creek are believed to broadly rely on water available from the soil layer above the water table, some of the dominant vegetation components are species considered to rely on groundwater to fulfil at least a portion of their environmental water requirements (i.e. they are facultative phreatophytes). *Eucalyptus victrix*, *E. camaldulensis* and *Melaleuca glomerata* are all considered to be facultative phreatophytes and all occur as dominant components of the vegetation in parts of the incised channel zone. Of these species, *E. camaldulensis* is likely to be the most dependant on groundwater and therefore may be a larger contributor to the evapotranspiration occurring from within the confines of the incised channel zone. Regardless of the moderate potential groundwater dependence of these species, the vegetation of Boolgeeda Creek can be broadly characterised as being adapted to unsaturated soil conditions, with periods of drought broken by groundwater recharge from surface flows and/or direct infiltration of rainfall.

Figure 13 to Figure 16 illustrate the general structure and density of different vegetation types as observed during a site visit on 30 July 2010 and during a helicopter trip on 6 October 2010.

Figure 13: Boolgeeda Creek tributary upstream of the BS4 discharge location (525178E; 7513121N)

Figure 14: Approximate location 483770E; 7494577N

Figure 15: Approximate location 478704E; 7493895N

Figure 16: Approximate location 474581E; 7496704N

[13] Land system mapping is equivalent to the RangeLand_LandSystems (MapInfo Tab format) data file acquired from Department of Agriculture by Rio Tinto Iron Ore in 2007, accessed 22 February 2011, <\\ PE-GIS.CORP.RIOTINTO.ORG\DEVDATA\Environment\LandUnit>.

11.2 Evapotranspiration

Little is known of the water uptake and transpiration rates of riparian vegetation in the Pilbara but they are likely to vary with vegetation type and distribution within the creek system. High water use (potentially groundwater dependent) species are generally likely to transpire more, and with less variability than species that are adapted to habitats experiencing greater variability in water availability. Due to the absence of evapotranspiration information for Boolgeeda Creek, rates estimated for vegetation commonly found in Marillana Creek and Weeli Wolli Creek (Peck 2007) were used as a baseline from which to estimate evapotranspiration from Boolgeeda Creek vegetation. Using information from vegetation surveys and from field observations during the site visits, the main vegetation types found in Boolgeeda Creek were categorised and compared with those in Marillana and Weeli Wolli Creeks. Scaling down from the typically more mesic vegetation communities of Marillana and Weeli Wolli Creeks; the relevant evapotranspiration rates for each vegetation group were estimated and are summarised in Table 3.

Table 3: Estimated evapotranspiration rates of vegetation found in Boolgeeda Creek

Broad Vegetation type	Typical creek zone occupied by vegetation	Example photo	Typical vegetation community present	Evapotranspiration (E_T) rate (mm/year)
IC1	**Incised channel/Low flow channel**	**Figure 16 & Figure 17**	*Eucalypt*us *victrix* and *E. camaldulensis* woodland over *Acacia citrinoviridis* low open woodland over *Acacia* and *Melaleuca* spp. Tall open shrubland o*ver open* Tussock grassland	**700** - despite similarity to below vegetation type, ET rate estimated to be greater due to increased vegetation density and topographical confinement of creek profile as observed from site visit.
IC2	**Incised channel/Low flow channel**	**Figure 15**	Open *Eucalypt*us *victrix* and *E. camaldulensis* woodland over *Acacia citrinoviridis* low open woodland over *Acacia* spp. tall open shrubland/ scattered shrubs over s*cattered to open* Tussock grassland	**600**
FP1	**Floodplain/ Terrace/ secondary channels**	**Figure 14**	*Corymbia hamersleyana* scattered trees to low open woodland over Acacia citrinoviridis tall open shrubland over *Acacia* spp. shrubland over open tussock grassland/open hummock grassland	**470**
FP2	**Floodplain/ Terrace/ secondary channels**	**N/A**	*Acacia citrinoviridis* low open woodland over *A. pyrifolia* tall open shrubland over mixed open shrublands over mixed open tussock grassland/very open hummock grassland	**450**

12. Input summary

Table 4 summarises the source of the input values for the water balance equations. Reach geometry inputs including the wetted perimeter (the cross section of the creek under water) and top width (the water surface exposed to evaporation) were determined using the Manning formula, which is an empirical formula for open channel flow.

Table 4: Model simulation inputs

Input value	Description
Reach geometry	Channel dimensions including channel base width and bank (side) slopes, reach length and bed slope were estimated based on 20m or 30m cell size spot heights or contours survey data.
Manning's roughness coefficient *n*	Manning's roughness coefficients were estimated according to the *Guide for selecting Manning's roughness coefficients for natural channels and floodplains*, (USGS 1990) in consideration of channel irregularities, variation in cross section, obstructions, vegetation density and meandering of the reach.
Flow conditions	The Manning formula was used to calculate the wetted perimeter, top width, velocity, and water depth of the flow. The average reach value was then used in the water balance equation.
Vegetation width	Estimated from 1: 10,000 geological mapping, available vegetation and flora surveys and aerial photographs, the extent of riparian vegetation growth is averaged for each reach. The vegetation width is used to estimate both the area of evapotranspiration and recharge as horizontal movement of water beyond the riparian zone is considered to be minimal.
Evaporation	Estimated from average annual point potential evapotranspiration for the Boolgeeda Creek catchment, 3,030 mm/year (from Bureau of Meteorology).
Evapotranspiration	The local evapotranspiration rate was estimated to range from 530 to 700 mm/year based on vegetation types and density (Table 3).
Recharge rate	The recharge rates represent the estimated loss of water to below the root zone. They were estimated based on the vertical hydraulic conductivities predicted for the bedrock units underlying the Boolgeeda Creek valley, ranging from 0.0001 m/d or 1.2×10^{-9} m/s to 0.1 m/d or 1.2×10^{-6} m/s (Aquaterra, 2005). However in areas where there is a lack of knowledge on the rate of recharge, regional estimates for the Pilbara, 1×10^{-7} m/s for clay materials and 2×10^{-7} m/s for sandy materials, were used. These estimates are used by the Bureau of Rural Science for 'loss' or 'recharge' estimation (Raupach et al., 2001). More recent modelling by Rio Tinto in 2013 (RTIO-PDE-0105955) has identified recharge rates as high as 0.05 m/d for Boolgeeda formation. Notwithstanding this, for the purpose of this report the lower values as defined by Aquaterra and Raupach et al. have been adopted to produce a more conservative estimate (i.e. a greater distance) for the surface water expression and the steady state distance. It is noted loss of water to below the root zone does not necessarily represent groundwater recharge. If used for groundwater recharge estimation, these values will overestimate recharge in groundwater fed creek systems and underestimate recharge rate over deep alluvial/sedimentary geology.
Surface infiltration rate	Soil infiltration rate of 6 mm/h is adopted for the Boolgeeda reaches as shallow alluvial is estimated for the channel. Where bed rock is exposed in the channel or water pools are sighted or clay like material is identified (e.g. a few Beasley reaches), this rate is reduced to 4 mm/h.

12.1 Survey Data and Modelling Accuracy

The accuracy of discharge footprint modelling is heavily dependent on the available survey data. The most accurate survey data available for Boolgeeda Creek is a 30 m DEM. Given the average bed width of Boolgeeda Creek is approximately 10 to 15 m and overall riparian width is about 40 to 50 m, assumptions for a trapezoidal channel have been made for each cross section profile.

Accurate infiltration and recharge rates cannot be made due to lack of sufficient geotechnical and hydrogeological data. Geological information from the existing drill holes have been referred for estimating water table and bed material. However, that most of the available holes are located distant from the river channel made the identification uncertain. With the aid of the radio matrix data, engineering judgment was made to determine the infiltration and the recharge rate.

Discharge modelling

13. Boolgeeda Creek discharge

Development of the BS4 MM deposits below the water table will generate an increased volume of surplus water as a result of dewatering. In order to meet dewatering requirements surplus water will need to be discharged. The total maximum predicted discharge rate may approach 35 ML/d.

In this scenario, discharge is presumed to be released from the existing Boolgeeda Creek discharge location. The response of the creek system to a continual discharge for a range of discharge rates varying from 17.5 ML/d to 40 ML/d was investigated. Discharge footprints were determined based on the assumption that steady state conditions were established.

14. Modelling results

14.1 Reach characteristics

An 82 km long section of Boolgeeda Creek was modelled from the discharge location. The creek was subdivided into six reaches with similar creek morphology, soil conditions and vegetation type and patterns. The reach locations are illustrated in Figure 17. Descriptions of the average reach characteristics, subsequently used in the water balance equations (reaches 1-3) and the predicted reaction of the creek to selected discharge volumes (20 ML/d, 25 ML/d, 30 ML/d and 35 ML/d) are provided in Table 5. Results for the modelled scenarios are presented in the next section.

Figure 17: Reach locations along Boolgeeda Creek

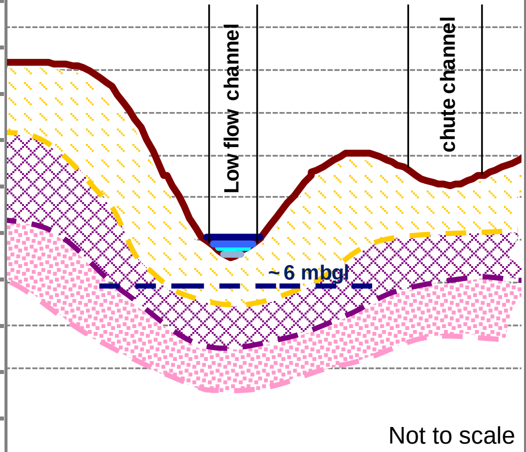
Table 5: Reach characteristics used for the water balance modelling and predicted response to selected modelled discharge rates at Boolgeeda Creek.

Reach 1

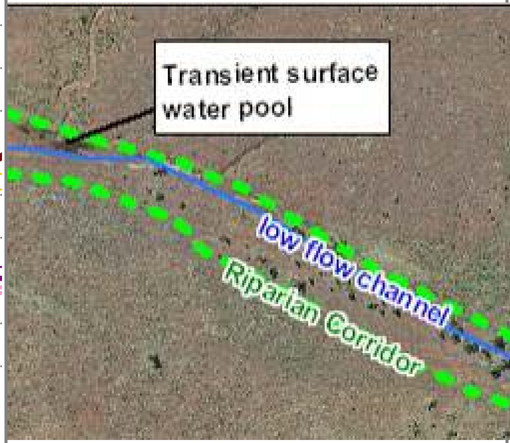
Reach characteristics

Reach length (m)	**12,508**
Low flow channel - base width (m)	13
Bed slope (m/m)	0.003
Manning's roughness	0.045
Riparian width (m)	42
Common riparian veg types	FP1 & IC2
ET (mm/year)	530
Alluvial/colluvial depth (m)	~ 20
SW&GW interactions	Losing
Recharge rate (m/s)	1.16×10^{-9}
Limiting factor to water loss	Subsurface geology

Typical cross section



Riparian vegetation corridor



Flow conditions

Peak discharge	Water depth (m)	Flow width (m)	Velocity (m/s)
20 ML/d 0.23 m^3/s	0.07	24	0.18
25 ML/d 0.29 m^3/s	0.08	24	0.20
30 ML/d 0.35 m^3/s	0.08	25	0.23
35 ML/d 0.41 m^3/s	0.10	27	0.25

Key

Alluvium/Colluvium
Boolgeeda Iron Formation
Woongara Volcanics
Estimated groundwater level

Modelled discharge rates:
20 ML/d
30 ML/d
25 ML/d
35 ML/d

Summary

Reach 1 defines the first reach of the Boolgeeda Creek, immediately downstream from the BS4 discharge location. It is located within a wide, flat floodplain that stretches several hundred metres across and is defined by a braided, meandering creek system that is capable of changing course during a large flood event. Water will be distributed across a wide area during floods in this reach, thereby reducing the average flood water levels and velocities. It potentially allows deposition of sediments along this reach. Riparian vegetation communities commonly found in Reach 1 were broadly classified to be representative of the FP1 & IC2 communities (in order of abundance) described in Table 2, and include notable species and formations such as *E. victrix*, *E. camaldulensis*, various *Acacia* species, open tussock grasslands, open hummock grasslands and some herblands.

The average groundwater elevation along Reach 1 was estimated to be approximately 6 m below ground level. Surface water pools can be observed from aerial photographs but they are likely to depend on rainfall, creek runoff and shallow alluvial interflow rather than groundwater. These pools are likely to be transient and accumulated water is expected to dissipate via infiltration and evaporation during dry periods.

Reach 1 is recognised as a losing system and subsurface geological constraints are identified as the likely limiting factor for the volume of water lost from the system. It was determined that the bedrock units underlying Reach 1 are generally of low permeability, hence recharge into the regional groundwater system is likely to be limited, which may lead to build up of water within the alluvials and/or valley fill materials following prolong surplus water discharge.

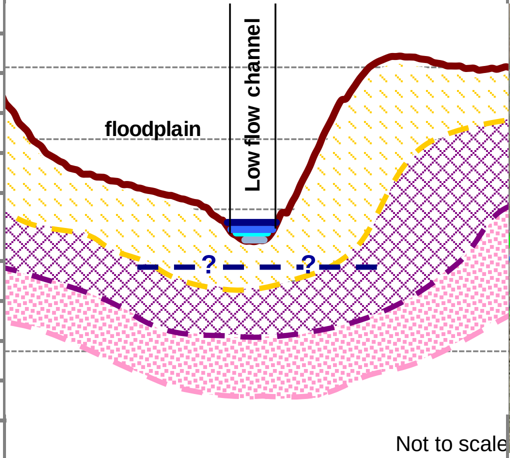
Water released into the creek is likely to be contained within the channel.

Reach 2

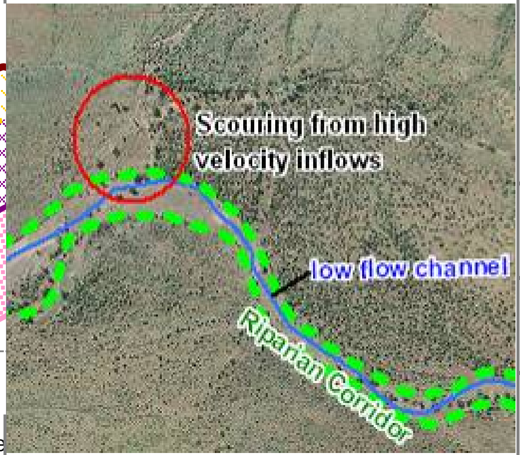
Reach characteristics

Reach length (m)	18,780
Low flow channel - base width (m)	13
Bed slope (m/m)	0.006
Manning's roughness	0.05
Riparian width (m)	61
Common riparian veg types	IC2, IC1, & FP2
ET (mm/year)	600
Alluvial/colluvial depth (m)	~ 20
SW&GW interactions	Losing
Recharge rate (m/s)	1.16 x 10^{-9}
Limiting factor to water loss	Subsurface geology

Typical cross section



Riparian vegetation corridor



Flow conditions

Peak discharge	Water depth (m)	Flow width (m)	Velocity (m/s)
20 ML/d 0.19 m^3/s	0.06	23	0.19
25 ML/d 0.25 m^3/s	0.06	23	0.23
30 ML/d 0.31 m^3/s	0.06	24	0.26
35 ML/d 0.36 m^3/s	0.08	27	0.28

Key

Alluvium/Colluvium
Boolgeeda Iron Formation
Woongara Volcanics
Estimated groundwater level

Modelled discharge rates:
20 ML/d
30 ML/d
25 ML/d
35 ML/d

Summary

Reach 2 is characterised by a meandering creek with an active floodplain that varies in width. Reach 2 is differentiated from Reach 1 by a slightly more incised channel with more defined banks and a floodplain that supports denser riparian vegetation. Riparian vegetation communities commonly found in Reach 1 were broadly classified to be representative of the IC2, IC1, and FP2 communities (in order of abundance) described in table 2, and include notable species and formations such as *Eucalyptus victrix*, *E. camaldulensis*, various Acacia species including *Acacia pyrifolia,* open tussock grasslands, very open hummock grasslands and some herblands. Scouring observed at tributary outlets along Reach 2 (an example is highlighted in the aerial imagery above) indicates high velocity runoffs can be generated from the northern and southern valley slopes.

Groundwater elevations along this reach are unknown but increase in vegetation density may indicate increased water availability. There is a distinctive water source contributing to Reach 2, originating from the southern valley, which results in the sudden increase in vegetation density within the floodplain (adjacent figure).

Reach 2 is recognised as a losing system and subsurface geological constraints are identified as the likely limiting factor for the volume of water lost from the system. Similar to Reach 1, the bedrock units underlying this reach are generally of low permeability thus limiting recharge into the regional groundwater table. This may lead to build up of water within the alluvials and/or valley fill materials following prolong surplus water discharge.

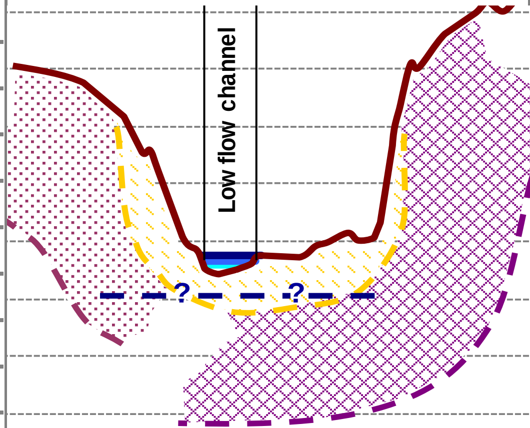
Water released into the creek is expected to be contained within the channel and overtopping of the creek banks is not anticipated.

Reach 3

Reach characteristics

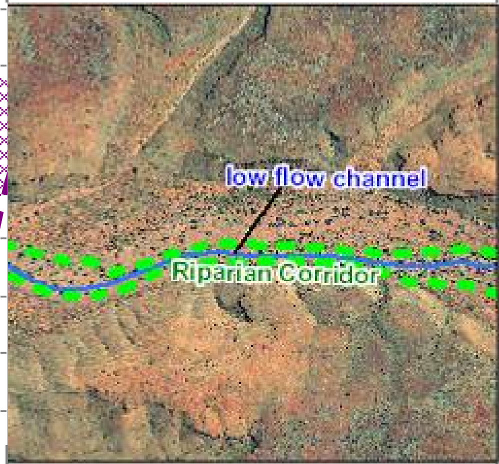
Reach length (m)	20,765
Low flow channel - base width (m)	13
Bed slope (m/m)	0.003
Manning's roughness	0.045
Riparian width (m)	81
Common riparian veg types	IC1, FP2.
ET (mm/year)	600
Alluvial/colluviall depth (m)	~ 10
SW&GW interactions	Losing
Recharge rate (m/s)	2 x 10^{-7}
Limiting factor to water loss	Subsurface geology

Typical cross section



Not to scale

Riparian vegetation corridor



Flow conditions

Peak discharge	Water depth (m)	Flow width (m)	Velocity (m/s)
20 ML/d 0.13 m^3/s	0.05	20	0.15
25 ML/d 0.19 m^3/s	0.06	21	0.19
30 ML/d 0.24 m^3/s	0.06	22	0.22
35 ML/d 0.29 m^3/s	0.08	24	0.23

Key

- Alluvium/Colluvium
- Woongara Volcanics
- Boolgeeda Iron Formation
- Estimated groundwater level

Modelled discharge rates:

- 20 ML/d
- 25 ML/d
- 30 ML/d
- 35 ML/d

Summary

Reach 3 illustrates the section of Boolgeeda Creek that drains the gorge system. The creek is flanked north and south by outcropping Boolgeeda Iron Formation and Robe Pisolite mesas, which constricts flows, thus increases the average water levels and velocities and may cause water to back up during large flood events. Similar to Reach 2, Reach 3 is likely to receive high velocity runoff generated from local sub-catchments that may scour the creek bed.

Riparian vegetation communities commonly found in Reach 3 were broadly classified to be representative of the IC1, and FP2 communities described in Table 2, and include notable species and formations such as *E. victrix*, *E. camaldulensis* woodlands, *Melaleuca glomerata* tall shrublands various *Acacia* species including *Acacia citrinoviridis* and *A. pyrifolia,* open tussock grasslands, and very open hummock grasslands.

Groundwater elevations are unknown along this reach but are expected to be deep, possibly > 5 m below ground level; riparian vegetation maintained within this reach is unlikely to be groundwater dependent but sustained by water available within the soil layer, recharged by surface flows and rainfall infiltration.

Reach 3 is recognised as a losing system and subsurface geological constraints are identified as the likely limiting factor for the volume of water lost from the system. Although the outcropping rock units are believed to be of low permeability, faults/fracture zones (generally found in this reach) will significantly increase the permeability of the rocks thus increase the recharge potential of this reach.

Water released into the creek is expected to be contained within the channel and overtopping of the creek banks is not anticipated. The footprint is terminated within this reach.

14.2 Results discussion

Results for the modelled discharge options are summarised in Table 6 and footprint distances, measured on the creek centreline from the BS4 discharge location, for 17.5 ML/d and 35 ML/d are presented in Figure 18. As shown the maximum footprint extent is expected to lie within the first three reaches of the creek and hence descriptions of reaches 4-6 were not required.

Table 6: Estimated footprint distances, for modelled volumes 12.5 to 40 ML/d, along Boolgeeda Creek.

Discharge volume (ML/d)	Surface water expression (km)	Steady state distance (km)	Maximum discharge footprint (km)
12.5	33.0	34.0	34.0
15	34.0	35.0	35.0
17.5	34.0	37.0	37.0
20	35.0	38.0	38.0
25	36.0	41.0	41.0
30	38.0	43.0	43.0
35	38.0	46.0	46.0
40	39.0	48.0	48.0

For all modelled discharge rates, the surface water expression footprint was less than the steady state distance. This suggests water released into the creek is likely to move in and out of the creek bed, creating transient pools in topographical depressions and associated saturated bank conditions within the reach. Modelling indicated that the maximum footprint distance would extend approximately 46 km downstream from the Boolgeeda Creek discharge location for the estimated peak surplus discharge rate of 35 ML/d.

The estimated peak flow rate of surplus water discharged into Boolgeeda Creek is significantly smaller than the peak flow rate generated by the catchment during any flood events; a 2 year ARI flood event would deliver 148 m^3/s at the BS4 discharge location, compared with estimated peak surplus discharge rate of 35 ML/d which is equivalent to 0.4 m^3/s. However the duration of flow events, days to weeks for flood events and months for discharge events, pose a change to the natural hydrological regime.

All potential discharge water movement is expected to be confined within the channel and overtopping of the creek banks is not anticipated during conditions where the creek would not normally flow. While the creek bed will remain saturated, the creek banks are likely to remain unsaturated such that bank vegetation should be largely unaffected by the flows. However, the continuous flow will increase water availability close to the creek. Thus the content of water in unsaturated zones moving away from the saturated creek bed may increase vegetation vigour and/or encourage sapling growth in some fringing zones and will also likely reduce vigour in some consistently waterlogged zones. Overall the effect of perennial flows within the creek is likely to lead to an increase in biomass and associated evapotranspiration. The extent of this augmentation is likely to be broadly kept in check by the regular natural peak flow events which scour out the incised channel zone of Boolgeeda Creek.

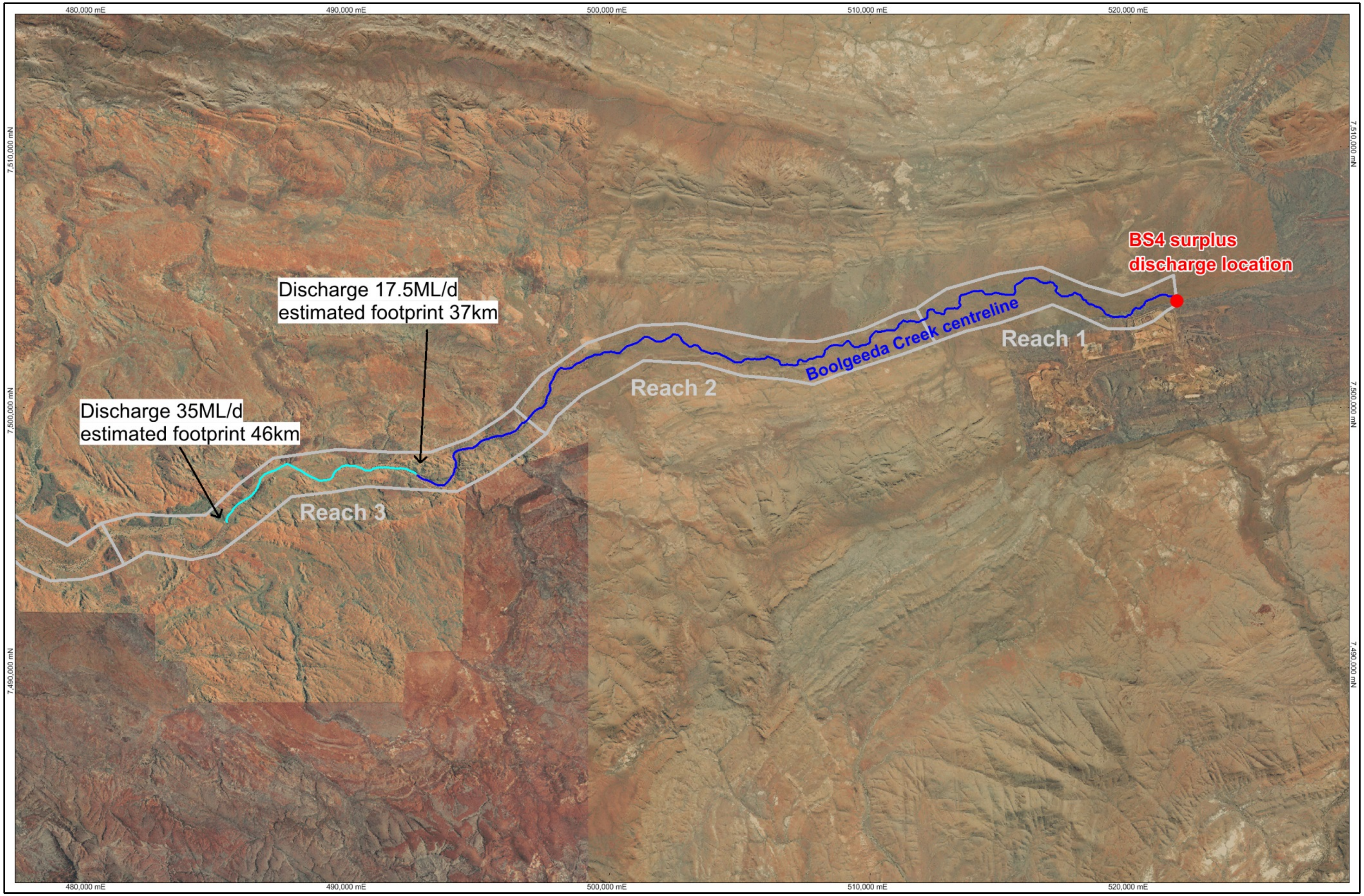


Figure 18: Estimated discharge footprint extents in Boolgeeda Creek for discharge volumes, 17.5 ML/d and 35 ML/d

Conclusion

Hamersley Iron Pty Limited (the Proponent) has approval under Ministerial Statement 1000 to discharge surplus water (from pit dewatering) from its BS4 operation into Boolgeeda Creek. The dewater discharge can extend no further than 37 km along Boolgeeda Creek from the discharge point under natural no-flow conditions. The development of BS4 MM, adjacent to BS4, will produce additional surplus water that will need to be disposed of. To minimise environmental impacts that would arise from alternative additional discharge locations, it is proposed that the additional water is discharged into Boolgeeda Creek at the same location as the existing BS4 discharge.

Hydrogeological modelling has estimated that the total surplus water required to be discharged from BS4 and BS4 MM will peak at a rate of 35 ML/d. Hydrologic modelling undertaken in this study indicates that the footprint from a peak discharge of 35 ML/d will extend 46 km downstream from the existing Boolgeeda Creek discharge location.

Discharge volume (ML/d)	Surface water expression (km)	Steady state distance (km)	Maximum discharge footprint (km)
12.5	33.0	34.0	34.0
15	34.0	35.0	35.0
17.5	34.0	37.0	37.0
20	35.0	38.0	38.0
25	36.0	41.0	41.0
30	38.0	43.0	43.0
35	38.0	46.0	46.0
40	39.0	48.0	48.0

The surface water expression footprint for all modelled discharge rates was predicted to be less than the steady state distance. This suggests that water discharged into the creek system is likely to move in and out of the creek bed, creating transient pools in topographical depressions and associated saturated bank conditions within the reach.

Water released into Boolgeeda Creek is expected to be contained within the channel and overtopping of the creek banks by discharged water alone is not anticipated. Pools created within local depressions may become permanent for the period of the discharge.

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Hamersley Iron Pty Limited

ABN: 49 004 558 276

Brockman Syncline 4 Closure Plan

April 2018

Mineral Field: 47 – West Pilbara

FDMS No: RTIO-HSE-0205402

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EXECUTIVE SUMMARY

Overview

Brockman Syncline 4 (BS4) is located in the Pilbara region of Western Australia, approximately 60 km from Tom Price in the Shire of Ashburton. The mine is located within the traditional lands of the Puutu Kunti Kurrama and Pinikura (PKKP) people and the Eastern Guruma people. BS4 is managed by Hamersley Iron Pty Limited, which is a wholly owned member of the Rio Tinto group.

BS4 commenced operations in 2010, and comprise open cut operations utilising conventional drill-and-blast and load-and-haul mining methods. Ore is processed on-site before being transported via rail to either Dampier or Cape Lambert ports for shipping. This closure plan incorporates the existing BS4 Main operation (approved under Ministerial Statement 1000) and has been extended to include the adjacent BS4 Marra Mamba and BS4 Endeavour deposits.

The currently approved BS4 Main mine has an operational life of eight years with completion of mining scheduled for 2026. The proposed development of BS4 Marra Mamba and Endeavour will extend mining until 2043.

Mineral waste generated by mining will be placed in a number of external dumps as well as progressively backfilled into pit voids as they become available. The site is expected to encounter some highly erodible and fibrous materials which will be used for pit backfill or placed in external waste dumps with appropriate final parameters, which may include conservative lift heights, wider berms and encapsulation of fibrous materials. The site has been assessed as having a moderate geochemical risk, with potentially acid forming (PAF) material expected to be encountered in a number of pits. PAF waste will also be used for pit backfill or placed in external waste dumps with appropriate final parameters including encapsulation and store & release covers. Pit wall exposures are proposed to be covered with backfill. No waste fine are produced at BS4, and no pit lakes are expected post-closure.

Scope

This document, titled ‘Brockman Syncline 4 Closure Plan April 2018’, represents the updated closure plan for the BS4 operations and supersedes previous closure plans. It is applicable to mine developments and all associated infrastructure at BS4 deposits.

In August 2014, a closure plan was submitted in line with Ministerial Statement 717 (**MS 717**) Condition 10.2, which required the closure plan to be reviewed and updated every five years from the commencement of operations. This plan was approved for the site in February 2015. In March 2015 the Minister for Environment authorised revisions to the BS4 proposal under the *Environmental Protection Act 1986 (***EP Act**) via Ministerial Statement 1000 (**MS 1000**). MS 1000 superseded MS 717 and included a new condition (Condition 6) on Rehabilitation and Closure, including the requirement to revise the closure plan every three years.

The most recent submission of the BS4 closure plan was in August 2017. This submission was approved by Department of Water and Environmental Regulation (DWER) in March 2018 as compliant with Condition 6 of MS1000.

Post-mining land use

Post-mining land use options in the Pilbara are generally limited due to the remote location. The proposed final land use assumes that the site will be rehabilitated to create a safe, stable and non-polluting landscape revegetated with native species, to maximise environmental and cultural heritage outcomes and ensure the site does not adversely impact on the current surrounding land use.

Due to the nature of the mining activity undertaken, the final landform will include large voids and waste dumps, and will therefore be unlikely to support pastoral activities in the immediate disturbed areas. However, it is recognized that surrounding areas are likely to remain subject to pastoral activity. For the purpose of this closure plan, it is assumed that the post closure landform will be shaped and rehabilitated to support ongoing pastoral activity. The final land use will be determined prior to closure during final planning phases and in consultation with relevant stakeholders.

Closure objectives

The following closure objectives have been set for the site:

- Public safety hazards have been managed;
- Contamination risks have been appropriately managed;
- AMD and Fibrous material risk is compatible with post-mining land use;
- Final landform is stable and considers ecological and hydrological factors;
- Vegetation on rehabilitated land is self-sustaining and compatible with the final land use;
- Infrastructure appropriately managed; and,
- Boolgeeda Creek functions similarly to the pre-mining state.

Indicative completion criteria have been proposed for each of these objectives; however these have not been the subject of consultation with stakeholders at this point, which is considered acceptable given the long timeframe for mining operations for this site.

These objectives remain the same as those in the August 2017 plan. One minor change was made to the criteria associated with the objective for pit lakes, where backfill will now be to supress pit lakes.

Anticipated closure outcome

Mine voids will be backfilled to prevent the formation of permanent pit lakes, although water may temporarily pool at the base of the voids following heavy rainfall. While groundwater is not predicted to recover to pre-mining levels in all areas, there are no groundwater dependent ecosystems (GDEs) in the area that may be impacted by a lowering of groundwater levels. Backfill will also occur to cover any pit wall exposure of PAF material. Waste dumps will be reshaped to be stable based on their material characteristics. PAF and fibrous waste will be encapsulated, with a store and release cover included on PAF waste dumps. It is assumed that all infrastructure will be removed, but this will be subject to negotiation with the Western Australian State Government as per State Agreement Act obligations. All other disturbed areas, except the majority of pit voids, will be rehabilitated. General rehabilitation practices include spreading of topsoil or another growth medium where available, and spreading native seed with the aim of creating self-sustaining ecosystems.

The area around pit voids may be unstable as pit walls are expected to collapse over time, and inadvertent access will be restricted by the use of physical barriers (e.g. abandonment bunds). Strategies for managing safety risks will be developed as the site approaches closure, but will need to consider the potential for ongoing public access resulting from a portion of the mining area being underlain by pastoral stations and access requirements of local indigenous groups.

CLOSURE PLAN CHECKLIST

The following table provides cross reference to the requirements of the Department of Mines and Petroleum / Environmental Protection Authority *Guidelines for Preparing Mine Closure Plans* (2015).

	Mine Closure Plan (MCP) Checklist	Y/N /NA	Page No.	Comments	Change from previous version (Y/N)	Page No.	Comments
1	Has the Checklist been endorsed by a senior representative within the operating company?	Y	viii		NA		
Public Availability							
2	Are you aware that from 2015 all MCPs will be made publically available?	Y	NA		NA		
3	Is there any information in this MCP that should not be publicly available?	Y	Appendix C		NA		
4	If "Yes" to Q3, has confidential information been submitted in a separate document / section?	Y	Appendix C		NA		
Cover page, table of contents							
5	Does the MCP cover page include: Project Title, Company Name, Contact Details (including telephone numbers and email address) Document ID and version number, Date of submission (needs to match the date of this checklist)	Y			NA		
Scope and purpose							
6	State why the MCP is submitted (e.g. as part of a Mining Proposal, a reviewed MCP or to fulfil other legal requirement)	Y	1	To support the approval for BS4 Marra Mamba deposits.	Y		New approval

	Mine Closure Plan (MCP) Checklist	Y/N /NA	Page No.	Comments	Change from previous version (Y/N)	Page No.	Comments
Project overview							
7	Does the project summary include land ownership details, location of the project, comprehensive site plans and background information on the history and status of the project?	Y	3-56		Y		New deposits and updated mine plan
Legal obligations and commitments							
8	Does the MCP include a consolidated summary or register of closure obligations and commitments been included?	Y	Appendix A		N		No new obligations
Stakeholder engagement							
9	Have all stakeholders involved in closure been identified?	Y	12 and Appendix B		N		No new stakeholders
10	Does the MCP included a summary or register of historic stakeholder engagement been provided, with details on who has been consulted and the outcomes?	Y	Appendix B		Y		New entries
11	Does the MCP include a stakeholder consultation strategy to be implemented in the future?	Y	12		N		No change to strategy or process
Post mining land use(s) and closure objectives							
12	Does the MCP include agreed post-mining land use, closure objectives and conceptual landform design diagram?	Y	13, 13, 77 and Appendix F		Y		New deposits and updated mine plan

	Mine Closure Plan (MCP) Checklist	Y/N /NA	Page No.	Comments	Change from previous version (Y/N)	Page No.	Comments
13	Does the MCP identify all potential (or pre-existing) environmental legacies which may restrict the post mining land use (including contaminated sites)?	NA	There are no known or suspected contaminated sites associated with the operation.		NA		
14	Has any soil or groundwater contamination that occurred, or is suspected to have occurred, during the operation of the mine, been reported to DER as required under the Contaminated Sites Act 2003?	NA	There are no known or suspected contaminated sites associated with the operation.		NA		
Development of completion criteria							
15	Does the MCP include an appropriate set of specific completion criteria and closure performance indicators?	Y	15		Y		Change to backfill strategy in pit lakes objective
Collection and analysis of closure data							
16	Does the MCP include baseline data (including pre-mining studies and environmental data)	Y	9 and Appendix C		Y		New deposits and updated mine plan
17	Has materials characterisation been carried out consistent with applicable standards and guidelines (e.g. GARD Guide)?	Y	26		N		No new characterisation completed
18	Does the MCP identify applicable closure learnings from benchmarking against other comparable mine sites?	Y	Appendix C		Y		New entries

	Mine Closure Plan (MCP) Checklist	Y/N /NA	Page No.	Comments	Change from previous version (Y/N)	Page No.	Comments
19	Does the MCP identify all key issues impacting mine closure objectives and outcomes (including potential contamination impacts)?	Y	58		N		No new risks
20	Does the MCP include information relevant to mine closure for each domain or feature?	Y	72		N		No new domains
Identification and management of closure issues							
21	Does the MCP include a gap analysis / risk assessment to determine if further information is required in relation to closure of each domain or feature?	Y	57 and Appendix D		N		No new risks
22	Does the MCP include the process, methodology and has the rationale been provided to justify identification and management of the issues?	Y	57 and Appendix D		N		No change to strategy or process
Closure Implementation							
23	Does the MCP include a summary of closure implementation strategies and activities for the proposed operations or for the whole site?	Y	72		N		No change to strategy or process
24	Does the MCP include a closure work program for each domain or feature?	Y	72	To be refined prior to closure	N		New deposits and updated mine plan
25	Does the MCP contain site layout plans to clearly show each type of disturbance as defined in Schedule 1 of the MRF Regulations?	Y	72	State agreement site not subject to MRF	Y		New deposits and updated mine plan

	Mine Closure Plan (MCP) Checklist	Y/N /NA	Page No.	Comments	Change from previous version (Y/N)	Page No.	Comments
26	Does the MCP contain a schedule of research and trial activities?	Y	Appendix E		Y		Redefined task titles and new tasks
27	Does the MCP contain a schedule of progressive rehabilitation activities?	Y	3	Indicative closure schedule provided in Table 1 and Table 2. Opportunities for rehabilitation assessed annually Other areas proposed for end of mine life.	Y		New deposits and updated mine plan
28	Does the MCP include details of how unexpected closure and care and maintenance will be handled?	Y	80		N		No change to strategy or process
29	Does the MCP contain a schedule of decommissioning activities?	N		To be refined prior to closure	N		No change to strategy or process
30	Does the MCP contain a schedule of closure performance monitoring and maintenance activities?	Y	81	To be refined prior to closure	N		No change to strategy or process
Closure monitoring and maintenance							
31	Does the MCP contain a framework, including methodology, quality control and remedial strategy for closure performance monitoring including post-closure monitoring and maintenance?	Y	81	To be refined prior to closure	N		No change to strategy or process

	Mine Closure Plan (MCP) Checklist	Y/N /NA	Page No.	Comments	Change from previous version (Y/N)	Page No.	Comments
Financial provisioning for closure							
32	Does the MCP include costing methodology, assumptions and financial provision to resource closure implementation and monitoring?	Y	83		N		No change to strategy or process
33	Does the MCP include a process for regular review of the financial provision?	Y	83		N		No change to strategy or process
Management of information and data							
34	Does the MCP contain a description of management strategies including systems and processes for the retention of mine records?	Y	84		N		No change to strategy or process

Corporate endorsement:

I hereby certify that to the best of my knowledge, the information within this Mine Closure Plan is true and correct and addresses the relevant requirements of the Guidelines for Preparing Mine Closure Plans approved by the Director General of Mines and Petroleum.

Cameron McNeilage

Acting General Manager – Orebody Knowledge and Planning

Date: 30 April 2018

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APPENDICES

TABLES

FIGURES

ABBREVIATIONS

AEP	Annual Exceedance Probability
AMD	Acid or Metalliferous Mine Drainage
AWT	Above Water Table
BS4	Brockman Syncline 4
BS4 EN	Brockman Syncline 4 Endeavour
BS4 Main	Brockman Syncline 4 Main
BS4 MM	Brockman Syncline 4 Marra Mamba
BWT	Below Water Table
DER	Department of Environmental Regulation
DMP	Department of Mines and Petroleum
DWER	Department of Water and Environmental Regulation
ENSO	El Niño Southern Oscillation
EPA	Environmental Protection Authority
ESP	Exchangeable Sodium Percentage
GDE	Groundwater Dependent Ecosystem
IBRA	Interim Biogeographic Regionalisation for Australia
ILUA	Indigenous Land Use Agreements
IOD	Indian Ocean Dipole
IODMS	Iron Ore Document Management System
MMP	Monitoring and Management Plan
mRL	Metres above Relevant Level (Sea Level)
MS1000	Ministerial Statement 1000
NVCP	Native Vegetation Clearing Permits
PAF	Potentially Acid Forming
PCO	Present Closure Obligation
PKKP	Puutu Kunti Kurrama and Pinikura
PLNb	Pilbara Leaf-Nosed bat
SCARD	Spontaneous Combustion and Acid Rock Drainage
TPC	Total Projected Closure
UBRR	Upper Beasley River Roost
ZOI	Zone of Instability

SCOPE AND PURPOSE

1. Purpose

Planning for closure of a site is a critical business process that demonstrates Rio Tinto's commitment to sustainable development. This closure plan follows the format and content requirements for mine closure plans as recommended in the Department of Mines and Petroleum (DMP) / Environmental Protection Authority (EPA) *Guidelines for Preparing Mine Closure Plans* (2015).

This closure plan has been updated to achieve the following goals:

- reflect the current knowledge and requirements for closure of the Brockman Syncline 4 (BS4) mine and identify the future requirements to continue to progress towards a planned and managed closure of the site;
- support environmental approval of the development of the Brockman Syncline 4 Marra Mamba (BS4 MM) deposits;
- to meet the internal requirements of the Rio Tinto Closure Standard (2015) mandated for all Rio Tinto businesses; and
- to inform the development of closure provisions.

2. Scope

This plan covers the current mining operations at Brockman Syncline 4 (BS4 Main), the proposed development of the BS4 MM deposits at the site (O, Q, R and S) and the conceptual development of the Brockman Syncline 4 Endeavour deposits (BS4 EN). This plan is applicable to areas and mine development features within the following leases[1]:

- ML4SA (AML70/4) Sections 104, 110, 119-125, 162-167, 239, 240, 242, 244-247, 279-283;
- G47/01225 (Brockman 4 plant and infrastructure);
- G47/01227 (Brockman 4 exploration camp);
- G47/01232 (Brockman 4 infrastructure);
- L47/00139 (Power and road)
- L47/00141 (Brockman 4 rail and road purposes)
- L47/00152 (Nammuldi West Borefield);
- L47/00153 (Brockman 4 airfield and infrastructure);
- L47/00161 (Wider White Quartz Road);
- L47/00178 (Rail upgrade);
- L47/00184 (Brockman 4 power line);
- L47/00185 (Brockman 4 general purpose); and
- surplus water discharge footprint along Boolgeeda Creek.

The plan excludes the following:

- potential future deposits within the Brockman 4 area that are not included in this plan, although these may be subsequently incorporated into future updates of this closure plan;
- other mines in Greater Brockman mining area (e.g. Brockman 2, Nammuldi and Silvergrass), which are subject to separate closure plans;
- the rail line beyond Brockman 2 that connects Brockman 4 to the ports; the rail network across the Pilbara is considered in a separate Rail Network Closure Statement;
- exploration areas and exploration infrastructure; and
- linear infrastructure that is connected to an integrated network (e.g. power, communications), which are subject to a separate closure plan.

This closure plan supersedes all previous closure, decommissioning and rehabilitation plans for BS4.

[1] Note that the scope of the closure plan has been aligned to tenure boundaries, which may differ from the footprint approved or referred under Part IV of the *Environmental Protection Act 1986*.

2.1 Closure Planning Process

Closure planning is an iterative process that commences during the planning phase of the mine development and is regularly updated and refined during the operational phase (Figure 1). Closure plans are updated to account for changes resulting from:

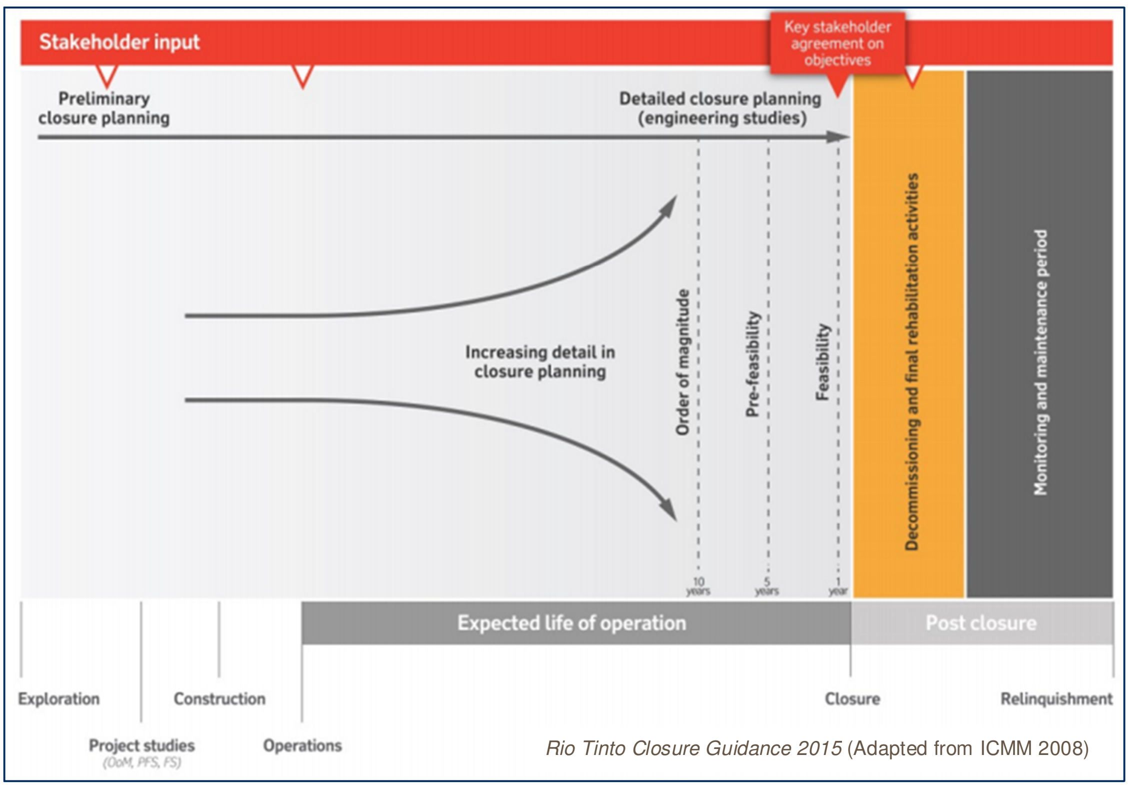
- amendments to the mine plan;
- improvements of the site closure knowledge base (e.g. through daily activities, technical studies and research actions, progressive rehabilitation);
- new or amended regulation;
- changes to surrounding land uses; and
- evolving stakeholder expectations.

The reviews brings specialists together to discuss current performance, proposed changes to the mine plan and opportunities to improve closure outcomes. At the end of the review, improvement actions are assigned and the closure plan is updated.

A key output of closure planning is the development of a closure cost estimate. Closure provisions are subsequently integrated into our business planning processes to ensure funds will be available to close the site effectively.

The detail of each closure plan increases as the knowledge base develops. When the site approaches scheduled closure, studies will be completed to define how infrastructure, decontamination, rehabilitation, the workforce and communications will be managed throughout the mine closure period (and beyond). Stakeholder engagement and endorsement of completion criteria is conducted at this time.

In the final closure plan, location specific management plans are provided for each closure domain. These detailed plans cover the physical closure, dismantling and subsequent rehabilitation implementation requirements. The supporting technical reports that have been used to predict the post-closure outcomes are appended to the final closure plan.



Rio Tinto Closure Guidance 2015 (Adapted from ICMM 2008)

Figure 1: Progression of closure planning

PROJECT OVERVIEW

3. Description of the operation

3.1 Ownership

The BS4 mine is owned and operated by Hamersley Iron Pty Limited, which is wholly owned by Rio Tinto Limited and hereafter referred to as Rio Tinto.

The site is not subject to any Joint Venture arrangements.

3.2 Location

BS4 is located in the Pilbara region of Western Australia, approximately 60 km West-north-west of Tom Price, and falls within the local authority of the Shire of Ashburton (Figure 2). It is in a relatively remote region of the State and there are no towns in the immediate vicinity. Tenure associated with current and proposed mining activities is shown in Figure 3.

The mine is located within the traditional lands of the Puutu Kunti Kurrama and Pinikura (PKKP) people and the Eastern Guruma people (Figure 4). The nearest Aboriginal community is located at Wakathuni, around 20 km to the south of Tom Price. There is a private camp located along White Quartz Road (referred to as the White Quartz Culture Camp) with one Eastern Guruma resident and is used intermittently by the Eastern Guruma people during lore time and for educational activities.

BS4 is significantly underlain by pastoral leases as shown in Figure 5. The majority of the site is on Rocklea Station (N050372) which is owned by Rio Tinto, while the western portion of the mining lease is on Cheela Plains Station (N050545), which is third party owned and operated. Small sections of the rail and infrastructure corridor are located on Hamersley Station (N050438), owned by Rio Tinto. Further west is Mt Stuart Station (N050169), also third party owned and operated. Whilst there is no direct disturbance on Mt Stuart Station, excess discharge water is predicted to extend onto the station footprint during operations.

3.3 Mine Operations

The BS4 mine commenced operations in 2010. It is an open cut operation utilising conventional drill-and-blast and load-and-haul mining methods. The approved layout is presented in Figure 6. The orebody consists of 22 pits spanning an area of approximately 24 km. The proposed BS4 MM group of deposits are adjacent to the south and east of those currently approved, including two pit expansions and 13 new pits across seven deposits. One further deposit is in conceptual phase. The proposed mine layout is also shown in Figure 6.

Mine planning schedules are continuously revised to maximise efficiencies and incorporate proposed new deposits. Several scenarios are still under evaluation, each of which would result in changes to the projected commencement and cessation dates of various deposits. The current central case scenario is presented in Table 1 below, however should be considered indicative only. The mine schedules and plans are subject to regular review to ensure optimised performance of the operations and are therefore subject to change.

The currently approved mine has an operational life of 18 years with completion of mining scheduled for 2036. The proposed development of the Marra Mamba deposits will extend the life of BS4 to 2042. The proposed developments change mining schedules, causing some BS4 Main pits to be pushed outside of 2036. It should be noted that there is the potential for further ongoing development of additional BS4 deposits subject to future approval. Should these exploration areas eventually be developed, mining at BS4 would continue significantly longer than indicated in Table 1. The addition of new deposits would also significantly affect the mining sequence and schedules for currently approved or proposed deposits.

The key landforms associated with the mine are shown in Table 2 below. The proposed construction and rehabilitation design criteria for these landforms are included in Appendix F.

Table 1: Indicative mining schedule

Deposit	Pit	Commencement	Completion	Description	Regulatory Status
BS4 Main	1	Operating	2039	BWT	Approved
BS4 Main	2	Operating	2030	BWT	Approved
BS4 Main	3	Operating	2033	BWT	Approved
BS4 Main	4	2019	2024	BWT	Approved
BS4 Main	5	Operating	2024	BWT	Approved
BS4 Main	6	2040	2042	BWT	Approved
BS4 Main	7	2035	2043	BWT	Approved
BS4 Main	8	2032	2034	AWT	Approved
BS4 Main	9	2040	2042	AWT	Approved
BS4 Main	10	2042	2043	BWT	Approved
BS4 Main	11	2023	2043	BWT	Approved
BS4 Main	12	2038	2043	BWT	Approved
BS4 Main	13	2042	2042	AWT	Approved
BS4 Main	14	2030	2037	AWT	Approved
BS4 Main	15	2036	2038	AWT	Approved
BS4 Main	16	2027	2028	BWT	Approved
BS4 Main	17	2021	2024	BWT	Approved
BS4 Main	18	2019	2042	BWT	Approved
BS4 Main	19	2041	2042	BWT	Approved
BS4 Main	21	Not planned	Not planned	BWT	Approved
BS4 MM	M1	2030	2038	AWT	Proposed
BS4 MM	M2	2035	2037	AWT	Proposed
BS4 MM	N1	2030	2039	AWT	Proposed
BS4 MM	N2	2030	2034	AWT	Proposed
BS4 MM	O1	2036	2038	AWT	Proposed
BS4 MM	O2	2036	2038	BWT	Proposed
BS4 MM	O3	2036	2036	AWT	Proposed
BS4 MM	O4	2036	2036	BWT	Proposed
BS4 MM	O5	2021	2035	BWT	Proposed
BS4 MM	Q2	2031	2036	BWT	AWT Approved, BWT Proposed
BS4 MM	Q3	2019	2042	BWT	AWT Approved, BWT Proposed
BS4 MM	Q4	Not planned	Not planned	BWT	Proposed
BS4 MM	R	Operating	2025	BWT	AWT Approved, BWT Proposed
BS4 MM	S1	2032	2035	BWT	Proposed
BS4 MM	S2	2036	2038	BWT	Proposed
BS4 EN	Endeavour 49	2022	2024	BWT	Conceptual
BS4 EN	Endeavour 61	2021	2021	AWT	Conceptual
BS4 EN	Endeavour 67	TBC	TBC	BWT	Conceptual
BS4 EN	Endeavour 88	TBC	TBC	BWT	Conceptual
BS4 EN	Endeavour 134	TBC	TBC	BWT	Conceptual

Table 2: Waste landform inventory

Landform	Type	Description	Status	Indicative Completion
DP1	Waste Dump	Fibrous minerals storage	Active	2041
DP2	Waste Dump	PAF storage	Active	Closure
DP4	Waste Dump	Fibrous minerals storage	Active	2020
DP5	Waste Dump	Inert waste	Approved	2036
DP6	Waste Dump	Inert waste	Approved	2036
DP8	Waste Dump	Inert waste	Proposed	2042
DP9	Waste Dump	Inert waste	Extension Proposed	Closure
DP11	Waste Dump	Inert waste	Proposed	N/R
DP12	Waste Dump	Inert waste	Proposed	N/R
DP22	Waste Dump	Inert waste	Active	2023
Landbridge 1	Landbridge	Inert waste	Active	2039

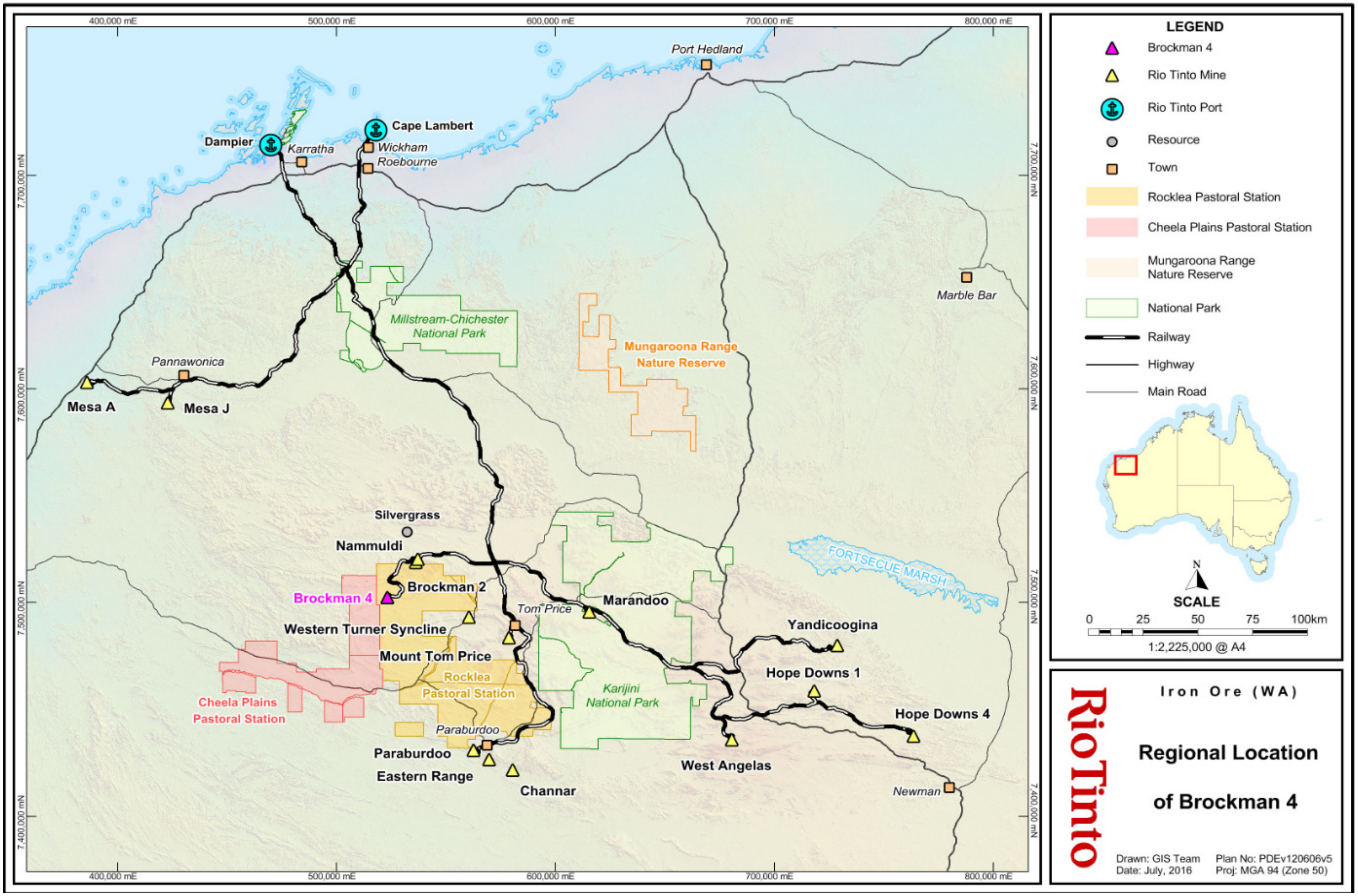


Figure 2: Regional location of Brockman Syncline 4

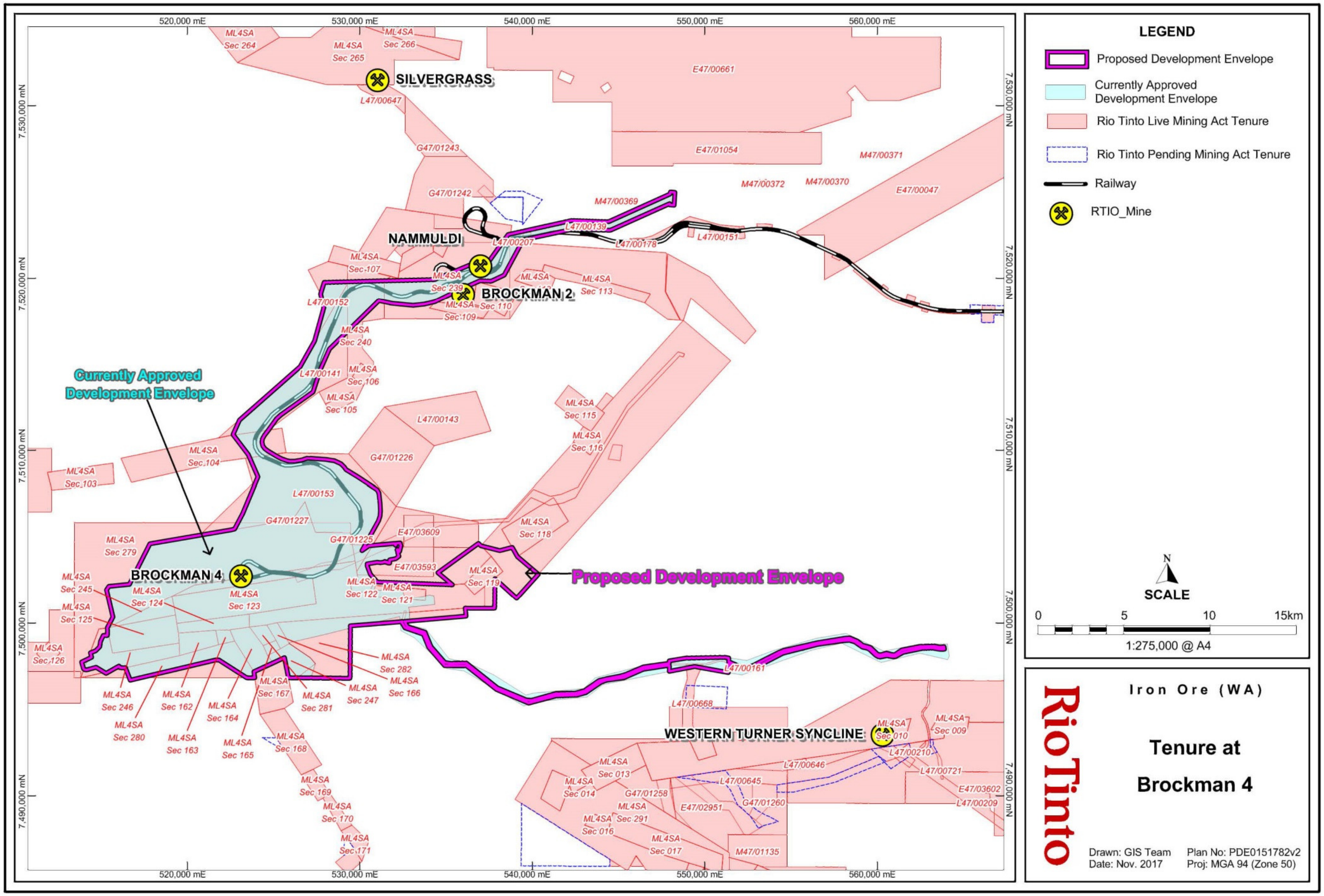


Figure 3: Brockman Syncline 4 tenure

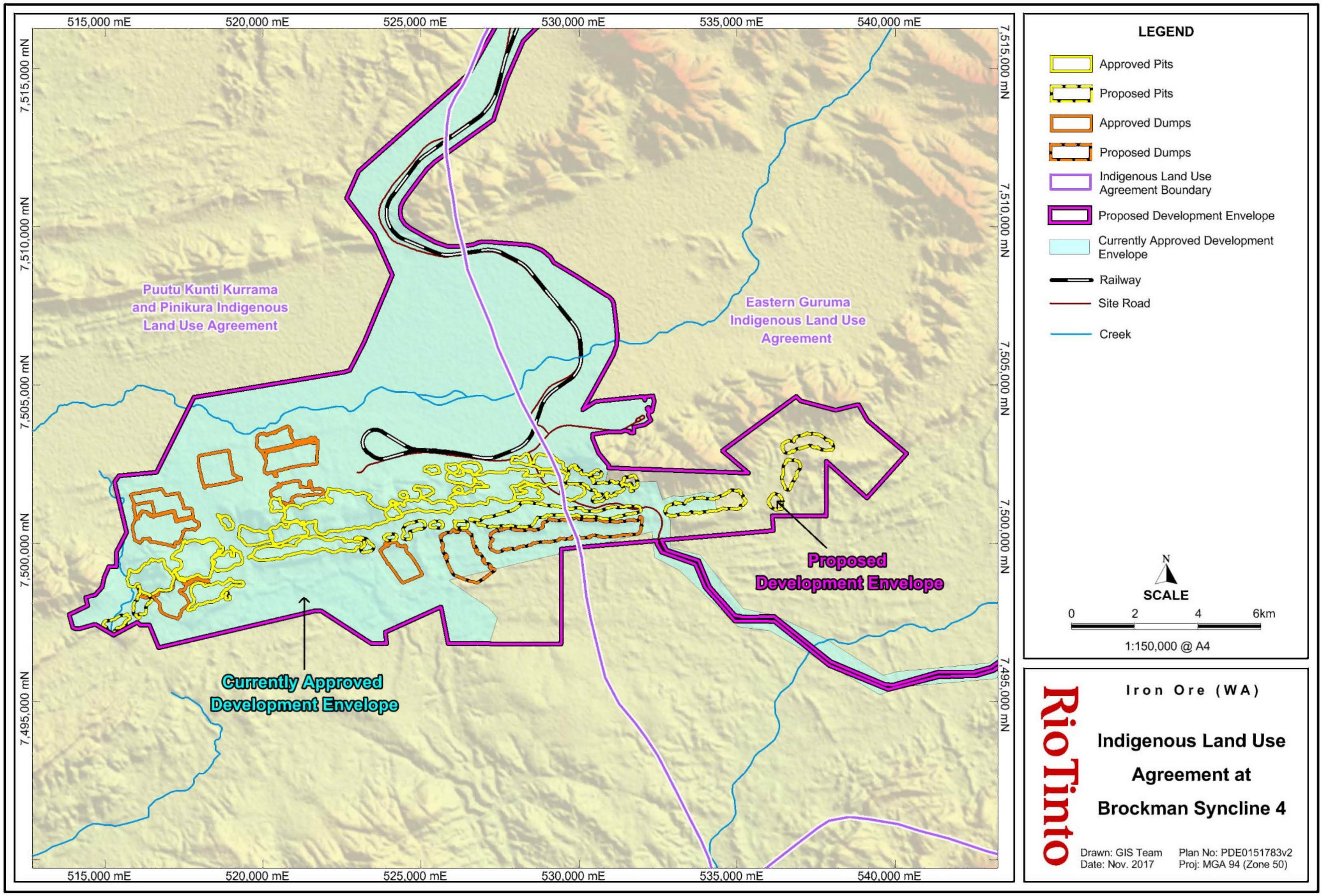


Figure 4: Traditional Owner locations

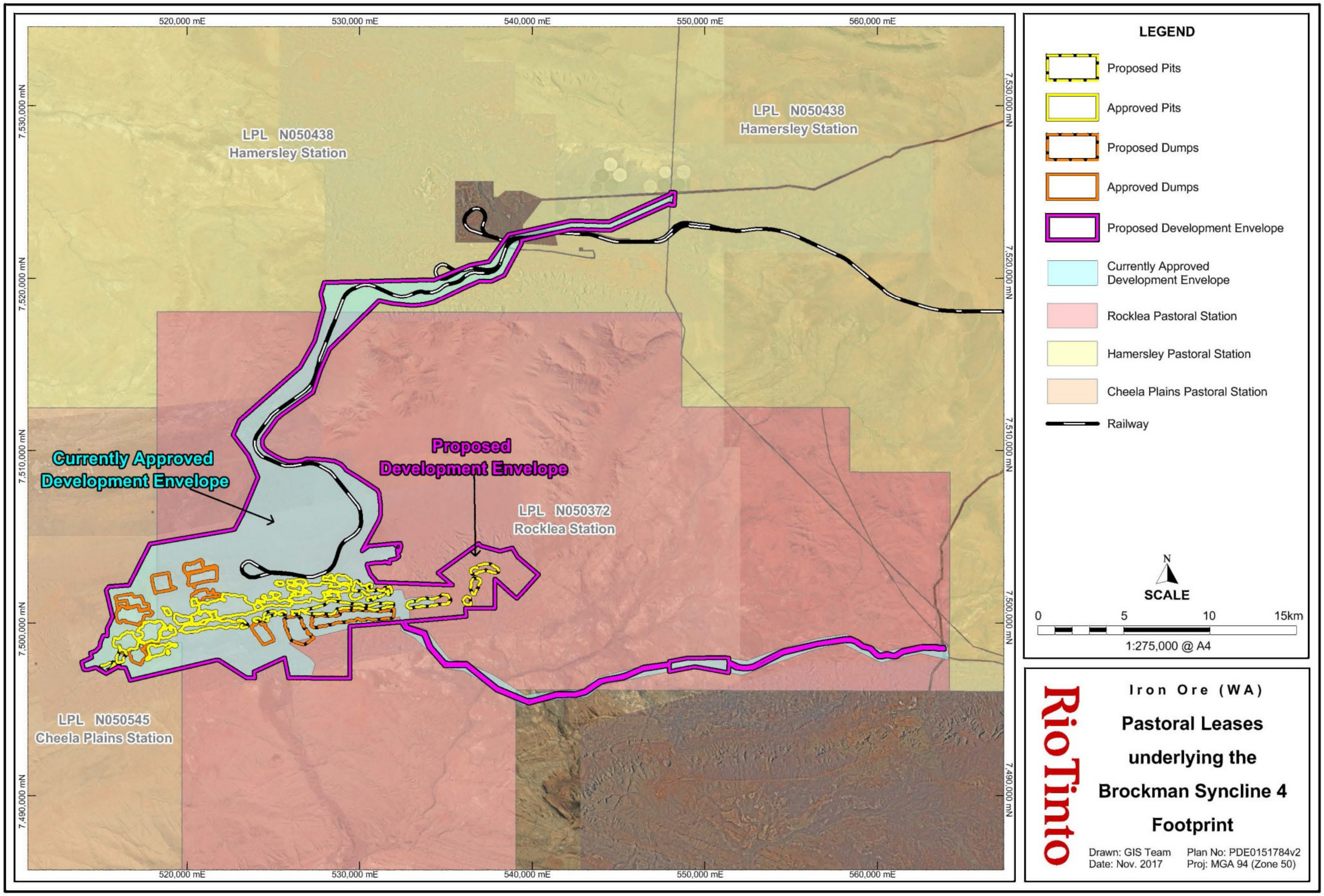


Figure 5: Pastoral leases underlying the Brockman Syncline 4 footprint

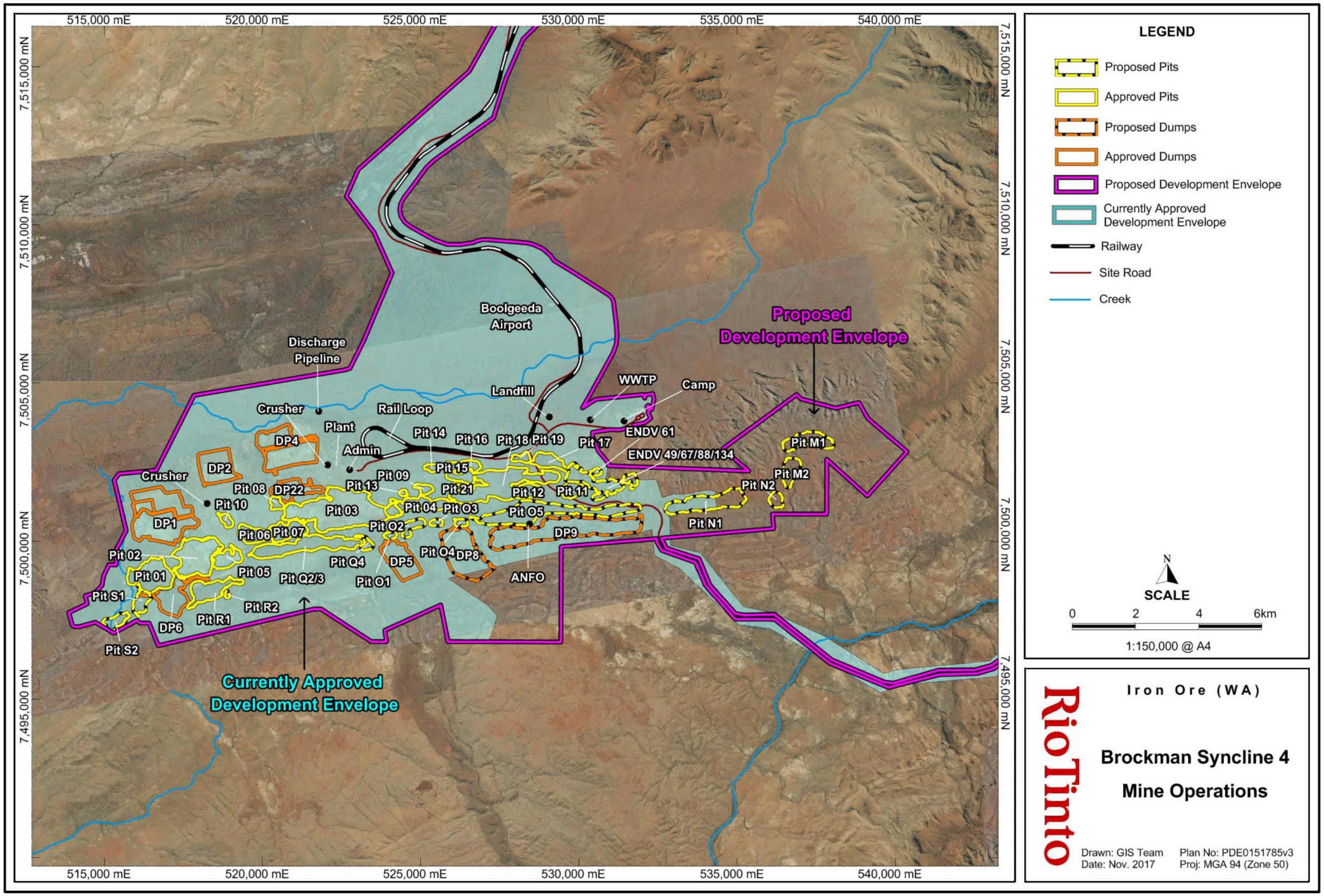


Figure 6: Brockman Syncline 4 Mine Layout

IDENTIFICATION OF CLOSURE OBLIGATIONS AND COMMITMENTS

4. Legal obligations

A closure obligations register is presented as Appendix A. It contains details of legal obligations from the following instruments:

- *Iron Ore (Hamersley Range) Agreement Act 1963;*
- Ministerial Statement 1000 (Brockman Syncline 4 Iron Ore – Revised Proposal);
- relevant Native Vegetation Clearing Permits (NVCP);
- mineral leases issued under the *Mining Act 1978* pursuant to the *Iron Ore (Hamersley Range) Agreement Act 1963*; and
- special leases and easements issued under the *Land Administration Act 1997* pursuant to approval under the *Iron Ore (Hamersley Range) Agreement Act 1963.*

The register also identifies legislation, standards and guidelines that may not apply to BS4 specifically, but that may be relevant to closure of mine sites generally.

This closure plan has been prepared to support approval for the BS4 MM proposal and additional obligations may arise through this process. Any new obligations will be documented in the next update of the BS4 closure plan.

STAKEHOLDER ENGAGEMENT

5. Stakeholder engagement

5.1 Engagement process

Stakeholder engagement is a key part of mine closure planning as it ensures that the expectations of stakeholders are understood by the mine operator and these can be considered and managed during the planning and implementation phase of closure. Rio Tinto has established processes for consultation with stakeholders, these are imbedded in both the Rio Tinto *Mine closure standard* (2015) and *Community and social performance standard* (2015). These standards are aligned with principles from the Australian and New Zealand Minerals and Energy Council and the Minerals Council of Australia (ANZMEC/MCA, 2000). Consultation commences at appropriate times during the early stages of exploration planning and will continue until the final relinquishment of the site.

As part of this process all likely impacted stakeholders are identified and recorded in a register. This register is used to ensure relevant and timely communications are held with stakeholders across a broad range of topics relevant to the mining operations, including closure. This register is regularly reviewed and updated to maintain currency. Regular consultation is conducted with a wide range of stakeholders via a variety of forums, for example various State and Local Government agency briefing meetings and Traditional Owner consultation forums established under Indigenous Land Use Agreements. Discussions regarding closure and related activities are included in these meetings as appropriate. The level of closure specific content and detail will increase as closure approaches (see Figure 1).

A communications register specifically for closure of BS4 is maintained and a copy as at the time of writing is included in Appendix B. This register is used to ensure stakeholder feedback is tracked and monitored to ensure that appropriate actions are taken to address these issues in a timely manner.

POST-MINING LAND USE AND CLOSURE OBJECTIVES

6. Post-mining land use

6.1 Historical land use

The lands surrounding the mine are the traditional lands recognised as belonging to the PKKP people and the Eastern Guruma people. Since European settlement, land uses in the region have included cattle grazing, exploration, mining and conservation. Aside from mining activity and associated infrastructure, the BS4 area is largely undeveloped. Pastoral activity in the region has historically been limited to grazing of cattle. The BS4 mine footprint is generally on areas of rugged terrain of low pastoral land value and as such, cattle were not grazed or mustered directly in the BS4 area prior to mining.

6.2 Proposed post-mining land use

Options for post-mining land use are limited in the Pilbara region, with mining and pastoralism the only industries that have historically proven viable. Inland regions are sparsely populated, with the largest inland towns (such as Tom Price, Paraburdoo and Newman) established specifically to support the mining industry. Beneficial uses for the mining area (e.g. recreation or aquaculture) that might have potential in areas supported with a higher population base are unlikely to be viable.

The proposed final land use assumes that the site will be rehabilitated to create a safe, stable and non-polluting landscape vegetated with native vegetation of local provenance, to maximise environmental and cultural heritage outcomes and ensure the site minimises adverse impacts on the current surrounding land use.

Due to the nature of the mining activity undertaken, the final landform will include large voids and waste dumps, and will therefore present challenges for effective pastoral operations. However, it is recognized that surrounding flat areas are likely to remain subject to pastoral activity and that BS4 closure needs to be undertaken in such a manner that minimizes land use impacts.

7. Closure objectives

7.1 Rio Tinto vision for closure in the Pilbara

Closure objectives have been developed with consideration of Rio Tinto's general vision for closure, which is to:

- Relinquish its mining leases to the Western Australian State Government.
- Preserve, protect and manage the cultural heritage values of the area in cooperation with the Traditional Owners and other stakeholders.
- Develop and implement strategies for closure that consider the implications on local communities.
- Achieve completion criteria that have been developed with stakeholders and agreed with WA Government.
- Develop landforms that are safe, stable, and compatible with the surrounding environment and post-mining land use.
- Achieve environmental outcomes that are compatible with the surrounding environment.
- Implement a workforce strategy that addresses the impacts of closure on employees and contractors.
- Achieve successful closure in a cost effective manner.

7.2 Brockman Syncline 4 closure objectives

The ultimate goal of mine closure at BS4 is to relinquish the site to the Government. This goal will be achieved once the government and community agree that the condition of the site is compatible with an agreed post-mining land use. Closure objectives reflect the aspects of the closure plan that the government and community agree are key to evaluating the site condition.

Revised closure objectives were submitted with the Brockman Syncline 4 Mine Closure Plan to the Department of Water and Environmental Regulation in August 2017, with a subsequent resubmission in March 2018. These revised objectives were approved as part of that Closure Plan in March 2018 by DWER. These objectives remain current for the proposed extension to BS4. Closure objectives are shown in Table 3. Due to the early stage of the operation, these objectives have yet to be agreed with key stakeholders and are likely to evolve in future versions of this plan as knowledge of closure issues progress and detailed closure discussions commence.

Table 3: Brockman 4 closure objectives

Number	Objective
1	Public safety hazards have been managed
2	Contamination risks have been appropriately managed
3	AMD and Fibrous material risk is compatible with post-mining land use
4	Final landform is stable and considers ecological and hydrological issues
5	Permanent pit lakes do not form within the pit voids
6	Vegetation on rehabilitated land is self-sustaining and compatible with the final land use
7	Infrastructure is appropriately managed
8	Boolgeeda Creek functions similarly to the pre-mining state.

Note that these objectives do not represent the full range of issues that need to be addressed upon closure of BS4; rather they represent the key objectives against which the ability to relinquish will be assessed.

Indicative completion criteria and measurement tools have been drafted for each of these objectives, and are discussed further in Section 8.

COMPLETION CRITERIA

8. Completion criteria

Completion criteria are defined as the indicators used to determine whether closure objectives have been met. They are used to measure the success of closure implementation against objectives, and to facilitate relinquishment of mining tenure.

The completion criteria, as detailed in Table 4, have been developed in consideration of the predicted closure outcomes. Measurement processes and the associated supporting data (evidence and / or metrics), that could be used to evaluate the success of closure are also described in Table 4.

The completion criteria are subject to ongoing review and update, informed by the outcome from studies, monitoring and ongoing stakeholder consultation. Given the number of years until scheduled closure, the completion criteria contained in this plan should be considered indicative only. As the site approaches scheduled closure, the completion criteria will contain more measurable and time-bound parameters.

8.1 Changes to completion criteria from the last closure plan

Rio Tinto has been continually refining its approach to establishing and presenting completion criteria for the past several years, and expects this process to continue in the future.

Due to the recent submission of the Brockman Syncline 4 Mine Closure Plan to the Department of Water and Environmental Regulation in August 2017, and subsequent resubmission in March 2018, no changes have been made to the objectives.

Only one change has been made to the completion criteria against the objective '*Permanent pit lakes do not form within the pit voids*'. The criteria has been updated to align with proposed approvals strategies, where backfill levels are sufficient to prevent pit lakes. The removal of the criteria to backfill above pre-mining water table levels is based on modelling discussed in Section 11.2 and Table 11, which shows groundwater recovery levels are unlikely to be to pre-mining levels. It should be noted that no GDEs are in the area that may be impacted by a lowering of groundwater levels.

Table 4: Indicative completion criteria

Objective	Indicative completion criteria	Verification process/method	Evidence
Public safety hazards have been managed.	1. Safety and health risks have been identified. 2. Measures to mitigate the identified public safety (and fauna where appropriate) and human health hazards have been agreed with key stakeholders and have been implemented. 3. Transfer of any residual liabilities is agreed with stakeholders.	1. Risk assessment conducted and mitigation actions implemented. 2. Relevant stakeholders have been engaged on risk mitigation measures to be employed. 3. Independent audit(s)/review to confirm that hazard mitigation measures have been implemented. 4. Process for transfer of residual liabilities is documented.	1. Risk assessment report. 2. Audit report to confirm effectiveness of controls. 3. Records of stakeholder engagement. 4. Liability transfer agreement/s.
Contamination risks have been appropriately managed.	1. Requirements under the *Contaminated Sites Act* 2003 (WA) have been met for the identification, recording, management, remediation and transfer of any contaminated sites as appropriate.	1. The site has been appropriately assessed for the presence of suspected or known contaminated sites. 2. Suspected or known contaminated sites have been appropriately reported under the Contaminated Sites Act 2003. 3. Appropriate management measures to address contamination have been implemented. 4. Process for transfer of residual liabilities is documented.	1. Contaminated sites investigation report/s. 2. Reports submitted to the Department of Water and Environmental Regulation (if required). 3. Liability transfer agreement/s (if required).
AMD and Fibrous material risk is compatible with post-mining land use.	1. Passive AMD and fibrous material control measures have been implemented to limit the likelihood and / or consequence of potential impacts. 2. The consequence of potential impacts from unexpected release of acid and / or metalliferous drainage is compatible with post-mining land use.	1. Geochemical risk assessment and evaluation. 2. Monitoring requirements are completed in alignment with the SCARD[2] management and Fibrous Management Plan. 3. Contaminant migration monitoring program including surface and groundwater.	1. Monitoring reports including store and release cover performance. 2. Pit wall mapping. 3. Static and Kinetic geochemical tests.

[2] Spontaneous Combustion and Acid Rock Drainage

Objective	Indicative completion criteria	Verification process/method	Evidence
Final landform[3] is stable and considers ecological and hydrological factors.	1. No erosion features that compromise landform integrity are present and if present, erosion features are stable. 2. The final landform was designed and constructed with consideration given to its stability during intense rainfall and large flood events. 3. Final landforms are outside predicted zones of instability of pits.	1. Rehabilitation monitoring program including quantitative evaluation of behaviour of rills and gullies (if required) over time. 2. Analysis of aerial imagery to provide qualitative analysis of landform stability. 3. Post-closure landform review to confirm that risks have been appropriately managed.	1. Rehabilitation monitoring results. 2. Post-closure landform evaluation report. 3. Survey data assessment.
Permanent pit lakes do not form within the pit voids	1. Pit voids are backfilled so that the final surface levels are sufficient to supress permanent pit lakes.	1. As constructed reports.	1. As constructed reports.
Vegetation on rehabilitated land is self-sustaining and compatible with the final land use.	1. Seed used in rehabilitation works is of local provenance[4]. 2. Native plants within rehabilitated areas are observed to flower and/or fruit. 3. Recruitment of native perennial plants is observed. 4. Species richness[5] of native perennial plants within rehabilitated areas is not less than reference sites. 5. Any weed species recorded within rehabilitation areas are present within the local area.	1. Rehabilitation monitoring/site inspections. 2. Analysis of historical monitoring data.	1. Rehabilitation monitoring reports.

[3] 'Landform' includes all post mining constructed features: waste dumps, waste fines storage facilities, abandonment bunds and pits.

[4] Note: Some seed used in rehabilitation predates accurate recording of collection area. Note 2: Local is defined as Pilbara IBRA

[5] Richness is defined as the number of different species in the defined area.

Objective	Indicative completion criteria	Verification process/method	Evidence
Infrastructure appropriately managed.	1. Legal agreement to transfer residual liability completed (if required). 2. Where transfer of liability is not established, infrastructure has been decommissioned and removed.	1. Appropriate agreements and transfer processes in place and communicated for any infrastructure remaining post closure.	1. Agreements in place with party assuming liability for infrastructure. 2. Close out report. 3. Visual inspection.
Boolgeeda Creek functions similarly to the pre-mining state.	1. The Boolgeeda Creek surplus water discharge area maintains flow regime and velocity comparable to natural conditions. 2. The Boolgeeda Creek surplus water discharge location has been rehabilitated/regenerated with appropriate native species and is self- sustaining. 3. Riparian vegetation down-stream of the surplus water discharge point is comparable to pre-mining conditions.[6] 4. Water quality in Boolgeeda Creek is comparable to regional pre-mining conditions.	1. Monitoring and assessment of flow regimes and velocity comparable to the undisturbed creek environment. 2. Rehabilitation close-out report and monitoring information. 3. Surface water quality monitoring.	1. Riparian vegetation Monitoring reports. 2. Rehabilitation monitoring reports. 3. Water quality and hydrological review reports.

[6] Comparable is defined in the Boolgeeda Creek Management Plan

COLLECTION AND ANALYSIS OF CLOSURE DATA

The closure knowledge base (Appendix C) is a collection of baseline studies, models and interpretations, which are used to inform the closure planning process presented in this closure plan. The knowledge may be specific to the site or generally applicable to the Pilbara region; and includes information on the performance of closure-related trials completed at other Pilbara mining operations (when appropriate). At this stage of the closure plan development, only summaries of these reports are provided and the relevant information is summarised in this section. The relevant knowledge base reports will be included in the final closure plan.

9. Climate

The closest official Bureau of Meteorology (BOM) weather recording station is at Paraburdoo Airport (station 007185). Climatic information has been captured from this site since 1974. In addition to the BOM weather station, Rio Tinto maintains automatic weather stations, including a station at BS4; which was installed in April 2011 (data from this station is not included in this closure plan due to limited records available for long-term trends). Climate data has been recorded at the nearby Brockman 2 mine since February 1998 and Cheela Plains since January 2001.

9.1 Climate and significant weather events

The climate in the area can be characterised as arid tropical with two distinct seasons, hot wet summers and cooler dry winters. Mean daily maximum temperatures range from 40°C in summer to 22°C in winter (Figure 7).

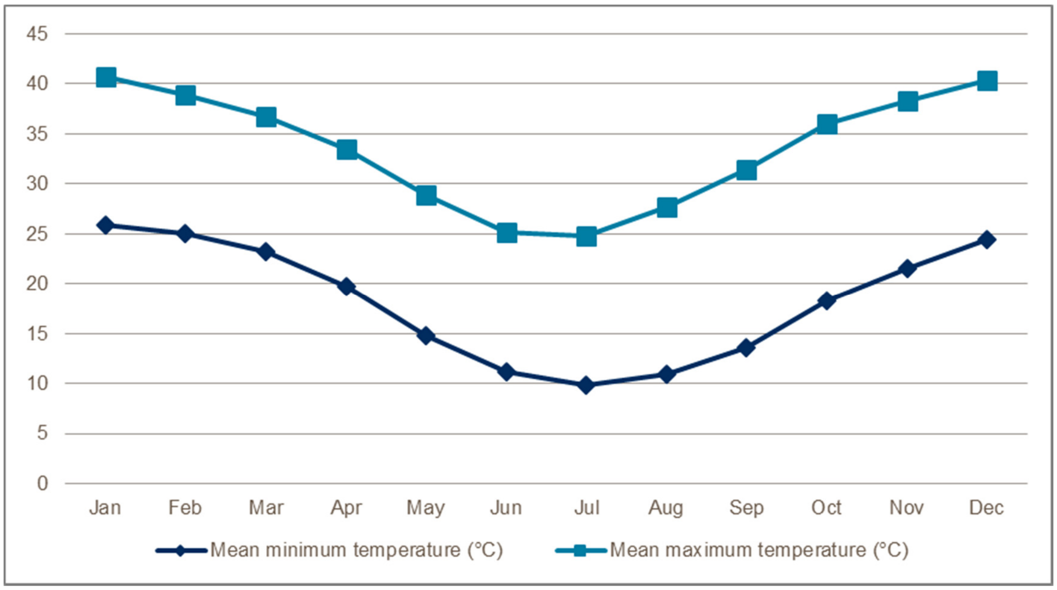


Figure 7: Mean monthly temperatures, Paraburdoo airport 1996-2016.

The north/north-western coastline of Australia has experienced more tropical cyclones than elsewhere on mainland Australia. Most tropical cyclones are observed during the late summer, occurring between November and April. Tropical cyclones can produce damaging wind gusts in excess of 150 km per hour, with heavy rains resulting in regional flooding. Seven tropical cyclones are typical off the coast of the Pilbara each year, with three expected to make landfall.

Precipitation is driven by summer cyclonic activity, with the months of August, September and October have the lowest average rainfall, and December, January and February the highest average rainfall (Figure 8). Annual rainfall is also highly variable (Figure 9). Evaporation rates in the region greatly exceed rainfall, which is typical for similar climate conditions around Australia. Average annual pan evaporation rate is 3200-3600 mm/year (Figure 10).

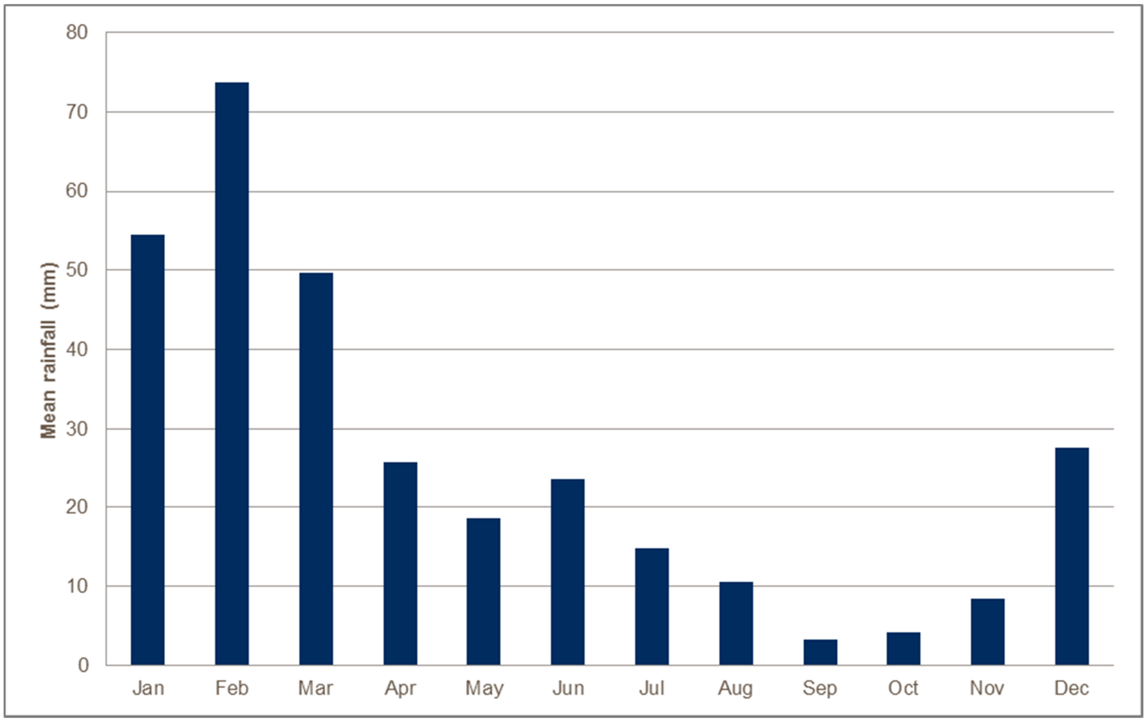


Figure 8: Mean monthly rainfall (1974 to 2016) at Paraburdoo Airport

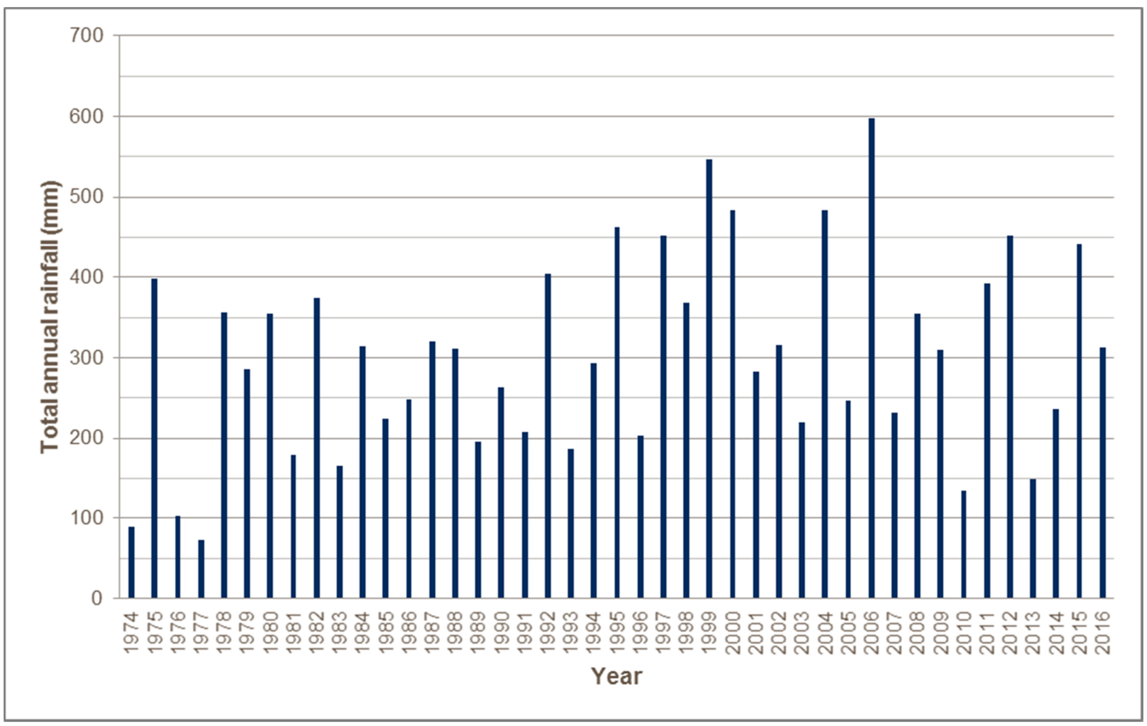


Figure 9: Historical annual rainfall (1974-2016) at Paraburdoo airport

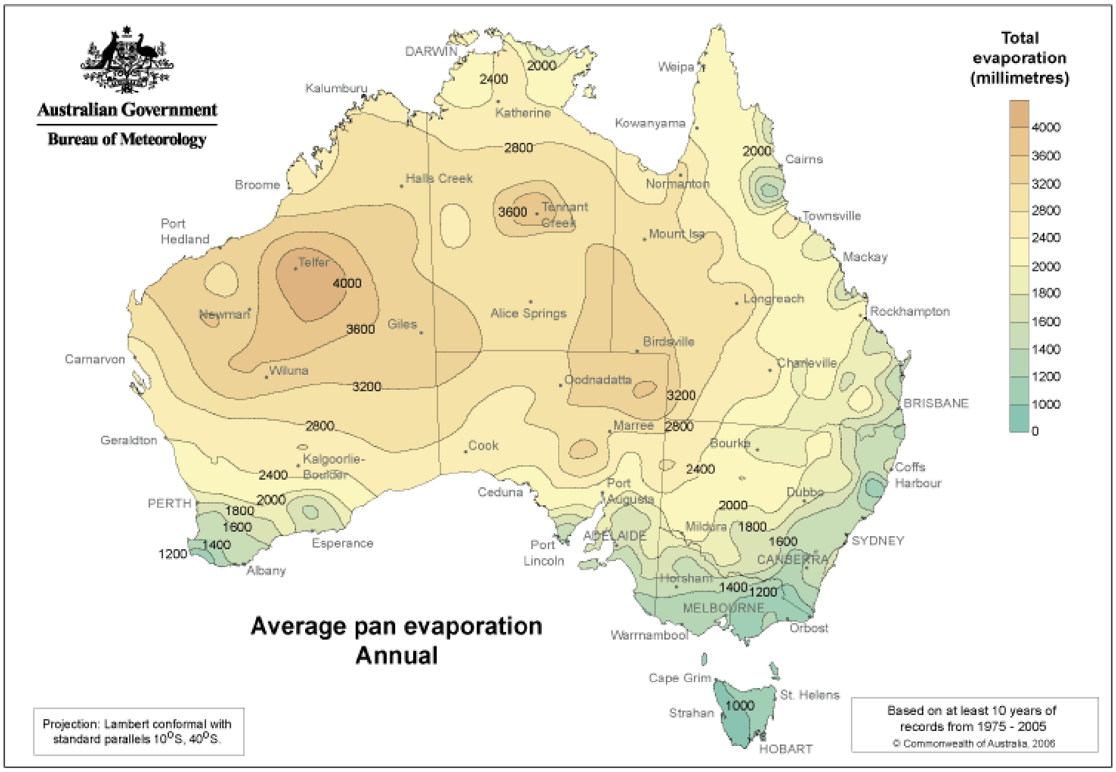


Figure 10: Average annual pan evaporation rates across Australia

9.2 Climate and landform stability

The heavy, intense rainfall experienced in the Pilbara makes rainfall the key climatic factor that influences surface stability in built landforms. Rainfall erosivity (measured in mega joule-millimetre, per hectare, per hour, per year - MJ.mm/ha/hr/yr) is the term used to describe the erosive force of rain. For Pilbara sites, long-term annual erosivity values range from ~1,000-1,600 MJ.mm/ha/hr/yr. Rainfall in the Pilbara is typically more erosive than Perth's rainfall, even though it only receives on average half the rainfall that Perth receives on an annual basis. For comparison, average annual erosivity values for Perth are ~1000 MJ.mm/ha/hr/yr from an average of 780 mm of rain a year.

Rainfall erosivity is highly variable for each rainfall event. Studies of Pilbara rainfall concluded that at Tom Price, for example, erosivity for the period 1998 to 2009 ranged from 212 – 6,349 MJ.mm/ha/hr/yr. A review of data in the Paraburdoo area indicates that the most erosive year recorded was 2007, where 421 mm fell during February, with only a further 283 mm during the rest of that year. This singular rain period embodied 11,994 MJ.mm/ha/hr/yr of erosive force, or 89% of the entire erosivity of rain for that year. Given the pattern of intense and infrequent rainfall events in the Pilbara, it can be expected that only a few events every year (~1-3 events) will generate the majority of runoff and erosion of that occurs each year.

The studies showed a rapid decline in erosion or sediment yield occurs when annual rain decreases below about 300 mm per year, due to a corresponding decline in rainfall volumes and rainfall erosivity. However, when annual rainfall increases above ~300 mm, vegetation growth increases and becomes increasingly effective in controlling soil erosion. Hence, there is a point of maximum erosion potential at an annual rainfall value of ~200-400 mm such that surface (vegetation) cover is low due to lack of rain and ineffective for controlling erosion, yet rainfall erosivity is sufficiently high to cause erosion, as observed in the Pilbara. Outcomes from these studies have informed development of the *Rio Tinto Iron Ore (WA) Landform Design Guidelines* for achieving stable waste dumps.

9.3 Climate and vegetation growth

Water is generally the limiting factor for plant growth in the Pilbara's arid environment. Due to the hot temperatures, high evaporative demand and infrequent and irregular rainfall, much of the vegetation displays xeromorphic adaptations (plant structural adaptations for survival in dry conditions). These adaptations include the ability to regulate water loss from leaves, extract water from very dry soils and match reproductive strategies with wetter periods. Many species are ephemeral and persist in soil seed banks in between wetter periods.

The adaptive capacity of Pilbara species implies a degree of resilience to changes to hydrological regimes. However, the impacts to Pilbara vegetation due to climate change are not clear. Changes in vegetation density and water use will alter the amount of runoff that occurs after a rainfall event, which in turn will alter creek flows and groundwater recharge.

Some initial studies within the wider Pilbara are underway to understand how the presence and absence of water affects vegetation growth within riparian corridors. The outcomes from these studies and other evolving research on climate change will be monitored and integrated into future closure studies to inform assumptions on climate influences and impacts.

9.4 Climate change

The understanding of how climate will change in the future in the Pilbara is guided by the outcomes of climate modelling, commissioned privately by Rio Tinto and other Australian government agencies. The main climate drivers for the Pilbara are the El Niño Southern Oscillation (ENSO) and Indian Ocean Dipole (IOD) ocean currents. However, these ocean currents are not well represented in most global climate models, and as a result, climate predictions for the northwest of Western Australia vary significantly. Consequently, the impact of climate change, the change in water availability and influence on ecosystems, in the Pilbara is still unclear.

The ENSO and IOD ocean currents are currently being researched by Commonwealth Scientific and Industrial Research Organisation (CSIRO). At the same time, modelling is being progressively improved by various Australian Government agencies to expand our understanding of the climate drivers in the southern hemisphere, to understand the associated impacts on water availability and to predict changes to existing ecosystems.

From the modelling completed to date, our understanding of Pilbara climate change suggests the region will experience the following climate trends:

- A shift in the historical tropical cyclone season, with an earlier start and potentially later finish.
  - For the period 2051 to 2099, compared to present day, tropical cyclone frequency could decrease by half, and the duration of a given tropical cyclone by 0.6 days on average. Projections also suggest that tropical cyclones could increase in size and intensity
- Continuation of the highly variable multi-decadal scale rainfall trends.
  - Projected rainfall reductions range from 1 to 24 percent for mid-century, and 9 to 24 percent for the end of the century
- A significant warming trend, influencing maximum temperatures, with the largest changes during the January to March period.
  - On average, maximum temperatures are expected to increase by 2.1 to 3.2 ˚C by mid-century and by a total range of 3.8 to 4.6 ˚C by the end of the century. For minimum temperatures the corresponding averaged increases are 1.9 to 2.4 ˚C (mid-century) and 4.1 to 4.6 ˚C (end of the century).

These changes, if realised as modelled, are likely to make successful rehabilitation in the Pilbara more challenging. Current landform designs are undertaken with inbuilt conservancy that allows for increased erosion factors, however lower average rainfall will affect ability to establish vegetative cover.

10. Land

10.1 Biogeographic overview

BS4 lies within the Pilbara Craton, a bioregion defined by the Interim Biogeographic Regionalisation for Australia (IBRA). The Pilbara bioregion is divided into four subregions: Chichester, Fortescue Plains, Hamersley and Roebourne Plains. BS4 is located in the Hamersley subregion, which is described as a *"mountainous area of Proterozoic ranges and plateaus with low Mulga (Acacia aneura) woodland over bunch grasses on fine textured soils, and Snappy Gum (Eucalyptus leucophloia) over Triodia brizoides on the skeletal sandy soils of the ranges."*

10.2 Geological setting

Mineralisation occurs along an east-west orientated ridge formed by outcrops of the Brockman and Marra Mamba Iron Formations, which rises over 150 m above the adjacent valley floors, and forms the major topographical feature in the area. This ridge forms the boundary between the Boolgeeda Creek and Beasley River catchments. Significant surface water features in the area include Boolgeeda Creek, Beasley River and Beasley River West. The BS4 area can be divided in two distinct regions:

- a northerly region of mild deformation with shallow north to north-east trending open folds (Boolgeeda Valley); and
- a southerly region of more intense deformation, where the more resistant iron formations form prominent ridges and the major iron deposits occur (Southern Strike Valley).

The northern Boolgeeda Valley is flanked by Brockman Iron Formation ridges to the north and to the south and lies in the centre of the Brockman Syncline. Small outcrops of the Turee Creek Group, underlain by the Boolgeeda Iron Formation, Wongarra Volcanics and Weeli Wolli Formation, occur in the centre of the valley. Basement subcrops are masked by a variable thickness of Cenozoic valley fill and lateritic sediments.

The Southern Strike Valley is limited by the Brockman Iron Formation ridge to the north and the Marra Mamba Iron Formation ridge to the south. The BS4 deposit lies within the Brockman Iron Formation along the southern limb of the Brockman Syncline. The east-west trending deposit has a length of approximately 14 km and consists of three broad lenses of mineralisation: Western, Central and Eastern. Bedded mineralisation occurs in both the Joffre and Dales Gorge members of the Brockman Iron Formation. The deposit is dissected by northwest trending, high angle, normal and strike-slip faults that frequently produce sharp kinks in the otherwise uniform east-west striking strata. Northwest-Southeast trending dolerite dykes that cross the BS4 deposit often intrude along these faults.

The proposed BS4 MM deposits occur in the Marra Mamba Iron Formation, which runs in an east-west direction. The BS4 MM deposits are separated from the neighbouring BS4 deposit to the north by a minor valley that developed following weathering of the more shale dominated Wittenoom and Mt Sylvia Formations, as well as Mount McRae Shale. A distinctive feature of this area is the series of linear trenches, with a northwest-southeast orientation, that cut across the area at irregular intervals, representing weathered dyke structures. Mineralisation within the Marra Mamba Iron Formation mainly occurs in the upper part of the Mount Newman Member and can be discontinuous along strike when insected by major dyke or fault structures.

Figure 11 shows the dominant geological units and general landscape position for the BS4 deposits. In general, the deposits are located on or towards the top of the ridges, with minor Brockman iron mineralisation within the valleys. Many of the deposits intersect, and will consequently mine out, minor drainage lines and gullies. Mineral waste generated at BS4 is subsequently categorised with respect to the geological origins of the material, namely:

- Detritals;
- Dolerite;
- Hydrated zone;
- Joffre;
- Whaleback shale;
- Dales Gorge;
- Footwall zone; and
- Mount McRae Shale.

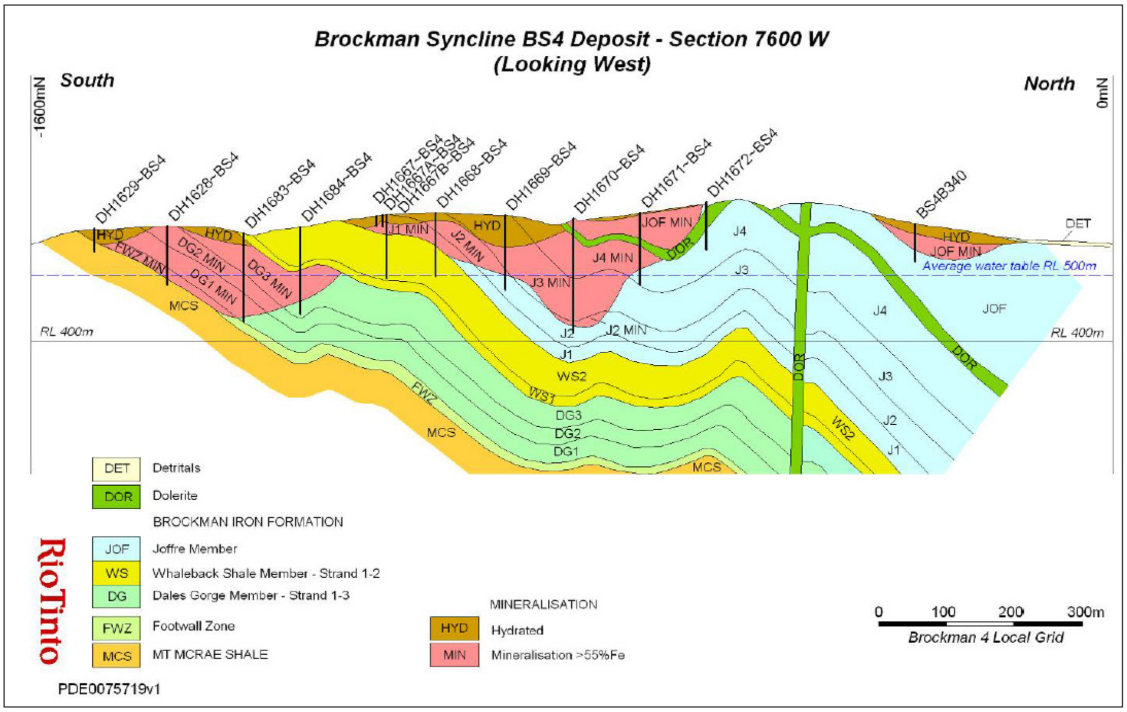


Figure 11: Local geology of BS4 looking west

10.3 Geotechnical stability of pit walls

Rio Tinto has committed to backfilling all below water table (BWT) pit voids at BS4 to avoid the formation of pit lakes; however, significant voids will remain after closure. Aside from pits that are likely to be backfilled close to ground level, there is no intent to reshape or rehabilitate these in-pit areas, and the remaining pit walls will be retained in the same configuration as when mining ceases. It is recognised that there will be some degree of geotechnical instability, and that walls will have the potential to collapse in some areas.

Preliminary zones of geotechnical instability have been identified around most pits covered within the scope of this closure plan (Figure 12). The Endeavour Pits will be developed as designs become more accurate, and all are refined over time with design changes. Methodology is based on the angle method described in DMP abandonment bund guideline, using the conservative assumption that all pit walls are embedded into weathered rock (i.e. the polygons are lines drawn at a 25º angle from the base of the pit). Further geotechnical evaluation is being undertaken, and is discussed further in Section 19.3.

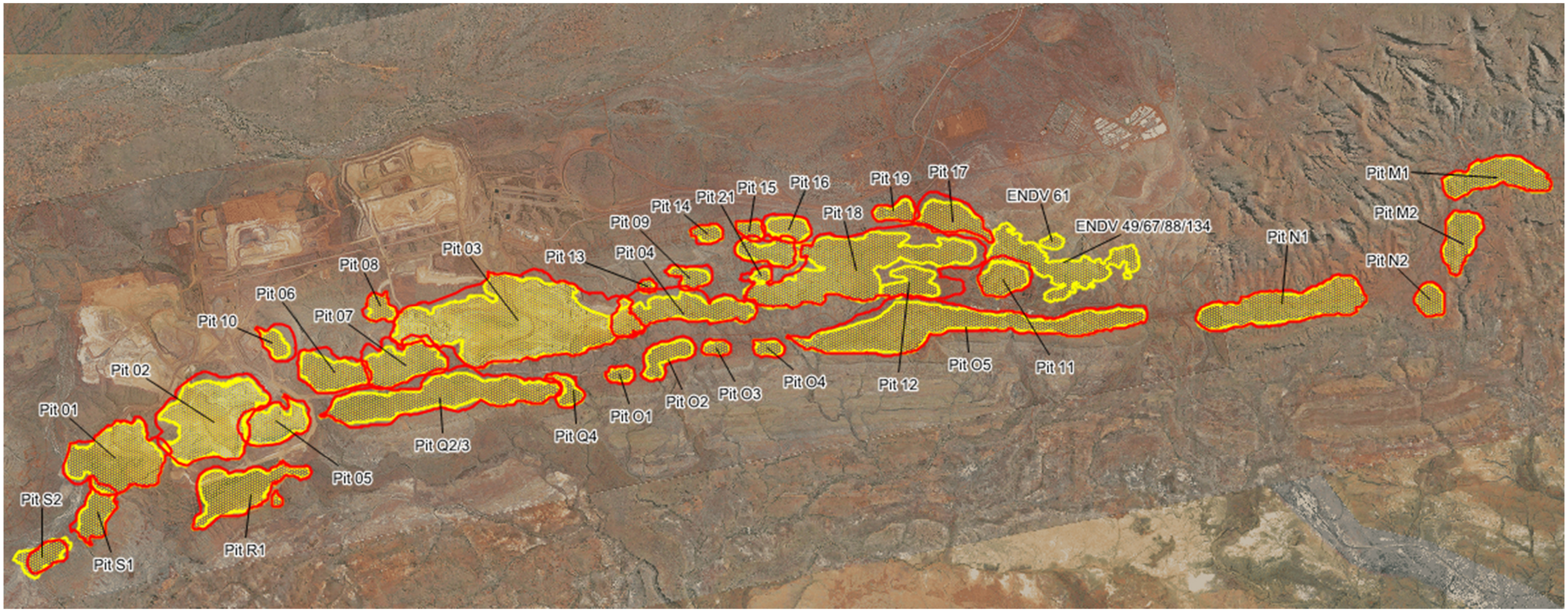


Figure 12: Zone of Instability of Pits at BS4

10.4 Mineral waste characteristics and inventory

Developing a comprehensive understanding of the types and volumes of materials that will remain at the completion of mining at BS4 is critical for the effective design, construction and rehabilitation of the mining landforms. Rio Tinto iron ore has a well-developed process for the collection and analysis of this data, early exploration works and continues through the life of the mine. Long-term material behaviour can also be predicted through characterisation of representative waste types and correlation to similar waste materials present at other sites.

10.4.1 Physical characteristics

The erodibility potential of waste types at BS4 have been assessed using a combination of site-specific geophysical test work and extrapolation from equivalent material at similar sites. Table 5 lists the waste material types by erodibility class and percentage of total mineral waste predicted to be generated by closure. This information is used to inform the landform design and management strategies during operations and closure. Volumes are based on current mining models and are subject to change.

A vast portion of the material contained within BS4 waste dumps is low erodibility (competent), although within individual dumps varying proportions of medium to high erodibility material is present (Table 6). The management of these dumps is addressed further in Section 19.2.The erosion classification of individual landforms is included in Appendix F.

Table 5: Waste material erodibility characterisation by type

Waste material type	Erodibility	Total waste (kt)	Total waste (%)
Detritals	High	159,658.3	21.26
Hydrated	Low	26,350.0	3.51
Dales Gorge	Low	67,016.3	8.92
Whaleback Shale	Moderate	36,462.4	4.86
Joffre	Low	88,169.8	11.74
Foot Wall Zone	Low	13,477.6	1.79
Dolerite	High	29,525.8	3.93
Fortescue	High*	99.5	0.01
MacLeod	Low*	19,014.3	2.53
McRae Shale	Moderate	7,992.6	1.06
Mount Sylvia	Moderate*	337.8	0.04
Nammuldi Member	Low*	1,625.8	0.22
Mount Newman	Low*	72,673.5	9.68
Wittenoom Formation	Moderate*	227,146.8	30.25
Yandi Shale	High*	1,352.6	0.18

* Materials assessed by extrapolation

Table 6: Waste material erodibility characterisation summary

Erodibility	Total waste (kt)	Total waste (%)
High	288,327.4	38.4%
Moderate	271,939.5	36.2%
Low	190,636.2	25.4%

10.4.2 Geochemical characteristics

Rio Tinto has undertaken an extensive program of geochemical testing over several years to understand the potential for acidification and/or metalliferous drainage to occur as a result of exposing various waste rock types common to mining operations in the Pilbara. The geochemical characterisation process aims to assess sulfur content as an indicator of acid generation potential, and to undertake static (acid base accounting) and, if appropriate, kinetic testing of materials. This information is applied to the geological block model and subsequent mining model, to ensure materials posing potential geochemical risks are identified prior to mining and managed appropriately. This work is in accordance with the *Rio Tinto Iron Ore (WA) Mineral Waste Management Plan for Undeveloped Resources and Studies* and the *Spontaneous Combustion and Acid Rock Drainage (SCARD) Management Plan*.

The most significant geochemical risk in Pilbara iron ore bodies is associated with sulfides, such as pyrite (FeS_2), which can form sulfuric acid when exposed to oxygen and water. Mining activities within the BS4 area include the disturbance of Potentially Acid Forming (PAF) materials. Mount McRae Shale, the geological unit most commonly associated with acid mine drainage in the Pilbara, is present at BS4. Static tests have been conducted on all waste types, with comprehensive kinetic tests undertaken on materials that pose a significant geochemical risk. Approximately 4.7 Mt of PAF material is expected from the approved pits (0.64% of all waste). Areas where PAF material may be intercepted during mining at BS4 are shown in Table 18. Geochemical risks associate with each pit are shown in Table 8 and Figure 13.

At Brockman 4 the Mount McRae Shale (MCS) can be classified into three: oxidised MCS, cold black MCS and hot black MCS. Both the cold and hot black MCS units are managed as PAF during operations with the hot black shale having higher total sulfur content (generally > 0.3%) and a greater potential for spontaneous combustion and reactivity with explosives. Oxidised MCS is considered inert. A summary is provided in Table 7.

Table 7: Summary of Mount McRae Shale (MCS) Geochemistry data

MCS classification	Average S (%)	Sulfur forms (as determined XRD)	Average organic Carbon (%)	Acid Neutralisation Capacity (kg H2SO4/t)	NAG pH	Total NAG (kg H2SO4/t)
Oxidised MCS	0.17	Sulfates	0.15	9.9	6.4	2
Cold Black MCS	0.06	Sulfates and Sulfides	3.7	32	5.9	4.7
Hot Black MCS	5.6	Sulfides	3.9	3.8	2.5	108

The geochemical risk assessment for BS4 was first undertaken in 2010 and updated in 2013 (based on the 2012 mine plan) and again in 2015 for future deposits. For the BS4 deposits, approximately 2.9% of all in-pit samples have sulfur levels greater than 0.1%, with approximately 0.3% of samples with sulfur greater than 0.3%. At BS4 MM approximately 1.6% of all in-pit samples have sulfur levels greater than 0.1%, with less than 0.5% of samples with sulfur greater than 0.3%. The assessment report concludes that although there is a relatively small volume of black shale material expected, the AMD risk for the site overall remains moderate (Table 8).

Pits at BS4 expected to encounter black shale include pits 1, 3, 5, 6, 7 and 18 (Figure 13). Backfilling of the pits will be used, where required, to cover all black shale exposures; thereby reducing the risk of acid or metalliferous drainage at closure. It should be noted that the pit shells might change over time and updates to the geological and mining models will be made; the figures reported in this document are subject to change. The management of these pits is addressed further in Section 19.1.

The proposed BS4 MM deposits are expected to pose a low Acid or Metalliferous Mine Drainage (AMD) risk based on the proposed pit design. Although material from Pit R has been flagged as sulfide risk of two, this only represents less than 0.005% of all the waste to be encountered. This material will require management as per the *SCARD Management Plan*.

Deposit S and Endeavour are scheduled for drilling in 2018. An updated risk assessment for BS4 MM and including Deposit S and Endeavour is expected to be available for the next closure plan submission.

Table 8: Assessed geochemical risk in the BS4 and BS4 MM mining areas

Mining Area	Geochemical Risk
Pit 1	Low
Pit 2	Low
Pit 3	High
Pit 4	Low
Pit 5	High
Pit 6	Low
Pit 7	Moderate
Pit 8	Low
Pit 9	Low
Pit 10	Low
Pit 11	Low
Pit 12	Low
Pit 13	Low
Pit 14	Low
Pit 15	Low
Pit 16	Low
Pit 17	Low
Pit 18	High
Pit 19	Low
Pit 21	Low
MM Deposit M	Low
MM Deposit N	Low
MM Deposit O	Low
MM Deposit Q	Low
MM Deposit R	Low
MM Deposit S	TBC
Endeavour	TBC

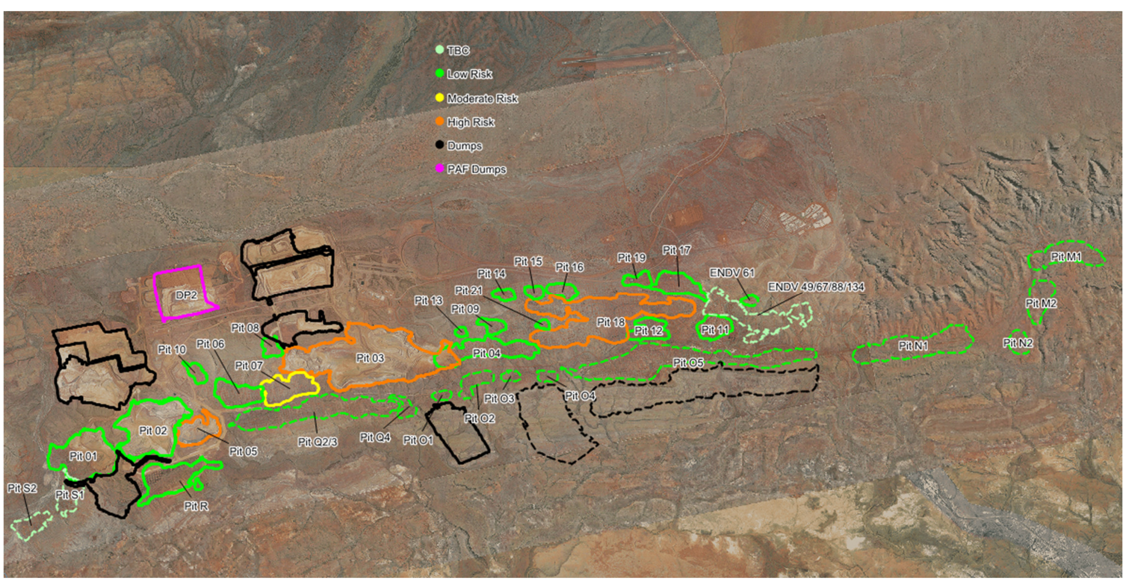


Figure 13: Geochemical risk of the pits at BS4 and B4MM.

10.4.3 Fibrous minerals

Naturally occurring silicate minerals can have fibrous characteristics. These minerals can be associated with iron ore deposits in the Pilbara. Respirable fibres of concern are defined as being approximately 6 microns. When respirable fibres are airborne and inhaled, these fibres pose a health risk.

The *Rio Tinto Iron Ore (WA) Fibrous Minerals Management Plan* describes guidelines for the management of fibrous minerals encountered during mine production, such as the encapsulation of intersected fibrous mineral waste in 2 m thickness of non-fibrous mineral waste within a waste dump.

A small volume of fibrous mineral waste will be exposed during operations at BS4. This material is expected from Pit 1, Pit 3, Pit 16, Pit 17, BS4MM Pit N1 and BS4MM Pit O5. Mined fibrous material will be stored in designated waste dumps as outlined in Table 2. The management of these dumps is addressed further in Section 19.5.

10.5 Local soils

Topsoil is recognised an important factor in achieving high quality rehabilitation results. Characterisation of soils provides an indication of soil properties and their potential impacts on vegetation establishment, growth and landform stability; although it is important to recognise they may be altered as part of mining processes. Appropriate characterisation can also help ensure soils with adverse properties are avoided in landform design.

In the Pilbara, hills and rock ridges have extensive areas without soil cover occur. The soils that do occur are shallow and skeletal. Rocks of this formation weather very slowly, and any soil which does form tends to be transported into the surrounding valleys and plains as a result of the sparse vegetation cover and erosion force of heavy rains derived from thunderstorms and cyclones. The soils on slopes, although having had more time to develop than the soils of the adjacent ridges, are still influenced by the parent rock and may be shallow and stony sands or loams. These soils are generally unfavourable for plant growth due to low moisture holding capacity and poor nutrient status. On pediments, older pediplains and alluvial plains hard alkaline red loamy soils tend to be dominant, and may be considered as the regional mature soil type. The surface of these areas may carry a layer of small gravel, which is derived from the more resistant rocks in the area.

The dominant soil types covering the BS4 area are shallow coherent and porous loamy soils with weak pedologic development. The physical and chemical properties of BS4 topsoil are provided in Table 9 and are within the range typical of that found elsewhere in the Pilbara. It is generally classified as sandy clay loam with a coarse material fraction value of 68.5%. Soil was classed as strongly acid (pH 5.3 to 5.6) through to neutral (6.5 to 8.0) in H_2O, non-saline and non-sodic. Both organic carbon and nutrient levels vary according to landscape position. The highest levels of organic carbon were found in the hilltop landscape; while the nutrient levels were highest in low-lying areas and drainage lines and they are typically very low in the higher portions of the landscape that account for most of the BS4 disturbance footprint. The soil organic carbon content was low and the plant-available nutrients were generally classed as ‘low’ for phosphorus and sulfur, and ‘high’ for potassium.

BS4 soils possess low hydraulic conductivity indicating that they could be naturally susceptible to increased surface run off, and thus less water availability to plants and surface erosion. Subsoil has physical properties suitable for plant growth and generally has chemical properties amenable to plant growth, although it does lack the nutrient content, organic matter and soil seed bank of topsoil.

Table 9: Comparison between BS4 soils and typical Pilbara soil parameters[7]

Properties		Pilbara Soils	BS4 Topsoil
Physical	Soil texture (<2 mm soil fraction)	Sand clay loam	Sand clay loam
	Coarse material content (%)	0 - 93	68.5
Chemical	Soil pH	5.3 – 9.5	5.3 – 8.0
	Salinity (dS/m)	0.007 – 0.233	0.0 - 0.2
	Organic Carbon (%)	0.07 – 3.74	0.37 – 1.56
	Macro-nutrient status	Low	Low
	Micro-nutrient status	Low - moderate	Low - moderate
	Effective Cation Exchange Capacity (meq/100g)	1.9 – 16.8	1.16 – 8.25
	Exchangeable Sodium Percentage (%)	0.21 – 6.39	<6.0
	Total metal concentrations	Low	Low

10.6 Soil inventory

Topsoil is often a limited resource in the Pilbara with topsoil recovery often being restricted due to the nature and terrain of the landscape. The goal of soil management is to maximise the collection of topsoil and subsoil, and to store it to maximise its viability and productivity to ensure there is sufficient soil for subsequent use in rehabilitation.

Where practical a minimum of 200 mm of topsoil and 600 mm of subsoil is collected when new areas are disturbed. However, some clearing areas are located on a steep range and it has been identified that stripping to a depth of 200 mm is not achievable due to lack of availability of material present on high topographical areas and steep nature of the topography not allowing for safe access of machinery. Table 10 provides the current and projected soil inventory for BS4, assuming recovery rates remain consistent over time.

Table 10: Predicted LOM soil balances for BS4 (as of December 2017)

	Current balance	Future predicted clearing and recovery	Total at Closure
Topsoil volume (m^3)	2,117,177	1,241,048	3,358,225
Subsoil volume (m^3)	2,051,953	1,202,815	3,254,768
Total soil volume (m^3)	4,169,130	2,443,863	6,612,993
Total disturbance area (ha)	3,356	1,967	5,323
Pit areas not rehabilitated (ha)	566	1,315	1,881
Completed rehabilitation (ha)	496	0	496
Area requiring topsoil (ha)	2,294	652	2,946
Soil volume required 200mm (m^3)	4,587,720	1,303,871	5,891,591
Soil Deficit/Surplus (m^3)	-418,590	1,139,992	721,402
Soil Deficit/Surplus (%)	91%		112%

Whilst it is predicted that BS4 will have sufficient soil resources to complete rehabilitation works at closure, each progressive rehabilitation project is assessed to determine the type and amount of soil used. This could include an assessment of:

- soil inventory at the time of scoping;
- landform and rehabilitation type;
- potential for trials;
- distance to soil stockpiles; or
- potential upcoming rehabilitation projects.

[7] Note that the typical ranges above apply to topsoil and may not be representative of subsoil properties.

10.7 Alternative growth media

In 2010, Rio Tinto commissioned a study into use of mine waste materials as an alternative rehabilitation growth medium. The study reviewed soil, tailing and mineral waste characteristics from select Pilbara mining operations, to identify material combinations that may be suitable as a topsoil substitute or supplement in cases where topsoil may be insufficient for rehabilitation requirements. In these cases, topsoil would be applied to high priority areas such as waste landforms first and lower priority areas such as laydown areas may receive alternative growth media.

The study showed plant-available nutrients held within the waste materials, although variable, was characteristically low and comparable to natural soils in the region. The majority of the waste materials had macro and micro nutrient concentrations within the range or above the levels measured in benchmark Pilbara topsoil and rehabilitated soils. The pH and phosphorus-buffering index of most waste materials were also comparable to that of the benchmark topsoil materials.

In general, Pilbara mineral wastes were non-saline and non-sodic, with no sample presenting above the 15% threshold for exchangeable sodium percentage (ESP), the indicator of high sodicity. The soil structure of waste materials were relatively stable, with only slight or no dispersion upon re-moulding, indicating a relatively stable structure that is not easily degraded, and were not prone to hard setting. However, estimated plant available water content of the waste materials ranged from <3% to >25%.

In 2016, Rio Tinto commissioned a further study into alternative growth mediums. The study reviewed soil, tailing and mineral waste characteristics from select Pilbara mining operations. The BS4 samples included in the study were deemed as moderately suitable as an alternative growth media. The tested materials were within soil thresholds, aside from permeability and coarse fragments. The samples had low permeability and were deemed likely to runoff rather than infiltrate rainfall, making less water available to plants and the surface more prone to erosion. Some samples were deemed too coarse which indicates rocky materials that often hold little water for plant use; while others were not coarse enough, suggesting they could be prone to erosion when used on steeply sloping batters.

Whilst rehabilitation areas have generally performed better with topsoil application, absence of topsoil does not necessarily mean that rehabilitation will fail, or that completion criteria will not be achieved. Trials have been conducted on waste dump rehabilitation without topsoil application (for example the Channar 84 East 5 waste dump trial) and are performing strongly against most success indicators. Further trials using detrital waste material have begun at Tom Price (recent MMW4 waste dump and Section 7 projects). Initial observations indicate stability and early growth.

11. Water

11.1 Surface water

BS4 mine is located on the divide between the Boolgeeda Creek and Beasley River regional catchments, within the Ashburton River catchment. The Boolgeeda Creek catchment is approximately 1,600 km^2 in size and drains to the southwest past the mining area then turns northwest to merge with Duck Creek. The Beasley River catchment is approximately 2,500 km^2 and drains southwest into the Hardy River. Boolgeeda Creek to the north of the mining area and Beasley River to the south represent the major surface water features near BS4. There are no major river systems passing directly through or located within the BS4 mining area (Figure 16).

The majority of creek systems in the area are ephemeral and generally only flow after significant rainfall events. Boolgeeda Creek and Beasley River West are intermittent streams, which carry underflow in their alluvial beds following intense rainfall events. Along Boolgeeda Creek, numerous small ephemeral pools have been observed. Three pools were identified in proximity to the development envelope of the BS4 MM project; Ephemeral Pool, Ridge Pool and Plunge Pool (Figure 16). An assessment of a Pilbara Leaf-nose Bat (PLNb) roost located behind the Brockman 4 and Nammuldi Villages has identified two of the pools are water sources for the PLNb. Ridge Pool is considered to be surface water fed and appears to be persistent, likely due to its relatively shaded position which reduces evaporation. Hydrogeological investigations are underway to determine if Plunge Pool is solely surface water fed or if groundwater is a component.

Water generally has high significance for Traditional Owners[8]. Purlykuti Creek has been identified during ethnographic surveys as being of high significance to the PKKP Traditional Owners - this is discussed further in Section 15. A report commissioned by Rio Tinto in 2011[9] explains '*that in Indigenous belief systems water is perceived as an elemental part of the broader cultural landscape, held and managed under customary systems of lore. Water sources are derived from the actions of mythic beings during the Dreaming and are the most important features in the Pilbara cultural landscape. Sustaining and protecting country, including the relationships traditional owners have with particular places, was found to be the primary obligation for people*'.

Understanding water and drainage systems and their significance to the Traditional Owners is an ongoing focus within Rio Tinto to ensure the successful management of cultural heritage values. Outcomes from this ongoing work may influence future revisions of this closure plan.

Currently, mining of below water table ore at BS4 generates surplus water, which can be discharged into nearby Boolgeeda Creek under the terms of MS 1000 with an authorised extent of less than 37 km from the discharge point under natural 'no-flow' conditions. In 2015 a new groundwater licence was obtained for the approved mine, increasing abstraction from 4.53 GL/a to 6.90 GL/a (6.4 GL/a for dewatering purposes and 0.6 GL/a for mine camp potable supply). Extensive mapping of the riparian area (approximately 41 km of Boolgeeda Creek downstream of the approved discharge point) has been conducted to establish baseline data. Dewatering discharge undertaken during operations extends the duration of creek flow within the naturally ephemeral creek system. This activity has created waterlogged areas and small pools contributed to by rainfall and discharge within the Boolgeeda Creek. As mining activities cease, the volume of discharge will taper then cease at the end of mining, returning the creeks to their ephemeral regime.

The elevated position of the BS4 deposits means that no major streams or tributaries are intercepted by the pits. All pits (active and proposed), barring two (Pits 1 and S2), are outside the modelled 1% Annual Exceedance Probability (AEP) floodplain extent. Both Pit 1 (Figure 14) and Pit S2 (Figure 15) will extend into the 1% AEP floodplain of Purlykuti Creek, which has an approximate catchment area of 30 km^2. Pit 1 will require a minor creek realignments and flood protection bunds. This will be further investigated and constructed during operations. Similarly, flood protection options for Pits S2 will be further investigated. There are no plans to reinstate original drainage, and options for making the diversions permanent will be investigated. The closure management of this proposed structure is discussed in Section 19.6.

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[8] Rumley and Barber, We Used to Get Our Water Free – Identification and Protection of Aboriginal and Cultural Values of the Pilbara Region, April 2004, Study report prepared for the Water & Rivers Commission.

[9] Barber & Jackson, Water and Indigenous People in the Pilbara: A Preliminary Study Funded by Rio Tinto Iron Ore, September 2011, CSIRO.

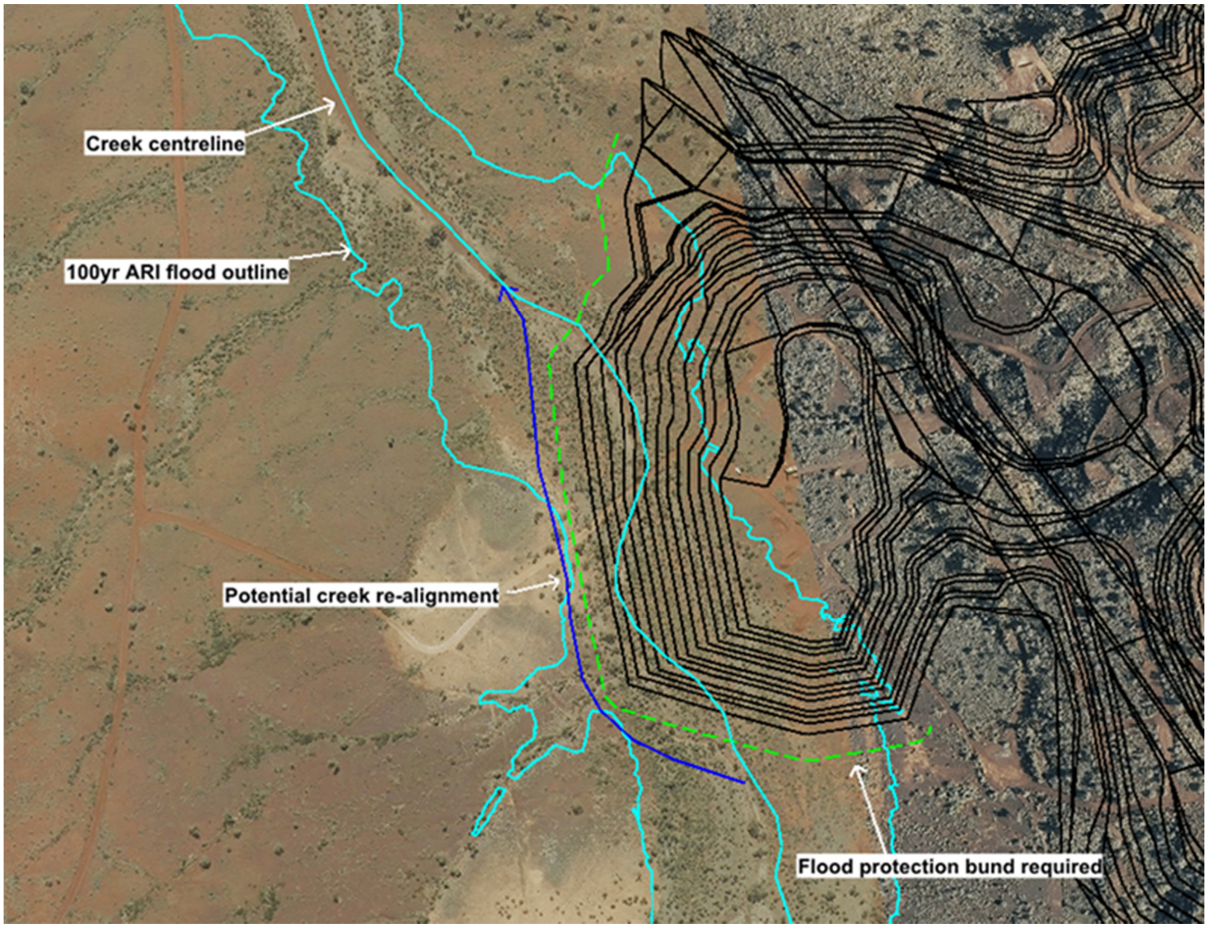

Figure 14: The proposed final pit shell of Pit 1 intersecting the Purlykuti Creek

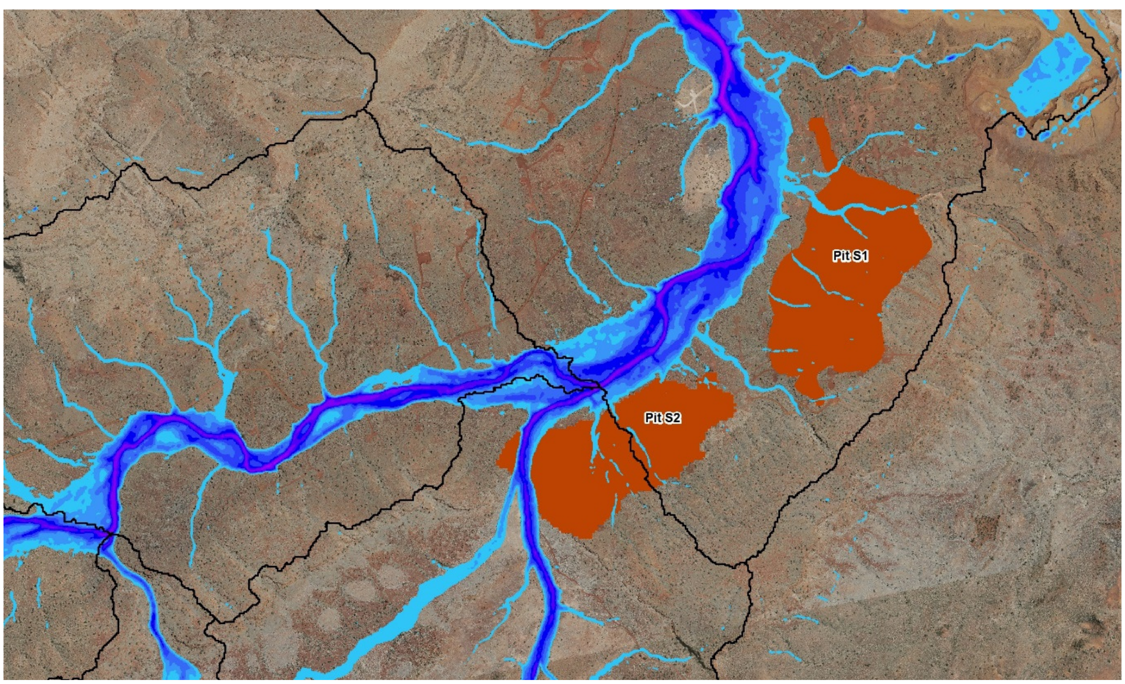

Figure 15: The intersection of the BS4MM S2 deposit and Purlykuti Creek

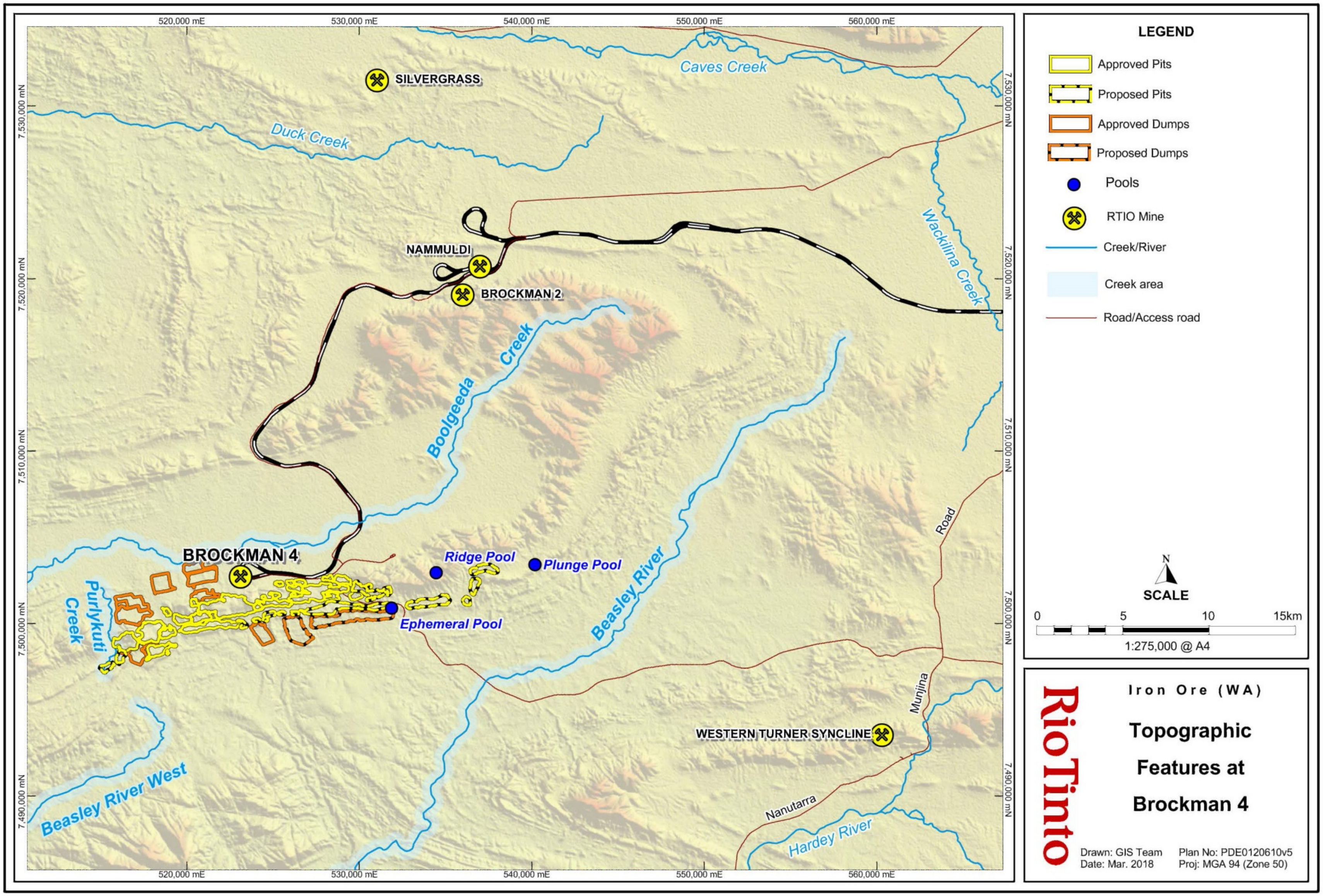

Figure 16: Surface hydrology surrounding BS4

11.2 Groundwater

The BS4 Main hydrogeology is presented in Figure 17. Regional hydraulic gradient in the area is generally from a northeast to southwest direction. Along the Boolgeeda Valley, groundwater gradients are higher and water levels vary approximately between 480 mRL to the southwest and 575 mRL to the northeast.

The water levels in the Southern Strike Valley range between 488 mRL along the fault zone between the Central and Western deposits, and 504 mRL to the east in the BS4 MM Deposit O. To the east in the area of BS4 MM Deposits M and N, the water table increases markedly to 535 mRL. This sharp increase is thought to be due to dolerite dykes acting as barriers to groundwater flow. The water table to the west of the valley is approximately 515 mRL and the hydraulic gradient is to the east to converge in the central fault zone. However, actual groundwater flow appears to be limited and compartmentalised by structural controls to the west that act as hydraulic barriers.

Groundwater quality ranges from fresh to slightly brackish. Salinity increases along the flow direction; in the Boolgeeda Valley system it ranges from 180 mg/L upstream and 1400 mg/L downstream, while in the orebody and Southern Strike Valley it ranges between 500 mg/L upstream and 700 mg/L downstream.

A hydrogeological drilling and testing program was undertaken in 2011 to confirm conceptual hydrogeological models for the area. In 2013, a regional groundwater model for the site was developed incorporating the latest geological and hydrogeological findings. The numerical groundwater model presents the results of predictive simulations to develop a dewatering strategy for the deposits. The purpose of the work was to extend the domain to include the BS4 MM deposits and was calibrated to all available water level and abstraction data. The numerical model also included additional dolerite dykes, identified through increased abstraction at Pit 2, 3 and 5, which are believed to act as hydraulic barriers. This groundwater model was updated in 2015 to support dewatering assessment and utilised for the recovery assessment.

The numerical model included some structural features and dolerite dykes truncating the ore bodies believed to act as hydraulic barriers. The area is divided into four separate hydrogeological zones, as depicted in Figure 18.

- Zone 1: This zone comprises those sediments of the Turee Creek Group within the Boolgeeda Valley and the Hamersley Group that lie above the dolerite sill within the Joffre Member. The zone also seems to be hydraulically disconnected from Zone 2, given the difference in groundwater levels up to 10 m.
- Zone 2. The second zone comprises the Brockman Iron Formation between the dolerite sill and the Mount McRae Shale. The ore bodies in this zone are often highly permeable with hydraulic conductivity in the order of 6 m/day. This zone appears compartmentalised by northwest trending dolerite dykes and low permeability horizons within the Whaleback Shale Member.
- Zone 3: The third zone comprises the Wittenoom Formation and the upper mineralised Newman Member of the Marra Mamba Iron Formation. The Southern Strike Valley bores and the BSSM Deposits O, Q and R are located within this zone. The hydraulic conductivities are of similar order of magnitude to Zone 2. This zone may also be compartmentalised by northwest trending dolerite dykes.
- Zone 4: The fourth zone comprises the lower Marra Mamba Iron Formation members and the Fortescue Group. This area is less well understood but generally comprises a water poor, low permeability aquifer and is disconnected from the Brockman Syncline South Marra Mamba deposits and Zone 3.

The Mount McRae Shale and the dolerite sill within the Joffre Member of the Brockman Iron Formation, form hydraulic barriers to groundwater flow between Zone 1 and 2, and Zone 3 and 4, respectively. However, the McRae Shale is assumed as a leaky barrier for the extensive faulting and fracturing. There are many dykes truncating the ore bodies and twelve have been identified as potential hydraulic barriers. These dykes have been identified through a combination of analysis of reverse circulation drill hole water level measurements, test pumping and water level observations during dewatering.

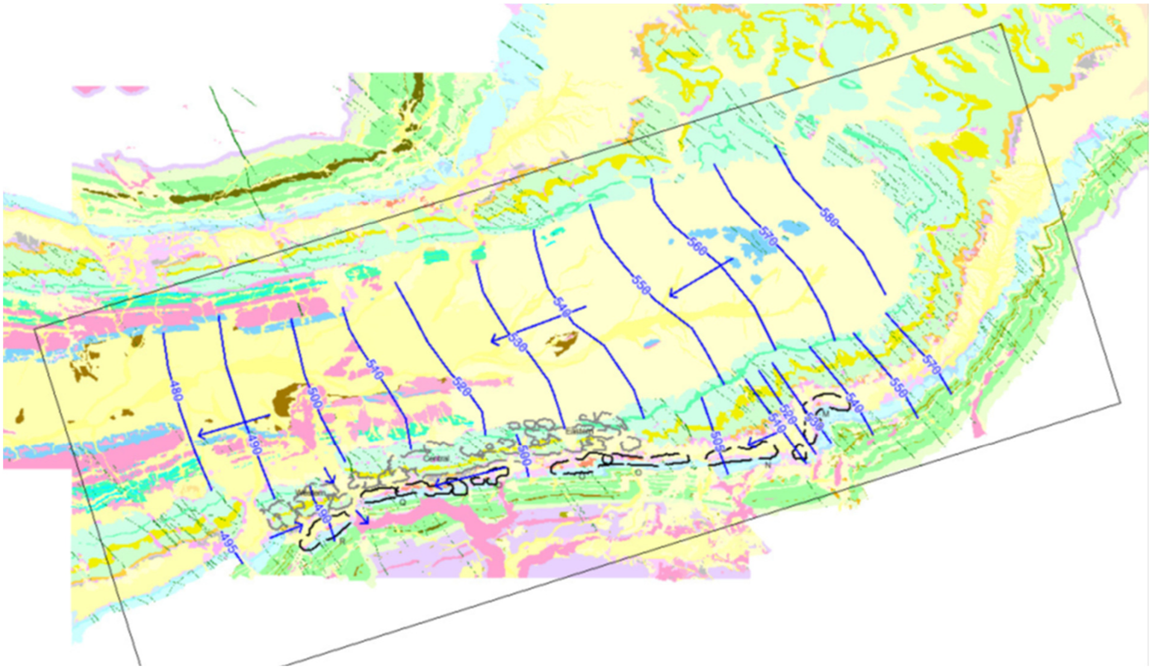

Figure 17: Hydrogeological map of the BS4 area

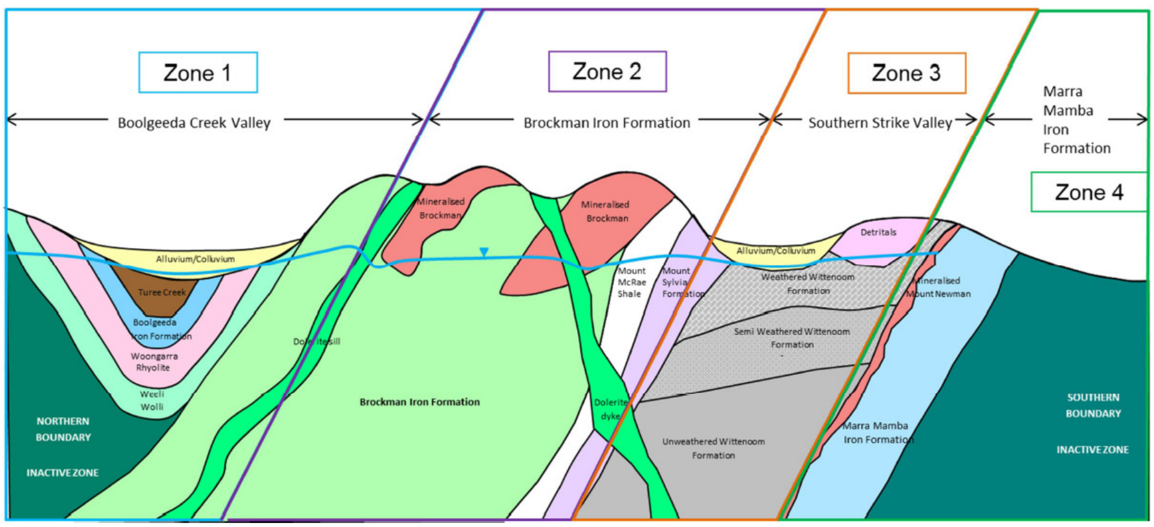

Figure 18: Conceptual hydrogeology zones present at BS4

The only source of recharge to the system is rainfall. The ground water modelling suggests that the approved dewatering will not result in the recovery of the water table to pre-mining levels (Table 11). The probable average recharge is less than 1% of the annual average rainfall volume. Over a 4.5-year monitoring period, little evidence of recharge across the area exists with the exclusion of bores in Zone 1, located near Boolgeeda Creek. For the Brockman Syncline South Marra Mamba Valley, it is suggested that rainfall in the catchment and surrounding ridges results in overland flow into the valley, which contains alluvium, colluviums and clay. Based on chloride mass balance calculations for the area, the results indicate that recharge to the aquifer is about 0.5% of the average annual rainfall, which is negligible.

The catchment created by the mine void will serve to focus rainfall runoff and thus recharge, resulting in localised ponding at the base of the mine voids following heavy rainfall, which will dissipate via infiltration and evaporation shortly after the event.

To model recovery of groundwater levels after closure, the following modifications were made to the dewatering model in the 2015 update:

- All (dewatering) abstraction wells were removed from the model.
- Hydraulic heads from the last time step of the dewatering model were assigned as initial conditions for the closure model.
- Pit voids and backfill material were represented by new zones (Zone 16 and Zone 17 respectively).
- Recharge and evaporation setup was modified from the dewatering model to reflect the presence of open water in the pit voids.

Three closure scenarios were modelled to assess groundwater level behaviour:

- **Option 1:** Pits are not backfilled and remain as voids.
- **Option 2:** Pits are backfilled to the levels of their recovery calculated in Option 1 (minimum backfill).
- **Option 3:** Pits are backfilled to the level determined in LoM 2014 plan (which is a nominal equivalent to the pre-mining groundwater level).

Further modelling is underway to extend the model across potential future deposits and to assess the connectivity and risk of potential impacts to the permanent pools described above. This modelling is due for completion before the next closure plan update.

Table 11: Predicted groundwater level and approximate time to recovery

Deposit	Pit	Pre-mining level (mRL)	Recovery level (mRL)	Time (years)
BS4 Main	1	493	460	18
BS4 Main	2	490	430	5
BS4 Main	3	495	460	11
BS4 Main	4	500	490	-
BS4 Main	5	488	430	6
BS4 Main	6	494	460	10
BS4 Main	7	495	461	10
BS4 Main	8	495	N/R[10]	N/R
BS4 Main	9	500	N/R	N/R
BS4 Main	10	488	-[11]	-
BS4 Main	11	502	460	10
BS4 Main	12	502	460	-
BS4 Main	13	500	N/R	N/R
BS4 Main	14	519	N/R	N/R
BS4 Main	15	519	N/R	N/R
BS4 Main	16	519	-	-
BS4 Main	17	522	511	4
BS4 Main	18	502	462	11
BS4 Main	19	522	-	-
BS4 Main	21	502	462	12
BS4 MM	M1	535	N/R	N/R
BS4 MM	M2	533	N/R	N/R
BS4 MM	N1	506	N/R	N/R
BS4 MM	N2	515	N/R	N/R
BS4 MM	O1	495	N/R	N/R
BS4 MM	O2	500	-	-
BS4 MM	O3	500	N/R	N/R
BS4 MM	O4	500	-	-
BS4 MM	O5	501	463	11
BS4 MM	Q2	494	460	10
BS4 MM	Q3	494	-	-
BS4 MM	Q4	495	492	-
BS4 MM	R	490	430	6
BS4 MM	S1	494	-	-
BS4 MM	S2	494	-	-
BS4 EN	Endeavour 49	502	-	-
BS4 EN	Endeavour 61	502	N/R	N/R
BS4 EN	Endeavour 67	502	-	-
BS4 EN	Endeavour 88	502	-	-
BS4 EN	Endeavour 134	502	-	-

[10] Recovery rates are not required where the pit remains Above Water Table

[11] Recovery rates are not available, due to the pit being an old AWT design, or the pit not being in the 2015 mine plan